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Scientific Section

Morphology of the Temporomandibular Joint in Skeletal Class III Symmetrical and Asymmetrical Cases: a Study by Cephalometric Laminography

YOSHIKO AKAHANE, D.D.S.

TOSHIO DEGUCHI*, D.D.S., M.S.D., PH.D.

Department of Orthodontics, Matsumoto Dental University School of Dentistry, 1780 Gohbara-Hirooka, Shiojiri city, Nagano-ken, Japan 399-0781

NIGEL P. HUNT, PH.D., M.SC., F.D.S.R.C.P.S., F.D.S.R.C.S., D.ORTH., M.ORTH.R.C.S.

Department of Orthodontics, Eastman Dental Institute for Oral Health Care Sciences, University College London, 256 Gray's Inn Road, London WC1X 8LD, UK

Abstract. *The aetiology of asymmetric growth in the mandible is not well understood. Previous studies have indicated that the functional lateral shift of the mandible in the period of prepubertal growth may translate to a true skeletal asymmetry, exclusively in skeletal Class III malocclusion. This asymmetry develops more characteristic features during the pubertal and post-pubertal growth periods. Early correction of a functional lateral shift of the mandible is recommended. The purpose of this study was to examine the relationship between the morphology of the temporomandibular joints and asymmetry in skeletal Class III malocclusion in adult female patients.*

Cephalometric and laminographic findings in 36 asymmetric skeletal Class III patients with a lateral shift of mandible (group 3) were compared to those of 25 symmetric skeletal Class I patients (group 1) and the same number of symmetric skeletal Class III malocclusions (group 2). All the patients had received no orthodontic treatment. The results showed that the TMJ of the side to which the mandible shifted showed a significantly narrower and shorter shape of the condyle head, smaller superior condylar space, and steeper eminence than those of the unshifted side.

Index words: Asymmetry, Laminography, Skeletal I, Skeletal III, TMJ

Introduction

The aetiology of asymmetric deformity of the mandible is not well understood (Erickson and Waite, 1974). Genetics, functional side shift of the mandible, and unbalanced lateral and vertical growth of the craniofacial structures could be factors in the young growing patients (Sakuda *et al*., 1969; Kobayashi *et al*., 1996' Sugawara, 1996). Mandibular asymmetry is often associated with an asymmetric occlusal plane and is characteristically accelerated through the adolescent growth period (Widman, 1988). A few studies have suggested that the asymmetric morphology of the temporomandibular joint may cause asymmetric growth of the mandible (Mongini and Schmid, 1987; Aoshima *et al*., 1992; Satoh *et al*., 1993).

Skeletal Class III malocclusion in Japanese adolescents tends to show the asymmetry not only the mandible, but also condylar inclination when compared with those of Class I and Class II malocclusion, studying a Sectograph (Ogawa and Deguchi, 1991). Sagittal arthrotomograms, obtained with a cephalometric laminograph (Sectograph), show a clear image of the temporomandibular joint and are of value in the study of the morphological changes with time in individuals (Hayasaka *et al*., 1983).

There is still a lack of information in relation of TMJ morphology and asymmetrical skeletal Class III malocclusion. In the present study, sagittal arthrotomograms were designed to examine morphological differences of the condyles and mandibular fossae in both skeletal Class I and Class III patients with or without asymmetry of the mandible.

However, difficulties may arise in standardization of the

Correspondence: Toshio Deguchi, International Centre for Excellence in Dentistry, Eastman Dental Institute for Oral Health Care Sciences, University College London, 123 Gray's Inn Road, London WC1X 8TZ, UK. Tel: +44(0)20-7-905-1219. Fax: +44(0)20-7-242-8685. E-mail: deguchi@po.mdu.ac.jp.
*Present address: International Centre of Excellence in Dentistry, Eastman Dental Institute for Oral Health Care Sciences, University College London, 123 Gray's Inn Road, London WC1X 8TZ, UK

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sectograph, according to the method of X-ray projection (Ogawa *et al.*, 1988). A pilot study was planned to evaluate the accuracy and utility of sectograph in TMJ morphology, using a dry skull. The magnification of the sliced image subject and the geometric distortion were also investigated.

Methods

The axial projected head plate

This projection was obtained to orientate the head with the axial X-ray projection perpendicular to the Frankfort plane and to assure the visualization of the sagittal plane across the center of the joint, using the laser analyser (Figure 1). The slice depth and the inclination of the slice path were measured on the tracings (Ogawa *et al.*, 1988; Figure 2). The conditions of projection were a focus-film distance (150 cm), voltage (54 kV), currency (50 mA) and the exposure time (0·5 seconds).

Estimating the cut surface obtained from the axial projected head plate

Five pieces of 2-mm^2 zinc foil were attached to the following sites: No. 1, the posterior border of the condyle; No. 2, the top of the condyle; No. 3, the anterior border of the condyle; No. 4, the anterior surface of the condyle neck; and No. 5, the retromolar site; Figure 3A,B).

