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3D-CT evaluation of facial asymmetry

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Objective. Recently, 3-dimensional−computed tomography (3D-CT) imaging has been used in the diagnosis and surgical treatment planning of patients with craniofacial deformities. The present authors have developed a 3D-CT imaging procedure for a 3-dimensional coordinate point evaluation system to assess and diagnose patients with facial asymmetry.

Study design. The CT data of 16 subjects was selected retrospectively as the control group from patients who had undergone CT examinations to diagnose conditions other than maxillofacial deformities. Anatomical landmarks modified from orthodontic craniometric (cephalometric) points were defined on the 3D-CT images and the asymmetry index of each point was calculated in millimeters. A diagrammatic chart with a baseline indicating the mean asymmetry indices plus the standard deviation in the control group was designed. The resulting diagrammatic chart was used to evaluate the degree of deformity in facial asymmetry patients.

Results and Conclusions. The topography of facial asymmetry was assessed. The 3D-CT imaging technique as described herein is a practical method of evaluating the morphology of facial asymmetry.

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Facial asymmetry is a relatively common feature in patients with craniofacial deformities. Traditionally, lateral and coronal (frontal) cephalometric radiographs have been the primary radiographic methods to analyze the morphology of the craniofacial bones. However, with these images it is difficult and sometimes impossible to evaluate facial asymmetry 3-dimensionally because of the many overlapping anatomical structures.

Recently, with the introduction of the spiral/helical computed tomography (CT) scanner, the clinical utility of 3-dimensional−CT (3D-CT) imaging for the diagnosis and surgical treatment planning of patients with craniofacial deformities has been reported.[1,2] Using 3D-CT imaging, the clinician can observe any of the craniofacial bones from various viewing angles with rapid and interactive repositioning of the 3D images. Although this feature is an advantage of 3D-CT imaging, 3D image-based measurements are not yet widely used in orthognathic surgery or for orthodontic treatment. In practice, a high level of accuracy is needed to use 3D image-based measurements and the accuracy of 3D-CT has been investigated and confirmed.[3-8] A 3D-CT image-based coordinate point evaluation system for facial asymmetry may therefore be useful in the diagnosis and surgical treatment planning of patients. To diagnose and evaluate the degree of deformity in facial

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asymmetry patients in a practical manner, it is necessary to compare the symmetry factor of craniofacial structures in patients with facial asymmetry with that of control subjects. In this study, we used a 3D-CT image-based coordinate point evaluation technique to define and delineate the symmetry factor of the craniofacial structures in control subjects. A diagrammatic chart was designed to delineate the symmetry factors of anatomical landmarks in control subjects. The primary goal of this study was to evaluate the degree of deformity in facial asymmetry patients compared with control subjects.

MATERIAL AND METHODS

Subjects

A control group of 16 subjects (12 males and 4 females) was retrospectively selected from patients who had undergone CT examinations to diagnose conditions other than maxillofacial deformities. These subjects were selected on the basis of the following criteria:

- The age at CT examination ranged from the late teens to early thirties.
- Anatomically, the region extending from the chin to the nasal bone was scanned in the CT examination.
- The first molars and central incisors were present and in function.
- The patient's teeth were positioned in centric occlusion during the scan.
- No craniofacial asymmetry in the initial hard tissue 3D-CT images was detected by a panel of 3 radiologists.

The diagnoses of the control subject group were as follows: maxillofacial injury without fracture, diffuse inflammation, soft tissue tumor, neuralgia, or unknown lesion.

Three patients with facial asymmetry that was corrected with orthognathic surgery were retrospectively examined using the present diagnosis and evaluation system. These patients were diagnosed with facial asymmetry by orthodontists using conventional procedures including a cephalometric radiographic analysis. The preoperative CT examination was performed between 1 month and 1 year prior to the corrective surgery.

CT data acquisition

The CT machine selected for this study was the X-Vision (Toshiba, Tokyo, Japan), which uses a helical scan to acquire the image. The protocol included images generated at 130 kV and 100 mA x-ray as well as a 3-mm rotation of the tabletop. The slice thickness of the reconstructed images was 3 mm with a 1.5-mm overlap. The image matrix size was 512×512 and the pixel size was approximately 0.3 mm. For most of the CT examinations, the occlusal plane was used as a reference line to avoid artifacts arising from metal restorations; however in several cases, the Frankfort horizontal plane (FHP) was used. The resultant image slice data were stored on a magneto-optical (MO) disk and then converted to create the 3D-CT images to be used for the coordinate point evaluation. Two Macintosh computer systems (Power Macintosh G3 and G4, Apple Computer Inc, Cupertino, Calif) were used to create the 3D-CT images.

