Morphologic Factors in Open Bite and Deep Bite

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An evaluation of skeletal patterns underlying anterior deep bite and open bite.

This study indentifies and evaluates facial and cranial patterns that relate to the composite anatomical relationships associated with deep overbite and anterior open bite. A sample of pretreatment, deband and postretention cephalometric radiographs is analyzed for dysplasias and compared to a control sample with normal occlusion.

The counterpart analysis (Enlow, *et al.* 1971*a*) is the principal method used to appraise anatomic interrelationships among key skeletal components.

In contrast to conventional cephalometric methods, most of the determinations involved in the counterpart analysis do not require comparison of individual components with population norms. Rather, the component parts of an individual's face and cranium are compared with each other to determine their goodness of fit and the anatomic effects of variations in size and assembly in that person.

Many standard cephalometric planes and angles are not appropriate for this analysis because they do not coincide with specific sites or fields of growth and remodeling, so they do not indicate identifiable morphologic and morphogenic relationships.

The counterpart principle states

that some of the principal skeletal parts of the skull are related to other specific parts (counterparts) that must match in appropriate dimensions and placement if anatomic balance is to exist. For example, the bony mandibular arch is a structural counterpart of the maxillary arch. If there is a dimensional or positional differential between them, a corresponding measurable anatomic misfit will be found.

Because a variation in any one part relative to its counterpart(s) usually affects the placement and relationships among other contiguous parts, a cumulative domino effect occurs. All become parts of the individualized, composite nature of each person's facial assemblage.

The counterpart concept is based on the morphogenic principle that the various regional part/counterpart relationships involve major boundaries which are coincident with key sites of growth and remodeling. The mandibular condyle, maxillary tuberosity, sphenoethmoidal junction and all borders of the ramus and palate are examples of such major sites of growth and remodeling.

Most of these growth boundaries also coincide with principal sites at which displacement (translatory movement) occurs. Growth displacement is the movement of a whole bone at an articular interface with a contiguous bone.

Two fundamental factors are involved in evaluation of the part/counterpart relationship. First, respective linear dimensions are determined and compared to see whether a balance or a discrepancy exists. Then, the inclination (angulation, tilt, cant or rotational position) is determined.

The factor of inclination is important because an upward, downward, forward or backward tilt directly alters the *expression* of a given part's actual vertical and horizontal dimensions, changing the nature of composite fit relative to other bones or parts.

If a part and its counterpart(s) fit in both linear dimension and inclination, then that particular relationship will be in a neutral balance. If they do not fit, the basis for retrusion, protrusion or other anatomic discrepancy may exist. The composite effects of all such relationships can thus be determined and evaluated.

Literature Review

Hellman (1931) suggested that short mandibular ramus and corpus, rather than a lack of vertical development in the nasomaxillary region, are the basis for open bite. He observed that about 50% of treated cases undergo relapse.

Swinehart (1942) also pointed to a short ramus and an abnormal mesiodistal relationship of the arches in open-bite cases, along with an obtuse mandibular plane. He also reported an infraocclusion of the maxillary teeth.

Hapak (1964), Subtelny (1964), Nahoum (1971, 1975) and Schendel (1976) also noted a steep mandibular plane and a large gonial angle with open bite.

Subtelny (1964) and Schendel (1976) also reported the mandible retruded relative to the cranial base.

Muller (1963) concluded that an open bite occurs in conjunction with deep positioning of the nasal floor relative to the cranial base, with less space for the tongue which in turn becomes displaced between the dentition. Subtelny (1964) observed a cranial base short posteriorly but normal anteriorly. He did not report differences in cranial base angulation or in the relationship of the palate to the cranial base. Aberrant muscle growth and function, and finger sucking were also considered to be etiologic factors in open bite.

Neff (1966) regarded the tongue as only a passive factor. Based on strain-gauge studies, he concluded that the source of open bite is a force pattern associated with swallowing and muscles of mastication.

Facial height has been considered by a number of investigators since the earlier reports of Hellman (1931) and Swinehart (1942). A normal upper facial dimension was observed by Hapak (1964), but he found high values for lower face height, total face height and mandibular incisor alveolar height related to a high mandibular plane angle.

Subtelny (1964) similarly found a greater lower face height with open bite.

Richardson (1967) reported greater lower face height in open bite than in deep overbite, attributing the structural difference between open and deep bite more to jaw and joint angles than to linear values (shape rather than size).

Nahoum (1975) also observed increased total face height in open bite, with lower face height large in relation to the upper face. In addition, he noticed a more upward cant of the anterior part of the palate related to short upper face height, further contributing to the height of the lower face. Nahoum concluded that anterior face height is greater relative to posterior facial height because of an open gonial angle and a steep mandibular plane.

Loufty (1973) similarly reported an large total face height in open bite compared with deep bite, due mostly to a large lower face dimension. He concluded that jaw angles rather than linear values are primarily involved, finding no discrepancies in the anteroposterior relationship between the maxilla and mandible.

In a logarithmic spiral study of the locations of the foramen ovale and the mandibular and mental foramina, Moss (1971) found that they were positioned more inferiorly very early in the facial growth of open-bite cases. With continued development, inferior growth movements of the foramina retained these lower locations, so the distance between the foramen ovale and the mandibular foramen was shorter in open bite than with normal occlusions.

Procedures

Of the various regional part-counterpart relationships used in previous studies (Enlow, *et al.*, 1971*a* and 1971*b*), those that hypothetically appeared to relate directly to open and deep bite were selected for evaluation. Some new counterpart relationships and certain standard cephalometric planes were also included because they seemed likely to provide relevant information.

Radiographs were measured to determine all of the relationships, which were then statistically evaluated to assess which might be associated with open or deep bite. This helped to identify which particular *combinations* might account for the composite, multifactorial morphological relationships underlying these two types of malocclusion.

All points were averaged between right and left.

