Clin Oral Invest (2011) 15:729–736
DOI 10.1007/s00784-010-0441-7

ORIGINAL ARTICLE

Three-dimensional evaluation of craniofacial asymmetry: an analysis using computed tomography

Rosa María Yáñez-Vico · Alejandro Iglesias-Linares · Daniel Torres-Lagares · José Luis Gutiérrez-Pérez · Enrique Solano-Reina

Received: 26 January 2010 / Accepted: 29 June 2010 / Published online: 15 July 2010

Abstract 3D image technology provides a very effective tool for evaluating, characterising, and drawing up the surgical treatment plan for potential orthognathic surgery patients. Patients with dysmorphic syndromes or incorrect jaw positions frequently show facial asymmetry. The objective of this cross-sectional survey is to evaluate facial asymmetry by means of three-dimensional computed tomography (CT) reconstructions. Twenty one consecutive patients were diagnosed using a CT scan. 3D reconstructions of the patients' skulls were made and then measurements taken of different craniometric landmarks and of the various structures presenting asymmetry. The gonion emerged as the most asymmetrical point in all subjects, and the anterior nasal spine showed least deviation. The *t* test produced statistically significant differences ($p<0.05$) between symmetric and asymmetric patients at all landmarks. The lateral inclination of the mandibular ramus was shown to present the greatest asymmetrical deviation, followed by the frontal inclination of the mandibular ramus. The angulation of the mandibular ramus, on both frontal and lateral planes, determines apparent facial asymmetry, as well as conditioning the surgical treatment plan for patients with craniofacial asymmetry.

Keywords Craniofacial asymmetry · 3D-computed tomography · X-ray diagnosis · Cephalometry · Maxillofacial surgery · Orthodontics

R. M. Yáñez-Vico · A. Iglesias-Linares
School of Dentistry, University of Seville,
Seville, Spain

D. Torres-Lagares · J. L. Gutiérrez-Pérez · E. Solano-Reina
Department of Stomatology, University of Seville,
Seville, Spain

D. Torres-Lagares (✉)
School of Dentistry of Seville,
C/Avicena s/n 41009,
Seville, Spain
e-mail: danieltl@us.es

Introduction

Facial asymmetry is a relatively common feature in patients with maxillomandibular deformities about to undergo orthognathic surgery. In addition, there are numerous dysmorphic syndromes associated with craniofacial abnormality, most of which show severe mandibular asymmetry [1, 2]. However, slight asymmetries of the basic structures are also frequently found, although their presence is not clinically significant. Even today, there is no consensus about exactly what degree of deviation from symmetry should be considered normal for patients who are to undergo surgery.

The conventional diagnosis of craniofacial asymmetry is generally made on the basis of a clinical and radiological evaluation. Most images used for this purpose are frontal cephalography, submentovertex, and panoramic X-rays [3]. However, with this kind of record, it is difficult—at times impossible—to obtain a three-dimensional assessment of the asymmetry, because of superposition of anatomical structures, difficulties in detecting deformities in the midface region, and inherent magnification. Furthermore, head positioning may modify the factors of symmetry.

Analysing the craniofacial complex has improved recently with the development of three-dimensional image technology [4], since the three-dimensional images obtained from computed tomography enable us to observe any one of the craniofacial bones from different angles. For this reason, our main objective is to use 3D reconstructions of computed tomography (CT) to evaluate facial asymmetry. To complement this, the morphological characteristics of craniofacial structures in patients with facial asymmetry are evaluated to determine and quantify possible factors contributing to the appearance of facial asymmetry.

