Analysis of the Anatomic Changes of the Aging Facial Skeleton Using Computer-Assisted Tomography

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Purpose: The bony skeleton serves as the scaffolding for the soft tissues of the face; however, age-related changes of bony morphology are not well defined. This study sought to compare the anatomic relationships of the facial skeleton and soft tissue structures between young and old men and women.

Methods: A retrospective review of CT scans of 100 consecutive patients imaged at Duke University Medical Center between 2004 and 2007 was performed using the Vitrea software package. The study population included 25 younger women (aged 18–30 years), 25 younger men, 25 older women (aged 55–65 years), and 25 older men. Using a standardized reference line, the distances from the anterior corneal plane to the superior orbital rim, lateral orbital rim, lower eyelid fat pad, inferior orbital rim, anterior cheek mass, and pyriform aperture were measured. Three-dimensional bony reconstructions were used to record the angular measurements of 4 bony regions: glabellar, orbital, maxillary, and pyriform aperture.

Results: The glabellar ($p = 0.02$), orbital ($p = 0.0007$), maxillary ($p = 0.0001$), and pyriform ($p = 0.008$) angles all decreased with age. The maxillary pyriform ($p = 0.003$) and infraorbital rim ($p = 0.02$) regressed with age. Anterior cheek mass became less prominent with age ($p = 0.001$), but the lower eyelid fat pad migrated anteriorly over time ($p = 0.007$).

Conclusions: The facial skeleton appears to remodel throughout adulthood. Relative to the globe, the facial skeleton appears to rotate such that the frontal bone moves anteriorly and inferiorly while the maxilla moves posteriorly and superiorly. This rotation causes bony angles to become more acute and likely has an effect on the position of overlying soft tissues. These changes appear to be more dramatic in women.

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The aging face has been an object of regard for artists and scientists for centuries. Likewise, the aesthetic and functional changes associated with the aging process of the face have been the subject of numerous studies by physicians and surgeons over the past several decades.[1–4] Most of these inquiries have focused on changes in surface landmarks or soft tissues, with commensurate changes in surgical technique to attempt to correct for such changes.[5–10] These data have culminated in a paradigm for facial aging that relies excessively on soft-tissue changes with some recognition of the contribution of fascial and ligamentous attachments and very little, if any, recognition of changes to the facial skeleton that occur as a result of aging.

Growth of the craniofacial skeleton is traditionally believed to terminate at adulthood with only degenerative and catabolic changes occurring after adolescence.[11–13] Thus, much of the focus has been on invasive and noninvasive manipulation of the soft tissues, which is known to change throughout life. However, in 1858, Humphrey[14] introduced the concept of continual change in the craniofacial skeleton, which challenged this traditional belief. This idea was expanded by Enlow[15,16] in the 1960s with the idea of "growth fields" to describe the maturation of bones in the facial skeleton and the concept of "drift," which occurs as a consequence of these growth fields (Fig. 1A).

Despite a small sample size, Pessa et al.[17,18] demonstrated that the facial skeleton changes throughout adulthood, formulating a model called Lambros's algorithm (Fig. 1B). This hypothesis states that the bones of the facial skeleton rotate clockwise around the orbit when the face is viewed from the side and facing to the right such that the forehead rotates anteriorly and slightly inferiorly while the midface rotates posteriorly and slightly superiorly. Interestingly, these changes complement Enlow's work. If these theories are true, then the angular rotation of the bones could result in loss of support to the overlying soft tissues.

Although there is clear evidence to support the concept that bony morphology affects the overlying soft-tissue appearance and function, there is no evidence in the oculoplastic literature to suggest that the facial skeleton changes throughout adulthood.[19–23] Instead, aging changes of the eyelids and facial soft tissues are attributed to the intrinsic changes of the soft tissues in which the soft tissues descend over time aided by progressive laxity and ptosis of facial muscles and ligaments.[8,24–26]

We propose that although soft-tissue changes do occur and likely contribute significantly to the functional and aesthetic changes associated with the aging face, the underlying bony skeleton continues to change throughout adulthood. Furthermore, we believe that these changes occur in a predictable manner, as postulated in Lambros's algorithm, and that these changes could have a significant effect on the aging changes of the face and ocular adnexa. This study aims to expand Pessa's work by increasing the sample size of the study, by including measurements of the orbit, and by examining the role of gender in such aging changes.