Calculation of the symmetry factors

Anatomical landmarks modified from orthodontic craniometric (cephalometric) points were defined in the axial slice CT images as shown in Figure 1. The lower border of the midmandibular suture was defined as point Menton (M). The midpoint of the bilateral infraorbital margins was defined as point Orbitale (Or). The superior surface of the external auditory meatus was defined as point Porion (Po), and the most inferior and posterior points at the right and left angles of the mandible were defined as points Gonion (Go). Similarly, the pulp cavity of the upper and lower first molars (Fm), the crest of the alveolar ridge between the central incisors (In), the odontoid process of the epistropheus (Dent), the condyles (Co) of the temporomandibular joint (TMJ), the pterygomaxillary fissure (Pt), the sella turcica (S), the anterior nasal spine (Ans), the coronoid process (Cop), and the junction of the nasal and frontal bones in the midline (N) were selected. Image-editing software (Adobe Photoshop 5.5, Adobe Systems Inc, San Jose, Calif) was used to draw the above craniometric points on the axial images. The VoxBlast rendering system (VayTek, Inc, Fairfield, Iowa) and a volume rendering technique were used to create the 3D images.

To evaluate skeletal asymmetry, a 3D reference plane joining points S, N, and Dent was selected as the midsagittal (x) reference plane. The coronal (y) and axial (z) reference planes were defined as being perpendicular to the midsagittal plane. The axial reference plane included points S and N, and the coronal reference plane included the Dent point. Observing the 3D images from the reference planes, the distances between each anatomical point and the 3 planes were measured in millimeters and defined as dx, dy, and dz. The differences in the values of dx, dy, and dz between the right and left sides were considered as the elements of a 3D vector. The asymmetry index of each bilateral point, that is the length of 3D vector, was calculated using the following formula, where R = right and L = left:

