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ORIGINAL ARTICLE

Association between mandibular asymmetry and occlusal asymmetry in young adult males with class III malocclusion

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Abstract

Objective. Our aim was to assess the association between mandibular asymmetry and sagittal and transverse occlusal asymmetry in young adult males with class III malocclusion. Our hypotheses were that (1) mandibular asymmetry increases with increasing mandibular length and (2) occlusal asymmetry is correlated with mandibular asymmetry. ***Material and methods.*** On lateral cephalograms of 54 subjects, skeletal class and mandibular length were measured. Mandibular asymmetry was evaluated on orthopantomograms as right–left difference between condylar or ramus heights. Occlusal asymmetry was assessed on dental casts by differences between right and left canine and molar relationship, anterior and posterior crossbite as well as midline deviation. ***Results.*** Mandibular asymmetry was significantly correlated with sagittal and transverse occlusal asymmetry ($p < 0.05$), but not with mandibular length ($p > 0.05$). Condylar asymmetry due to a longer condyle on one side was correlated with asymmetric aggravation of canine and molar class III on the ipsilateral side ($r = -0.53$ and -0.62, respectively). In contrast, ramus asymmetry was related to contralateral aggravation of canine and molar class III relationships ($r = 0.27$ and 0.29, respectively). Correlations existed between asymmetry in total height of the condyle and ramus and asymmetric aggravation of anterior crossbite ($r = -0.33$), posterior crossbite ($r = -0.30$) and lower midline deviation ($r = -0.27$) to the contralateral side ($p < 0.05$). ***Conclusions.*** Mandibular asymmetry is associated with occlusal asymmetry, especially in the sagittal plane. Condylar asymmetry had 28% and 38% of variance in common with sagittal canine and molar asymmetry, respectively. Asymmetry in total height of the condyle and ramus was related to transverse occlusal asymmetry.

Key Words: *Angle class III, asymmetry, dental occlusion, malocclusion, mandible, mandibular condyle*

Introduction

Treatment of occlusal asymmetry is challenging for the orthodontist, who has to decide whether dentoalveolar correction using asymmetric mechanics is sufficient or whether combined orthodontic–orthognathic treatment is necessary in order to create occlusal symmetry. The dental and skeletal factors that possibly play a role in the development of occlusal asymmetry have to be considered. Occlusal asymmetry can be caused by asymmetric eruption patterns. For example, undermining resorption can cause premature loss of deciduous teeth on one side, followed by migration of adjacent teeth [1]. Furthermore, occlusal asymmetry can be caused by unilateral absence of teeth due to agenesis or by unilateral extraction due to caries, orthodontic treatment planning or trauma [2]. In addition, unilateral abnormal tooth shape due to inborn variation (conoid or hypoplastic teeth) or iatrogenic intervention (restauration) can be responsible for occlusal asymmetry. Besides these dental factors, occlusal asymmetry can be associated with skeletal asymmetry. Asymmetric positioning of the condyles correlates with occlusal asymmetry [3]. Similarly, mandibular asymmetry per se should be related to occlusal asymmetry.

Mandibular asymmetry is the primary cause of facial asymmetry [4]. It is generally present in healthy young subjects and can be regarded as a naturally occurring phenomenon in most subjects, not requiring any treatment [5]. However, the threshold above which mandibular asymmetry becomes noticeable is unknown. The association between mandibular asymmetry and occlusal symmetry is of great interest to orthodontists. In subjects with occlusal asymmetry, moderate-to-severe skeletal asymmetry should be

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ruled out before starting dentoalveolar correction [6]. In the presence of pronounced mandibular asymmetry, combined orthodontic–orthognathic treatment is required. The severity of mandibular asymmetry has been compared among different types of occlusion [7–12]. However, to the best of our knowledge, the association between mandibular asymmetry and occlusal asymmetry has yet to be investigated. Up to a certain degree of mandibular asymmetry the occlusion is able to withstand the skeletal forces of developing mandibular asymmetry, provided dental interdigitation is stable. In these cases the skeletal abnormality is masked by dental compensation [13]. However, when differences in right and left mandibular growth potential are strong enough to overcome the occlusal resistance, mandibular asymmetry induces occlusal asymmetry. On the other hand, occlusal asymmetry may also be the causative factor for asymmetric skeletal development, possibly by favouring unilateral functional patterns.

An association between mandibular and occlusal asymmetry may especially be found in class III malocclusion, when the maxillary arch does not embrace the mandibular arch completely and control of mandibular growth and occlusal development is limited. An increased growth potential of the condylar cartilages has been found among young adults with class III malocclusion, of whom approximately 40% present with mandibular growth excess (mandibular macrognathia) [14]. If differences in right and left condylar growth potential exist, they can be expressed by encountering only restricted maxillary resistance, resulting more easily in mandibular asymmetry and possibly also in occlusal asymmetry. Furthermore, the limited interdigitation in class III malocclusion may directly facilitate the development of occlusal asymmetry, which in turn can induce asymmetric mandibular growth.

