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Characterization of facial asymmetry in skeletal Class III malocclusion and its implications for treatment

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Abstract. Jaw deviation is frequently seen in Class III patients. The aim of the study was to investigate asymmetric features of skeletal, dental and soft tissues in three types of jaw asymmetry based on our previously reported classification system. The cone-beam computed tomography (CBCT) images of 70 Class III patients were analysed. Group 1 patients showed large shift of menton and synchronous but smaller ramus deviation. The maxillomandibular complex had roll and yaw rotations to the menton-deviation side. Maxillary and dental asymmetry was obvious in transverse and vertical dimensions. Cant of occlusal plane and lip line was apparent. Group 2 patients also exhibited menton and ramus deviation to the same side but the discrepancy in ramus width was larger than menton shift. Asymmetry in Group 2 resulted from a bodily side shift of the maxillomandibular complex without obvious rotation. Group 3 patients had menton and ramus deviated in opposite directions which seemed secondary to a yaw rotation. Double-jaw surgery is generally required for Groups 1 and 3 while Group 2 patients may be successfully treated by mandibular surgery only provided that arch width discrepancy can be managed by orthodontic measures.

Key words: Class III malocclusion; facial asymmetry; maxillomandibular complex rotation; cone-beam computed tomography.

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Facial asymmetry is frequently seen in patients with skeletal malocclusion, especially those with Class III deformity[1–3]. Lateral deviation of chin is usually the most noticeable feature in patients with facial asymmetry[4], which may result from positional displacement or morphological alteration of mandibular structures[5,6]. Asymmetric growth of maxilla may accompany mandibular deviation[7]. Classifications of jaw asymmetry recommended in previous studies usually focus on complicated forms of bodily shifts and rotations of mandibular body, ramus and maxilla[8]. They are usually too complex for the guidance of effective clinical management. Therefore, we have proposed a new classification of mandibular asymmetry in Class III patients which is based on the extent and direction of chin deviation relative to transverse ramus discrepancy.

We found that our classification system is easy to use and predictive of treatment outcome[9].

However, limitations do exist in our classification system. In the previous study we aimed only at the lower jaw and associated maxillary deviation was not addressed. Special attention should also be paid to dental asymmetry because transverse dentoalveolar compensation is usually evident in jaw deviation. Dentoalveolar decompensation is important for maximization of surgical outcomes and normalization of stomatognathic function in patients with jaw asymmetry[10–12]. Soft tissue assessment is also essential in the evaluation of facial asymmetry. Research showed that appraisal of facial asymmetry based on clinical photographs was not always consistent with that using frontal cephalometric radiographs[13], indicating that soft tissue could be of compensation for the asymmetry of skeleton[14–16].

The aim of this retrospective cone-beam computed tomography (CBCT) study was to investigate the asymmetric features of skeletal, dental and soft tissues in skeletal Class III patients based on our classification system of mandibular asymmetry[9]. The subjects were categorized into three groups according to whether chin deviation was synchronized with transverse ramus discrepancy. In each group, skeletal, dental and soft tissue parameters in the sagittal, horizontal, and vertical planes were compared between the chin deviation and non-deviation sides. The asymmetric growth patterns in the three groups of patients were analysed and the implications on surgical-orthodontic treatment were discussed.

Materials and Methods

Patients

The study included a total of 70 consecutive patients (38 males and 32 females; age: 25.1 ± 4.8 years) with Class III malocclusion on at least one side of the dentition. All patients asked for surgical-orthodontic treatment to correct dentofacial deformity at the National Taiwan University Hospital from 2013 to 2014. Patients with other congenital anomalies or history of maxillofacial trauma were excluded from the study. The patients