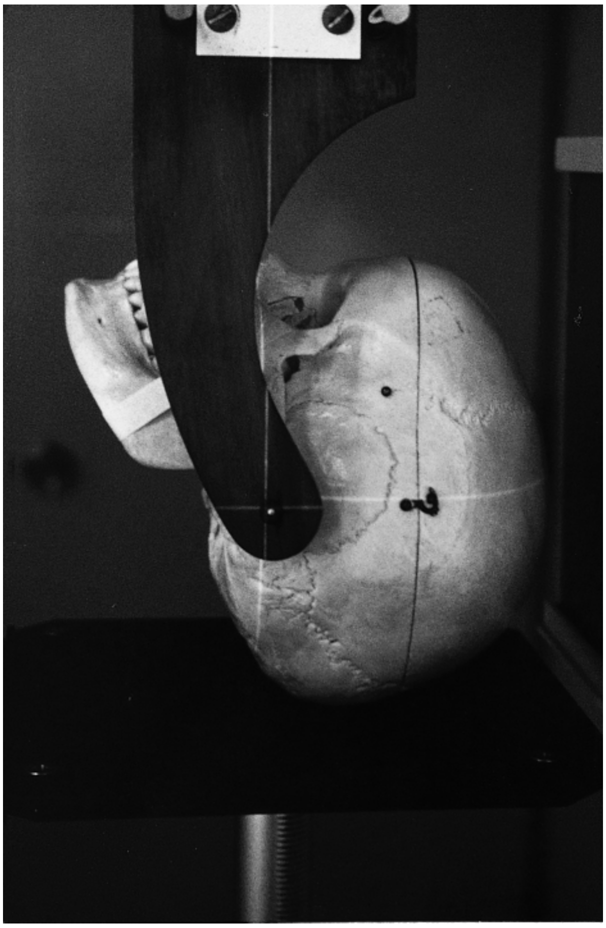


FIG. 1 The axial projected head plate perpendicular to the Frankfort plane, using the laser analyser.

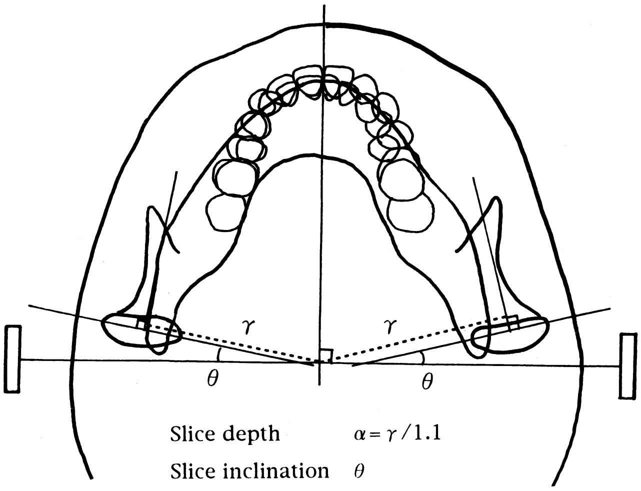


FIG. 2 The slice depth and the inclination of the slice path were measured on the tracings.

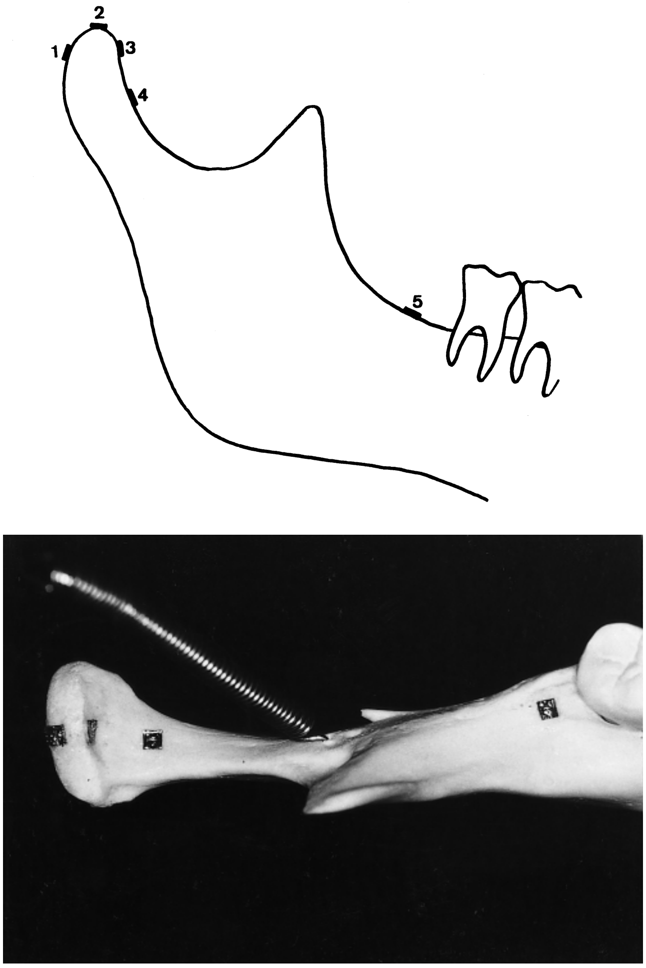


FIG. 3A,B Localization on five pieces of 2 mm^2 zinc foil.

