The Human Chin and Its Relationship to Mandibular Morphology

BRUCE S. HASKELL, D.M.D., PH.D.

Despite numerous studies of the phylogenetic and morphogenetic development of the human *protuberantia mentalia* or "chin," there remains an aura of uncertainty, controversy and confusion concerning its function and role in the dentofacial complex.

Although it is recognized that the chin is a particularly human trait among the living primates, other animals, such as the elephant, also possess a chin. Theories on chin development have ranged from its being implicated as an accessory of the speech mechanism to its action as a stress mediating buttress. An explanation for the extreme variability existing in modern hominid populations could conceivably shed light on several fundamental problems of skeletal biology. These include the present concepts of intrinsic morphogenetic potential, "functional" theories of contiguous anatomical interaction, and questions dealing with the kinematics of the developmental plasticity of bone.

Ricketts[1] made the observation that the chin appears to be generally small in leptoprosopically developing faces. It is possible that the study of symphyseal form may also provide an important tool in the morphologic analysis of human skeletal dysplasias of the face and jaws.

LITERATURE REVIEW

The first fossil evidence of a human chin in the Neanderthals found in Europe and Israel appears not earlier than 120,000 years ago in "La Ferrassie I" and in Skhul IV.[2-7]

According to Pliny the Roman historian, ancient Greeks would touch the chin during religious supplication to demonstrate an affinity with the divine. This demonstrated a fitting recognition of the chin as a particularly human trait not thought to be shared with the lower animals.[8]

Walkhoff[9-11] advocated the stressful role of the muscular attachments of the tongue-hyoid-symphyseal complex as being crucial to symphyseal morphology. He claimed that, during speech, the genial tubercles transmitted the forces of the attached musculature through the body of the symphysis, which resulted in the structural reinforcement of the chin.

Other workers have stated that the chin is a natural result of tooth size and alveolar bone reduction. This reduction left the basal portion of the mandible well forward and resulted in a protuberance.[12-14] Riesenfeld,[15] in a study on rats, performed surgical procedures on the masticatory musculatures and extracted the mandibular incisors. A bony knob or chin appeared in his experimental animals.

Gorvanic-Kramberger[16] explained the evolutionary appearance of the chin as the result of the angle of prognathism or relative proclination of the dentition and alveolar bone. With the development of a backward angulation of the incisors relative to the symphysis, the chin became more pronounced. Gorvanic-Kramberger based this claim on a comparative anatomical evaluation of bimaxillary dental reduction. He maintained that, as the head assumed a brachycephalic trend, the relative widening of the palatal area "arched" the anterior position of the incisors inward so that they would no longer project. As the face became more retruded and followed a flatter facial angulation, the teeth also conformed and became less prognathic. He also considered the prominent chin to be the result of the unique "overbite" situation which appears in the human jaws. In an overbite the maxillary teeth overlap the lower incisors thus plac-

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From the department of orthodontics, Univ. of Louisville, Louisville, Kentucky.

ing the lower teeth in a more lingual position. A lack of incisor overlap is found only in the racial groups with a high frequency of prognathism.

Wallis[8] stated that in man the mental protuberance is traversed by the mentalis muscles which run at right angles to the platysma and insert into the orbicularis oris. In anthropoids such as the chimp, the muscles are so thoroughly interwoven as to make differentiation extremely difficult. Wallis felt the comparative range and facility of facial expression between man and the apes could explain the existence of numerous tubercles in man which cover the outer surface of the mandible, as these muscles are used extensively in speech and laughter. The platysma has also been implicated as an effector of chin contouring during the rotation and lifting of the head.

Eliot[17] was the first advocate of a "cross-tension" theory of mandibular strain with the chin acting as a strengthened buttress. According to him, brachycephalization and the shortening of the jaws have resulted in strain and cross-tensions to be thrown on the extreme forward points of the mandible. The external chin must act as a structural reinforcement to counteract the effect of masticatory stress transmission.

Wegener[18] also suggested that there were strong lateral forces on the symphysis resulting from the brachycephalic trend of the skull in primate evolution. Wegener felt that, as the skull broadened, the outward pull of the temporal and masseter muscles caused the rotation upward and outward of the ramus and an outward bend of the lower border from gonion to the symphysis. This torsion resulted in the development of the external bracing effect of the chin. It was maintained that the inward pull of the medial pterygoids was insufficient to stop the outward and rotating effects of the temporal and masseter muscles.