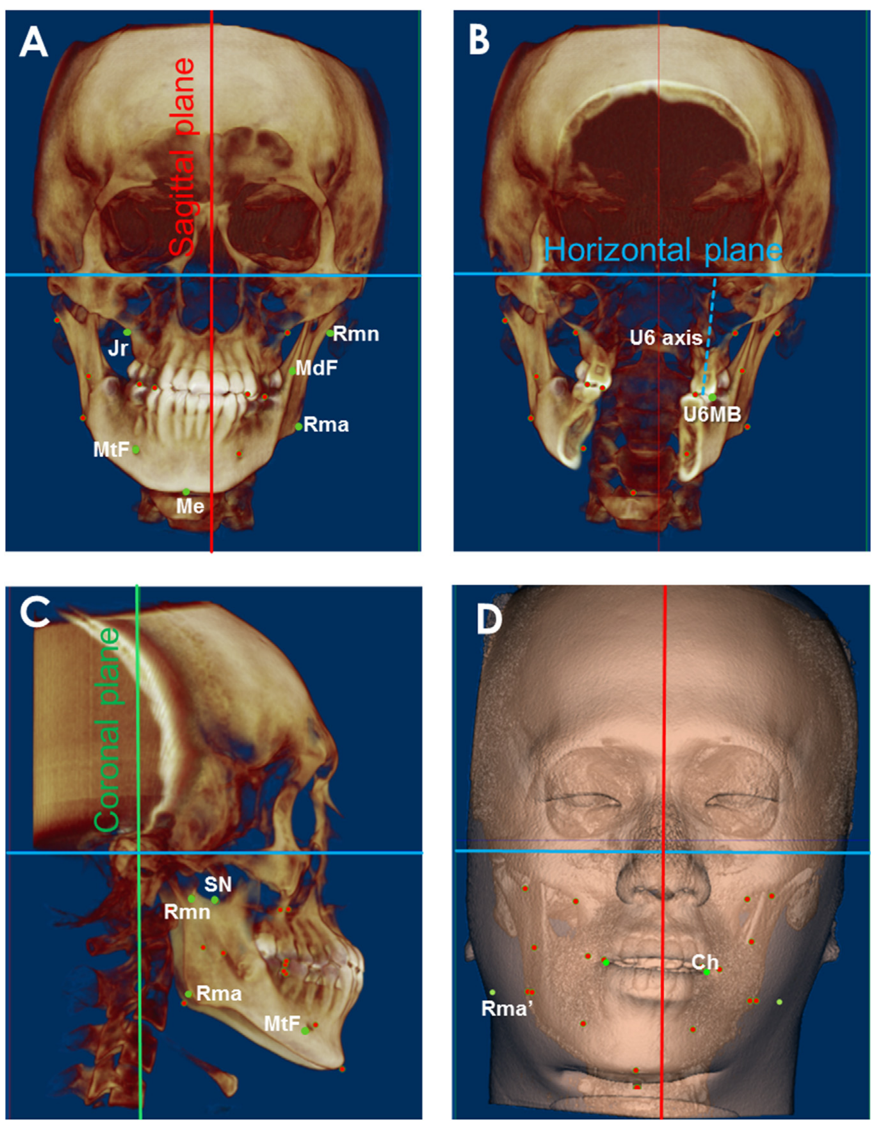

Fig. 1. Landmarks used in the study. (A) Skeletal landmarks in frontal view. (B) Dental landmarks in frontal view. (C) Skeletal landmarks in sagittal view. (D) Soft tissue landmarks in frontal view. Please refer to Table 1 for detailed definitions.

Table 1. Landmarks used in the study.

Abbreviation	Landmark	Definition
N	Nasion	Middle point of nasofrontal suture
S	Sella turcica	Centre of sella turcica
Ba	Basion	Most anterior point of foramen magnum
Po	Porion	Most superior point of external auditory meatus
Or	Orbitale	Most inferior point of lower margin of orbit
Me	Menton	Most inferior point of symphysis of mandible
Jr	Jugulare	Midpoint at the concavity of zygomaticoalveolar crest in frontal view
SN	Sigmoid notch	Most concave point of sigmoid notch
MdF	Mandibular foramen	Most superior point of mandibular foramen
MtF	Mental foramen	Most superior point of mental foramen
Rmn	Ramal point at the level of sigmoid notch	Most lateral point of ramus contour at the level of SN
Rma	Ramal point at the level of gonion	Most lateral point of ramus contour at the level of gonion, the point on mandibular angle at the junction of ramus and body
Rma'	Soft tissue counterpart of Rma	Most lateral point of facial contour at the level of gonion
Ch	Cheilion	Most lateral point at the angle of lips
U6MB	Mesiobuccal cusp of maxillary first molar	Mesiobuccal cusp tip of maxillary first molar
U6 axis	Axis of maxillary first molar	A line connecting root furcation and the midpoint between mesiobuccal and mesiolingual cusp tips of maxillary first molar

were categorized into three groups according to the direction and magnitude of transverse ramus discrepancy relative to menton deviation[9]. Groups 1 and 2 included patients with ramus and menton shifted to the same side, that is, a larger ramus distance to midsagittal plane on the menton deviation side. Patients in Group 1 exhibited greater menton deviation than ramus discrepancy and the condition was reversed for Group 2 in which ramus discrepancy was equal to or larger than menton shift. Group 3 patients had a larger ramus width contralateral to the side of menton deviation.

CBCT data acquisition

Pre-treatment CBCT images were acquired with i-Cat CBCT scanner (Imaging Sciences International, Hatfield, PA, USA). The machine setting parameters were 120 kVp, 47.74 mA, and 40 s with an isotropic 0.4-mm voxel size. The scan data were exported in a DICOM format and processed using Dolphin3D software (Dolphin Imaging & Management solutions, Chatsworth, CA, USA) to reconstruct craniofacial three-dimensional (3D) models. Three reference planes were used for the analysis of asymmetry as described previously[9]. Midsagittal plane was determined by the point nasion, sella turcica, and basion. Horizontal plane was defined as the plane passing through the midpoints between porion and orbitale on both sides and perpendicular to midsagittal plane. Coronal plane was the plane perpendicular to horizontal and midsagittal planes and passing through basion. After re-orientation of the CBCT 3D images, relevant landmarks were identified via checking the anatomic structures from different views (Fig. 1) by the same author (K.-J.Y.). Linear and angular measurements were then calculated.

Table 2. Measurements used in the study.

