The Morphological and Morphogenetic Basis for Craniofacial Form and Pattern

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This study is presented in two parts. The purpose of *Part I* is to describe the conceptual basis for an evaluation of headfilms utilizing actual growth and remodeling patterns rather than anatomically and developmentally arbitrary planes and angles. The objectives of *Part II* are (1) to apply this approach to an evaluation of individual persons independent of population standards, and (2) to utilize the resultant information in a study of the factors underlying structural patterns which characterize Class I, II, and III individuals.

PART I

Conceptual Basis

This study does not represent a conventional cephalometric "analysis," and the procedures do not parallel other, established systems of diagnosis or headfilm appraisal. Measurements, as such, are not utilized, and comparisons of individuals with population means or standards are not made. The purpose, rather, is to account for the individual combination of anatomical and developmental characteristics that have produced the craniofacial composite pattern in any given person. Most conventional methods of analysis, as well as cephalometric studies of growth, are intended essentially to determine *what* a particular craniofacial growth or form pattern is. The present procedure has been developed to explain *how* such a pattern was produced in a given person. Actual linear and angular measurements are irrelevant for this purpose since intrinsic skeletal relationships are determined and evaluated on the basis of the individual's own anatomical and growth circumstances and characteristics. Most conventional cephalometric planes and angles are not intended to coincide with or recognize the actual sites, centers, and fields of growth and remodeling and are thereby inappropriate and not usable for the present purpose. Since these planes and angles do not directly represent the patterns and distribution of growth fields, conventional methods of analysis ordinarily require a comparison of the individual with population standards because there is no other basis for interpretation due to the nature of the planes themselves. However, if planes are constructed in such a way that the activities of such growth and remodeling fields are in fact directly represented, a built-in and morphologically natural set of "standards" is identifiable which allows a meaningful evaluation of over-all craniofacial form and pattern without need for population comparisons. The reason is this. Most bones do not ordinarily grow as isolated, unrelated, independent units. When a given anatomical part enlarges, some other specific, collateral or geometrically comparable part or parts must also enlarge or become displaced in the same direction and to an equivalent, parallel extent if the same anatomical pattern and form balance is to be retained. If the bony maxillary arch lengthens, for example, the mandibular bony arch must also elongate to the same extent if the same direct, proportionate relationship between them is to be sustained. Many other pairs or sets of such anatomical counterparts exist throughout the skull. If any two of these architecturally correspondent parts should not enlarge to an equivalent degree relative to each other, a dimensional offset is then established between them, and the basis for a morphological form or pattern variation is thereby created. If the boundaries of the various sets of corresponding, co-equivalent, collateral anatomical and growth counterparts can be identified, the basis for meaningful *comparisons* becomes available. This makes possible a direct appraisal of the actual anatomical effects of their respective sizes and angular relationships. In this way the specific combinations of structure and growth that produce the composite, over-all anatomical pattern in any particular person can be accounted for and explained. Significantly, the major sites and fields of growth and remodeling mark these functional boundaries and also identify the important locations involving the displacement of whole bones away from each other as they all enlarge in an interrelated manner.

Of the many regional craniofacial growth and remodeling fields that exist, the particular sites and boundaries pertinent to the present study include (1) the maxillary tuberosity, (2) the mandibular condyle, (3) the posterior extremity of the mandibular corpus (ramus-corpus junction) and the anterior and posterior borders of the ramus, (4) the anterior surfaces of both the maxillary and mandibular bony arches, (5) the posterior part of the anterior cranial floor (that portion extending from *Ar* to *SE* in Figure 2-1), (6) the occlusal plane, including the composite effects of both alveolar and dental growth (the occlusal junction can be regarded as a specialized kind of movable articulation essentially comparable with other bone-to-bone junctions), and (7) the sphenoethmoidal junction together with continuous lateral sutures. The latter anatomically align with the nasomaxillary complex below and naturally divide the functionally separate anterior from the posterior portions of the anterior cranial floor and also mark the important anatomical boundary between the nasomaxillary region and the common area comprising the pharynx, posterior part of the cranial floor, and the ramus.

The vertical and horizontal spans between these various growth field boundaries are naturally arranged in such a manner that the growth and resultant dimensional effect of one given part relates directly to another specific, collateral part or parts. The occurrence of exactly equal growth additions between each part and its respective counterpart sustains a constant morphological pattern. Any growth differentials, however, become expressed as variations of structural pattern and can be determined and precisely located by direct comparisons of the growth changes among them. An evaluation of the effects of these major sites of growth, remodeling, and displacement provides morphological and morphogenetic information that is essentially comparable with some results obtained by the use of metallic implant markers. Our approach represents a "form and pattern" evaluation rather than an actual, conventional "cephalometric analysis." In a later part of the present report, this method of approach is applied to a detailed study of the developmental and structural basis for the craniofacial patterns characterizing Class I, II, and III malocclusions.

The distribution of growth fields throughout the skull is illustrated in Figure 1. These fields of growth involve the differential deposition and resorption of bone tissue that produce over-all craniofacial enlargement and, at the same time, provide the remodeling changes which are an integral part of this same growth process. The interrelated role of each of these fields in the

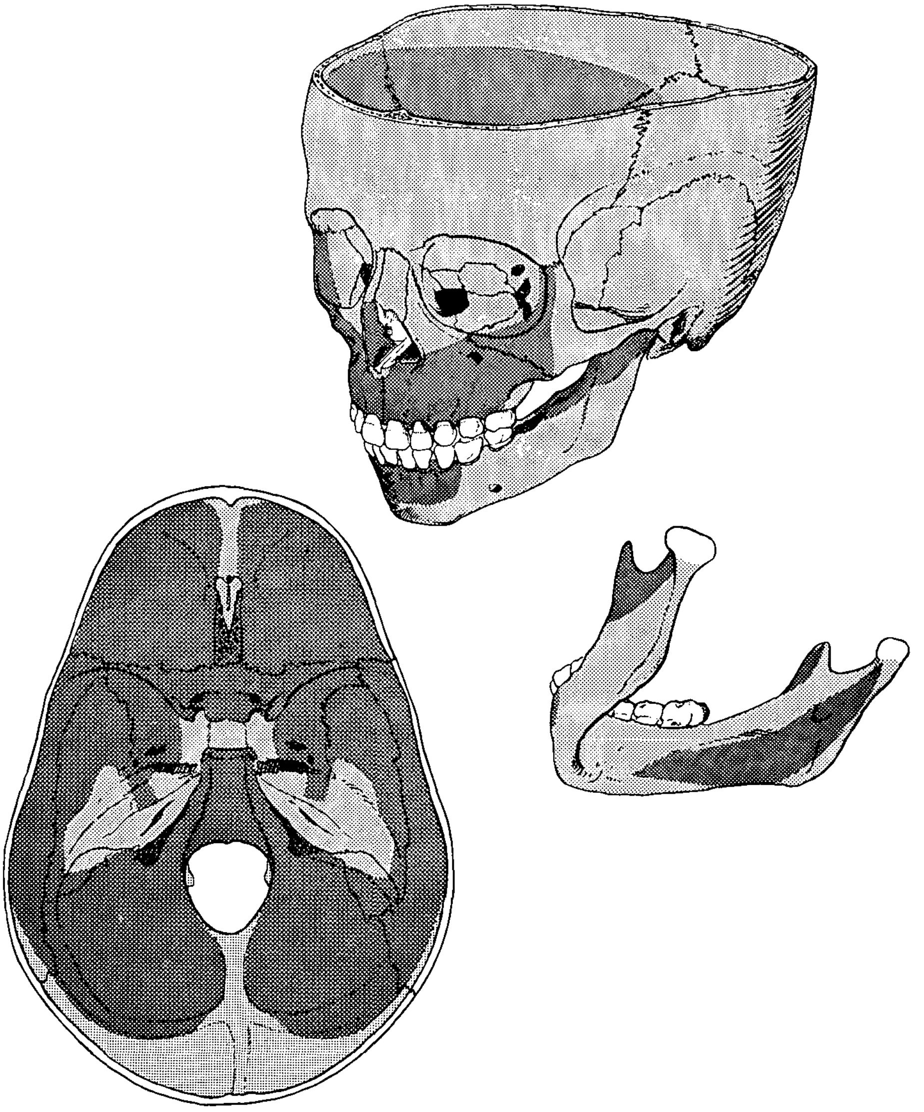


Fig. 1 The distribution of growth and remodeling fields is shown. Periosteal surfaces that are depository are represented by the light stipple pattern, and surfaces which are resorptive are indicated by dark stippling.

over-all, composite, three-dimensional pattern of craniofacial growth and remodeling has previously been described in detail.[4] These same processes have been described and interpreted in terms of static, two-dimensional headfilms.[6] Using block diagrams, an abbreviated model of cephalometric "planes" has also been developed which represents the direct effects of the various fields of growth.[6] The present study is a sequel to these previous reports. The purpose is to evaluate the results and effects of the complex growth processes in individual persons as produced by the actual fields of growth illustrated in Figure 1, and to acquire this information from headfilms without the use of implant markers or the need for microscopic study and vital staining of the actual bone tissues involved. The construction lines and planes used in Figure 2 were developed to express in a direct way the growth results produced by the particular growth fields listed in an earlier paragraph. These planes represent a simplified form of the basic craniofacial block diagrams previously used.[6]

Dimensions and the factor of alignment.

Two factors of a basic nature are important in determining the architectural role of a given bone or part of that bone within a composite assembly involving several separate bones: (1) the actual *dimensions* of that bone (horizontal and/or vertical), and (2) the relative *alignment* ("rotational" position) which directly affects the *expression* of actual dimensions and can either increase or decrease them. For example, if a skeletal part has an oblique alignment of 45°, a different alignment of that same bone to a more vertical position will increase the expression of its vertical dimension, but at the same time decrease the expression of the horizontal dimension, even though the actual overall anatomical length of the bone itself is the same. Similarly, an alignment in a more horizontal position will decrease the vertical but increase the horizontal expression of the actual anatomical dimensions. Such effects are passed on from bone to bone and can significantly affect the positioning and the relationships of other separate skeletal parts.

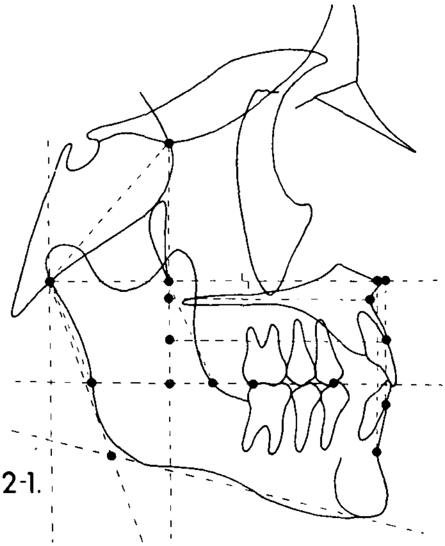
Rationale.