The sectograph

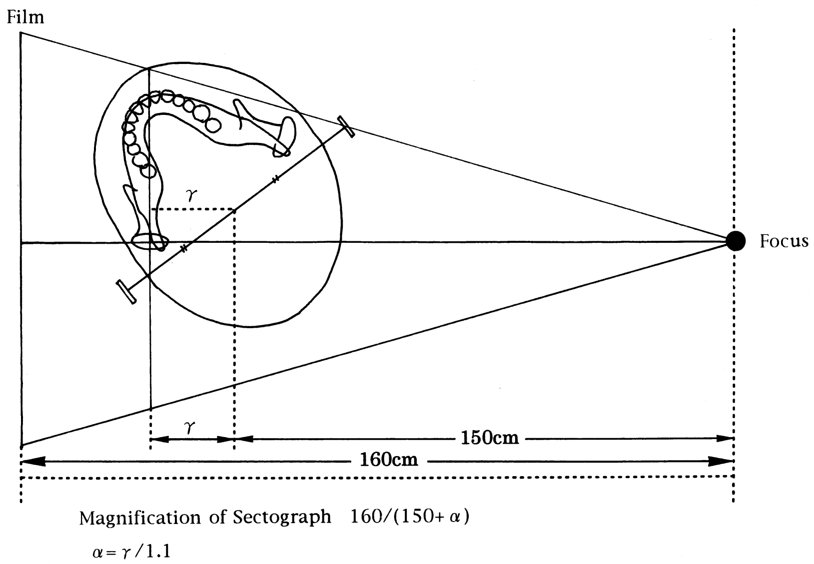
The dry skull was positioned with the Frankfort plane (FH) horizontal, using laser analysis. The sectograph was taken to calculate the slice depth (α) and the inclination of the slice (θ) obtained from the axial projected head plate, with the sliced cut of the x-ray projection intersecting the center of the condylar head and perpendicular to its long axis. The conditions of the x-ray projection were as follows: a focus-film distance (160 cm), focus-mid point of ear rods (150 cm), voltage (54 kV), currency (50 mA), exposure time (3 seconds: Figure 4A,B).

The measurements on the dry skull

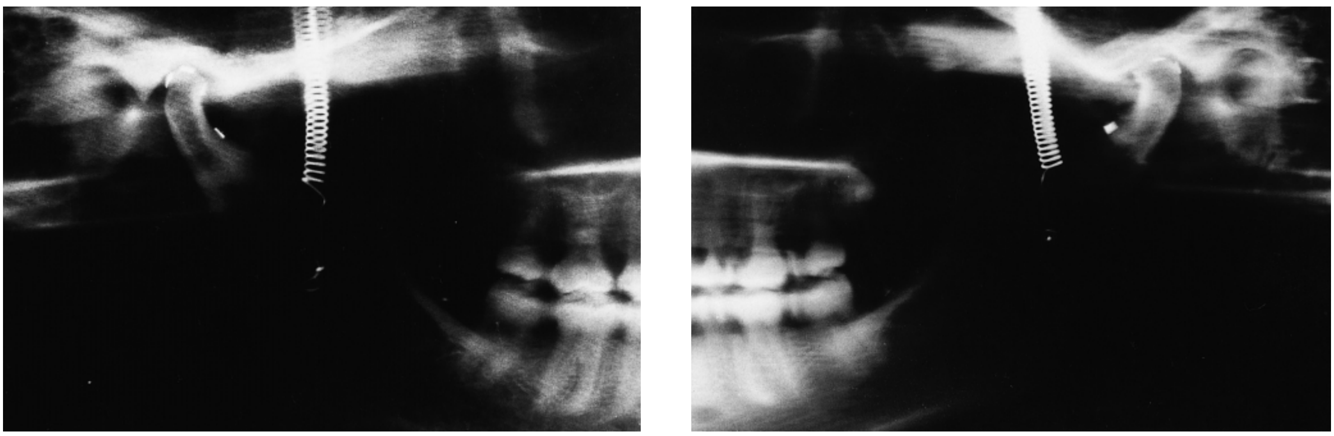
The distance between the centers of the attached zinc foils was measured directly, using a digital caliper (NSK MAX-CAL, 15, Japan Micrometer MFG Co. Ltd, Tokyo, Japan). The distances between the following zinc foils were measured; No. 1–No. 3., No. 2–No. 4., No. 2–No. 5. Each of the measurements was taken 10 times and the procedure repeated five times. The same procedure was repeated at the next day (Table 1). The distances were calculated to the second place of decimals. The same analysis was applied to the sectograph on the tracings.

Statistical evaluation between the measurements obtained from the dry skull and the sectograph

The measurements obtained directly from dry skull, were multiplied by the theoretical magnification of the projection and statistically compared to those obtained from the sectograph. The theoretical magnification of the projection on the dry skull was obtained from the formula; 160/(150 + α). Alpha was calculated from the formula; α = γ/1·1 (Figure 2). The significance of the difference of the measurements from the skull and sectograph was statistically analysed with the Student's *t*-test, Statt-view, Abacus concepts Inc.).



(A)



(B)

FIG. 4 (A) Calculation of the slice depth and the inclination of the slice. (B) Sectograph of TMJ taken from a dry skull.

TABLE 1 *The distances between the following zinc foils were measured; Nos 1–3, Nos 2–4 and Nos 2–5*

	1st measurement			2nd measurement			3rd measurement			4th measurement			5th measurement		
zinc foil No.	No. 1–3	No. 2–4	No. 2–5	No. 1–3	No. 2–4	No. 2–5	No. 1–3	No. 2–4	No. 2–5	No. 1–3	No. 2–4	No. 2–5	No. 1–3	No. 2–4	No. 2–5
Dry skull right															
Mean	6·01	10·62	53·75	6·01	10·63	53·8	6	10·62	53·81	6·02	10·61	53·79	6	10·6	53·8
SD	±0·03	±0·02	±0·03	±0·03	±0·02	±0·03	±0·03	±0·02	±0·03	±0·03	±0·02	±0·02	±0·03	±0·02	±0·02
Dry skull left															
Mean	6·19	13·42	57·5	6·19	13·41	57·51	6·21	13·4	57·5	6·2	13·41	57·51	6·19	13·41	57·5
SD	±0·01	±0·01	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02	±0·02
Sectograph right															
Mean	5·79	11·01	55·58	5·78	11	55·6	5·79	11	55·6	5·81	11	55·6	5·79	11·02	55·6
SD	±0·03	±0·03	±0·02	±0·03	±0·03	±0·02	±0·02	±0·03	±0·02	±0·03	±0·03	±0·02	±0·03	±0·04	±0·02
Sectograph left															
Mean	6·5	13·81	59·42	6·49	13·79	59·37	6·48	13·77	59·37	6·48	13·8	59·38	6·47	13·79	59·38
SD	±0·02	±0·03	±0·03	±0·02	±0·02	±0·02	±0·02	±0·03	±0·03	±0·01	±0·03	±0·02	±0·02	±0·03	±0·03