	Definition
Skeletal	
Me-S	Distance from menton to midsagittal plane
Rmn-S	Distance from Rmn to midsagittal plane
Rma-S	Distance from Rma to midsagittal plane
Ramus width	The mean of Rmn-S and Rma-S
Coronal ramus angle	The medial angle between horizontal plane and the line connecting Rmn and Rma
Jr-S, Jr-C, Jr-H	Distances from jugulare to midsagittal, coronal, and horizontal planes, respectively
MdF-S, MdF-C, MdF-H	Distances from MdF to midsagittal, coronal, and horizontal planes, respectively
MtF-S, MtF-C, MtF-H	Distances from MtF to midsagittal, coronal, and horizontal planes, respectively
Rmn-H	Distance from Rmn to horizontal plane
Rma-H	Distance from Rma to horizontal plane
Dental	
U6MB-H	Distance from mesiobuccal cusp tip of maxillary first molar to horizontal plane (molar height)
U6MB-S	Distance from mesiobuccal cusp tip of maxillary first molar to midsagittal plane (molar width)
U6 axis angle	The medial angle between U6 axis and horizontal plane
Soft tissue	
Cheilion-H	Distance from cheilion to horizontal plane
Rma'-S	Distance from Rma' to midsagittal plane (lower face width)
Rma'-Rma	The difference between Rma'-S and Rma-S (soft tissue thickness of lower face)

Landmarks and measurements

Table 1 and Fig. 1 show the landmarks used in the study. The measurements for skeletal, dental and soft tissues in left and right hemifaces were obtained by calculating 3D coordinates of the landmarks (Table 2, Fig. 2). Menton deviation from midsagittal plane was recorded. Ramus width was defined as the mean of the distances of upper and lower ramus contour points (Rmn and Rma, respectively) to midsagittal plane. Ramus asymmetry was the difference between left and right ramus widths. Coronal ramus angle represented the mediolateral inclination of mandibular ramus. The distances of jugulare (Jr), mandibular foramen (MdF) and mental foramen (MtF) to the three references planes were measured. The difference between menton-deviation and non-

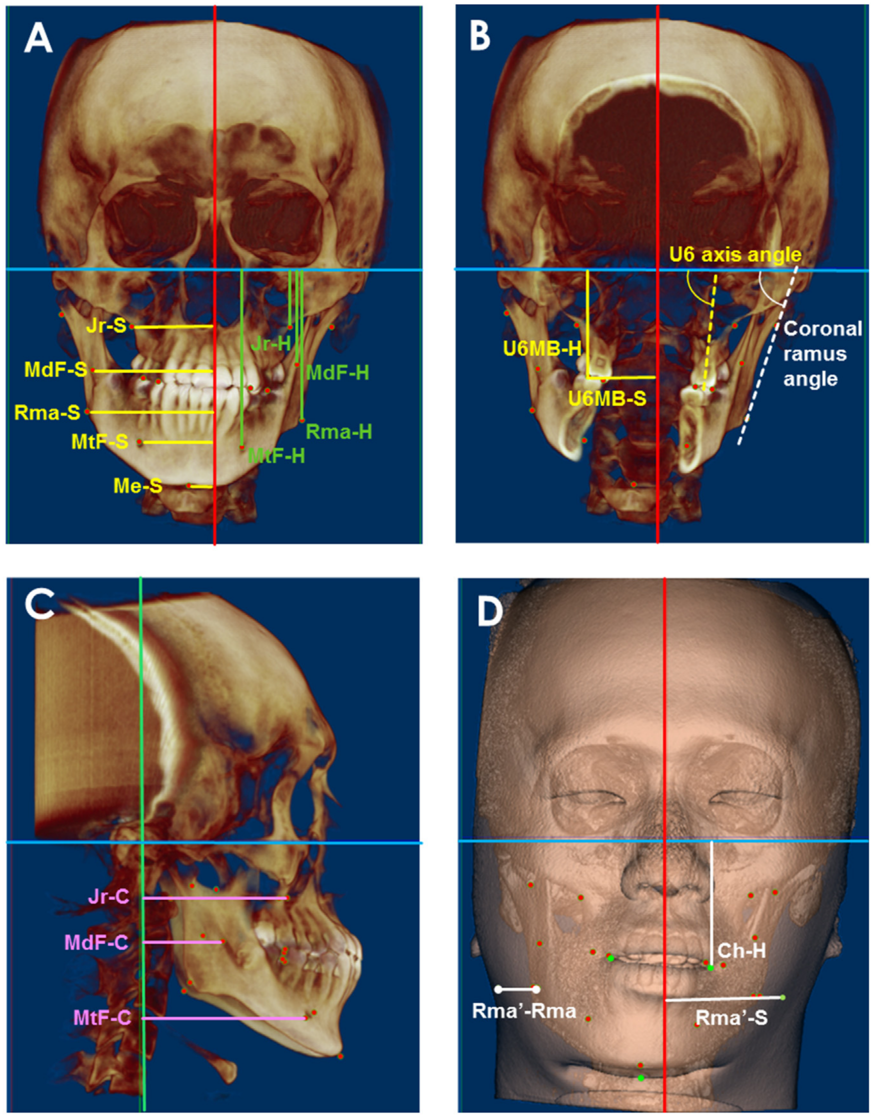

Fig. 2. Measurements used in the study. (A) Skeletal measurements in frontal view. (B) Coronal ramus angle and dental measurements in frontal view. (C) Skeletal measurements in sagittal view. (D) Soft tissue measurements. Please refer to Table 2 for definitions.

deviation sides was calculated for each measurement, and a positive value denoted a greater measurement on the side of menton deviation and vice versa. The distances of bilateral Rma to horizontal plane were measured to assess vertical asymmetry of mandibular angle.

