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Mandibular outline assessment in three groups of orthodontic patients

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SUMMARY The feasibility of using computer-based parameters for quantifying mandibular asymmetry was investigated. Four methods of calculating asymmetry were used, based on the digitized facial photographs of three groups of patients: those with no observable asymmetry, a group with mild asymmetry, and a group presenting for orthognathic surgery. Three of the methods involved right/left difference ratios, namely, area, perimeter length, and compactness. The fourth, moment ratio (centre of area), was expressed as a percentage. Repeatability of both photography and digitization proved satisfactory, the standard deviation of the differences between repeated photographs being 0.016 and 0.014 for area and compactness ratios, respectively. Area, perimeter, and compactness successfully discriminated between the three groups. For area, median ratios (deviations from 1.00) for the 'normal', 'mild asymmetry', and 'surgical' groups were 0.015, 0.030, and 0.078, respectively. Those patients in the surgical group for whom asymmetry correction had been the main reason for surgery recorded higher asymmetry scores than the other subjects in that group. Moment ratio did not adequately distinguish between the three groups. Better repeatability for digitization was found when a baseline involving the ear insertions was used, than either the outer or inner canthi of the eyes. The potential uses of this approach are presented in relation to clinically relevant mild asymmetry, as well as auditing the outcome of surgical correction.

Introduction

Bearing in mind the relative conformity with which skeletal discrepancies in the antero-posterior and vertical planes are measured, there does not seem to be much agreement on the most appropriate method of assessing transverse plane discrepancies and, in particular, mandibular asymmetry. A variety of techniques have been recommended for both clinical and research purposes. Most of the methods are based on the postero-anterior (PA) cephalogram, including methods using linear or angular measurements (Grummons and Kappeyne van de Copello, 1987; Severt and Proffit, 1997a) or triangulation (Hewitt, 1975). In addition, right/left differences have been presented in a variety of ways (Chebib and Chamma, 1981; Peck *et al*., 1991; Skolnick *et al*., 1994). It appears that no particular technique has proved universally popular. This also applies to different asymmetry assessments based on submento-vertex (SMV) radiographs (Forsberg *et al*., 1984; Arnold *et al*., 1994; Rose *et al*., 1994). Furthermore, radiographic assessments are invasive and also do not take into account the effect of overlying soft tissue morphology. Yet as suggested by Park and Burstone (1986), variations in soft tissue thickness affect perceptions of antero-posterior skeletal discrepancies and this principle may well also apply to the transverse plane.

For clinical use, it would be appropriate to assess asymmetry according to soft tissue appearance and, ideally, the method should be non-invasive. Three-dimensional imaging techniques, such as photogrammetry or laser scanning, have been used for asymmetry assessment (Moss *et al*., 1991), but these methods remain expensive and are not widely available. For the routine quantification of clinically observed mandibular asymmetry, it should be possible to employ a two-dimensional technique. The recent approach described by Greenhill *et al*. (2000) and Edler *et al*. (2001) may help to achieve this. Standardized facial photographs are scanned, digitized, and right/left differences identified as ratios. In a preliminary study, differences in right/left areas, compactness (a measure of shape), and moment ratios were identified as possible useful indicators of asymmetry (Edler *et al*., 2001).

There is anthropometric (Farkas and Cheung, 1981) as well as radiographic evidence (Hewitt, 1975; Shah and Joshi, 1978; Melnik, 1992) that 'normal' faces are mildly asymmetric. At present, there is no agreement as to which side of the face is dominant. The right side was found to be larger in some studies (Shah and Joshi, 1978; Farkas and Cheung, 1981; Melnik, 1992), but this is contradicted by others (Letzer and Kronman, 1967; Burke, 1971; Vig and Hewitt, 1975; Chebib and Chamma, 1981; Melnik, 1992). This discrepancy is presumably related to the type of population studied and sample size. Additionally, one-third of the orthognathic patients reported by Severt and Proffit (1997b) presented clinically apparent facial asymmetry, of which over 80 per cent of chin deviations were to the left. Studies that have investigated asymmetry in relation to the sex of the subjects have not identified any significant difference (Chebib and Chamma, 1981; Farkas and Cheung, 1981; Melnik, 1992; Arnold *et al*., 1994).