TABLE 2 *No significant difference between the measurements obtained from dry skull multiplied with the theoretical magnification and the sectograph*

Zinc foil No.	1 Measure on dryskull	2 Measure on Sectograph	1 × 1·032	1 × 1·032 vs 2
Right				
Nos 1–3	5·78 ± 0·03	5·77 ± 0·04	5·95 ± 0·04	*P* = 0·1576 NS
Nos 2–4	11·01 ± 0·04	11·01 ± 0·03	11·36 ± 0·03	*P* = 0·1431 NS
Nos 2–5	55·51 ± 0·03	55·52 ± 0·04	57·29 ± 0·04	*P* = 0·5082 NS
Left				
Nos 1–3	6·2 ± 0·02	6·41 ± 0·02	6·61 ± 0·02	*P* = 0·1103 NS
Nos 2–4	13·41 ± 0·03	13·85 ± 0·015	14·3 ± 0·04	*P* = 0·5472 NS
Nos 2–5	57·51 ± 0·02	59·41 ± 0·04	61·32 ± 0·04	*P* = 0·0619 NS

Accuracy on sectograph

The measurements obtained from the dry skull and sectograph showed a small variation in each of the trials (Table 1). However, there was no significant difference between the measurements obtained from the dry skull multiplied by the theoretical magnification and the sectograph (Table 2). The theoretical magnification was close to the real magnification (right side; 1·032, left; 1·0.33).

Materials

The materials consisted of 25 skeletal Class I cases (group 1), 25 skeletal Class III symmetrical cases (group 2) and 36 skeletal Class III with mandibular asymmetry cases (group 3). All the subjects were female Japanese adults who had received no orthodontic treatment and showed no symptoms of TMJ disorder. The mean age of the patients was 22 years (range 16 years to 33 years) for group 1; 19 years (range 16 years to 29 years) for group 2 and 20 years (range 16 years to 29 years) for group 3 (Table 3). Growth is considered to be complete in Japanese females around 17 years of age (Asai, 1973).

Skeletal classification was based on Ballard's classification (Ballard, 1951) as follows; skeletal I (2 degrees < ANB angle < 4 degrees), skeletal III (ANB angle < 2 degrees; Walther, 1967; Figure 5).

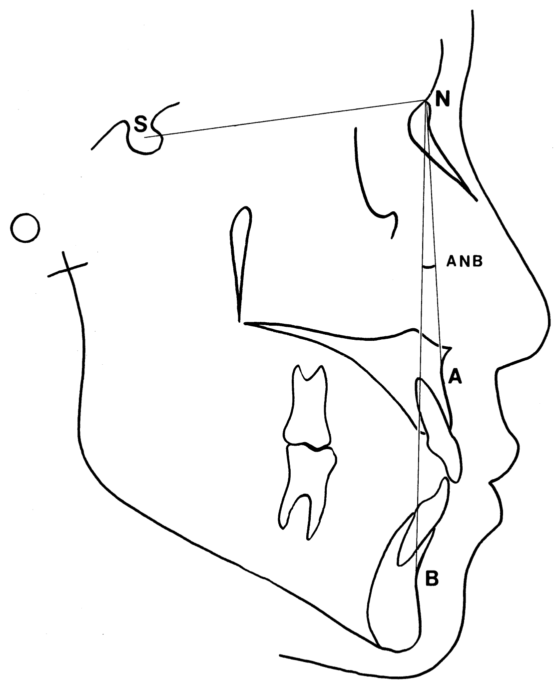


FIG. 5 Skeletal classification according to ANB angle.

Asymmetry of the mandible

The clinical examinations were performed by one of the authors. Standard axial projected head plates were obtained in a cephalostat (Figure 1). The median point of the cranium was marked on a line connecting the center of both spinous foramina. A perpendicular to this axis at the median point was then constructed as the facial midline (Marmary *et al.*, 1979). The line through this median point to the mental spine was designated as the mid-sagittal mandibular plane.

The angle of these two planes was measured to determine the lateral shift of the mandible. The angle of shift value larger than ± 3·5 degrees was designated in asymmetrical skeletal class III malocclusion (group 3; Satoh *et al.*, 1994; Figure 6).

TABLE 3 *The mean age and the number of the subjects*

Group	Skeletal classification	Mean age (range)	Number
1	Skeletal I, symmetry	22 years (16–33)	25
2	Skeletal III, symmetry	19 years (16–29)	25
3	Skeletal III, asymmetry	20 years (16–29)	36

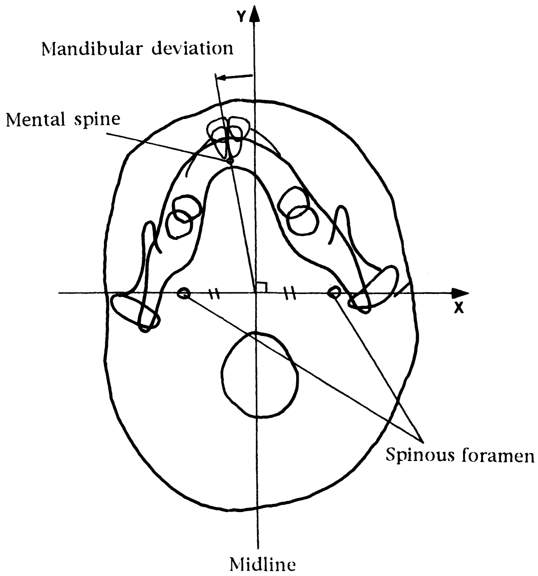


FIG. 6 The angle (larger than ± 3·5 degrees) of shift value in group 3.

