Evaluation of the centroid method of occlusion for studying mandibular and maxillary growth

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SUMMARY The aim of this study was to evaluate the centroid method of occlusion for studying mandibular growth and development. This novel technique comparatively expresses the direction of growth of the maxilla and mandible as a single unit. The centroid 'G' was geometrically calculated from the triangle Δ abc, which comprised the palatal, articulare–gnathion (Ar–Gn), and A–B planes. The plane angles and positional relationship of the centroid with the upper first molar was investigated, focusing on differences between genders and malocclusions.

Lateral cephalograms were obtained of 26 males and 51 females with a 'normal' Class I occlusion, 216 females with a Class III incisor relationship, and 230 females, all aged >18 years, with a Class II incisor relationship. Bolton standards and Sakamoto's data were used to determine changes in the angle of the palatal plane to the Ar–Gn plane.

Non-significant levels of variation were observed in the angle of the palatal plane to the Ar–Gn plane during the developmental period from childhood to adulthood. Among Class I adult subjects, Δ abc was similar between genders and the centroid G was located near the occlusal surface of the upper first molar. There was no difference in the area of Δ abc between malocclusion types. The positional relationship of the centroid G with the upper first molar revealed a shift of the centroid mesially and cervically during the transition from Class II to Class I to Class II.

These findings indicate that the centroid method can contribute to orthopaedic diagnosis and the planning of treatment strategies.

Introduction

Conventionally, the direction of mandibular growth has been determined from cephalograms on the basis of the angles between the cranial base (Graber, 1952a,b, 1954) and the facial region (Tweed, 1946, 1954; Downs, 1948), such as the *Y*-axis (SN, FH), the facial plane angle, or the sella–nasion plane. However, the upper jaw has been reported to shift downwards in relation to the cranium in order to allow horizontal maxillary growth (Brodie, 1941, 1946). Furthermore, in order to study tooth alignment in the upper and lower arches, it is common to set a standard plane for each jaw and to measure the two separately.

A novel analysis, the centroid method of assessment, was devised to comparatively express the direction of growth based on both the upper and lower arches. This technique involves two planes that form the axis of the cranial region: the palatal plane connecting points, anterior nasal spine (Ans) and posterior nasal spine (Pns), which is chosen as the standard plane for the upper arch, and the standard plane connecting articulare (Ar) and gnathion (Gn). This method can be used to carry out maxillo-facial and dental evaluation by geometrically calculating the centroid from the triangle Δ abc made up of three planes: the palatal, Ar–Gn, and A–B planes that define the dentoalveolar base of the maxilla and mandible (Figure 1).

The first aim of the present study was to determine the changes with age in the angle of the palatal plane to the Ar–Gn plane. This angle needs to remain relatively stable for developmental growth to be measured in the maxillo-facial region. The second was to determine the characteristics of the centroid of the triangle made up of the three planes described above, as well as its positional relationship with the upper first molar. In particular, differences between the two genders and from variations in malocclusion type were investigated.

Material and methods

Materials

This research was approved by the Ethics Committee of Toyohashi City Dental Association and all subjects gave their informed consent. The Bolton standards (Broadbent *et al.*, 1975) and the data of Sakamoto (1959) were used to determine variations in the angle of the palatal plane to the Ar–Gn plane during development. To investigate the triangle formed by the three planes (palatal, Ar–Gn, and A–B), lateral cephalograms were obtained from the following subjects aged >18 years: individuals with a normal Class I occlusion (Class I, 51 females and 26 males), those with a



Figure 1 The centroid method of occlusion. Point a is the intersection of the palatal and A–B planes. Point b is the intersection of the articularegnathion (Ar–Gn) and A–B planes. Point c is the intersection of the palatal and Ar–Gn planes. The centroid G was geometrically calculated from the triangle Δabc , which comprised the palatal, Ar–Gn, and A–B planes. The three median lines of Δabc naturally meet at one point: the centroid.

Class III incisor relationship (overjet <0 mm, Class III, 216 females), and subjects with a Class II incisor relationship (overjet >6 mm, Class II, 230 females).

Measurements

Figure 2 shows the cephalometric measurements utilized in the study.

Statistical analysis

The means and standard deviations (SDs) for each of the parameters were determined. A Student's *t*-test was undertaken to compare the results between the two genders; a one-way analysis of variance (ANOVA) and a Bonferroni's *t*-test were also performed on the data in order to establish any variations between the different occlusions.

