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Research Paper
Imaging

Fluctuating asymmetry of the normal facial skeleton

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Abstract. The purpose of this study was to produce reliable estimations of fluctuating facial asymmetry in a normal population. Fifty-four computed tomography (CT) facial models of average-looking and symmetrical Chinese subjects with a class I occlusion were used in this study. Eleven midline landmarks and 12 pairs of bilateral landmarks were digitized. The repeatability of the landmark digitization was first evaluated. A Procrustes analysis was then used to measure the fluctuating asymmetry of each CT model, after all of the models had been scaled to the average face size of the study sample. A principal component analysis was finally used to establish the direction of the fluctuating asymmetries. The results showed that there was excellent absolute agreement among the three repeated measurements. The mean fluctuating asymmetry of the average-size face varied at each anthropometric landmark site, ranging from 1.0 mm to 2.8 mm. At the 95% upper limit, the asymmetries ranged from 2.2 mm to 5.7 mm. Most of the asymmetry of the midline structures was mediolateral, while the asymmetry of the bilateral landmarks was more equally distributed. These values are for the average face. People with larger faces will have higher values, while subjects with smaller faces will have lower values.

Key words: fluctuating asymmetry; normal facial skeleton; computed tomography; Procrustes analysis; principal component analysis.

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The human face has bilateral symmetry, i. e. it can be divided in two, each part being the mirror image of the other[1,2]. Like in other biological forms, this symmetry is approximate[3–5]. Normal populations have small random variations in symmetry, called fluctuating asymmetry[2,6]. Certain individuals, however, have an asymmetric deformity, a condition where the asymmetry is so large that it is no longer considered normal[7].

There is at present no reliable cephalometric method to quantify asymmetric deformity. A logical way of measuring facial asymmetry is to compare the right and left facial halves after the halves have been superimposed. This superimposition requires four steps. In the first step, the face is split along the boundary outlined by all midline features. In the second step, one of the facial halves is flipped to create a mirror-image. In the third step, the mirror-image is moved until it is situated in the middle of the opposite half. In the fourth step, the moved image is rotated (about its center) until the difference between the two facial halves is minimal[8].

The above method works very well when the face has minor asymmetries, but it is inaccurate when the asymmetries are large. The problem is that the asymmetric regions of the face can skew the superimposition[9]. This problem can be avoided by assigning different weights to the different facial regions during the superimposition. For example, a facial region that is very asymmetric can be given low importance, while other more symmetric regions can be valued higher. To calculate these weights, however, one needs to know the fluctuating asymmetries of the normal population. Unfortunately, current available data are unreliable[1,10–19].

Prior studies of fluctuating facial asymmetry can be divided into two groups: old studies done on cephalograms and newer studies done on computed tomography (CT) scans. Old studies measured the skeletal asymmetries on cephalograms – radiographs that are taken with the head lined up in a cephalostat[10,11,13,15,17,19]. Unfortunately, the cephalostat places both external auditory canals in the same vertical and horizontal position causing an artificial alignment. This alignment minimizes any asymmetry that may be present near the ear, while maximizing the asymmetry of distal structures. Perhaps because of this phenomenon, some studies have shown that the cranial base is more symmetric than the rest of the face[13,14]. However, most conditions that produce facial asymmetry affect the mandibular condyles, the cranial base, or both (e.g., hemifacial macrosomia, unilateral condylar hyperplasia, and plagiocephaly).

Newer studies done on CT scans have avoided a cephalostat and have provided three-dimensional (3D) information; however the data are skewed for another reason: they measure the asymmetry using Cartesian coordinate systems[16,18]. Cartesian systems can be used to measure asymmetry, but only if they contain the subjects' real planes of symmetry. Finding these planes, however, is difficult. In the prior CT studies, the investigators erected their Cartesian frames using a few cephalometric landmarks[13,15–18]. This approach is flawed, because criss-crossing a frame of reference through some landmarks makes these landmarks symmetric, even if they are not. Also because, in any face, one can build hundreds of different frames depending on what cephalometric points are picked. Furthermore, each different frame of reference will yield a different study result[9].

It is clinically important in the treatment of patients with asymmetry to establish a threshold separating the normal subjects with fluctuating asymmetry (i.e., clinical symmetry) from the abnormal subjects with obvious asymmetry. However, in order to accomplish this, reliable estimations of fluctuating facial asymmetry in a normal population need to be established first. Such new estimations will provide important information to any investigator trying to develop a diagnostic test for facial asymmetry and convey to any clinician the size, distribution, and direction of normal facial asymmetry in future studies.

Materials and methods

Subjects

A collection of 54 CT facial models of normal-looking and symmetrical Chinese subjects was obtained from the digital archive at the Department of Oral and Craniomaxillofacial Surgery of Shanghai 9th People's Hospital, Shanghai, China. The models had been obtained for an unrelated study[20], and were de-identified in accordance with the Health Insurance Portability and Accountability Act (HIPAA), including the removal of the soft tissues of the face. Prior to initiating this study, the Institutional Review Board (IRB) was contacted and it was determined that no IRB approval was necessary.

In the original prospective study, the selection criteria for the normal subjects were as follows: (1) subjects with normal-looking, symmetrical and harmonic facial features; (2) subjects with no noticeable craniofacial asymmetry; (3) subjects with no history of orthodontic treatment, orthognathic surgery, cosmetic surgery, facial trauma, or temporomandibular disorder; (4) subjects with a normal overbite, overjet, class I occlusion, and complete dentition (except the third molars); and (5) subjects with no noticeable crowding, spacing, or upper and lower dental midline deviations[20]. The subjects were evaluated and selected together by three experienced oral and maxillofacial surgeons and three orthodontists. The full-head CT models of these normal subjects were obtained using a GE CT scanner (General Electric, Little Chalfont, UK), with a 25-cm of field of view, 512 × 512 matrix, and slice thickness of 1.25 mm. The CT data were segmented and a 3D bone model was reconstructed using Mimics software (Materialise NV, Leuven, Belgium). Each 3D model was divided into two pieces: a combined cranium and midface, and a mandible.

Landmarks

At the beginning of the study, the 3D models were imported into the software 3ds Max (Autodesk, San Rafael, CA, USA). In 3ds Max, a single investigator (T.L.J.) digitized 35 landmarks on each 3D model. Eleven midline landmarks and 12 pairs of bilateral landmarks were located (Table 1). Each landmark was situated on the surface of the hard tissue model, except for sella. Sella was located by first constructing the largest sphere that fitted the confines of sella turcica, and then by selecting the center of the sphere as sella. The three-dimensional Cartesian coordinates (x, y, z) of each landmark were transferred from 3ds Max into an Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA) following the right-hand rule (positive x, y, and z coordinates indicating left, posterior, and superior). A second investigator (K.C.C.) verified the transfer of data.

Error analysis

The repeatability of the landmark digitization was evaluated. For this, 10 models were selected using a random number table. The original investigator (T.L.J.) digitized all of the landmarks a second and a third time at intervals of more than 1 month. During the digitization, the previously digitized landmarks were hidden.

Three sets of coordinates were generated for each landmark. The overall intraclass correlation (ICC) with absolute