It would be useful for the orthodontist to have an idea of a 'threshold' level of mandibular asymmetry, beyond which clinical problems might arise. Similarly, auditing the outcome of asymmetry correction by orthognathic surgery requires a quantitative method that is not only valid and reproducible, but ideally one that is non-invasive and convenient to use, additionally taking soft tissue morphology into account. In a previous study, it was found that computerized assessment of mandibular asymmetry was consistent with clinical judgement, based on photographs alone (Edler *et al*., 2001).

The aim of this study was to apply computer analysis to study mandibular outlines of patients with different degrees of mandibular asymmetry. In particular, the analysis was to be used to compare subjects who had no clinically observable mandibular asymmetry with a group who had mild asymmetry and a third group assessed as requiring orthognathic surgery.

Subjects and methods

Full face photographs were taken of the following groups of orthodontic patients:

1. 'Normal' group (subjects with no observable asymmetry). This comprised 26 patients: 16 female, 10 male. The patients were randomly selected, the sole criterion being the absence of any record of clinically relevant asymmetry, either at diagnosis or during treatment.
2. 'Mild' asymmetry group. This comprised 20 patients: 10 female, 10 male. The basis for selection was a recorded comment concerning asymmetry during treatment planning, once the patient's name had been taken off the treatment waiting list. In this group, asymmetry was mild enough not to have been obvious during the initial diagnostic visit and only became apparent during treatment planning or, in some cases, during treatment itself, for example, as in the case shown in Figure 1a,b.
3. 'Surgical' group. This consisted of 20 patients: 14 female, six male. These patients all had some evidence of mandibular asymmetry and were scheduled for orthognathic correction. In the majority of cases, the asymmetry was incidental to the need for surgical correction of antero-posterior/vertical discrepancy, but in some, the asymmetry formed the key element in the need for surgery.

The median age of the 'normal' group was 13 years (range 12–21 years), for the mild asymmetry group 14 years (range 8–19 years), and for the surgical group 21 years (range 10–38 years).

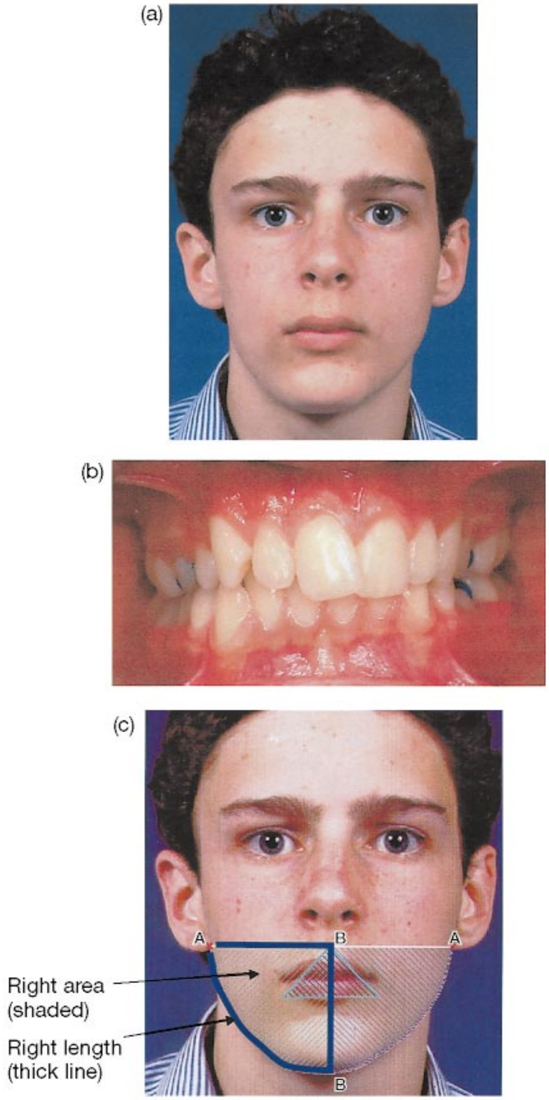

Figure 1 Patient A, from the 'mild' mandibular asymmetry group. (a) Full face view (mandibular asymmetry not noticed at first consultation). (b) Anterior intra-oral view, lower centreline deviation due to mandibular asymmetry, upper centreline deviation of dental origin. (c) Digitized full face view, indicating right/left; area, perimeter, compactness, and centre of area (moment) ratios. Area ratio = 1.05; Perimeter ratio = 1.01; Compactness ratio = 0.95; Moment ratio = –1.109.