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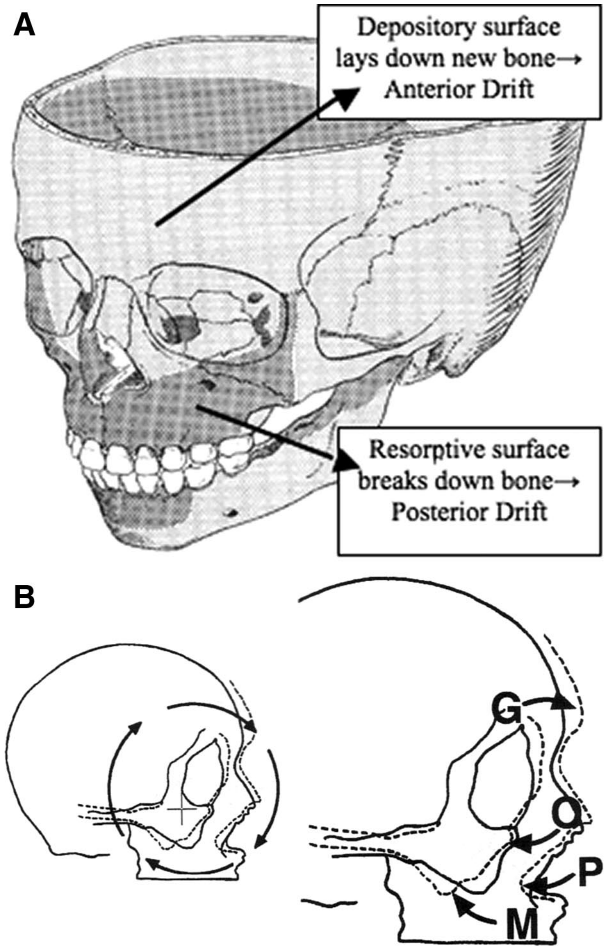

FIG. 1. **A,** Growth fields as defined by Enlow demonstrating the resorptive and depository surfaces of craniofacial bones (reprinted with permission from Enlow DH. *The Human Face: An Account of the Postnatal Growth and Development of the Craniofacial Skeleton.* New York: Harper and Row Publishers, 1968: 196). **B,** Lambros's algorithm describes a clockwise rotation of the facial bones about the orbit in a right-facing craniofacial skeleton (reprinted with permission from *Plast Reconstr Surg.* 2000;106:483).

METHODS

An institutional review board approved, retrospective review of the computer-assisted tomographic scans of 100 consecutive patients imaged at Duke University Medical Center between 2004 and 2007 was performed using the Vitrea software package. The study population included 25 younger women (aged 18–30 years), 25 younger men, 25 older women (aged 55–65 years), and 25 older men. Patients with incomplete upper dentition, facial fractures, and known craniofacial deformities were excluded.

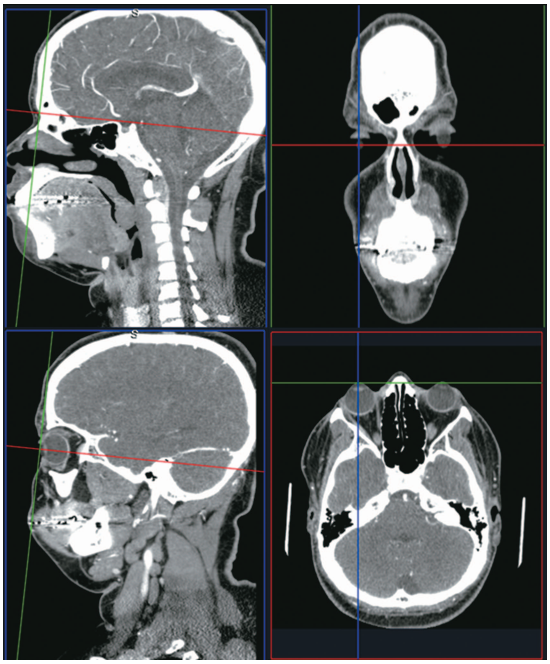

FIG. 2. Each scan was standardized by obtaining a left-facing midsagittal view and drawing a reference line from the sella through the nasion, so that this line served as the reference for the z axis. Once the sella-nasion line was drawn, a perpendicular line was passed through the anterior corneal plane of the right eye. This plane served as the reference point for obtaining the linear measurements.