In the series of structural variation possibilities shown in Figure 2, each anatomical part (plane) is evaluated separately for, first, the effect of its actual dimension and second, the effect of its alignment position. The anatomical effects of each are analyzed as having (1) a maxillary protrusion effect, (2) a mandibular protrusion effect, or (3) a neutral effect. All dimensional and most alignment effects are determined solely by a comparison of each bony part with its various anatomical counterparts in that individual with no need for reference to population standards. One plane, representing the vertical maxilla (PM), is used as the base reference plane for evaluating all of the various alignment interrelationships and is thereby retained in a constant vertical position. The rotational status of the other planes is then determined relative to *PM*. Note: any of the planes utilized may be selected for this purpose with identical end results. However, the *PM* plane is used because it is approximately perpendicular to the line of vision, regardless of the rotational positions of the various other planes, and thereby represents a plane that is consistent with the anatomically "neutral" position of the head.

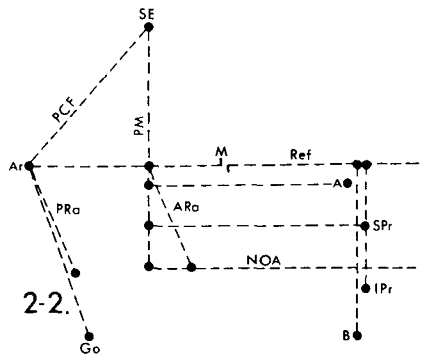
For the purpose of the present, essentially anatomical form and pattern study, numerical values for the dimensions and angular relationships involved are irrelevant, and any comparison of a bone's length in millimeters with a statistical standard is meaningless. The purpose is to determine simply whether any given bony part is vertically and horizontally "long" or "short" relative to its particular, correspondent counterpart, and whether it is aligned one way or the other within the composite skeletal assembly of that individual. This information, in turn, is used to determine how that bone contributes to the skeletal and dental basis for the Class I, II, or III status of that individual. The effects of the different regional dimensional and alignment variations schematized in Figure 2 are summarized below.

a. *Long maxillary arch* (skeletal and/or dental).

A maxillary protrusion effect is produced (Fig. 2a). Whether either arch is found to be "long" or "short" is en-



2-1.



2-2.

Fig. 2-1 This tracing shows the placement of construction lines; see accompanying Figure 2-2 for labels. All lines and points are averaged between right and left landmarks on headfilms. The vertical *PM* is the first line drawn. It extends inferiorly from a point (*SE*) located by the intersection of the shadows of the great wings of the sphenoid with the floor of the anterior cranial fossa (representing the boundary between the anterior and posterior portions of the anterior cranial base as well as the boundary between the anterior and middle endocranial fossae).[10] The *PM* line extends down from *SE* point through the inferior point of *PTM*. A second line is then drawn through articulare (*Ar*) parallel with *PM*. Another line is drawn perpendicular to *PM* through the posterior-inferior-most contact point of the last fully erupted maxillary molar and represents the neutral occlusal axis (*NOA*). The *functional occlusal plane* is then drawn and extends through the above-mentioned inferior and posterior-most molar contact point to the maxillary-mandibular first premolar occlusal contact point. The neutral occlusal axis and the functional occlusal plane exactly coincide in Figures 2-1 and 2-2. Note how they diverge, however, in Figures 3-8. A line is now drawn anteriorly from *Ar* parallel with the functional occlusal plane. This is a reference line (*Ref*) used to mark the horizontal mandibular dimensions. A line is drawn from *Ar* to *SE* and represents the effective posterior part of the cranial floor (*PCF*). Another line extends inferiorly from *Ar* to the constructed (not anatomical) gonion (*Go*). This is used to determine the alignment of the ramus. The ramus itself is represented by a line (*PRa*) from *Ar* to the posterior margin of the ramus where it intersects the functional occlusal plane, and another (*ARa*) from the intersection of the anterior ramus margin with the functional occlusal plane up to the reference line (*Ref*) parallel with *PRa*. Lines from Downs' *B* point and *IPr* are now extended to the reference line perpendicular to the functional occlusal plane. Maxillary horizontal dimensions are represented by lines from Downs' *A* point and *SPr* to the individual's own *PM* line (not the neutral, dashed *PM* line) parallel with the functional occlusal plane. Finally, the *neutral* positions of the upper and lower first molars (*M*) are projected to the reference line, as described on page 173.

Fig. 2-2 In this figure the basic construction lines are shown without the underlying headfilm tracing. These lines represent the model used to demonstrate the effects of alignment and dimensional variations as shown in Figures 2a-2j.

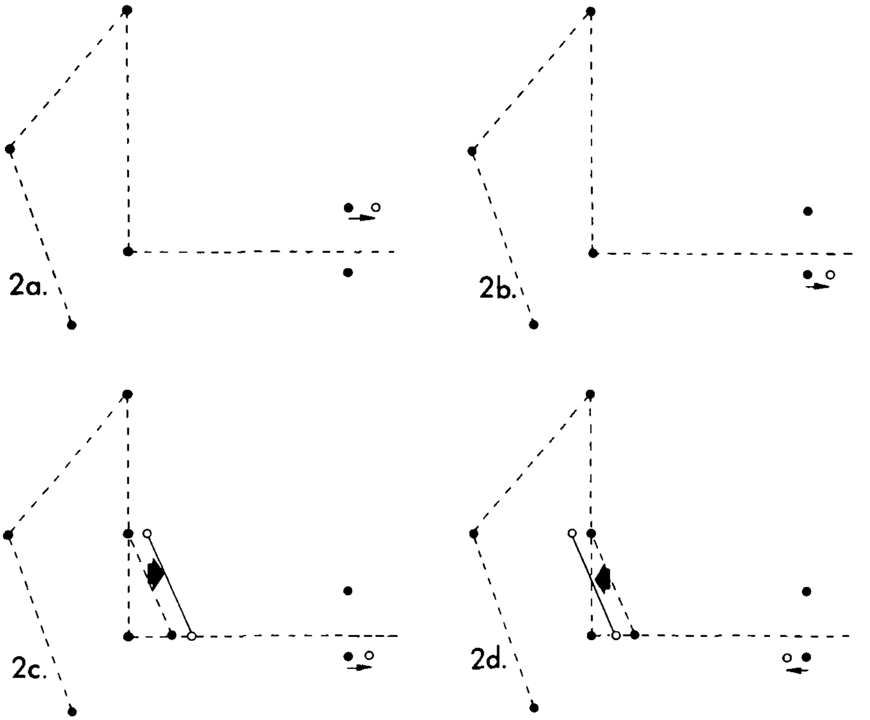


Fig. 2a Maxillary protrusion effect caused by a relatively "long" maxillary arch. *SPr* becomes displaced anteriorly beyond *IPr*. The actual growth, remodeling, and displacement processes which lead to this pattern, and those outlined below, are described in a separate report.[6] In diagrams 2a-2j, black *SPr-IPr* markers represent original positions, and white markers indicate altered positions.

Fig. 2b Mandibular protrusion effect caused by a relatively "long" mandibular corpus, with *IPr* becoming extended beyond *SPr*.

Fig. 2c Mandibular protrusion effect caused by a wide ramus relative to *PCF*. *IPr* becomes displaced anteriorly to *SPr*. The dashed lines represent original positions and solid lines altered positions (Fig. 2c-2j).

Fig. 2d Maxillary protrusion effect caused by a narrow ramus relative to *PCF*. *IPr* becomes located posteriorly to *SPr*.

tirely relative and is determined by a direct comparison of one arch to the other.

b. *Long mandibular arch* (skeletal and/ or dental).

A mandibular protrusion effect is produced (Fig. 2b).

c. *Long horizontal ramus or short horizontal PCF dimension* (*posterior part of the anterior cranial floor*). These two segments are counterparts, and their horizontal (not oblique) lengths are compared directly with each other (Fig. 2c). If the ramus is "long" relative to *PCF*, a mandibular protrusion effect exists. A skeletal basis for a Class III molar relationship is produced.[6] Note: the *PCF* dimension is intended to represent the lateral portions of the cranial floor overlying the mandibular condyle and not the mid-

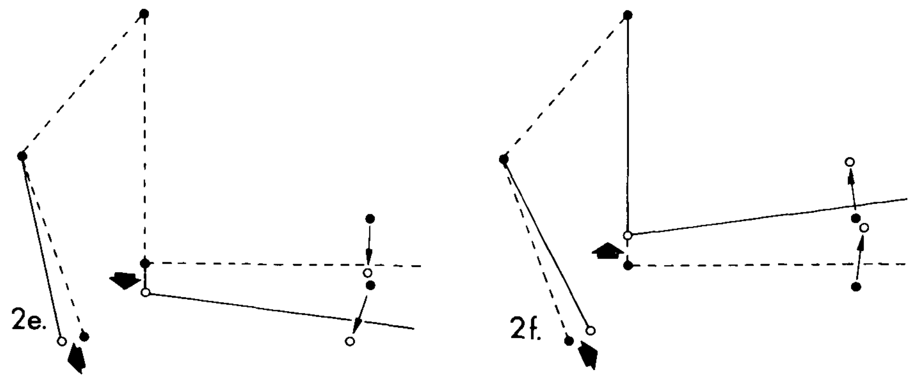


Fig. 2e Maxillary protrusion effect caused by a vertically long *PM*. This results in a downward and backward alignment of the ramus. Note also the downward rotation of the functional occlusal plane from the neutral occlusal axis. *SPr* now lies anterior to *IPr*.

Fig. 2f Mandibular protrusion effect caused by a relatively short vertical *PM*. This results in an upward and forward ramus rotation and, also, an upward occlusal rotation. *IPr* now lies anterior to *SPr*.

line spheno-occipital part. The relevant landmark point is actually *Ar* and not basion. Any cranial floor growth activity posterior to *Ar* has a common effect for the entire craniofacial complex anterior to the condyle. The particular segment between *Ar* and the nasomaxilla (and the contiguous anterior part of the cranial fossa overlying the maxilla) is the particular portion where growth effects of the posterior part of the cranial floor relative to the ramus are directly expressed. The condyle thus represents the key site of growth, remodeling and, importantly, displacement where the cranial floor, mandible, and also the zygomatic arch converge.

d. *Short horizontal ramus or long horizontal PCF dimension.*

A maxillary protrusion effect is produced, since *PCF* positions the nasomaxillary complex more anteriorly than does its counterpart, the ramus, position the mandibular corpus (Fig. 2d). The maxillary and mandibular arches are thereby displaced into offset positions with respect to each other even though their own relative dimensions can be equal. A skeletal basis for a Class II molar relationship now exists.

e. *Long vertical posterior nasomaxillary dimension or a short composite ramus/PCF vertical dimension.*

A maxillary protrusion effect is produced due to a consequent posterior rotation of the ramus, as described in *g* below (Fig. 2e). The vertical *PM* dimension necessarily includes the effect of the height of the mandibular as well as the maxillary posterior teeth,[6] since both are involved in contributing to any rotation of the ramus.

f. *Short vertical nasomaxillary dimension or a long composite ramus/PCF vertical dimension.*

A mandibular protrusion effect occurs due to a consequent forward alignment of the ramus (Fig. 2f).

g. *Posterior direction of ramus alignment.*

A maxillary protrusion effect is produced. The expression of the vertical length of the ramus is increased by a downward and backward rotation to accommodate a long *PM* (see Fig. 2e

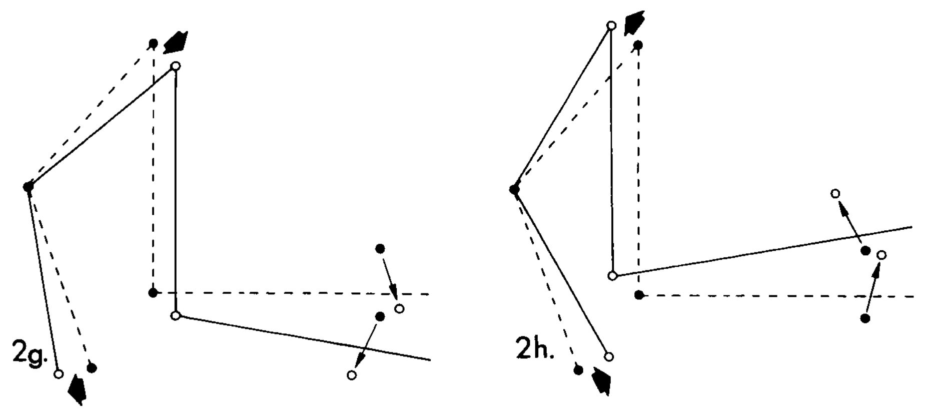


Fig. 2g Maxillary protrusion effect caused by a forward and downward alignment of *PCF* which carries *SPr* anteriorly. A backward ramus rotation is also produced which carries *IPr* posteriorly.