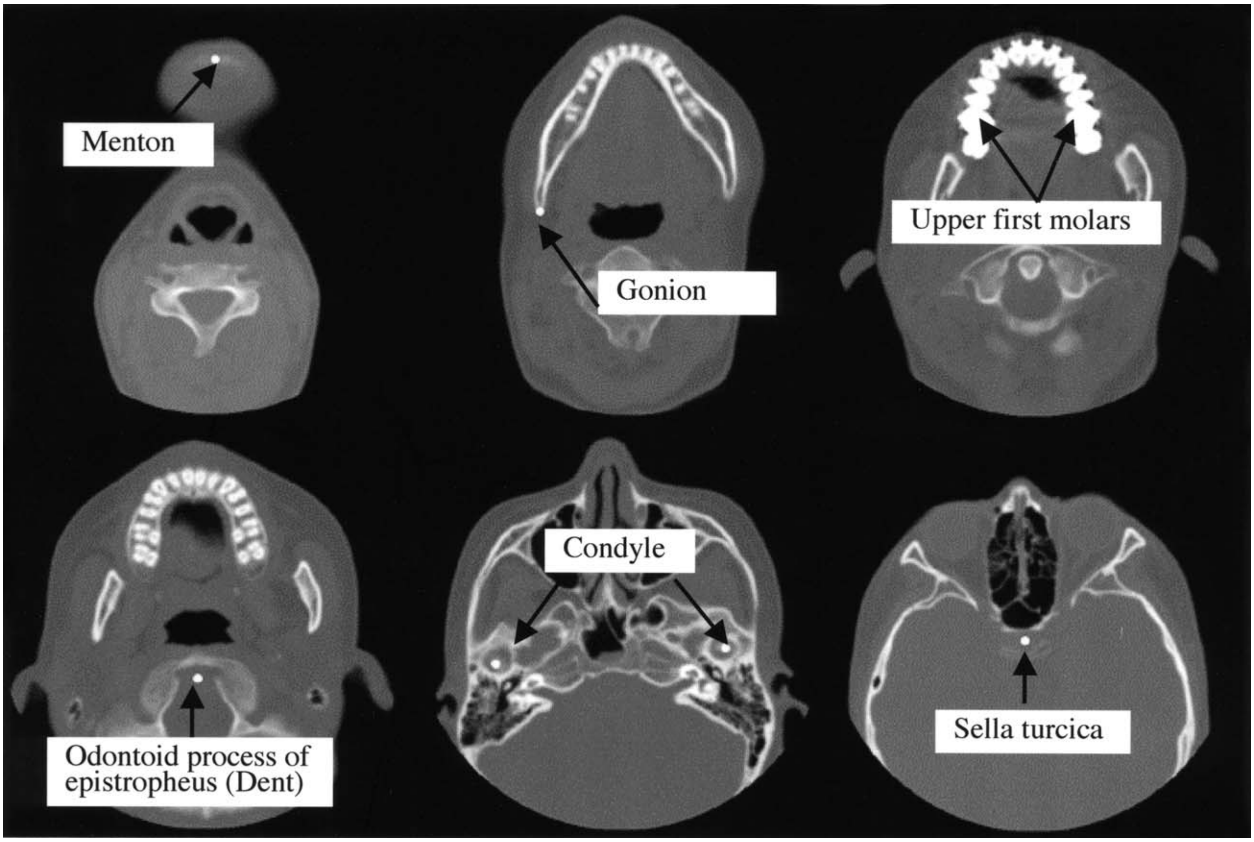

Fig 1. Selected anatomical landmarks as defined in the axial slice CT images.

Asymmetry index

$$= \sqrt{(\mathrm{R\,dx} - \mathrm{L\,dx})^2 + (\mathrm{R\,dy} - \mathrm{L\,dy})^2 + (\mathrm{R\,dz} - \mathrm{L\,dz})^2}$$

As there is no difference in the dy and dz values between the right and the left sides for solitary paramedial points in this instance, we assigned dx to the asymmetry index. Figure 2 shows a schematic image of the selected 3D reference planes and the linear measurements of dx, dy, and dz from the left Gonion (Go) point.

Before these calculations were finalized, interobserver precision for errors in the linear measurements of dx, dy, and dz was tested. Five cases were selected randomly from the control group. The measurement procedure (ie, from the landmark identification to the linear measurements) was repeated twice by different observers.

RESULTS

Control subjects

The errors in linear measurement precision were expressed as the following coefficient of variance values: 4.6% for dx, 3.2% for dy, and 2.2% for dz.

The mean asymmetry indexes of the anatomical points in control subjects are shown in Table I. The mean asymmetry indices of the anatomical points ranged from 0.8 to 4.6, and the standard deviation ranged from 0.7 to 1.7. The asymmetry index and standard deviation of point Gonion (Go) were larger than for the other anatomical points, while those of the anterior nasal spine (Ans) were the smallest. Figure 3 shows a graph indicating the mean asymmetry indices and mean asymmetry indices plus the standard deviation of each anatomical point as lines. This diagram was used to evaluate the degree of deformity in facial asymmetry patients.

Facial asymmetry subjects

We classified asymmetric anatomical points using the special criteria as shown in Figure 3. A baseline indicating the mean asymmetry indices plus the standard deviation in control subjects was used as the threshold to define an anatomical point as asymmetric or not. We defined an anatomical point as asymmetric when the asymmetry index was larger than the baseline value. Similarly, when an anatomical point demonstrated

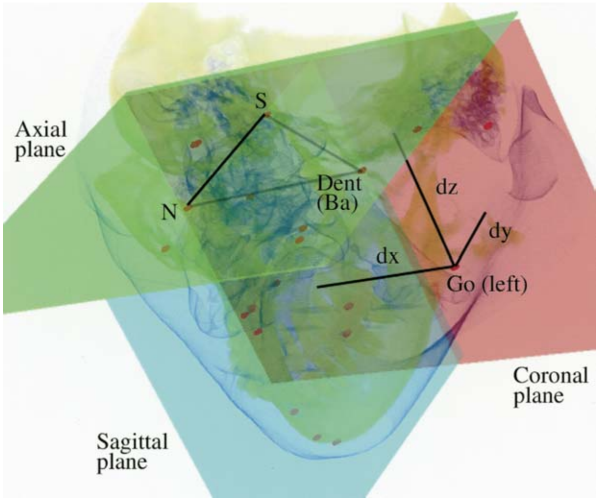

Fig 2. Three-dimensional reference planes and linear measurements of dx, dy, and dz of the left Gonion (Go) point. Midsagittal (x), coronal (y), and axial (z) reference planes are shown in green, red, and blue, respectively.