Ramus inclination

The ramus (Figures 1, 2, 3), is a horizontal counterpart to the middle cranial fossa. A more forward position

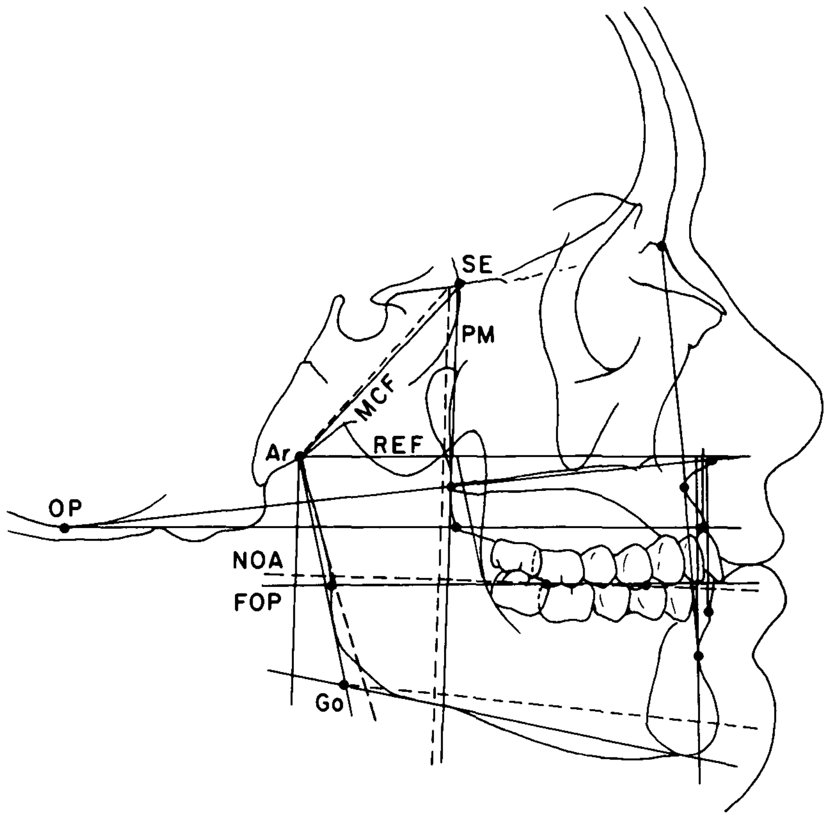

Fig. 1 Landmarks and planes.

SE	sphenoethmoidal point	OP	occipital point
PM	posterior maxillary plane (vertical)	NOA	neutral occlusal axis
MCF	plane of middle cranial fossa	FOP	functional occlusal plane
Ar	articulare	Go	gonion.
REF	reference plane		

may be expected to contribute to a deep bite. Conversely, a more backward position may be expected to contribute to an anterior open bite.

A solid line from articulare (Ar) to gonion (Go) represents the posterior vertical plane of the ramus, and a dashed line from articulare to the horizontal midpoint between Ar and PM (posterior maxillary tuberosity) represents the neutral ramus plane (Enlow, *et al.*, 1972).

The PM plane extends from the sphenoethmoidal junction (SE) to the pterygomaxillary fissures.

Middle cranial fossa inclination

The anteroinferior inclination of this part of the basicranium affects the placement of the nasomaxillary complex relative to the mandible (Figs. 4 & 5). A greater forward-downward middle cranial fossa inclination may be expected in deep bite, less in open bite.

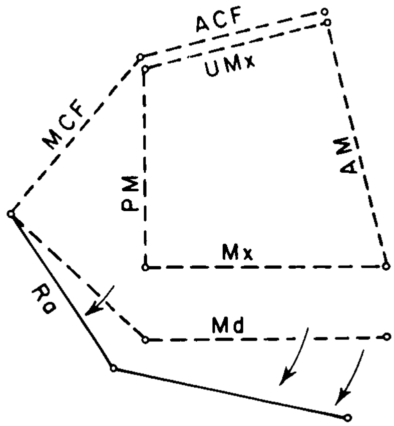

Fig. 2 A posteroinferior inclination of the mandibular ramus and corpus contributes to an anterior open bite.

ACF	anterior cranial fossa
MCF	middle cranial fossa
UMx	upper maxillary region
PM	posterior part of maxilla (vertical)
AM	anterior part of maxilla
Mx	maxillary arch
Ra	ramus
Md	mandibular arch

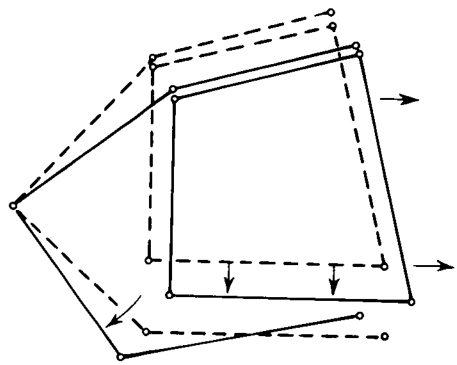

Fig. 4 A marked anteroinferior inclination of the middle cranial fossa and closure of the gonial angle contribute to deep bite. When the mandibular corpus is horizontally short relative to the maxillary arch, and the vertical dimension of the maxilla (PM) is short, the closed bite effect is augmented (see Figs. 7 and 10).

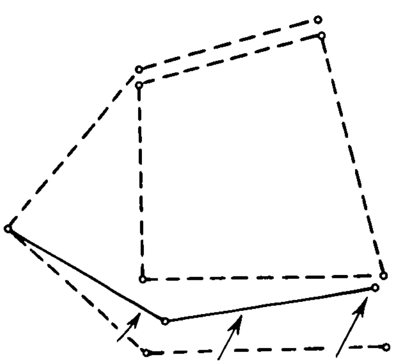

Fig. 3 Anterosuperior inclination of the mandible contributes to deep bite.

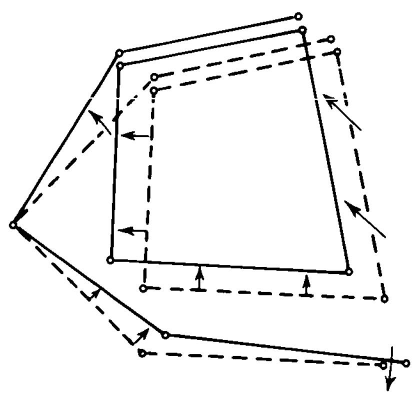

Fig. 5 A posterosuperior (more upright) inclination of the middle cranial fossa and opening of the gonial angle contribute to anterior open bite. When the horizontal dimension of the mandibular arch is long and the vertical dimension of the maxilla (PM) is long, the open-bite effect is augmented (see Figs. 6 and 11).

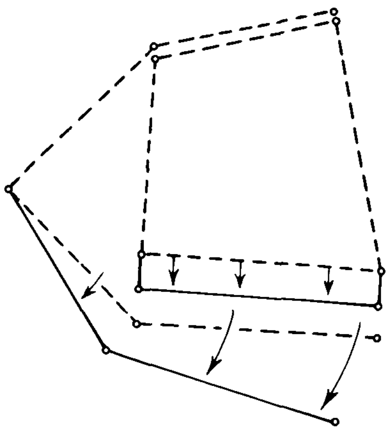

Fig. 6 A vertically long nasomaxillary dimension (PM) contributes to open bite..

