Original Article

Changes in Articular Eminence Inclination During the Craniofacial Growth Period

Elias G. Katsavrias DDS, MSD[a]

Abstract: The articular eminence of the temporomandibular joint dictates the path and type of condylar-disk complex movement. It has been suggested that a steep articular eminence inclination may predispose to temporomandibular joint dysfunction. When using functional appliances in orthodontic therapy, the bite registration is greatly affected by the articular eminence inclination. Furthermore, the articular eminence morphology has been related to specific facial types. Knowledge of how the articular eminence inclination behaves during the craniofacial growth period could help establish more biological treatment modalities. We took silicone impressions of both left and right articular fossae from 90 dried skulls. This sample consisted of three equal subgroups of skulls, each group presenting a deciduous, mixed, or permanent dentition. After the impression had set, they were removed and cut into sagittal sections 2.5 mm thick. The three middle sections were photocopied and enlarged by 200%. The inclination of each section was calculated trigonometrically, and the mean value was assigned to the inclination of the respective eminence. The data indicated that the inclination of the articular eminence changes rapidly until the completion of deciduous dentition, attaining more or less 45% of its adult value. By the age of 10 years, it was 70%–72% completed, and by the age of 20 years, it was 90%–94% completed. In conclusion, normally, the articular eminence inclination shows a symmetrical growth pattern, and it grows at a very rapid rate, attaining almost half of its adult value by the age of two years. (*Angle Orthod* 2002;72:258–264.)

Key Words: Temporomandibular joint development; Articular eminence slope; Growth

INTRODUCTION

The articular eminence is that part of the temporal fossa over which the condyle-disk complex slides during the various mandibular movements. It is often confused with the articular tubercle, which is an entirely different structure. The articular tubercle[1,2] is the small bony projection at the lateral part of the articular eminence that serves as the origin of the temporomandibular ligament.

The articular eminence inclination is defined as the angle formed by the articular eminence and the Frankfort horizontal (FH) plane or any other horizontal plane, such as the occlusal or palatal plane. It can be measured by two methods.[2,3] One method is to measure the angle between the best fit line on the slope of the eminence and the FH plane (Figure 1), hereafter referred to as method 1; the other method is to measure the angle between the FH plane and a line connecting the roof of the fossa with the highest point of eminence (Figure 2), hereafter referred to as method 2. It must be stressed that although both angles represent the articular eminence inclination, the first angle (best fit line–FH) focuses primarily on the posterior surface of the eminence, whereas the other angle (fossa roof–eminence top, FH) focuses on the location of the eminence crest relative to the fossa roof.

The normal value of this angle in adults has been reported to be 30°–60°.[4] Articular eminences having inclination values smaller than 30° have been characterized as flat, whereas those having values greater than 60° have been characterized as steep. However, this distinction has not been universally accepted since Ichikawa and Laskin[5] and Granda[6] have, based on subjective criteria, divided articular eminence inclinations into flat, moderate, and protuberant types.

The flatness or steepness of the articular eminences dictates the path of condylar movement, as well as the degree of rotation of the disk over the condyle. The steeper the articular eminence, the more the condyle is forced to move inferiorly as it shifts anteriorly. This results in greater vertical movement of the condyle, mandible, and mandibular arch upon opening.[7] It has been reported that during mouth

[a] Associate Professor in Orthodontics, Department of Orthodontics, School of Dentistry, University of Athens, Athens, Greece.

Corresponding author: Elias G. Katsavrias DDS, MSD, Department of Orthodontics, School of Dentistry, University of Athens, 2 Thivon St, Goudi 11527, Athens, Greece.
(e-mail: elkats@Otenet.gr).

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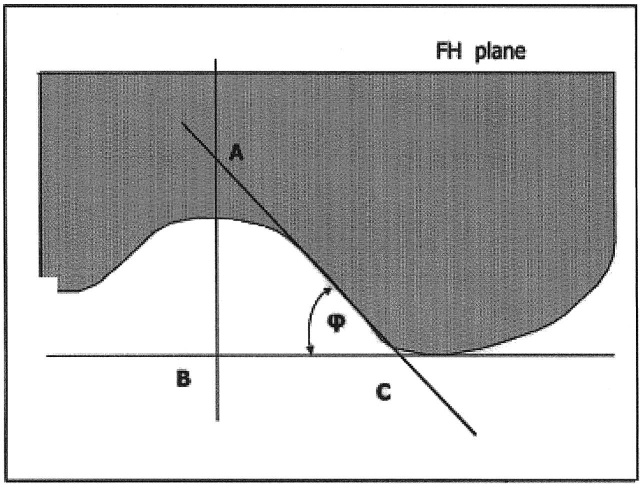

FIGURE 1. The articular eminence inclination presented as the best fit line (method 2).