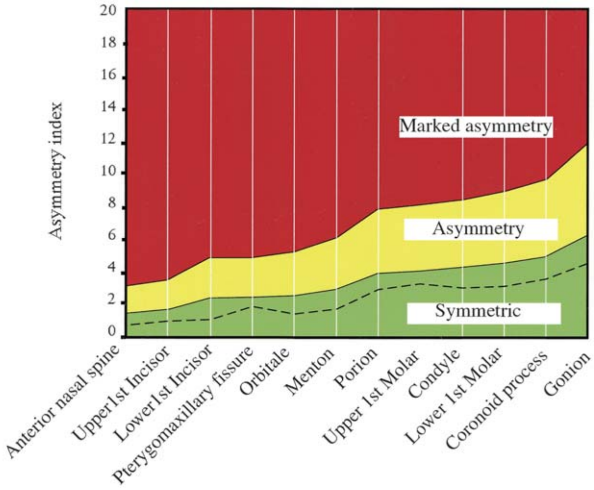

Fig 3. A diagrammatic chart to classify the degree of deformity in facial asymmetry patients. When the asymmetry index of a patient's anatomical point was in the green, yellow, and red areas, the point was diagnosed as "Symmetric," "Asymmetry," and "Marked asymmetry," respectively. A line between the green and the yellow areas indicates the mean asymmetry indexes plus the standard deviation of each anatomical point (baseline). Another line between the yellow and the red areas indicates twice the baseline value. The dotted line indicates the mean asymmetry indexes.

Table I. Asymmetry index of measurement landmarks in control subjects (n = 16)

	Mean	*SD*
Anterior nasal spine	0.8	0.7
Upper central incisor	0.9	0.8
Lower central incisor	1.2	1.2
Pterygomaxillary fissure	1.9	0.5
Orbitale	1.7	0.8
Menton	1.8	1.1
Porion	2.7	1.0
Upper 1st molar	3.1	1.0
Condyle	2.9	1.4
Lower 1st molar	3.2	1.4
Coronoid process	3.7	1.3
Gonion	4.6	1.7

an asymmetry index greater than twice the baseline value, we defined it as marked asymmetry. For anatomical points that revealed marked asymmetry, the degree and the direction of the deviation were studied based on the data from the 3D (dx, dy, and dz) measurements.

Figures 4 to 6 show the 3D-CT images and diagrammatic charts of the asymmetry indices of 3 facial asymmetry subjects.

Case 1. The subject is a 20-year-old female. The 3D-CT images and diagrammatic charts revealed the presence of marked asymmetry in the lower central incisor, Menton, and lower first molar. Although points Gonion and the upper first molar were also asymmetric, they did not reach the marked asymmetry level. In this case these findings suggest the asymmetry was present mainly in the body of the mandible (Fig 4).

Results from measurements indicated that the lower central incisor was shifted 6 mm to the left of the midsagittal reference plane. Similar deviations were seen in Menton (10 mm) and in the lower first molar (14 mm).

Case 2. The patient is a 26-year-old male. Here marked asymmetry was present in the following points: lower central incisor, Menton, condyle, lower first molar, coronoid process, and Gonion (Fig 5). In this case, Menton was shifted 13 mm to the right from the midsagittal reference plane. As compared with the opposite side, right Gonion was positioned 15 mm laterally, 21 mm superiorly, and 3 mm anteriorly.

Case 3. This person is a 20-year-old female. Marked asymmetry was present in the lower central incisor, Menton, and lower first molar points (Fig 6). In this case, not only anatomical points in the mandible but also points in the maxilla such as upper central incisor and first molar showed marked asymmetry. The following points revealed shifts to the left side: 11 mm for Menton, 9 mm for the lower central incisor, and 5 mm for the upper central incisor. As compared to the opposite side, the upper left first molar was positioned 9 mm latero-inferiorly.