The aim of the present study, therefore, was to assess the association between mandibular asymmetry and occlusal asymmetry in a group of young adult males with class III malocclusion. Our hypotheses were that (1) mandibular asymmetry increases with increasing mandibular length and (2) occlusal asymmetry is correlated with mandibular asymmetry. In addition, we aimed to define a threshold of mandibular asymmetry above which occlusal asymmetry may be expected.

Material and methods

Out of a random population of 3358 young adult male Swiss Army recruits of Caucasian origin, subjects with class III malocclusion had been identified and invited to our university, where an orthodontic documentation had been undertaken in 2004 [14]. For the present retrospective study, we used the records of 54 subjects with class III malocclusion with a complete and adequate documentation. The documentation comprised a lateral cephalogram (standardization: Frankfurt horizontal parallel to the floor), an orthopantomogram and dental casts. As required for measurement of mandibular asymmetry, the mandibular contours, including the condyles, had to be visible on the orthopantomograms, otherwise the subject was excluded.

Among the sample were two subjects for whom records from the respective orthodontist were used instead of those from our documentation. We used pre-treatment records from the orthodontist of one subject who was being prepared for orthognathic surgery at the time of our clinical examination and radiographs from the orthodontist of another subject who refused radiographic exposure as part of our documentation.

The mean age of the subjects was 20.4 years (standard deviation 1.4 years).

Since we aimed to include non-growing subjects and since Caucasians often receive orthodontic treatment before puberty, not all subjects were treatment-free. A total of 25 subjects (46.3%) had previously undergone orthodontic treatment and/or were missing teeth due to asymmetric agenesis or extraction. Because these two parameters may have influenced the symmetry of occlusion, we divided our study group (n = 54) into two subgroups: one group of 29 subjects without and one group of 25 subjects with previous orthodontic treatment and/or asymmetric absence of teeth.

Measurements

Lateral cephalograms and orthopantomograms. The radiographs were scanned, adjusted for magnification and analysed by means of cephalometric software (Viewbox version 3.1.1; dHAL Software, Kifissia, Greece).

From each lateral cephalogram, variables describing skeletal class (ANB angle; Wits appraisal) and mandibular length (ArPog, GoPog) were extracted. In order to avoid subjects with generally larger but harmonious craniofacial relations erroneously appearing as having an oversized mandible (ArPog, GoPog), mandibular length was related to the anterior cranial base (SN) (Table I, Figure 1).

Orthopantomograms were used in order to measure condylar height (distance between condylion and incisura), ramus height (distance between incisura and gonion) and total height of condyle and ramus (distance between condylion and gonion) perpendicular to the ramus line [15] (Figure 2). Besides these absolute values, relative values were used by relating these distances to mandibular length (ArPog) as measured on the lateral cephalograms.

Table I. Descriptive statistics for the group without ($n = 29$) and with ($n = 25$) previous orthodontic treatment and/or asymmetric absence of teeth.

	Orthodontic treatment and/or asymmetric absence of teeth						
	Without			With			
		Percentile			Percentile		Comparison
	Median	25th	75th	Median	25th	75th	*p*
Skeletal class (cephalogram)							
ANB (°)	–0.70	–1.80	0.55	–0.74	–1.84	0.18	0.842
Wits appraisal (mm)	–4.26	–5.23	–1.54	–3.00	–5.09	–1.44	0.504
Mandibular length (cephalogram)[a]							
ArPog/SN (mm/mm)	1.58	1.56	1.63	1.62	1.54	1.69	0.310
GoPog/SN (mm/mm)	1.11	1.06	1.16	1.14	1.08	1.16	0.302
Mandibular asymmetry (orthopantomogram)[b]							
Condylar height (mm)	2.23	0.84	2.76	0.98	0.43	1.89	0.060
Ramus height (mm)	1.43	0.90	3.15	1.57	0.46	2.88	0.761
Condylar and ramus height (mm)	2.25	1.10	3.85	1.71	1.02	2.36	0.235
Occlusal asymmetry (cast)[b]							
Canine sagittal relationship (cusp width)	0.25	0.25	0.25	0.25	0.00	0.50	0.839
Molar sagittal relationship (cusp width)	0.25	0.00	0.38	0.25	0.06	0.50	0.084
Anterior crossbite (number of teeth)	0.00	0.00	0.50	0.00	0.00	1.00	0.140
Anterior edge-to-edge (number of teeth)	0.00	0.00	1.00	0.00	0.00	1.00	0.663
Anterior crossbite or edge-to-edge (number of teeth)	1.00	0.00	1.00	0.00	0.00	1.00	0.976
Posterior crossbite (number of teeth)	0.00	0.00	1.50	0.00	0.00	2.00	0.846
Posterior edge-to-edge (number of teeth)	0.00	0.00	1.00	0.00	0.00	1.00	0.728
Posterior crossbite or edge-to-edge (number of teeth)	1.00	0.00	2.00	0.00	0.00	2.00	0.696
Lower midline deviation (mm)	0.50	0.50	1.65	1.00	0.50	2.50	0.304