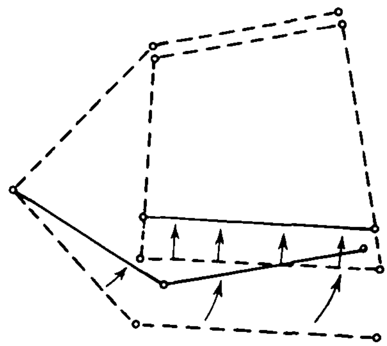

Fig. 7 A vertically short nasomaxillary (PM) dimension contributes to deep bite.

A solid line representing the individual's middle cranial fossa (MCF) extends from Ar to SE (Figure 1). The neutral MCF is a dashed line from Ar to a dashed PM plane, with an intersection angle of 40° (Enlow, *et al.*, 1971*a*).

Posterior maxillary height

If the posterior part of the nasomaxillary complex is long vertically with respect to its counterparts, which are the combined heights of the ramus and middle cranial fossa, a relative downward and backward relationship of the entire mandible and open bite will be expected (Figs. 6, 7).

If the maxilla is short vertically relative to the ramus and middle cranial fossa, a forward-upward mandibular relationship and deep bite may be expected. When the MCF is tilted either forward or backward, and the ramus rotates by the same amount but in an opposite direction, the vertical dimension of PM is neutral. However, if the ramus is tilted either more or less than MCF, the effective vertical PM dimension will be relatively long or short.

Horizontal maxillary inclination

An anteroinferior tilt of the maxillary alveolar plane relates to deep bite, an anterosuperior tilt to open bite (Figs. 1, 8, 9). The neutral maxillary plane (Enlow, 1975) extends from superior prosthion (SPr) through the posteroinferior point of the maxillary tuberosity to the most inferior point on the endocranial surface of the occipital fossa (OP).

If an anteroinferior or anterosuperior inclination exists, the alveolar plane will lie above or below OP. A latitude of ±3mm from OP was accepted as a normal range, and only relatively severe alveolar arch inclinations were considered for evaluation.

Palatal inclination

A anteroinferior cant of the palate relates to a deep bite, and an antero-

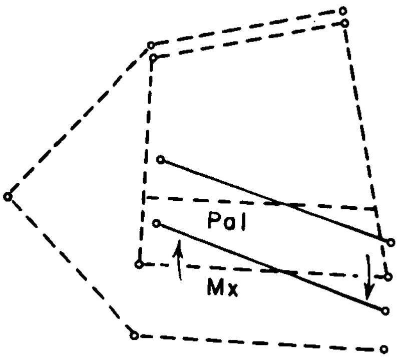

Fig. 8 Anteroinferior inclination of the palate (Pal) and maxillary alveolar arch (Mx) contribute to deep bite.

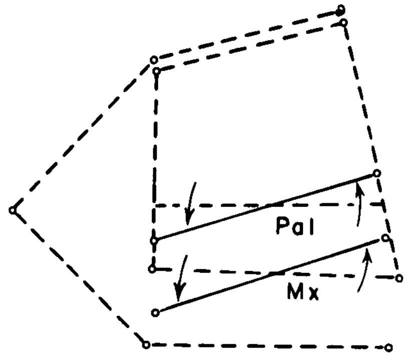

Fig. 9 Anterosuperior inclination of the palate and maxillary alveolar arch contribute to anterior open bite.

superior cant to open bite (Figs. 8 and 9). A line from the anterior to the posterior nasal spine (palatal plane) is considered to be in a neutral inclination when it projects to the most inferior point on the endocranial surface of the occipital fossa (OP). A latitude of ±3mm from OP was accepted as a normal range, so only relatively severe palatal angulations were considered for evaluation.

Effective horizontal ramus + corpus length compared to maxilla + middle cranial fossa length

A horizontally long mandible (ramus and corpus) may be expected with an open bite, and a short horizontal length with deep bite (Figs. 1, 10, 11). To determine which maxillary and mandibular points are relatively mesial or distal, points A and B, and points SPr and IPr are projected perpendicularly to a reference line (REF) parallel to the occlusal plane (Enlow, *et al.*, 1971*a*).

Curve of Spee

The curve of Spee indicates dentoalveolar compensation that contributes to anterior occlusal closure (Enlow, 1975). An upward and forward drifting of the lower anterior teeth can serve to close a bite that otherwise would be open. This can be beneficial with a backward-downward ramus inclination, open ramus/corpus (gonial) angle or anterosuperior tilt of the palate and/or maxillary arch.

However, this adjustment process can fall short or fail entirely in some individuals. The extent to which the incisal edge of the mandibular central incisor lies above FOP indicates the extent of compensatory vertical drift. Lower incisors at or below FOP indicate a zero or negative curve of Spee and inadequate compensation.

Ramus/corpus (gonial) angle

A more open angular relationship may be expected with open bite, and a more closed angle with deep bite (Figs. 10 and 11). The neutral value used for the gonial angle was adopted from Riolo, *et al.* (1974).

Mandibular plane inclination

A downward-inclined mandibular plane may be expected with open bite,

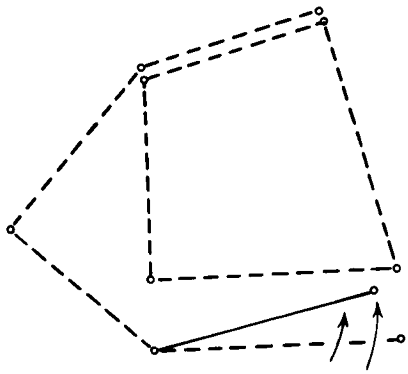

Fig. 10 A mandibular arch that is horizontally short relative to the maxillary arch, closure of the gonial angle and superior drifting of the mandibular anterior teeth (deep curve of Spee) contribute to a deep bite.

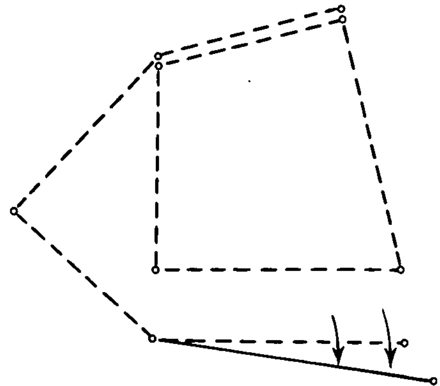

Fig. 11 A horizontally long mandibular arch, opening of the gonial angle and lack of a compensating curve of Spee contribute to anterior open bite.

and a more horizontal plane with deep bite. The extent of an individual's divergence upward or downward is measured at the level of point B, perpendicular to the functional occlusal plane and compared to the neutral value based on the neutral gonial angle value.