The Vitrea program (Vital Images, Inc., Minnetonka, MN, U.S.A.) allows the investigator to precisely control the orientation and rotation of the scan along the x, y, and z axes. Each scan was standardized by obtaining a left-facing midsagittal view and drawing a reference line from the sella through the nasion, so that this line served as the reference for the z axis (Fig. 2). This reference axis is standard in cephalometric studies and duplicates the reference axis used in Pessa's work. Once the sella-nasion line was drawn, a perpendicular line was passed through the anterior corneal plane of the right eye. The distances from this plane to the superior orbital rim, lateral orbital rim, lower eyelid fat pad, inferior orbital rim, anterior cheek mass, and pyriform aperture were measured. Next, the Vitrea program was used to obtain a sagittal section through the midglobe of the right eye, and the distance from the globe to the roof and floor of the orbit was measured (Fig. 3).

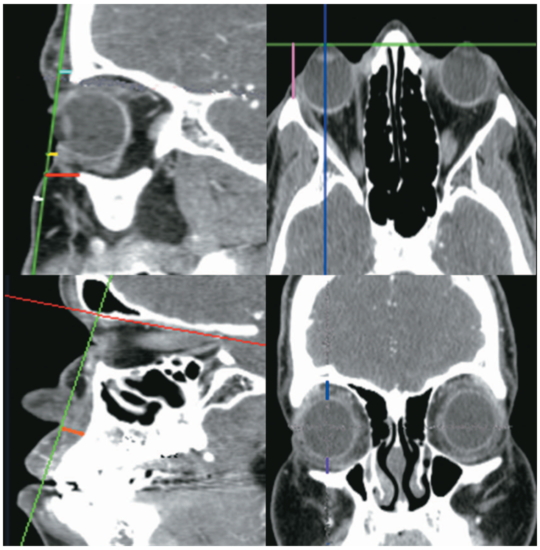

FIG. 3. The distances from the anterior corneal plane to the superior orbital rim, lateral orbital rim, lower eyelid fat pad, inferior orbital rim, anterior cheek mass, and pyriform aperture were measured. Next, the Vitrea program was used to obtain a sagittal section through the midglobe of the right eye, and the distance from the globe to the roof and floor of the orbit was measured.

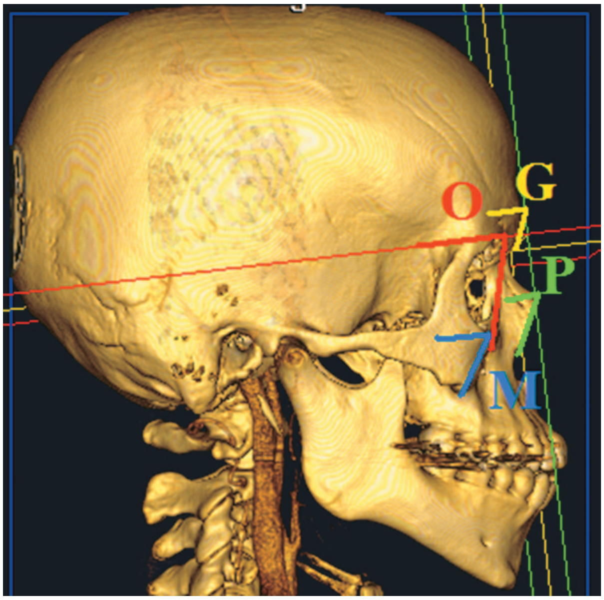

FIG. 4. Three-dimensional bony reconstructions were used to record the angular measurements of 4 bony regions: glabellar, orbital, maxillary, and pyriform aperture.

Three-dimensional bony reconstructions were used to record the angular measurements of 4 bony region: glabellar, orbital, maxillary, and pyriform aperture (Fig. 4). Each of these measurements was also taken relative to a line through the sella and nasion. The glabellar angle was defined as the maximal prominence of glabella to nasofrontal suture. The orbital angle was defined as from the superior midorbit to inferior midorbit. The pyriform angle was measured from the nasal bone to the lateral inferior pyriform aperture. The maxillary wall angle was defined as the superior to inferior maxilla at the articulation of the inferior maxillary wing and alveolar arch.

RESULTS

Mean demographic data were similar across study groups. The mean ages of patients were: younger cohort 24.2 years, older cohort 60.0 years, younger male cohort 23.5 years, older male cohort 60.0 years, younger female cohort 24.9 years, and older female cohort 60.1 years. Table 1 summarizes data of the racial distribution of patients.