[a]Mandibular length (ArPog, GoPog) was related to the anterior cranial base (SN), in order to avoid subjects with generally larger craniofacial relations appearing to have an oversized mandible.
[b]The absolute value of the difference between the right and left sides was used.

Dental casts. The sagittal and transverse relationships of the anterior and posterior dental segments were assessed.

Sagittal relationship. The presence of crossbite or an edge-to-edge position of the upper incisors was recorded. A tooth was considered in crossbite or an edge-to-edge position when at least half of its width was in this position. The evaluation of sagittal canine and molar relationship was based on Angle's classification [16] (Figure 3).

Transverse relationship. Lower midline deviation was measured in relation to the maxillary midline, defined by the raphe palatina. The presence of posterior crossbite or an edge-to-edge position of the upper premolars and molars was recorded.

Evaluation of asymmetry

Orthopantomograms. The difference between right and left "condylar height", "ramus height" and "total height of condyle and ramus" was calculated in order to assess mandibular asymmetry.

Dental casts. Occlusal asymmetry was assessed by the differences between right and left canine and molar relationship, anterior and posterior crossbite, as well as midline deviation.

Sagittal relationship. In the anterior segment, the difference between the number of incisors in crossbite and/or edge-to-edge position on the right minus the left side was calculated. In the posterior segment, occlusal asymmetry was defined as the difference between right and left canine or molar relationship.

Transverse relationship. Lower midline deviation to the right side was given a positive value and to the left side a negative value. In the posterior segment, the difference between the number of premolars and molars in crossbite and/or edge-to-edge position on the right minus the left side was recorded.

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (version 15.0; SPSS, Chicago, IL). The level of significance was set at

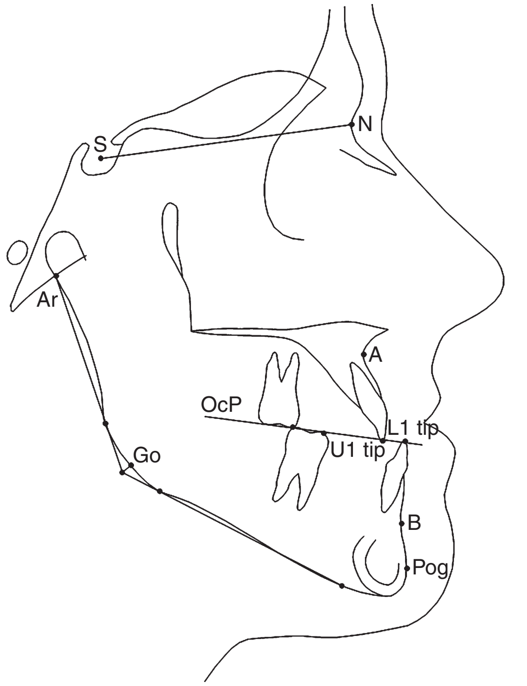

Figure 1. Landmarks on the cephalograms used for measuring skeletal class (ANB angle; Wits appraisal) and mandibular length (ArPog/SN, GoPog/SN). N = Nasion, S = Sella, A = A-point, B = B-point, OcP = Occlusal plane, U1 tip = Upper incisor tip, L1 tip = Lower incisor tip, Ar = Articulare, Go = Gonion, Pog = Pogonion.

