Intrinsic Craniofacial Compensations*

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In previous reports the morphologic and developmental basis for the nature of individual craniofacial form, configuration, and composite assembly pattern has been described.[1,2] A "counterpart-comparison" procedure was used in which the many regional anatomical *parts* are compared with developmental and geometric *counterparts* within the craniofacial composite in order to determine the structural effects of the complex interrelationships among them. In comparing each anatomical part directly with its particular architectural, developmental counterpart (i.e., the bony maxillary arch compared with the bony mandibular arch), two factors are considered: the effect of the *alignment* ("rotational" position) of the parts relative to each other and second, the anatomical effect of the *sizes* (vertical and horizontal) of the parts relative to each other. The factor of alignment is of basic importance because any upward, downward, backward, or forward rotational position directly affects the expression of the actual horizontal and vertical dimensions of each part. The specific anatomical results of these regional cranial and facial counterpart relationships, and all of them in interrelated combinations, are determined by noting simply whether a consequent maxillary or a mandibular protrusive effect is produced by each. Protrusive effects in one region of the craniofacial composite are passed from part to part so that a given effect can become expressed in other locations quite distant from the actual source. A given counterpart relationship, for example, between the vertical span of the cranial base and the posterior, vertical part of the midface can produce a consequent, horizontal protrusive relationship between the maxillary and mandibular skeletal and dental arches at their anterior ends.

In our previous studies the counterpart-comparison procedure was utilized in detailed analyses of the specific anatomical features and regional counterpart combinations that underlie and characterize Class I, II, and III types of craniofacial patterns.[1,2] Such combinations and the extent of their effects vary widely among different individuals as well as the Class groups. In Class II and III individuals most of the regional counterpart relationships (alignment and comparative dimensional effects) throughout the various cranial and facial regions were found to contribute in an aggregate manner to the establishment of a *composite* basis for over-all maxillary or mandibular protrusive patterns. A single morphologic feature does not ordinarily produce such protrusive relationships because the presence of a structural imbalance in any one area also affects the nature of balance in other areas as well. Thus, a number of separate but interrelated, regional, cause-and-effect factors tend to augment each other in a cumulative, composite manner. The Class I individuals, however, are characterized by an effective balance between variable numbers of offsetting maxillary and mandibular protrusive effects among the various regional counterpart relationships. Class

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II and III individuals may also show a degree of such intrinsic compensation. The nature and the severity of their over-all skeletal dysplasia is determined by the distribution and the extent of cumulative, regional, protrusive effects in conjunction with the extent of some other offsetting effects that provide a greater or lesser degree of intrinsic compensation.

Importantly, the nature of the regional relationships and the effects of these relationships for our Class I North American Caucasoid sample show a distinct similarity with Class II types of craniofacial relationships and effects.[2] The difference is essentially in the extent of the effects and the greater number of offsetting and compensating relationships among the various regional counterparts. The purpose of the present study is to examine the role and the incidence of these intrinsic compensating factors and to relate them to the different major categories of craniofacial patterns.

Our previous work has shown that at least two basic types of Class I and two corresponding, basic types of Class II patterns exist. These basically different patterns are produced by different combinations of many regional structural characteristics. The composite result may be recognized by noting the consequent positioning of maxillary *A* point relative to mandibular *B* point. If *A* point lies anterior to *B* point with respect to the functional occlusal plane, the craniofacial pattern is designated as a Class I *A* or a Class II *A* type. The difference between the I *A* and II *A* is essentially quantitative, since the basic nature of underlying alignment and dimensional counterpart relationships is similar for individuals in both groups. If *B* point lies anterior to *A* point with respect to the functional occlusal plane, however, the craniofacial pattern is designated as a Class I *B* or a Class II *B* type. The *B* group, either Class I or II, is different from the *A* type in that a variable but usually greater number of mandibular protrusion (Class III) features and their effects are present in different regional parts of the craniofacial skeleton. The *B* group is the most frequent among the Class I's in our sample and comprises those individuals usually having a more proportionate facial "balance" when considering the composite of all the component parts. Their facial configuration is usually characterized by an orthognathic or slightly prognathic profile, a somewhat lower nasal bridge, shorter nose, shorter midface appearance, and prominent-appearing cheek bones. These features produce a slight maxillary-mandibular prominence (a "muzzle") which is more noticeable in the female due to smaller frontal sinuses. The Class I *A* group includes those individuals having a "Class II" (maxillary protrusion) tendency. Their facial configuration is often characterized by a more retrognathic, convex type of profile, a higher nasal bridge, long nose, a vertically longer midface appearance, and less prominent cheek bones. In our sample the *A* group is the most common of Class II's and includes those individuals tending to have a more severe type of skeletal dysplasia. The Class II *B* group, in contrast, has a much lesser incidence of severe skeletal dysplasias due to the greater number of compensating "Class III" anatomical effects in the different parts of the craniofacial skeleton.

Procedure

In our previous study[2] a series of 137 Class I, 118 Class II, and 47 Class III untreated individuals at various ages were analyzed using the counterpart-comparison procedure. The relative dimensions and, separately, the alignment for each of a number of the basic anatomical parts and counterparts were evaluated as to (1) a maxillary protrusion effect, (2) a mandibular protrusion effect, or (3) a neutral effect with neither maxillary nor mandibular protrusion caused by that particular regional relationship in that individual. In the present study various combinations among the different sets of parts and counterparts are examined to determine which can have compensating effects that offset, wholly or in part, protrusive effects exerted by other parts and counterparts. Also, the anatomical effects of alignment are compared with the separate effects produced by relative dimensions within any given counterpart set. The incidence of all such compensatory combinations among the sample is shown in Table I, and the anatomical relationships involved are described below.