The distances of maxillary first molar to horizontal plane (molar height) and mid-sagittal plane (molar width), as well as its mediolateral inclination were measured. Occlusal plane was defined as the plane passing through mesiobuccal cusp tips of bilateral maxillary first molars and perpendicular to coronal plane. As for the soft tissues, the vertical position of cheilion was assessed by measuring its distance to horizontal plane. Lip line was defined as the line connecting bilateral cheilions. The width and soft tissue thickness of lower face were quantified at the level of Rma.

Statistical analysis

CBCT scans of 10 randomly selected subjects were analysed for intra-observer reliability. Measurements were performed at an interval of 2 weeks and the errors were calculated according to Dahlberg's formula. All data were analysed using IBM SPSS Statistics for Windows, version 19.0 (IBM Corp., Armonk, NY, USA). Student's *t*-test was performed to compare differences in measurements between menton-deviation and non-deviation sides in each of the three groups.

Results

Measurement errors

Measurement errors were smaller than 1 mm for linear assessment and less than 1° for angular evaluation. The maximum errors were noted in Go-H (0.98 mm) and U6 axis angle (0.43°).

Patient distribution

Representative CBCT images from each of the three groups are shown in Fig. 3. About half of the 70 patients belonged to Group 1 (33, 47.14%). The other half of patients were distributed almost equally across Group 2 (18, 25.71%) and Group 3 (19, 27.14%).

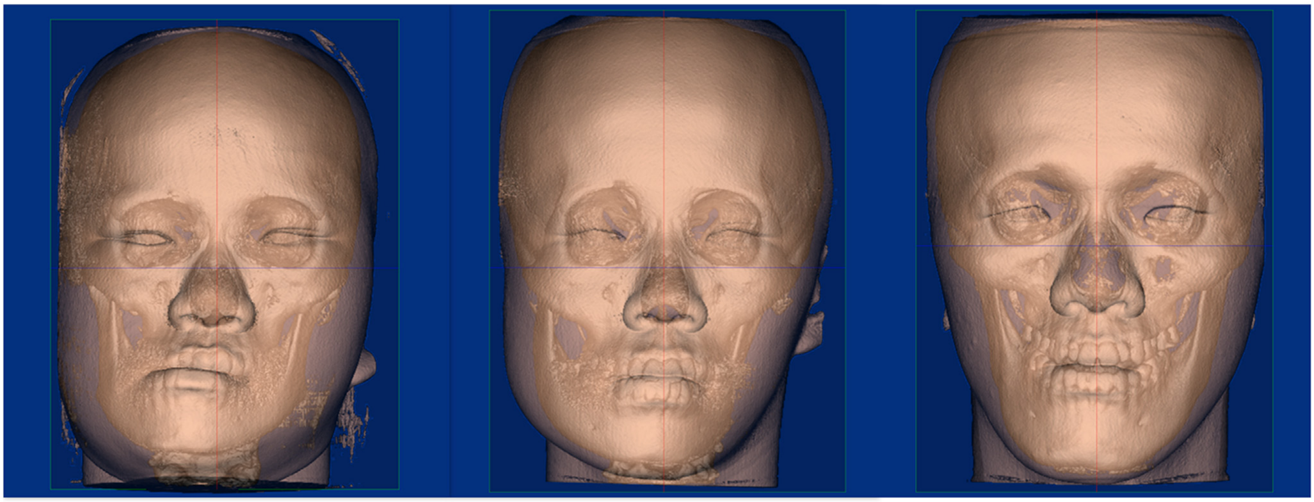

Fig. 3. Representative cone-beam computed tomography (CBCT) images from each of the three groups. Group 1 patients had chin and ramus shifted to the same side and chin deviation was larger than ramus width discrepancy. Group 2 patients also had synchronized chin and ramus deviation, but ramus width discrepancy was equal to or larger than menton shift. Patients in Group 3 had a larger ramus width on the side opposite to chin deviation.

Characteristics of facial asymmetry in Group 1

Tables 3 and 4, respectively, show skeletal and dental/soft tissue measurements in the three groups of patients and the differences between menton-deviation and non-deviation sides. Characteristics of facial asymmetry of the three groups from frontal and axial views are illustrated, respectively, in Figs 4 and 5. Patients in Group 1 exhibited the greatest magnitude of menton deviation (6.49 ± 5.20 mm), which was 2.3-fold that of ramus width discrepancy (2.77 ± 2.71 mm). On the deviation side the ramus was more laterally inclined (larger coronal ramus angle) and mandibular foramen more distant from midsagittal plane (Table 3). Bilateral difference in coronal ramus angle significantly correlated with the extent of menton deviation ($r = 0.763$, $P < 0.001$). Transverse deviation of mental foramens was more obvious than that of mandibular foramens (ΔMtF-S larger than ΔMdf-S). On the non-deviation side the mandibular and mental foramens were more anteriorly (larger MdF-C and MtF-C) and inferiorly (larger MdF-H and MtF-H) positioned. However, the vertical position of lower ramus contour points was not significantly different between the two sides.