Photography

Full face photographs were taken under standardized conditions on 35 mm slide film. The lighting and positioning of the patient has been described previously (Edler *et al*., 2001). Essentially, the key element was to avoid inappropriate shadow through the use of four Bowen Esprit lights, two positioned as background, one on either side of the patient (250 W seconds strength), with another two (500 W seconds) in front, aimed at 45 degrees to the patient who was sitting upright, with the visual axis horizontal. The photographs were taken with the cheek teeth in contact.

Computerized assessment

Slides were scanned using a Hewlett Packard Deskscan II flatbed scanner. The scanned images were then analysed according to the method described by Greenhill *et al*. (2000) and Edler *et al*. (2001). In summary, the digitized images are displayed on the computer screen, the user then marking with a mouse the inferior insertions of the ears (Otobasion inferius; Figure 1c); the computer then draws a line (A) between the ear insertions (Otobasion inferius). The user then clicks points around the mandibular outline from right to left, and the computer draws line segments between the points around the mandibular outline. The computer draws a line (B) at the bisection of A and perpendicular to A (Figure 1c). The lower portion of the face is thus effectively divided into two segments bounded by the mandibular outline. When required the programme can also provide an alternative baseline, based on the inner or outer canthus of each eye, which may be more appropriate in cases of asymmetric ear position. In this way, the lower portion of the face can be analysed as right and left segments. Four ratios were used to assess the extent of asymmetry (Figure 1c):

(A) The area of the right segment compared with the left.
(B) Perimeter length of the right segment compared with the left.
(C) 'Compactness', namely the square of the perimeter divided by the area, providing a measure of shape (Gonzales and Woods, 1993), again, comparing right and left segments.
(D) Moment ratio: the centroid (centre of area) of both areas combined was calculated, and

its distance from the point of bisection of line A calculated and divided by the length of line A; this was then multiplied by 100 to provide the ratio as a percentage.

The system has a resolution of 0.01. Thus, for 'ideal' symmetry, the right/left ratios for area, perimeter, and compactness would be 1.00; for moment ratio ideal symmetry would be represented as 0.00.

Analysis

For comparison of the three groups, the mean of the two readings for each patient was calculated; analysis of two moment ratio results for each set of readings was performed by taking the mean of the absolute data. The distributions for each group were tested for normality with the Ryan-Joiner method using Minitab Release 13.1 (Minitab Inc., State College, PA, USA).

Repeatability

In order to assess repeatability associated with baseline position, photographs of 14 of the surgical group patients were analysed by computer using different baselines, twice for each baseline. The baselines used were ear level (inferior insertions), and the outer and inner canthi of the eyes. The results were assessed using the method of Bland and Altman (1986).

Photographs of an additional 20 patients (not included in the main assessment) were taken on two occasions with an interval of approximately one month. The photographs were scanned, and then digitized and analysed twice using the computer system. For analysis the means of the two measurements from each session were compared, using the method of Bland and Altman (1986).

Results

The distribution of some sets of data, for area deviation, compactness, and centre of area deviation data, was not found to be normally distributed and, hence, the data were analysed using non-parametric tests. For example, the distribution of data for area deviation and compactness deviation of the normal group was not consistent with a normal distribution. For assessing the difference between two groups, the Mann–Whitney test was used. For assessing all three groups for each type of analysis the Kruskal–Wallis test was used. These statistical tests were performed using Minitab Release 13.1. Data for the three groups are shown in Tables 1–3. For three of the parameters, namely area, perimeter, and compactness, the ratio representing ideal symmetry is 1.00. Accordingly, the ratio increases from 1.00 (right side dominant) or decreases from 1.00 (left side dominant), representing the level of asymmetry. The median 'deviations' from 1.00 are shown. For moment ratio, the deviations are zero-based.

Table 1 Asymmetry ratios for the 'normal' group.