If the effects between any two groups of parts and counterparts are *reciprocal* (i.e., one has a maxillary protrusive effect while the other has a mandibular protrusive effect), the composite anatomical result is thereby partly or wholly offsetting and compensatory. This is a morphologically advantageous situation since a protrusive effect produced by either the alignment or the dimensions of one such part-counterpart relationship is, at least in part, cancelled by an opposite protrusive effect in some other craniofacial region. If the two different part-counterpart groups have a common protrusive effect, however, the relationship is *synergic* and their respective effects are cumulative within that individual. Such synergic relationships may be either advantageous or disadvantageous in a given person. Regional relationships that produce a cumulative, synergic maxillary protrusion effect in a Class II individual augment and worsen the over-all extent of his composite maxillary prognathism. Conversely, regional relationships having synergic mandibular protrusive effects in a Class II individual are advantageous because they contribute a degree of regional compensation within the craniofacial framework and thereby reduce the aggregate extent of maxillary protrusion.

Incidence of Synergic and Reciprocal Relationships

1. *PCF alignment/Ramus alignment.* The posterior part of the anterior cranial floor *(PCF)* and the mandibular ramus are horizontal counterparts to each other. However, the alignment of each directly affects the expressed dimensional values of one to the other. A forward rotation of *PCF* has a maxillary protrusion effect, and a backward alignment has an opposite mandibular protrusive effect. A forward alignment of the ramus has a mandibular protrusion effect, and a backward and downward rotation has a maxillary protrusion effect. Schematic diagrams illustrating the basic nature of these various relationships have been presented in a previous report.[2]

The Class II *A* group representing the most common Class II type has the lowest incidence (28 per cent) showing a desirable reciprocal relationship in the relative alignments of these two anatomical parts (Table I). In the synergic relationships both the Class II *A* and II *B* groups have a relatively high distribution (65, 64 per cent) with a maxillary protrusion effect, as does the Class I *A,* which includes those Class I individuals with a more marked "Class II" tendency. This indicates that a forward cranial floor rotation tends to occur in conjunction with a backward ramus rotation *in the same individual* in these three groups. A relatively high incidence of mandibular protrusion occurs in the synergic type of relationship among the Class III individuals, since a backward cranial floor rotation tends to occur in conjunction with a forward

ANATOMICAL RELATIONSHIP	CLASS	SYNERGIC RELATIONSHIPS mandibular protrusion %	SYNERGIC RELATIONSHIPS maxillary protrusion %	RECIPROCAL RELATIONSHIP %
1. PCF alignment/Ramus alignment	I B	8	46	46
	I A	0	65	35
	II B	3	64	33
	II A	7	65	28
	III	43	5	52
2. PCF alignment/Ramus-PCF dimensions, skeletal	I B	13	13	74
	I A	4	4	92
	II B	15	15	70
	II A	5	30	65
	III	26	13	61
3. PCF alignment/A-B skeletal arch dimensions	I B	22	7	71
	I A	5	33	62
	II B	16	6	78
	II A	3	50	47
	III	71	2	27
4. PCF alignment/SPr-IPr skeletal arch dimensions	I B	12	20	68
	I A	0	54	46
	II B	7	30	63
	II A	1	65	34
	III	64	2	34
5. PCF alignment/PM vertical dimension	I B	3	27	70
	I A	0	30	70
	II B	3	32	65
	II A	4	51	45
	III	33	2	65
6. Ramus-PCF skeletal dimensions/Ramus alignment	I B	13	26	61
	I A	8	16	76
	II B	10	33	57
	II A	5	34	61
	III	22	12	66
7. Ramus alignment/A-B skeletal arch dimensions	I B	18	18	64
	I A	4	61	35
	II B	14	11	75
	II A	8	63	29
	III	71	2	27
8. Ramus alignment/SPr-IPr skeletal arch dimensions	I B	13	39	48
	I A	0	76	24
	II B	14	48	38
	II A	4	71	25
	III	63	9	28
9. Ramus alignment/PM vertical dimension	I B	21	66	13
	I A	13	65	22
	II B	14	64	22
	II A	17	71	12
	III	55	33	12
10. Ramus-PCF skeletal dimensions/SPr-IPr skeletal dimensions	I B	24	11	65
	I A	12	24	64
	II B	19	11	70
	II A	3	40	57
	III	37	2	61
11. Ramus-PCF skeletal dimensions/PM vertical dimension	I B	26	24	50
	I A	30	22	48
	II B	24	31	45
	II A	12	35	53
	III	25	22	53

