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A computerized photographic assessment of the relationship between skeletal discrepancy and mandibular outline asymmetry

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SUMMARY The aim of this study was to investigate the relationship between mandibular outline asymmetry and skeletal discrepancy in a sample of orthodontic patients (33 females, 33 males) aged from 8 to 19 years. Skeletal discrepancy was assessed in both the anteroposterior and vertical planes, using standard cephalometric analyses. All were photographed under standardized conditions and the photographs were then digitized for analysis using a computerized system to assess differences in four variables (area, perimeter, compactness and moment-ratio) between the right and left sides of the mandibular outline.

The results showed good repeatability of the photographic, cephalometric and digitization methods. A statistically significant relationship was found between mandibular outline asymmetry and both anteroposterior and vertical skeletal discrepancy in this sample, when compared with patients with an average skeletal pattern. There appeared to be a statistically significant relationship between a reduced ANB angle (<3 degrees) and mandibular outline asymmetry ($P = 0.051$), as well as between an increase in lower face height and mandibular asymmetry ($P = 0.023$).

Introduction

There is little information in the literature as to the relationship between mandibular asymmetry and skeletal pattern, from either the anteroposterior or vertical aspect. Anecdotally, it has been suggested that there is an increased incidence of mandibular asymmetry in patients with a Class III skeletal discrepancy (Reyneke *et al.*, 1997). Severt and Proffit's (1997) retrospective study of orthognathic patients identified those with Class II skeletal patterns as being the least asymmetric.

Mandibular asymmetry has been shown to alter during mandibular growth, and longitudinal studies have shown that it can be variable over time (Melnik, 1992). This was disputed by both Namano *et al.* (2000) and Ferrario *et al.* (2001) who found no relationship between age and mandibular asymmetry, but this may be a result of the many different aetiologies of asymmetries. Haraguchi *et al.* (2002) attributed this inconsistency in the literature to the different research methods used in investigating mandibular asymmetry. Quantitative measurement of the degree of mandibular asymmetry is important, both in the initial assessment of an individual patient and particularly for monitoring patients over time, to be able to accurately record the degree of any change in asymmetry through growth or treatment. Quantification of mandibular asymmetry is also essential in auditing the results of treatment methods (i.e. in groups of patients) and for research purposes. It would also be helpful for clinicians to be able to grade asymmetry, as is currently undertaken for other dimensions of skeletal and dental discrepancy. Chebib and Chamma (1981) recognized the need for an index of facial asymmetry, and described the use of a two-axis co-ordinate system and its application via a computer program, developed for use on postero-anterior (PA) radiographs. Indeed the PA cephalogram has been widely reported in the literature as being beneficial in the assessment of both mandibular and facial asymmetry, with a multiplicity of analyses used (Thompson, 1943; Mulick, 1965; Letzer and Kronman, 1967; Solow and Tallgren, 1971; Vig and Hewitt, 1975; Shah and Joshi, 1978; Cook, 1980; Chebib and Chamma, 1981; Major *et al.*, 1994; Martins de Araujo *et al.*, 1994). Methods of analysis of PA cephalograms have been described to quantitatively evaluate vertical, transverse and sagittal dimensions of the craniofacial complex (Ricketts, 1981; Grummons and Kappayne van de Coppello, 1987). However, routine use of measurements taken from the PA cephalogram has been limited, mainly due to difficulty in landmark identification (Cook, 1980; Pirttiniemi *et al.*, 1996; Athanasiou, 1999). Similarly, other radiographic films that have been used in the assessment of mandibular asymmetry, such as the submentovertex, have been criticized (Peck *et al.*, 1991).

Although radiography has been the most common choice for previous studies in this field, recent work has demonstrated standardized photography to be as useful clinically (Edler *et al.*, 2001, 2002, 2003). Coghlan (1996) and Coghlan *et al.* (1987, 1993) showed the use of standardized photography in the assessment of alar base asymmetry in patients with cleft

lip and palate, and Greenhill *et al.* (2000) designed computer software to assess asymmetry of the mandibular outline from photographs. Other methods described in the literature include comparison of anthropometrical measurements, and three-dimensional methods such as stereophotogrammetry. A variety of three-dimensional scanning techniques could be considered for this type of study (e.g. Ferrario *et al*., 1994; Hajeer *et al*., 2004), but currently, access to the facilities would limit the majority of clinicians from using the method. Therefore, conventional photography was chosen for this study, as it is non-invasive, inexpensive, and an accessible technique of proven validity.