Fig. 2h Mandibular protrusion effect caused by a backward and upward alignment of *PCF* which carries *SPr* posteriorly. A forward rotation of the ramus carries *IPr* anteriorly.

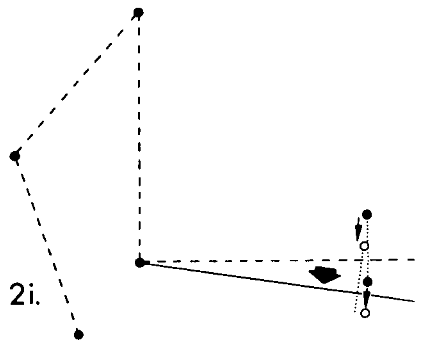
above) or a downward and forward *PCF* alignment (Fig. 2g). The expression of the horizontal ramus dimension is decreased at the same time, however, and thereby has a mandibular retrusion effect as a result of its more upright orientation. This also contributes to the skeletal basis for a Class II type of molar relationship. Note the consequent downward rotation of the corpus and functional occlusal plane.

h. *Anterior direction of ramus alignment.*

A mandibular protrusion effect occurs, and a skeletal basis for a Class III type of molar relationship is produced. The expression of the vertical length of the ramus is reduced to accommodate a "short" midface, which can be produced by a relatively short *PM* length (see Fig. 2f above) or by an upward alignment of *PCF* (Fig. 2h). The horizontal expression of the ramus dimension is increased because of its anterior direction of rotation. The occlusal plane may also become rotated in a superior manner.

i. *Downward alignment of the mandibular corpus and occlusion.*

A mandibular protrusion effect is produced (Fig. 2i). A skeletal basis for a Class III molar relationship also occurs due to the consequent offset positioning of the two dental arches. This alignment-rotation effect is independent of ramus rotation. Essentially, three different parts are involved in the rotational factors operative for the mandible as a whole: (1) the ramus, which is directly associated with relative *PM* height, (2) the corpus, and (3) the occlusion. The latter two are related to any adaptive adjustments in occlusal positioning required because of the nature of ramus alignment in conjunction with the vertical anterior and posterior over-all maxillary dimensions. Importantly, the effects of corpus and occlusal rotations are opposite to those produced by ramus rotation. Any one or all three factors may contribute to either an upward or downward composite direction of rotation of the functional occlusal plane. As seen in Figure 2i, a downward corpus/



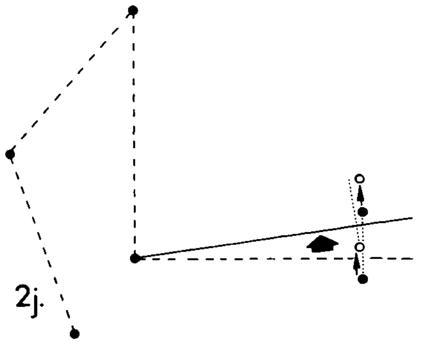


Fig. 2i Mandibular protrusion effect caused by a downward corpus-occlusal (not ramus) alignment. Because of different axes of rotation, *IPr* becomes anteriorly offset beyond *SPr* with reference to the occlusal plane (not the facial profile). Note that a downward ramus rotation has an opposite effect (Fig. 2e).

Fig. 2j Maxillary protrusion effect caused by an upward corpus-occlusal (not ramus) alignment. *SPr* becomes located anteriorly beyond *IPr* relative to the occlusal plane (not the facial profile). An upward ramus rotation has an opposite effect (Fig. 2f).

occlusion alignment independent of any ramus rotation alters the positioning of the mandibular arch in relation to the maxillary arch in a manner that produces direct mandibular protrusion due to the resultant offset between them. Note especially that this protrusive effect is relative to the downward-rotated occlusal plane; with reference to the vertical facial profile itself, the alignment between the two arches is unchanged. The whole mandible also becomes lengthened in actual dimension by opening the ramus/corpus angle. This increases the expression of the horizontal ramus dimension because it becomes placed in a more parallel position to the downward-rotated functional occlusal plane. The corpus and occlusal plane may rotate in conjunction with each other or they may rotate separately. That is, the corpus may rotate in an inferior direction, but the anterior teeth can erupt or become extruded so that the occlusal plane itself rotates in an opposite, superior direction. Various other combinations of corpus and occlusal rotations have been noted including posterior or anterior dental intrusions and the common formation of a curved occlusal plane. The latter is produced by a downward rotation of the ramus and corpus but with only a partial downward rotation of the anterior part of the maxillary occlusal plane in conjunction with an extrusion of the anterior mandibular teeth. The present study considers the composite result of any rotation of both the mandibular corpus and the functional occlusal plane.

j. *Upward alignment of the mandibular corpus and occlusion.*

A maxillary protrusion effect is produced relative to the occlusal plane, not the facial profile (Fig. 2j). The positioning of the mandibular arch relative to the maxillary arch is such that the maxilla becomes offset in an anterior direction with respect to the mandible, and a skeletal basis for a Class II type of molar relationship occurs. The over-all length of the mandible is also decreased due to the closing of the ramus-corpus angle.

These simple relationships may be visually demonstrated in the following manner. Hold together two pencils of the same length perpendicularly against a wall. When the pencils, representing the two arches, are rotated together in an upward manner using the wall contact point as a pivot, the top pencil becomes protruded. When rotated downward, the bottom pencil becomes protruded.

k. *Forward and downward alignment of PCF.*

A maxillary protrusion effect occurs and is produced by two basic but separate factors (Fig. 2g). First, a direct positioning of the nasomaxillary complex to a more anterior location is seen due to an increase in the expression of the horizontal *PCF* dimension relative to the horizontal dimension of the ramus. Thus, the posterior part of the cranial floor places the nasomaxilla in a more forward position than the ramus places the mandibular bony arch, thereby producing maxillary protrusion. Second, the nasomaxilla is lowered in relative position since the expression of the *PCF* vertical dimension is reduced. This has the effect of increasing the relative length of the vertical *PM* dimension which causes, in turn, a consequent posterior and downward rotation of the ramus. This has the direct effect of mandibular retrusion which thereby adds to the maxillary protrusion effect mentioned above (see 2g). All of these factors contribute to the skeletal basis for a Class II molar relationship.

l. *Backward (more upright) alignment of PCF.*

A mandibular protrusion effect occurs and a Class III type of molar relationship can be produced (Fig. 2h). First, the nasomaxillary complex is positioned more posteriorly due to a decreased expression of the horizontal *PCF* dimensions. Second, the vertical *PCF* expressed dimension is increased at the same time, thereby resulting in a decreased *PM* relative dimension. Or, more simply, the entire nasomaxilla is "raised and carried backward" due to the more vertical alignment of *PCF.* A forward rotation of the ramus then takes place that, in turn, produces a direct mandibular protrusion effect which materially adds to the over-all extent of maxillary retrusion.

It is apparent that the evaluation of *dimensions* in the present study is based on the nature of direct, comparative relationships between collateral, correspondent *counterpart* anatomical components. The actual length in millimeters of the maxillary arch, if considered by itself, is meaningless. A given individual's maxilla may be regarded as long by population standards but with respect to his own anatomical characteristics, a satisfactory maxillary-to-mandibular match can exist. The maxillary and mandibular arch-to-arch length *comparison* is the key relationship that is relevant and which is determined by this procedure. Similarly, the ramus-to-*PCF* horizontal (not oblique) dimensions are appraised relative to each other. The vertical *PM* is compared with the combined vertical ramus and *PCF* composite dimension. The basis for identifying just which anatomical parts are to be compared with each other is determined by the distribution of growth fields and the nature of the activities associated with them. If some given part within the whole craniofacial complex enlarges, *where* must an equivalent, parallel enlargement *also* take place in order to sustain a constant pattern within the over-all skeletal assembly? Whichever other correspondent part is directly involved is then singled out for a comparison of its growth, dimensional, and alignment characteristics. The arrangement of the major growth fields establishes the natural boundaries for these various parts, and this feature provides a basis for the appraisal of the anatomical effects of their relative growth, remodeling, and displacement activities in that individual. In making these comparisons, the sole objective is to determine if, in relation to each other, the resultant anatomical effects produced by respective dimensions and the influence of alignment on the expression of these dimensions are (1) neutral, i.e., in "balance" so that their parallel horizontal or vertical lengths precisely match with neither maxillary nor mandibular disproportionate protrusion produced; (2) maxillary protrusion; or (3) mandibular protrusion.

Wherever appropriate, dimensions are appraised both skeletally and dentally in order to compare and contrast the growth results relative to these two basic considerations.

It is important that all dimensions be compared and evaluated in "neutral" alignment positions in order to eliminate the effects of increasing or decreasing the expressed values of these dimensions due to any forward, backward, upward, or downward rotational positions. Therefore, construction lines representing each dimension are, first, placed in such neutral positions, and the dimension comparisons then made. Following this, the effect of the alignment status itself for each of the different bones in that particular individual is then determined. It is the composite of both the actual dimension and the alignment for each separate part that represents the final structural role of that part within the over-all craniofacial assembly. "Neutral" dimensions and alignment, it is emphasized, must be evaluated separately in order to determine the nature of the contributions for both factors independently.

Explanation of Relationships. The anatomical factors that underlie the various regional maxillary and mandibular protrusion effects were outlined in the preceding section and schematically illustrated in Figures 2a-2j. These selected relationships, as they are seen and analyzed in actual headfilms, are described and explained below. Maxillary protrusion effects are symbolized by a (+), and mandibular protrusion effects are indicated by a (—). If the effect of either the comparative dimensions or the alignment factor is slight or relatively moderate (up to 2.5 mm), it is indicated by a single (+) or (—). If the effect is more extreme (exceeding 2.5 mm), it is represented by a (+ +) or a (— —). The reason for including the latter designations is that some combinations of effects can have a more severe end result, particularly in extreme types of malocclusions, as will be pointed out. If any relationship is "neutral," with neither a maxillary nor mandibular protrusion effect present, it is represented by a (0).

