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Three-dimensional prediction of the human eyeball and canthi for craniofacial reconstruction using cone-beam computed tomography

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ABSTRACT

An anatomical relationship between the hard and soft tissues of the face is mandatory for facial reconstruction. The purpose of this study was to investigate the positions of the eyeball and canthi three-dimensionally from the relationships between the facial hard and soft tissues using cone-beam computed tomography (CBCT). CBCT scan data of 100 living subjects were used to obtain the measurements of facial hard and soft tissues. Stepwise multiple regression analyses were carried out using the hard tissue measurements in the orbit, nasal bone, nasal cavity and maxillary canine to predict the most probable positions of the eyeball and canthi within the orbit. Orbital width, orbital height, and orbital depth were strong predictors of the eyeball and canthi position. Intercanine width was also a predictor of the mediolateral position of the eyeball. Statistically significant regression models for the positions of the eyeball and canthi could be derived from the measurements of orbit and maxillary canine. These results suggest that CBCT data can be useful in predicting the positions of the eyeball and canthi three-dimensionally.

1. Introduction

Craniofacial reconstruction is the process of recreating the face of an individual from skeletal remains through forensic science or anthropology for the purpose of assisting in facial identification [1]. There has been substantial research quantifying the relationship between the skull and the overlying soft tissues of the face with the aim of facilitating facial reconstruction [2]. An accurate anatomical relationship between the bony and soft tissues of the face is essential for facial reconstruction and anthropological research concerned with the prediction of faces [3].

There have been several studies about the placement of the eyeball or canthi [3–6], cadaver-based studies [3,4] for instance, can provide the empirical evidence of the positions of the eyeball and canthi with surrounding hard tissue structures. However, these studies can have limitations due to skin shrinkage in the cadavers or the use of only elderly cadaver samples. Wilkinson and Mautner [5] used magnetic resonance image (MRI) for measuring the eyeball protrusion and orbital depth in their study. MRI study provides a clear image of soft tissue structure containing fat and water. However, this study was limited to the only anteroposterior position of the eyeball [5].

Guyomarc'h et al. [6] studied three-dimensional (3D) placement of the eyeball using computed tomography (CT) images in which they suggested a probable position of the eyeball in the orbit. While the relationship of hard and soft structures can be identified three-dimensionally using the CT data, one drawback of a multi-slice CT is that the images are obtained with the subject in a supine position, and not in a natural posture. The eyeball position in a supine position can be different from a seated or an upright posture. In a study regarding comparison in facial soft tissue thickness between ultrasound system and multi-slice CT, De Greef et al. [7] stated that measurement differences were attributed to a difference in the subject's position, in other words, a supine position during CT scan.

Recently-developed cone-beam CT (CBCT) allows images to be obtained with the subject in an upright position. It provides a natural shape of the facial mask as the subject can be scanned in the seated position [8–10]. CBCT also produces images that are

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obtained with the natural head posture of the subject, making it useful for a study about the positions of the eyeball and canthi. In addition, it has been reported that the radiation dose is lower in CBCT scan compared with multi-slice CT [11–13]. Few studies are available on the 3D positions of the eyeball and canthi using CBCT images. The purposes of this study were to investigate the hard and soft tissue spatial relationships using CBCT images, and to generate regression models to predict the eyeball and canthi positions three-dimensionally.

2. Materials and methods

The subjects were selected from the graduate students at Chonnam National University in Gwangju, Korea. All subjects had Korean ancestry, and none of the subjects had undergone orthodontic treatment. The subjects with an abnormal body mass index, malocclusion, and dentofacial deformity were excluded. The individuals who were over 35 years old were also excluded due to the age-related changes on the face. One hundred students, 50 men (age range: 25.3–31.1 years; mean: 28.6 years; SD: 2.3 years) and 50 women (age range: 23.0–30.2 years; mean: 26.2 years; SD: 3.2 years) were enrolled in this study. This research was approved by the Institutional Review Board for Medical Science at the Chonnam National University Hospital, Gwangju, Korea.

2.1. CBCT scan and 3D image reconstruction

The CT scans were obtained using a CBCT scanner (Alphard Vega, Asahi Roentgen Co., Kyoto, Japan) under the following conditions: 80 kV, 8 mA, voxel size of 0.39 mm, and field of view of 200 (diameter) mm × 179 (height) mm. The subjects were scanned while seated with their eyes open and their face relaxed. To obtain a standardized volume data, the CBCT scans were obtained with the use of a reference ear plug (REP) and head posture aligner (HPA) [14]. Each REP with a 1.0 mm diameter titanium ball marker at its center was inserted into the subject's ear canal so that the two ball markers could be viewed in the 3D volume renderings. The HPA, which contained a fluid level equalizer with a pivot form and a wire indicator, was placed on the patient's left zygoma area. The fluid level equalizer was adjusted to register the degree of vertical head rotation at a natural head position.