Occlusal plane inclination

An upward or downward inclination of the functional occlusal plane (FOP) relative to the neutral occlusal axis (NOA) may also be expected to relate to deep or open bite. NOA is a line extending perpendicular to PM through the most posterior occlusal contact of the last fully-erupted molars. The individual's FOP is the straight-line plane from the most posterior occlusal contact point to the most anterior contact point of the first bicuspids. Divergence between NOA and FOP is measured at the level of IPr perpendicular to FOP (Fig. 1).

Sample

The sample consisted of 5 groups of 15 subjects, selected according to the criteria described below.

Because of the small sample size, possible sex differences were not considered in the evaluation of any group.

Group A, control

This group of 11 males and 4 females all had Class I or normal occlusion, an A-N-B value of 0-5°, no history or orthodontic treatment, normal overbite (approximately 2mm) and normal overjet.

Age ranged from 13.2 to 15.9 years, with an average of 14.6 years.

Group B, Class I open bite

The 11 males and 4 females in this group had been treated orthodontically and pre-treatment, deband, and postretention cephalometric radiographs were available. Skeletal anterior open bite (no incisal edge contact when upper and lower incisors are graphically rotated on their apices into the same vertical plane) was present in all, and the A-N-B values were 0-5°.

Pretreatment age ranged from 8.5 to 18.4 years, with an average of 12.9 years. Age at debanding ranged from 13.2 to 20.8 years, with an average of 15.7 years. After-retention ages ranged from 15.5 to 22.8 years, with an average of 18.4 years.

Group C, Class II open bite

This group of 9 males and 6 females was selected according to the same criteria as Group B, except that the A-N-B angle was greater than 4.5°.

Pretreatment age ranged from 6.6 to 15.5 years, with an average of 12.0 years. Ages at debanding were 13.1 to 17.5 years, with an average of 15.2 years. Postretention ages ranged from 14.1 to 23.0 years, with an average of 17.2 years.

Group D, Class I deep bite

The 7 males and 8 females in this group were also selected on the same criteria as Group B, except that a deep rather than an open bite existed, with the mandibular central incisor edge contacting at or above the maxillary central incisor cingulum with a tooth overlap of 80% or greater.

Pretreatment ages ranged from 10.5 to 14.6 years, average 13.0 years. Ages at debanding ranged from 12.4 to 16.7 years, averaging 15.3 years. Postretention ages ranged from 15.4 to 18.6 years, with an average of 17.5 years.

Group E, Class II deep bite

This group included 9 males and 6 females, selected according to the same criteria as Group D, except that the A-N-B values were greater than 4.5°.

Pretreatment ages were 7.3 to 16.2 years, with an average of 12.9 years. Debanding ages ranged from 13.7 to 18.4 years, with an average of 15.6 years. Postretention ages ranged from 15.1 to 20.8 years, averaging 17.9 years.

Statistical Methods

Descriptive analyses provided the means, standard errors and variances for each anatomic relationship. Analyses of variance (Table 1) were used to determine which variables exhibited statistically significant differences in relation to bite (normal, open, deep) and Class of molar occlusion (I, II). Discriminant analyses were used to determine which linear combinations

TABLE 1
Analysis of Variance

Anatomic Relationship	*F*	*Significance of F*	*Standard Error*
Ramus Inclination	5.46	$<.05$	0.16
Middle Cranial Fossa Inclination	6.53	$<.05$	0.20
Vertical Maxillary Length	10.66	$<.01$	0.29
Horizontal Maxillary Plane Inclination	10.08	$<.01$	0.05
Palatal Inclination	16.97	$<.001$	0.08
Aggregate Ramus + Corpus and MCF + Maxilla at A and B	22.48	$<.001$	0.22
Aggregate Ramus + Corpus and MCF + Maxilla at SPr and IPr	37.74	$<.001$	0.19
Curve of Spee	155.73	$<.001$	0.15
Gonial Angle	20.21	$<.001$	0.52
Mandibular Plane Inclination	23.19	$<.001$	0.75
Occlusal Plane Inclination	5.28	$<.05$	0.22

of variables distinguished most significantly between open, deep, and normal bite (Table 2).

Findings

Examination of the analyses of variance indicated no reason for separation of Class I and II cases with either open or deep bite, so all were accordingly pooled for the other statistical analyses (Table 1).

1. Ramus inclination (Table 1 and Fig. 12)

The difference between open- and deep-bite groups was significant ($p < .05$).

The posterior ramus angulation was least in the control group.

The ramus was tipped more posteriorly relative to the neutral ramus plane in the open bite than in control and deep bite. Interestingly, the extent of posterior inclination in open bite had increased even farther at debanding and postretention.

The posterior angulation of the ramus before treatment in the deep bite group was less than in those with open bite but greater than in the normal subjects. This had increased somewhat at debanding and decreased slightly at postretention.

2. Middle cranial fossa inclination (Table 1 and Fig. 13)

Forward inclination of MCF before treatment in both open- and deep-bite cases was greater than in the control group, and significantly greater in deep bite than in open bite ($p < .05$).

At debanding in the open-bite cases, there was a slight decrease in the forward inclination of MCF, with a slight posterior movement noted after retention.

In the deep-bite cases, the forward inclination of MCF before treatment was greater than in either control or open bite, with a slight decrease at debanding and postretention (Table 6 and Fig. 4).

3. Vertical maxillary length (Table 1 and Fig. 14)

In the control group, the vertical PM dimension was intermediate between open and deep bite.

The difference between open- and deep-bite groups was significant ($p < .01$). There was a relatively long vertical PM dimension before treatment with open bite, greater than in either control or deep bite. This dimension had increased farther at debanding and again at postretention.

TABLE 2
Discriminant Analysis

Discriminating Relationship	*Univariate F*	*Discriminant Coefficient*
Mandibular Plane Inclination	1.04	—0.07
Occlusal Plane Inclination	9.55	—0.29
Curve of Spee	154.42	—0.63
Aggregate Ramus + Corpus and MCF + Maxilla at A and B	3.23	—0.09
Middle Cranial Fossa Inclination	6.52	—0.19
Palatal Plane Inclination	6.88	—0.10
Inferior Maxillary Plane Inclination	2.78	—0.24

All ten anatomic relationships were tested. The particular combination that discriminated most thoroughly between open bite and deep bite are listed here. The number of individuals in our open- and deep-bite samples correctly classified by this combination was 100%.