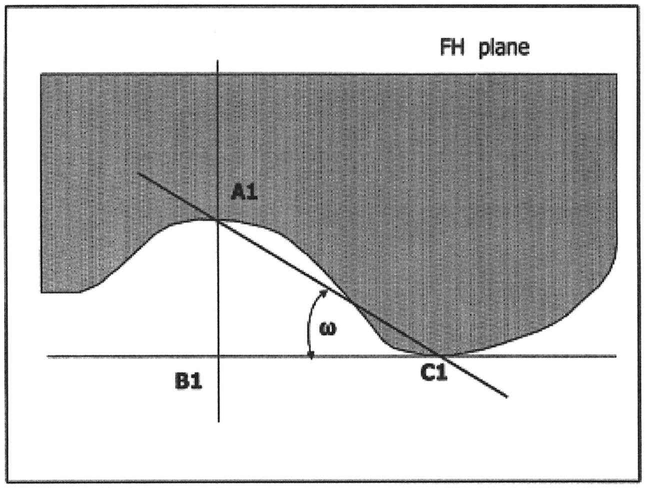

FIGURE 2. The articular eminence inclination presented as the roof-fossa and eminence-top line (method 2).

opening, the posterior disk rotation is more prominent in joints with a steep articular eminence than in joints with a less steep eminence.[8,9]

Furthermore, because of the rotary movement of the disk on the condyle as the whole complex moves forward, the total bodily movement of the condyle, in relation to the fossa, exceeds that of the articular disk. This difference increases as the steepness of articular eminence increases. It has been suggested that a steep articular eminence predisposes to disk interference problems. Once these problems occur, the effect of inclination is augmented.[4]

The articular eminence inclination has been studied in relation to its height,[10] facial morphology,[11,12] posterior loss of teeth,[13,14] tooth inclination,[15–19] and temporomandibular joint derangement.[20–30] However, studies on articular eminence growth are scant. The purpose of this study was to assess the inclination of the articular eminence during the craniofacial growth period.

MATERIALS AND METHODS

The materials consisted of 90 dry skulls from Asiatic Indian individuals selected from a greater skull collection stored at the Orthodontic Department of Philips University in Marburg, Germany. The cause of death of the individuals was unknown.

The selection of skulls was based on the following criteria: good general condition (no damage), no apparent skull asymmetry, no bony pathology, good condition of the dentition, and stage of the dentition development.

These skulls were divided into three groups, A, B and C, each of which was composed of 30 skulls. Group A skulls had deciduous dentition; group B skulls had mixed dentition (first molars and maxillary and mandibular incisors present); and group C skulls had permanent dentition. For every skull, the dental age was assessed by the method of Schour and Massler.[31] No sex determination was undertaken. The procedure used for each skull has been described elsewhere.[32]

Briefly, a facial bow (Dentatus, Sweden) was stabilized on each skull by inserting the ear sets into the acoustic meatus and the plane indicator into the right infraorbital foramen (DMG-Hamburg, Germany). Using a silicone-type material, we took impressions of both temporomandibular fossae. Care was taken to level the base of the impression to be parallel to the FH plane. The material was sliced with a common egg slicer (Westmark, Germany). The surfaces facing the midsagittal plane of the three middle sections were photocopied on a 200% scale. In each photocopy, a line from the top of the articular eminence was drawn parallel to the upper surface of the impression, and hence, parallel to the FH plane. Two additional lines were drawn: one line was the best fit line on the posterior surface of the articular eminence (anterior surface of the fossa) (Figure 1), and the other line connected the deepest point of the roof of the fossa and the top of articular eminence (Figure 2). These two lines, together with the FH plane, formed the angles ϕ and ω, respectively. Both of these angles present a measure of articular eminence inclination.