Reference lines for the measurements on the cephalometric laminogram

The slice depth and the inclination of the slice path were measured on the tracing and the sectograph was set to intersect the center and long axis of the condylar head in each patient (Ogawa *et al.*, 1988; Mimura and Deguchi, 1994; Satoh *et al.*, 1994).

The FH plane and two lines parallel to the FH plane in contact with mandibular fossae and eminence were drawn on the tracings. Subsequently, a tangent to the posterior border of the ramus was drawn (the ramus plane). From the superior contact point of the ramus plane, a line parallel to the FH plane was drawn. On this line, the median point of the superior contact point and the point intersecting the anterior outline of the mandibular neck was marked. This was considered as the median point of the mandibular neck. A line parallel to the ramus plane, crossing the median point of mandibular neck, was drawn. This was designated as the condylar head angle.

The coefficient of reliability for almost all cephalometric parameters satisfied the level of confidence (<0·90), shown at Tables 4–6. A few results, however, had a low coefficient

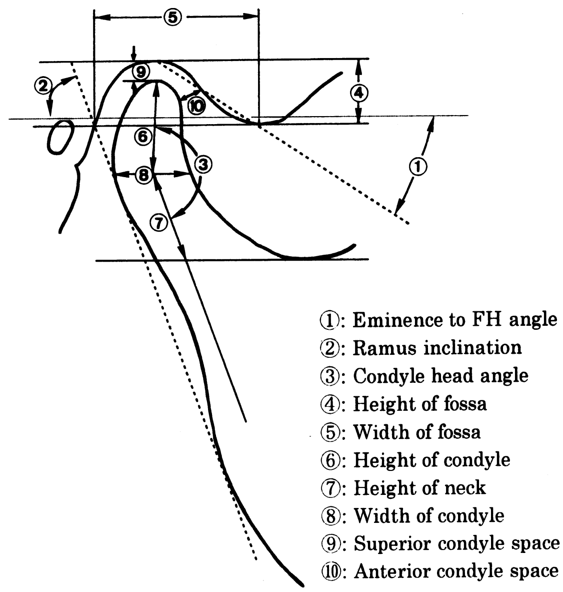


FIG. 7 Measurements on cephalometric laminograph. 1–3 are angular measurements and 4–10 are linear measurements.

TABLE 4 *Statistical analysis between the right and the left sides in 10 measurements of skeletal Class I group*

	Right		Left		
Measurement site	Mean ± SD	Coefficient of reliability	Mean ± SD	Coefficient of reliability	Significant
Eminence to FH plane angle	35·2 ± 7·1	0·99	36·3 ± 6·0	0·98	
Ramus inclination	83·0 ± 6·8	0·99	83·9 ± 7·1	0·96	
Condyle head angle	167·9 ± 7·1	0·98	169·5 ± 7·7	0·97	
Height of fossa	8·2 ± 1·6	0·9	8·4 ± 1·8	0·92	
Width of fossa	17·6 ± 2·2	0·94	16·6 ± 1·8	0·88	*
Height of condyle	8·6 ± 2·0	0·9	9·0 ± 1·9	0·91	
Height of neck	12·0 ± 3·4	0·96	12·0 ± 3·6	0·85	
Width of condyle	9·2 ± 1·5	0·97	8·7 ± 1·5	0·91	
Superior condyle space	2·4 ± 0·7	0·94	2·5 ± 0·7	0·96	
Anterior condyle space	2·9 ± 1·4	0·96	2·9 ± 1·5	0·98	

*$P < 0·05$.

of reliability which should be evaluated with caution (Houston, 1983).

The significance of difference for each of these values for right and left sides was statistically analysed using the Student *t*-test (paired *t*-test) for parametric data.

Results

Intra-group comparisons

Group 1 showed a significant difference between sides in the width of the fossae ($P < 0{\cdot}05$) and also in the anterior condyle space ($P < 0{\cdot}05$) in group 2 (Tables 4 and 5). Group 3 showed a significant difference between the sides in the eminence to FH angle, width of fossae, height of fossae, width of condyle ($P < 0{\cdot}05$) and superior condyle space ($P < 0{\cdot}01$; Table 6). In summary, TMJ morphology in the shifted side showed a steeper eminence to FH angle, smaller width of fossae, and smaller superior condyle space. The head of the condyle in the shifted side showed a shorter height and smaller width.

Inter-group comparisons

Comparison of group 1 and group 2 showed a statistical difference in the values of eminence to FH angle ($P < 0{\cdot}01$) and superior condylar space ($P < 0{\cdot}05$; Table 7).

Discussion

Accuracy on sectograph

The pilot study based on a dry skull indicated that a Sectograph was an accurate sagittal arthrotomogram for representing the morphology of the TMJ.

