The Inheritance Of Symphyseal Size During Growth

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In the study of normal craniofacial growth, at least three guiding principles have come to be acknowledged.[3,7,9,10] The first of these is that the measurements made and analyzed should refer to anatomically simple and developmentally independent growth entities. The second is that the structures represented should be uncomplicated from an evolutionary point of view. And the third principle is that the measurements made should first refer to genetically determined dimensions rather than those largely susceptible to environmental modification.

Emphasis on developmentally simple components of craniofacial growth necessarily follows from the fact that many structures, even anatomical "units," involve regionally different rates of growth and localized differences in the timing of completion. The importance of evolutionarily uncomplicated measurements stems from the related fact that portions of such anatomical units as the mandible have evolved in a complex way. And, finally, the need for genetically determined dimensions is apparent in ascertaining the extent to which exogenous influences can interfere with the genetic code during postnatal and even prenatal life.

We have, therefore, given attention in the present study to the development of the mandibular symphysis as exemplifying these three principles. First, the evolutionary simplicity of the symphyseal area may be noted. Second, as will be documented in this paper, the main dimensions of the mandibular symphysis are largely independent. not only of each other, but also of related facial and dental structures, and bodily size. And third, as shall become apparent in the experimental design involving two generations of subjects. the dimensions of the mandibular symphysis during growth show clear evidence of being largely gene-determined.

METHODS AND MATERIALS

The present investigation is based upon serial and two-generational radiogrammetric measurements of the mandibular symphysis, separate measurements of arch size and tooth size, and stature measurements and radiographic measurements of the bony-frame size in 435 white participants in the Fels Longitudinal Program.

In establishing the symphyseal measurements, a number of possible dimensions were first explored on a pilot series of thirty selected lateral-head radiographs. Of the total, the two measurements having (1) highest replicability and (2) greatest communality were then selected for further study and were further tested for replicability on a second series of thirty radiographs measured on two separate occasions by the same investigator (J. H. V.).

For symphyseal height (i.e., the maximum vertical diameter as shown in Fig. 1) replicability was 0.986 and the error variance was 3%. For symphyseal thickness (the maximum antero-posterior thickness at right angles to the above) the replicability coefficient

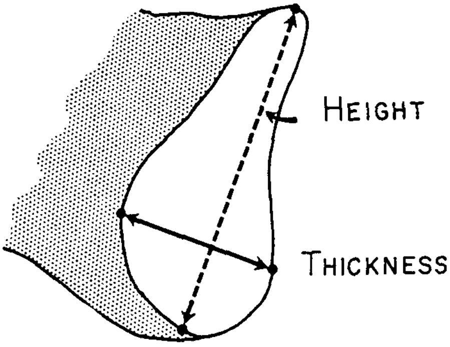

Fig. 1. Symphyseal height and thickness as measured in the present study. Symphyseal height here is the maximum vertical diameter ignoring secondary shadows cast by the inferior borders of the mandible. Symphyseal thickness is the maximum diameter at right angles to the above. All measurements were made with Fisher vernier calipers No. 12-130 with ground tips. Values were recorded to 0.1 mm and corrected for radiographic enlargement.[8]

was 0.975 and the variance was 5%. Repeated exploratory studies on a series of nine skeletalized mandibles, rotated both horizontally and vertically to predetermined extents, set the limits for allowable rotation as seen on the radiographs. Accordingly, as first verified on thirty-six experimental films, lateral-head radiographs showing more than 5 mm of vertical rotation (or "tilt") were then excluded from the major study.

Besides the measurements of symphyseal size (duly corrected for radiographic enlargement*) other metrical information included (1) the mesiodistal diameters of I_1 and M_1, as measured on casts,[6] and (2) the bimolar diameter, again measured on the casts. Adult stature (i.e., maximum standing height) was employed as the conventional measure of body size in man, while the adult bony-chest breadth, measured directly on posteroanterior 6-foot chest plates, served as an objective measure of the bony-frame size.[5]

Symphyseal measurements in the parental series involving 123 adult males and 135 females, aged 22 years and over, served to establish the various mating combinations for symphyseal size.

Breaking the two sex-specific adult size distributions at the median, all adult males in excess of 33.1 mm in symphyseal height, and all females in excess of 29.1 mm were characterized as "High," and those below these respective medians as "Low" in symphyseal height. Similarly, symphyseal thicknesses were characterized as either "Thick" or "Thin," again using the sex-specific adult medians, 14.2 mm and 13.1 mm, respectively.