An intermediate "Class I range" of relationships and effects is not identifiable as such between the Class II and III groups. The reason is that each variable has a direct (+) or (—), or much less frequently, a precise (0) effect, and different Class I individuals tend to demonstrate slight-to-extreme "Class II" effects for some relationships, but "Class III" types of effects for others. In most cases a typical Class I person has a combination of many offsetting (+) and (—) features. There is only a slight increase in the incidence of (0) effects among the Class I group. Class I individuals thus do not constitute an anatomically different group with their own unique and separate characteristics, but rather a group in which a greater or lesser degree of balance between contrasting Class II and Class III types of features occur.

1. *Aggregate cranial floor/maxilla compared with ramus/corpus horizontal dimensions at A and B points.* This comparison simply indicates whether the sum total of relationships 3-13 below have produced a cumulative aggregate length at maxillary *A* point that is shorter (—), equal to (0), or

longer (+) than the composite, overall length at mandibular *B* point.

2. *Aggregate cranial floor/maxilla and ramus/corpus horizontal dimensions at SPr and IPr.* This gives the same information as (1) above but utilizing superior and inferior prosthion. Relationships 3-13 below, which reveal the separate effects of the component parts, are now evaluated in order to account for and explain the anatomical basis for any given aggregate situation found at *A/B* and *SPr/IPr*.

3. *Cranial floor (PCF) and posterior maxillary (PM) relative alignment.* The *neutral* position of the *PCF/PM* angle in accompanying Figures 3-8 is shown by a dashed line, and the individual's own alignment is represented by a solid line. The neutral position used in the present study has been placed at 40.3°, as described below, and represents a relative standard to determine if an individual's *PCF* is aligned in either a forward or a backward manner from the neutral midpoint between extremes. A population mean has been determined for this particular value and is the only such population standard used. The reason is that the alignment of the cranial floor relative to *PM* is used as a starting point so that *intrinsic* alignment comparisons of all the other various parts can then be determined relative to it and to each other. Some other results in this study have been compared with and tested using population data, as will be described, but the actual manner of their determinations is based entirely on an individual's own particular intrinsic anatomical relationships.

The *PCF/PM* neutral reference value used was first approximated by observing the *PCF* alignment relationships in Class I individuals who have vertical and horizontal equivalent dimensions in good structural balance.[5] These individuals had a value of 40° to 41°. A more precise and meaningful "neutral" value was determined, however, by calculating the mean between the average value for 47 Class III and the average value for 118 Class II individuals in order to establish a "balance point" between the extremes. These values were 38.6° and 42.0°, respectively, and the mean is 40.3°, which is the figure that has been utilized as our neutral standard. Thus, a higher angular value in any given individual indicates a "Class II" (forward-rotated) direction of cranial floor alignment, and a lower value indicates a "Class III" (backward-rotated) direction.

The relationship is recorded as a (0) effect if this neutral *PCF* plane coincides with the individual's own *PCF*. If the individual's *PCF* is in a backward-aligned position, it is recorded as a mandibular protrusion (—) effect. If the individual's *PCF* is forward aligned, it is recorded as a maxillary protrusion (+) effect. If the dimensional effect of any alignment difference is up to 2.5 mm in either direction, as seen by the resultant difference between the positions of the individual's *PM* and the neutral *PM* lines, it is given a single (+) or (—) value, as appropriate. If the resultant effect (distance between the two *PM* lines) exceeds 2.5 mm, it is then given the more extreme (+ +) or (— —) value. Although numerical values in millimeters can be determined and recorded, if desired, for this as well as any of the other counterpart relationship effects considered, such measurements are not appropriate for the purpose of this study.

4. *Ramus alignment.* The "neutral" point as used in this study is the midpoint between *Ar* and the *PM neutral* (dashed) line at the level of gonion. If gonion lies anterior to this geometric midpoint, the posterior border of the ramus is then aligned so that it lies within the anterior portion of the span between the mandibular condyle and the maxillary tuberosity. Conversely, if gonion lies posterior to this point, the

ramus then occupies a corresponding backward-aligned or rotated position within the over-all distance from the condyle to the posterior maxillary tuberosity. This neutral alignment plane was tested against the "balance point between extremes" as represented by the mean between our Class II and Class III samples. The Class III and Class II average values were —2.3 mm and +3.5 mm, respectively, and the mean (population neutral point) is +0.6 mm from the geometric neutral point described above.

The position of the individual's own vertical ramus plane (*Ar* to *Go,* solid line), either anterior or posterior to the neutral plane (*Ar* to the geometric midpoint, dashed line), determines whether a relative maxillary or a mandibular protrusion effect thus exists. The extent of the effect is determined simply by noting the distance between these two oblique ramus planes where they intersect the functional occlusal plane. If the individual's ramus plane lies anterior to the neutral line, it is given a (—) or (— —) value, and if posterior to the neutral line a (+) or (+ +) value, depending on a ±2.5 mm distance between the lines where they intersect the functional occlusal plane.

5. *Ramus/PCF horizontal dimensions (skeletal).* The purpose is to evaluate the positioning of the bony maxillary arch by *PCF* in relation to the positioning of the mandibular bony arch by the ramus. Both the ramus and *PCF* bridge the common span from *Ar* to their respective arches. The distance between *Ar* and the ramus/corpus junction on the reference line extending anteriorly from *Ar* parallel with the functional occlusal plane (or simply, the width of the ramus from the posterior to the anterior border along the functional occlusal plane itself) is compared with the cranial floor dimension from *Ar* to the neutral (dashed) *PM* plane along the above-mentioned reference line. If the ramus is wider, it is recorded as a mandibular protrusion effect, and if it is more narrow, as a maxillary protrusion effect. If they exactly match, a neutral effect exists. This comparative dimensional relationship was also tested, using actual linear measurements, against the "balance point" between Class II and Class III average values. The mean value between them is +0.2 mm from a perfect neutral (0) match.

With regard to both the ramus and the posterior part of the cranial floor, two variable relationships are thus determined: (1) the comparative dimensions in neutral rotation positions, and (2) the effect of rotations (alignment) as either increasing or decreasing the expression of these actual dimensions.

6. *Ramus/PCF horizontal dimensions (dental).* The positions of the posterior edges of the maxillary and mandibular first molars are first corrected to neutral positions by adding or subtracting, as appropriate, the extent of (—) or (+) effects of *PCF* alignment for the maxillary molar and *Ra* alignment for the mandibular molar. The resulting positions, *M,* Figure 2-2, then represent the "neutral" molar positions with posterior skeletal rotation effects removed. The distance from *Ar* to this neutral maxillary molar edge is then compared with the distance from *Ar* to the neutral mandibular molar edge on the reference line extending anteriorly from *Ar* parallel to the functional occlusal plane. This is recorded as a neutral, maxillary protrusion, or mandibular protrusion effect, as appropriate. It is noted that a (—) position is normal, since the mandibular molar position should be anteriorly offset relative to the maxillary molar. A (0) value is regarded as an actual maxillary protrusion relationship for this particular comparison.

7. *Molar positions (composite).* The

positions of the maxillary and mandibular molars including the effects of cranial floor and ramus alignment are also determined. This is done by measuring any distance between their respective posterior edges without the the skeletal rotation corrections to neutral positions as described above. The result merely indicates the conventional "molar relationship" as customarily determined. A normal relationship has a (—) value due to the anterior offset of the mandibular molar. Reasons for the inclusion of this relationship are discussed in later sections.

8. *Maxillary/mandibular arches, skeletal dimensions, A point compared with B point.* The distance from *A* to the individual's own *PM* line (*not* the neutral *PM*) parallel with the functional occlusal plane is compared with the distance from *B* to the ramus/corpus junction (intersection of *ARa* and *Ref*). The relationship is recorded as neutral, a maxillary protrusion, or a mandibular protrusion effect, as appropriate for that individual.

9. *Maxillary/mandibular arches, dental dimensions, A point compared with B* point. The distance from *A* point to the posterior edge of the maxillary first molar is compared with the distance from *B* point to the posterior edge of the mandibular first molar, and the neutral, maxillary, or mandibular protrusion effect of this comparative relationship noted and recorded.

10. *Maxillary/mandibular arches, skeletal dimensions, SPr compared with IPr.* The procedure described in 8 above is repeated using superior and inferior prosthion rather than *A* and *B* points.

11. *Maxillary/mandibular arches, dental dimensions, SPr compared with IPr.* The procedure described in 9 above is repeated substituting superior and inferior prosthion.

12. *PM as compared with ramus/PCF vertical dimensions.* The relative vertical length of *PM* is determined simply by comparing the direction and the extent of *PCF* rotation with the direction and extent of ramus rotation. If both the directions and the extent of each are the same, the *PM* is thereby neutral (0) in vertical length. If a downward and backward ramus rotation and its consequent dimensional effect is greater than any forward and downward *PCF* rotation, however, the *PM* is vertically "long," and this has caused the greater resultant ramus rotation. It is given either a (+) or (+ +) value as determined by the difference in the extent of their respective effects (see following paragraph). If a forward and downward *PCF* rotation exceeds the extent of downward ramus rotation, a vertically "short" *PM* is present, and a (—) or (— —) value is given as determined by the difference in the extent of their respective effects. Note: these relationships indicate relative lengths of the cranial floor, ramus, and the nasomaxilla within that particular individual. This is a different consideration from any population tendency toward a vertically long or short midface as seen in various ethnic or family groups. An individual may have a vertical nasomaxillary region that is quite long, but relative to his own cranial base and ramus, it may be neutral in length or actually short, as will be seen. If an upward *PCF* rotation is greater than an upward ramus rotation, the *PM* relative dimension is long and thus is given a (+) or (+ +) value since a maxillary protrusion effect is produced. If an upward and backward *PCF* alignment is less than any upward ramus rotation, the *PM* is short as a relative dimension and has a mandibular protrusion (—) or (— —) effect. The amounts for either of the above are determined by noting the difference in their respective extents. If an upward *PCF* alignment occurs in conjunction with a downward ramus rotation, the

PM is long and the amount of the consequent maxillary protrusion effect (+ or + +) is determined by adding their respective values. If downward *PCF* and upward ramus rotations exist, the *PM* is short as a relative dimension, and the values are added to determine the extent (— or — —) of the resultant effect.

In all of the above combinations the direction of *PCF* alignment is determined by noting whether the solid *PCF* line is forward of the neutral (dashed) *PCF* line to produce a (+) effect, or behind it to give a (—) effect. The consequent extent of the effect is determined by noting the distance between the solid and dashed *PM* lines. The direction of ramus alignment is determined by noting whether the solid *PRa* line is posterior to the dashed (neutral) *PRa* line to give a (+) effect, or anteriorly to result in a (—) effect. The consequent extent of the effect is determined by noting the distance between these two oblique lines where they intersect the functional occlusal plane.