The aim of this study was to identify the possibility of a relationship between mandibular outline asymmetry and skeletal discrepancy in a sample of orthodontic patients, using digitized facial photographs. A positive outcome could subsequently provide the basis for a wider investigation.

Subjects and methods

Patient sample

Sixty-six patients (33 female, 33 male) ranging in age from 8 to 19 years (mean age 12 years, 10 months) were selected for this study from new patient clinics, or as they were taken off the waiting list at Kingston Hospital, Surrey, UK. To be included in the sample, the patients' records required a lateral cephalogram, taken within the previous six months by the radiography department at Kingston. The patients were photographed by one of the authors (SG) before the start of orthodontic treatment. The sample was selected so as to provide comparable numbers of patients with Class I, Class II and Class III skeletal patterns.

Photographic procedure

Photographs of the samples were taken under standardized conditions, as suggested by Strauss *et al.* (1997) and Claman *et al*. (1990), using a 35 mm Canon 300 EOS camera, with a Canon 1:1 lens and a Canon ring flash (Canon UK Ltd, Reigate, Surrey). The camera settings were uniformly set at an f-stop of 4.5, with shutter speed at 1/60th of a second, and a focal length of 1 metre. The same Fuji 100 ASA transparency film was used for each patient, then developed and mounted at the Fuji laboratory (Fuji Photo Film (UK) Ltd, London). The patients were given identical instructions, including tying back hair to allow visualization of the inferior ear insertions. Large earrings were removed. The patients were asked to stand straight with their toes just behind a line drawn on the floor, look straight at the camera with visual axis horizontal, and remain expressionless. The line on which the patients stood was 30 cm in front of an unlit light box, and 1 metre behind a second line from which the photograph was taken. To avoid shadows, the patient was asked to hold an A4 size card covered with crushed metallic foil, with both hands at the level of the clavicles, which reflected ambient light back under the chin. Two photographs were taken of each patient. Whilst Edler *et al.* (2001) used complex lighting methods, in the present study the lighting method was deliberately kept simple. Once developed, the slides were checked and the 'cleaner/most suitable' of the two was scanned. Selection was made on the basis of good mandibular outline definition, no tilting or rotation of the head, and the absence of facial expression.

Computerized assessment

The slides were scanned using a Hewlett Packard Desk Scan II flatbed scanner (Hewlett-Packard Co., Palo Alto, CA, USA) with Paint Shop Pro (Jasc software, Eden Prairie, Minnesota, USA) on a Pentium based PC. Each image was cropped, colour and brightness adjusted, and saved as a bitmap file. These digitized images were then imported to the Image Processing Tool program as described by Greenhill *et al.* (2000) and Edler *et al*. (2001) for analysis (Figure 1). This involves using the mouse to mark the inferior insertion of the ears on both the left and right side, on the digitized image. The computer constructs a line separating the lower part of the face into left and right segments. The mandibular outline is traced using the mouse to click on between 45 and 55 points from right to left ear insertions. Inaccurate points can be deleted and corrected as necessary. Once a satisfactory outline has been traced the program calculates a series of results using the '*x*-axis' method described by Greenhill *et al*. (2000):

A function of the perimeter of left and right segments of the face (L); of the areas of the left and right segments of the face (A), i.e. comparing the relative sizes of the segments and of the 'compactness' of the left and right sides of the face (C). Compactness is the square of the perimeter divided by the area and provides a measure of shape (Gonzales and Woods, 1993). The lowest value possible is for that of a circle, 4π, and as the value of compactness approaches this figure the complexity of the shape decreases.

The moment-ratio (M per cent). The centroid (centre of area of both sides combined) was identified and its distance from the point of bisection of line A measured and divided by the length of line A. This was then multiplied by 100 to provide a percentage.

The system has a resolution of 0.001. Perfect symmetry for the calculations of perimeter, area and compactness would be 1.000, and 0.000 for the moment-ratio.