Results

Change in the Ar–Gn plane angle

The Bolton standards showed that the angle of the palatal plane to the Ar–Gn plane ranged from 41.0 to 43.0 degrees between the ages of 2 and 18 years, with a 2-degree difference between males and females. Sakamoto's (1959) data (Stages 1–5) indicated that this was not significant, with values ranging from 46.0 to 47.5 degrees in males and 46.5 to 48.0 degrees in females. It also indicated a maximum difference of 1.5 degrees between the two genders (Table 1).



Figure 2 Cephalometric measurements utilized in the study. Measurements were taken of the following parameters: the palatal plane to articulare–gnathion plane angle (1); the palatal plane to A–B plane angle (2); the a–c distance (3); the area of Δ abc (4); G–G', the length of a perpendicular line from G to the palatal plane (5); Ms–Ms', the length of a perpendicular line from the midpoint (Ms) of the occlusal surface of the upper first molar to the palatal plane (6); G–Ms, the difference between the length of the perpendicular lines from G and Ms to the palatal plane (7); c–G', the distance between points c and G in relation to the palatal plane (8); c–Ms', the distance between points c and Ms in relation to the palatal plane (9); and G'–Ms', the distance between points G and Ms in relation to the palatal plane (10).

Table 1 Changes with age in the angle of the palatal plane to articulare–gnathion plane.

2 years	6 years	10 years	14 years	18 years
42.0 1	43.0 2	41.5 3	42.0 4	41.0 5
ata 46.5	48.0	47.0	47.0	47.0
	2 years 42.0 1 lata 46.5 47.5	$\begin{array}{cccc} 2 \text{ years} & 6 \text{ years} \\ $	2 years 6 years 10 years 42.0 43.0 41.5 1 2 3 lata 46.5 48.0 47.0 47.5 46.5	$\begin{array}{cccccccccccccccccccccccccccccccccccc$

Comparison of males and females with normal occlusion

There was no significant difference between the two genders in terms of the angle of the palatal plane to the Ar–Gn plane or the angle of the palatal plane to the A–B plane (Table 2). Consequently, it was observed that the Δ abc values were similar, as one of the characteristics of similar triangles is that they have two angles of the same size. However, the area of Δ abc and a–c were significantly greater in males (P < 0.01).

In the vertical evaluation of the centroid, the G-G' and Ms-Ms' values were significantly greater in males at the 5 and 1 per cent levels, respectively. In addition, the G-Ms value for males was significantly smaller at the 1 per cent level than that for females. In the horizontal evaluation, the c-G' and c-Ms' values were significantly greater in males at the 1 per cent level. However, there was no significant difference in the G'-Ms' values between the two genders

Variable (Figure 2)	Males $(n = 26)$		Females $(n = 51)$.)	
	Mean	SD	Mean	SD	Significance	
(1) Palatal plane to Ar–Gn plane angle (°)	46.1	4.2	47.5	3.2	ns	
(2) Palatal plane to A–B plane angle (°)	84.5	4.6	83.4	3.8	ns	
(3) a–c (mm)	81.3	5.0	75.9	4.8	**	
(4) Δabc (cm2)	31.2	3.3	28.0	3.3	**	
Vertical						
(5) G–G' (mm)	25.6	2.5	24.5	1.8	*	
(6) Ms–Ms' (mm)	26.9	2.2	24.6	2.1	**	
(7) G–Ms (mm)	-1.3	1.7	-0.1	1.4	**	
Horizontal						
(8) $c-G'(mm)$	51.7	3.6	47.8	3.4	**	
(9) c–Ms' (mm)	51.3	4.8	46.7	4.8	**	
(10) G'–Ms' (mm)	0.4	2.0	1.1	2.2	ns	

 Table 2
 Comparison of males and females with normal occlusion.

SD, standard deviation; *P < 0.05; **P < 0.01; ns, not significant.

(1.1 mm for females and 0.4 mm for males). The G–Ms values were -0.1 mm for females and -1.3 mm for males. These results show that G was close to the Ms region in both genders.

Comparison of the three groups

The results revealed no significant difference between the Class III and Class I groups in the angle of the palatal plane to the Ar–Gn plane (Tables 3 and 4). However, there were significant differences at the 1 per cent level between Class I and Class II and between Class III and Class II subjects. The results indicated the following relationship between the groups for this parameter: Class II > Class I = Class III. The data for the angle formed by the palatal plane and the A-B plane showed that there were significant differences (P < 0.01) between Class III and Class I, Class I and Class II, and Class III and Class II. The results indicated the following relationship between the groups: Class III > Class I > Class II. With reference to the distances and area of Δabc , there were significant differences in a-c between Class III and Class I and between Class III and Class II (P < 0.01). However, there was no significant difference between the Class I and II subjects. These results revealed the following relationship between the groups for this parameter: Class II = Class I > Class III. There were no significant differences in Δabc area between the three groups.