DuBrul and Sicher[19] suggested that with the evolutionary shortening of the cranial base and masticatory complex, the origin of the external pterygoids moved to a position more directly medial of the insertion on the condylar process of the mandible. While the masseter/internal pterygoid complex may cancel out their respective forces, there is no lateral compensation for the inward vector of pull of the external pterygoids. As the external pterygoids contract, they were said to pull the two halves of the mandible together and develop stress at the symphysis. The bracing effect of the chin is the result of the stresses induced by the opening and protruding of the jaws. Riesenfeld[20] severely criticized DuBrul and Sicher's work for a lack of understanding of bone physiology and comparative anatomy. He claimed that a marked transverse orientation of the external pterygoids occurs in rats and other rodents without the formation of a chin, and also referred to other workers[21,22] who presented evidence for bone deposition on the concave side of a badly set fracture or graft under compression stress.

It should be noted that Riesenfeld's choice of the rat as an experimental model may have been a poor one with which to argue against DuBrul and Sicher. The rodent symphysis is not fused to form a single dentary bone, and tension or compression cannot traverse the bony span of the arch as these forces are dampened by a midline cartilaginous union.[23]

With the use of the Benninghoff split-line technique, Seipel did an exhaustive study on the trajectories of the jaws.[24] He stated that the mandible might be best considered as a long tubular bone that has been subjected to modifications of form and muscular attachment. He believed that the trajectories of force analyzed for the mandible indicate that the compressive forces turn more to the inside with tensile forces on the outside. The masseter and medial pterygoids were found to insert transversely into the longitudinal basal trajectories and seemed to only superficially deflect the basal bone. The muscular insertions were very shallow, whereas in deeper layers the trajectories go through the area transversely in the direction of the muscles. For this reason he claimed the muscle insertions of the angular process of the ramus do not appear to markedly influence overall longitudinal tensile and compressive trajectories in the mandible.

Seipel stated that when a well-developed chin exists in adult humans, it represents a break in the longitudinal trajectorial system. The superficial layers of the chin are not amenable to split-line staining and produce an amorphous pattern. Incoming trajectorial patterns unite into larger lamellae or turn into whirlshaped irregularities. If, after acid preparation, the chin is peeled away, the deeper layers of the bone exhibit an increasing degree of trajectorial organization with strong lines flowing through below the surface. If no external chin is present, the trajectories continue through the chin region with little or no irregularities in trajectory. Seipel explained that the mental region appears to be at the crossing or intersection of tensile trajectorial elements following the external oblique ridge and compressive elements following the internal mandibular base. The amorphous surface layers of the mental protuberance were explained to derive from the bony reinforcement and nutritional conditions in such a "trajectorial knot."

In specimens with an excessively developed lower jaw, "accessory" tubercles usually developed bilaterally just below the mental foramina. The assumed etiology of these extra processes is a reinforcement of the external oblique, tensile trajectory. Seipel concluded that the chin must be an example of heredity and extrinsic functional influences. There is now considerable evidence available that lamellar systems and composite elements of bone are constantly undergoing changes during life. This continuous remodeling has been examined by Benninghoff,[25] Enlow[26,27] and others and is considered to be a characteristic of mammalian bone.

The most recent studies of the functional relevance of the symphysis deal with controversies concerning the action of the mandible as a lever during biting.[28,29]

Tattersall[30] suggests that the human mandible does not function as a lever during chewing or biting. His model, based on an extinct lemur of Malagasy (Archaeolemurinae), proposes that a lever system operating with a muscle reaction force at the condyle is inefficient and could not have evolved. His second point is that the morphology of the condyle is incapable of dissipating stress and is lined with fibrocartilage, a tissue adapted to shear stress and not compression. Tattersall's nonlevel condylar action supports a concept of symphyseal buttress adaptation (lingual) in lemuroids that acts to resist laterally-directed forces that tend to spread the dentary bones apart. These forces are due to the balancing-side stresses from the posterior temporalis. He claims that the tension on the posterior symphyseal border has lead to symphyseal fusion and lingual buttress in anthropoids.

Hylander[28] disagreed with Tattersall and referred to an earlier work of Gingerich,[31] which suggested that the operation of the jaw acts as both a lever *and* a nonlever depending on the mode of biting. Hylander insists that the condyle and its neck are easily able to withstand masticatory lever forces which are maximal during incisal biting. In incisal biting the posterior teeth are disoccluded and the condyles are moved forward and downward on the compact bone of the articular eminence. All reactive forces are now channeled through the anterior surface of the condyles and the temporal bone. This suggests that portions of the mandibular body will be heavily loaded under tension and act as a Class III lever resulting in areas of bony reinforcement.