Materials and methods

Subjects

Twenty one subjects, 11 female ten male, were retrospectively selected from the Virgen del Rocío University Hospital and the Faculty of Dentistry, both in Seville, Spain; their mean age was 38.38±9.24. The present study was carried out with the full knowledge and written consent of each subject and in accordance with the ethical principles governing medical research and human subjects, as laid down in the Helsinki Declaration (2002 version, www.wma.net/e/policy/b3.htm). The data has been treated with absolute confidentiality. Methods of gathering and storing data are subject to the Spanish Organic Law governing personal data protection (Ley Orgánica de Protección de Datos de Carácter Personal). The Ethical Committee for experimentation in the University of Seville (Spain) independently approved the procedure. The criteria for inclusion were: that a CT scan had been performed on the subject during diagnostic testing; that the CT was of sufficient quality and had a minimum extension from the nasion to menton points; and that the patient had given informed consent. The sample was subdivided into two groups, based on the presence or non-presence of facial asymmetry, the latter being understood as a menton deviation of more than 4 mm from the facial midline [5]. These groups were: the control group (n=10; mean age: 37.87±9.01) and the asymmetrical group (n=11; mean age: 38.45±9.87).

Processing and image acquisition

To evaluate the structural geometry of the craniofacial complex, a multi-slice helical *LightSpeed* (General Electric Healthcare, Spain) scanner was used, generating images at 120 kV tube voltage, 120 mA tube current, 8-s scan time, 0.625 mm slice thickness. Data was stored in DICOM format and transferred to two hard discs with storage capacities of 80 and 150 GB, respectively.

To convert the data into three-dimensional images, a personal computer (Intel® Core™2CPU ASUSTeK Computer Inc, Germany) was used, with the Windows XP (Microsoft Corporation, USA) operating system.

The converted DICOM reconstructions and measurements were carried out with VirSSPA software 1.0 (SSPA, Spain), which enables both the craniofacial skeleton and the patient's skin to be reconstructed. This software is being developed by the Andalusian Health Service (Servicio Andaluz de Salud) in Spain and is still at the experimental stage.

Reference planes

To standardise the orientation of the three-dimensional image, reliably localised landmarks were established in accordance with our objectives and using recent scientific evidence [6]. These landmarks were: a reference point located equidistant to the points located in the centre of each foramen spinosum (ELSA); right/left bilateral points located on the supero-lateral border of the external auditory meatus (SLEAM); the mid-dorsal point of the foramen magnum (MDFM).

To evaluate skeletal asymmetry, we took a plane in the 3D model linking the bilateral SLEAM and ELSA as the horizontal (xy) reference plane. The sagittal reference plane (yz) was defined perpendicularly to the horizontal plane, passing through ELSA and MDFM. The coronal reference plane (zx) included the MDFM landmark and was perpendicular to the sagittal and horizontal planes (Fig. 1).

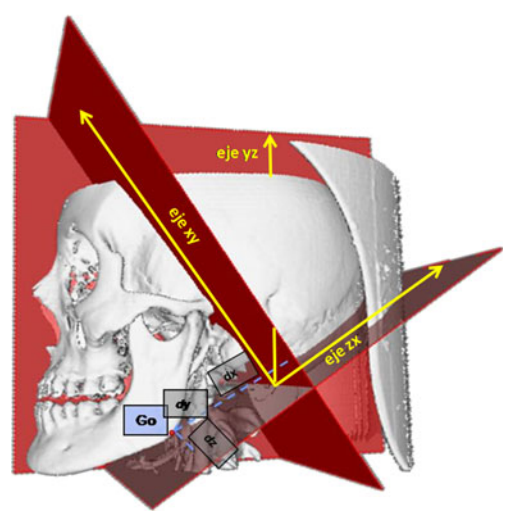

Fig. 1 Reference planes and calculation of asymmetry index. Reference planes used: *xy, yz, zx* axes. Measurement of the asymmetry index for the left gonion: *dx* (distance to *xy* plane), *dy* (distance to *yz* plane) and *dz* (distance to *zx* plane)

Table 1 Anatomical landmarks used to calculate asymmetry index

Point	Definition
Menton (Me)	The lowest point of the jaw at the level of the midsagittal plane of the symphysis
Orbitale (Or)	The point coinciding with the lowest point of the lower edge of the orbitale
Porion (Po)	The uppermost external point of the external auditory meatus
Gonion (Go)	The lowest, most posterior point on the gonial angle of the mandible
Condylion (Co)	The uppermost point of the mandibular condyle
Sella (S)	Point representing the centre of the pituitary fossa
Anterior nasal spine (ANS)	The most anterior point of the nasal spine on the upper jaw
Coronoid process (Cop)	Upper end of the coronoid process
Nasion (N)	Most anterior point of the frontonasal suture on the midplane

Landmarks

The anatomical points to be analysed in the 3D models created are shown in Table 1.