Volume data for each subject were exported to InVivo 5® (version 5.1, Anatomage, San Jose, Calif) software, in DICOM (Digital Imaging and Communications in Medicine) format, and were used to render the 3D head images. To reorient the head image into the standard position, the two ball markers and the wire indicator were used. First, an imaginary line was constructed using the two ball markers, and the head image was rotated vertically using the imaginary line as a rotating axis until the wire indicator became parallel. The center point of the two ball markers was set to zero (x, y, and z = 0, 0, and 0) in the 3D coordinate system using the function of *patient orientation* in the program. Hard and soft tissue images were rendered by using the function of *bone* and *soft tissue* in the software, respectively. The Hounsfield units for the hard tissue were 720–750 and for the soft tissue, they were 1170–1195.

2.2. Measurements and reference planes

Three landmarks, pupil (P), medial canthus (MC), and lateral canthus (LC), were measured to represent the positions of eyeball and canthi. As the related hard tissue structures, nine landmarks were identified in the orbit, nasal bone, nasal cavity and maxillary canine (Fig. 1). The definitions of the landmarks are presented in Table 1.

To measure the 3D positions of the eyeball, canthi, and related hard tissue structures, reference planes were constructed in this study. First, the horizontal and vertical reference planes were established. The horizontal reference plane was constructed parallel to the wire indicator in HPA, passing through the two ball markers from the REP. The vertical reference plane was constructed perpendicular to the horizontal reference plane, passing through both ball markers as depicted in Fig. 2*A*. Also, reference planes were constructed for the orbit that included the medial orbital plane (MOP), lateral orbital plane (LOP), supraorbital plane (SOP), infraorbital plane (IOP), and orbital plane (OP) as depicted in Fig. 2B and C. OP was constructed parallel to a line connecting medial orbital margin (MOM) and lateral orbital margin (LOM), passing through supraorbital margin (SOM) and infraorbital margin (IOM). With the nasal bone and nasal cavity, nasion transverse plane, nasion coronal plane, nasal cavity plane, and anterior nasal spine (ANS) transverse plane were established as shown in Fig. 2D and E. The canine sagittal plane was constructed with the maxillary canine (Fig. 2F). All planes except

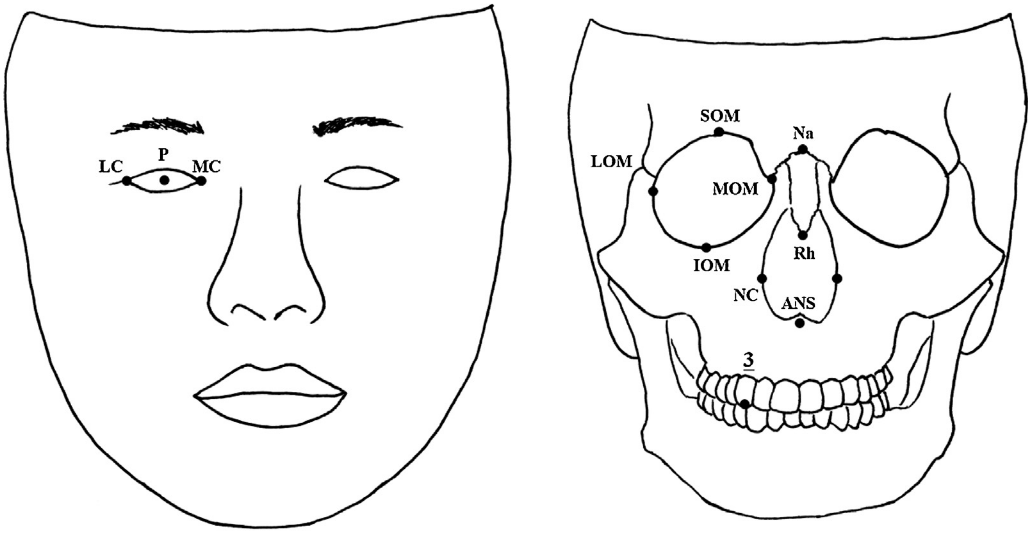

Fig. 1. Landmarks used in this study. P, Pupil; MC, medial canthus; LC, lateral canthus; SOM, supraorbital margin; IOM, infraorbital margin; MOM, medial orbital margin; LOM, lateral orbital margin; Na, nasion; Rh, rhinion; NC, nasal cavity; ANS, anterior nasal spine; 3̲, canine cusp tip. See Table 1 for definitions.

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