Patient	Area	Perimeter	Compactness	Moment ratio
1	1.005	1	1	0.63
2	0.995	1	1	0.07
3	1.005	1	0.995	0.525
4	0.97	0.995	1.02	0.795
5	0.9	0.98	1.065	0.72
6	1.01	1	0.99	0.545
7	1	1	1	0.56
8	0.985	1	1.02	0.15
9	0.975	0.99	1.01	0.07
10	0.915	0.98	1.04	0.885
11	0.99	1	1.01	0.09
12	1.005	1	0.995	0.615
13	1.005	1	1	0.05
14	0.97	0.995	1.01	0.639
15	1	1	1	0.75
16	0.95	0.99	1.04	0.635
17	0.965	0.99	1.02	1.05
18	1.025	0.995	0.985	0.92
19	1.02	1	0.985	0.145
20	0.995	1	1.005	0.355
21	1.01	1.005	0.995	1.165
22	0.97	0.99	1.015	0.58
23	0.97	0.995	1.02	0.33
24	0.955	0.99	1.03	0.875
25	0.98	1	1.015	0.275
26	0.99	0.995	1	0.34
Deviation				
Median	0.015	0.0025	0.0125	0.57
Min	0	0	0	0.05
Max	0.1	0.02	0.065	1.165

Deviation from 1 for area, perimeter, and compactness ratio, and from 0 for moment ratio.

Table 2 Asymmetry ratios for the 'mild asymmetry' group.

Patient	Area	Perimeter	Compactness	Moment ratio
27	1.09	1.025	0.955	1.22
28	1.04	1.01	0.975	0.32
29	0.895	0.975	1.065	1.44
30	1.03	1	0.97	0.22
31	0.995	1	1	0.19
32	1	1.005	1.005	0.4
33	0.96	0.99	1.02	0.305
34	1.05	1.005	0.965	0.54
35	1.005	1	0.995	1.065
36	1.005	1	0.995	0.525
37	0.915	0.985	1.05	0.345
38	1.03	1.005	0.98	1.37
39	0.945	0.985	1.03	0.105
40	0.95	0.985	1.025	0.195
41	0.985	0.995	1.005	0.195
42	0.99	0.995	1.005	0.125
43	1.06	1.01	0.96	0.17
44	1	1	1	0.325
45	1	0.995	0.99	1.31
46	1	1	1	0.265
Deviation				
Median	0.03	0.005	0.02	0.3225
Min	0	0	0	0.105
Max	0.105	0.025	0.065	1.44

Deviation from 1 for area, perimeter, and compactness ratio and from 0 for moment ratio.

Table 3a Asymmetry ratios for the 'surgical' group.

Patient	Area	Perimeter	Compactness	Moment ratio
47	0.905	0.975	1.055	1.165
48	0.95	0.99	1.03	0.225
49	0.98	0.995	1.01	0.31
50	0.975	1	1.015	0.745
51	0.915	0.98	1.05	0.37
52	1.015	1.005	0.99	0.225
53	0.985	1	1.01	0.265
54	1.089	1.02	0.96	0.165
55	0.967	0.995	1.025	0.3375
56	0.96	0.9915	1.025	1.3255
57	1.0925	1.023	0.96	0.482
Deviation				
Median	0.04	0.01	0.025	0.3375
Min	0.015	0	0.01	0.165
Max	0.095	0.041	0.055	1.3255

Deviation from 1 for area, perimeter, and compactness ratio and from 0 for moment ratio.

Table 3b Asymmetry ratios for the 'surgical' group where cases specific for asymmetry correction.

Patient	Area	Perimeter	Compactness	Moment ratio
58	0.92	0.975	1.035	0.45
59	1.21	1.045	0.895	2.405
60	1.08	1.015	0.95	1.5
61	1.075	1.02	0.97	0.652
62	0.835	0.96	1.105	4.015
63	0.905	0.985	1.07	0.8
64	0.893	0.9715	1.065	0.2085
65	0.872	0.9715	1.08	2.40175
66	0.9375	0.9815	1.03	0.23
Deviation				
Median	0.08	0.025	0.065	0.8
Min	0.05	0.015	0.03	0.2085
Max	0.21	0.045	0.105	4.015
For full surgical group				
Deviation				
Median	0.0775	0.02	0.0375	0.466
Min	0.015	0	0.01	0.165
Max	0.21	0.045	0.105	4.015

Deviation from 1 for area, perimeter, and compactness ratio and from 0 for moment ratio.