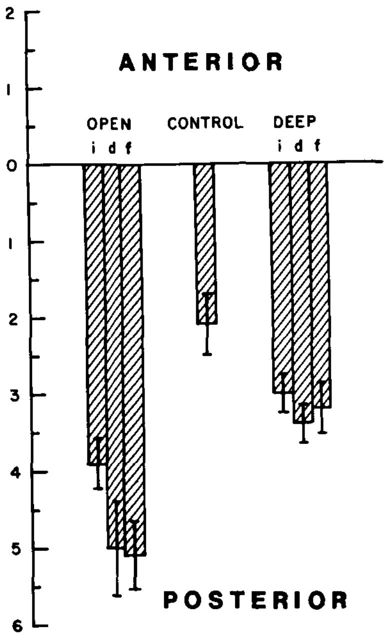

Fig. 12 Mean values and standard errors for Ramus Alignment measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

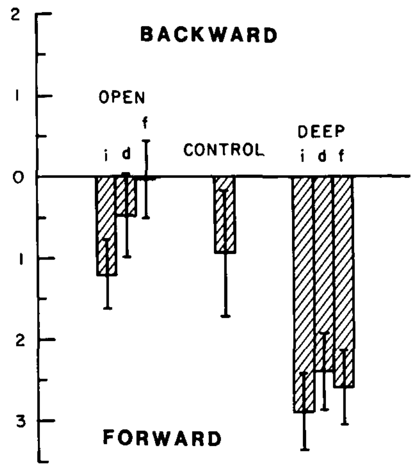

Fig. 13 Mean values and standard errors for Middle Cranial Fossa orientation, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

In deep bite, the PM vertical dimension was short before treatment and had increased at debanding, but it was still small. At postretention, this dimension had decreased to almost two-thirds of the original distance below the normal mean.

4. Horizontal maxillary inclination (Table 1 and Fig. 15).

The difference between open and deep bite was significant ($p < .01$).

In the control group, the maxillary alveolar plane showed a neutral relationship in 11 of the 15 individuals.

In the combined open-bite group, a more downward angulation was found in 12 individuals, and a more horizontal angulation in only 5.

Conversely, in the combined deep-bite group 15 individuals exhibited a downward tilt, and only 4 showed a more horizontal relationship.

At debanding in the open-bite group, the deviation of the maxillary alveolar plane had been reversed in 8 of the 12 individuals who had shown a downward tilt, and this had partially rebounded at postretention in 3 of them.

At debanding in the deep-bite group, the direction of deviation had been reversed in 5 of the 15 individuals showing an original downward tendency with a partial postretention rebound in 2 cases.

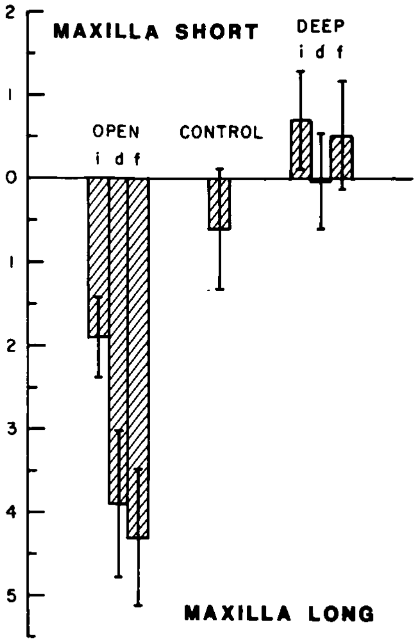

Fig. 14 Mean values and standard errors for Vertical Maxillary Length measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

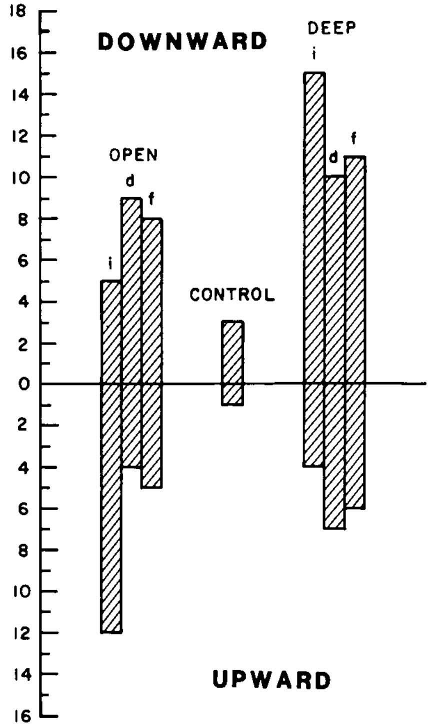

Fig. 15 Frequency distribution of number of subjects with upward and downward inclination of the Horizontal Maxillary Plane.
i initial
d deband
f final

5. Palatal inclination (Table 1 and Fig. 16).

The difference between open and deep bite was significant ($p < .001$).

In the control group, the projection of the palatal plane coincided with or was within ±3mm of the deepest surface of the occipital fossa (occipital point) in 11 of 15, indicating a neutral inclination, with the remainder showing a lower relationship indicating an upward cant anteriorly.

The projection of the palatal plane in 23 of the open-bite cases was well below the occipital point, with the remaining 7 having a neutral relationship. No individuals had a clockwise inclination.

In 7 of the deep-bite cases, the projected palatal plane was well above the deepest surface of the occipital fossa, a relationship not found in any of the controls or in open bite. Thirteen showed a neutral relationship, and 10 had an upward cant.

This shows a much stronger tendency for a downward tilt of the palatal plane anteriorly during the vertical development of the nasomaxillary complex in open bite, with the opposite tendency in deep bite.

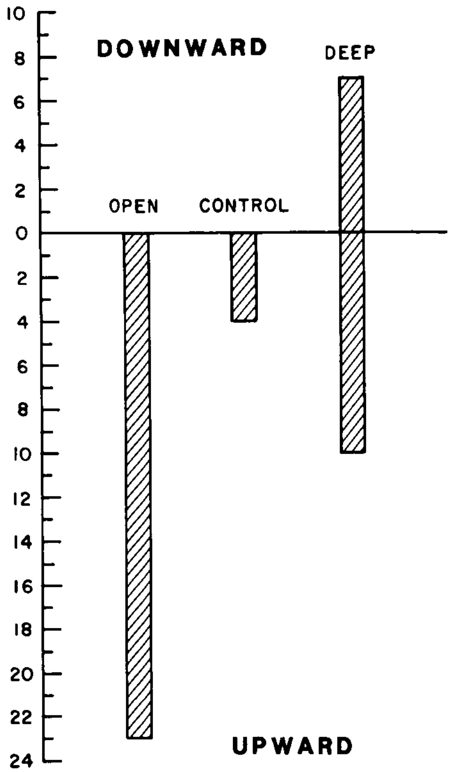

Fig. 16 Frequency distribution of untreated subjects with upward and downward inclination of the Palatal Plane.

In contrast to the changes found in horizontal maxillary plane inclination, during treatment in either open or deep bite.

6. Ramus + corpus horizontal length compared to maxilla + middle cranial fossa (Table 1 and Figs. 17 and 18).

Measured at points A and B, the difference between open and deep bite was significant ($p < .001$).