ANATOMICAL RELATIONSHIP	CLASS	SYNERGIC RELATIONSHIPS mandibular protrusion %	maxillary protrusion %	RECIPROCAL RELATIONSHIP %
12. A-B skeletal dimensions/ PM vertical dimension	I B	34	21	45
	I A	24	52	24
	II B	37	15	48
	II A	14	59	27
	III	60	0	40
13. PCF alignment/Occlusal alignment	I B	8	18	74
	I A	0	41	59
	II B	18	11	71
	II A	7	42	51
	III	55	5	40
14. SPr-IPr skeletal arch dimensions/Occlusal alignment	I B	40	31	29
	I A	12	67	21
	II B	45	18	37
	II A	9	59	32
	III	73	5	22
15. PCF alignment/Corpus alignment	I B	19	25	56
	I A	11	37	52
	II B	22	25	53
	II A	17	35	48
	III	65	9	26
16. Ramus alignment/Corpus alignment	I B	22	33	45
	I A	7	52	41
	II B	12	33	55
	II A	14	33	53
	III	55	4	41
17. Ramus alignment/Occlusal alignment	I B	19	42	39
	I A	4	66	30
	II B	21	21	58
	II A	11	54	35
	III	63	22	15
18. A-B skeletal dimensions/ Corpus alignment	I B	47	12	41
	I A	13	39	48
	II B	65	3	32
	II A	17	29	54
	III	84	0	16
19. A-B skeletal dimensions/ Occlusal alignment	I B	48	19	33
	I A	24	57	19
	II B	79	4	17
	II A	20	55	25
	III	80	2	18
20. PM vertical dimension/ Corpus alignment	I B	28	28	44
	I A	16	28	56
	II B	29	26	45
	II A	20	25	55
	III	49	7	44
21. PM vertical dimension/ Occlusal alignment	I B	31	44	25
	I A	25	55	20
	II B	44	17	39
	II A	22	53	25
	III	53	20	27

TABLE I

ramus rotation in the same individual. Even in the Class I *B* group, nearly half of the individuals have a maxillary protrusive synergic relationship, which indicates that a forward-aligned cranial floor often occurs in conjunction with a backward-rotated ramus. In this group, however, the incidence of a reciprocal, compensatory relationship is somewhat higher, and the incidence of maxillary protrusive relationship is lower. The sum of both gives the I *B* group a 37 per cent lower incidence of a maxillary protrusive effect than the II *A* group and about 30 per cent lower than either the I *A* or II *B* groups.

2. *PCF alignment/Ramus-PCF skeletal dimensions.* The purpose of this determination is to see if the horizontal dimension of the ramus relative to the horizontal dimension of the posterior part of the cranial floor can reciprocally offset the effect of any forward or backward alignment position of the cranial floor. Thus, a forward-rotated cranial floor would be compensated, wholly or in part, by a horizontally wide ramus (relative to the cranial floor dimension). A backward-aligned *PCF,* similarly, would be reciprocally compensated by a more narrow ramus-to-cranial floor dimensional relationship. If their relationships are synergic, however, a forward-aligned *PCF* would be accompanied by an augmenting narrow ramus (both producing maxillary protrusion), or a backward-aligned *PCF* would be augmented by a wide ramus (both producing mandibular protrusion). The former relationship would tend to worsen a composite Class II pattern but help a Class III pattern. The latter would be advantageous to a Class II individual but detrimental to a Class III pattern.

Significantly, all groups show a desirable, reciprocal tendency for this important relationship. This indicates a compensatory effect which is operative in each of the classes with regard to the horizontal width of the ramus relative to its anatomical counterpart, the posterior part of the cranial floor. Thus, a forward "rotated" cranial floor is often accompanied by a "wide" relative ramus dimension, and a backward-aligned cranial floor most frequently occurs in conjunction with a more narrow relative ramus dimension. The resulting effects thereby partially or completely offset each other. A tendency toward a slightly wide ramus among Class I individuals also contributes to the normal offset positioning of the mandibular molars with respect to the maxillary molars. Note the increase in maxillary and mandibular protrusion tendencies, however, in the synergic relationships of the Class II *A* and III groups, respectively.

3. *PCF alignment/A-B skeletal arch dimensions.* The effects of cranial floor alignment are compared with the effects of the bony maxillary-mandibular arch relative dimensions as measured from *A* and *B* points. Significantly, the Class II *A* and III groups have a much less frequent incidence of a desirable, compensating type of reciprocal relationship. In the synergic type of relationships, also, note the much higher incidence of maxillary protrusion among the Class II *A* and I *A* groups and the higher tendency for a mandibular protrusion effect among Class III individuals. This augments and worsens their respective tendencies toward maxillary and mandibular protrusion. Conversely, a very high percentage of I *B* and II *B* individuals have either a reciprocal compensating or a desirable mandibular protrusive type of relationship.

4. *PCF alignment/SPr-IPr skeletal arch dimensions.* The above determination is repeated using superior and inferior prosthion rather than *A* and *B* points. The Class III, II *A*, and I *A*

groups have a lower percentage distribution showing desirable reciprocal compensation between these important relationships. In those individuals with a synergic type of relationship, similarly, a higher percentage shows a maxillary protrusion effect among the Class II *A* and I *A* groups, and a mandibular protrusion effect among the Class III's. This increases regional Class II and III characteristics. Conversely, a high incidence of either reciprocal compensation or a mandibular protrusive synergic effect occurs among the Class I *B* and II *B* individuals.

5. *PCF alignment/PM vertical dimension.* The effect of cranial floor alignment is compared with the effect produced by the *PM* dimension. The latter is the relative height of the midface compared with the combined vertical lengths of the posterior cranial floor and the ramus.[2] A distinct reciprocal compensatory tendency is noted in all groups except, importantly, the Class II *A* individuals. In the other groups a forward and downward aligned cranial floor tends to be offset, at least in part, by a vertically shorter midface, and an upward aligned cranial floor tends to be offset by a longer *PM* vertical dimension. Note: these relationships are relative. Even though a given *PM* dimension can be somewhat "shorter" in relation to the cranial floor and ramus, its over-all length may nevertheless be long or short in actual size. Thus, a person of a given ethnic or family pattern can have a characteristically long or short midface, but with respect to his own intrinsic, composite skeletal relationships, a *relative* shortening or lengthening can occur and thereby provide partial compensation for cranial floor alignment.