The values of these angles were estimated. Using an electronic digital caliper (54496 Pro-Max Caliper, Ted Pella Inc., Redding, CA) with a resolution of 0.01 mm, the distances AB and BC and A1B1 and B1C1 (Figures 1 and 2, respectively) were recorded. The values of angles ϕ and ω were then calculated trigonometrically as

$\tan(\phi) = BC/AB$ and $\tan(\phi) = (B1C1/A1B1)$.

The mean value of the three calculated angles was assigned as the inclination of the corresponding articular eminence. The findings were tabulated and processed further with SPSS for Windows software (7.5 Release SSPS, Inc., Chicago, IL). The left and right sides were plotted separately against the dental age. Using the lowest procedure (SPSS), which is a locally weighted regression scatter plot

TABLE 1. Descriptive Statistics for All Groups[a]

	Dentition Type					
	Deciduous		Mixed		Permanent	
	Left	Right	Left	Right	Left	Right
Method 1						
Mean	26.81	29.45	40.29	40.47	56.15	56.66
SD	5.15	5.30	6.61	7.24	8.39	9.41
SEM	0.94	0.97	1.21	1.32	1.53	1.72
Minimum	14.81	19.98	24.28	29.09	38.73	40.36
Maximum	35.63	40.99	55.43	55.75	69.66	77.13
Method 2						
Mean	21.87	22.32	28.11	29.33	36.19	36.10
SD	4.65	4.37	4.10	5.79	8.49	7.14
SEM	0.85	0.79	0.75	1.05	1.55	1.30
Minimum	13.18	15.06	18.46	16.95	16.68	23.79
Maximum	23.51	22.18	36.16	39.13	53.83	51.58

[a] Values are mean articular eminence inclination angles in degrees.

TABLE 2. Unpaired *t* tests Between Left and Right Side for All Groups

	Type of Dentition	*df*	*t* Value	*P*
Method 1	Deciduous	58	−1.96	.065
	Mixed	58	0.08	.993
	Permanent	58	0.22	.826
Method 2	Deciduous	58	0.38	.702
	Mixed	58	0.94	.350
	Permanent	58	0.04	.964

smoothing method, each growth curve was smoothed to 50%.

Error of the study

Twenty-four skulls (eight from each group) were selected at random, and the whole methodology was reapplied. Testing for systematic errors was performed using a paired *t*-test, whereas testing for random errors was done using the Dahlberg formula. The *t*-test at the .05 level was not significant. The random error for the measurements for the inclination calculated as the angle between FH and the best fit line on the posterior surface of the articular eminence was 1.66 (4%). The random error for the measurements for the inclination calculated as the angle between FH and the line of deepest point of the roof of the fossa and top of the articular eminence was 0.43 (1.5%).

Statistics

Descriptive statistics are presented in Table 1. Data were analyzed by applying an unpaired *t*-test between left and right sides (Table 2) and using analysis of variance to assess significant differences between age groups (Table 3). Significant differences between groups were further analyzed using multiple comparison tests, such as the Tukey-HSD test (Table 4). The levels of significance used were $P < .05$.

TABLE 3. Analysis of Variance Between Groups

	Side[a]	F	*P*
Method 1	Left	138.06	<.001
	Right	95.72	<.001
Method 2	Left	42.870	<.001
	Right	43.33	<.001

[a] Calculations for each side include data from groups A, B, and C.

TABLE 4. Tukey-HSD Test[a]

	Group A	Group B	Group C
Method 1			
Left side	26.81	40.29	56.15
Right side	29.45	40.47	56.66
Method 2			
Left side	21.87	28.11	36.19
Right side	22.32	29.33	36.10
Statistical significance		*	**

[a] Values are mean articular eminence inclination angles in degrees.
* Statistical significance between groups A–B.
** Statistical significance between groups A–C and B–C.

RESULTS

In general, there was a statistically significant increase in the articular eminence inclination when plotted against age. Details for each method of articular eminence inclination measurement are presented.

Articular eminence inclination measured as the best fit line on its posterior surface (method 1)

The mean articular inclination was 26° at age 2, 42° at age 10, 56° at age 20, and 59° at age 30. The inclination had attained 40% of its final size by age 2, 70% by age 10, and 94.5% by age 20, and gained the remaining 5.5% by the age of 30 (Figure 3).

