The Relationship between Bone Remodeling and the Clockwise Rotation of the Facial Skeleton: A Computed Tomographic Imaging–Based Evaluation

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Background: Information on the onset and gender differences of midfacial skeletal changes, including the complete understanding of the theory behind the clockwise rotational theory, remains elusive.
Methods: One hundred fifty-seven Caucasian individuals (10 men and 10 women aged 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, 70 to 79 years, and 80 to 89 years, and eight men and nine women aged 90 to 98 years) were investigated. Multiplanar computed tomographic scans with standardized angle and distance measurements in all three anatomical axes and in alignment to the sella-nasion (horizontal) line were conducted.
Results: Both men and women displayed an increase in orbital floor angle ($p < 0.001$, maximum at 60 to 69 years), decrease in maxillary angle ($p = 0.035$, 40 to 49 years), increase in palate angle ($p < 0.001$, 50 to 59 years), increase in vomer angle ($p = 0.022$, 30 to 39 years), but a decrease in the pterygoid angle ($p = 0.002$, 80 to 89 years). Orbital width decreased ($p < 0.001$, 60 to 69 years), pyriform aperture width increased ($p = 0.015$, 60 to 69 years), and midfacial height decreased with aging ($p < 0.001$, 60 to 69 years).
Conclusions: Age-related changes of the midfacial skeleton occurred independently of gender, but at various time points in different locations. The observed changes seem to be driven by a bone resorption center located in the posterior maxilla, rather than by a rotational movement of the facial skeleton. (*Plast. Reconstr. Surg.* 142: 1447, 2018.)

Facial aging is a multifactorial process involving different facial tissues: bone, ligaments, muscles, fat, and skin. The onset and the pace of age-related changes of each tissue type or structure vary between different individuals, genders, and ethnic backgrounds. The different facial bones provide the foundation for all overlying structures, and several previous studies have identified the importance of their age-related changes when trying to evaluate and treat the signs of facial aging.[1–13] Pessa,[2] using three-dimensional stereolithography and rapid prototyping, identified a decrease in the glabellar, orbital, maxillary, and pyriform angles in a sample of 12 men (age range, 21 to 68 years). They then formulated the clockwise rotation of the facial skeleton theory (when viewed from the right side).

In the following years, several additional investigations were conducted[3–7] that expanded our knowledge of the age-related changes that occur in the facial bones. It was reported that with increasing age, in addition to the changes in facial angles, the pyriform aperture enlarges, the inferior orbital rim descends, and the area of the orbital aperture increases.[3–7] Because these types of analyses are prone to high variability as a result of

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interindividual and gender-related morphologic differences,[7] some of the results were inconsistent when compared with one another. When evaluating the signs of facial aging, it is of great clinical relevance to understand the progress of bony facial aging and the differences between men and women to plan the best therapeutic strategies.

The aim of the present investigation was to measure, in a large, gender-balanced sample size, the changes in angles and widths of the midfacial skeleton, to identify in which decade the greatest bony changes occur, and to understand the gender-specific differences during bony facial aging. In addition to the traditional midfacial angles and widths, we expanded our measurements to include angles of the orbital floor, the palate, vomer, and the pterygoid plate to test whether the clockwise rotation theory applies to the total viscerocranium (element of the skull that is not a part of the brain case) or whether it applies only to the surface of the facial skeleton.

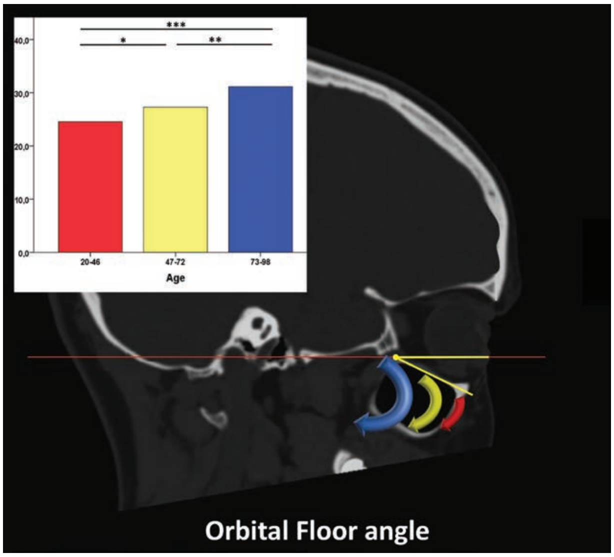

Fig. 1. Computed tomographic scan showing the measurement for the inclination of the orbital floor. Images were aligned in all three anatomical axes (*x*, *y*, and *z*). The *red horizontal line* represents a line parallel to the sella-nasion (horizontal) line. *Inset* shows mean values as a bar graph for the young (*red*) (20 to 46 years; $n = 56$), middle (*yellow*) (47 to 72 years; $n = 50$), and old (*blue*) (73 to 98 years; $n = 51$) age groups. The *arrows* show the amount of change in orbital floor angle according to their size and the age group according to their color. *Significant difference between age groups with $p < 0.05$ to 0.01; **significant difference between age groups with $p < 0.01$ to 0.001; ***significant difference between age groups with $p < 0.001$.