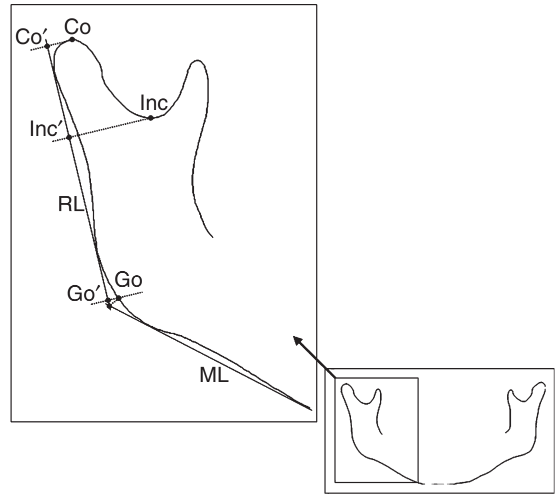

Figure 2. Mandibular asymmetry assessed on orthopantomograms. On each side of the mandible, "condylar height" (Co′–Inc′), "ramus height" (Inc′–Go′) and "total height of condyle and ramus" (Co′–Go′) were measured perpendicular to the ramus line. The difference between the right and left sides was calculated in order to assess mandibular asymmetry. RL = ramus line (tangent to the mandibular ramus), ML = mandibular line (tangent to the lower mandibular border), Co = condylion (the superior point on the condylar head), Inc = incisura mandibulae (the deepest point between processus coronoideus and processus condylaris), Go = gonion (intersection of the bisector of RL and ML with the mandibular border).

$p < 0.05$. Since the data were not normally distributed as assessed by the Kolmogorov–Smirnov test, non-parametric tests were used. Spearman's correlation coefficient was used to investigate possible correlations between skeletal morphology on the cephalograms and mandibular asymmetry on the orthopantomograms. Absolute values were used for mandibular asymmetry when the cephalometric variables were positive only (ArPog/SN, GoPog/SN). Correlations were calculated for mandibular asymmetry (right–left difference) versus occlusal asymmetry (right–left difference) and multiple regression analysis was performed. The threshold values of mandibular asymmetry above which occlusal asymmetry may be expected were defined by visualizing the 99% confidence interval of the linear regression line of occlusal asymmetry plotted against mandibular asymmetry.

The Mann–Whitney test was used in order to detect differences between the group with (n = 25) and without (n = 29) previous orthodontic treatment and/or asymmetric absence of teeth.

Error estimation. In order to test reliability, lateral cephalograms and orthopantomograms of 15 randomly selected subjects were redigitized by the same examiner after a minimum delay of 2 weeks. A paired t-test was performed for each pair of replicates in order to detect systematic error [17]. The random error and the coefficient of reliability were calculated [18].

In order to find out if distortion might have influenced the measurements on the right and left sides of the orthopantomograms, we compared the length of the lower first molar on the right and left sides in all subjects (Wilcoxon test). The length was measured as the perpendicular distance from the mesiobuccal cusp to an apical reference line connecting the mesial and distal root apices [5].

The incisor, canine and molar relationships were remeasured on 15 study models after at least 2 weeks. Reproducibility was tested by analysis of intra-observer agreement using a weighted Kappa statistic.

Reliability. No statistically significant systematic error was found for the measurements on the radiographs. The random error was 0.20° for angular measurements and 0.20–0.75 mm for linear measurements. The coefficient of reliability was ≥ 0.97. The comparison of the lower first molar length on the right and left sides did not show significant differences (p = 0.544). When the dental relationships were measured on the casts, intra-observer agreement was very good (Kappa ≥ 0.8).

Results

Between the groups with and without previous orthodontic treatment or asymmetric absence of