Radiographic methods

Lateral cephalograms were taken at Kingston Hospital radiography department. Standardized methods were used. The patients were positioned whilst standing in the cephalostat with the Frankfort plane horizontal to the floor. Each radiograph was hand-traced, by the same clinician (SG), to identify nasion, point A, point B, anterior nasal spine, posterior nasal spine, menton and angle ANB. Lower

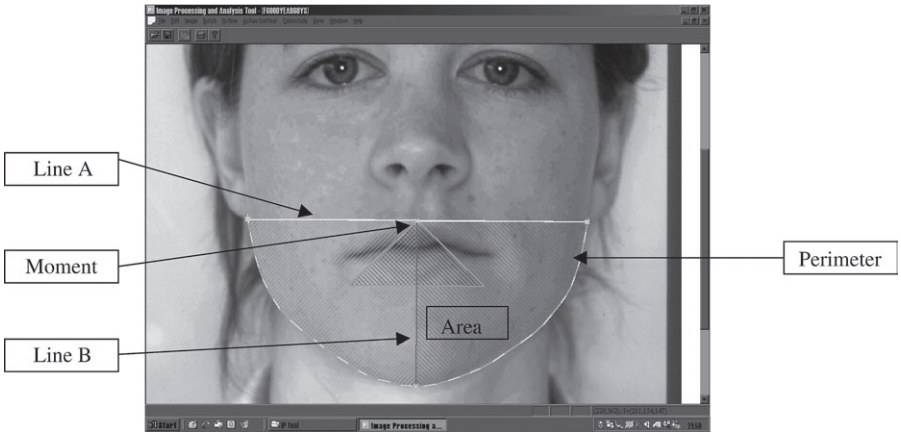

Figure 1 Digitization of mandibular outline. Parameters measured: Line A, constructed from the right to the left inferior insertion of the ears (Otobasion inferius); Line B, separating the lower part of the face into left and right sides. The line bisects line A and is perpendicular to it at this point; Perimeter, constructed from the right to the left inferior insertion of the ears (*Otobasion inferius*) defining the outline of the mandible; Area, the area of the mandiblular outline defined by line A and the perimeter and divided into right and left sides by line B; Moment, the moment triangle is constructed from the centroid of the left mandibular area to the centroid of the right mandibular area. These points are then connected to midpoint of line B. The construction of this area enables the moment-ratio to be calculated.

anterior face height (LAFH) and total face height (TFH) measurements were also traced. The patients were classified as Class I, Class II or Class III on the basis of their ANB value. Patients with an ANB value of 3–4 degrees were classified as Class I, those with an ANB value above 4 degrees as Class II, and those with and an ANB value of less than 3 degrees as Class III. The skeletal pattern classification is presented in Table 1. Similarly, the patients were classified as having either average (LAFH 53 to 55 per cent of total face height), reduced (less than 53 per cent of total face height) or increased (over 55 per cent of total face height) anterior face height. Lower face height (ANS–menton) was calculated as a percentage of TFH (nasion–menton; Bhatia and Leighton, 1993). The distribution within the sample is also presented in Table 1.

Repeatability

To assess repeatability of the photographic method, 12 patients were chosen randomly from the orthodontic sample to be re-photographed. Additionally, a sample of 12 scanned images and 14 lateral cephalograms were randomly chosen to be re-digitized or re-traced, respectively.

The results of each of the repeatability tests were analysed using the method described by Bland and Altman (1986). In order to identify those patients with an asymmetric outline, the following criteria were used: for area difference, a value greater than 2.49 per cent; for compactness difference, a value greater than 1.49 per cent; for length difference, a value above 2.49 per cent; and for moment-ratio, a value above 1 per cent. The area and compactness values were approximately equivalent to the difference ratio values used in an earlier study (Edler *et al*., 2001).

Table 1 Skeletal classification within the patient groups.

	n = 66
Class I	31
Class II	18
Class III	17
Increased LAFH (%)	13
Average LAFH (%)	36
Decreased LAFH (%)	17

LAFH, lower anterior face height.

Statistical methods

Fisher's exact test for 2 × 2 tables was used to compare proportions between different groups. Repeatability was assessed using the method of Bland and Altman (1996).

Results

No relationship was seen between LAFH percentage and skeletal classification (Figure 2). The Class I group was used as a control group for comparison with the Class II and III groups (Table 1).

Class I versus Class III

Comparison was made between the patients who showed asymmetry in area, length, compactness or moment percentage in the Class III group and those in the Class I group. In the Class III group, there were six asymmetric patients (35 per cent) compared with a total of three (6 per cent) in the Class 1 group. This was significant ($P = 0.051$; Table 2a).