A mandibular protrusive tendency, as indicated by point B being anterior to point A, was found in the control group and in untreated open bite.

The tendency toward mandibular protrusion was smaller in untreated open bite. At debanding, this had reversed to a mandibular retrusive tendency, with a slight postretention decrease.

Conversely, a definite tendency toward maxillary protrusion was found before treatment in those with deep bite, with a slight decrease at debanding and postretention.

Measuring at SPr and IPr, the difference between open and deep bite groups was also significant ($p < .001$).

In open bite, there was a slight maxillary protrusive relationship of SPr before treatment but much less than in the deep-bite group. At debanding and postretention, this effect had decreased slightly.

In deep bite, a maxillary protrusive relationship of SPr before treatment was found much more frequently than with open bite, with some reduction at debanding and postretention.

7. Curve of Spee (Table 1 and Fig. 19)

The difference between the open- and deep-bite groups was significant ($p < .001$).

The curve of Spee in the control cases was intermediate between the curvatures found in open and deep bite.

A negative curve of Spee was found in untreated open bite, with the incisal edge of the mandibular central incisor below the functional occlusal plane. At debanding a positive occlusal curve had developed, with a slight postretention rebound.

In deep bite, there was a deep curve of Spee before treatment, some reduction at debanding and a slight rebound at postretention.

8. Gonial angle (Table 1 Fig. 20)

The difference between the open-

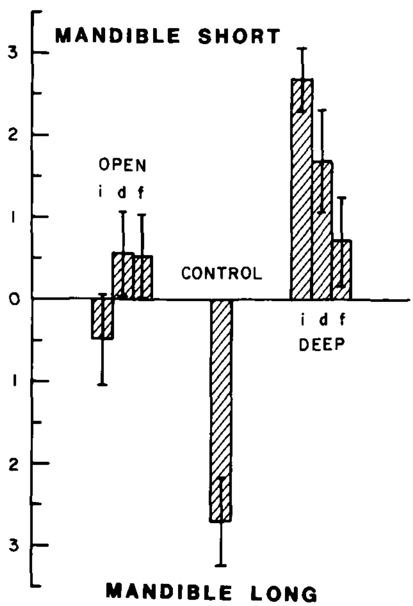

Fig. 17 Mean values and standard errors for Ramus + Corpus compared to Middle Cranial Fossa + Maxilla at points A and B, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

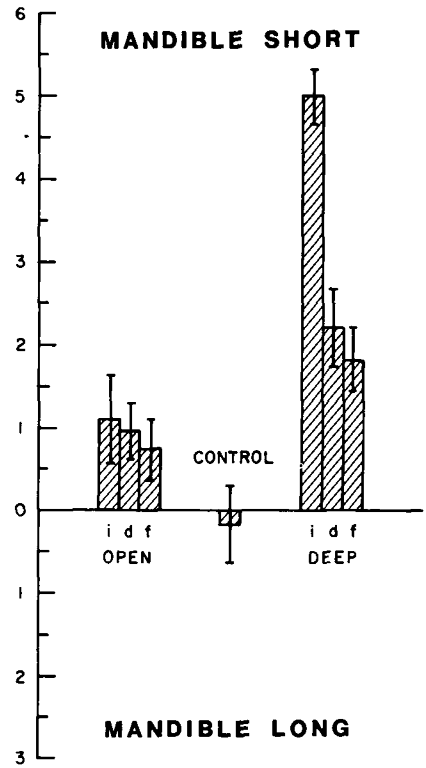

Fig. 18 Mean values and standard errors for Ramus + Corpus compared to Middle Cranial Fossa + Maxilla at SPr and IPr, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

and deep-bite groups was significant ($p < .001$).

In the control group, the gonial angle was intermediate between the open-bite and deep-bite groups and slightly below the norm of the Michigan Standards (Riolo *et al.*, 1974).

The gonial angle was most open in open bite, and had increased further at debanding. It had closed slightly after the dentition had settled at postretention, but it was still greater than before treatment.

It was most closed (smallest) in deep bite, where it opened slightly during treatment. At postretention the angle had become even smaller than before treatment.

9. Mandibular plane inclination (Table 1 and Fig. 21).

The difference between open- and deep-bite groups was significant ($p < .001$).

In the control group, the mandibular plane was above the neutral mandibular plane, but intermediate between the open- and deep-bite groups.

In open bite the average mandibular plane was below the neutral mandibular plane, with a further increase

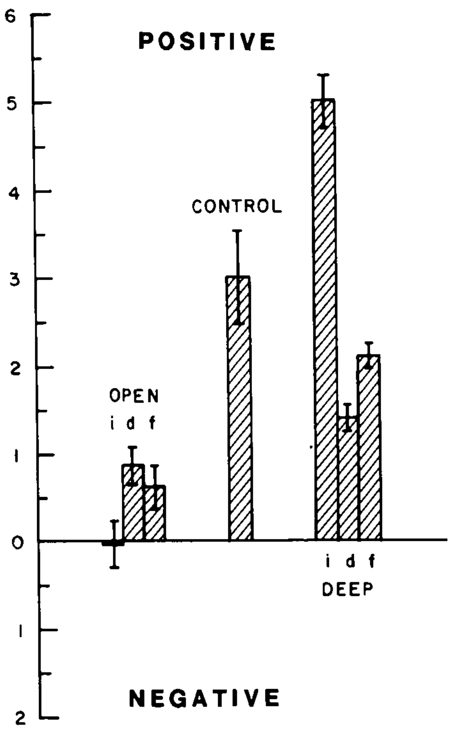

Fig. 19 Mean values and standard errors for the curve of Spee, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

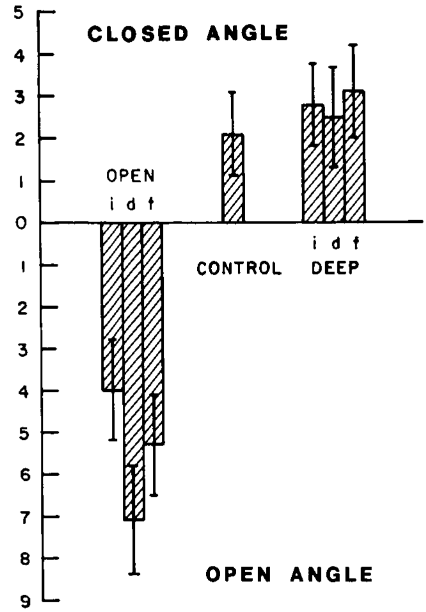

Fig. 20 Mean values and standard errors for Gonial Angle, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

at debanding. The mandibular plane to neutral mandibular plane distance had decreased somewhat at postretention, but the divergence was still greater than before treatment.