Asymmetry index

The distances in centimetres between each of the previously defined anatomical points in the three planes were measured directly on the generated 3D model, using the measurement tools included in the software. These measurements were defined as *dx*, *dy*, and *dz*. The differences in *dx*, *dy*, and *dz* values between right and left sides were considered to be elements of a three-dimensional vector. The asymmetry index for each bilateral point was the length of the three-dimensional vector, as previously defined by Katsumata et al. [7], and calculated according to the following formula:

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

with *dx* being the distance from any one point to plane *xy*, and *dy* the distance from any one point to plane *zx*; R was measured on the patient's right side, and L on the patient's left side (Fig. 2). At paramedian points, there is no difference between right and left sides for values *dx* and *dz*, so that, in such cases, the asymmetry index was calculated from *dy*.

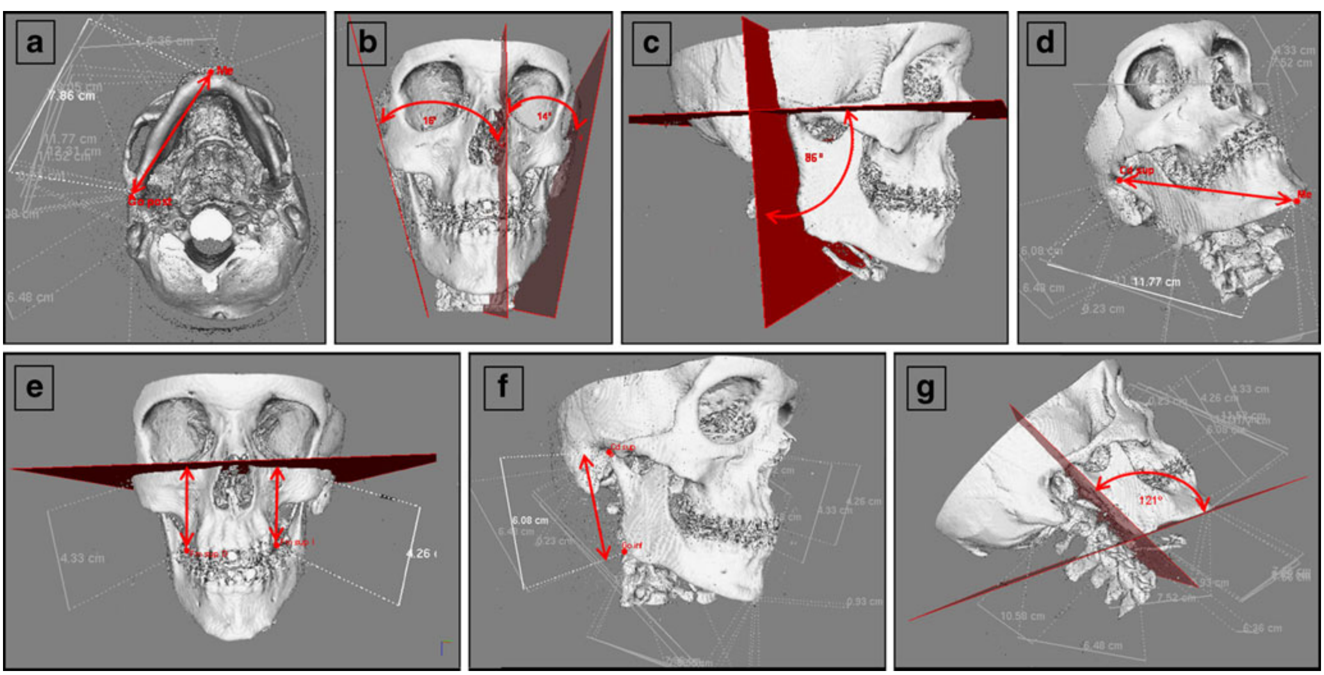

Fig. 2 Causes of asymmetry. **a** Mandibular body length, **b** frontal inclination of mandibular ramus, **c** lateral inclination of the mandibular ramus, **d** mandibular length, **e** maxillary height, **f** mandibular ramal height, **g** mandibular angle