A backward or forward ramus alignment can also produce a direct upward or downward occlusal plane alignment. However, this relationship cannot always be utilized to evaluate the relative nature of the *PM* vertical dimension since an independent corpus and occlusal rotation may also occur, as described below.

13. *Corpus-occlusal alignment.* A dashed line perpendicular to *PM* is used as a "neutral occlusal axis." This is not intended to represent a "normal" occlusal plane but is utilized solely as a constant reference line to evaluate the direction and the extent of any occlusal rotation in a given individual. The purpose is to identify separately any occlusal and corpus rotation that has occurred in addition to that produced directly by the ramus. To do this, the direction and the extent of ramus rotation, either forward or backward, is compared with the direction and the extent of rotation between the neutral and functional occlusal planes. If the two have rotated equally in the same direction, the occlusal/corpus rotation is neutral (0). This is a frequently encountered situation. Any differential between them, however, which involves an upward rotation of the corpus/occlusal plane *relative* to the ramus rotation (as in a closing of the gonial angle and/or an extrusion of the anterior mandibular teeth) results in a maxillary protrusion effect (+). A differential which involves a downward corpus/occlusion rotation relative to the ramus rotation (as in an opening of the gonial angle and/or an extrusion of the posterior mandibular teeth) produces a mandibular protrusion (—) effect.

Part II

Incidence and Distribution of Maxillary and Mandibular Protrusion Effects among Class I, II, and III Individuals.

A series of headfilms representing 137 Class I, 118 Class II, and 47 Class III *untreated* individuals at various ages has been analyzed according to the (1) dimension and (2) alignment factors and their respective effects, as described in the preceding section. The results are summarized in Tables I and II. It has been found useful to group both the Class I and Class II individuals into two basic categories each: those with a protrusive maxillary *A* point relative to *B* point, as projected to the functional occlusal plane, and those with a protrusive mandibular *B* point relative to *A* point. These will be referred to as Class I types A and B, and Class II types A and B, respectively. Significant and basically different skeletal and dental relationships and characteristics have been noted in these essentially different craniofacial types.

1. *Aggregate cranial floor/maxilla and ramus/corpus horizontal dimen-*

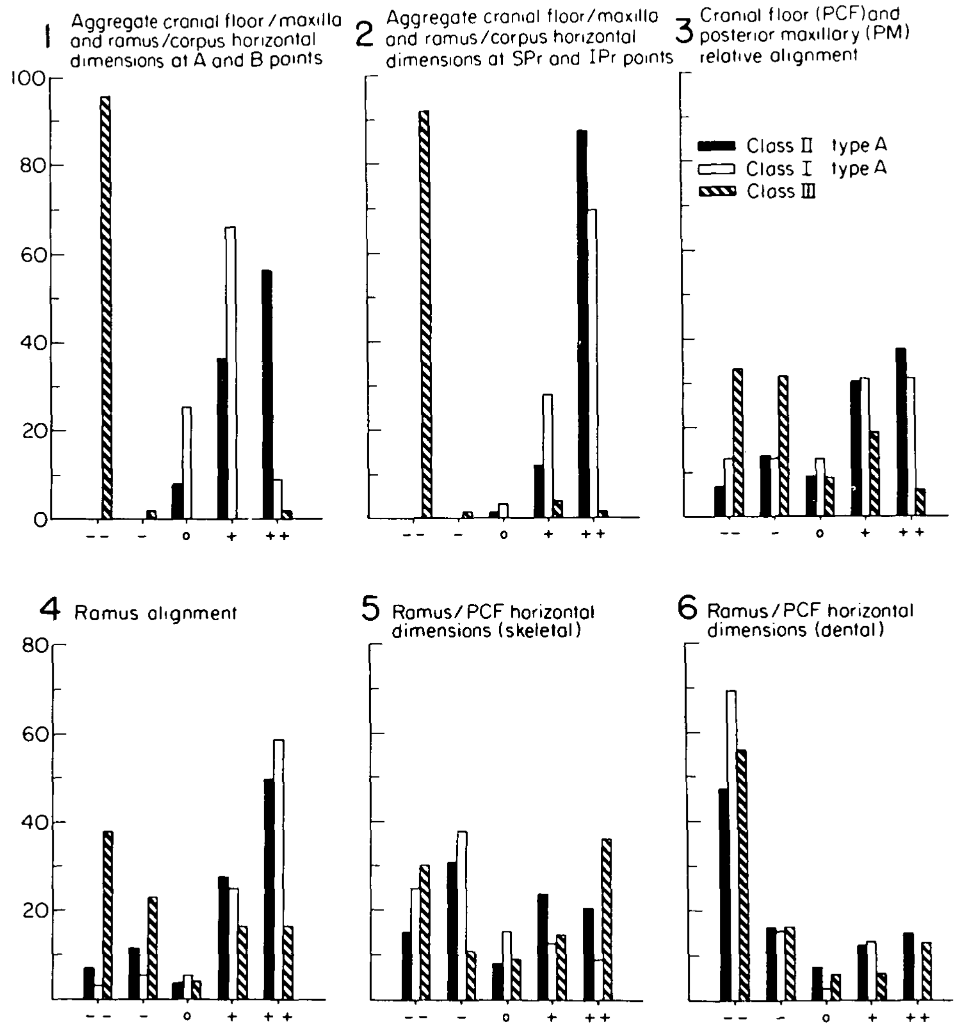


TABLE I
Percentage distributions for anatomical relationships among Class I A, II A, and III individuals.

sions at A and B points. The purpose of this determination (and 2 below) is simply to demonstrate the summation of the composite effects and results of all the regional dimensional and alignment effects described in 3-13 below. Class III individuals, of course, show a protrusive *B* point, and most Class II and I type A individuals show a protrusive *A* point (a few have a (0) value). The Class I and II type B individuals, by definition, have a protrusive mandibular *B* point. An evaluation of all the interrelated, cumulative relationships described below is intended to explain the morphologic basis for these characteristic patterns.

2. *Aggregate cranial floor/maxilla and ramus/corpus horizontal dimensions at SPr and IPr.* Like 1 above, this determination shows the composite effects of all the regional variables described in the following paragraphs as seen at superior and inferior prosthion.

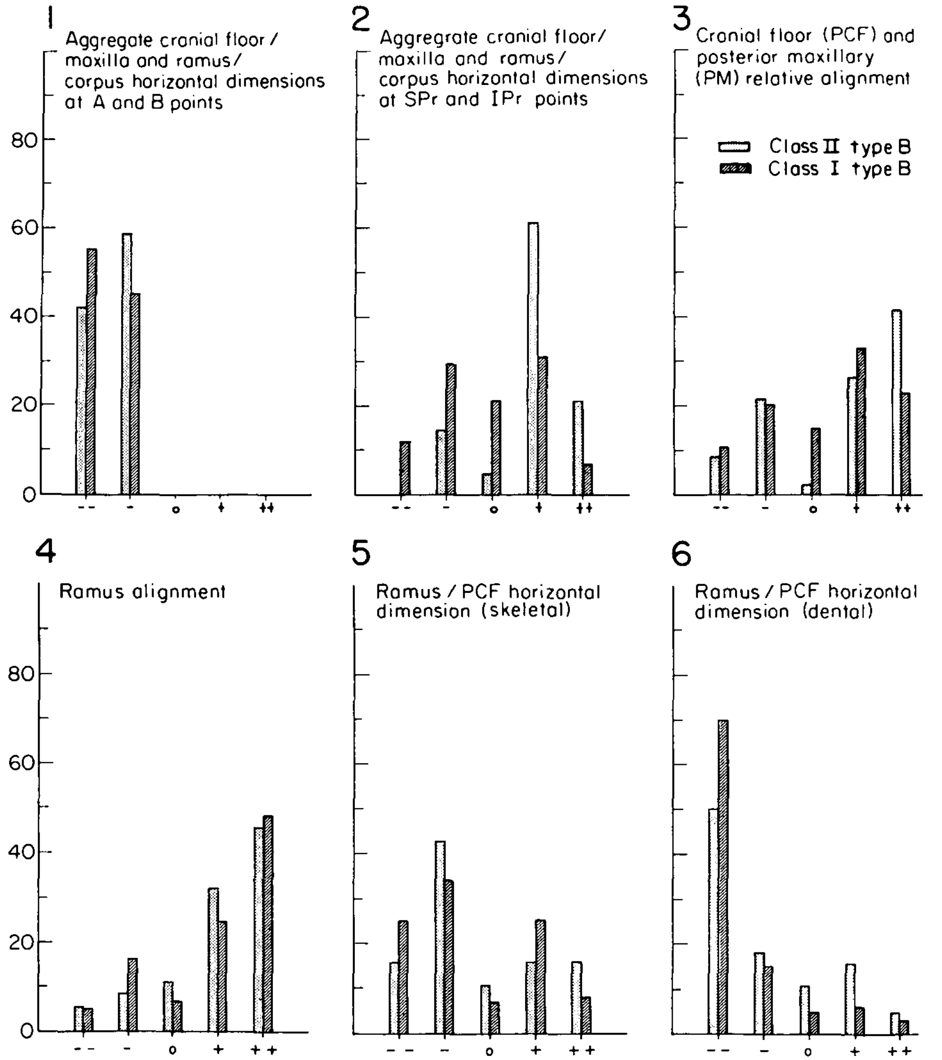


TABLE II
Percentage distributions for anatomical relationships among Class I B and II B individuals.

The Class III group is protrusive at *IPr*, and both the Class II and Class I type A individuals are protrusive at *SPr*. The Class I type B, however, shows a much less prominent distribution (37%) of *SPr* protrusion, with 42% having an *IPr* protrusion. Significantly, in the Class II type B, although 82% have some degree of *SPr* protrusion, the number of extreme cases (+ +) is much less than the Class II type A group. Thus, in a Class II individual that has an *A/B* relationship in which *B* point tends to protrude beyond *A* point, the anatomical severity of any malocclusion present is likely to be much less marked. Severe *SPr/IPr* relationships in the Class II B number only 21% as compared with 87% in the II A. It is also interesting to note that in the Class II B group about 13% have a mandibular prosthion (*IPr*) that actually protrudes anteriorly beyond maxillary prosthion. In this situation a labial tipping and a protrusion of the maxillary incisors occurs due to a displacement effect caused by the more forward placement of the mandible and its incisors. It is apparent that a basic difference exists between the A and B types of Class II, since the B group has an actual underlying Class III character, any molar relationship or maxillary incisor protrusion not withstanding.

3. *PCF/PM alignment.* The Class III group distribution has 66% with a mandibular protrusion effect with regard to this relationship, and only 25% have an opposite maxillary protrusion type of effect. This illustrates the tendency toward a cranial floor alignment that contributes, to a greater or lesser extent in different individuals, to the causative basis for Class III skeletal and occlusal characteristics. In contrast, the nature of cranial floor alignment among Class II individuals (both A and B types) shows a high percentage (70% and 68%) with a contributing maxillary protrusion type of relationship. Together with the vertical *PM* and ramus rotation tendencies, the "Class II" type of cranial floor alignment also contributes to the long midface characteristic of many Class II persons, in contrast to a short midface appearance and overbite associated with many Class III individuals. This is because the factor of cranial floor alignment increases or decreases the effective height of the nasomaxillary region (see Figures 2g and 2h). Interestingly, both the two Class I groups have a Class II tendency with regard to cranial floor alignment. Note the similarity of their (+) and (—) distribution with the Class II's in the accompanying tables.