Thus, taking area deviation for the three groups as an example, the median area deviation from 1.00 was 0.015 for the normal group (Table 1), 0.030 for the mild asymmetry group (Table 2), and 0.078 for the surgical group (Table 3). For compactness ratio the median values were 0.013, 0.020, and 0.038, respectively. In 11 of the 20 surgical cases the need for surgery was primarily based on the correction of sagittal and/or vertical skeletal discrepancies. In Table 3 the values for these cases are compared with the other nine patients for whom mandibular asymmetry correction was a key requirement. The values for the latter group are clearly greater, representing a more marked level of asymmetry. Tables 4 and 5 summarize the results of the statistical tests. In summary, the centre of area (moment ratio) deviation was not found to be useful in discriminating between the three groups. However, both area ratio and compactness ratio deviation could distinguish between the mild and surgical groups, as well as the normal and surgical groups. Perimeter deviation also appeared to be useful in discriminating between the groups. When

Table 4 Statistical significance of differences between the three groups.

	Area deviation	Compactness deviation	Centre of area deviation	Perimeter deviation
Normal versus mild	NS	NS	NS	NS
Mild versus surgical	$P < 0.005$	$P < 0.01$	NS	$P < 0.005$
Normal versus surgical	$P < 0.001$	$P < 0.001$	NS	$P < 0.001$

NS = not significant ($P > 0.05$).

Table 5 Significance seen for all three groups for each type of analysis using the Kruskal–Wallis test.

	Area deviation	Compactness deviation	Centre of area deviation	Perimeter deviation
Significance	$P < 0.001$	$P < 0.002$	NS	$P < 0.001$

examining the asymmetric surgical cases in comparison with the normal and mild groups for the moment ratio there was a significant difference when compared with the mild group ($P < 0.05$), but not the normal group; this may be because of the spread in values observed for the moment ratio.

Repeatability of digitization was assessed by plotting the difference between each of the readings for each patient against the mean in accordance with the method of Bland and Altman (1986). It had previously been suggested that the variation seen when the calculations were performed with reference to a baseline at ear level would be less than at the inner canthus of the eye (Greenhill *et al*., 2000). This was confirmed, as shown in Figure 2, which illustrates the variation for area ratio assessment. Fourteen patient images were digitized on two occasions with an interval of at least one week and analysed using the ear-based reference plane as originally described (Figure 2a). Subsequently the analysis process was repeated, using the outer canthus of the eye as the baseline (Figure 2b) and, finally, the inner canthus (Figure 2c). The inner canthus-based measurements can be seen to show the greatest variation as would be expected, since the narrower the baseline, the greater the error sensitivity at the boundary, or mandibular outline (Greenhill *et al*., 2000).

The analysis of the repeatability of the photographs generally showed low variation as illustrated in Figure 3. The results from two patients were excluded: for one patient hair was covering one ear on one of the photographs and one photograph of another patient had been taken when the soft tissues were clearly not relaxed. Thus, results on 18 patients were analysed.

The standard deviation of the differences between the measurements on each subject was calculated: the standard deviations (and mean) were 0.016 (0.001), 0.005 (0.001), 0.014 (0.001), and 0.494 (0.077) for area ratio, perimeter ratio, compactness ratio, and moment ratio, respectively.

Discussion

Repeatability for both taking the photographs and their digitization appeared to be satisfactory. Figure 3 shows that in general the variations between the data were small. Comparison of the repeatability of digitized photographs with other techniques such as PA cephalogram analysis is not really appropriate; however, it is noted that inter-examiner errors of 0.31–4.79 mm were found by Major *et al*. (1994). Moss *et al*. (1991) suggested a level of accuracy for 3D laser scanning of approximately 0.5 mm. At present, the photographic set-up is rather complex (Edler *et al*., 2001) and further work, using a simpler