Hylander said the symphysis functions in transferring muscle forces from the balancing side to the working during posterior mastication. The chin thereby maximizes occlusal force during unilateral posterior biting by allowing a greater utilization of the balancing, opposite musculature. A symphyseal buttress would also help counter the tendency for the two halves of the mandible to shear dorsolaterally. Hiiemae and Kay[32] in a study of the evolution of primate mastication suggested that symphyseal fusion development in the higher primates resulted from a trend of increased anterior incisal biting as the symphysis must resist disparate Class III lever forces.

Beecher[33] carried out a histological investigation of the symphysis of eleven prosimians and found a similar pattern of fibrocartilage and ligaments in all of these primates. Since fibrocartilage is most efficient in resisting tension and shear instead of compression, Beecher says these tissues resist the anteroposterior shear and spreading of the symphysis during mastication on the working side. Dorsoventral shear from the transfer of balancing forces would also be countered. Beecher reported that those species which resisted dorsoventral shear due to a marked working-balancing masticatory pattern had evidence of a calcifying or ossifying symphysis. He concluded that patterns and types of tissues designed to resist stress and the presence of a stressful pattern should be causally correlated. Smith[34] has emphasized that there are inherent faults in attributing a mechanical analogy, whether link lever, couple system or stationary beam model, to mammalian mandibular function. The forces and vectors exerted by ligaments, soft tissues and muscles, and the force and direction of the bite are mostly unknown. Smith claims that once the jaw is in occlusion it is supported through the joint and bite point. Therefore, once tooth contact occurs, the mandible must be treated as a stressed beam supported at its ends. During elevation of the mandible, structural and functional changes in the resulting morphology are unlikely as the forces must be slight. Only when contact is made does Smith contend that stress occurs in the mandibular body, at the condyle/articular eminence and the interincisal or buccal segment bite point. A calculation of reaction forces revealed that a 50 kg bite force at the first molar resulted in a total condylar force of nearly 39 kg, while a 14 kg condylar load occurs with an incisal bite of 10 kg. This model illustrates that the mandible must bear heavy stresses throughout its length, which necessarily includes the symphyseal region.

Other workers have suggested that symphyseal form and size are dependent on strictly intrinsic hereditary factors. Garn et al.[35] reported that symphyseal thickness is probably independent of the major mass of muscle action although an exact mode of inheritance is not known. Garn's study implied that the symphysis can be measured as a separate unit which develops independently from other morphologic expressions in the same mandible. In a study by Nanda[36] symphyseal morphology was compared to the dental classification of the molars. He concluded that the chin "button" was not found to belong to any particular classification of dental occlusion, and was, therefore, the result of hereditary potential rather than a functional use/disuse mechanism.

It appears that there remain many unanswered questions concerning the variability of chin form. Riesenfeld[20] said, "The formulation of theories on this subject (chin morphology) is almost unlimited so long as these are based on postfacto speculation of comparative anatomy and mere 'logical' conceivability instead of experimentation." In view of the amount of investigation of chin morphology, it seems surprising that several major questions still remain unanswered.

1. Does the chin really demonstrate an ongoing adaptive response to functional stress?
2. To what degree are we willing to accept the role of intrinsic genetic potential in manifesting the final morphology of the mandible?

RATIONALE FOR THE CONCEPTUAL MODEL

Most experimental morphologic studies performed involve situations where muscular tissues are cut with function grossly altered or destroyed. These procedures usually result in some demonstrable response with a change in bony form. One must be extremely careful in concluding that such experiments prove the role of mechanical stress in morphogenesis as this type of research presents a variety of uncontrolled variables in the experimental design. These include vascular and nerve interruption and alterations in pH, oxygen tension and temperature. All of these are known to affect bone growth.[27]

We are perhaps fortunate that a readily available human condition exists to give us a functional model with which to test the hypothesis that chin morphology reflects function, or the lack of it. Tattersall,[30] Hiiemae and Kay,[32] Hylander,[28,29] and Smith[34] have stated that extreme forces are placed on the mandibular body during incisal biting. Hiiemae and Kay attributed the development of incisal biting as the most important factor in the development of the fused symphysis. The human condition of a vertically developed mandible with an "open-bite" is characterized by an extremely steep mandibular plane angle and the nonocclusion of the anterior dentition so that incisal biting is impossible.[37] To masticate with this condition, only the posterior or cheek teeth can be used to chew. The function of incision is taken over by the premolars. The individual may hold the bolus in the teeth and use the hands to tear away the food.