TMJ morphology and skeletal pattern

This study showed significant differences in the values of the eminence to FH angle and superior condylar space between groups 1 and 2. There are a few reports that TMJ morphology has a strong correlation with skeletal morphology (Widman, 1988; Yamaki *et al*., 1990; Ogawa, 1991), and exclusively an inverse relationship between the angle of the articular eminence, and the occlusal and the mandibular planes (Widman, 1988). Skeletal Class III pattern tended to be more closely associated with the asymmetry of condylar inclination than skeletal I and II groups (Ogawa, 1991). The small angle of eminence to FH plane and the large superior condylar space in the asymmetric skeletal III subjects supports the finding that mandibular movement in skeletal class I is induced by the lingual surface of maxillary incisors at anterior guidance whereas on the other hand skeletal Class III does not have anterior guidance, showing the different eminence to FH angle and mandibular movement (Yamaki *et al*., 1990).

TABLE 5 *Statistical analysis in the side difference in 10 measurements of symmetrical skeletal Class III group*

	Right		Left		
Measurement site	Mean ± SD	Coefficient of reliability	Mean ± SD	Coefficient of reliability	Significant
Eminence to FH plane angle	32·6 ± 5·7	0·99	32·1 ± 6·1	0·99	
Ramus inclination	80·9 ± 7·6	0·99	81·3 ± 6·5	0·99	
Condyle head angle	168·2 ± 10·8	0·99	168·8 ± 9·3	0·99	
Height of fossa	7·8 ± 1·8	0·91	7·3 ± 1·6	0·91	
Width of fossa	17·6	± 1·9	0·94	17·6 ± 2·0	0·95
Height of condyle	9·2	± 2·1	0·97	9·0 ± 1·9	0·92
Height of neck	13·3 ± 3·7	0·97	12·9 ± 3·8	0·99	
Width of condyle	9·3	± 1·4	0·91	8·9 ± 1·5	0·96
Superior condyle space	2·1 ± 1·1	0·97	2·0 ± 0·7	0·93	
Anterior condyle space	2·8 ± 1·2	0·89	3·7 ± 1·7	0·99	*

*$P < 0{\cdot}05$.

TABLE 6 *Statistical analysis between the shifted sides and the unshifted sides in 10 measurements of asymmetrical skeletal Class III group*

	Shifted side		Unshifted side		
Measurement site	Mean ± SD	Coefficient of reliability	Mean ± SD	Coefficient of reliability	Significant
Eminence to FH plane angle	32·6 ± 5·7	0·99	32·1 ± 6·1	0·99	
Eminence to FH plane angle	34·3 ± 7·0	0·97	32·0 ± 6·3	0·98	*
Ramus inclination	83·6 ± 7·8	0·98	81·6 ± 7·3	0·98	
Condyle head angle	168·7 ± 8·2	0·97	168·2 ± 8·1	0·98	
Height of fossa	8·3	± 1·9	0·92	8·1 ± 1·9	0·91
Width of fossa	17·8 ± 2·3	0·95	18·7 ± 2·1	0·89	*
Height of condyle	8·2 ± 2·2	0·89	8·9 ± 2·2	0·96	*
Height of neck	14·0 ± 5·2	0·97	15·1 ± 4·6	0·98	
Width of condyle	8·7 ± 1·3	0·87	9·1 ± 1·1	0·89	*
Superior condyle space	1·9 ± 0·6	0·89	2·3 ± 0·7	0·88	**
Anterior condyle space	3·1 ± 1·7	0·94	3·2 ± 1·2	0·9	

*$P < 0{\cdot}5$; **$P < 0{\cdot}01$.

TABLE 7 *Statistical analysis in the difference on both group 1 and group 2*

	Group 1		Group 2		Significant
Measurement site	Mean ± SD right	Mean ± SD left	Mean ± SD right	Mean SD left	Group 1 vs group 2
Eminence to FH plane angle	35·2 ± 7·1	36·3 ± 6·0	32·6 ± 5·7	32·1 ± 6·1	**
Ramus inclination	83·0 ± 6·8	83·9 ± 7·1	80·9 ± 7·6	81·3 ± 6·5	
Condyle head angle	167·9 ± 7·1	169·5 ± 7·7	168·2 ± 10·8	168·8 ± 9·3	
Height of fossa	8·2 ± 1·6	8·4 ± 1·8	7·8 ± 1·8	7·3 ± 1·6	
Width of fossa	17·6 ± 2·2	16·6± 1·8	17·6 ± 1·9	17·6 ± 2·0	
Height of condyle	8·6 ±·2·0	9·0 ± 1·9	9·2 ± 2·1	9·0 ± 1·9	
Height of neck	12·0 ± 3·4	12·0 ± 3·6	13·3 ± 3·7	12·9 ± 3·8	
Width of condyle	9·2 ± 1·5	8·7 ± 1·5	9·3 ± 1·4	8·9 ± 1·5	
Superior condyle space	2·4 ± 0·7	2·5 ± 0·7	2·1 ± 1·1	2·0 ± 0·7	*
Anterior condyle space	2·9 ± 1·4	2·9 ± 1·5	2·8 ± 1·2	3·7 ± 1·7	

*$P < 0·05$; **$P < 0·01$.

Asymmetry of TMJ and mandible

Group 3 showed a significant side difference in the morphology of the TMJ; a smaller superior condylar space with upward position of the condyle, shorter height and smaller width of the condyle being evident in the shifted side. For the non-shifted side, the condylar head was positioned downward in relation to the fossae and tended to be longer than that of the shifted side.

Studies associated with transcranial radiographs (Myers *et al.*, 1980) and corrected tomograms (Hesse *et al.*, 1997) have reported asymmetries in condylar position in the fossa in unilateral posterior crossbite children prior to treatment. However, Lam *et al.* (1999) was unable to demonstrate any differences in condylar position between the crossbite and Class I non-crossbite groups at pre- and post-treatment stages, demonstrating a large standard deviation.

