Recent Knowledge Concerning Craniofacial Aging

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Orthodontics has characteristically concerned itself with cranial and facial development in individuals up to the second decade of life. Through its role in the treatment of dental malocclusion it has sought to accumulate information and incorporate it into a form usable in patient care. There are, however, conspicuous gaps in our knowledge and one of these involves craniofacial changes in persons who have attained adult status. The later life sequelae very likely have a profound influence on the ultimate success of therapy and long term maintenance of the dentition. Hellman[1] felt strongly concerning this fact, and he sought information that would allow him to better understand growth, dental occlusion and retention of the dentition throughout life. In 1927 he studied later life changes in the adult face and cranium. He wanted to better understand, ". . . the risk of attempting to do something with orthodontic appliances that might be accomplished in the course of time by natural development." Therefore, he designed a rather complex investigation upon skeletalized material which looked beyond the adolescent years and well into adulthood, middle-age, and later life. His conclusion that, "The face does keep on growing until old age" encountered severe criticism and one respondent expressed disbelief in his presentation and stated, ". . . I am practically convinced (of the) fallacy . . . that the face goes on growing until old age."

Hellman's insight and encompassing approach to the study of aging may have been lightly regarded in 1927, but his basic premise stands afield today because there is now very solid evidence that he was, in fact, correct. This review deals with continuing growth in the craniofacial complex as an individual ages. Hopefully, the information will be useful to those individuals concerned with dental and facial development. By extending the study of craniofacial development beyond the early years, it is hoped that better insight can be gained toward the concept of maintenance of the dentition for the life of the individual.

LITERATURE

Continuing growth in the craniofacial skeleton among adults is not a new concept. Humphry[2] over one hundred years ago noted that the cranium became thicker as an individual aged. Pfitzner[3] some years later provided new impetus for documenting aging skeletal change and he reported that growth continued throughout life and occurred in such proportions that it could be detected anthropometrically. Hrdlička[4] in summing almost forty years of observation stated that, ". . . growth does not completely or in all individuals cease by 22-24 years but that, on the average, it proceeds slowly in some features to the fourth decade, in others to the fifth, and in a few, even later. Elements included are stature, various head and face diameters, the chest, hands and feet, and especially the mouth, nose and ears." He also mentioned that, "In some characters, such as the stature and head size, the growth when senility begins to set in is followed by gradual diminution; . . . ." Hrdlička also made men-

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tion of the fact that previous investigations of Parchappe and Quetelet in 1836 presented evidence for growth during later life.

T. Wingate Todd[5] examined the male cranium and his cross-sectional studies led him to suggest that cranial thickness increased slightly with age up to the seventh decade, and thereafter there was no observable evidence of alteration. Hellman, as already mentioned, carried this further. Jarcho[6] found a size gain in the head with age among individuals from Russia. Goldstein[7] was a lone dissenter and he concluded, "With regard to old age, excepting the minimum frontal dimension as already noted, there is apparently a slight diminution in average size of all the head diameters." Büchi[8] undertook a longitudinal investigation and his work was impressive in that he found an increase in head size among older individuals. Essentially, he noted a steady gain between the young age group and the oldest category which was the eighth decade. In 1951 Hooton and Dupertuis[9] expressed surprise when they found continuing facial growth into the sixth decade of life among Irishmen. Lasker[10] reported on the age factor and body measurements of adult male and female Mexicans, and his work led him to comment that facial measurements were on the average larger in older age groups than younger. Zuckerman[11] focused on the same problem in the cranial base but could find no remarkable dimensional alteration among older age individuals in a cross-sectional sample. Moore[12] published extensively on hyperostosis cranii. His work included radiogrammetrics on the normal skull in a large sample but he could not become convinced that any definite trend toward craniofacial enlargement with age occurred. The published graphs in the text of his work suggested continuing facial growth even though he tended to disregard it.

The intention of this review is to describe human changes in the cranium and face after adulthood has been reached. The subjects for this study were white women from the Yellow Springs, Ohio area. Many of the individuals were part of the Fels Institute sample while others were area residents. The subjects were presumably of good health and ranged in age from twenty-six to ninety years. This was a radiogrammetric study and all of the films were exposed at the Fels Institute in the Dental Research Unit where carefully controlled methodology was followed. The highest majority of radiographs were made using a headholding device, but a few of the films did not have the benefit of this type of equipment. Nevertheless, extremely rigid standards assured the use of high quality films.