Identifying the presence of asymmetry

The following values, as modified by Hwang et al. [8], were measured as factors contributing to facial asymmetry (where bilateral, both were measured; Fig. 2):

- Ramal height: the distance between the highest point of the condyle head (Cdsup) and the lowest point of the gonial region (Goinf; mm)
- Mandibular body length: the distance between the most posterior point of the gonial region (Gopost) and the lowest point of the mandibular symphysis (Me; mm)
- Mandibular length: Mandibular length is the distance between Cdsup and Me (mm)
- Mandibular angle: is defined as the angle formed by the most lateral point of the condyle head and the most lateral point of the gonial region (Cdlat-Golat) with Me-Goinf (º)
- Maxillary height: from the pulp cavity of the upper first molars (Fmsup) to the Frankfort horizontal plane (Po-Or-Po) (mm)
- Frontal ramal inclination: Cdlat-Golat to the midsagittal reference plane (*yz*), the angle formed by the midsagittal reference plane and the external border of the ramus (º)
- Lateral ramal inclination: the angle formed by the most posterior points of the condyle head and the gonial region (Cdpost-Gopost) with the Frankfort plane (º)

Distances between points and angles were calculated between the three-dimensional coordinates of the skeletal structures, thus eliminating errors due to magnification or head position.

Reliability of the method

To prevent interobservational error, all the previously defined procedures were carried out by the same operator. Errors in the localization of landmarks during 3D image processing were evaluated by comparing the coordinate differences on the three planes in space, angle and linear measurements for ten randomly chosen patients, separated by a 2-week interval. Method error was calculated in the following way: $SE = \sqrt{(\sum d^2/2n)}$, where d is the difference between the double measurements and n the number of paired double measurements [9].

Statistical analysis

The data obtained was analysed using SPSS 14.0 software for Windows (LEAD Technologies, USA).

Univariate analysis of the results consisted of a descriptive analysis of the quantitative variables (mean and standard deviation), with a 95% confidence interval. For the bivariate analysis, intraobservational error was calculated for a random group of ten patients drawn from the sample, who were tested twice at an interval of 2 weeks. It was calculated using the Student's *t* test for paired samples, with absence of significance regarded as indicative of concordance between mean values.

The differences between the two groups (control and asymmetrical) were compared in the bivariate analysis with 95% significance after verifying randomness, using the Student's *t* test for independent samples (the Wald-Wolfowitz runs test at $p>0.05$ for all variables in both groups) and for normality (the Shapiro-Wilk test for normality at $p>0.05$ for all variables in both groups).

The Pearson correlation coefficient was calculated to evaluate the strength of association between the variables of the different craniofacial structures.

Results

The accuracy of intraobservational error was 0.78, 1.05, and 1.07 mm for the *x*, *y*, and *z* coordinates, respectively, and likewise 1.36 mm for linear measurements and 0.91º for angle measurements. There were no statistically significant differences between original and repeat measurements ($p>0.05$).

In the control group, the gonion presented the greatest index of asymmetry, followed by the coronoid. The most stable was the anterior nasal spine, followed by the sella and nasion points. Table 2 shows the asymmetry indices for both control and asymmetrical groups, and the statistical differences between them ($p<0.05$ for all variables).

The subjects of the asymmetrical and control groups coincided, both in the distribution of landmarks with the highest asymmetry indices (gonion and coronoid) and with the most stable (anterior nasal spine). The menton point was the third in the asymmetry index for these subjects. The *t* test showed statistically significant differences of $p<0.05$ for each one of these landmarks (Table 2).