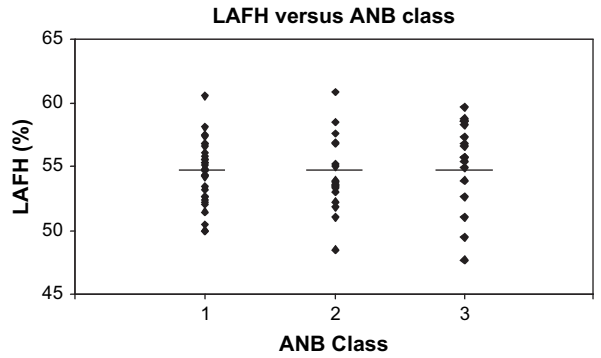

Figure 2 Lower anterior face height (LAFH) percentage versus skeletal classification. The horizontal lines show the mean LAFH percentage for each group.

The same comparison was made using only those patients with area asymmetry of the mandibular outline. There were four patients in the Class III group (23 per cent) compared with only 1 (2 per cent) in the Class I group. This was significant ($P = 0.047$), although the number of asymmetric patients being analysed was low.

Class I versus Class II

There were three patients (10 per cent) in both the Class I and Class II groups whose results showed asymmetry in area, length, compactness or moment percentage [$P = 0.656$; not significant (ns); Table 2b]. Only one patient in each of these groups showed asymmetry in the area of the mandibular outline ($P = 1.00$; ns).

Comparison was made between the different LAFH percentage groups:

Normal LAFH versus reduced LAFH: When all asymmetries (area, length, compactness, and moment-ratio) were considered, of the 17 patients with a reduced LAFH percentage, four (24 per cent) demonstrated asymmetry. This was compared with three patients in the group with an average LAFH percentage ($P = 0.193$; ns; Table 3a).

Normal LAFH versus increased LAFH: Comparing the groups of patients with asymmetry in any of the four variables, there were five (38 per cent) asymmetric patients out of 13 with an increased LAFH percentage compared with three asymmetric patients (8 per cent) out of 36 in the normal group ($P = 0.023$; Table 3b).

Repeatability

When compared with the criteria for assessing asymmetry, repeatability was considered to be good for the digitising technique [standard deviation (SD) of differences for area difference index = 0.002]. Repeatability was also considered to be good for the digitization of repeated photographs (SD of the area difference index = 0.008). Similarly, repeatability was good for cephalometric tracing, as represented by the reproducibility of the measurement of ANB angle (SD of the differences = 0.62) and LAFH percentage (SD of the differences = 0.64).

Table 2a Comparison of the incidence of asymmetry in any of the four variables (area, length, compactness and moment-ration) between the Class I and Class III groups.

	Asymmetry	No asymmetry*	Total
ANB <3	6	11	17
ANB 3, 4	3	28	31
Total	9	39	48

*All asymmetries, $P = 0.051$.

Table 2b Comparison of the incidence of asymmetry in any of the four variables (area, length, compactness and moment-ration) between the Class I and Class II groups.

	Asymmetry	No asymmetry*	Total
ANB <3	3	15	18
ANB 3, 4	3	28	31
Total	6	43	49

*All asymmetries, $P = 0.656$.

Table 3a Incidence of asymmetry in any of the four variables (area, length, compactness and moment-ration) in patients with an average or reduced lower anterior face height (LAFH).

LAFH (%)	Asymmetry	No Asymmetry*	Total
<53	4	13	17
53–57	3	33	36
Total	7	46	53

*All asymmetries, $P = 0.193$.

Table 3b Incidence of asymmetry in any of the four variables (area, length, compactness and moment-ration) in patients with an average or increased lower anterior face height (LAFH).

LAFH (%)	Asymmetry	No asymmetry*	Total
>57	5	8	13
53–57	3	33	36
Total	8	41	49

*All asymmetries, $P = 0.023$.

Discussion

The results of this study confirmed that mild mandibular outline asymmetry is a common finding amongst patients

seeking orthodontic treatment. This asymmetry was seen either as a difference in the length of the outline of the left and right sides of the mandible, or as a difference of area (i.e. size), or of compactness (i.e. shape). Asymmetry of the centroid (moment-ratio) of the right and left sides of the mandible was also observed. Whilst the asymmetry seen in the total sample analysed ($n = 66$) was generally mild, in six patients it was considered to be more significant, according to the levels previously recorded by Edler *et al.* (2002).