This work included one hundred and seventy-six subjects. In twenty-six of them, extensive records were available to allow for longitudinal assessment from over a fourteen to twenty-eight year time span. The fact that skeletal aging was examined with both a longitudinal and cross-sectional approach was important from the standpoint that each method individually offered its unique value and collectively they were complementary in the sense of minimizing the possibility of erroneous conclusions. Such obvious problems as secular trend or selective deletion could not be indicted for having eclipsed the findings.

Data handling and computations have all been reported in detail elsewhere.[13] Some fifty measurements were made in what could be called ten separate craniofacial categories. These included cranial thickness, skull size, cranial base, facial compartment, paranasal sinuses, sella turcica, sella position, mandible, palate and cervical vertebrae. The final one will not be reviewed here, but information on the

cervical vertebrae has been reported.[14] Suffice it to say orthogonal polynomial curve fitting procedures were undertaken for each separate cross-sectional measurement in order to define size change on the basis of age. The longitudinal material was assessed on a simple gain versus no gain basis. None of the computational information is given herewith, but a summarization of the findings along with the most exemplary illustrations of change will be detailed.

Findings

Cranial Thickness

A fairly clear picture emerges as regards thickness of the cranium at the midline location viewed from a lateral skull radiograph.[13,15] Continuing thickening occurs in the frontal region back to the bregma area. Posteriorly, in the parietal and occipital segments the increase is not nearly so definite. In fact, the area beyond vertex thickens very little especially when comparing it to the amount of change anteriorly. This is not surprising in view of the work by Moore[12] who documented the extreme skull thickening by hyperostosis cranii frontalis. Essentially then, the skull thickens in the frontal region and apparently in the more distal segment the tendency toward enlargement diminishes. As nearly as it is possible to say, the frontal thickening amounts to approximately fifteen per cent from adulthood to later life. The findings in this study are in agreement with earlier works of Todd.[5] He suggested that skull thickening occurs from early adulthood to about age sixty when the trend peaks. The information here is unable to give any clear confirmation or rejection of a suggestion about later decline but this work demonstrates thickening well beyond sixty years of age.

The lateral radiograph depicts midline areas and therefore measured enlargement incorporates the region surrounding the sulcus of the superior sagittal sinus. It is not possible to speculate on the role venous sinus drainage plays nor is it actually possible to meaningfully speculate on any mechanisms behind skull widening as a person ages. At this time it is even unknown which components change, whether they are the tables and the interspersed diplöe in single or combination. This is as yet a matter of conjecture.

Skull Size

Some rather profound growth patterns are noteworthy in the calvarium. The information at hand leaves little doubt that skull size increases from adulthood into senescence and probably in the five to seven per cent range (Figs. 1 and 2). Concomitant with external skull size increase of the vault, the distance between the inner walls enlarges as well indicating that the cavity of the cranium also becomes greater over extended periods.

The skull was measured in total diameter from both its outer and inner aspects. In addition, intersutural distances between nasion, bregma and lambda were also evaluated. The results are remarkably consistent for change.

One other aspect which is interesting from the standpoint of differential growth involves the simultaneous ecto- and endocranial measurements. Every skull size evaluation had two components; one was a measurement between outer table locations and another was between the inner tables. This produced similar measurements which differed only in the thickness of the skull at the particular site being evaluated. The obvious reason for this type of assessment was to attempt to understand changes ectocranially as well as endocranially. Though the information is not as yet confirmatory, there are some results which warrant at least preliminary discussion. The outer