Correction of a unilateral posterior cross bite eliminates the funcational side shift in children and allow the mandible to assume a symmetric position (Myers *et al.*, 1980; Pullinger *et al.*, 1985; Ishii, 1992; Hesse *et al.*, 1997). Consequently, early treatment has been recommended (Schroder and Schroser, 1984; Thilander *et al.*, 1984; Lindner *et al.*, 1986; Vig and Vig, 1986; Mongini and Schmid, 1987; Lindner, 1989). The facial asymmetry describing the shifted position of mandible shows the strongest correlation with condyle path asymmetry (Pirttiniemi *et al.*, 1990; Fukui *et al.*, 1992; Mimura and Deguchi, 1994). Furthermore, the degree of asymmetry was found to be twice as great in the untreated as in the treated groups, emphasizing the importance of early treatment of posterior crossbite (Pirttiniemi *et al.*, 1990). As functional corrector appliances in Class II cases and orthopedic forces in Class III malocclusions produce orthopedic effects on the TMJ experimentally (McNamara and Carlson, 1979; McNamara *et al.*, 1982) and clinically (Mimura and Deguchi, 1996), a functional shift of the mandible in children resulting in a asymmetric position of condyle suggests that this functional shift may transmit forces to the skeleton resulting in asymmetry in the adult (Myers *et al.*, 1980).

Although asymmetrical skeletal Class III adults are commonly treated by ortho-surgical procedures (Sugawara, 1996), asymmetry of TMJ morphology in group 3 in the present study may have effects on the stability of the treatment results. Interestingly, there are only a few reports in the literature, which describe the relationship between mandibular asymmetry and asymmetry (plagiocephaly) of the cranial vault (Kushima, 1979; Yoshikawa *et al.*, 1986; Satoh *et al.*, 1994). However, these findings suggest that plagiocephaly is a factor in the etiology of posterior crossbite.

Asymmetry of the mandible shows a high incidence of TMJ disorders (Sato *et al.*, 1993), these being especially observed on the shifted side of mandible (Fushima *et al.*, 1989). In those cases where the head of condyle is located at a posterior site, the articular disc is anteriorly dislocated and symptoms (e.g. sound) of TMJ disorders are induced at anterior guidance (Bandou *et al.*, 1993). In this study, the position of the condyle on the shift side is located posteriorly which may induce anterior dislocation of the articular disc, causing a clicking.

Conclusions

1. A pilot study on a dry skull showed that a sectogram is an accurate sagittal laminogram.
2. Symmetric skeletal Class III (group 2) showed a smaller angle of articular eminence ($P < 0·01$) and larger superior condyle space ($P < 0·05$) than those of Class I.
3. Asymmetric skeletal Class III (group 3) showed a significant difference in the values of articular eminence (eminence to FH angle), width of fossa, height of fossa, width of condyle ($P < 0·05$) and superior condyle space ($P < 0·01$).

References

Aoshima, O., Yamashita, T., Imamura, R. and Uehara, S. (1992)
Morphological examination of condyle with basilar view cephalogram of true Class III and crossbite requiring surgical orthodontics treatment,
Nihon University Journal of Oral Science, **18,** 274–279.

Asai, Y. (1973)
Growth changes of maxillofacial skeleton of Japanese from 12 to 20 years of age. A longitudinal study by means of cephalomeric roentogenograms,
Journal of the Japanese Orthodontic Society, **32,** 61–98.

Bandoh, E., *et al.* (1993)
Color Atlas of Temporomandibular Disorders—New system of Diagnosis and Therapy,
Ishiyaku Publishers Inc., Tokyo, Japan.

Erickson, G. E. and Waite, D. E. (1974)
Mandibular asymmetry,
Journal of the American Dental Association, **89,** 1369–1373.

Fukui, T., Satoh, Y., Tamada, K., Morita, S. and Hanada, K. (1992)
Relationships between mandibular lateral deviation and bilateral condylar paths on mandibula protrusive movement,
Journal of the Japanese Orthodontic Society, **51,** 203–209.

Fushima, K., Akimoto, S., Takamoto, K., Sato, S. and Suzuki, Y. (1989)
Morphological feature and incidence of TMJ disorders in mandibular lateral displacement cases,
Journal of the Japanese Orthodontic Society, **48,** 322–328.

Hayasaka, M., Takahashi, K., Kataoka, Y. and Tajima, T. (1983)
A study of condylar position with sectograph. Part 1. Condylar position with reference to the various mandibular positions,
Journal of the Japan Prosthodontic Society, **27,** 550–572.

Hesse, K., Artun, J., Joondeph, D. R. and Kennedy, D. B. (1997)
Changes in condyle position and occlusion associated with maxillary expansion for correction of functional unilateral posterior crossbite,
American Journal of Orthodontics Dentofacial Orthopedics, **111,** 410–418.

Houston, W. J. (1983)
The analysis of errors in orthodontic measurements,
American Journal of Orthodontics, **83,** 382–390.

Ishii, K. (1992)
A histological study on the maxillary change to lateral deviation of the mandible and morphologic recovery after renovation of it,
Journal of the Japanese Orthodontic Society, **51,** 109–125.

Kobayashi, M., Saito, I., Ishii, K., Takeyama, M., Morita, S. and Hanada, K. (1996)
Long-term observation of mandibular protrusion cases worsen in pubertal growth spurt,
Journal of the Japanese Orthodontic Society, **55,** 234–245.

Kushima, F. (1979)
The relationships between the horizontal cranial contour and the position or form of the maxillary dental and basal arches-A study by means of roentgenocephalograms in vertico-basillar direction,
Ohsaka Dai Shi Shi, **24,** 211–236.