Similar to the mandibular ramus and body, the transverse dimension of maxilla (Jr-S) was greater on the menton-deviation side. The position of Jr was more anteriorly and inferiorly (larger Jr-C and Jr-H) on the non-deviation side. This indicated that the maxillomandibular complex had roll and yaw rotations to the menton-deviation side. The centres of rotations seemed close to the condyle of non-deviation side, thus structures more distant from the condyle had larger transverse deviations (Figs 4 and 5). In Group 1 patients, dental asymmetry associated with maxillomandibular rotations was obvious, as evidenced by the significantly greater width and buccal inclination of maxillary first molar on the deviated side. A significant occlusal plane cant was noted by the difference in molar heights between the two sides. Synchronized with the occlusal plane cant, the lip line was inclined to the same side as shown by a lower position of cheilion on the non-deviated side. The transverse dimension of facial soft tissue (Rma'-S) was larger on the deviated side. However, the thickness of soft tissue (Rma'-Rma) was not significantly different between the two sides, indicating that the wider lower face was secondary to skeletal deviation.

Characteristics of facial asymmetry in Group 2

Group 2 patients presented the lowest magnitude of menton deviation (2.10 ± 1.76 mm) among the three groups. Coronal ramus angle was larger on the menton-deviation side but to a lesser extent than that in Group 1. MdF-S and MtF-S were greater on the deviation side but unlike that in Group 1, the bilateral differences were similar in extent. Also dissimilar to the situations in Group 1, MdF was positioned slightly more anteriorly on the menton-deviation side, and there was no significant difference in the sagittal position of MtF and vertical positions of MdF, MtF, and Rma between the two sides. Regarding maxilla, Jr-S was larger on the deviation side but no significant bilateral difference was noted for Jr-C and Jr-H. The asymmetry feature of Group 2 was a bodily side shift of the maxillomandibular complex without obvious rotation (Figs 4 and 5). Transverse dental asymmetry was also noted in Group 2 patients as shown by the greater molar width on the deviation side. However, molar heights and angulations were not significantly different between the two sides, which meant that there was no obvious occlusal plane cant. Correspondingly, lip cant was not evident. Soft tissue analysis revealed a wider lower face on the deviation side, but there was no apparent bilateral difference in soft tissue thickness.

Characteristics of facial asymmetry in Group 3

Patients in Group 3 had mild to moderate deviation of menton (2.59 ± 1.05 mm) and ramus width was greater on the opposite side. Coronal ramus angles were not different between the two sides. Corresponding to the narrower ramus width on the menton-deviation side, MdF was closer but MtF more distant to midsagittal plane on that side. As for the sagittal position of mandibular landmarks, MdF and MtF located more anteriorly on the

Table 3. Skeletal measurements between menton deviation and non-deviation sides.