In the control group, Pearson's correlation coefficient was significant at $p<0.05$ (two tailed) for the menton-anterior nasal spine (0.676). In the asymmetrical group, the coronoid process and the condyle were negatively correlated (−0.687) at $p<0.01$ (two tailed), while the structures at the base of the skull, such as sella and nasion, were positively correlated (0.753) at $p<0.01$ (two tailed; Table 3)

The various anatomical structures of the asymmetrical subjects were analysed in order to identify the greatest asymmetrical deviations as factors contributing to craniofacial asymmetry. The results showed that the lateral ramal inclination was the angular relationship with the greatest deviation (mean difference between right and left: 14.35± 0.54º), followed, in descending order, by the frontal ramal

Table 2 Comparison of asymmetry indices of anatomical points for control and asymmetrical groups

Variables	Control group (n=10)		Asymmetrical group (n=11)		P
	Mean	SD	Mean	SD	
Orbitale (Or)	0.2650	0.0998	0.3573	0.0542	0.015
Porion (Po)	0.3480	0.1331	0.8936	0.0928	<0.001
Anterior nasal spine (ANS)	0.0250	0.0127	0.1445	0.0411	<0.001
Menton (Me)	0.1880	0.0790	1.2291	0.0903	<0.001
Gonion (Go)	1.7270	0.0873	2.0864	0.0743	<0.001
Condyle (Co)	0.3430	0.0657	0.6282	0.1535	<0.001
Coronoid (Cop)	0.9260	0.1090	1.8100	0.0885	<0.001
Sella (S)	0.0300	0.0115	0.5136	0.0463	<0.001
Nasion (N)	0.1030	0.0226	0.1973	0.0496	<0.001

P value indicates statistically significant differences between control and asymmetrical groups

inclination (3.02±0.4º) and the mandibular angle (2.87±0.88). With regard to linear relationships, the deviations were, in descending order: mandibular length (0.9±0.33 mm), mandibular body length (0.62±0.18 mm), ramal height (0.34±0.25 mm), and maxillary height (0.07±0.03 mm; Table 4).

The correlations between the structures and craniofacial dimensions that possibly affect the asymmetry of subjects with clinically apparent facial asymmetry and craniometric landmarks are shown in Table 5. The asymmetry index of the menton correlates positively with asymmetry of the frontal ramal inclination (r=0.711, p<0.05) and negatively with mandibular body length (r=−0.81, p<0.01), such that the greater the asymmetry of the menton, the greater the difference between the frontal inclinations of both ramuses (left and right) and the greater the symmetry between left and right mandibular body lengths. The lateral ramal inclination correlates positively with the porion (r=0.827, p<0.01) and gonion points (r=0.683, p<0.05).

Discussion

Most images used to analyse and diagnose abnormalities of the craniofacial complex are X-rays, particularly lateral and panoramic views. It is, therefore, somewhat problematic to distinguish between the various anatomical points of right and left sides. Furthermore, two-dimensional X-rays have inherent limitations, such as elongation or distortion of the image, which may lead to a wrong diagnosis. Grummons and Kappeyne van de Copello [10] used frontal analyses to study asymmetry and found that the cephalometric measurements were subject to distortion as a result of the projection technique, and could not be used for either quantitative or comparative purposes. Given that a quantitative measurement is critical to a diagnosis of asymmetry, the use of a two-dimensional X-ray should clearly not be regarded as valid.

Rachmiel et al. [11] took measurements from frontal images. For horizontal and vertical reference lines, a horizontal plane was taken at the level of the frontozygomatic suture passing through the orbitales on both sides and intersected by a perpendicular vertical line passing through the crista galli. Using this, they mainly evaluated the degree of shift in the midmandible point, the degree of deviation of the occlusal plane with respect to the horizontal reference line, and the difference between ramal heights. The main limitations were identifying anatomical landmarks such as the sella and basion points located in the posterior part of the skull, due to superposition and obscuration by more anterior anatomical structures. This means that, in studies of this type, a reference plane based on the anatomy of the base of the skull should not be used.