Lam, P. H., Sadowsky, C. and Omerza, F. (1999)
Mandibular asymmetry and condylar position in children with unilateral posterior crossbite,
American Journal of Orthodontics Dentofacial Orthopedics, **115,** 569–575.

Lindner, A., Henrickson, C. O., Odenrick, L. and Modeer, T. (1986)
Maxillary expansion of unilateral crossbite in preschool children,
Scandinavian Journal of Dental Research, **94,** 411–418.

Lindner, A. (1989)
Longitudinal study on the effect of early interceptive treatment in 4-year old children with unilateral crossbite,
Scandinavian Journal of Dental Research, **97,** 432–438.

Marmary, Y., Zilberman, Y. and Mirsky, Y. (1979)
Use of foramina spinosa to determine skull midlines,
Angle Orthodontist, **49,** 263–268.

McNamara, J. A. and Carlson, D. S. (1979)
Quantitative analysis of temporomandibular joint adaptations to protrusive function,
American Journal of Orthodontics, **76,** 593–611.

McNamara, J. A., Hinton, R. J. and Hoffman, D. L. (1982)
Histologic analysis of temporomandibular joint adaptation to protrusive function in young adult rhesus monkeys,
American Journal of Orthodontics, **82,** 288–298.

Mimura, H. and Deguchi, T. (1994)
Relationship between sagittal condylar path and the degree of mandibular asymmetry in unilateral cross-bite patients,
Journal of Craniomandibular Practice, **12,** 161–166.

Mimura, H. and Deguchi, T. (1996)
Morphologic adaptation of temporomandibular joint after chincup therapy,
American Journal of Orthodontics Dentofacial Orthopedics, **110,** 541–546.

Mongini, F. and Schmid, W. (1987)
Treatment of mandibular asymmetries during growth. A longitudinal study,
European Journal of Orthodontics, **9,** 51–67.

Myers, D. R., Barenie, J. T., Bell, R. A. and Williamson, E. H. (1980)
Condylar position in children with functional posterior crossbites: before and after crossbite correction,
Pediatric Dentistry, **2,** 190–194.

Ogawa, Y. (1991)
Investigation of the relationship between the inclination of the condylar head and maxillofacial morphology,
Journal of Fukuoka Dental College, **18,** 137–153.

Ogawa, Y., Yoshikawa, Y., Maruyama, K., Nichimoto, M., Kato, Y. and Deguchi, T. (1988)
Application of subtraction to T.M.J. Cephalometric laminagraph,
Journal of the Japanese Stomatological Society, **37,** 81–88.

Pirttiniemi, P., Kantomaa, T. and Lahtela, P. (1990)
Relationship between craniofacial and condyle path asymmetry in unilateral cross-bite patients,
European Journal of Orthodontics, **12,** 408–413.

Pullinger, A., Thurston, M. and Turley, P. (1985)
Condylar adaptation to unilateral posterior crossbite in adults,
Journal of Dental Research, **64,** 269, Abstract 851.

Sakuda, M., Nakago, T., Matsumoto, M., Katayama, T., Yoshida, K. and Ishizawa, M. (1969)
A case of posterior cross-bite: changes in form and function following orthodontic treatment,
Journal of the Japanese Orthodontic Society, **28,** 329–343.

Sato, S., Kawamura, H., Nagasaka, H., Goto, S., Motegi, K., Sugawara, J., Mitani, H. (1993)
Incidence of temporomandibular joint disorders in patients with orofacial deformities,
Journal of Japanese Society for Temporomandibular Joint, **5, 8**–16.

Satoh, Y., Fukui, T., Hara, S., Yamada, K., Morita, S., Hanada, K. (1993)
Relationship among mandibular deviation, condylar morphology and condylar movement,
Journal of Japanese Society for Temporomandibular Joint, **5,** 58–68.

Satoh, Y., Matsugishi, K., Fukui, T., Yamada, K., Morita, S. and Hanada, K. (1994)
Relationship between mandibular lateral deviation and morphology of the cranial vault,
Japanese Journal of Jaw Deformities, **4,** 96–103.

Schroder, U. and Schroser, I. (1984)
Early treatment of unilateral posterior crossbite in children with bilaterally contracted maxillae,
European Journal of Orthodontics, **6,** 65–69.

Sugawara, J. (1996)
Surgical orthodontic treatment for facial asymmetry,
Journal of Orthodontic Practice, **Dec.,** 11–28.

Thilander, B., Wahllund and Lennartsson, B. (1984)
The effects of early interceptive treatment in children with posterior crossbite,
European Journal of Orthodontics, **6,** 25–34.

Vig, P. S. and Vig, K. W. L. (1986)
Hybrid appliances: a component approach to dentofacial orthopedics,
American Journal of Orthodontics, **90,** 273–285.

Walther, D. P. (1967)
Orthodontic Notes,
John Wright & Sons Ltd. Bristol.

Widman, D. J. (1988)
Functional and morphologic considerations of the articular eminence,
Angle Orthodontist, **58,** 221–236.

Yamaki, M., Mohri, T., Terada, K., Hanada, K., Nishi, K., Iwakata, S., Saitou, A. and Ishioka, K. (1990)
The relationship between mandibular movement and dentofacial morphology: a preliminary report,
Journal of Japanese Society for Temporomandibular Joint, **2,** 22–33.

Yoshikawa, Y., Takagi, S., Kato, Y., Deguchi, T. (1986)
The outline of skulls with unilateral posterior cross bite,
Matsumoto Shigaku, ***12,*** 145–149.