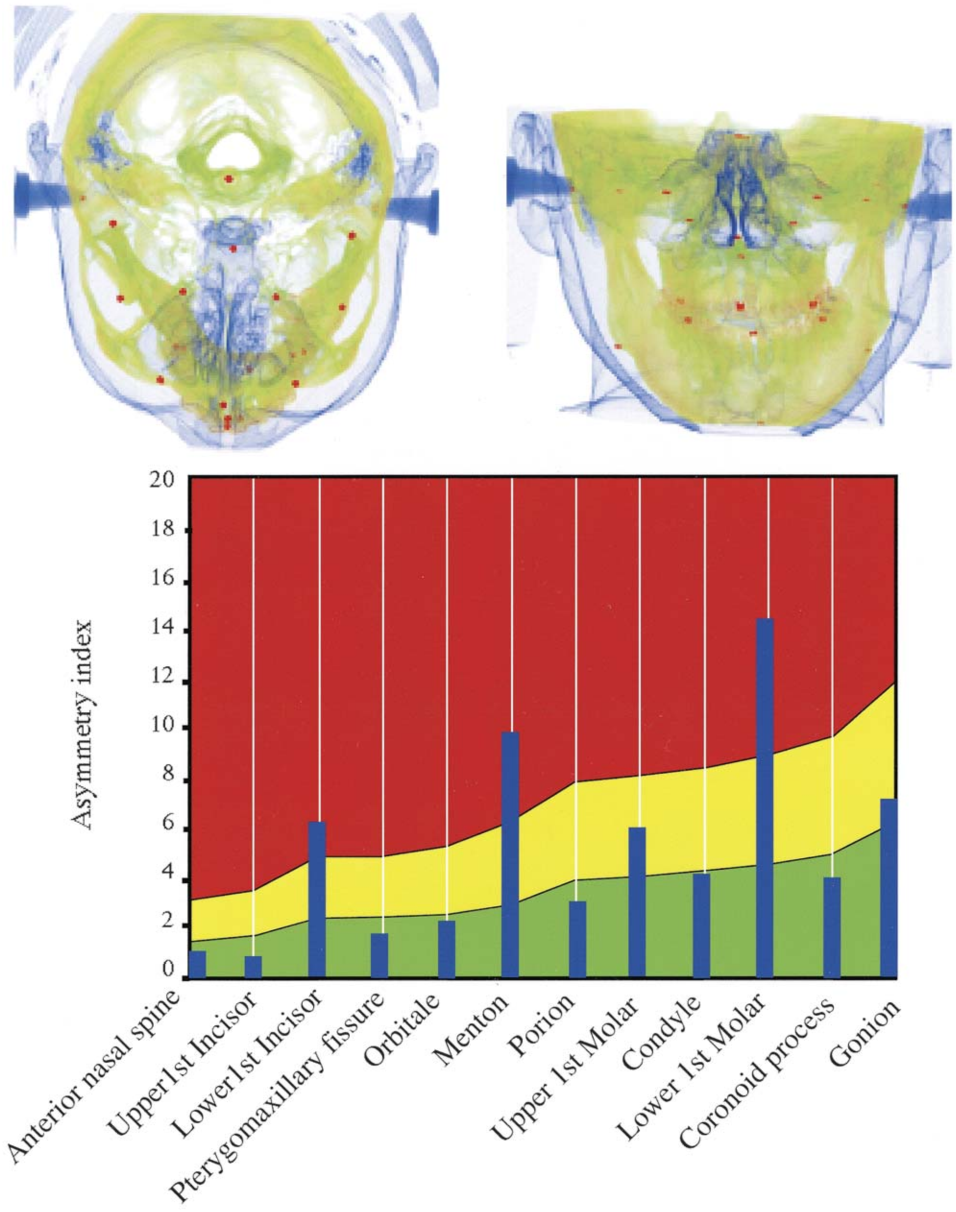

Fig 4. Case 1, a 20-year-old female patient. Marked asymmetry was present mainly in the mandibular body.

DISCUSSION

The most common conventional images used for the analysis of craniofacial anomalies are cephalometric and panoramic radiographs. As it is difficult to make a distinction between right and left side anatomical landmarks on a lateral cephalometric view, mainly coronal (posteroanterior [PA]) cephalometric radiographs have been used in the quantitative assessment of facial asymmetry.[9-11] Rachmiel et al[11] performed measurements based on coronal cephalometric images. The horizontal plane at the level of the fronto-zygomatic suture, defining a line connecting bilateral latero-orbitals and a vertical line perpendicular to the horizontal line through the crista galli were employed as horizontal and vertical reference lines. The degree of shift (deviation) in the midmandible point, the degree of deviation of the occlusal plane from the horizontal plane, the ratio of the bilateral mandibular ramus height, and others were measured to evaluate facial asymmetry. The reliability of the quantitative analysis of the symmetry factor using coronal cephalometric radiographs is limited. First, in the coronal cephalometric view, it is difficult to identify