All 4 types of angular measurements demonstrated a statistically significant decrease in older versus younger cohorts, indicating more acute angular measurements in older subjects (Table 2). This statistically significant decrease in each measurement was also demonstrated within each gender subgroup (Tables 3 and 4). The mean angular measurements of older and younger male cohorts became more acute with age: glabellar angle (72.3° younger vs. 66.0° older, [$p = 0.003$]), orbital angle (78.0° vs. 72.8°, [$p = 0.01$]), pyriform angle (67.8° vs. 61.7°, [$p = 0.02$]), and maxillary angle (63.8° vs. 57.1°, [$p = 0.002$]). Women demonstrated similar angular changes of their facial skeleton when comparing the younger and older cohorts: glabellar angle (76.1° younger vs. 71.0° older, [$p = 0.01$]), orbital angle (79.4° vs. 74.6°, [$p = 0.01$]), pyriform angle (64.0° vs. 59.3°, [$p = 0.04$]), and maxillary angle (60.6° vs. 52.4° [$p = 0.0001$]) (Tables 3 and 4).

TABLE 1. Demographic data

	Younger	Older	Younger men	Older men	Younger women	Older women
White (%)	50	66	48	68	52	64
African American (%)	40	20	40	16	40	24
Other (%)	10	14	12	16	8	12

TABLE 2. Angular measurements of all subjects

	Younger	Older	*p*
Glabellar (°)	74.4	68.1	0.03
Orbital (°)	78.9	73.4	0.001
Pyriform (°)	65.8	60.4	0.02
Maxillary (°)	62.3	54.6	0.0002

A gender dimorphism was revealed with regard to the absolute angular measurements (Tables 3 and 4). Men demonstrated a trend toward more acute measurements in the upper face—specifically the glabellar and orbital angles—compared with women in the same age cohort. Women demonstrated a trend toward more acute angular measurements in the lower face—the maxillary and pyriform angles—compared with men in the same age cohort. Such differences between the genders might be expected when one considers that men are known to have more prominent foreheads and superior orbital rims than women, whereas women are known to have a more diminutive midface than men.

The difference in glabellar angle between genders reached statistical significance in both cohorts (72.3° for men vs. 76.0° for women in the younger cohort [$p = 0.006$] and 66.0° for men vs. 71.0° for women in the older cohort [$p = 0.002$]). The orbital measurements were more acute in men versus age-matched women but did not reach statistical significance (78.0° for men vs. 79.4° for women in the younger cohort [$p = 0.18$] and 72.2° for men vs. 74.6° for women in the older cohort [$p = 0.07$]). The maxillary measurements were more acute in women and reached statistical significance in the older cohort (60.6° for women vs. 63.8° for men in the younger cohort [$p = 0.09$] and 52.4° for women vs. 57.1° for men in the older cohort [$p = 0.02$]). The pyriform measurements were likewise more acute in women but did not reach statistical significance (64.0° for women vs. 67.8° for men in the younger cohort [$p = 0.07$] and 59.3° for women vs. 61.7° for men in the older cohort [$p = 0.18$]).

Comparison of mean linear measurements revealed an anterior migration of the inferior fat pad between younger and older cohorts (4.2 mm vs. 3.1 mm, respectively [$p = 0.007$]). The anterior shift was also noted between male and female subgroups (Table 5). A regression of the inferior orbital rim (7.6 mm vs. 9.0 mm [$p = 0.04$]) and anterior cheek mass (-3.6 mm vs. -0.7 mm [$p = 0.003$]) occurred with age. This trend was also found in the subgroup of female patients (Table 5). A posterior migration of the maxillary pyriform (4.1 mm vs. 6.2 mm [$p = 0.01$]) occurred with age in the female subgroup.

TABLE 3. Angular measurements of women

	Younger	Older	*p*
Glabellar (°)	76.1	71.0	0.01
Orbital (°)	79.4	74.6	0.01
Pyriform (°)	64.0	59.3	0.04
Maxillary (°)	60.6	52.4	0.0001

TABLE 4. Angular measurements of men

	Younger	Older	p
Glabellar (°)	72.3	66.0	0.003
Orbital (°)	78.0	72.8	0.01
Pyriform (°)	67.8	61.7	0.02
Maxillary (°)	63.8	57.1	0.0002

DISCUSSION

This study demonstrates that the craniofacial skeleton undergoes a change over time when comparing measurements in older versus younger subjects. Furthermore, these differences support the aging changes predicted by Lambros's algorithm, demonstrating both linear and angular changes to the craniofacial skeleton. Linearly, there is anterior displacement of the skeleton superior to the orbit and posterior displacement of the skeleton inferior to the orbit. These changes are accompanied by a decrease in angular measurements with age, best described as a clockwise rotation of the facial skeleton when viewed from the side and facing to the right. Unlike Pessa's study, however, we found that these changes were not uniform across the subset of subjects; they were more dramatic in women, especially in the midface region.