In those individuals with a synergic type of relationship a higher incidence having a maxillary protrusion effect is noted among the Class II and I individuals, particularly the Class II *A* group, and a higher incidence with a mandibular protrusion effect is seen in Class III individuals.

6. *Ramus-PCF skeletal dimensions/Ramus alignment.* Just as a reciprocally wide or narrow ramus dimension relative to the horizontal cranial floor dimension has a tendency to offset in part any forward or backward cranial floor rotation, this same desirable, reciprocal ramus dimensional feature similarly provides compensation for ramus rotations. A high percentage in all classes, including even the II *A* and III, shows this reciprocal type of relationship. In those individuals with a synergic type of relationship, however, note the higher incidence of a maxillary protrusion effect among both the Class I and II groups and a mandibular protrusion effect in the Class III individuals.

7. *Ramus alignment/A-B skeletal arch dimensions.* The purpose of this comparison is to determine the incidence of compensation between relative bony arch lengths and the forward or backward nature of any ramus rotation present in a given individual. A much lower incidence of the desirable, reciprocal type of relationship occurs among the Class II *A,* I *A,* and III individuals. In these same groups note the tendencies toward maxillary and mandibular protrusion, respectively, in individuals having a synergic relationship between these two anatomical factors. Thus, a backward ramus alignment in conjunction with a long bony maxillary arch (relative to the mandibular arch) in the I *A* and II *A,* and a forward ramus alignment together with a long relative bony mandibular arch in the Class III's augments their respective protrusive tendencies. In contrast, note the high total incidence of a reciprocal and a desirable type of synergic relationship among the Class I *B* and II *B* individuals.

8. *Ramus alignment/SPr-IPr skeletal arch dimensions.* The above determination is repeated using superior and inferior prosthion. A relatively low incidence of reciprocal compensation is present in the Class I *A* and II *A* groups. These same groups also show a much higher distribution having an undesirable maxillary protrusion effect in those individuals with a synergic type of relationship. The Class III group, similarly, has a low incidence of reciprocal compensation and a very high distribution with a mandibular protrusive type of synergic relationship.

9. *Ramus alignment/PM vertical dimension.* This relationship is synergic (the sum of the maxillary and mandibular protrusion values) in a high percentage of all groups since the long or short relative nature of the *PM* dimension directly predisposes any downward or upward direction of ramus rotation (Figs. 1 and 3). A marked tendency exists for a long *PM* in conjunction with a backward ramus rotation in all Class I and II groups (resulting in a maxillary protrusive effect), and a shorter *PM* in conjunction with an upward ramus rotation in the Class III group (producing a mandibular protrusive effect). Contrast with the *PM/* corpus alignment relationship in Number 20 below.

10. *Ramus-PCF skeletal dimensions/ SPr-IPr skeletal arch dimensions.* This comparison shows the incidence of a horizontally wide or narrow ramus, relative to the posterior part of the anterior cranial floor, in conjunction with either a long or short maxillary to mandibular arch relationship. A tendency for a reciprocal, intrinsic compensating effect of the relative ramus dimension is seen in this relationship, as it was in Numbers 2 and 6 above. The sum of the reciprocal percentage plus the desirable mandibular protrusive type of synergic relationship shows a very high total incidence for a ramus dimensional compensating feature among the I *B*, I *A*, and II *B* groups. Note the higher incidence of a synergic maxillary protrusion effect, however, among the Class II *A* individuals and a synergic mandibular protrusive relationship among the Class III's.

11. *Ramus-PCF horizontal skeletal dimensions/PM vertical dimension.* Each of these anatomical parts has a compensating effect relative to a number of other parts in some or all of the Class groups (2, 5, 6, and 10 above). When their relationship to each other is considered, a high incidence of a reciprocal plus a desirable type of synergic effect is seen. Thus, *all* groups have a sixty-five or higher percentage in which these parts, acting in conjunction with each other, function to partially offset any other regional protrusive effects.

12. *A-B horizontal skeletal arch dimensions/PM vertical dimension.* A lower incidence of the reciprocal type of relationship is seen, significantly, in the Class I *A* and II *A* groups. In these same two groups a much higher percentage has an undesirable, maxillary protrusive type of synergic relationship. Note also the higher incidence of a synergic, mandibular protrusive relationship in the Class III group. Conversely, the I *B* and II *B* groups have a very high incidence of individuals with either a reciprocal compensatory or a desirable mandibular protrusive type of composite effect between these anatomical relationships.

13. *PCF alignment/Occlusal alignment.* This comparison shows the incidence of a forward and downward (maxillary protrusive) or a backward and upward (mandibular protrusive) *PCF* in conjunction with a downward occlusal alignment (mandibular protrusive, see Fig. 1) or an upward occlusal alignment (maxillary protrusive). A

high incidence of a desirable type of reciprocal relationship is seen in the I *B* and II *B* groups. In contrast, the Class I *A*, II *A*, and III groups all show relatively high percentages having adverse types of synergic effects.