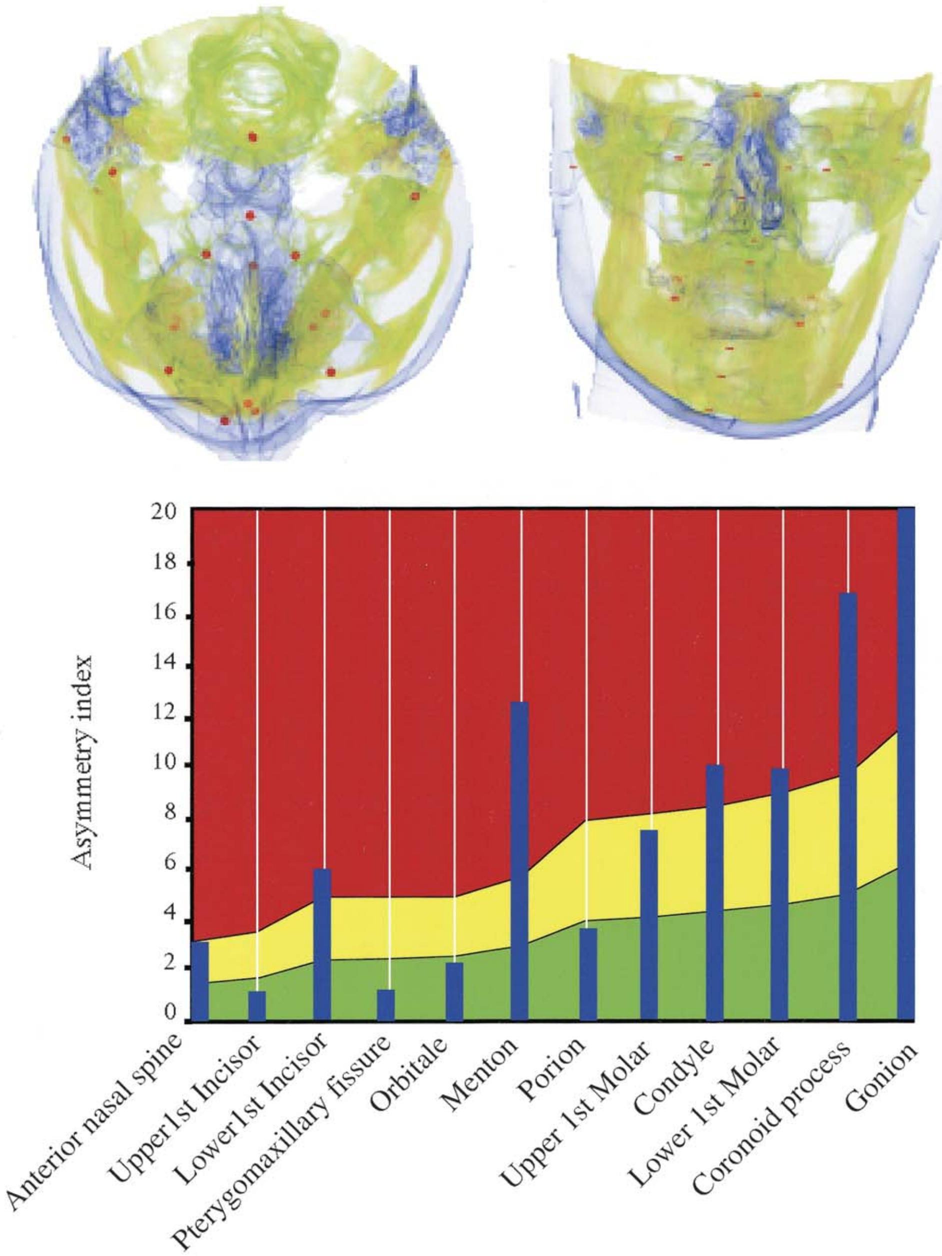

Fig 5. Case 2, a 26-year-old male patient. The predominant type of facial asymmetry was shown to be in the mandibular ramus.

anatomical landmarks on the posterior part of the skull, such as the sella and basion points, because these are overlaid or obscured by the more anterior anatomical structures. This means the 3D midsagittal reference plane, based on the anatomy of the cranial base, could not be used as the evaluation basis for absolute facial asymmetry. Second, as head positioning for cephalometry is based on the external auditory meatus, asymmetric external auditory meati may modify the symmetry factor of other anatomical structures. For these reasons, it may be difficult to reach any conclusion regarding the actual measurement of symmetry factors using frontal cephalometric radiography. A simplified 3D computer graphic image of a patient's facial skeleton has been generated using coordinates corresponding to anatomical landmarks that can be seen in conventional frontal and lateral cephalograms.[12,13] The problem with this latter approach is that only anatomical landmarks that are well defined on both the frontal and lateral cephalograms are visible. As a solution to these imaging