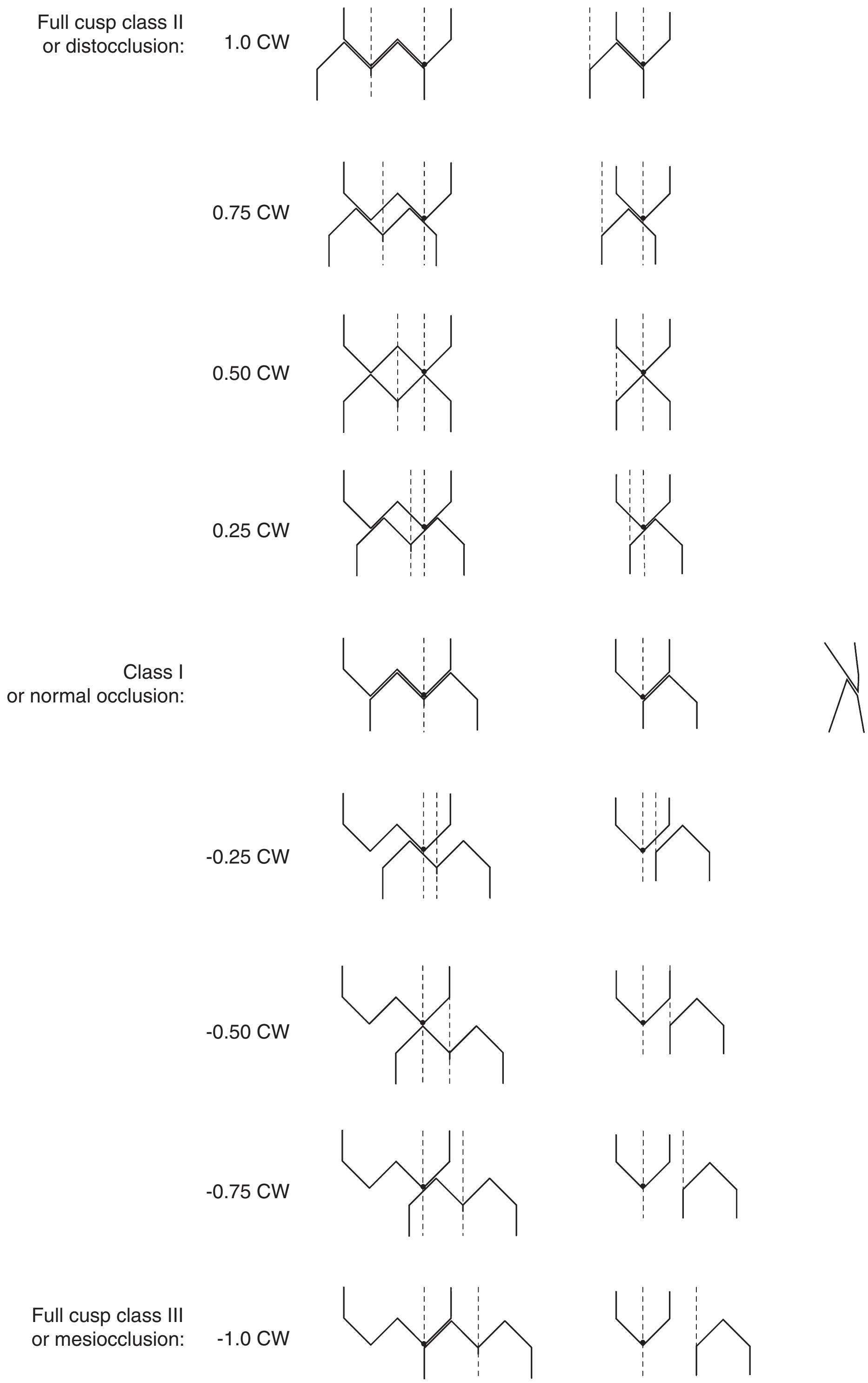

Figure 3. Classification of sagittal canine and molar relationships. Compared to class I, a more distal (positive value) or mesial (negative value) position of the mandibular canine or molar in relation to the maxillary tooth was graded as a quarter (± 0.25), half (± 0.5), three-quarters (± 0.75) or full (± 1.0) cusp width (CW) class II or class III malocclusion, respectively. Reproduced with permission from Staudt & Kiliaridis [16].

teeth, no significant differences were found in the variables describing skeletal class, mandibular length, and mandibular and occlusal asymmetry (Table I). Therefore we decided to merge the two groups (Tables II and III).

A certain degree of mandibular asymmetry was present in the whole sample (minimum = 0.02 mm, maximum = 11.7 mm) (Table II). In 50% of subjects (median), this exceeded 1.5 mm, and in 25% (75th percentile) this exceeded 2.5 mm. Occlusal asymmetry in canine and molar relationships exceeded a quarter cusp width in 50% of the sample and a half cusp width in 25%. Subjects with symmetric occlusion were also present.

Table II. Descriptive statistics for the total sample (n = 54).

	Median	Minimum	Maximum	Percentile 25th	Percentile 75th
Skeletal class (cephalogram)					
ANB (°)	–0.72	–6.43	3.37	–1.78	0.40
Wits appraisal (mm)	–3.29	–10.99	2.34	–5.22	–1.51
Mandibular length (cephalogram)[a]					
ArPog/SN (mm/mm)	1.60	1.43	1.78	1.56	1.66
GoPog/SN (mm/mm)	1.13	0.95	1.25	1.07	1.16
Mandibular asymmetry (orthopantomogram)[b]					
Condylar height (mm)	1.60	0.06	11.74	0.64	2.45
Ramus height (mm)	1.47	0.03	9.15	0.77	2.92
Condylar and ramus height (mm)	1.90	0.02	7.60	1.08	3.04
Occlusal asymmetry (cast)[b]					
Canine sagittal relationship (cusp width)	0.25	0.00	1.75	0.00	0.50
Molar sagittal relationship (cusp width)	0.25	0.00	2.25	0.00	0.50
Anterior crossbite (number of teeth)	0.00	0.00	2.00	0.00	1.00
Anterior edge-to-edge (number of teeth)	0.00	0.00	2.00	0.00	1.00
Anterior crossbite or edge-to-edge (number of teeth)	0.50	0.00	2.00	0.00	1.00
Posterior crossbite (number of teeth)	0.00	0.00	4.00	0.00	2.00
Posterior edge-to-edge (number of teeth)	0.00	0.00	3.00	0.00	1.00
Posterior crossbite or edge-to-edge (number of teeth)	1.00	0.00	4.00	0.00	2.00
Lower midline deviation (mm)	1.00	0.00	9.00	0.50	2.00

[a]Mandibular length (ArPog, GoPog) was related to the anterior cranial base (SN), in order to avoid subjects with generally larger craniofacial relations appearing to have an oversized mandible.
[b]The absolute value of the difference between the right and left sides was used.