14. *SPr-IPr skeletal arch/Occlusal alignment.* Significantly, higher percentages are noted for a maxillary protrusive type of synergic relationship among the I *A* and II *A* individuals and a mandibular protrusive relationship in the Class III group. The Class I *B* and II *B* groups both have a high incidence of individuals with either a desirable, synergic mandibular protrusive relationship or a reciprocal, compensatory type of relationship.

15. *PCF alignment/Corpus alignment.* The incidence of upward or downward *PCF* alignment in conjunction with upward or downward corpus alignment is determined in this comparison. Note that *corpus* alignment and *occlusal* alignment are evaluated separately in these various comparisons (13, 14, 16, 17, 18, 19, 20, and 21) since a functionally significant divergence between the extent or the directions of their respective alignment positions can occur in some individuals. Among Class III persons a backward-aligned cranial floor most often occurs in conjunction with an inferiorly rotated corpus, both of which have mandibular protrusion effects. This produces the characteristic downward slope of the corpus that is present in many Class III individuals.

16. *Ramus alignment/Corpus alignment.* In the synergic type of relationship a maxillary protrusive trend is seen for the Class I and II groups, and a mandibular protrusive tendency is seen in the Class III's. However, half or more of the individuals in all groups have either a reciprocal or a desirable type of synergic relationship. This is of significance when comparing corpus rotations with the sometimes independent rotation of the occlusion (17 below).

17. *Ramus alignment/Occlusal alignment.* Opposite directions of rotation between these two parts (and also between the ramus and corpus in 16 above) have a synergic effect. That is, downward ramus and upward occlusal rotations relative to each other produce synergic maxillary protrusion effects, and upward ramus and downward occlusal rotations have synergic mandibular protrusive effects (Fig. 1). Conversely, if these two parts both rotate in the same direction, either upward or downward, the anatomical protrusive effects produced are reciprocal to each other.

In comparing the incidence of relationship effects between ramus alignment/corpus alignment and ramus alignment/occlusal alignment, the occurrence of different percentages indicates that the nature of functional occlusal plane rotation relative to the ramus can diverge from the rotational position of the corpus relative to the ramus. The decrease in the incidence of reciprocal effects and the increase in synergic maxillary protrusion effects for the ramus/occlusion relationship (in all but Class II *B*) shows that the mandibular dental arch can rotate in an upward manner to a greater or lesser extent in conjunction with a downward ramus rotation. This is independent of the mandibular corpus itself. Thus, the extent of a downward angulation of the occlusal plane caused by a direct downward rotation of the ramus can be partially offset by an opposite, superior direction of rotation by the mandibular dental arch, thereby reducing the degree of resultant downward-directed occlusal plane alignment. The process involved is important in establishing a full-length closed occlusion (see Discussion below).

Note also the increase among Class

III individuals in the incidence of an upward ramus rotation occurring in conjunction with a downward occlusal plane rotation to produce composite, synergic mandibular protrusion effects.

18. *A-B skeletal arch dimensions/Corpus alignment.* The sum of the reciprocal percentages and the percentages for the mandibular protrusive type of synergic relationship among all Class I and II groups shows a very high combined incidence of a desirable compensation. Thus, a "long" maxillary arch in Class I and II individuals is most often accompanied by a downward *corpus* (not ramus) rotation, which has a mandibular protrusive effect in relation to the bony maxillary arch. The Class III group stands by itself with a strong tendency for undesirable relationships with respect to both the reciprocal and the synergic effects.

19. *A-B skeletal arch dimensions/Occlusal alignment.* A lower incidence of a compensating reciprocal type of relationship is seen in the Class I and II groups when compared with 18 above. Of the synergic relationships, a higher incidence with maxillary protrusion is seen in the II *A* and I *A* individuals when compared with 18 above. These relationships further demonstrate that the mandibular dental arch can have an independent rotational behavior in some individuals as it relates to rotations of the corpus and also the ramus. Note that the Class III group has a low incidence of individuals with a desirable, compensatory, reciprocal effect and a very high percentage with an undesirable mandibular protrusive type of synergic relationship.

20. *PM vertical dimension/Corpus alignment.* This relationship shows an approximate one-to-one ratio in all classes between the reciprocal and the synergic types of effects. The latter include both the maxillary protrusive relationship (long *PM* combined with an upward corpus, not ramus, rotation) and a mandibular protrusive relationship (short *PM* together with a downward corpus rotation). The purpose of including this comparison is to demonstrate that any upward or downward rotation of the corpus, unlike the ramus, is essentially independent of *PM* relative height in a direct cause-and-effect relationship. This is in contrast to the high incidence of individuals with such a direct relationship between ramus rotation and the relative vertical length of the midface *(PM),* as shown in 9 above. See Figures 1 and 3.

21. *PM vertical dimension/Occlusal alignment.* This relationship shows a significant increase among the I *A* and II *A* individuals in the incidence of composite maxillary protrusion effects (upward mandibular dental arch rotation in conjunction with a vertically long midface) as compared with the *PM*/corpus alignment relationship described in 20 above. As previously pointed out, the rotation of the mandibular dental arch can be independent of the mandibular corpus itself in some individuals. Thus, regardless of any downward-inclined ramus and corpus position, an extrusion of the anterior mandibular teeth can serve to align the functional occlusal plane somewhat more superiorly and thereby reduce the over-all extent of downward occlusal plane angulation caused by the downward rotation of the ramus and/or corpus.