It seems reasonable to determine if the bony morphology expressed as a result of these muscular forces varies with differential loading characteristics associated with nonfunction. Dysplastic mandibles may show different characteristics in form from the norm in suggested areas of high loading or stress such as the chin is purported to be. In addition to examining a group of individuals with normally growing mandibles and fully functional dentitions, mandibles with morphologic attributes opposite to those of the dysplastic-open bite group should also be examined, i.e., a sample of extreme "horizontal" mandibular growers who have an extremely flat mandibular plane angulation and acute gonial angles.

Ricketts[38,39] has suggested that individuals with micrognathic mandibles may develop a myriad of temporomandibular joint disorders, as the condyles cannot gain a proper position in the fossa during an attempt at normal masticatory function.

If through a compensatory mechanism a narrow micrognathic dysplastic jaw is "reaching" in attempting to achieve a reasonable functional insertion in the glenoid fossa, a compression of the anterior portion of the symphysis and tension on its lingual surface may occur. A minimal *anterior* buttressing might develop in this situation. Alternately, an excessively wide mandible with exaggerated bicondylar width could undergo a reversed symphyseal pattern with an "external" buttress.

This study attempted to determine if symphyseal form is related to mandibular dysplasia in a range of individuals with horizontal, normal and vertically growing mandibles with anterior "open-bite." Lateral and posterior-anterior cephalometric radiographs and dental casts were used to evaluate the relationship of the percentage of area of external or labial chin buttress to total symphyseal area on the basis of: 1) age, 2) sex, 3) mandibular plane, 4) mandibular base angle, 5) gonial angle, 6) transverse gonial angle (lateral ramal flair), 7) transverse gonial angle' (lateral ramal flair measured without the condyles), 8) bicondylar-gonial width ratio, 9)mandibular basal arch form and 10) maxillary basal arch form.

METHODS AND MATERIALS

Sixty pretreatment orthodontic cases

were randomly selected on the basis of having complete radiographs and casts from the Eastman Dental Center, University of Rochester School of Medicine and Dentistry. The sample was comprised of an equal number of Caucasian males and females, divided into three groups of twenty subjects on the basis of vertically dysplastic cases with open bite, normally, and extremely horizontally-developed mandibular form. The ages of the cases examined ranged from 11 to 22 years with a mean age of 16.8 years.

Initial lateral cephalometric radiographs and posterior-anterior films were used to describe general mandibular form and the percentage of "external" or protruding chin to total symphyseal area. Dental casts were also used to determine a mandibular basal arch form ratio.

Cephalometric landmarks and constructions as described by Björk[40-42] were used to evaluate vertical, horizontal, and normal mandibular morphology so that each case could be placed in one of the three respective categories. Landmarks included: articulare (Ar), orbitale (O), porion (Po), pogonion (Pog), menton (Me), Frankfort horizontal (FH), mandibular plane (MP), gonion (Go), ramus Line (Ar-Go) and gonial angle (Ar-Go-MP). A less commonly used landmark of Björk's is the mandibular base angle ('B'). This angle is formed by the mandibular plane and a line from articulare intersecting the mandibular plane at a point where a line perpendicular to the mandibular plane and tangent to the most anterior point on the symphysis intersects the mandibular plane (Fig. 1).

Other cephalometric constructions were also devised to evaluate symphyseal morphology. These include:

Menton prime (Me'), the point at which the radiographic overlap of the lower border of the mandible ceases at the lower border of the symphysis as seen in norma lateralis (Fig. 1).

Transverse gonial angle, the degree of lateral flair as measured on a frontal headpiece by describing the angulations of intersection of a line drawn from gonion to gonion, and a line tangent to the lateral aspect of the condyle head projected to gonion. The right and left measurements are averaged to arrive at a single value (Fig. 2).

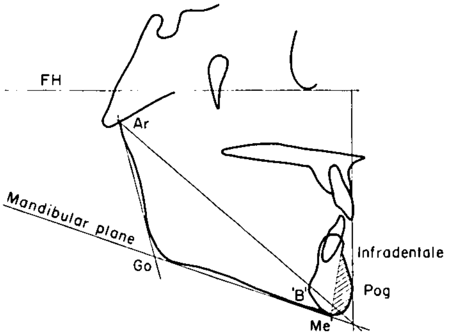

Fig. 1

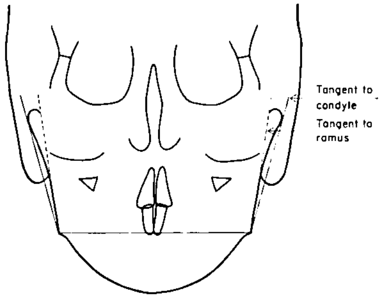

Fig. 2

Transverse gonial angle prime (lateral ramal flair measured without the condyles), the degree of lateral flair in the measurement is also obtained on a posterior-anterior headplate by describing the angulations of intersection of a line drawn from gonion to gonion and a line tangent to the lateral aspect of the ascending ramus, without the condyles, projected to gonion. The right and left measurements are averaged to arrive at a single value (Fig. 2).