	Group 1 ($n = 33$)			Group 2 ($n = 18$)			Group 3 ($n = 19$)		
Skeletal	D-side	N-side	Difference[a]	D-side	N-side	Difference[a]	D-side	N-side	Difference[a]
Menton deviation (mm)	6.49 ± 5.20			2.10 ± 1.76			2.59 ± 1.05		
Ramus width (mm)	54.56 ± 3.37	51.80 ± 2.76	2.77 ± 2.71	53.07 ± 2.25	48.70 ± 3.30	4.38 ± 3.87	52.08 ± 2.72	53.45 ± 3.15	−1.38 ± 1.27
Coronal ramus angle (°)	85.06 ± 4.57	80.15 ± 5.20	4.91 ± 5.63	81.78 ± 4.28	78.37 ± 4.02	3.41 ± 4.71	82.19 ± 2.02	81.24 ± 3.21	NS
Jr-S (mm)	34.83 ± 2.53	32.92 ± 2.72	1.91 ± 2.36	33.98 ± 2.15	32.38 ± 2.09	1.61 ± 1.42	33.35 ± 2.21	32.96 ± 2.67	NS
Rma-S (mm)	52.30 ± 3.96	47.71 ± 2.89	4.60 ± 4.50	50.06 ± 2.99	44.24 ± 4.04	5.82 ± 5.44	49.09 ± 2.58	50.20 ± 2.90	−1.11 ± 1.51
MdF-S (mm)	45.12 ± 3.16	41.13 ± 2.95	3.99 ± 3.93	44.93 ± 2.76	39.33 ± 3.20	5.60 ± 4.74	42.78 ± 2.39	44.08 ± 2.38	−1.29 ± 1.63
MtF-S (mm)	28.70 ± 4.44	18.02 ± 4.88	10.68 ± 9.04	25.31 ± 2.69	20.92 ± 2.41	4.39 ± 4.18	25.73 ± 1.85	22.60 ± 1.79	3.13 ± 2.70
Jr-C (mm)	63.59 ± 4.26	64.82 ± 4.76	−1.23 ± 1.81	65.51 ± 9.81	65.28 ± 9.51	NS	65.33 ± 4.77	66.95 ± 4.74	−1.62 ± 1.81
MdF-C (mm)	32.87 ± 4.65	35.13 ± 4.76	−2.27 ± 2.86	34.12 ± 6.64	32.78 ± 6.87	1.33 ± 3.27	33.83 ± 5.14	36.48 ± 5.26	−2.65 ± 2.25
MtF-C (mm)	77.93 ± 7.80	79.53 ± 7.97	−1.60 ± 2.31	78.02 ± 11.65	77.01 ± 12.16	NS	78.44 ± 9.18	80.36 ± 9.09	−1.92 ± 1.35
Jr-H (mm)	27.39 ± 3.50	28.28 ± 3.19	−0.90 ± 1.39	26.84 ± 2.99	26.78 ± 3.33	NS	27.02 ± 3.77	27.11 ± 3.69	NS
MdF-H (mm)	45.34 ± 4.30	46.39 ± 4.29	−1.06 ± 2.56	44.72 ± 2.72	45.17 ± 2.88	NS	43.73 ± 4.33	44.17 ± 4.23	NS
MtF-H (mm)	76.87 ± 6.95	78.34 ± 6.68	−1.47 ± 2.49	75.63 ± 5.79	75.09 ± 6.04	NS	75.25 ± 5.99	75.99 ± 6.16	−0.74 ± 1.34
Rmn-H (mm)	20.07 ± 3.73	21.05 ± 3.78	−0.98 ± 2.12	19.49 ± 2.64	19.44 ± 3.21	NS	19.38 ± 4.49	19.70 ± 3.96	NS
Rma-H (mm)	63.89 ± 6.55	64.58 ± 6.11	NS	63.17 ± 6.13	63.05 ± 6.75	NS	60.91 ± 7.07	61.11 ± 6.37	NS

D, deviation side; N, non-deviation side; NS, non-significant. Data are expressed as mean ± standard deviation.
[a] *P*-values that reached statistical significance (<0.05) are shown; positive values indicate larger measurement on deviation side and vice versa.

Table 4. Dental and soft tissue measurements between menton deviation and non-deviation sides.

	Group 1 ($n = 33$)			Group 2 ($n = 18$)			Group 3 ($n = 19$)		
	D-side	N-side	Difference[a]	D-side	N-side	Difference[a]	D-side	N-side	Difference[a]
Dental									
U6MB-H (molar height) (mm)	49.59 ± 4.24	50.89 ± 4.35	−1.30 ± 1.53	49.07 ± 3.75	49.53 ± 3.79	NS	48.28 ± 4.18	48.53 ± 4.23	NS
U6MB-S (molar width) (mm)	28.96 ± 3.13	25.16 ± 2.92	3.80 ± 3.27	28.47 ± 2.48	25.25 ± 2.01	3.22 ± 2.31	27.89 ± 2.11	27.05 ± 2.54	NS
U6 axis angle(°)	98.45 ± 7.51	92.00 ± 6.17	6.45 ± 7.29	96.63 ± 6.51	92.96 ± 6.99	NS	96.84 ± 6.19	95.22 ± 5.18	NS
Soft tissue									
Cheilion-H (mm)	54.11 ± 5.21	55.72 ± 5.62	−1.60 ± 1.32	52.69 ± 3.88	53.12 ± 4.14	NS	53.13 ± 3.58	53.61 ± 3.68	−0.48 ± 0.92
Rma'-S (mm)	64.94 ± 4.89	60.21 ± 4.29	4.73 ± 4.32	62.52 ± 3.90	57.16 ± 4.46	5.37 ± 3.83	62.73 ± 3.90	62.71 ± 3.74	NS
Rma'-Rma (mm)	12.63 ± 2.77	12.50 ± 3.13	NS	12.46 ± 2.26	12.92 ± 3.02	NS	13.64 ± 3.32	12.51 ± 2.79	1.14 ± 1.58

D, deviation side; N, non-deviation side; NS, non-significant. Data are expressed as mean ± standard deviation.
[a] *P*-values that reached statistical significance (<0.05) are shown; positive values indicate larger measurement on deviation side and vice versa.