Mandibular length versus mandibular asymmetry

No significant correlations were found between mandibular length and mandibular asymmetry or between skeletal class and mandibular asymmetry.

Mandibular asymmetry versus occlusal asymmetry

Mandibular asymmetry was significantly correlated with sagittal and transverse occlusal asymmetry (Table III). In the subgroup without previous orthodontic treatment and/or asymmetric absence of teeth, significant correlations were found between condylar asymmetry and sagittal occlusal asymmetry and these correlations were stronger than in the total sample. In the subgroup with previous orthodontic treatment and/or asymmetric absence of teeth, these correlations were weaker, but the total height of the condyle and ramus showed additional correlations. Significant correlations went in the same direction in both subgroups and, once they were merged, the following results were obtained.

Sagittal occlusal asymmetry. Condylar height. Condylar asymmetry due to a longer condyle on one side was associated with asymmetric aggravation of the dental class III relationship (more negative value) on the ipsilateral side (r = –0.53 and r = –0.62, p <0.001 for canine and molar relationships, respectively) (Figure 4). Simultaneously, anterior asymmetry increased due to more incisors in crossbite/edge-to-edge position on the contralateral side (r = –0.32, p = 0.018).

Concerning the threshold values, we found that condylar asymmetry more severe than –2.5 or 2.1 mm involves molar asymmetry with a probability of 99% (Figure 4). A side difference of 2.5 mm can thus be considered as a general limit above which molar asymmetry may be expected. When condylar height is related to mandibular length, the corresponding limit is a side difference of 3%.

Ramus height. Presence of ramus asymmetry due to a longer ramus on one side was related to contralateral aggravation of canine and molar class III relationships (r = 0.27, p = 0.047 and r = 0.29, p = 0.034, respectively) (Figure 5). Correlations between ramus asymmetry and incisor asymmetry were not statistically significant.

Condylar and ramus height. Asymmetry in the total height of the condyle and ramus was not significantly related to asymmetry in canine or molar relationships.

Table III. Correlation coefficients between mandibular asymmetry and occlusal asymmetry in the group without (n = 29) and with (n = 25) previous orthodontic treatment and/or asymmetric absence of teeth as well as in the total sample (n = 54).

	Mandibular asymmetry (right–left difference)								
	Condylar height			Ramus height			Condylar+ramus height		
Occlusal asymmetry (right–left difference)	Without	With	All	Without	With	All	Without	With	All
Sagittal									
Canine relationship	–0.55**	–0.45*	–0.53***	0.29	0.32	0.27*	–0.10	–0.02	–0.13
Molar relationship	–0.66***	–0.55**	–0.62***	0.25	0.37	0.29*	–0.26	–0.09	–0.22
Anterior crossbite	–0.24	0.15	–0.16	0.11	–0.31	–0.12	–0.14	–0.38	–0.33*
Anterior edge-to-edge	–0.23	–0.23	–0.22	–0.02	0.11	0.02	–0.15	–0.13	–0.18
Anterior crossbite or edge-to-edge	–0.42*	–0.03	–0.32*	0.07	–0.24	–0.10	–0.25	–0.42*	–0.40**
Transverse									
Posterior crossbite	–0.17	0.30	–0.03	0.26	–0.30	0.00	0.05	–0.40*	–0.16
Posterior edge-to-edge	–0.07	–0.12	–0.09	–0.13	–0.04	–0.08	–0.20	–0.15	–0.17
Posterior crossbite or edge-to-edge	–0.20	0.20	–0.08	0.05	–0.39	–0.14	–0.15	–0.50*	–0.30*
Lower midline deviation	–0.34	–0.04	–0.27*	0.09	–0.15	–0.02	–0.15	–0.31	–0.27*

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Significant correlations existed with asymmetric aggravation of anterior crossbite (r = –0.33, p = 0.015) and crossbite/edge-to-edge relationship (r = –0.40, p = 0.002) on the contralateral side.

Transverse occlusal asymmetry. Asymmetry in the total height of the condyle and ramus was correlated with asymmetric aggravation of posterior crossbite/edge-to-edge position (r = –0.30, p = 0.028), as well as with lower midline deviation (r = –0.27, p = 0.050) to the contralateral side. The correlation between condylar asymmetry alone and midline deviation was similar (r = –0.27, p = 0.046).

When ramus and condylar heights were related to mandibular length, correlations were similar to those obtained with the absolute values.