This dichotomous division of adult symphyseal dimensions yielded three possible mating combinations for symphyseal height (High × High, High × Low, Low × Low) and also for symphyseal thickness (Thick × Thick, Thick × Thin, Thin × Thin). Examples of such combinations are shown in Figure 2. Tests for homogamy

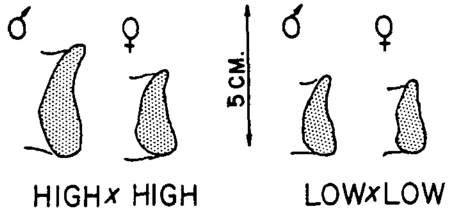

Fig. 2. Examples of High × High and Low × Low parental matings as categorized in the present study. It is clear that the different mating combinations differ markedly in symphyseal size, and therefore offer an ideal opportunity to examine size inheritance in their offspring.

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* Radiographic enlargement was first calculated following Kemp[8] and then determined experimentally. Since the calculated correction (0.925) corresponded closely to the experimentally derived value (0.923), the calculated value was used throughout.

showed no tendency for like to marry like with respect to symphyseal size*; the ratio of observed mating combinations, therefore, closely adhered to the theoretical 1:2:1 proportions for each of the two dimensions considered.

Having characterized the parents as to symphyseal height, symphyseal thickness and mating combination, in turn, attention was then directed to their children. Measurements were begun at eight years of age, after completion of incisor eruption, and continued at even years through sixteen years of age in a total of 177 children for whom complete radiographic records were available, and for whom the parental mating combination was also known.

With the very large number of radiographic and anthropometric measurements involved, work was expedited by the use of standard 80-column punch cards and the IBM 1620 Electronic Calculator. Percentiles as well as means were calculated for each age and sex from 8.0 through 16.0 years of age, and for symphyseal heights and thicknesses, respectively. Subgroup means were calculated, at each age, for the progeny of the various parental mating combinations previously described.

Otherwise, data manipulation was kept at a minimum. The main question in this study was whether, and to what extent, children of the various parental combinations (High × High, High × Low, etc.) differed during growth in symphyseal height and thickness. The results were again such that exact tests of significance were not needed (*vide infra*).

Besides the attention paid to replicability, elimination of errors stemming from positioning and necessary corrections for radiographic enlargement, unsuitable radiographs and incomplete or attenuated series were excluded from the tabulations. The radiographs of skeletalized mandibles served to check on the identity of the measuring points used since radiographic shadows frequently yield measuring points that are not identical with conventional anatomical landmarks.

Finally, the pedigree method[2] was employed in this study, selecting particular lineages representing various parental mating combinations (for symphyseal size) and involving four or more offspring old enough for adequate comparison. These lineages provided a direct indication of the relevance of parental symphyseal size to the prediction of symphyseal growth in the offspring (cf Ref. 4).

It should be clearly understood that the mating combination to which each child was assigned was determined entirely on the basis of the symphyseal dimensions of the parents. Selection, therefore, was prenatal rather than postnatal.

FINDINGS

As shown in Table I, where eleven correlations involving symphyseal size and various other parameters are set forth, the two symphyseal dimensions here considered are effectively independent of the others in adult life. Symphyseal size and tooth size are largely unrelated, using I_1 and M_1 as samples of anterior and posterior teeth, respectively.[6] Similarly, both symphyseal height and symphyseal thickness are unrelated to the width of the arch, using the bimolar diameter of M_1 - M_1 as an indication of arch size. Further, symphyseal height and symphyseal thickness prove quite unrelated to stature (standing height) and to the bony-chest diameter, an effective measure of the lean body mass.[5] Even in respect to

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* For 80 parent pairs, there was no tendency for like to marry like, as shown by parental correlation coefficient of −0.01 and 0.10 for symphyseal height and symphyseal thickness, respectively.