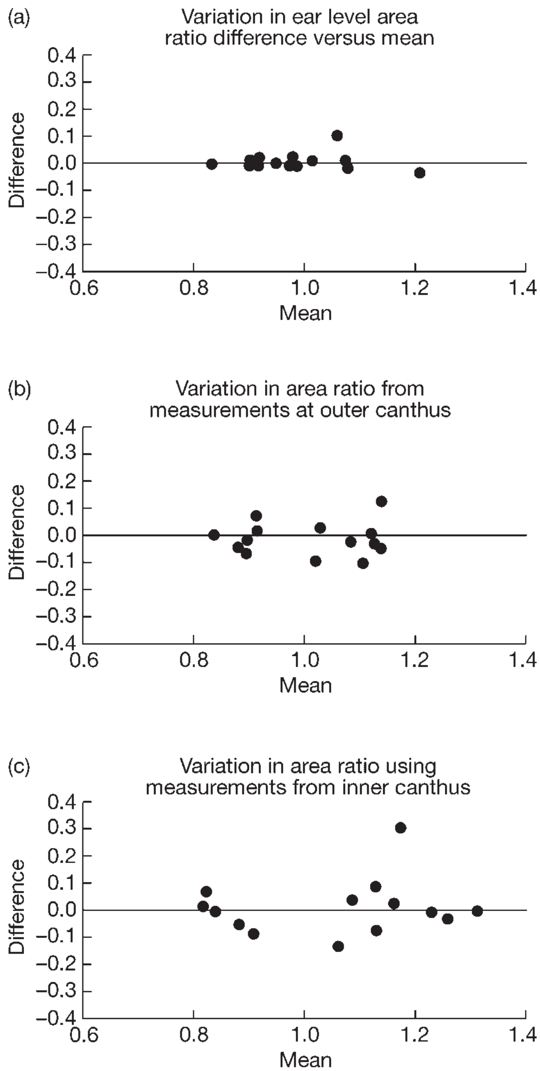

Figure 2 Repeatability of digitization. (a) Area ratio reproducibility of a sample of 14 patients from the surgical group; digitization repeated after an interval of at least one week using the base of ear insertion (otobasion inferius), SD 0.03. (b) Area ratio reproducibility of the same sample, using a line based on the outer canthus of the eyes (exocanthion), SD 0.06. (c) Area ratio reproducibility of the same sample, using a line based on the inner canthus of the eyes (endocanthion), SD 0.10.

approach more representative of routine orthodontic practice, is presently being undertaken.

It would be useful for the orthodontist to have an idea of a 'threshold' level of asymmetry beyond which clinical problems might arise; for example, the subject illustrated in Figure 1 presented with a deviation of the lower centreline due to an element of mandibular asymmetry that was not immediately apparent, and not associated with a displacement of the mandible. Preliminary measurement of this mandibular asymmetry, allowing comparison with baseline data for 'normal' patients, might well have been useful in aiding treatment planning. One aim of the study was to identify threshold values of asymmetry, beyond which one might anticipate clinical problems. For the mild asymmetry group, the (deviation from 1.00) range was 0.00–0.105 (area), 0.00–0.025 (perimeter), and 0.00–0.065 (compactness), respectively. In four cases, the computer assessment did not identify any asymmetry (Table 3). In the others, at least one of the four parameters revealed some evidence of asymmetry.

The levels of asymmetry recorded in the surgical group (Table 3) were clearly greater than in the other groups and the nine cases for whom asymmetry correction was the key clinical aim had higher scores (larger deviations from 1.00) than the others. However, for all three groups, it is clearly necessary to investigate a larger cohort, ideally taken from the public at large, before being able to recommend possible 'cut-off' asymmetry measurements.

No attempt was made in this study to identify any tendencies towards right or left sided dominance, or to determine greater or lesser asymmetry trends in males or females. No such tendencies were apparent.

Auditing the outcome of asymmetry correction by orthognathic surgery requires a quantitative method that is not only valid and repeatable, but ideally one that is non-invasive and convenient to use, additionally taking soft tissue morphology into account. Currently, it should be possible to quantify differences in improvement in surgical correction as in the two patients shown in Figures 4 and 5, by digitizing the mandibular outlines as shown. It had previously been noted clinically that the surgical correction of the case shown in Figure 4 had clearly been highly successful, whilst the improvement seen in the case illustrated in Figure 5 was more modest. From the ratio differences shown, the percentage