Multiple regression analysis. The predictive value for occlusal asymmetry could not be improved by combining different variables describing mandibular asymmetry.

Discussion

The present investigation showed that mandibular asymmetry is associated with occlusal asymmetry, in the sagittal as well as in the transverse plane. In the sagittal plane, condylar asymmetry had 28% and 38% of variance in common with canine and molar asymmetry, respectively. Asymmetric elongation of the condyle on one side was correlated with asymmetric aggravation of canine and molar class III relationships on the ipsilateral side. The association with ramus asymmetry was weaker (common variance below 10%) and, in contrast to condylar asymmetry, ramus asymmetry was related to contralateral aggravation of class III malocclusion. The previous observations, together with the lack of equivalent correlations with total condylar and ramus height, suggest that ramus asymmetry reduces the association between condylar asymmetry and sagittal occlusal asymmetry. While endochondral bone formation is responsible for growth in the condylar cartilage, periosteal bone apposition related to muscular attachments takes place at the lower border of the ramus [5]. Muscularly induced ramal growth is able to compensate for reduction in condylar height [19,20]. In the present study, a similar mechanism of compensation may be involved.

In the transverse plane, asymmetric elongation of the total height of the condyle and ramus on one side was related to asymmetric aggravation of posterior crossbite on the contralateral side. This finding is in agreement with previously reported reduction in mandibular height [21] and masseter thickness on the crossbite side [22]. Furthermore, a strong correlation between deviation of menton and aggravation of posterior crossbite on the ipsilateral side has been described in the past [23]. However, it cannot be excluded that menton deviation was due to positional mandibular asymmetry, given that sagittal condylar position is more asymmetric in subjects with posterior crossbite [3]. Asymmetry in the sagittal position of the condyles is moreover correlated with dental midline asymmetry [3]. This observation is complemented by our study, showing that increased mandibular height

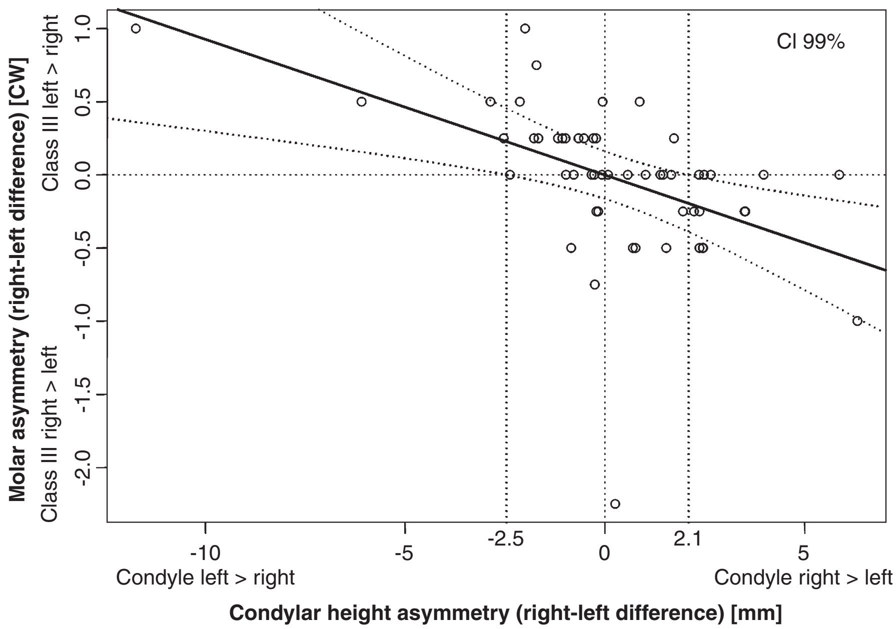

Figure 4. Molar asymmetry (CW = cusp width) plotted against condylar height asymmetry (right–left differences). Condylar asymmetry due to a longer condyle on one side was correlated with asymmetric aggravation of the molar class III relationship (by definition a more negative value) on the ipsilateral side ($r = -0.62$, $p < 0.001$). The 99% confidence interval of the linear regression line is shown. The intersections of the lower and upper confidence interval lines with the *x*-axis demarcate the zone of condylar asymmetry containing cases without molar asymmetry. Beyond these threshold values of condylar asymmetry (–2.5 and 2.1 mm), molar asymmetry may be expected with a probability of 99%. In general, a side difference of 2.5 mm can be considered as the limit above which molar asymmetry may be expected.