TABLE I

CORRELATIONS INVOLVING SYMPHYSEAL SIZE, TOOTH SIZE AND BODY SIZE

Symphyseal Measurement		Other Measurement	N	Correlation*
1.	Symphyseal height	Symphyseal thickness	258	0.24
2.	height	Stature	196	0.09
3.	thickness	Stature	196	0.12
4.	height	Bony-chest breadth	93	0.15
5.	thickness	Bony-chest breadth	93	0.23
6.	height	Bimolar width	81	0.09
7.	thickness	Bimolar width	81	-0.01
8.	height	Mesio-Distal Crown M_1	64	0.10
9.	thickness	Mesio-Distal Crown M_1	64	0.23
10.	height	Mesio-Distal Crown I_1	67	0.21
11.	thickness	Mesio-Distal Crown I_1	67	0.38

* Combined-sex correlations using weighted sex-specific Z transforms of *r* (see Ref. 1). Only correlations 1 and 11 are significantly different from zero at the p= .05 level.

each other, the interrelationship between the two symphyseal dimensions is low after growth has ceased. One may conclude, therefore, that both symphyseal height and symphyseal thickness can be studied as developmentally independent dimensions without correction for gross body size, for arch size or for tooth size.

With this evidence for developmental independence of symphyseal height and symphyseal thickness, it is possible to compare the growth of both diameters in children categorized according to symphyseal size combinations in their parents. Accordingly, children of the High X High, High X Low and Low X Low parental mating combinations can be contrasted taking the precaution to restrict the investigation to children who have completed incisor eruption. And, as shown in Figure 3, there is a very clear difference in symphyseal-height attainment during growth of children of the three parental mating categories for symphyseal height.

For boys and girls taken separately, children of the High X High parental mating combination tend to be highest in symphyseal height from age 8 through age 16 (Fig. 3). Children of the Low X Low parental mating combination, in turn, tend to be lowest in symphyseal height during the same time period. And children of the heterogamous parental mating combinations High X Low and Low X High tend toward size intermediacy in symphyseal height attainment during the growing years. Clearly, parental size makes a difference in the way symphyseal height is attained in children to an extent that does not

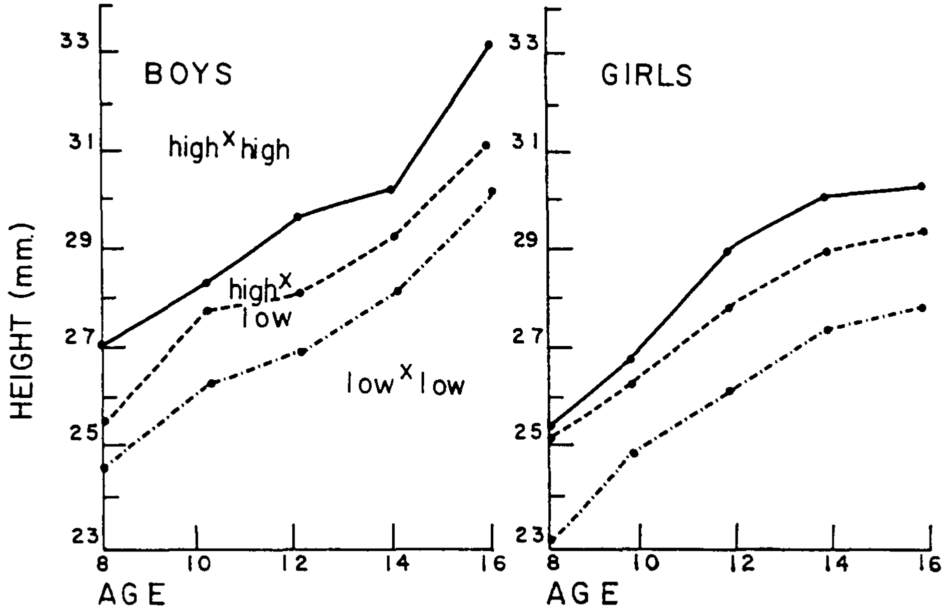

Fig. 3. Symphyseal growth in children of the High × High, High × Low and Low × Low parental mating combinations. As shown, progeny of the different symphyseal mating combinations are systematically different in symphyseal height during growth.