For the centroid, the vertical evaluation revealed significant differences in G-G' at the 1 per cent level between Class III and Class I and between Class III and Class II. However, there was no significant difference between Class I and II subjects. These results indicated the

Table 3Analysis of variance.

Variable (Figure 2)	<i>F</i> -value	Significance
(1) Palatal plane to Ar–Gn plane angle (°)	62.2	**
(2) Palatal plane to A–B plane angle (°)	765.3	**
(3) a - c (mm)	121.1	**
(4) Δabc (cm2)	0.5	ns
Vertical		
(5) G-G' (mm)	86.7	**
(6) Ms–Ms' (mm)	1.8	ns
(7) G–Ms (mm)	104.1	**
Horizontal		
(8) c-G' (mm)	603.0	**
(9) $c-Ms'$ (mm)	9.0	**
(10) G'–Ms' (mm)	181.2	**

**P < 0.01; ns, not significant.

following relationship: Class III > Class I = Class II. ANOVA revealed no significant differences in the Ms-Ms' values between the three groups, which suggested the following relationship for this parameter: Class III = Class I = Class II. For G-Ms, significant differences were detected between Class III and Class I, Class I and Class II, and Class III and Class II (P < 0.01). These results indicated the following relationship: Class III > Class I >Class II. The horizontal evaluation showed that there was no significant difference in c-G' between Class III and Class I subjects. However, there were significant differences at the 1 per cent level between Class I and Class II and between Class III and Class II, indicating the following relationship: Class III = Class I > Class II. For c-Ms', there was no significant difference between Class I and Class II. Nevertheless, there were significant differences at the 1 per cent level between Class III and Class I and between Class III and Class II, revealing the following relationship: Class III < Class I = Class II. With regard to G'-Ms', there were significant differences between Class III and Class I, Class I and Class II, and Class III and Class II (P < 0.01). These results showed the following relationship between the three groups: Class III > Class I > Class II.

Discussion

Conventional analytical method

Although many cephalogram-based analytical methods have been described, none of these techniques have evaluated both the upper and lower arches as a single unit. There are many dental methods based on upper and lower anterior teeth (Tweed, 1946, 1954; Wylie, 1947; Downs, 1948; Graber, 1952a,b, 1954; Ricketts *et al.*, 1972). Dental treatment plans tend to establish the position of the anterior

Variable (Figure 2)	Class III $(n = 216)$		Class I $(n = 51)$		Class II $(n = 230)$		Significance		
	Mean	SD	Mean	SD	Mean	SD	Class III versus Class I	Class I versus Class II	Class III versus Class II
(1) Palatal plane to									
Ar–Gn plane angle (°)	46.8	4.1	47.5	3.2	51.4	4.9	ns	**	**
(2) Palatal plane to A–B									
plane angle (°)	95.0	5.5	83.4	3.8	76.2	4.8	**	**	**
(3) a–c (mm)	68.8	5.6	75.9	4.8	76.0	4.6	**	ns	**
(4) Δabc (cm2)	27.8	3.1	28.0	3.3	27.6	2.9	ns	ns	ns
Vertical									
(5) G-G' (mm)	27.0	2.6	24.5	1.8	24.2	2.1	**	ns	**
(6) $Ms-Ms'$ (mm)	25.3	2.4	24.6	2.1	25.2	2.4	ns	ns	ns
(7) G–Ms (mm)	1.7	2.2	-0.1	1.4	-1.0	1.9	**	**	**
Horizontal									
(8) $c-G'$ (mm)	48.3	3.5	47.8	3.4	44.7	3.6	ns	**	**
(9) c–Ms ² (mm)	44.3	5.5	46.7	4.8	46.1	4.6	**	ns	**
(10) G'–Ms' (mm)	3.9	3.6	1.1	2.2	-1.4	2.5	**	**	**

Table 4Comparison of the three groups.

SD, standard deviation; **P < 0.01; ns, not significant.

teeth, which then determines the position of the molar teeth (Tweed, 1946, 1954; Steiner, 1953; Ricketts *et al.*, 1972); in other words, the position of the molar teeth is dependent on the position of the anterior teeth, which gives the impression that the molar teeth are 'merely supplementary to the anterior teeth'.