The photographic method described was shown to be sufficiently reproducible to be used for longitudinal assessment of mandibular asymmetry. The method was simple to achieve in a conventional orthodontic setting, without the need for specialist lighting equipment, as had been used in previous studies. The digitising repeatability was also shown to be good, in agreement with previous research using this program (Edler *et al.*, 2001, 2002, 2003). It should be pointed out that the digitising method purely records the level of mandibular asymmetry as it appears on a patient's photograph. The asymmetry could be entirely of skeletal origin, with or without an element of mandibular displacement, or due to displacement alone. An extended study would be needed to explore these factors.

The sample included a greater percentage of patients with low ANB angle values than would be found in an average population sample. This was due to the selection process, which aimed to provide a suitable spread of skeletal discrepancies. Anecdotally, it had been assumed that patients with a Class III skeletal discrepancy were more likely to have mandibular asymmetry than those with an average, or Class II skeletal relationship, although there has been little published evidence to support this. Severt and Proffit (1997) showed, in a retrospective study of 1460 orthognathic patients, that there was an increased percentage (78 per cent) of chin deviation of at least 2 mm from the midline in Class III patients.

The results suggest that there may be an association between the incidence of mandibular outline asymmetry, and a reduced ANB angle. This relationship was demonstrated when all four variables of asymmetry (area, length, compactness and moment-ratio) were combined and also in the values for area asymmetry alone. In addition, the results of this study showed a relationship between increased LAFH percentage and mandibular outline asymmetry, expressed as a combination of any of the four variables measured ($P = 0.023$). This would seem to indicate that patients with an increased LAFH are more likely to exhibit mandibular asymmetry.

The range of values for LAFH in this study does not account for the change with age. This was felt to be unnecessary as the normal values (Bhatia and Leighton, 1993) for the ages of the patients in this sample were included in the normal range given. There are several different aetiological possibilities for an increased LAFH percentage that may explain its increased incidence in patients with mandibular asymmetry. However, it would be difficult to prove a direct relationship between specific factors due to the multifactorial aetiology of malocclusions. As indicated earlier, the purpose of the present study was to identify a possible trend in mandibular asymmetry incidence that might justify an investigation in a larger, more comprehensive sample. This would seem to be justified.

Conclusions

1. A significant difference in the degree of mandibular outline asymmetry was found when comparing patients with a reduced ANB angle (<3 degrees) with those with average or increased ANB angles.
2. A significant difference was also found in the degree of mandibular outline asymmetry when comparing patients with an increased LAFH (>57 per cent) with those with an average LAFH
3. These results justify a wider investigation, in order to establish their existence amongst a larger, more representative sample.

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References

Athanasiou A E, Miethke R, van der Meij A J 1999 Random errors in localization of landmarks in postero-anterior cephalograms. British Journal of Orthodontics 26: 273–284

Bhatia S N, Leighton B C 1993 A manual of facial growth: a computer analysis of longitudinal cephalometric growth data. Oxford Medical Publications, Oxford

Bland M J, Altman D G 1986 Statistical methods for assessing agreement between two methods of clinical measurement. The Lancet 8: 307–310

Chebib F S, Chamma A M 1981 Indices of craniofacial asymmetry. Angle Orthodontist 51: 214–227

Claman L, Patton D, Rashid R 1990 Standardized portrait photography for dental patients. American Journal of Orthodontics and Dentofacial Orthopedics 98: 197–205

Coghlan B A 1996 A system of image analysis for the repaired cleft lip nose. Thesis, Bristol University, UK

Coghlan B A, Matthews B, Piggot R W 1987 A computer based method of measuring facial asymmetry. Results from an assessment of the repair of cleft lip deformities. British Journal of Plastic Surgery 40: 371–376

Coghlan B A, Laitung J K G, Pigott R W 1993 A computer aided method of measuring nasal symmetry in the cleft nose. British Journal of Plastic Surgery 46: 13–17

Cook J T 1980 Asymmetry of the craniofacial skeleton. British Journal of Orthodontics 7: 33–38

Edler R, Wertheim D, Greenhill D 2001 Clinical and computerized assessment of mandibular asymmetry. European Journal of Orthodontics 23: 485–494

Edler R, Wertheim D, Greenhill D 2002 Mandibular outline assessment in three groups of orthodontic patients. European Journal of Orthodontics 24: 605–614

Edler R, Wertheim D Greenhill D 2003 Comparison of radiographic and photographic measurement of mandibular asymmetry. American Journal of Orthodontics and Dentofacial Orthopedics 123: 167–174

Ferrario V F, Sforza C, Poggio C E, Tartaglia G 1994 Distance from symmetry: a three-dimensional evaluation of facial asymmetry. Journal of Oral and Maxillofacial Surgery 52: 1126–1132.