Deep bite was associated with a mandibular plane well above the neutral mandibular plane. At debanding, the mandibular plane had opened toward the neutral mandibular plane, but by postretention it had closed farther above the neutral mandibular plane than before treatment.

10. Occlusal plane inclination (Table 1 and Fig. 22)

The difference between open- and deep-bite groups was significant ($p < .05$). In the control group, the occlusal plane was below the neutral occlusal axis, but less than in both the open-bite and deep-bite groups.

In open bite the functional occlusal plane was rotated downward anteriorly more than in deep bite. At debanding and postretention, the downward divergence of the functional occlusal plane from the neutral occlusal axis had decreased, but it still remained below the neutral occlusal axis.

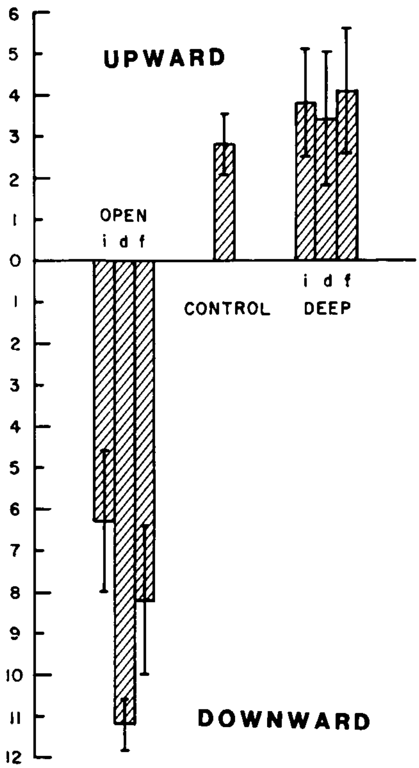

Fig. 21 Mean values and standard errors for Mandibular Plane Inclination, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

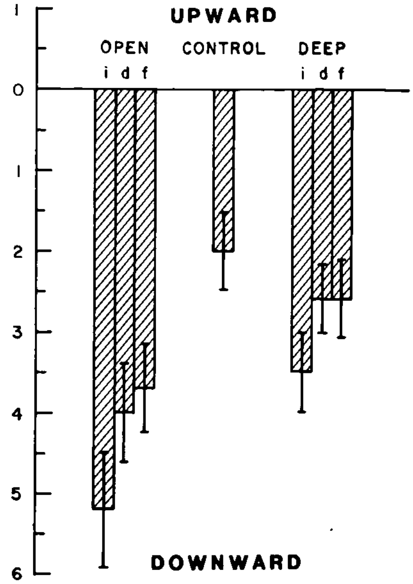

Fig. 22 Mean values and standard errors for Functional Occlusal Plane inclination, measured in mm of deviation from the neutral (0) value.
i initial
d deband
f final

In deep bite, the occlusal plane was also below the neutral occlusal axis before treatment, but much less than with open bite. This distance had decreased at debanding and the mean difference remained unchanged at postretention.

Discriminant analysis

The anatomic relationships found to be statistically significant on the basis of bite contribute to the aggregate morphology underlying open and deep bites.

A discriminant analysis of all ten of those anatomic relationships was used to construct a combination which most effectively discriminated between open-bite and deep-bite individuals. The variables included in this combination were palatal plane inclination, occlusal plane inclination, curve of Spee, aggregate cranial + maxilla and ramus + corpus dimensions at points A and B, inferior maxillary plane inclination, mandibular plane inclination and middle cranial fossa inclination.

This combination of anatomic relationships correctly classified 100% of the cases evaluated (Table 2).

Discussion

In every individual of the control ("normal" occlusion) group, some skeletal imbalance existed for one or more of the various anatomical relationships. These structural imbalances had been largely compensated by other offsetting anatomical relationships, so that no net overall anatomic dysplasia was expressed.

This effect of composite compensation had been previously described (Enlow, *et al.*, 1971*b*).

One or more of the variations in anatomic features evaluated in the present study may also be present in persons not demonstrating an open or closed bite. However, when such regional imbalances are not offset by intrinsic morphologic adjustments during growth, they can contribute to any one of a variety of more or less severe malocclusions.

It is especially important to note that when *multiple combinations* of the particular relationships considered in this study occurred, an open or deep bite was almost always found.

Skeletal imbalances as such do not represent primary biological causes for open or deep bite. Such imbalances are usually the result of other developmental and functional (e.g. airway) conditions, leading to the skeletal consequences associated with open or deep bite.

In the control group, values for the gonial angle, mandibular plane inclination, curve of Spee, vertical maxillary height, inferior maxillary plane inclination, and palatal plane inclination were intermediate between those of open-bite and deep-bite groups.

The control group had the least angulation of the middle cranial fossa and ramus, and the least downward tilt of the occlusal plane. It also showed the greatest mandibular protrusive effect from the aggregate cranial floor + maxilla and ramus + corpus dimensions at points A and B and at SPr and IPr.

In open bite, the gonial angle is more open than normal, although an open gonial angle is not a sole factor underlying open bite. However, the combination of a large gonial angle in conjunction with a posteriorly inclined ramus, lack of a compensating curve of Spee, certain rotations of the maxilla and basicranium, large vertical maxillary height and long horizontal mandibular dimension, underlie the aggregate composite morphological basis for an open bite.

The curve of Spee provides a degree of dental compensation for other skeletal imbalances (Enlow *et al.*, 1975). Facial development that otherwise could lead to open bite can be compensated for, at least in part, by the vertical drifting of the anterior mandibular teeth, with the result being a more closed anterior occlusion.

The nature of the anatomic variations analyzed in the present study indicate that deep bite and open bite are essentially opposite anatomic and developmental entities. Opposite inclinations and dimensional relationships are common for the particular variables considered in this study.

In open bite, the gonial angle is inclined into a more open position during development. In deep bite, the gonial angle has assumed a more closed relationship.

The curve of Spee is absent or actually negative in open bite, but there is a markedly positive curve in deep bite.

There is a greater vertical posterior maxillary dimension in open bite, but a smaller dimension in deep bite.

During vertical development of the

nasomaxillary complex, both the inferior maxillary plane and the palatal plane tend to be angulated more downward in deep bite, but upward (more closed) in open bite. The ramus and mandible tend to be inclined more downward in open bite and less so in deep bite.

The middle cranial fossa tends to be oriented more anteriorly and inferiorly in deep bite, and less so in open bite.

A tendency for mandibular protrusion exists in open bite, in contrast to a retrusive tendency with deep bite.

Orthodontic treatment effects

Anatomic effects associated with orthodontic treatment were also evaluated, although of course it is not possible to distinguish between treatment-induced changes and those that would have occurred during that period with or without treatment.