In contrast, Angle (1907) advocated the constancy of the position of the upper first molar-his approach is known as the 'key to occlusion' because of the importance it places on this tooth. The upper first molar is the largest of all the teeth and, as masticatory ability is related to the area of the occlusal surface, it has the highest masticatory efficiency. The upper first molar is located within the area through which the masseter muscle acts. Nagahara et al. (1999) used a three-dimensional finite element method to analyse differences in the control points of occlusion during clenching of the mandible, and also performed stress analysis at each mandibular joint. They found that stress at the mandibular joints was lowest when the first molar was restrained. On the basis of these results, it appears that the first molar has an important role in masticatory as well as mandibular function.

Characteristics of the centroid method of occlusion

Palatal plane to Ar–Gn plane angle. This novel, analytical method used the palatal plane connecting points Ans and Pns as the standard plane for the upper jaw. The standard plane connecting Ar and Gn points was used to determine growth of the mandibular axis. There are no areas of muscle attachment or additional absorption within these measured points. Both Bolton standards and Sakamoto's data demonstrated that there was no significant change in the angle of the palatal plane to

the Ar–Gn plane during the period of development from childhood to adulthood. It is therefore considered that this is a good method to use in estimating the direction of mandibular growth in relation to the upper arch.

Palatal plane to A–B plane angle and relationship with the antero-posterior dysplasia indicator (APDI). Kim and Vietas (1978) reported that the APDI was a good predictor of lateral disharmony between the upper and lower arches. Clinically, skeletal mandibular protrusion can be diagnosed as increasingly severe with greater APDI values, and skeletal maxillary protrusion as increasingly severe with smaller APDI values. APDI was defined as the facial plane angle \pm the A–B plane angle \pm the palatal plane angle, although geometrically it is the angle of the palatal plane to the A–B plane.

Geometric features of the centroid. The three median lines of Δ abc naturally meet at one point: the centroid. Three triangles of equal area are formed within Δ abc as a result of the centroid, which is therefore sometimes called the 'centre of gravity' or the 'valance point'.

Positional relationship of the centroid with the upper first molar. Considering the palatal plane to Ar–Gn plane angle, the relationship between the groups was Class II > Class I = Class III, for the palatal plane to A–B plane angle Class III > Class I > Class II, and for a–c Class II = Class I > Class III. However, there was no difference between the groups for the area of Δ abc, which indicated that this parameter was not dependent on the type of occlusion. Using a two-dimensional quantitative analysis, rather than one-dimensional cephalogram analysis, it was demonstrated that Δ abc has a fixed area value regardless of differences in the occlusion.

In the vertical evaluation, G–Ms values showed the following relationship between groups: Class III > Class I > Class II. In addition, in the horizontal evaluation, the G'–Ms' values showed the relationship Class III > Class I > Class II. On the basis of these results, it was demonstrated that G moves diagonally towards the maxilla during the transition from Class III to Class I to Class II. It is therefore suggested that G is parallel to the lateral position of the lower jaw because this is anterior relative to the maxilla in Class II subjects and posterior relative to the maxilla in Class II subjects. In contrast, the position of Ms shifts towards the mandible during the transition from Class III to Class III subjects. In contrast, the position of Ms shifts towards the mandible during the transition from Class III to Class

Clinical application of the centroid method of occlusion

Occlusal locus of control. Nakamura (2003) reported the existence of many control fields within the oral cavity related to the overall balance of the body, including the centroid of occlusion, temporomandibular joint, masseter muscle, and cervical vertebra, which are in turn related to factors such as sporting ability and hearing loss. He renamed this area as the 'occlusal locus of control' (OcLOC; Figure 3). In the permanent dentition, the OcLOC is equivalent to the region between the upper second premolar and the first molar. The mandible is subjected to traction towards the OcLOC region by the masseter muscle and temporo-mandibular joint, which then enables occlusal function.

Many clinical studies have shown that occlusion-related symptoms can develop if an imbalance occurs in the mandibular function of the OcLOC, which can be the result of a range of occlusal disorders. According to Iwasawa and Namura (1964), this region is anatomically equivalent to the lowest point of the curve of Spee, and Yazaki (1929) reported that the curve of Wilson tends to disappear here. The mesial root of the upper first molar, which bites against the mesial buccal cusp of the lower first molar, is almost perpendicular to the second premolar root. Therefore, it is difficult for lateral interference to develop in the OcLOC region, which can tolerate vertical compression. Despite these facts, no previous methods have objectively determined the position of the OcLOC.