SUBJECTS AND METHODS

Study Sample

We investigated cranial computed tomographic images obtained from 157 Russian Caucasian individuals (78 men and 79 women) with a mean age of 58.23 ± 22.68 years. The total sample consisted of 10 men and 10 women aged 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, 70 to 79 years, and 80 to 89 years, and eight men and nine women aged 90 to 98 years.

Computed tomographic images were sampled from the cranial computed tomographic image database of the Research and Practical Center of Medical Radiology of the Department of Health Care. Computed tomographic scans were previously obtained during routine cranial computed tomographic examinations. Scans showing current or previous viscerocranial or neurocranial fractures or irregularities of cranial fusion were not included in this analysis. The study was approved by the ethics committee of the Department of Health, Moscow, Russia, and patients gave their informed consent before enrolment for the use of their computed tomographic scans for scientific purposes.

Image Analyses

Computed tomographic images were generated by a Toshiba Aquilion LB scanner (Toshiba Medical Systems Corp., Ōtawara, Tochigi, Japan) using the following parameters: 220-mm field of view, 0.47-mm slice thickness, 140-mA tube current, and 120-kV voltage. Analyses relied on multiplanar reconstructions with standardized angle and distance measurements in all three anatomical axes (*x*, *y*, and *z*) and were aligned to the sella-nasion (horizontal) line.[4–6] All measurements were conducted by experienced computed tomography analysts using Intellispace 8.0 (Philips, Koninklijke, Amsterdam, The Netherlands). The following nine measurements were performed:

1. Orbital floor angle: Angle between the sella-nasion line and the slope of the orbital floor as measured in the (vertical) midpupillary line (Fig. 1).
2. Maxillary angle: Angle between the sella-nasion line and the anterior surface of the maxilla inferior to the infraorbital foramen (Fig. 2).
3. Midfacial angle: Angle between the sella-nasion line and the direct connection between the nasion and the base of the nasal spine as seen in the midline.

4. Palate angle: Angle between the sella-nasion line and the slope of the hard palate as seen in the midline (Fig. 3).
5. Vomer angle: Angle between the sella-nasion line and the posterior border of the vomer as seen in the midline.
6. Pterygoid angle: Angle between the sella-nasion line and the slope of the anterior border of the pterygoid process (posterior boundary of the pterygomaxillary fissure) (Fig. 4).
7. Orbital width: Distance between the internal medial and most anterior lateral orbital margin as measured in the (horizontal) midpupillary line in a transverse plane.
8. Pyriform width: Distance between left and right internal bony margin at the level of the infraorbital foramen, measured in a computed tomographic slide where the first total closure of the pyriform aperture in the frontal plane was observed.
9. Midfacial height: Distance between nasion and base of the nasal spine.

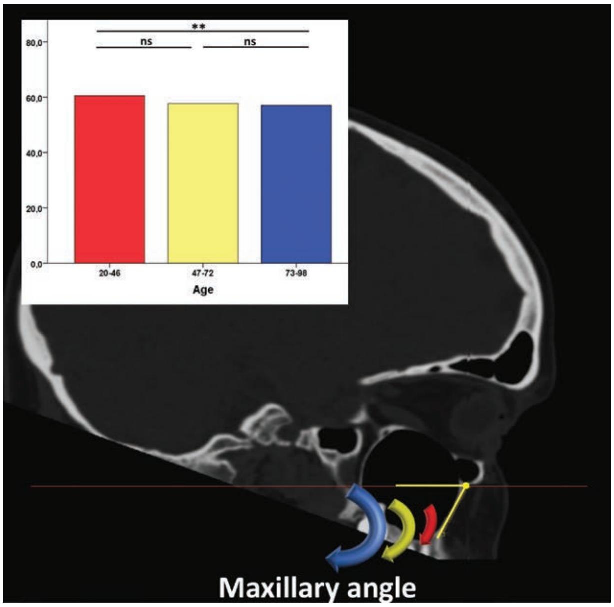

Fig. 2. Computed tomographic scan showing the measurement for the inclination maxillary angle. Images were aligned in all three anatomical axes (*x*, *y*, and *z*). The *red horizontal line* represents a line parallel to the sella-nasion (horizontal) line. *Inset* shows mean values as a bar graph for the young (*red*) (20 to 46 years; $n = 56$), middle (*yellow*) (47 to 72 years; $n = 50$), and old (*blue*) (73 to 98 years; $n = 51$) age groups. The *arrows* show the amount of change in maxillary angle according to their size and the age group according to their color. **Significant difference between age groups with $p < 0.01$ to 0.001; *ns*, not significant (i.e., $p > 0.05$).