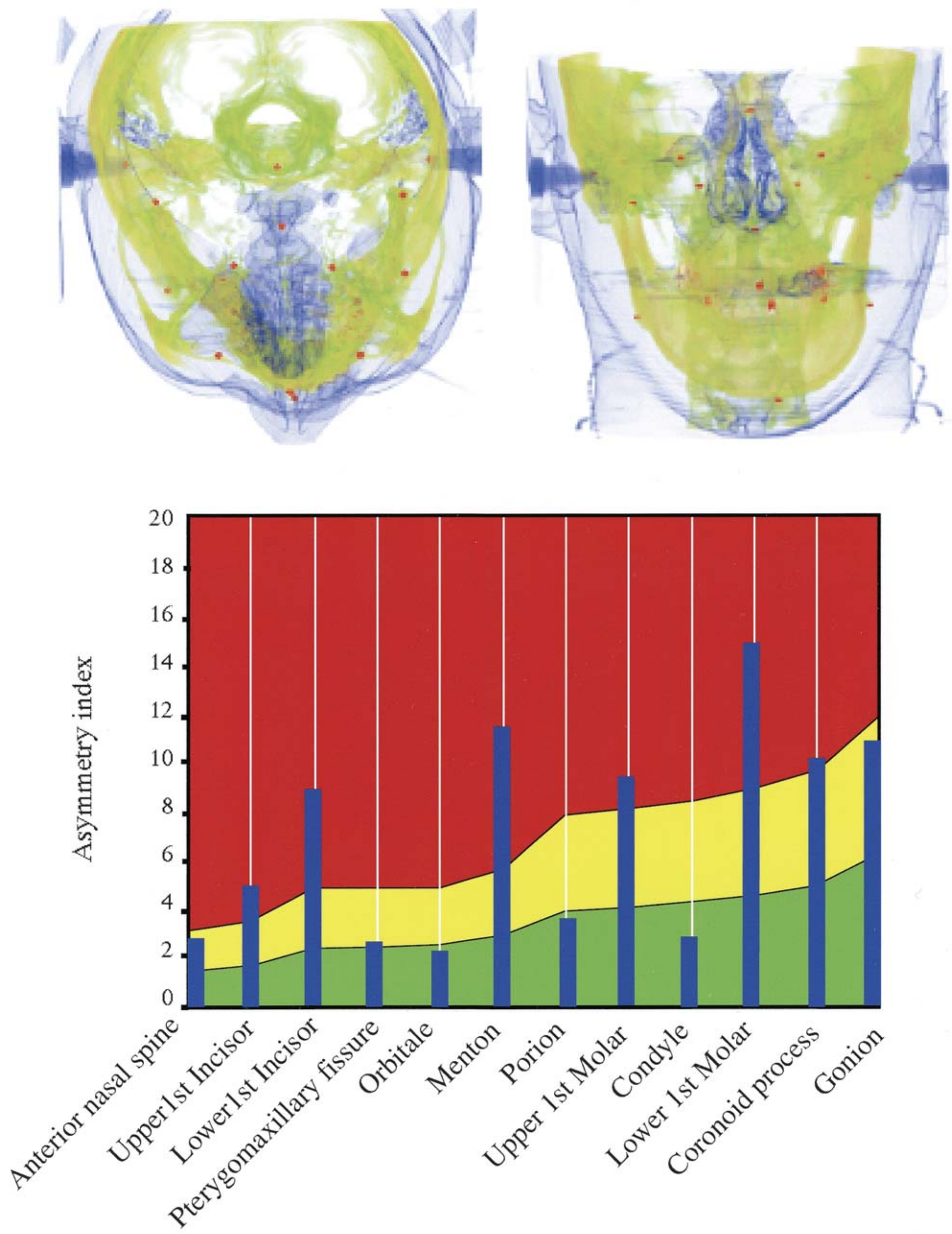

Fig 6. Case 3, a 20-year-old female patient. Anatomical points in both the mandible and maxilla were asymmetric.

problems, 3D-CT analysis will be indispensable in this type of study.

Panoramic radiographs are also used to evaluate asymmetry.[14] Although the length and angles cannot be measured accurately on the panoramic view, it may be a practical method to compare the left and right sides. Habets et al[14] measured the condyle and ramus heights in panoramic radiographs and reported a significant difference between patients in a routine dental group and those treated for craniomandibular disorders regarding condyle height symmetry.

Unlike cephalometric and panoramic radiographs, with 3D-CT images there are no problems with structure superimposition, and the absolute position of anatomical landmarks could be defined. Furthermore, it is possible to produce images that can be viewed from any aspect, such as orthogonal viewing angles from 3D reference planes. The accuracy and reproducibility of 3D-CT has been confirmed. In earlier studies in which conventional nonspiral/helical whole body CT scanners were used, Matteson et al[3] and Hildebolt et al[4] measured the skull using 3D-CT and reported favorable results.