Discussion

While each of the above relationships is self-explanatory, it is also evident that consistent, meaningful patterns and trends are identifiable among them. Except for the *PM*/ramus alignment relationship the Class I *B* group has at least a fifty per cent, and usually much greater, incidence of either a reciprocal compensating effect or the desirable, mandibular protrusive type of synergic effect for each of the various combinations of relationships. *Importantly, the cumulative combinations of all of these many different interrelationships in the I B group produce a highly effective composite compensatory result.* Contrast this situation with the Class II *A* and III groups.

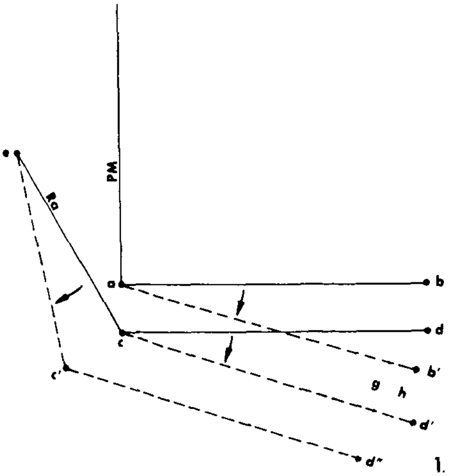
Our previous counterpart-comparison studies have shown that most Class I Caucasoid individuals (both *A* and *B* types) have a strong "Class II" tendency with regard to several basic anatomical relationships.[2] These characteristic features underlie the basis for the much higher incidence of Class II than Class III types of malocclusions and craniofacial dysplasias in our North American Caucasoid population. The characteristics themselves include a forward-aligned type of cranial floor, a backward-aligned ramus, a vertically long midface relative dimension, and a long maxillary dental arch relative to the mandibular dental arch (as measured at *SPr/IPr*). In the Class I *B* group, particularly, the occurrence of the cumulative compensatory effects of the many combinations described in the present report effectively counteracts and offsets these commonly-present, maxillary protrusive characteristics.

The II *B* group also shows relatively high percentages with either the reciprocal compensatory or the advantageous (mandibular protrusive) type of synergic relationship. In this group the many offsetting, counteraction effects greatly reduce the extent of any maxillary protrusive tendency caused by other regional cranial and facial anatomical relationships.[2] In contrast, the I *A* group (those Class I individuals usually having a Class II tendency) consistently show a much lower incidence of reciprocal compensation and/or a marked increase in the maxillary protrusive type of synergic relationship in many of the combination effects. Significantly, it is in the Class II *A* and Class III groups that most of the functional, operative compensatory mechanisms largely fail. Thus, the incidence of reciprocal compensation among the individuals of these two groups drops sharply or, at least, the occurrence of an undesirable type of synergic protrusive relationship increases markedly. The exceptions include those particular relationships involving, notably, the relative *horizontal ramus dimension*. The nature of the ramus-to-cranial floor dimensions (anatomical counterparts to each other) in relation to the nature of cranial floor alignment represents a compensatory feature that appears to be particularly prevalent among all classes and especially effective in the I *B*, I *A*, and II *B* groups. The angulation of the corpus also provides a greater or lesser degree of compensation in Class I and II individuals because of a high incidence of a downward aligned corpus relative to the ramus and the vertical *PM* (an effect produced by both the reciprocal and the synergic mandibular protrusion types of relationships). Paradoxically, this particular relationship slightly worsens a retrognathic type of profile even though an actual mandibular protrusive effect is produced with respect to the downward-rotated functional occlusal plane (see Fig. 1). The extent of any mandibular protrusive effect provided by such a downward corpus rotation, however, can be partially cancelled in some individuals by an upward rotational positioning of the occlusal plane itself to a less downward-inclined alignment, as seen in relationships 17, 19, and 21 above.

Corpus-occlusal compensatory relationships.

Three essentially different rotational sites are incorporated within the mandible as a whole: (1) the *ramus*, which can rotate upward and forward or downward and backward, (2) the *cor-*

pus, which can rotate either upward or downward (opening and closing the ramus-to-corpus angular junction), and



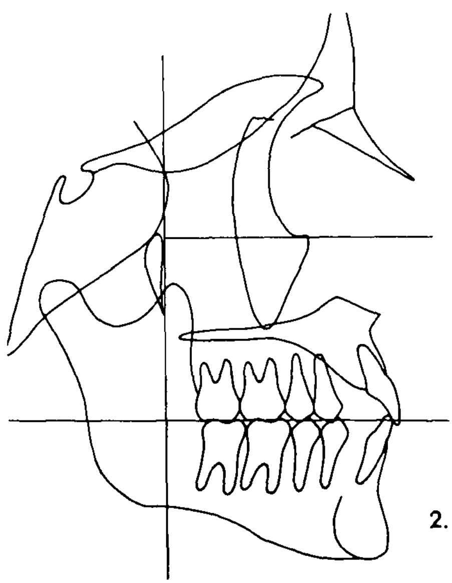
1.

Fig. 1 This diagram illustrates the basis for the opposite nature of protrusive effects produced by rotations of the ramus in contrast to rotations of the maxillary (a-b) and mandibular (c-d) bony and/or dental arches. A lengthening of the posterior, vertical part of the midface (*PM*) causes a direct downward and backward alignment of the ramus (*Ra*), as also seen in Figure 3. The axis of rotation is the mandibular condyle (*e*). The gonial angle (ramus-corpus angular junction, *e c d* and *e c' d"*) can remain constant. The resultant anatomical effect is mandibular retrusion. Note that mandibular point *d"* lies posteriorly to maxillary point *b'* relative to a perpendicular line (*g*) from the downward-rotated functional occlusal plane. Although not shown in this diagram, an opposite, forward rotation of the ramus has a corresponding mandibular protrusive anatomical effect.