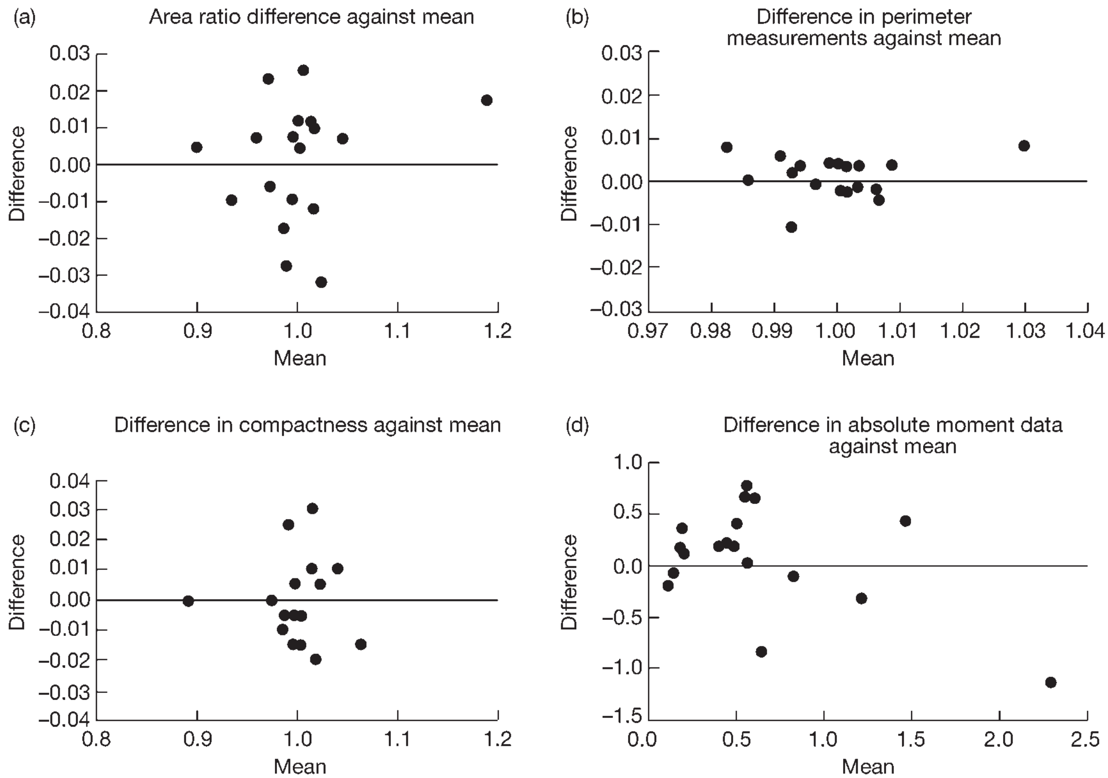

Figure 3 Repeatability of photography. (a) Area ratio repeatability of repeated photographs of a sample of 18 patients, SD 0.016. (b) Perimeter ratio repeatability of the same sample, SD 0.005. (c) Compactness ratio repeatability of the same sample, SD 0.014. (d) Moment ratio repeatability of the same sample, SD 0.494.

improvements in the case in Figure 4 for area, perimeter, compactness, and moment ratios were: 14, 3, 12, and 3.16, respectively, whilst those for the case in Figure 5 were 2, –1, 2, and 1.07.

It is not yet clear which ratio most appropriately quantifies mandibular asymmetry and its improvement, but the moment ratio did not discriminate between the three patient groups in this study, whilst the other three ratios did. Previous work (Edler *et al.*, 2001) found that perimeter measurements were not reconciled with clinical assessments as readily as those of area and compactness. Whilst further work needs to be undertaken, area and compactness may be the most appropriate means of 'scoring' levels of asymmetry of the mandible; this may be explained by area ratio detecting size differences and compactness ratio detecting shape differences. The technique is intended purely as a means of quantification, rather than as an aid to diagnosis or treatment planning. Furthermore, its use is specific to mandibular outline assessment, rather than to other forms of facial asymmetry.