Nowadays, spiral/helical CT scanners have improved the accuracy of linear measurements in the z or vertical axis. Faster scanning speeds also appear to have had an impact on the accuracy of 3D images in patients because a shorter scan time can greatly reduce motion artifacts. Several authors have studied the reliability and accuracy of spiral/helical CT-based 3D images and have reported high measurement accuracy.[5-8]

As mentioned previously, an appropriate midsagittal reference plane based on the anatomy of the cranial base was needed to evaluate absolute facial asymmetry. Ono et al[15] designed a 3D-CT morphological analysis system that they termed "skeletograms" in which the craniofacial bones are delineated. In our study we applied the same midsagittal reference plane consisting of the sella, nasion, and basion points. This procedure differs from conventional radiographic analyses because the horizontal reference plane may be first defined in cephalograms. Although our midsagittal reference plane may become obscured in cases of severe deformities of the cranium, it is an available parameter for the majority of the cases of maxillofacial deformity treated by orthognathic surgery.

For this study we selected defined anatomical landmarks in the axial CT images as modified from cephalometric points. The points on the 3D-CT images do not precisely represent the same points on lateral and coronal cephalograms. In cephalograms, many landmarks are defined as the uppermost or lowermost point of structures, such as point Menton and the inferior orbital rims. A point on the edge of a structure in a lateral cephalogram may not correspond to the same point in the coronal cephalogram. For example, 2 different areas of the osseous rim tangent to the 2 different x-ray beam projections represent the uppermost or lowermost points of a structure in the lateral and coronal cephalograms respectively. On the other hand 3D-CT coordinate points are located in the 3D space and can be used in any view that pinpoints the exact same anatomic locus.

It was not unusual to find that in normal subjects with objective and/or subjective symmetric maxillofacial features, a slight asymmetry in their craniofacial structures was revealed. The results of this study showed that point Gonion has a discrepancy of approximately 5 mm between the left and right sides and point Menton shifts approximately 2 mm to the right or left side in subjects with average features. The relatively small sample size of 16 control patients is one disadvantage of this report. However, healthy young people are no longer permitted to undergo CT examinations without a specific diagnostic prescription. We reviewed over 3000 sets of CT image data of the maxillofacial region to identify subjects with a normal craniofacial morphology and only 16 sets of data met the criteria we established. To augment the number of control subjects, a multi-institutional collaboration would be necessary to gather additional CT-image data sets.

In our analysis of facial asymmetry patients, we defined an anatomical point as asymmetric when the asymmetry index was larger than the mean asymmetry indices plus the standard deviation in control subjects. Using previous reports,[14,16] a formula to calculate the asymmetry index was designed. In the evaluation of craniofacial morphology, the asymmetry index was often expressed as a percentage to exclude interindividual differences in size. In this study, we did not express the asymmetry index as a percentage because it was impossible to compare the right and left sides for solitary paramedial points. In addition, we did not distinguish between the affected and nonaffected sides because insufficient normative CT data to define the "ideal" coordinate point of each anatomical landmark were available. However, using the coordinate point data from this study, it may be possible to identify the optimal surgical relocation of landmarks to reposition them symmetrically.

Recent progress in orthognathic surgical techniques and orthodontic treatments such as bone transplantation and intraoral distraction for craniofacial deformities[17] has led to an increased demand for more advanced diagnostic image information other than that available from conventional radiography. Three-dimensional life-sized medical models based on CT data can be used to design orthognathic surgical procedures.[17,18] As the CT image data involves both hard and soft tissue structures, 3D-CT images allow visualization of the surfaces of soft tissues such as muscle surfaces. Ariji et al[19] studied the morphology of the masseter muscle in patients with mandibular prognathism using 3D-CT. In follow-up studies of maxillofacial deformities, we designed a technique to superimpose the postoperative 3D-CT image onto the preoperative image, and evaluated postoperative condylar displacement in the TMJ.[20] In addition, we employed a volume rendering technique and designed semitransparent and cutoff 3D-CT images to observe morphologic airway changes after mandibular setback osteotomy for prognathism.[21] One advantage of 3D-CT imaging is that various newer or different images and models can be created with the repeated use of stored complete CT image slice data sets. Thus it is possible to establish an integrated 3D-CT image-based diagnosis and evaluation system for maxillofacial deformities by combining the above techniques. The present 3D coordinate point evaluation system for facial symmetry will play an important part in this integrated system. In the near future a potential exists for the powerful diagnostic capabilities of 3D-CT images to replace conventional radiographic examinations.

However, reducing the radiation dose to patients in spiral/helical CT scanning without impairing image quality is a goal to be achieved as soon as possible.

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