4. *Ramus alignment.* The Class III group has 62% of the individuals with a forward-aligned ramus (mandibular protrusive effect) and, in contrast, 34% with a backward-aligned ramus. Conversely, the Class II A and B groups have a high distribution of individuals (78% and 76%, respectively) with a backward-aligned (maxillary protrusive) ramus. Like the cranial floor feature, the Class I A and B individuals also show a distinct Class II tendency with regard to ramus alignment. Note the similarity between the Class I and II percentage distributions in the accompanying tables.

5. *Ramus/PCF horizontal dimension relationship (skeletal).* The Class I individuals, both A and B types, show a trend toward a mandibular-protrusive (wide) ramus relative to the cranial floor (63% wide to 22% narrow, and 59% wide to 33% narrow, respectively). Percentage distribution tendencies are much less apparent in the Class II and III distributions. However, a significant finding is that a reciprocal relationship exists among all the Class I, II, and III groups between this ramus/cranial floor relative dimension and the cranial floor alignment effect. This indicates a counteraction and adjusting effect in which a forward-aligned (+) cranial floor is at least partially offset or compensated by a wider ramus (—), and a backward-aligned cranial floor (—) is at least in part compensated by a more narrow ramus (+). A separate report describing these and other specific compensatory anatomical effects is being presented as a sequel to the present study.[7]

6. *Ramus/PCF horizontal dimension relationship (dental).* This reveals the ramus-to-cranial floor relative widths as measured dentally after the effects of ramus and cranial floor rotations have been eliminated from the anatomical placement of the mandibular and maxillary bony arches. It is apparent (Tables I and II) that all classes have a similar percentage distribution. Note particularly that the Class II A is very similar to the Class II B. Compare with relationship 7 below, how-

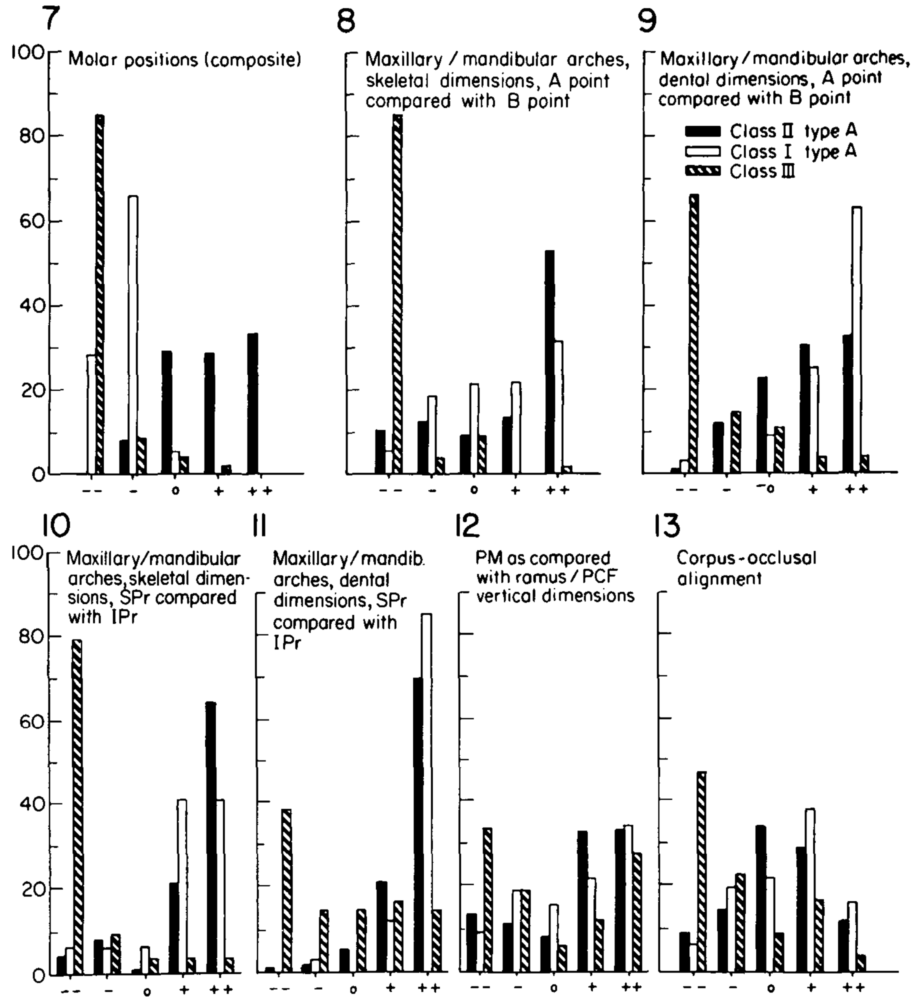


TABLE I (continued)
Percentage distributions for anatomical relationships among Class I A, II A, and III individuals.

ever, which describes the conventional molar relationship and which does include the effects of cranial floor and ramus rotations. In relationship 7, 29% more individuals have severe (++) maxillary protrusion for the Class II A individuals than the Class II B group. In the Class II B's, more individuals have a neutral or a mandibular protrusion tendency. This demonstrates that the alignment of the cranial floor posterior to the maxilla and the rotation of the ramus are both important factors which are operative in contributing to a Class II molar relationship as well as the more severe nature of malocclusions in the Class II A group.

7. *Molar positions (composite).* The histograms show the conventional "molar relationship" as it exists in the headfilm with no correction for cranial floor and ramus alignment effects. Except for the observations noted above with respect to differences between Class II A and B individuals, the nature of distribution for this particular relationship

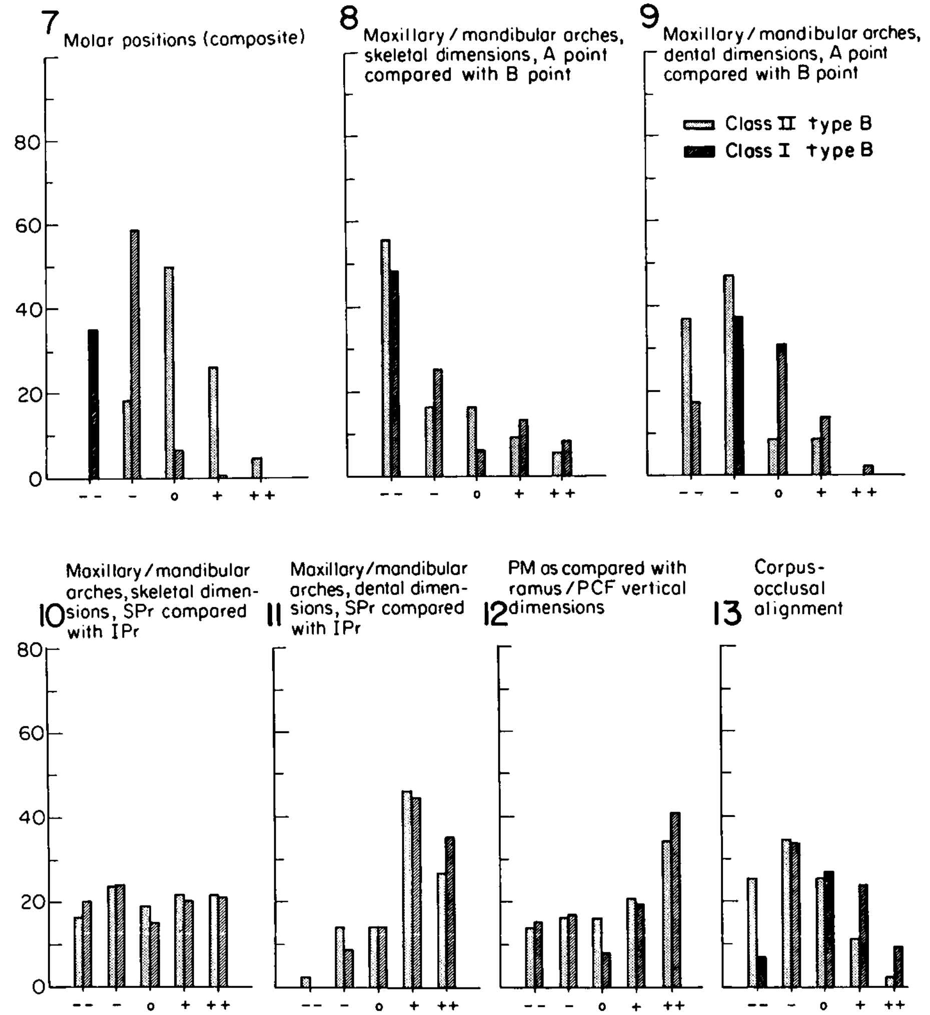


TABLE II (continued)
Percentage distributions for anatomical relationships among Class I B and II B individuals.

is used only as an aid in distinguishing the three classes according to conventional standards. It has little direct meaning since this relationship merely shows a resultant characteristic produced by the composite of many other regional factors accounted for in the various separate relationships considered.

8. *Maxillary/mandibular arches, skeletal, A point compared with B point.* The distribution tables show a high percentage of Class II type A individuals with a "long" maxillary bony arch relative to the mandibular corpus, and a high percentage of Class III persons with a long mandibular corpus relative to the bony maxillary arch. Significantly, the Class II type B group has a strong tendency toward a long mandibular corpus as measured at *B* point relative to *A* point. Note especially that the Class I A and Class II A show a marked similarity with

each other in their respective distribution patterns, as do the Class I B and II B groups.

9. *Maxillary/mandibular arches, dental, A point compared with B point.* These dental arch comparisons are essentially similar in distribution to the skeletal arch relationships described in 8 above. The Class III group has a high percentage with a long mandibular dental arch as compared with the maxillary dental arch (as measured at *A* and *B* points, not prosthion). Conversely, both the Class II *A* and Class I *A* individuals have a high percentage with a longer maxillary dental arch as compared with the mandibular dental arch. In contrast, however, both the Class II *B* and Class I *B* groups have an opposite relationship in which a much higher percentage of individuals have a mandibular dental arch that exceeds the length of the maxillary dental arch.

10. *Maxillary/mandibular arches skeletal, SPr compared with IPr.* Like the relationships just described, the skeletal arch length comparisons between the maxilla and mandible at superior and inferior prosthion show a high percentage of long mandibular arches in the Class III's and long maxillary arches among the Class II A and I A. However, in the Class II B and Class I B groups, about as many had long mandibular arches as had a long maxillary arch, a feature that follows the B type character with respect to many of the other regional variables described in this report.

11. *Maxillary/mandibular arches, dental, SPr compared with IPr.* In the Class III group the tendency toward a long mandibular dental arch relative to the maxillary dental arch as measured at superior and inferior prosthion is somewhat less marked than the skeletal arch relationship seen above (53% long to 32% short dentally as compared with 87% long to 9% short skeletally). Among the Class II A and B as well as Class I A and B individuals, however, a marked tendency toward a long maxillary dental arch relative to the mandibular dental arch exists.