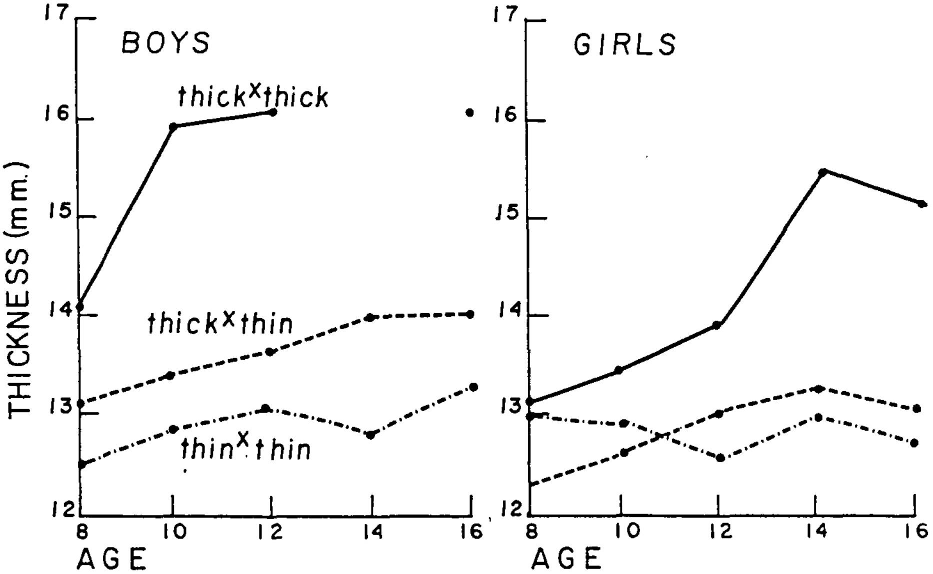

Fig. 4. Symphyseal thickness in children of Thick × Thick, Thick × Thin and Thin × Thin parental combinations. Here, there is a tendency toward size segregation during growth with the Thick × Thick progeny vastly thicker than the rest.

TABLE II

SYMPHYSEAL GROWTH ACCORDING TO PARENTAL MATING COMBINATION

		Parental Combinations* (Symphyseal Height				Parental Combinations* (Symphyseal Thickness)			
Age	Sex	N	High × High	High × Low	Low × Low	N	Thick × Thick	Thick × Thin	Thin × Thin
			*percentiles***				*percentiles***		
8	Boys	37	76	48	29	39	75	56	11
8	Girls	32	68	59	21	37	68	43	58
10	Boys	42	69	55	28	46	92	42	26
10	Girls	33	68	61	34	34	72	44	60
12	Boys	38	71	41	24	36	75	45	31
12	Girls	31	75	68	33	32	79	58	42
14	Boys	30	46	37	24	31	88	54	23
14	Girls	27	68	57	34	27	97	52	45
16	Boys	30	79	41	28	30	89	52	26
16	Girls	25	74	60	44	25	92	51	39

*See Fig. 2 and text.

**Age and sex-specific percentiles.

require statistical tests for trend. It is sufficient to note that in all thirty possible age and sex pairings children of the High × High exceed those of the High × Low, and children of the High × Low exceed those of the Low × Low parental combination for symphyseal height.

In a general way comparable findings obtain with respect to symphyseal thickness, as depicted in Figure 4. The homogamous parental mating combination Thick × Thick inevitably yields progeny who have thicker mandibular symphyses than is true for progeny of the homogamous Thin × Thin parental matings. However, and unlike the preceding example, the progeny of the heterogamous Thick × Thin parental matings are not simply intermediate, but rather tend to resemble (in both sexes) the progeny of Thin × Thin parental matings. This situation, involving segregation of the offspring, is unique among the growth parameters we have studied to date and strongly resembles classical mendelian inheritance. Since the progeny of Thin × Thin parents are not grossly distinguishable from the progeny of the Thick × Thin parents, while the progeny of the Thick × Thick parents are vastly different from either, the situation suggests a mendelizing pair with Thin (i.e., below-average symphyseal thickness) being dominant over Thick.

Inasmuch as the size-attainment graphs reproduced in Figures 3 and 4

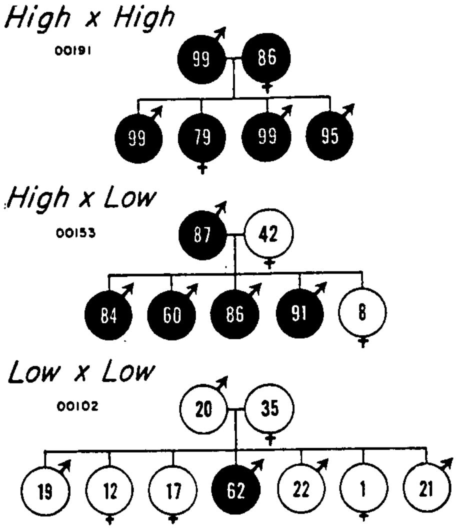

Fig. 5. Three families illustrating the inheritance of symphyseal height. As shown by the percentile values within the sex symbols, both symphyseal height and variability in the offspring can be predicted from the parental values.