Developments in CT and information technology give us easy access to three-dimensional images of the craniofacial

Table 3 Correlations between landmarks in asymmetrical subjects

	Or	Po	ANS	Me	Go	Co	Cop	S
Po	−0.351							
ANS	0.068	−0.501						
Me	−0.084	−0.060	0.460					
Go	−0.374	0.405	−0.570	−0.427				
Co	−0.320	−0.077	0.295	0.246	−0.382			
Cop	0.491	0.192	−0.341	−0.601	0.465	**−0.687**[a]		
S	0.095	0.392	0.059	0.080	−0.405	0.129	−0.083	
N	−0.281	0.489	−0.131	0.078	−0.288	0.056	−0.307	**0.753**[a]

[a] Significant correlation in bold to 0.01 level (two tailed).

Table 4 Descriptive analysis (mean and standard deviations) of factors contributing to craniofacial asymmetry

Variables	Asymmetrical group	
	Mean	SD
Lateral ramal inclination	14.3573	0.05424
Frontal ramal inclination	3.0273	0.40023
Mandibular angle	2.8727	0.88215
Mandibular length	0.9	0.33968
Mandibular body length	0.6291	0.18881
Ramal height	0.3473	0.2566
Maxillary height	0.0782	0.03868

complex; CT images enable us to visualise both the soft tissues and the skeletal structure in three dimensions [12]. The accuracy of three-dimensional CT reconstructions (3D-CT) is sufficiently high for the linear measurements [13, 14]. Cavalcanti et al. [14] researched the accuracy of these by comparing the results of linear measurements on 3D-CT images with physical measurements taken on corpses. They concluded that the difference between the two measurements was minimal and that the 3D images were of high precision. In studies using helical CT, Matteson et al. [15] and Hildebolt et al. [16] measured the skull using 3D-CT, and reported favourable results. Building on these advantages, we developed a 3D-CT image system for evaluating facial asymmetry.

The choice of a correct reference plane poses a real problem for analysing the three-dimensional images and also for assessing craniofacial asymmetry, since it is essential for the basic structures not to be affected by the deformity. The bilateral SLEAM landmarks, MDFM, and ELSA were used to standardise plane orientation for the 3D images. The external auditory meatus has been proposed as a stable landmark for analysing craniofacial asymmetry because its shape remains stable [17]. The ELSA point is also considered suitable for standardising the three-dimensional image [18]. These four points are located in the middle and posterior cranial base, so that using them gives greater stability when comparing the changes brought about by treatment, for example, since this region reaches more than 85% of its total size by the age of [19–21]. In addition, high reproducibility has been demonstrated when these points are localised in three-dimensional images [6]. Using plane standardisation also eliminates the effect of head positioning when the image is made.

To assess the degree of asymmetry, the asymmetry indices were compared with those of the control subjects. Every landmark studied presented statistically significant differences when the means of the asymmetry indices for the control and asymmetry groups were compared (Table 2). It was discovered that, in symmetrical subjects, asymmetries of the menton point were also accompanied by asymmetries in the location of the anterior nasal spine. This fact favoured the facial appearance of symmetry in those subjects because both the maxillary (anterior nasal spine) and the mandibular (menton) landmarks were found, in a frontal view, to deviate in the same direction.

However, the supposedly symmetrical control subjects also showed slight traits of asymmetry. The results of the present study show a mean deviation of 17.2 mm between the right and left hand sides of the gonion point in these patients (Table 2). Most of these differences, with the exception of the anterior nasal spine and menton, are greater than those in Katsumata's study [7]. These differences may be conditioned by the use of different reference planes in the two studies, although it should be pointed out that Katsumata et al. [7] carried out landmark identification on axial CT images, while ours were based on a reconstruction of the three-dimensional image.

In asymmetrical subjects, the sella and nasion points were positively correlated (r=0.753; p<0.01) in such a way that these structures in the cranial base shift with each other; there was, however, no correlation between these landmarks and structures manifesting asymmetry. These results differ from those found by Kwon et al. [22] for

Table 5 Correlations between landmark asymmetry index and factors contributing to asymmetry