This suggests that relative dental arch length, in itself, is less significant in contributing to the Class III than to the Class II type of composite craniofacial pattern. Also, when comparing dental arch lengths at *A* to *B* and *SPr* to *IPr,* the *A/B* relationship shows a higher percentage with a relatively longer mandibular arch than does the *SPr/IPr* relationship. This can be based on the upright or lingually tipped nature of the lower incisors together with a labial inclination of the uppers among some Class III individuals. If the distribution of the Class I B group is compared with 2 above, which shows the aggregate effects of all dimensional and alignment relationships, note that the effect of a "long" maxillary dental arch, as measured at *SPr,* is much reduced due to the cumulative effects of the various other factors.

12. *PM as compared with ramus-PCF vertical relationships.* In all Class II and I groups, a tendency toward a "long" vertical *PM* exists. This is directly associated with a high percentage having a downward and backward alignment of the ramus in these same groups. Among the Class III individuals a trend toward a "short" *PM* vertical relationship occurs, although somewhat less marked than the opposite tendency among the other groups. Interestingly, all groups except, significantly, the Class II A show a high percentage having a reciprocal relationship between *PM/PCF* alignment (the direction of cranial floor-to-maxillary "rotation") and the relative vertical length of the midface. As will be described in a separate report,[7] this indicates an adjusting or compensatory relationship between these two variables, just as it did between the *PCF*/ramus relative

dimensions. Thus, if the cranial floor has a forward and downward alignment, the vertical *PM* dimension, although actually long in relative length, has a tendency to be "less" long, thereby in part, at least, offsetting the effect of the rotation involved. Conversely, if the cranial floor has a more upward and backward alignment, the vertical midface length can be somewhat longer although still actually short in relative length, thus partially adapting to the particular rotation situation present.

13. *Corpus and occlusal alignment.* The Class III individuals have a high percentage with a mandibular protrusion effect (70% with a downward and 21% with an upward alignment). The Class II A and I A groups each have about a 2:1 ratio for a maxillary protrusion effect. The Class II B individuals, in contrast, have a 61% to 13% distribution for a mandibular protrusive effect. The Class I B group has about 60% falling within the neutral to slight mandibular protrusion range.

Discussion

The distribution of maxillary versus mandibular protrusion effects with regard to the basic regional anatomical relationships considered in this study show that the Class III and the Class II type A individuals have distinctly different and essentially converse underlying pattern combinations. With the exception of the horizontal ramus-to-cranial floor relative dimensions and in some cases the *PM* dimension, most other regional relationships have clear-cut characteristics which contribute to mandibular prognathism among Class III's and maxillary protrusion among Class II A's.

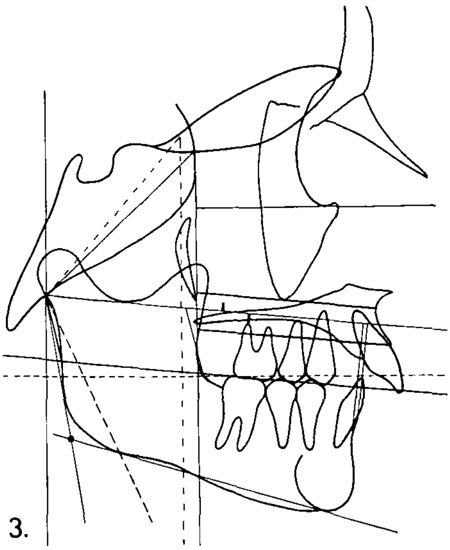
The Class II A and Class I A groups are quite similar in the basic nature of their population distributions for the various anatomical relationships. Most of the regional relationships described in the previous section have a definite "Class II" character among most Class I A individuals, and these contribute to an underlying, composite tendency toward maxillary protrusion.

The Class II B and I B groups are also quite similar to each other in the basic character of their craniofacial form and pattern. Both share a number of distinctive mandibular-protrusion features that combine with some other maxillary-protrusion characteristics. The Class II B individuals tend to have a much less severe extent of composite maxillary protrusion than do those in the Class II A group. Indeed, some individuals may lack maxillary protrusion altogether even though classified on the basis of molar relationship or incisal alignment as a so-called Class II. In both the Class I B and Class II B, an actual underlying "Class III" disposition exists for many of the regional anatomical relationships.

The A type is the most frequent among the Class II group, and the B type is more common among Class I's. In our sample the A type numbered 86 out of a total of 118 Class II's, and the B type, 105 out of a total of 137 Class I's.

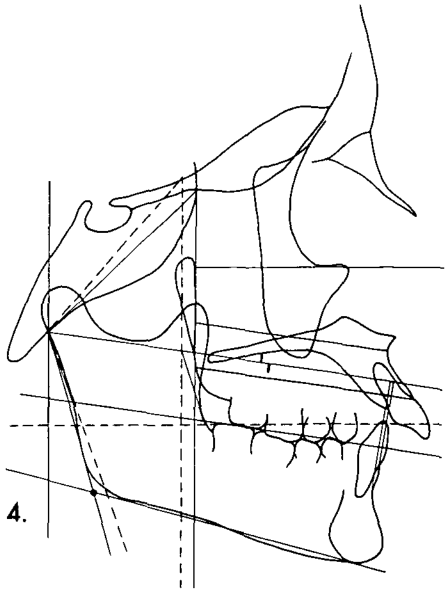
The difference between the Class II A and the Class I A is essentially quantitative, since the underlying nature of their respective morphologic patterns is basically the same. The Class I A individuals are either less extreme for some of the regional relationships, or they have a somewhat greater number of offsetting (mandibular-protrusion) effects in a particular individual, especially in skeletal arch lengths and horizontal ramus dimensions.

The distinction between the Class II B and Class I B groups is based primarily on the nature of offsetting combinations among the various maxillary and mandibular protrusion effects in individual persons. There is little actual difference between them in terms of percentage distributions for most of the



3.

Fig. 3 Individual 1, Class II, type A. In Figures 3-8, "neutral" alignment positions are indicated by dashed lines, and the individual's own alignment positions are represented by solid lines.



4.

Fig. 4 Individual 2, Class II, type B.

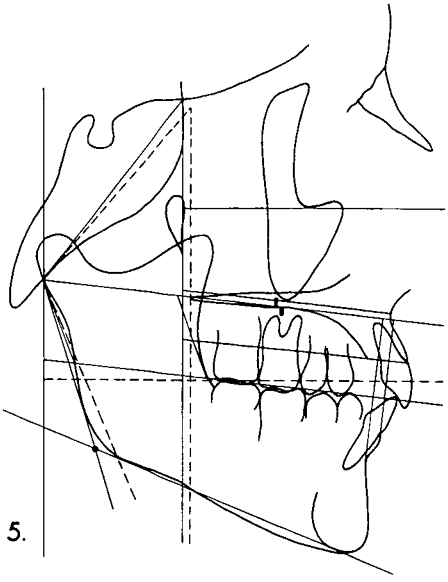
various anatomical relationships. In the Class II B's, maxillary incisor protrusion can be produced, paradoxically, by a long mandible (rather than a long maxillary arch) due to labial tipping of the maxillary incisors caused by the displacement effect of the more anteriorly placed mandibular incisors.

The considerations described above illustrate the anatomical basis for the much higher incidence of Class II than Class III individuals in the North American Caucasoid population, this in contrast to a higher frequency of Class III individuals in some other major ethnic groups. These considerations are to be elaborated in a future report.

Evaluation of Individuals

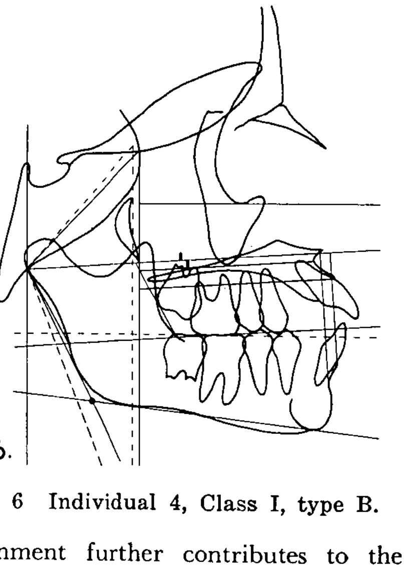
The variable manner of combinations that can exist among different anatomical relationships and the cumulative, composite nature of their effects are demonstrated below for several individual persons. The subjects have been selected to illustrate a moderately severe Class II A pattern and, in contrast, Class II B type. A severe Class III craniofacial composite is presented and one example of a Class I A. Two separate Class I B individuals are analyzed to show how a similar end result can be produced by basically different patterns of combinations.

Individual 1. Class II type A. In Figure 3 and in accompanying Table III, it is seen that this individual has a moderately severe aggregate, cumulative pattern involving maxillary protrusion at both *A* and *SPr* points (relationships 1 and 2 in Tables I and II). The evaluation of relationships 3-13 accounts for the anatomical basis as to *how* this situation was produced. The cranial floor-to-maxillary alignment relationship has a marked maxillary protrusion effect, as does the backward manner of ramus alignment. A "long" *PM* relative dimension predisposed the latter situation. The maxillary arch, measured skeletally as well as dentally, is "long" compared with the mandibular arch. Note that *A* point protrudes well beyond *B*. The factor of corpus/occlusal



5.

Fig. 5 Individual 3, Class I, type A.



6.

Fig. 6 Individual 4, Class I, type B.

alignment further contributes to the over-all maxillary protrusion result. Most of these various regional relationships have severe (++) protrusive effects. However, the skeletal and dental ramus/cranial floor counterpart dimensions have an actual mandibular protrusion effect and serve to partially offset and reduce the extent of forward cranial floor and backward ramus rotations.

Individual 2. Class II type B. The aggregate pattern (Fig. 4, Table III) shows a composite combination of regional relationships that have resulted in mandibular *B* point protrusion beyond maxillary *A* point, which is the characteristic feature of this group, and a maxillary *SPr* protrusion beyond *IPr*. The remaining relationships (3-13) serve to explain the structural basis for this pattern.

Both the cranial floor and ramus alignment positions have maxillary protrusion effects, as do both of the relative arch lengths measured at *SPr/IPr*. However, the ramus dimension (measured dentally) and the vertical *PM* dimension produced effects which have partially compensated for the cranial floor and ramus alignment factors and have reduced their effects. The skeletal and dental arch lengths as measured at *A/B* points indicate an underlying "long" mandibular corpus, and the downward manner of corpus/occlusal (not ramus) alignment has increased the resulting mandibular protrusion effect. Although a "Class II" type of over-all pattern exists, the malocclusion is less severe due to the several distinctive "Class III" features involved within the composite pattern. Compare and contrast with the Class II type A individual described above.