Ferrario V F, Sforza C, Ciusa A, Dellavia C, Tartaglia G M 2001 The effect of sex and age on facial asymmetry in healthy subjects: a cross-sectional study from adolescence to mid–adulthood. Journal of Oral and Maxillofacial Surgery 59: 382–388

Gonzales R C, Woods R E 1993 Digital image processing. Addison Wesley Publishing Co., Reading

Greenhill D, Wertheim D, Edler R, Belsham A, Jones G A 2000 Computer assessment of mandibular outlines. Institution of Electrical Engineers, London, pp. 192–199

Grummons D C, Kappeyne van de Coppello M A 1987 Frontal asymmetry analysis. Journal of Clinical Orthodontics 21: 448–465

Hajeer M Y, Ayoub A F, Millett D T 2004 Three-dimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. British Journal of Oral and Maxillofacial Surgery 42: 396–404

Haraguchi S, Takada K, Yasuda Y 2002 Facial asymmetry in subjects with Skeletal III deformity. Angle Orthodontist 72: 28–35

Letzer G M, Kronman J H 1967 A posteroanterior cephalometric evaluation of craniofacial asymmetry. Angle Orthodontist 37: 205–211

Major P W, Johnson D E, Hesse K L, Glover K E 1994 Landmark identification error in posterior anterior cephalometrics. Angle Orthodontist 64: 447–454

Martins de Araujo T, Wilhelm R S, Almeida M A 1994 Skeletal and dental arch asymmetries in individuals with normal occlusions. International Journal of Adult Orthodontics and Orthognathic Surgery 9: 111–118

Melnik A K 1992 A cephalometric study of mandibular asymmetry in a longitudinally followed sample of growing children. American Journal of Orthodontics and Dentofacial Orthopedics 101: 355–366

Mulick J F 1965 An investigation of craniofacial asymmetry using the serial twin-study method. American Journal of Orthodontics 51: 112–129

Namano S, Behrend D A, Harcourt J K, Wilson P R 2000 Angular asymmetries of the human face. International Journal of Prosthodontics 13: 41–46

Peck S, Peck L, Kataja M 1991 Skeletal asymmetries in aesthetically pleasing faces. Angle Orthodontist 61: 43–47

Pirttiniemi P M, Miettinen J, Kantomaa T 1996 Combined effects of errors in frontal-view asymmetry diagnosis. European Journal of Orthodontics 18: 629–636

Reyneke J P, Tsakiris P, Kienle F 1997 A simple classification for surgical treatment planning of maxillomandibular asymmetry. British Journal of Oral and Maxillofacial Surgery 35: 349–351

Ricketts R M 1981 Perspectives on clinical application of cephalometrics. Angle Orthodontist 51: 115–150

Severt T R, Proffit W R 1997 The prevalence of facial asymmetry in the dentofacial deformities at the University of North Carolina. International Journal of Adult Orthodontics and Orthognathic Surgery 12: 171–176

Shah S M, Joshi M R 1978 An assessment of asymmetry in the normal craniofacial complex. Angle Orthodontist 48: 141–147

Solow B, Tallgren A 1971 Natural head position in standing subjects. Acta Odontologica Scandanivica 29: 591–607

Strauss R A, Weis B D, Lindauer S J, Rebellato J, Isaacson R J 1997 Variability of facial photographs for use in treatment planning for orthodontics and orthognathic surgery. International Journal of Adult Orthodontics and Dentofacial Orthopedics 12: 197–203

Thompson J R 1943 Asymmetry of the face. Journal of the American Dental Association 30: 1859–1871

Vig P S, Hewitt A B 1975 Asymmetry of the human facial skeleton. Angle Orthodontist 45: 125–129