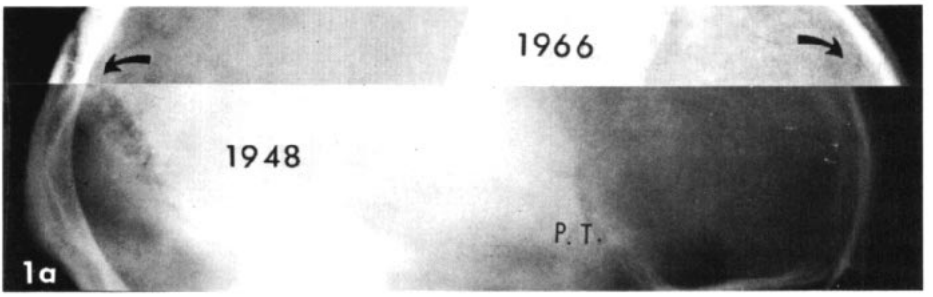

Fig. 1 This is an example of a male subject who demonstrates skull enlargement very clearly. From the earlier age of 43 years there has been sizable expansion. The illustration was produced by cropping two prints at similar locations on the skull and aligning the occipital tables. Illustration courtesy of Archives of Oral Biology.[25]

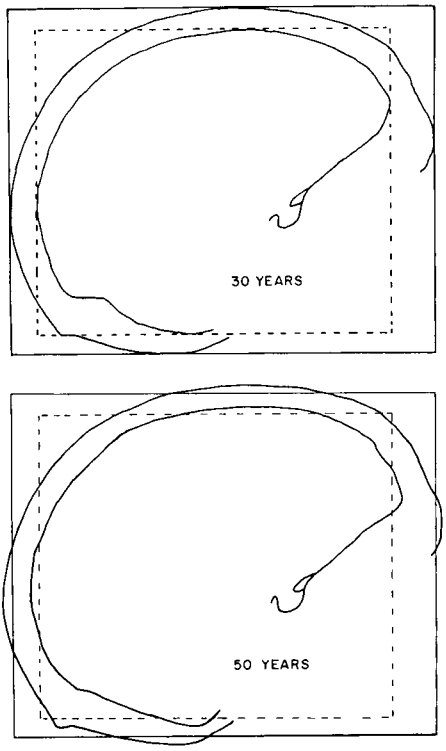

Fig. 2 This tracing depicts skull enlargement with the assistance of two rectangles. The above younger age skull has a rectangle fitted to both the outer and inner surfaces. The lower reproduction has the same sized rectangles imposed on it; in this way expansion is easily observable.

skull diameter measurements tend to rise and thus indicate skull enlargement. They peak at about age seventy and then begin to regress. The associated inner diameter representing a measure of the cranial cavity follows the same pattern. This infers, then, that net bone apposition occurs on the outer table until about age seventy when net resorption begins. The converse can be said about the inner distance. Here resorption is occurring until about age seventy as demonstrated by the enlargement in the cranial cavity. From then on apposition apparently results because of the gradual reduction in size. Therefore, the pattern of change with age follows a course in which there is net apposition outside with net resorption inside until the later years when resorption externally and apposition from within indicate a complete reversal of the process. This alternative phenomenon of differential patterns of net remodeling with age has only tentative support as yet but it is informative and deserves mention.

Cranial Base

Cranial base seems to enlarge with age also. The distances between nasion and basion and those from sella to both nasion and basion demonstrate the change. Importantly, though, the basal angle formed by the sella to nasion and sella to basion lines fails to alter with

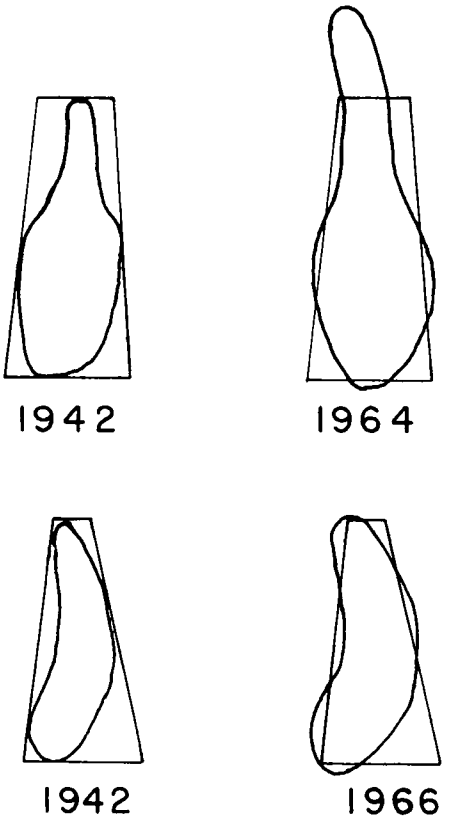

Fig. 3 Frontal sinus alteration is demonstrated by encasing tracings from two subjects in a quadrilateral polygon. The sinus boundries are enclosed at younger adult age and then these same figures are fitted around the air spaces at older age. In this way the magnitude of enlargement can be appreciated. The above example was 39 years old in 1942 while the subject displayed below was 30 years old at the earlier period. (Illustration reproduced through the courtesy of the *American Journal of Physical Anthropology*).

age.