Individual 3. Class I type A. Compare this individual (Fig. 5, Table III) with the Class II type A previously described. Most of the regional counterpart relationships contribute to a tendency toward composite maxillary protrusion, including the alignment and the skeletal dimension of the ramus, the relative lengths of the arches, and the vertical *PM* dimension. The manner of *PCF* alignment in this individual, however, and the horizontal dimension of the ramus as measured dentally serve to reduce the extent of over-all maxillary protrusion (Note: a forward rather than a backward alignment of *PCF* is

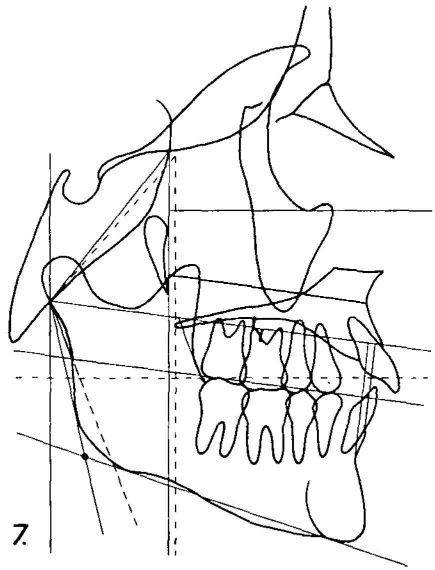


Fig. 7 Individual 5, Class I, type B.

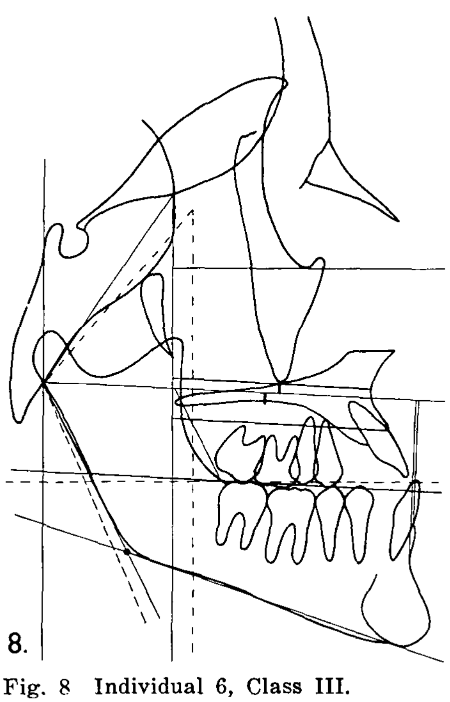


Fig. 8 Individual 6, Class III.

more frequently encountered in this group, as seen in Table I.)

Individual 4. Class I type B. Cranial floor alignment and dental arch dimensions as determined at *SPr/IPr* have produced maxillary protrusion effects (Fig. 6, Table III). Conversely, the relative ramus dimension, the alignment of the ramus, corpus-occlusal alignment, the vertical midface relative dimension (*PM*), and the skeletal arch lengths as measured at *A* and *B* points all contribute to mandibular protrusion. The combined, aggregate result shows a slight *B* point protrusion in conjunction with a slight *SPr* protrusion. Note the upward direction of functional occlusal plane rotation.

Individual 5. Class I type B. The midface is vertically long with a consequent and extreme backward rotation (+ +) of the ramus, thereby adding to the maxillary protrusion effect contributed by the relative lengths of the arches (Fig. 7, Table III). The nature of cranial floor alignment and the relative ramus horizontal dimension, however, have served to offset these maxillary protrusion effects to produce an aggregate, composite pattern in which *B* point is slightly protrusive beyond *A* point, and *SPr* protrudes somewhat beyond *IPr*. The end result has produced a Class I B type of craniofacial composite, but the regional combinations involved are basically different from those seen in the preceding Class I B case.

Individual 6. Class III. With the exception of the ramus dimension (skeletal as well as dental) and the vertical *PM*, all of the various relationships have contributed moderate to severe mandibular protrusion effects (Fig. 8, Table III). Thus, this individual has a "long" mandibular corpus relative to the maxillary arch (skeletal and dental), a marked upward and backward alignment of the cranial floor, a forward and upward rotation of the ramus, and a downward rotation of the corpus/occlusion. The horizontal ramus and vertical midface dimensions serve to partially compensate for these features

TABLE III
Analysis of individuals. See also Figures 3-8. Maxillary protrusion effects are indicated by a (+), and mandibular protrusion effects are indicated by a (—). Effects that exceed 2.5 mm are represented by a (+ +) or (— —).

Anatomical Relationship	Indiv. 1 Class II type A	Indiv. 2 Class II type B	Indiv. 3 Class I type A	Indiv. 4 Class I type B	Indiv. 5 Class I type B	Indiv. 6 Class III
1. Aggregate horizontal lengths at *A* and *B* points	+ +	—	+	—	—	— —
2. Aggregate horizontal lengths at *SPr* and *IPr*	+ +	+ +	+ +	+	+	— —
3. *PCF/PM* alignment	+ +	+ +	—	+	—	— —
4. Ramus alignment	+ +	+	+ +	—	+ +	—
5. Ramus/*PCF* horizontal relative dimensions, skeletal	—	0	+ +	—	—	+ +
6. Ramus/*PCF* horizontal relative dimensions, dental	— —	—	—	—	— —	+ +
7. Molar positions, composite	+	+ +	—	— —	—	— —
8. Maxillary/mandibular arches, skeletal, *A* and *B* points	+	— —	+	— —	+	— —
9. Maxillary/mandibular arches, dental, *A* and *B* points	+	— —	+	0	0	— —
10. Maxillary/mandibular arches, skeletal, *Spr* and *IPr*	+ +	+	+	0	+ +	— —
11. Maxillary/mandibular arches, dental, *SPr* and *IPr*	+ +	+ +	+ +	+ +	+ +	— —
12. *PM*/ramus-*PCF* relative vertical dimensions	+	—	+ +	— —	+ +	+ +
13. Corpus/occlusal alignment	+ +	— —	0	—	0	— —

but are insufficient to offset the severe Class III end result produced by the composite of all the other regional relationships.

Summary

This study describes and applies a procedure of craniofacial form and growth evaluation for *individuals* in which the kinds of information obtained by direct microscopic bone tissue examinations, vital staining, and implant markers can be effectively derived from ordinary headfilms. The approach is based on a *"counterpart-comparison"* concept for the analysis of intrinsic structural assembly and growth. This concept states that any one skeletal part has some other separate part or parts which function as architectural or geometric counterparts, just as one leg of an expandable tripod is a counterpart to either or both of the other two. If such separate parts are balanced in respective dimensions, angles, and growth, geometric symmetry is produced and sustained. If differences occur, however, consequent architectural and structural variations result. By *comparing* the dimensions, angular relationships, and growth changes for each of the many basic anatomical *parts* with their respective *counterparts,* the craniofacial form and growth patterns of any given individual can be meaningfully appraised and the actual anatomical basis for them explained. Specific sets of anatomical parts and counterparts throughout all regions of the skull can be recognized and located by the following simple criterion. If any bone or part of that bone grows a given amount, what other specific, separate bone or bony part must also grow to an equivalent extent if the same over-all, proportionate structural configuration is to be sustained? Should such collateral, counterpart bony segments not enlarge to an equivalent extent, changes in form and pattern are introduced, and the anatomical and developmental reasons for these changes can be precisely identified and explained. It is necessary that all of the various, relevant sets of counterpart segments be evaluated in order to account for the complex cause-and-effect interrelationships among them. A dimensional or angular disproportion in any one set is usually passed on from bone to bone and thereby alters the fitting of some other counterpart groups in quite different regions.

The distribution of the major sites and fields of growth and remodeling naturally delineates the boundaries for these anatomical counterparts and thus provides built-in comparison "standards" for any particular person. These in turn can be readily utilized for the evaluation of that individual. The procedure in brief is this: (1) Planes are drawn on headfilm tracings in a manner that directly represents and coincides with appropriate, major fields of growth and remodeling. The resultant groups of counterpart segments so identified are then evaluated by comparing each segment directly with its own correspondent counterpart segment. (2) The anatomical *effect* of each comparison is noted and, if desired, measured. The morphologic effects of their respective *sizes,* either horizontal or vertical as appropriate, are determined by these comparisons. (3) Next, the morphologic effects of their relative *alignment* (rotation) are determined, since the manner of a bone's alignment directly affects the expression of its actual dimensions. (4) The nature of the interrelationships among all of the different groups of counterparts is then evaluated. The cumulative combinations of these many separate, localized structural effects which have produced the composite anatomical pattern in any one individual are thus accounted for at any one or successive age levels. Comparisons with population standards are unnecessary.

The key morphologic features associated with Class I, II, and III individuals, as revealed by the counterpart-comparison procedure, have been studied, described, and evaluated. The dimensional and alignment relationships for certain basic sets of regional anatomical parts and counterparts were each analyzed according to (1) a maxillary protrusion effect, or (2) a mandibular protrusion effect. A simple five-point scale for these morphological effects was used in lieu of linear and angular measurements in order to more readily identify and establish the nature of the complex morphological relationships involved. Among Class II and Class III individuals, certain specific types of regional counterpart relationships were clearly identifiable with the over-all, composite maxillary or mandibular protrusion conditions present. These relationships are described and explained. In both groups it was observed that a given protrusion effect produced by one counterpart set can be the basis, in turn, for a consequent and corresponding protrusion effect in another contiguous counterpart set. The aggregate anatomical effects, thus, are interrelated and can be mutually aggravating. Our North American Caucasoid Class I sample showed a distinct Class II tendency in the nature of their many regional counterpart relationships. In all groups, however, a factor of intrinsic compensation was noted in certain specific relationship effects. This was particularly evident among the Class I individuals. Also, two basic and separate categories of both Class I and II persons were noted. The features which characterize these distinct craniofacial types are described and explained.

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REFERENCES

1. Björk, A., The use of metallic implants in the study of facial growth in children: Method and application. *Am. J. Phys. Anthropol.*, 29:243-254, 1968.
2. Coben, S. E., Growth and Class II treatment. *Am. J. Orthodont.*, 52:5-26, 1966.
3. Downs, W. B., Variation in facial relationships: their significance in treatment and prognosis. *Am. J. Orthodont.*, 34:812-840, 1948.
4. Enlow, D. H., *The Human Face.* Hoeber Medical Division, Harper and Row, Publishers, New York, 1968.
5. Enlow, D. H., R. E. Moyers, W. S. Hunter, and J. A. McNamara, Jr., A procedure for the analysis of intrinsic facial form and growth. *Am. J. Orthodont.*, 56:6-23, 1969.
6. Enlow, D. H., and R. E. Moyers, Growth and architecture of the face. *J. Am. Dent. Assoc.*, 82:763-774, 1971.
7. Enlow, D. H., T. Kuroda, and A. B. Lewis, Intrinsic craniofacial compensation effects. *Angle Orthodont.*, In press.
8. Ricketts, R. M., Cephalometric synthesis. *Am. J. Orthodont.*, 46:647-673, 1960.
9. Salzmann, J. A., *Roentgenographic cephalometrics.* Proceedings of the Second Research Workshop. Lippincott, Philadelphia, 1961.
10. Van der Linden, F. P. G. M. and D. H. Enlow, A study of the anterior cranial base. *Angle Orthodont.*, 41:119-124.