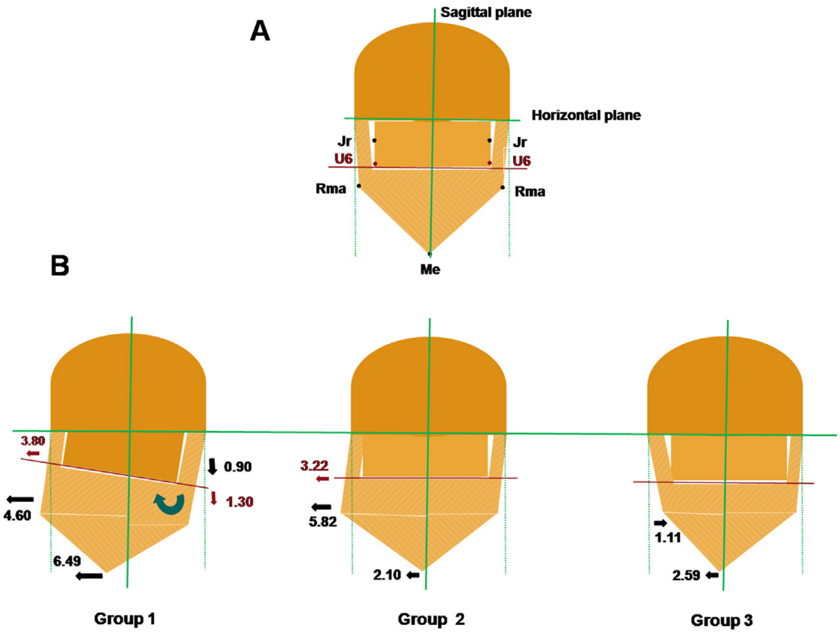

Fig. 4. Frontal outlines of a symmetric face and the averaged faces in each of the three groups. Landmarks are shown in (A) and vectors of landmark deviation (in mm) are illustrated in (B). Group 1 shows roll rotation and Group 2 exhibits bodily side shift of the maxillomandibular complex. Asymmetry in Group 3 is atypical from the frontal view.

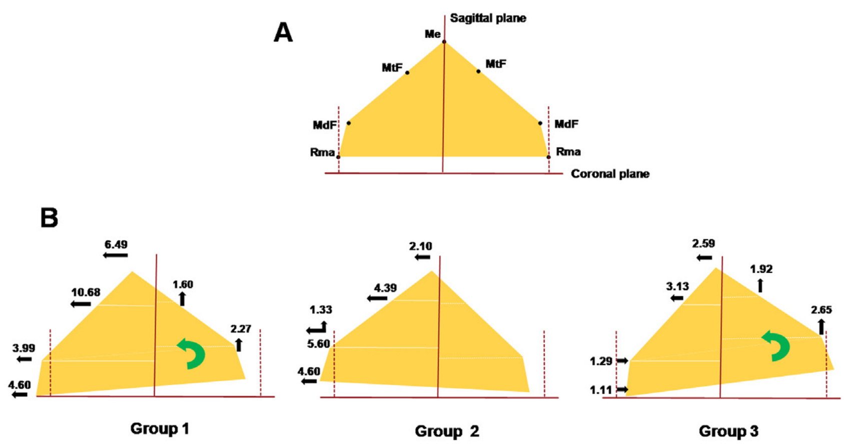

Fig. 5. Axial outlines of a symmetric mandible and the averaged mandibles in each of the three groups. Landmarks are shown in (A) and vectors of landmark deviation (in mm) are illustrated in (B). Groups 1 and 3 show the lateral deviation due to yaw rotation. Asymmetry in Group 2 is the result of a bodily side shift.

non-deviation side. However, no significant difference in vertical position of MdF and Rma was noted between the two sides, and MtF located slightly more inferiorly on the non-deviation side. A more forward position of maxilla on the non-deviation side was also noted (larger Jr-C) whereas there was no significant bilateral difference in the sagittal and vertical positions of Jr. This picture indicated that asymmetry in Group 3 mainly resulted from yaw rotation of the maxillomandibular complex, making menton and ramus deflected in opposite directions (Figs 4 and 5). Group 3 patients had no obvious transverse or vertical asymmetry of maxillary molars. Although statistically significant, the magnitude of lip cant was small. Interestingly, there was no significant bilateral difference in lower face width (Rma'-S). Soft tissue thickness (Rma'-Rma) was greater on the side with narrower ramus width, and the bilateral difference in soft tissue thickness significantly correlated with the extent of ramus width discrepancy ($r = 0.544$, $P = 0.016$). This unique feature of soft tissue compensation was observed only in Group 3.

Discussion

Our previous research investigated the relationship between ramus asymmetry and menton deviation in skeletal Class III patients and developed a classification system to predict the outcomes of surgical-orthodontic treatment for mandibular asymmetry[9]. The present study further delineated dentofacial characteristics of the three types of facial asymmetry. To our knowledge, this was the first study to depict the three-dimensional characteristics of skeletal, dental and soft tissue asymmetry in patients with Class III malocclusion.

In our study, about half of the patients belonged to Group 1 who exhibited a roll/yaw rotational asymmetry of the maxillomandibular complex. Chin deviation and bilateral difference of coronal ramus angle were most obvious in this group of patients. Because of the roll rotation, they had the greatest vertical discrepancy between the two sides. Asymmetry in Group 1 patients can be explained by the relative overgrowth of mandibular condyle on the non-deviation side. Excessive condylar elongation pushes ipsilateral mandibular structures forwards, downwards and towards the opposite side. Displacements of maxillary and dental structures then follow the asymmetric growth of the mandible. The features of Group 1 patients are similar to the 'unilateral condylar hyperplasia asymmetry' described by Baek et al.[8] and the 'roll type asymmetry' reported by Tyan et al.[17]