In broad perspective then, the cranial base appears to follow the trend, as seen in the segments already mentioned, of age related size increase; the magnitude of change approximates that for skull size. This latter fact along with no solid evidence for any basal angle alteration speaks strongly for a symmetrical type of growing or remodeling pattern. Any differential changes would most likely have an effect upon the basal angle, and none were detected.

Facial Compartment

The upper face evaluation is very limited in scope; it consists only of the distance between nasion and anterior nasal spine and there exists an increase in size of about six percent. This area has not yet received the suitable and extensive attention that it deserves.

Paranasal Sinuses

Examination of the air spaces of the skull is limited to the frontal sinus. It lended itself to easy analysis and from every viewpoint there is overwhelming evidence that this pneumatic space enlarges greatly with age. A number of separate measurements indicates a nine to fourteen per cent enlargement which is considerably greater than the five to seven per cent value found in other compartments.

Figure 3 exemplifies the marked enlargement of the sinus as an individual ages. The idea of continuing expansion of the cranial air cavities is not a new one and has been stated as axiomatic in anatomic reference sources.[16,17]

Sella Turcica

Sella turcica bears a close relationship with the hypophysis and therefore its bony outline was examined on the premise that the fossa reflects gland size.[15,18] Extensive investigation leaves little doubt that the height, width and area of the fossa increases over an extended period of time. Just as cranial capacity presents interesting considerations regarding contents so does sella's association with the gland raise questions: What is the meaning behind sella enlargement with age? Does it reflect gland enlargement and also what are the mechanisms behind sella size gain? Whether the pituitary gland fits the fossa less closely as an individual ages or occupies less and less of sella area is not properly answered but continuing gain in sella leaves the possibility that the

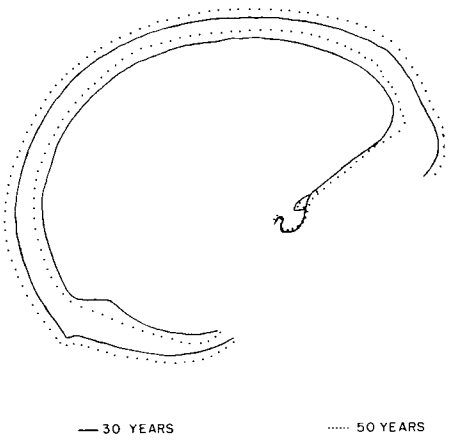

Fig. 4 This is the superimposition of radiographic tracings of the same woman at 30 and 50 years of age oriented along sella turcica and the floor of the anterior cranial fossa. Generalized and symmetrical cranial enlargement is evident. (Illustrations reproduced through the courtesy of the *American Journal of Physical Anthropology*).

gland morphology is less and less reflected by the bony outline of the fossa.

Sella Position in Relation to Various Other Cranial Landmarks

A series of measurements from sella to bregma, to the sinus, and to lambda was designed to test the possibility that change with age in the cranial base and neurocranium could vary from one area to the next in such fashion as to produce a relative shifting of the components. Differential growth was searched for, as discussed in a previous section relating to the cranial base and basal angle. Sella was not meant to be considered a fixed point, rather it was selected as a reference area. These measurements give an excellent profile into sella position as it relates to other cranial landmarks. There is little doubt that the distances between sella and sinus, sella and bregma and sella and lambda increase with age and again in the five to seven per cent category. This can be best illustrated by viewing the associated figure which uses sella and the floor of the anterior cranial fossa as a reference (Fig. 4). There seems to be little or no subtle shifting in the relationship of the hypophyseal fossa to the landmarks on the calvarium. Rather it seems clear that the neurocranium remodels in symmetrical fashion with resulting enlargement and very little or no irregular reshaping of the skull.