Gonial-bicondylar width ratio, the relative proportion of mandibular width at the widest part of the condyles is divided into the width at gonion, when seen on a posterior-anterior radiograph.

When a headfilm exhibited a gonial angle of more than 127°, a 'B' angle of less than 17.5°, and an anterior open bite, the case was selected for the vertical mandibular group. A range of gonial angulation from 118.5° to 126.5° and a 'B' angulation from 18.0° to 22.0° placed the case in the normal mandibular form group. If the gonial angle was less than 118.5° and 'B' more than 22.5°, the case was assigned to the horizontal mandibular form group.

The transverse gonial angle, both with and without the condyle included, and the gonial-bicondylar width ratio were constructed and measured for each patient.

The basal arch form of the subject's mandible was mathematically described by establishing a ratio dividing the width of the posterior basal segment below the buccal groove of the first molars into the anterior basal segment width at the canine fossa. Vernier scale calipers accurate to the nearest one-tenth of a millimeter were used. A high ratio indicated a square arch form, whereas a lower ratio represented a tapered form. The basal arch form ratio of the maxilla was determined in the same fashion.

The percentage of external or protruding chin area *(protuberantia mentalia)* to total symphyseal area in a cross-sectional lateral cephalometric perspective was determined. The complete symphyseal outline was first traced on the lateral headfilm and a line then projected from infradentale to menton prime. An architectural instrument, the polar planimeter, was used to calculate in square millimeters the area of the entire symphysis. The area of the external chin, as restricted posteriorly by the infradentale menton' line was also assessed. This measurement of the protruding portion of the chin was divided by the total symphyseal area and expressed as a percentage (Fig. 1).

Since menton is defined as the most inferior point of the symphysis, the relative position of Me will change as a mandible changes position with different head and jaw postures. A new point, Me', was determined by examining at what point the radiographic overlap of the lower border of the mandible corpus ceased at the intersection of the lower border of the symphysis. In almost every case examined Me' coincided with true menton. However, in vertical cases with the mandible nearly "standing on its end" true menton appears to be positioned anteriorly when compared with menton in a horizontally-growing mandible.

With the use of Me' a more consistent anatomical reference was established on the inferior surface of the symphysis, regardless of mandibular posture.

FINDINGS

The mean and standard deviation for each of the eleven variables for the total sample were calculated. The variables included: the mandibular plane, age, sex, gonial angle, mandibular base angle, transverse gonial angle, transverse gonial angle prime, gonial-bicondylar width ratio, mandibular base arch form ratio, maxillary basal arch form ratio, and the percentage of external chin present. The mean and standard deviations were also calculated separately for each of the three groups (Table 1). To statistically determine that the variables for each of the three groups represent distinct populations of measurements, a one-way analysis of variance was performed. Significant differences at the $(P<.01)$ level were found for the mandibular plane, gonial angle, mandibular base angle, mandibular and maxillary basal arch ratio, and the external/total symphyseal area percentage.

A correlation matrix was also tabulated for the total sample.* The matrix was designed to correlate all eleven variables with each other in every possible combination. The correlations of primary interests in this study are those involving the chin. Table II presents the correlations comparing the chin with the other ten variables in

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*Complete statistical data may be obtained from the author.

TABLE I

TABLE OF MEANS AND STANDARD DEVIATIONS FOR THE TOTAL SAMPLE AND INDIVIDUAL GROUPS

VARIABLE	Total Sample (n=60)		Vertical Group (n=20)		Normal Group (n=20)		Horizontal Group (n=20)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Mandibular Plane	28.01	7.58	34.02	5.37	30.10	4.76	19.92	4.31
Age	16.85	2.06	15.80	2.87	17.50	1.31	17.25	1.29
Sex	0.50	0.50	0.40	0.50	0.50	0.51	0.60	0.50
Gonial Angle	123.25	8.45	131.00	6.03	124.75	3.64	114.10	4.30
Mandibular Base Angle	20.80	3.97	16.60	1.35	20.52	1.83	25.27	2.23
Trans-Gonial Angle (with condyle)	101.04	3.49	100.00	3.68	102.30	2.85	99.92	3.66
Trans-Gonial Angle[1] (without condyle)	96.60	3.90	96.17	4.96	97.92	2.75	95.70	3.62
Gonial-Bicondylar Width Ratio	0.83	0.05	0.83	0.04	0.81	0.03	0.84	0.06
Mand. Basal Arch Ratio	0.629	0.045	0.595	0.033	0.641	0.030	0.651	0.051
Max. Basal Arch Ratio	0.678	0.041	0.648	0.035	0.694	0.038	0.691	0.036
External/Total Symphyseal Area Ratio	21.76	5.08	17.36	1.95	20.86	1.55	27.10	4.86