If the postulated rotation of the craniofacial skeleton is correct, one would predict the following changes in bony measurements with age: a decrease in each of the angular measurements; a decrease in all linear measurements superior to the orbit, including a decrease in the globe-to-orbital roof distance; and an increase in all linear measurements inferior to the orbit, including an increase in the globe-to-orbital floor measurements.

Each of these predictions was demonstrated by a statistically significant decrease in all angular measurements, both with respect to the total population and in the individual female and male subgroups (Tables 2–4). Only the inferior orbital rim and maxillary pyriform distances reached significance in the female subgroup, and none of the linear bony measurements achieved statistical significance in the male subgroup (Table 5).

In contrast to the skeletal measurements, both of the soft-tissue parameters studied, the anterior cheek mass and the lower eyelid fat pad, demonstrated anterior displacement with age. Such a displacement might be predicted by the loss of soft-tissue support associated with the angular rotation of the facial skeleton. The angular rotation may stretch and weaken facial fascia and ligamentous attachments, inducing mid facial ptosis and fat prolapse of the inferior fat pad.

More importantly, the nature and direction of the skeletal changes suggested by this study and by Lambros's algorithm could have profound effects on not only the aesthetics of the aging face but also the functional changes seen in the aging face. The rotation of the craniofacial skeleton centers around the orbit. As such, it may have particular relevance to oculoplastic surgeons in that it could contribute to many of the eyelid malpositions seen in aging patients. The intimate relationship between the lower eyelid and the inferior orbital rim make it reasonable to suggest that changes in inferior orbital rim position and midface might have direct effects on lower eyelid position.

Specifically, inferior and posterior displacement of the inferior orbital rim in aging might place inferiorly directed tension on the lower eyelid through the shared attachments of the orbital septum and lower eyelid retractors. Furthermore, angular rotation of the midface could cause loss of soft-tissue support for the cheek mass, resulting in an increased downward vector on the lower eyelid. The combination of these factors could lead to the increased inferior scleral show noted in aging patients; they could also be a contributing factor to lateral canthal tendon laxity and ectropion and entropion pathogenesis.

The negative vector concept describes this scenario where an exophthalmic orbit (or a relatively retrusive midface) is associated with a triad of clinical findings, including inferior scleral show, prominent lower eyelid fat pads, and tear trough deformity. Furthermore, patients with this bony morphology have been shown to be at increased risk of lower eyelid retraction after lower eyelid surgery.[7,17,19,21]

The differences in angular and bony measurements support the concept that the facial skeleton continues to change throughout adulthood. This study also demonstrates that the relative position of the soft tissues also change with age. It remains unclear what relative part soft-tissue changes and skeletal changes play in the aging face. This question is further complicated by the fact that soft-tissue changes have been demonstrated to affect bone physiology, and bony changes likely affect soft-tissue support. It is even further complicated by the yet unknown but likely confounding variables of gender, race, and general health, among others. Despite this, these findings warrant the consideration of skeletal changes as a possible contributing factor to the aesthetic and functional changes associated with aging.

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TABLE 5. Comparison of linear measurements by age and gender

	Younger (mm)	Older (mm)	Δ Overall	Δ Women (mm)	Δ Men (mm)
Superior orbital rim	5.1	4.4	−0.7	−1.2	−0.3
Inferior fat pad	4.2	3.1	−1.1* (p = 0.007)	−1.1* (p = 0.007)	−1.1* (p = 0.05)
Inferior orbital rim	7.6	9.0	1.4* (p = 0.04)	2.0* (p = 0.01)	0.5
Anterior cheek mass	−3.6	−0.7	2.9* (p = 0.003)	4.0* (p = 0.003)	1.1
Maxillary pyriform	4.6	5.9	1.3	2.1* (p = 0.01)	0.3
Lateral orbital rim	18.2	18.3	0.1	0.4	0.0
Globe–roof	6.1	5.7	−0.4	−0.1	−0.7
Globe–floor	7.5	8.0	0.5	0.3	0.8

*Statistically significant p values are noted where applicable. All other comparisons are not statistically significant and p values ≥0.05 are omitted for reading clarity.

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