Mandible

The mandible assessment produced some interesting results, and these are generally diametrically opposed to previous thinking regarding aging and loss of teeth in the lower jaw.[13,15,19] First, continuing growth in over-all mandibular size is noteworthy. There is consistent five to seven per cent enlargement. Just as in the cranial base, remodeling seems to be symmetrical as the gonial angle demonstrates no tendency toward becoming more obtuse with advancing age. Put more succinctly, neither age nor dental status has an effect upon the mandibular angle. This finding fails to support previous thinking in which an overwhelming majority of investigators felt that loss of teeth over long periods of time produces extreme widening of the mandibular angle.[2,16,20,21] Brodie[22] doubted that the angle would widen and this work bears out his feelings. Figure 5 capably demonstrates how aging and loss of teeth leave the mandibular angle unaltered. Though only a single example is given here the entire series of both longitudinal and cross-sectional material coincides with that which is demonstrated.

One additional factor is that the symphysis of the mandible tends to increase in thickness with advancing age. This happens to be the only area in which a lateral skull film could in any way represent thickness of the body of the mandible. It is interesting that this enlargement appears to substantiate a previous finding from skeletalized material in which it was tentatively dem-

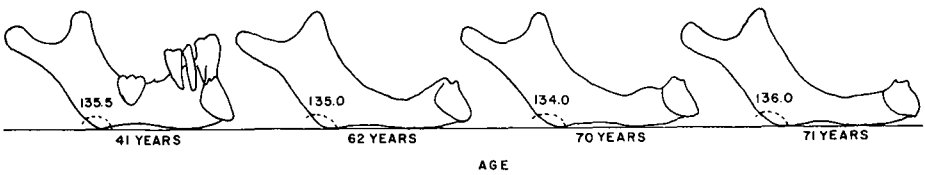

Fig. 5 Minimal change in the mandibular or condylar angle is noted. This subject has been completely edentulous for at least 20 of the 30 year period depicted by these tracings. In addition, the so-called gonial angle, as differentiated from the condylar angle, also shows little evidence of alteration. This latter point was confirmed by superimposing tracings. (Illustration reproduced through the courtesy of the *Journal of Dental Research*).

onstrated that the mandible gains in thickness with age.[23]

Summary

The evidence made available through extensive evaluation of adult and older age individuals has important implication. The craniofacial complex apparently remodels throughout life. Both the neural and visceral skeletal components cannot be considered to have attained a static relationship once adulthood has been reached. It is no longer valid to speak of so-called growth cessation as a termination of the entire growing process. Growth cessation is figurative and denotes rates, amounts, and location where change is taking place rather than the simplistic approach that has been considered previously. Certainly the later life changes in the craniofacial skeletal system are subtle, but change does occur and these tacit alterations very likely bear upon the dentition as they relate to occlusal status and the periodontium. The results show rather clearly that remodeling of bone produces demonstrable change. It appears as though the potential for bony enlargement persists in both the neural and visceral cranium with a net result of continuing growth. This "growth" in no way compares to that found in the younger years but it exists nevertheless. Figure 6 gives a summation of the over-all findings. The bony configuration of the skull in young adulthood is seen above. To the right is the edentulous skeleton as it has been considered up until now. The focus of aging heretofore has been on the teeth, their supporting bone and the mandible. These changes entail loss of teeth and tooth bearing bone, and drastic mandibular alteration which includes widening of the angle, atrophy of the condyle, and accentuation of the coronoid process. The results presented here suggest a different aging story. The specimen on the left gives a composite of change. The teeth and supporting bone have been represented on the basis that there is no evidence to incriminate age alone as the responsible agent for loss of teeth. Discounting the dental situation, changes appear as follows: Over-all enlargement is in the amount of five to seven per cent throughout. This includes the neurocranium and the visceral aspects as well. The upper face and mandible enlarge although the maxillary portion has been studied in only a limited way. The mandibular angle fails to change on the basis of either aging or loss of teeth alone. Although suitable assessment is difficult because it is not simple to determine these anatomic relationships by lateral skull x-ray, the condyle and coronoid processes do not appear to drastically remodel beyond the generally described profile of enlargement. Later life craniofacial "growth" is virtually a magnification process and the work in a previous publication actually utilized an enlargement method to dem-