TABLE II

Correlations Between External/Total Symphyseal Area Ratio and All Other Variables for the Total Sample (n=60)

VARIABLE	"r"	Sign.
Mandibular plane	.680	.01
Age	.237	*
Sex	.011	*
Gonial angle	-.678	.01
Mandibular base angle	.708	.01
Trans-gonial angle (with condyles)	-.097	*
Trans-gonial angle[1] (without condyles)	-.045	*
Gonial-bicondylar width ratio	.048	*
Mandibular basal arch ratio	.394	.01
Maxillary basal arch ratio	.362	.01
External/Total chin percent	1.000	—

*= >.05 significance level

the total sample. Significant correlations ($P<.05$) are apparent between the external/total symphyseal area percentage and the mandibular plane, gonial angle, mandibular basal angle, and the mandibular and maxillary basal arch form ratios.

A stepwise regression analysis was performed for the entire sample with external/symphyseal area percentage as the dependent variable.

The mandibular base and mandibular plane angle were significant at the .05 level for use as predictors of the external/total symphyseal area ratio. The remainder of the values of the independent variables were not significant for use in a predictive equation ($P>.05$).

A regression equation for the prediction of the external/total symphyseal area ratio was expressed based on the beta coefficients of the three significant independent variables:

$$Y = A + B_1X_1 + B_2X_2 + B_3X_3$$

where

Y = predicted value of chin form (dependent variable)

X_1 = mandibular base angle (independent variable)

X_2 = mandibular plane angle (independent variable)

X_3 = age (independent variable)

A = calculated regression constant

B_1, B_2, B_3 = the calculated regression weights associated with X_1, x_2, X_3, respectively.

TABLE III

External/Total Symphyseal Form Ratio: Percentage of Predictive Improvement as Each Independent Variable Is Added to the Prediction Equation; Independent Variables Listed in Descending Order of Value

	Prediction %
Mandibular base angle[1]	50.16
Mandibular plane[1]	55.19
Age[2]	58.02
Sex[3]	59.55
Maxillary basal arch ratio[3]	60.93
Trans-gonial angle prime (without condyles)[3]	61.56
Trans-gonial angle (with condyles)[3]	62.20
Gonial angle[3]	62.51
Mandibular basal arch ratio[3]	62.82
Gonial-bicondylar width ratio[3]	62.94

1 - $p<.01$
2 - $p<.05$
3 - $p>.05$

The percentage of predictive improvement for each variable, based on the increments of the Multiple R Square, is presented in Table III. An accuracy of 58.02% was found using only the three significant independent variables.

The results of this study clearly indicate that the amount of protruding chin is related to certain morphologic features in the mandible.

1. There is a demonstrably smaller percentage of protruding bony chin in a vertically growing open-bite mandible as compared with normally and horizontally growing types as defined by the measurement of the mandibular plane, mandibular base angle, and gonial angle.

2. The mandibular basal arch form was found to vary from a tapered form in the vertical cases to a "square" form in the horizontal cases. The more square the basal arch form, or higher the ratio, the larger the percentage of bony chin demonstrable; the lower ratio and more tapered the arch form, the less bony chin present.

There was also a significant positive correlation between the maxillary basal arch form ratio and the percentage of bony chin.

3. There was no relationship between the transverse gonial angles and the percentage of bony chin.

4. Age and sex did not appear to be correlated with the percentage of bony chin in the total sample.

5. Stepwise regression analyses indicate that three significant independent variables are statistically useful in predicting the external/total symphyseal area ratio.

DISCUSSION

While positive statistical correlations do not necessarily reflect causality, the results of this study support the hypothesis that the morphology of the *protuberantia mentalia* is related to the mandibular form. A likely explanation for these findings may lie within the models proposed by Tattersall, Hiiemae and Kay, and Smith. That is, a reduced functional mandibular stress due to a lack of incisal biting in the open-bite vertically developed cases correlates quite well with the diminution of a protruding chin.

Evidence has been available to show that dysplastic mandibles may be capable of undergoing compensatory morphologic changes to accommodate function. Ricketts[43,44] has noted that in patients with extreme vertical growth, the gonial process is small and the coronoid process is elongated. This could be a response to active anterior temporalis muscle fibers which function maximally during posterior biting. A similar mandibular morphology of small gonial process and high coronoid process can be seen in mammalian carnivores where incisal action is minimal. According to Moss,[45] the masticatory pattern of carnivores is typified by an extremely active component of the temporalis muscle action to aid in the sectorial or cutting action of the cheek teeth.