Articular eminence inclination measured as the angle of FH plane to the line of deepest point of the roof of the fossa and the top of the articular eminence (method 2)

The mean articular eminence inclination was 20° at age 2, 30° at age 10, 36° at age 20, and 40° at age 30. There was no statistically significant difference between the right and left sides, although small differences were noted. At age 2, the inclination had attained 50% of its final value, while at age 10 it had attained 72.5% of its final value. During the next 10 years, the eminence inclination attained 90% of its final value, acquiring the remaining 10% during subsequent years (Figure 4).

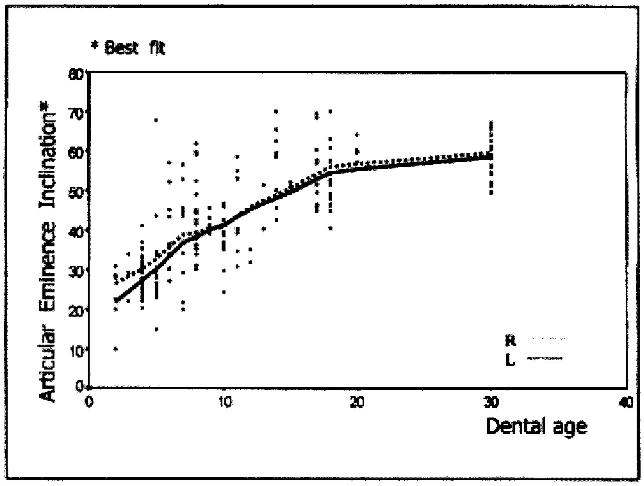

FIGURE 3. The growth curve of the articular eminence inclination, presented as the best fit line, separately for left and right sides. Each curve was smoothed through the lowest (50%) method (a locally weighted regression scatter plot smoothing method) of the SPSS statistical software.

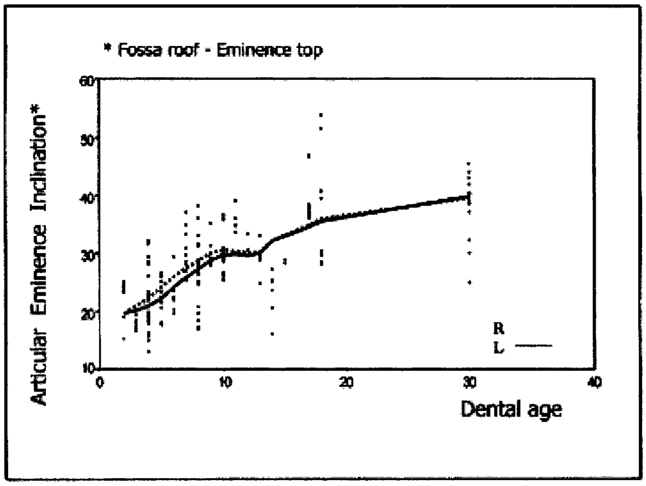

FIGURE 4. The growth curve of the articular eminence inclination, presented as the fossa-roof and eminence-top line, separately for left and right sides. Each curve was smoothed through the lowest (50%) method (a locally weighted regression scatter plot smoothing method) of the SPSS statistical software.

DISCUSSION

In summarizing the findings of the present study, it is clear that the inclination of articular eminence has a very rapid growth rate during development of the deciduous dentition, attaining almost half of its adult value by the age of two years. It then continues to grow, although at a reduced rate, until the age of 30 years. Viewed in conjunction with the development of adjacent areas such as the middle cranial fossa and the muscles of mastication, it seems plausible that this initial very rapid growth is intended to prepare temporomandibular joint morphology to withstand the load of future masticatory function. The fact that it gains the remaining percentage over a long period of time denotes susceptibility but also an opportunity for therapeutic intervention.

It should be recognized that the skulls used in our study, strictly speaking, were not randomly selected. As stated, these skulls were selected on the basis of condition, symmetry, and type of dentition. It should be further recognized that the stage of dentition development does not necessarily correspond to the stage of skeletal development. However, we feel that these shortcomings did not in any way affect the reliability of our results. Furthermore, one may question the representativeness of these skulls to the modern population. However, because the study concentrated on the changes of articular eminence inclination during the craniofacial growth period, the findings are not likely to be affected by this possible flaw.

It is well known that the articular eminence is strongly convex, anteroposteriorly, and slightly concave, mediolaterally. This profile leads to variation in inclination from point to point. Thus, one could question the validity of our method since we considered the articular eminence inclination to be the mean value of three consecutive sections taken 2.5 mm apart. However, the fact that these three sections belong to the central part of the eminence and cover a distance of 7.5 mm out of 10.34–17.72 mm[33] enables us to consider the mean value of these sections as a good representative sample of measurement.