Conclusions

1. Measurements of area, perimeter, and compactness ratio deviations were found to distinguish adequately between patients with a mild degree of asymmetry and a group requiring orthognathic surgery. These parameters were also found to be able to discriminate between those surgical patients for whom asymmetry correction was a key element, as opposed to the other patients in the group.
2. Similar discrimination proved possible between patients without noticeable clinical

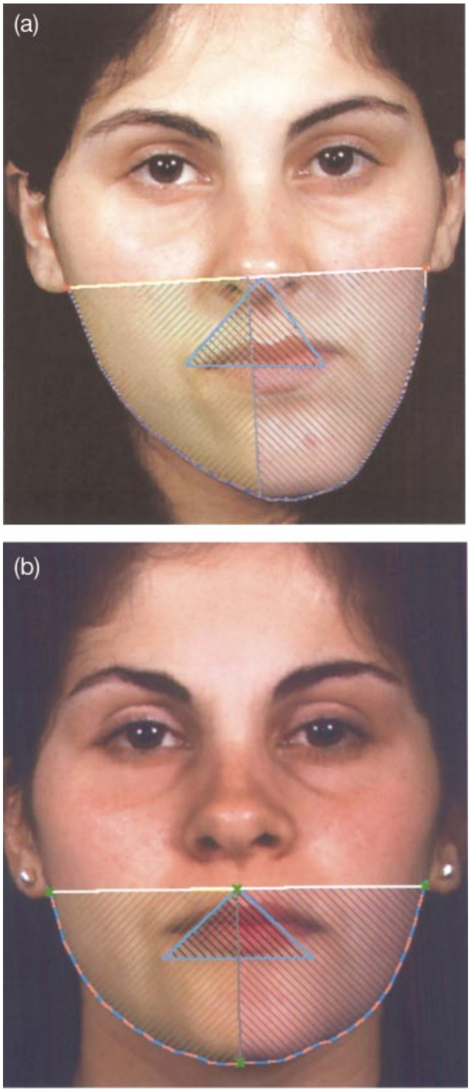

Figure 4 Patient B, from the 'surgical' group. (a) Pre-treatment. (b) Post-treatment, involving fixed therapy and bimaxillary osteotomy.

	Pre-treatment	Post-treatment	% Change
Area ratio	0.84	0.98	14
Perimeter ratio	0.96	0.99	3
Compactness ratio	1.12	1.0	12
Moment ratio (centre of area)	4.33	–1.17	3.16

asymmetry (the 'normal' group) as opposed to the surgical group.

3. Moment ratio (centre of area) did not seem to be a sensitive enough indicator of the

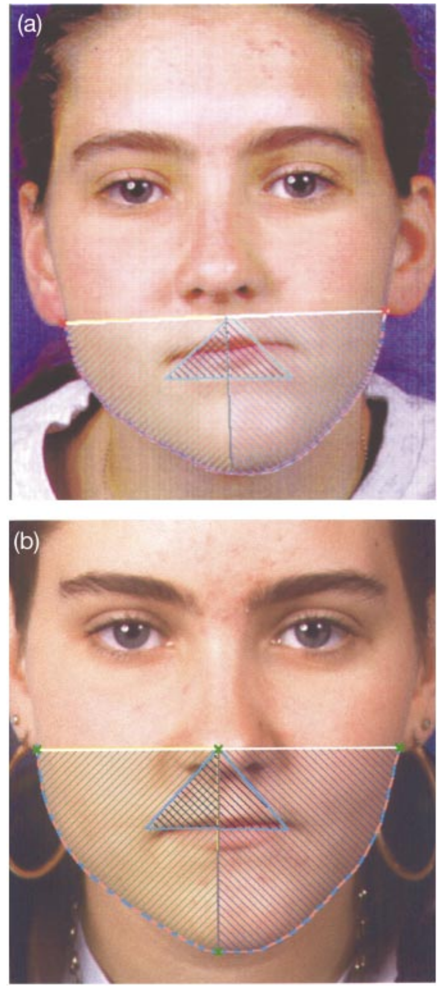

Figure 5 Patient C, from the 'surgical' group. (a) Pre-treatment. (b) Post-treatment, involving fixed therapy and bimaxillary osteotomy.

	Pre-treatment	Post-treatment	% Change
Area ratio	0.93	0.95	2
Perimeter ratio	0.99	0.98	–1
Compactness ratio	1.05	1.03	2
Moment ratio (centre of area)	1.84	–0.77	1.07

differences between the groups used in this study.

4. Use of a baseline involving the inferior ear insertions provided a higher level of repeatability than either the outer or inner canthi of the eyes.

5. Further investigation, involving larger patient samples, is required to determine 'cut-off' measurements for clinical application. In addition, there may be potential to develop the technique as an audit tool for quantifying asymmetry correction.

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