Pearson's correlation coefficient	Orbitale	Porion	ANS	Menton	Gonion	Condyle	Coronoid	Sella	Nasion
Ramal height	0.473	−0.397	0.158	0.349	−0.444	−0.147	−0.073	−0.371	−0.201
Mandibular body length	0.077	−0.180	−0.350	**−0.81**[b]	0.020	0.105	0.249	−0.077	−0.036
Mandibular length	−0.364	−0.287	0.250	0.049	−0.130	−0.149	−0.115	−0.037	0.104
Mandibular angle	−0.323	0.236	−0.116	−0.328	0.364	−0.579	0.274	0.361	0.436
Maxillary height	−0.411	0.275	0.194	0.446	0.298	−0.250	−0.031	0.044	0.156
Frontal ramal inclination	0.192	−0.552	0.520	**0.711**[a]	−0.561	0.167	−0.550	−0.437	−0.345
Lateral ramal inclination	−0.249	**0.827**[b]	−0.375	−0.209	**0.683**[a]	−0.280	0.406	0.217	0.220

[a] Significant correlation in bold to 0.05 level (two tailed)

[b] Significant correlation in bold to 0.01 level (two tailed)

symmetrical and asymmetrical subjects, and by Hayashi [23] for symmetrical subjects. In their studies, a clear relationship was reported. This fact is probably due, firstly, to the sample size which would need to be increased in order to reinforce the statistical trends and attain statistical significance, and secondly, to the different methodologies used. Furthermore, it would be advisable to amplify the description of the anterior cranial base, rather than concentrating solely on the sella and nasion points.

Identifying the structures implicated in clinically observable apparent facial asymmetry is extremely important for drawing up the treatment plan for surgery. Chin deviation may have various causes. We considered seven variations as possibilities (modified from Hwang et al. [8]), to do with both length (mandibular length, mandibular body length, maxillary height, ramal height) and angulation (frontal and lateral inclinations of the mandibular ramus, mandibular angle). The results showed that the structure with greatest deviation between right and left sides was the lateral ramal inclination, which, additionally, correlated positively with asymmetry of the gonion. In the light of the results, however, the frontal ramal inclination (the second most deviated structure) correlates positively with the facial appearance of asymmetry, with the menton being considered the most critical landmark for facial appearance [3]. It is important to bear this in mind during the surgical treatment of the patient, so that, once orthodontic-surgical corrective treatment has been carried out, they do not suffer from specific asymmetrical features which cause them to feel particularly self-conscious [8]. Other authors [11, 24] have already stated that evaluation of the ramus may influence choice of surgical treatment.

To sum up, the diagnosis of craniofacial asymmetries may be performed using conventional radiographic methods, although three-dimensional methods are necessary for a more complete diagnosis. Using the proposed method with three-dimensional reconstructions, the gonion emerged as the most asymmetrical landmark in all subjects. Possible causes of greater symmetrical deviations included the lateral inclination of the ascending ramus, followed by the frontal inclination of the same structure, this separate angulation being crucial to apparent facial asymmetry in the subjects. For subjects liable to orthognathic surgery, it is important to identify the structures involved in the facial appearance of asymmetry in order to handle the patient correctly in surgery. The system developed in the present study contributes data which is helpful in making a reliable diagnosis for the orthodontic surgery of patients with facial deformities.

Acknowledgements The authors gratefully acknowledge funding granted to the Department of Stomatology (CTS-523; CTS-353) by the Research Institute of the University of Seville (Spain).

The authors wish to thank Dr. Esther Sánchez Cobo for her technical assistance and Dr. David González Padilla, Medical Director of Maxillofacial Surgery, Virgen del Rocío Hospital, for permission to use the facilities required for the study.

Funding sources This work was supported by a grant to the Department of Stomatology (CTS-523) (CTS-353) awarded by the Research Institute of the University of Seville (Spain). The development of the virtual reality tool for planning and optimising surgical treatment is jointly funded by the Consejería de Salud de la Junta de Andalucía [the Regional Health Ministry for Andalucía] and the European Union (FEDER).

Conflict of interest The authors declare that they have no conflict of interest.

Authors' contributions Dr. Yáñez Vico has contributed to all stages of the research and manuscript preparation. Dr. Iglesias Linares contributed to literature research, data collection and statistical analysis. Dr. Torres Lagares contributed to study design, organised the research and reviewed the manuscript. Dr. Gutiérrez Pérez and Dr. Solano Reina have contributed to the revision and editing of the manuscript.

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