If the mandibular *corpus* (*c-d*) and its *dental arch* rotate inferiorly at the ramus/corpus junction *(c)*, the resultant positioning of the corpus (*c d'*) has a mandibular protrusive effect relative to a line *(h)* perpendicular to the downward-rotated occlusal plane, even though a slight retrognathic effect is produced with respect to the over-all facial profile. An upward direction of rotation of the mandibular and maxillary bony and/or dental arches has an opposite, maxillary protrusive effect. These types of rotations are essentially independent of relative *PM* height, and they may occur in a number of combinations with different directions and extents of ramus rotations.

(3) the *dental arch,* which can undergo an independent upward or a downward rotation by an extrusion or intrusion of the anterior or posterior teeth. Significantly, a downward rotation of the ramus has an opposite protrusive effect to a downward rotation of either the corpus or the occlusion. In the former a maxillary protrusion (mandibular retrusion) effect is produced, while the latter both have a direct mandibular protrusion effect relative to the occlusal plane (Fig. 1). Note: The ramus-corpus angle normally decreases during growth in conjunction with the development of a progressively more upright ramus accompanying proportionate vertical nasomaxillary lengthening. The protrusive effects discussed in this report are the results of supplemental rotations that occur in addition to this growth change.

The rotational status of the ramus, using the condyle as a pivot, is directly dependent in a cause-and-effect relationship with the long or short nature of the relative *PM* (midface) vertical dimension (relationship 9 above). A "short" midface relative vertical length



2.

Fig. 2

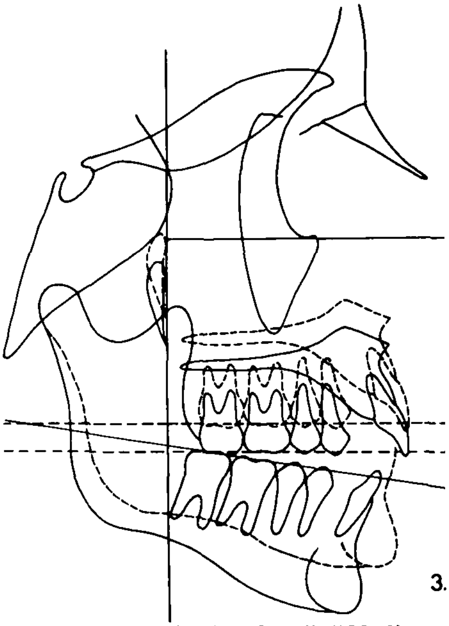


Fig. 3 A vertically "long" *PM* dimension, relative to the vertical, composite dimensions of the posterior part of the cranial floor and the ramus, produces a direct downward and backward alignment of the ramus. The axis of rotation is the mandibular condyle. Note that the mandibular occlusal plane has a resultant, downward-inclined alignment. The horizontal dashed lines are the neutral occlusal axes, before and after lengthening the *PM*.

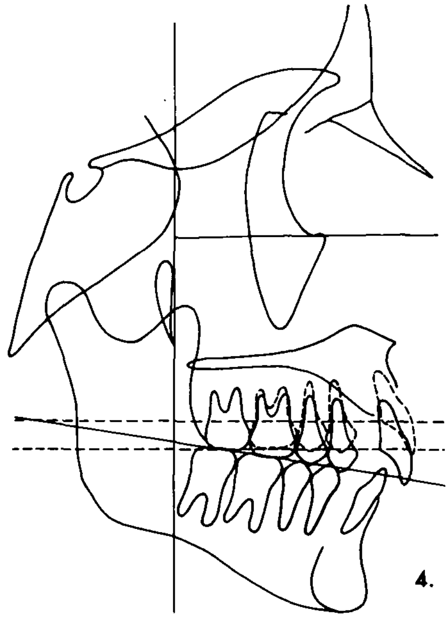


Fig. 4 In response to the circumstances shown in Figure 3, the maxillary teeth may erupt for a progressively increasing extent from back to front. A downward-aligned, closed occlusal contact line is produced. Note that the maxillary and mandibular incisors slightly overlap the functional occlusal plane to an approximately equal extent in this particular situation.

is associated with a consequent, more forward and upward ramus alignment. A "long" midface relative vertical length (and often a forward and downward rotation of *PCF* as well), conversely, is related to a more backward and downward alignment of the ramus. The alignment of the corpus, however, is essentially independent of relative *PM* height since about as many individuals have an upward as downward corpus rotation relative to either a long or short *PM* length (relationship 20 above).