In the present study, the comparison of G and Ms revealed that G was close to Ms in both genders; that is, it was located close to the occlusal surface of the upper first molar. As the OcLOC is located in the region between the upper second premolar and the first molar, G is contained within the OcLOC. Therefore, it is suggested that the position of the OcLOC can be objectively determined from G. This method also makes it possible to distinguish any positional abnormality of the upper first molar.

An example of the assessment method. An 11-year 8-monthold girl presented with a protruding lower lip and jaw. Intraoral findings showed a Class III relationship between the upper and lower first molars, with crowding in both arches. A panoramic radiograph revealed the presence of all teeth including upper and lower third molars, and there were no abnormalities detected (Figures 4 and 5).

Cephalography showed that the palatal plane to Ar–Gn plane angle (APDI) was high (92.4 degrees), and that the antero-posterior positional relationship between the maxilla and the mandible was one of skeletal mandibular protrusion (Table 5). Regarding the position of the upper first molar (Ms), G–Ms was an insignificant 0.2 mm distance perpendicular (mean \pm SD: -0.1 ± 1.4 mm), but G'–Ms' was displaced 6.3 mm horizontally (mean \pm SD: 1.1 ± 2.2 mm), distal to the upper first molar (Ms).



Figure 3 Occlusal locus of control.



Figure 4 Intraoral photographs of a patient diagnosed using the centroid method of occlusion. (A) Pre-treatment, age 11 years 8 months; (B) post-treatment, age 15 years 1 month; (C) post-retention, age 18 years 5 months.



Table 5Cephalometric measurements using the centroid methodof occlusion.

Variable (Figure 2)	Pre-treatment (11 years 8 months)	Post-treatment (15 years 1 month)	Post-retention (18 years 5 months)
(1) Palatal plane to Ar–Gn plane angle (°)	44.9	49.0	49.0
(2) Palatal plane to A–B plane angle (°)	92.4	82.5	84.5
(3) a–c (mm)	63.5	72.4	71.5
(4) ∆abc (cm2)	20.9	26.2	26.3
Vertical			
(5) G–G' (mm)	22.0	24.1	24.5
(6) Ms–Ms' (mm)	21.8	24.5	25.0
(7) G–Ms (mm)	0.2	-0.4	-0.5
Horizontal			
(8) $c-G'(mm)$	43.2	45.0	45.0
(9) c–Ms' (mm)	36.9	40.5	40.5
(10) G'–Ms' (mm)	6.3	4.5	4.5

Figure 5 Panoramic radiographs of the subject in Figure 4. (A) Pre-treatment, age 11 years 8 months; (B) post-treatment, age 15 years 1 month.

The diagnosis was a Class III malocclusion with crowding. The following treatment strategies were selected: (1) improvement of the reverse overjet by chin-cap therapy, followed by anterior movement of the maxilla and maxillary dentition with a face mask, and (2) upper and lower fixed appliances to treat the crowding.

Active treatment was completed at 15 years 1 month. As a result, the palatal plane to Ar–Gn plane angle (APDI) decreased to 82.5 degrees, improving the skeletal mandibular protrusion, and the upper first molar (Ms) moved anteriorly, with the G'–Ms' decreasing to 4.5 mm. Retention treatment was provided thereafter, and at 18 years 5 months, the occlusion was stable and treatment was completed. The above findings indicate that the centroid method of occlusion is useful for orthopaedic diagnosis and the planning of treatment strategies.

Conclusion

This novel analysis, the centroid method of occlusion, was designed to comparatively express the direction of mandibular growth based on both the maxilla and the mandible as a single unit. This new analytical method was used to carry out maxillo-facial and dental evaluation by geometrically calculating the centroid G from Δ abc, which comprised three planes: the palatal plane, the Ar–Gn plane, and the A–B plane.

Minimal variation in the angle of the palatal plane to the Ar–Gn plane during the developmental period between childhood and adulthood makes it suitable for the study of maxillo-facial developmental growth. A comparison of males and females with normal occlusion showed that Δabc was similar in the two genders with the centroid G close to the occlusal surface of the upper first molar.

There was no difference in the area of Δ abc regardless of differences in the condition of the jaw. On the basis of the positional relationship between the centroid G and the upper first molar, it was found that the upper first molar shifts towards the lower front during the transition from Class III to Class I to Class II. These results demonstrate a role for the centroid method of occlusion in both orthopaedic diagnosis and the planning of treatment strategies.

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