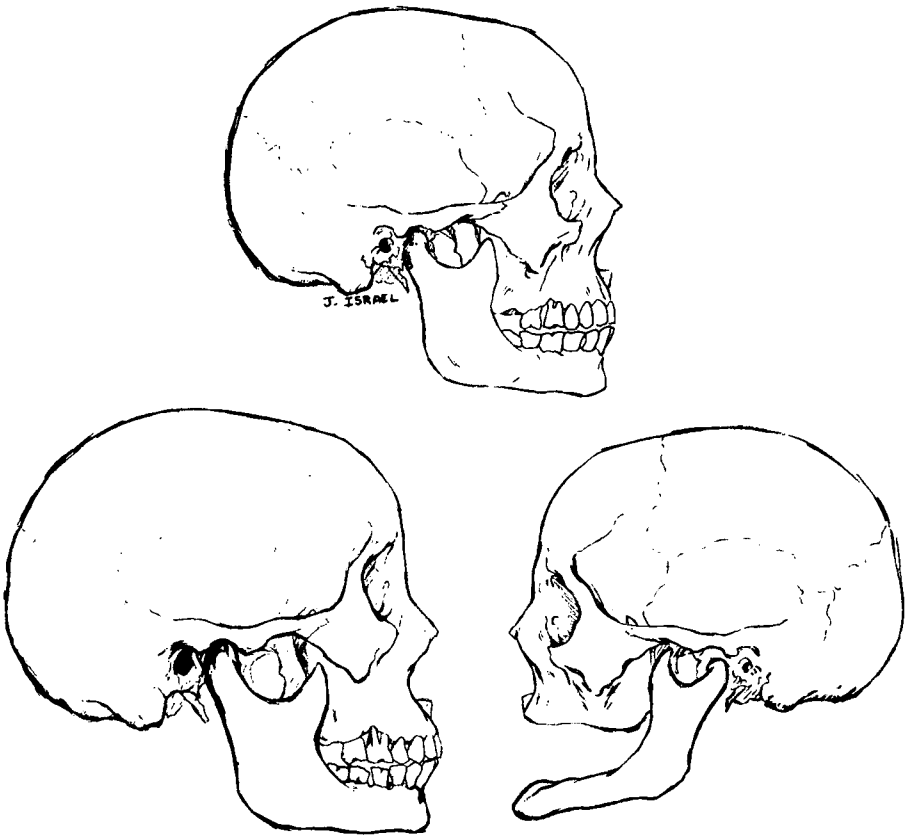

Fig. 6 Two avenues of aging are depicted here. The first is customary thinking regarding the progression from young adulthood (top) to older age (lower right). This consists of loss of teeth and tooth bearing bone followed by profound mandibular modification. The present study suggests a more complete sequence (lower left). In contrasting younger adulthood from older age, it appears as though there is size increase by magnification and this is continuing skeletal growth with age. The dentition, of course, is guided by specific pathologic situations. (Illustration reproduced through the courtesy of the *American Journal of Physical Anthropology*).

onstrate the fact that magnification of a younger age radiograph produces extremely close approximation to its later life counterpart. Skull thickness, frontal sinus, and sella turcica are something of an exception though because the amount of their enlargement is much greater than the other areas studied. They expand and generally in a symmetrical fashion but to a larger degree than other segments.

Orthodontists are familiar with early development. Work such as Enlow's[24] has outlined remodeling of surfaces and displacement brought about by major growth site activity. The infant undergoes extensive growth until he takes on adult form. Adult growth is less dramatic and alteration is through surface remodeling.

Over-all enlargement of the neural and visceral cranium is clear, but continuing work will be necessary to precisely define some of the more subtle aspects. This investigation shows in a general way that growth does not cease in the third decade of life, but continues well into older age. There is still

insufficient information to fully understand either a plateau effect or senescent decline in the later years as considered by both Todd and Hrdlička.

Upon purviewing the findings it appears that much of the further work in aging will need to come from investigators working in their own special interest areas before we more fully appreciate the net results of bony remodeling in the face and cranium. It will necessarily take time before it is known whether these broad investigative concepts can be converted into practical and meaningful clinical usefulness.

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