One may wonder why we used two different methods to calculate the articular eminence inclination. One method, the best fit line method (method 1), is a measure of the inclination of the posterior surface of the eminence. The other method, the fossa roof–eminence top method (method 2), is a measure of the relationship of the eminence top relative to the fossa roof. It is obvious that the second method is greatly affected by the eminence height development, whereas the first method is the factor that dictates the type of condylar path.

Many methods have been used in measuring the articular eminence inclination. These methods include impressions done with modeling clay,[14] direct measurements,[5,16] arthrograms,[26] panoramic radiographs,[29] tomographic radiographs (both corrected and uncorrected),[23,24,34] cephalometric radiographs,[15,27,35] scaled photographs,[36] cephalometry using intensifying screens,[37] protrusive condylar path,[38] and wax.[39] The method used is a very important factor, as it influences the results. Modeling clay and wax have been criticized as being vulnerable to distortion and shrinkage. Panoramic radiographs of the joint are distorted, making it very difficult to accurately and reliably interpret its morphology.[40] The protrusive condylar path[38] is an indirect method of measuring the steepness of the eminence. However, whether the protrusive condylar path tracing can accurately reveal the articular eminence inclination is questionable. Cephalometry, photography, and uncorrected tomograms cannot overcome the anatomic difficulties of the region. It should be realized that, in using a radiographic technique, it is very important to select one that is capable of imaging the articular eminence at the sagittal plane, where the condyle-disk complex translates. This requires the projection x-rays to be individually corrected according to the angulation of the width (long axis) of the condyle and fossa. The silicone-type material used in our study, we believe, offered a reliable means of articular eminence impression. Hence, the calculation of the articular eminence inclination was reliable because the physical properties of this material are well known in our profession.

It has been reported that at birth, there is no articular eminence, making the first months of life the only period during which the mandible can be moved forward or laterally without any inferior movement.[41–43] Taking this for granted, it follows that the articular eminence develops almost entirely postnatally.

The fact that the congenital absence of condyles is accompanied by articular eminence underdevelopment or absence[44] denotes strong functional dependence, a view that is further supported by the findings of Pirttiniemi et al.[35] They concluded that articular eminence development is affected more by function than by skull base characteristics. Demirjian[45] concluded that articular eminence growth is affected more by function than by genetics. However, Ikai et al[11] and Ingervall[12] supported the view that facial morphology affects articular eminence inclination.

Assuming functional dependence, it is worth searching for the functions affecting its development. A widely held view has been that development is related to the presence of overbite and overjet in the human dentition.[46] Human mastication requires both incising and grinding functions. Incision requires separation of the posterior teeth, whereas grinding requires lateral mandibular movements that are free of incisor or canine interference. These actions can only be achieved by permitting the condyles to slide forward and downward, and this requirement is fulfilled by the articular eminence. However, according to Johnson and Moore,[47] this type of mandibular movement can be achieved even in the absence of an articular eminence. Furthermore, it has been noted that in jaw joints of ancient forms of hominids and great apes, all of the incisors meet edge to edge during maximum intercuspation. It is obvious that our data cannot enlighten the above mentioned arguments.

However, knowledge of the way in which the articular eminence grows is considered to be very important, as such knowledge will help to establish and apply more biological therapeutic orthodontic modalities, especially in cases of Class II malocclusion. For instance, it is well known that cases of Class II division 2 malocclusion are characterized by steep and high articular eminences. However, it is not known which factors influence this development or if the lingual inclination of the upper incisors has any participation. Extending this line of thinking, it is also unknown if the characteristics of the articular eminence have any effect in treating cases of Class II malocclusion with functional appliances.

Unfortunately, as was stated, reports dealing with the growth-related changes of articular eminence inclination are scant. To the best of our knowledge, these reports include those of Nickel et al,[36] Ricketts,[34] Scott,[48] Angel,[49]and Humphreys.[50]

Humphreys[50] stated that until the age of six, the fossa is shallow, and the articular eminence is absent. The eminence then begins to grow at a very slow rate until the age of 10, when it receives a marked and sudden impetus in growth. Its growth is practically complete by the 12th year of life. Our findings do not support Humphreys' findings and, since no details were given in that study, we cannot determine the reason for such divergence.