Deviant gonial angles showed an average tendency to continue to change even farther from median values.

In open bite, the average gonial angle was actually larger at debanding than before treatment. It had decreased slightly by postretention, but not to pretreatment levels. A more open final position of the corpus resulted, associated with a partial return of the open bite.

In deep bite, the average gonial angle had opened only slightly at debanding, and had decreased to an even smaller angle than before treatment by the time of the postretention radiographs. The corpus position was more closed, with a partial return of the deep bite.

The mandibular plane followed the same pattern of mean change as the gonial angle.

The functional occlusal plane had rotated upward at debanding in the open-bite cases, with further rotation by postretention. An overlap of the central incisor edges resulted, closing the open bite.

In deep bite, the functional occlusal plane had rotated upward at debanding with essentially no change at postretention. As a result, there was a net increase in overlap of the incisor edges.

The curve of Spee had increased at debanding in open bite, with a slight reduction at postretention. This resulted in a net decrease in the open bite.

In deep bite, the curve of Spee was much less than before treatment, contributing to a net decrease in the depth of the bite.

The aggregate cranial floor + maxilla and ramus + corpus dimensions demonstrated an overall decrease in the mandibular protrusive effect in open bite and an increase in deep bite. As a result, the mandible could be positioned to a more closed position in open bite, and in deep bite it could occlude in a more open position, favoring the desired treatment effects.

In both open and closed bite, the ramus became inclined even more posteriorly than before treatment. The change continued through postretention, but less in deep bite. This indicates a rotation of the entire mandible into a more open position, with a bite-opening effect.

During treatment of most of the open-bite cases, the upward tendency for horizontal maxillary alveolar plane inclination was reversed, contributing to a decrease in the open bite. Most of these changes were stable at postretention. In deep bite, the desired change in inclination is opposite, but this occurred in less than half of the cases.

The vertical maxillary dimension relative to the combined vertical length of the ramus and middle cranial fossa continued to increase throughout treatment and through postretention in the open-bite cases, consistent with the mandibular changes and partial return of the open bite. In deep bite, the relative vertical maxillary dimension had also increased at debanding, contributing to a decrease in the deep bite, but it had rebounded slightly at postretention.

The occlusal plane rotated downward less in relation to ramus rotation from debanding through postretention in the open-bite cases, along with a net closing rotation of the corpus; these changes are favorable for a decrease in the open bite. Similar changes in deep bite favored a partial return of the deep bite.

In aggregate, orthodontic treatment and/or growth effects were seen in the gonial angle, mandibular plane inclination, vertical maxillary height, horizontal maxillary plane inclination, occlusal plane, curve of Spee, aggregate cranial floor + maxilla and ramus + corpus dimensions, palatal depth and ramus inclination. There was no significant change in the palatal plane, and only a very slight change in the inclination of the middle cranial fossa, which was probably unaffected one way or the other by the treatment procedures used.

Class III

Not included in the present study is another category of open bite having an essentially different anatomic and morphogenic basis. This is the open bite type associated specifically with Class III malocclusions. Developmental factors which often lead to the Class III condition include an anterior angulation of the ramus and a relatively short vertical dimension of the nasomaxillary complex (Enlow, *et al.*, 1971*a*). As already seen in the present study, these particular conditions relate to a deep bite rather than an open bite in Class I and II.

In the Caucasian Class III type of malocclusion, there is usually a marked posterosuperior rather than a more horizontal inclination of the middle cranial fossae, and this circumstance alters the effects of the ramus angulation and short maxillary height. The more upright inclination of the middle cranial fossae causes a retrusive and superior placement of the maxilla, together with a forward and protrusive angulation of the mandible.

Because a horizontally long mandibular corpus and an anterior crossbite also exist in the Class III, the composite aggregate result can be an opening of the ramus/corpus (gonial) angle to allow the lower arch to meet with the upper arch, albeit with an anterior open bite (Fig. 11).

An upward cant of the palate and maxillary arch, and the inadequacy of relative vertical drifting of the anterior mandibular teeth (curve of Spee), both have bite-opening effects.

REFERENCES

Enlow, D. H.: Handbook of Facial Growth. W. B. Saunders Co., Philadelphia. 1975.

Enlow, D. H., T. Kuroda, and A. G. Lewis: The morphological and morphogenic basis for craniofacial form and pattern. Angle Orthod., 41:161-188, 1971*a*.

Enlow, D. H., T. Kuroda, and A. B. Lewis: Intrinsic craniofacial compensations. Angle Orthod., 41:271-285, 1971*b*.

Hapak, F. M.: Cephalometric appraisal of the open-bite case. Angle Orthod., 34:65-72, 1964.

Hellman, M.: Open-bite. The Internat. J. Orthod. Oral Surg. and Radiol., 17:421-444, 1931.

Loufty, M. S.: Cephalometric evaluation of deep overbite and anterior open bite in Kuwait school children. Trans. Europ. Orthod. Soc.. 281-285, 1973.

Moss, M. L. and L. Salentijn: Differences between the functional matrices in anterior open-bite and in deep overbite. Am. J. Orthod., 60:264-279, 1971.

Muller, G.: Growth and development of the middle face. J. Dent. Res., 42:385-399, 1963.

Nahoum, H. I.: Anterior open-bite: A cephalometric analysis and suggested treatment procedures. Am. J. Orthod., 67:513-521, 1975.

Nahoum, H. I.: Vertical proportions and the palatal plane in anterior open-bite. Am. J. Orthod., 59:273-282, 1971.

Neff, C. W. and W. L. Kydd: The open bite: Physiology and occlusion. J. Dent. Res., 36:351-357, 1966.

Richardson, A.: A cephalometric investigation of skeletal factors in anterior open bite and deep overbite. Tr. Europ. Orthodont. Soc., 43:159-171, 1967.

Riolo, M. L., R. E. Moyers, J. A. McNamara, and W. W. Hunter: An Atlas on Craniofacial Growth: Cephalometric Standards from the University School Growth Study. Center for Human Growth and Development, The University of Michigan, 74, 1974.

Schendel, S. A., J. Eisenfeld, W. H. Bell, B. N. Epker and D. J. Mishelevich: The long face syndrome: Vertical maxillary excess. Am. J. Orthod., 70:398-408, 1976.

Subtelny, J. D. and M. Skuda: Open-bite: Diagnosis and treatment. Am. J. Orthod., 50:337-358, 1964.

Swinehart, E. W.: A clinical study of openbite. Am. J. Orthod., 28:18-34, 1942.

Trouten, J. C.: Analysis of Skeletal Open Bite and Deep Bite Utilizing the Counterpart Analysis. M.S. Thesis, Orthodontic Department, Case Western Reserve University, Cleveland, Ohio, 1980.