Riesenfeld's[15] claim of "hypofunction"

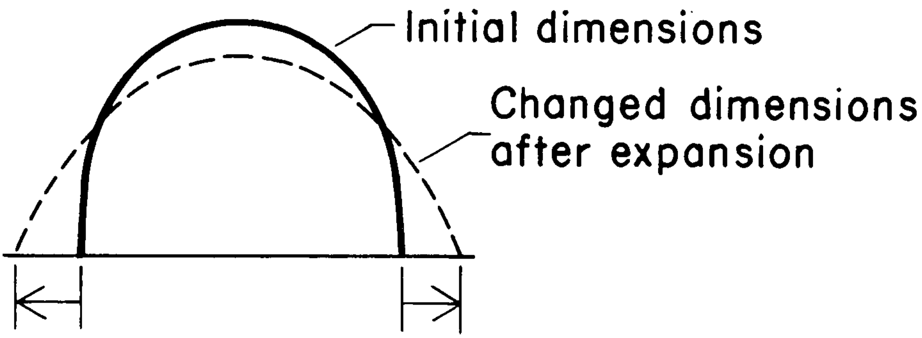

Fig. 3

as the basis of present human mandibular morphology may be particularly relevant. He claims that in the higher primates and man the relative disappearance of large gonial processes is obviously tied to the lack of function of the medial pterygoids and masseter muscles. It might follow that the lack of a chin is also related to the further hypofunction of these muscles. Without the posturing of the mandible forward during incisal biting, there might be a diminished medial strain by the external pterygoid muscles on the condyles. According to DuBrul and Sicher it is precisely this force which accounts for the stress causing chin formation. It does seem likely that incisal biting could not be *entirely* responsible for chin morphology, as the open-bite, vertically developed cases also exhibit a protruding chin, albeit in a significantly reduced proportion compared with the other groups in our sample.

Hylander[28,29] Tattersall,[30] and Beecher[33] all proposed that the symphysis is necessary to mitigate shear stress distributed through the mandible as a result of a "balancing" posterior bite. The reduction of protruding chin in the open-bite cases may be due to the loss of incisal bite stress in mastication.

Ricketts[44] identified a potential source of malocclusion as a result of the varying direction of growth of the temporal bone and its glenoid fossa. According to him a more posterior vector of growth of the glenoid fossa could result in retrognathia, while a more lateral vector of growth might result in a jaw that was prognathic. It seems possible that an extreme lateral vector of temporal growth could be reflected in the mandibular morphology. The results of this study of chin form indicate that the basal arch form was found to vary from a tapered form in the vertical cases to a square form in the horizontal cases. The more square the basal arch form, the larger the percentage of protruding chin present. If a narrow growing mandible is forced to adapt to a cranial base that is expanding in an extreme lateral vector, it might account for a tapered mandibular corpus ratio and reduced chin.

This might be explained in two ways:

1. A horizontal accommodation of any curved object of fixed length results in an increased tapered shape and a reduced height of curvature. This means a paraboloid arch will become wider in configuration (Fig. 3). This same mechanism could be operating in the basal bone of the mandible.

Enlow[27] claims that mandibular basal bone is not very sensitive nor labile to physical strain. This is most likely a reflection of the intrinsic genetic component of this type of bone. One might expect a minimal bony response; a slight change in corpus divergence rather than an overall basal bone enlargement as a conservative adaptative response to extreme brachycephalic growth. This explanation coincides with Rickett's findings of inadequate or poor condylar positioning in the glenoid fossa in severely micrognathic and retrognathic cases.

Previous evidence presented by Gingerich, Hylander and Tattersall have made a case for a *balanced* muscle relationship between the masseter, medial pterygoids, and temporalis during normal function. Studies by Horowitz and Shapiro,[46] Avis[47] and Moss[48-50] have found the gonial process of the ramus to which the masseter and medial pterygoids attach to be labile to functional change. It is therefore hardly surprising that, if "expansile compensation" is really occurring, no evidence is found of an extremely divergent transgonial angulation or gonial-bicondylar ratio.

2. If "expansile compensation" is occurring, growth stimulating tensions are formed on the *lingual* surface of the growing mandible and compressive forces on the labial. The combination of both (1) and (2) might present a cumulative effect manifested in the relative *lack* of a protruding chin in open bite vertical dysplasias.