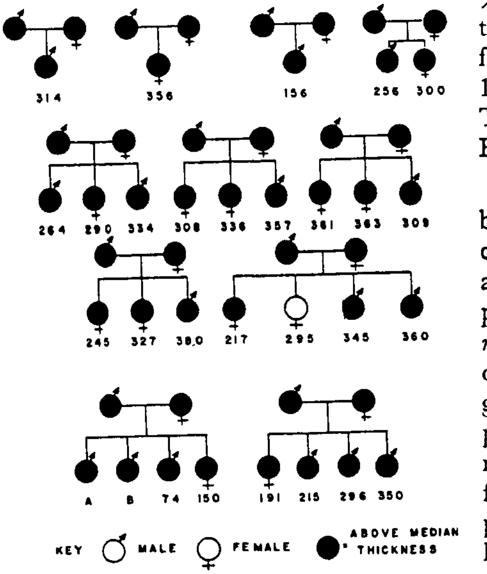

Fig. 6. Pedigrees showing the inheritance of symphyseal thickness in children of the Thick × Thick parental mating combination. This parental group yields over 97% of progeny with thick mandibular symphyses as might be expected for a mendelian recessive.

do not make use of group-specific data on symphyseal size, it is appropriate to restate the results in terms of sex and age-appropriate percentiles. After all, the difference between High × High and Low × Low progeny is only a few millimeters. How great are the differences when restated in percentile terms? The results are obvious in Table II where percentiles are given (for the children of the various parental mating combinations) separately by age and sex. Children of the High × High parental mating combinations average, during growth, in the 70th percentile; those of the Low × Low parental mating combination average near the 30th percentile. Turning to symphyseal thickness, progeny of the Thick × Thick parental mating combination average above the 80th percentile and those of the Thin × Thin mating combination well below the 40th percentile. Clearly, the parental combination Thick × Thick yields boys and girls with thick symphyseal diameters, as can be further demonstrated by a review of 11 lineages, involving 29 progeny of Thick × Thick parents (Fig. 5 and Fig. 6).

But these comparisons, which are based on symphyseal-size attainment during growth of children preselected according to the symphyseal size of their parents, do not effectively bear on the *rate* of growth. Granted that children of the High × High parents have greater symphyseal height than do the progeny of the Low × Low parental mating combination, do they grow faster? And if so, to what extent? Computing the rate of growth in symphyseal height as mm/year, both boys and girls from the High × High parental mating combination have the highest rate of growth, 0.8 and 0.6 mm/year, respectively. Boys and girls from the Thick × Thick parental mating combination similarly exceed (in rate of growth) progeny of the other parental mating combinations with growth rates—expressed as mm/year—of 0.3 mm/year in both sexes. In contrast, children of parents with minimal symphyseal thicknesses average far lower in the rate of growth per year, the value being approximately 0.10 mm/yr for boys, and virtually nothing (0.0 mm/yr) for girls. Thus, when the thickness of the parental symphyses is taken as a sorting criterion, distinct genetic lines are obtained with marked differences in the symphyseal growth rates of the children.

It seems obvious, then, that adult differences in symphyseal size are both (1) genetically determined and (2) distinguished by differences in the rate of size attainment. While there are also important divergences in the rate of symphyseal growth during adolescence and in the magnitude of growth well into adulthood, one simple generalization seems justified. Taking symphyseal height and symphyseal thickness as independent vectors, which indeed they are, adult-size attainment would seem to be mediated (to the largest extent) by genetically determined differences in the rate of growth, beginning well before incisor eruption is complete and extending for more than a decade thereafter.