Our findings, however, agree in general with those of Nickel et al,[36] who stated that the eminence has acquired more than 50% of its mature size by the age of three. The method they used to measure the articular eminence inclination is similar to the method of the best fit line on its posterior surface that we used in the present study (method 1). However, our findings reveal that by the age of 3, the articular eminence inclination has acquired 42% of its mature value. There seems to be an overestimation in the findings of Nickel et al,[36] which is probably a function of the method used.

Ricketts,[34] using a sample of 200 joints from individuals with Class I and Class II malocclusions, concluded that at age 7.5 years, the inclination was 46° (77.9% of its mature form), and at ages 12.5, 18.5, and 22 years, the inclination was 52° (88%), 57° (96,6%), and 59°, respectively. It is obvious that Rickets'[34] mean values are larger than ours, but it should be noted that his measurements were obtained using no individually corrected temporomandibular joint laminagrams.

A remaining unanswered question is the point at which growth of the articular eminence inclination stops. Riesner[51] reported that the fossa grows until age 25, whereas Angel[49] reported that growth continues until age 33. However, Moffet[52] showed that a gradual increase in size of eminence occurs until the age of 40. The disagreement about when articular eminence inclination growth ends is reflected in the fact that reported adult values for the inclination show great dispersion. For instance, Nickel et al[36] reported an adult value of 45°, while Moffet[53] reported 42.8° (±10°) for whites, 39.2° (±10°) for shell mound Indians, 36.5° for West Africans, and 33.9° for Australian aborigines. Ichikawa and Laskin[5] reported adult values of 65.9° (±7.7°) for steep eminences, 54.8° (±10.4°) for moderate eminences, and 47.4° (±12.3°) for flat eminences. Panmekiate et al[26] reported a value of 36.4° (±4.9°); Kerstens et al,[29] 49.4° (±21.7°); Hall et al,[30] 52°; Ricketts,[34] 59° and Widman,[37] 52.5° (±4.2°). It has been reported that the temporomandibular joint undergoes a continuous morphologic alteration, and that this alteration is mediated by dental occlusion.[3] If this is true, then it seems difficult to differentiate real growth changes from those changes of an adaptive nature. However, considering that craniofacial growth more or less stops around age 20, it seems logical to assume that growth changes of the temporomandibular joint should also stop around this age. It follows that all subsequent changes should be considered as adaptations to altered functions. On the other hand, it has been reported that sutures around the temporomandibular joint, such as the petrooccipital, squamosal, and occipitomastoid sutures, fuse around age 30.[54] This feature forced us to regard age 30 as the age of maturation.

The differences between right and left sides were not statistically significant. These findings are in accordance with those of Dorier et al,[55] Weinberg,[56] and Ichikawa and Laskin,[5] but contradict those of Lindblom,[57] who claimed that left temporomandibular joints were larger than right temporomandibular joints.

In summary, the articular eminence inclination, regardless of the method of measurement, has a period of very rapid change during development of the deciduous dentition. Changes in this inclination then slow, and growth of the articular eminence seems to follow a growth pattern very similar to that of facial development. The fact that the articular eminence inclination develops almost exclusively postnatally denotes strong functional dependence. What remains to be investigated is the interaction of growth of the articular eminence inclination with facial structures and the role, if any, of articular eminence inclination in temporomandibular joint dysfunction. In addition, further investigation is needed into the role of the articular eminence inclination in treating cases of Class II malocclusion with functional appliances and approaches for guiding the development of the articular eminence inclination.

CONCLUSIONS

Based on the findings of this work, the following conclusions can be drawn:

1. Under normal conditions, the articular eminence inclination has a symmetrical pattern of growth, meaning that there is no statistically significant difference between the development of the right and left sides.
2. By the age of two, the articular eminence inclination acquires 40% to 50% of its final value. The percentage figure depends on the method by which the inclination is measured.
3. The inclination reaches about 71% of its final value by the age of 10, 92% by the age of 20, and full inclination by the age of 30.
4. Although the eminence belongs to the cranium, its growth pattern more closely resembles that of the face.
5. The fact that 50% of the eminence's adult inclination value is attained over a long period denotes not only vulnerability, but also a possible opportunity for therapeutic intervention.

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