Figure 2 illustrates the "neutral" alignment relationships among the maxillary and mandibular dental and skeletal arches.[2]

As the ramus rotates downward and backward, the corpus is necessarily also carried downward with or without any increase or opening of the gonial angle (Fig. 3). A downward-aligned corpus is thereby produced, but the direct cause is a rotation of the ramus at the condyle and not a rotation of the corpus. Or, in some individuals, the corpus itself can become rotated inferiorly, independently of the ramus. The mandibular occlusion, in either case, is also carried into such a downward-aligned position by the ramus and/or corpus rotation. If no corresponding occlusal rotational adjustments occur, it is apparent that a possible anterior open-bite situation is created. Either of two basic compensatory responses or, frequently, a com-

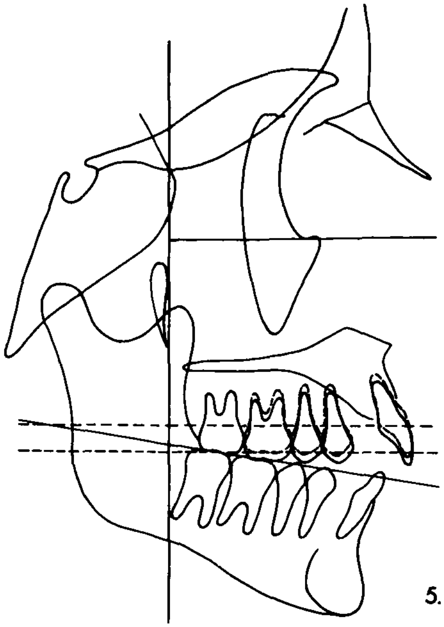


Fig. 5 In contrast to the adaptive adjustments seen in Figure 4, the eruption of the maxillary teeth in the middle and anterior spans of the arch can fall short of the sizable distances required for full occlusal closure. The intervening distance between the upper and lower dental arches is greater in the incisal region due to the downward-inclined angle of the mandibular arch. Note the curved nature of the maxillary occlusal contact line.

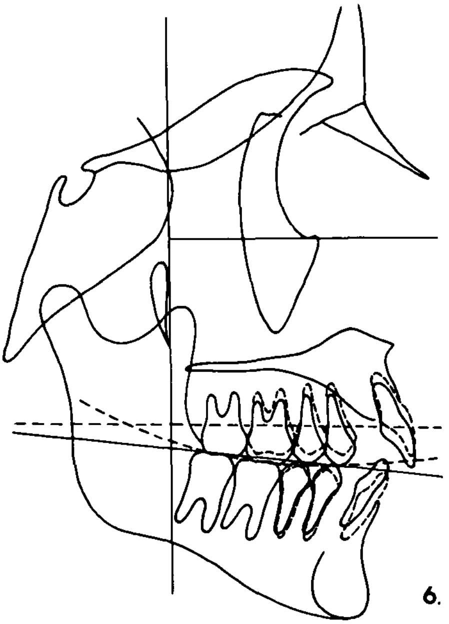


Fig. 6 In response to the relationships seen in Figure 5, the anterior mandibular teeth can erupt to close the occlusion. The edges of the maxillary incisors, which had fallen short of full eruption down to the mandibular occlusal plane, now lie above the resultant functional occlusal plane. The edges of the mandibular incisors, however, bypass this plane and thus lie well above the level of the mandibular molars and premolars. The maxillary-to-mandibular contact line has a characteristically curved appearance due to the partial extents of adaptive eruption by both the maxillary and mandibular anterior teeth to provide full-length closed occlusion.

bination of both can occur to maintain full-length closed occlusion.

First, the maxillary teeth can extrude and descend for a progressively increasing vertical distance from the posterior to the anterior ends of the arch. The posterior-most maxillary tooth remains in the same vertical position, but each succeeding tooth moves inferiorly for a greater distance until full-length occlusal contacts are made (Fig. 4). In this situation the maxillary and mandibular incisors slightly overlap the functional occlusal plane (a line drawn through the last molar occlusal contact point and the first premolar contact point) in an approximately equal manner similar to that seen if no downward ramus rotation had occurred (as in Fig. 2).

Second, the mandibular teeth can become extruded to a progressively increasing extent from the posterior to anterior ends of the arch until contact is made with each corresponding maxillary tooth. A vertically "long" alveolar region characterizes such individuals in the anterior portion of the mandibular corpus due to the upward direction of incisor positioning. A combination of these two adaptive processes (progressively increasing dental extrusion from posterior to anterior ends by both the maxillary and mandibular teeth) has been frequently encountered in our samples, and the consequent anatomical relationships are shown in changes from Figure 5 to Figure 6. In this instance the middle span of the maxillary teeth descends, as in the first type of adaptive response described above, but the progressively increasing extent of extrusion required for each subsequent tooth in the more anterior part of the maxillary arch falls short (Fig. 5). However, a progressive extrusion of the corresponding anterior mandibular teeth completes closure of the intervening distance to provide full-length occlusal contact. The result is a distinctive *curved* contact line from the posterior molars to the incisors, as seen in Figure 6. Note, however, that the incisal edges of the maxillary incisors stop well short of the straight-line *functional* occlusal plane, as defined above, but that the edges of the extruded mandibular incisors bypass this functional occlusal plane for a noticeable distance. The superior edges of the mandibular incisors thus lie well above the level of the mandibular molars and premolars.

Should the above adjustments not occur, an anterior open bite necessarily results. The maxillary teeth do not fully descend in a progressively increasing manner from back to front into occlusal contact, although a partial descent in a curved line often occurs as noted above. The anterior mandibular teeth, however, do not correspondingly rise to close the intervening distance.

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BIBLIOGRAPHY

1. Enlow, D. H., and R. E. Moyers, Growth and architecture of the face. *J. Am. Dent. Assoc.*, 82:763-774, 1971.
2. Enlow, D. H., T. Kuroda, and A. B. Lewis, The morphological and morphogenetic basis for craniofacial form and pattern. *Angle Orthodont.*, 41: 161-188, 1971.