McCown and Keith[51] and Howell[3,4] have described the relative position of the posterior wall of the glenoid fossa which is the tympanic plate of the temporal bone in "progressive" and "classic" Neanderthal specimens. A modern cranial flexure with a vertically oriented plate is characteristic of Neanderthal, Skhul IV, whereas a horizontally-oriented tympanic plate and reasonable flatter cranial base angulation is associated with the classic Neanderthals such as Gilbraltar I.[52] With the open cranial base and no forward thrusting of the posterior aspect of the glenoid fossa, it does not seem surprising that the classic Neanderthal is considered chinless. If the final position of the mandible is assumed to be dependent upon the amount and direction of the growth of the cranial base,[27] it is not unlikely that in this instance the lack of a protruding chin is due to: (a) retrusion of the basal portion of the mandible to accommodate a more distal position of the temporal bones, and (b) compensatory anterior positioning of the labile alveolar bone to maintain a harmonious dental relationship.

The available evidence seems to indicate that the morphology of the symphysis is based on a multitude of factors including the working relationship of the dentition, hypofunction and imbalance of the masticatory muscles, and almost certainly the proportional development of the mandible to the cranial base and cranial base angulation.

It seems extremely unlikely that a specific genetic system exists for determining chin form. A probable source of *indirect* control lies in the growth potential of the cranial base cartilages that influence head width. All of the cranial base has been regarded as having an autonomous growth potential that develops in conjunction with the brain, but independent of it. The ultimate potential of cranial base development is presumed to be genetically controlled by the various cartilages such as the spheno-occipital synchondrosis. Enlow[27] reports that cranial base flexure and growth is at least partially separate from brain development as it continues even with developmental abnormalities such as brain agenesis. Babineau and Kronman[53] have also reported only slightly more acute cranial base angulations in severe microcephalics. Koski[54] has shown that, while the independent capacity of cranial synchondroses is not as great as in epiphyseal plates, it still has potential for independent development. This suggests that extrinsic control factors are present, but not understood.

DuBrul and Laskin[55] have suggested that the cartilaginous cranial base has been a source of potential "pre-adaptive" value in the development of upright posture. These authors suggest that by shifting the allometries of growth from one specific site along the skull base to another, an explanation presents itself for mammalian intraspecies variation in skull morphology. Experimental evidence by Riesenfeld[20] suggests that a longitudinal "rolling up" in the evolution of the hominid skull most likely represents an adaption to the changed balance of the skull in an upright body position with bipedal locomotion.

If such an adaptive potential, albeit limited, is available in the human cranial base, it seems likely that differential growth of these cartilages is responsible for a modicum of variation in the cranial base angulation and width in a population. This potential may be a contributing factor in mandibular adaption and morphology including ultimate symphyseal form.

SUMMARY AND CONCLUSION

This study evaluated the proportion of the external chin *(protuberantia mentalia)* in relation to the total symphyseal area in normal jaws and those with a diverse morphology.

A sample of 60 cases was randomly selected and divided into three groups of 20 each on the basis of normal growth, horizontal growth and vertical growth with an open bite. Tracings of lateral and frontal radiographs were used to describe general mandibular form and to determine the percentage of external/total symphyseal area. Dental casts were also examined to determine a basal arch form ratio.

The results of this study indicate that the amount of bony chin present is related to certain morphologic features of the mandible. The most significant findings illustrate:

1. The chin increases in size as the mandibular type varies from a vertical type, to a normal type, to a horizontal type of growth pattern.
2. With dental "hypofunction" in combination with an exaggerated vertical development of the mandible, a smaller proportion of the protruding chin is present.
3. The chin increases in size as the mandibular basal arch form varies from a tapered shape for the vertical cases to a more square form in the horizontal cases.
4. The degree of lateral ramal flair does not appear to influence the proportion of protruding chin present.

Several models have been presented which attempt to explain *protuberantia mentalia* variation. The evidence in this study supports the concept that mandibular morphology is the result of the action of compensative adaption in a developing structure. There appears to be an implied polygenic influence on symphyseal morphology operating from the cartilaginous cranial base and mandibular basilar bone. This may be manifested in the relative proportion of mandibular basal bone to cranial base width, and to the vector of cranial base growth.

The ultimate proportion of the bony chin is viewed to be the result of mandibular adaption to a functional musculoskeletal balance in the craniofacial complex. The extreme variability of chin form in man may be considered to be the result of compensative growth developing in response to the most structurally efficient jaw form, the contiguous soft and hard tissue environment, and the intrinsic genotype of the mandible.

School of Dentistry
Univ. of Louisville
Louisville, KY 40232

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