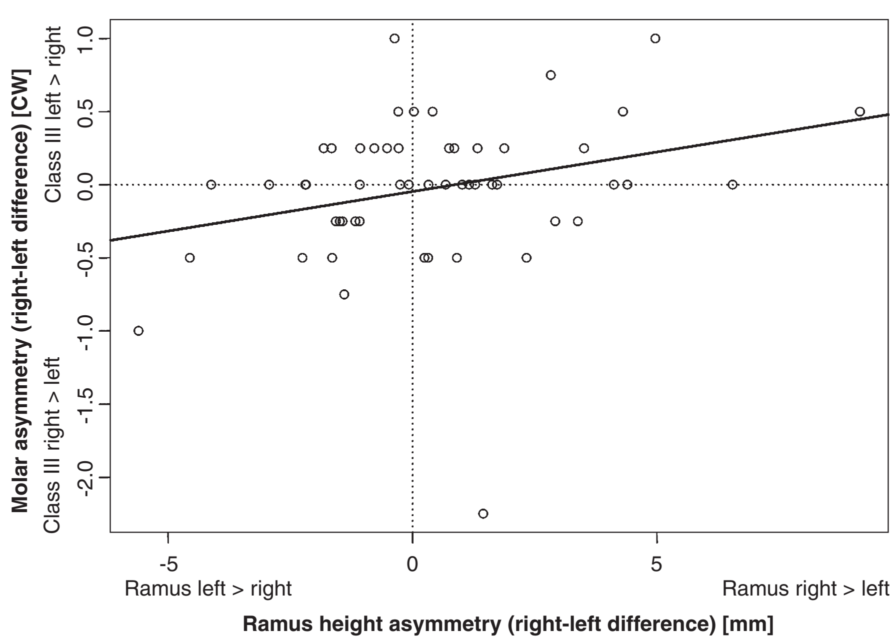

Figure 5. Molar asymmetry (CW = cusp width) plotted against ramus height asymmetry (right–left differences). Ramus asymmetry due to a longer ramus on one side was correlated with asymmetric aggravation of the molar class III relationship (by definition a more negative value) on the contralateral side ($r = 0.29$, $p = 0.034$).

on one side is related to dental midline deviation to the contralateral side.

Caution is advised when assessing mandibular asymmetry by orthopantomograms, given the possible errors in magnification, positioning and distortion [24]. However, vertical measurements, as used here, are less affected [25,26]. We further tried to limit possible errors by using the same radiographic machine and imaging conditions and by very accurately orientating each head in a standardized position. A possible impact of distortional effects on our findings could be ruled out by comparing molar length on both sides, thus confirming that side differences in our sample were reliable findings.

As we aimed to include non-growing subjects and were constrained by the fact that Caucasians often receive orthodontic treatment before puberty, 46% of our subjects had previously undergone orthodontic treatment or were missing teeth asymmetrically. In order to identify bias in the sample, we compared the treated with the untreated group, without however detecting differences in the extent of their occlusal asymmetry. This may have been due to more severe initial asymmetry, incomplete correction of asymmetry or considerable relapse in the treated group. However, the influence of treatment was noticeable when looking at the most relevant correlations between mandibular and occlusal asymmetry, which were lower in the group with than in the group without previous orthodontic treatment or asymmetric absence of teeth. The correction, at least partly, of occlusal asymmetry by orthodontic treatment or the development of occlusal asymmetry due to asymmetric absence of teeth may be independent from mandibular asymmetry, thus resulting in lower correlations. Since significant correlations went in the same direction in both groups, we decided to merge the two groups.

Before starting dentoalveolar correction in subjects with occlusal asymmetry, agreement exists on the necessity to exclude moderate-to-severe mandibular asymmetry [6], without however knowing from which point on mandibular asymmetry becomes relevant [5]. In the present study we found a threshold value of mandibular asymmetry above which occlusal asymmetry may be expected. If the side difference in condylar asymmetry exceeds 2.5 mm (or 3% relative to mandibular length), molar asymmetry may be assumed with a probability of 99%. Thus, in subjects with molar asymmetry, mandibular asymmetry can be supposed to be associated with the occlusal asymmetry, if condylar asymmetry exceeds 2.5 mm. This finding is a clinically useful threshold to keep in mind when evaluating patients. Neither increasing skeletal class III nor mandibular length seem to be related to mandibular asymmetry. In teenagers, reduction in mandibular asymmetry has been found with an ANB angle below 1° compared to those with an ANB angle above 1° [27]. The present findings are based on young adults and should be applied with caution to growing subjects in whom asymmetry can be transient or not yet expressed due to residual mandibular growth [5].

Conclusions

Mandibular asymmetry is associated with occlusal asymmetry, especially in the sagittal plane. Condylar asymmetry had 28% and 38% of variance in common with sagittal canine and molar asymmetry, respectively. Asymmetry in the total height of the condyle and ramus was related to transverse occlusal asymmetry. No significant correlations were found between mandibular length and mandibular asymmetry.

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