DISCUSSION

It is now abundantly clear that the two symphyseal dimensions considered in this two-generational study are effectively independent of body size, arch size, tooth size; they are also independent of each other. Symphyseal height, primarily reflecting variations in trabecular bone, may be viewed as both anatomically and ontogenetically independent once anterior tooth eruption is complete. Symphyseal thickness, reflecting variations in compact as well as trabecular bone, is similarly independent of the other calcified structures here considered. Symphyseal thickness is probably independent of the total muscle mass though obviously not independent of the muscles of the lower face. However, the size independence of the two symphyseal dimensions in adults and their obvious developmental autonomy during growth is particular warning against measuring the mandible as a unit, or the face as a unit. Furthermore, these findings suggest caution in appraising big jaws and big teeth in fossil hominids as if they were simple manifestations of a single genic determinant.

Both symphyseal height and symphyseal thickness show uncontestable evidence of genetic control. Grouping the parents according to mating combinations (High × High, High × Low, etc.), clear differentiation is shown in the growth of their children. Parents with high symphyseal dimensions yield children with greater symphyseal heights, and parents with thicker symphyses yield progeny with thicker symphyses. The extent of differentiation between the genetic "lines" so obtained suggests that the genetics of symphyseal size is not unduly complex. Were either dimension excessively complicated as to mode of inheritance, the degree of differentiation obtained in the F_1 generation would not have been as great as observed here.

However, it seems likely that the mode of inheritance of symphyseal height during growth is different from that of symphyseal thickness. For height (the maximum vertical diameter) the children of the High × Low or Low × High parental combinations are neatly intermediate between those of the remaining two parental mating combinations. But for symphyseal thickness, involving the maximum anteroposterior diameter, the Thick × Thick children are separated from the progeny of

Thick × Thin and Thin × Thin parental combinations. From inspection of the trend lines for both sexes and from the percentiles as well, it would appear that the parental combinations Thick × Thin and Thin × Thin yield more nearly similar results, compatible with the suggestion that (in this particular dimension) "Thick" is recessive to "Thin." Obviously, it could be an artifact due to breaking the parental continuum at the median rather than at some genetically more meaningful point. Fortunately, this suggestion, which is still tentative, can be confirmed or rejected by further studies.

Leaving the exact mode of inheritance for future research, the implications of this two-generational study of symphyseal size are certain enough. Without question, parental size must be taken into account in "predicting" symphyseal growth. The use of mean values or mean increments would clearly lead to error. For either parental homogamous combination (High × High, Low × Low, Thick × Thick or Thin × Thin) the growth of the offspring in the symphyseal region must be related to the parent-specific values. Only for the heterogamous parental combinations, High × Low or Thick × Thin, can mean values be applied; even here symphyseal thickness does not fit with the assumption of simple intermediacy in the offspring.

Furthermore, the findings illustrate the need for regional, local "atomistic" measurements in the study of craniofacial growth, measurements that may or may not relate to conventional anatomical entities. While the mandible can be measured as a unit, it certainly does not grow as a unit and, quite obviously, mandibular size is not inherited as a unit. It is therefore quite unlikely that in abnormal growth the mandible deviates as a unit, or can be profitably investigated as a unit.

This particular study is admittedly unique in the human material involved, utilizing over 400 subjects, covering two full generations, and including serial radiographs that have required a quarter of a century to amass. It is unique in that it involves family lines and employs the "natural experiment" of different parental mating combinations. It documents the independence of symphyseal size during growth, proof that even a piece of a bone has its own growth autonomy. It confirms the inheritability of symphyseal dimensions during growth and thus draws increasing attention to the limitations of averaged growth data. Lastly, the results suggest different modes of inheritance (as well as different functional determinants) for symphyseal height and symphyseal thickness, respectively.

SUMMARY

1. The inheritance of symphyseal size during growth was investigated in 258 adults and 177 children, the latter followed in true longitudinal fashion from 8 through 16 years of age.
2. Symphyseal height and symphyseal thickness proved independent of stature, frame size, tooth size, arch width and each other.
3. Arranging parental mating combinations for symphyseal height, children of the High × High, High × Low and Low × Low mating combinations proved consistently different during the growing period.
4. The same was true for the offspring of the Thick × Thick, Thick × Thin and Thin × Thin parental mating combinations.
5. The data suggested genetic simplicity for both symphyseal height and thickness and the possibility of mendelian inheritance of symphyseal thickness.
6. The data further showed the inutility of simple mean values in pre-

dicting the mandibular growth of individual children and focussed attention on the potential value of parent-specific growth data in orthodontic appraisal.

Fels Institute

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