Groups 2 and 3 each encompassed about one-quarter of our study sample. Asymmetry in Group 2 patients largely resulted from a bodily side shift of the maxillomandibular complex which is similar to the 'lateralization' and 'translation type' asymmetry described in previous studies[8,17]. Patients in Group 2 had a marked discrepancy between bilateral ramus widths and only minor deviation of menton. Corresponding side sifts of maxillary and dental structures were found but there was no significant vertical discrepancy. Group 3 patients had a yaw rotation of the jaws leading to ramus and menton deviated in opposite directions. This group is comparable to the 'atypical asymmetry' depicted by Baek et al.[8] However, we found no significant vertical asymmetry or maxillary occlusal plane cant in this group of patients. The etiology of asymmetry in Groups 2 and 3 is obscure. Joondeph[18] noted that functional mandibular shift due to occlusal interference may encourage glenoid fossa remodelling and asymmetric growth of mandible. Conversely, although the cause–effect relation is not known, studies have shown that the size of masticatory muscles are different between chin-deviated and non-deviated sides in patients with jaw asymmetry[19,20]. Therefore, functional factors may contribute to the asymmetric growth of jaw structures in patients of Groups 2 and 3, for whom disparate condylar growth cannot account for the features of asymmetry.

In clinical management of orthognathic patients, it is important to appreciate the association of lip cant with occlusal plane cant and vertical asymmetry of maxilla. Lip cant has been reported to be positively correlated with menton deviation and occlusal plane cant[21]. In our study, the cant of the lip line was most obvious in Group 1 and only this group of patients had significant occlusal plane cant and bilateral difference of maxillary molar inclination. The direction of the lip line cant was largely synchronized with the slant of maxilla and occlusal plane. The correlation between the maxillary first molar cant and the lip line cant in Group 1 was significant ($r = 0.559$, $P < 0.001$). Therefore, dental decompensation and correction of maxillary and occlusal plane cant are critical parts in the treatment of Group 1 patients. The principle of orthognathic therapy for Group 1 patients is relatively straightforward. Because asymmetry in Group 1 is mainly the result of roll and yaw rotations of the maxillomandibular complex, generally double-jaw surgery to roll and yaw rotate the jaws in the opposite directions is needed. Three-dimensional asymmetry of mandibular body and menton is more easily corrected by roll/yaw rotations in addition to the side shift movement. Double-jaw surgery could also facilitate the levelling of lip cant by equalization of the underlying bony structures[22]. Because roll rotation of the proximal segments is permissible in sagittal split osteotomy and bilateral difference in coronal ramus angle is most obvious in Group 1, ramus asymmetry in this group of patients is most responsive to orthognathic therapy[9].

Asymmetry in Group 2 patients is of a side-shift nature and vertical discrepancy between bilateral structures is not obvious. Mandibular surgery alone is possible for the correction of chin deviation provided that maxillary arch width can be coordinated via orthodontic means or skeletal expansion to accommodate the side-shifted mandible. However, ramus asymmetry is expected to be less responsive to orthognathic therapy than that in Group 1 because the difference between bilateral coronal ramus angles is smaller. Trimming of gonial angle or second surgery may be required if mandibular side shift is not sufficient for the correction of ramus asymmetry[11].

Group 3 patients primarily have a yaw rotation of the maxillomandibular complex along an axis in the ramus/body region of the non-deviation side. A simple side shift of mandible by bilateral sagittal split osteotomies to correct chin deviation may exaggerate ramus asymmetry. Thus, double jaw surgery is often indicated to achieve a counteracting yaw rotation of the jaws. This type of yaw rotation is expected to concomitantly improve the asymmetry between bilateral maxillary prominence and transverse asymmetry of mandibular body and menton. Because coronal ramus angles are not very much different between the two sides, ramus discrepancy is not easy to correct[9]. Interestingly, Group 3 patients exhibit a greater soft tissue thickness on the deviation side, which on one hand may mask the skeletal asymmetry but on the other make the facial morphology less responsive to mandibular movement[14]. Second surgery may be needed to augment the facial contour on the deficient side[11].

In conclusion, our study delineated the structural characteristics of skeletal, dental and soft tissues in Class III patients with different forms of jaw asymmetry. Group 1 patients show large shift of menton and synchronous but smaller ramus deviation. Their asymmetry was mainly the result of roll and yaw rotation of the maxillomandibular complex which can be explained by excessive growth of mandibular condyle on the non-deviation side. Double-jaw surgery is expected to achieve good result for this group of patients. Group 2 patients also exhibit synchronous menton and ramus deviation but the discrepancy in ramus width is larger than menton shift. Asymmetry in Group 2 is of a side shift nature and may be corrected by mandibular surgery alone. Group 3 patients have menton and ramus deviated in opposite directions which may be secondary to a yaw rotation centered at the non-deviation side. Double-jaw surgery is recommended for Group 3. However, in addition to orthognathic jaw movement, bony recontouring may be needed for patients in Groups 2 and 3.

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Competing interests

None.

Ethical approval

This study protocol was approved by the Institutional Review Board of National Taiwan University Hospital (201511037RINA).

Patient consent

Not required.

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