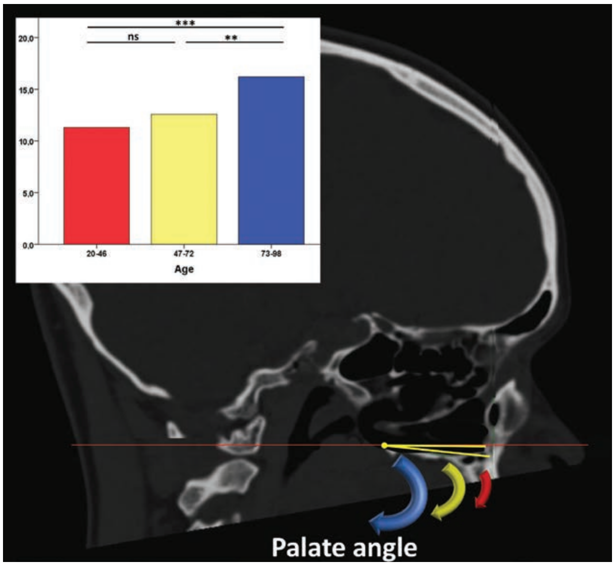

Fig. 3. Computed tomographic scan showing the measurement for the inclination palate angle. Images were aligned in all three anatomical axes (*x*, *y*, and *z*). The *red horizontal line* represents a line parallel to the sella-nasion (horizontal) line. *Inset* shows mean values as a bar graph for the young (*red*) (20 to 46 years; $n = 56$), middle (*yellow*) (47 to 72 years; $n = 50$), and old (*blue*) (73 to 98 years; $n = 51$) age groups. The *arrows* show the amount of change in palate angle according to their size and the age group according to their color. **Significant difference between age groups with $p < 0.01$ to 0.001; ***significant difference between age groups with $p < 0.001$; *ns*, not significant (i.e., $p > 0.05$).

Statistical Analyses

Measurements were performed at least three times and validated by two independent observers. Bilateral measures were conducted for each side individually, and the mean value was used for further statistical analyses. Differences in angles and distances between genders were computed using the independent *t* test and across age groups using one-way analysis of variance with the Tukey post hoc test using IBM SPSS Version 23 (IBM Corp., Armonk, N.Y.). Age groups were stratified by decade (20 versus 30 versus 40 versus 50 versus 60 versus 70 versus 80 versus 90 years; $n = 20$ each) and by trimester [young, 20 to 46 years ($n = 56$); middle, 47 to 72 years ($n = 50$); and old, 73 to 98 years ($n = 51$)]. If gender differences were detected, generalized linear models with a robust estimator were calculated to identify the independent effect of both. Results were considered statistically significant at a probability level of $p \leq 0.05$ to guide conclusions.

RESULTS

The mean orbital floor angle was 24.55 ± 5.02 degrees for the young, 27.30 ± 5.10 degrees

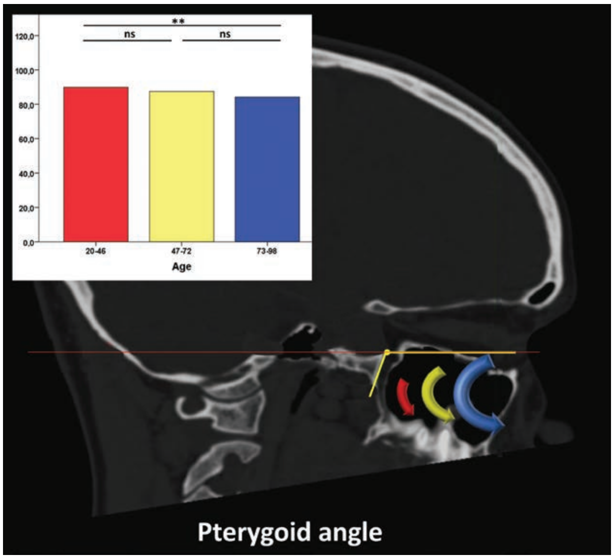

Fig. 4. Computed tomographic scan showing the measurement for the change in pterygoid angle. Images were aligned in all three anatomical axes (*x*, *y*, and *z*). The *red horizontal line* represents a line parallel to the sella-nasion (horizontal) line. *Inset* shows mean values as a bar graph for the young (*red*) (20 to 46 years; *n* = 56), middle (*yellow*) (47 to 72 years; *n* = 50), and old (*blue*) (73 to 98 years; *n* = 51) age groups. The *arrows* show the amount of change in pterygoid angle according to their size and the age group according to their color. **Significant difference between age groups with $p < 0.01$ to 0.001; *ns*, not significant (i.e., $p > 0.05$).

for the middle, and 31.16 ± 6.69 degrees for the old age groups ($p < 0.001$), with no statistically significant difference between genders ($p = 0.285$). Using adjusted models revealed that age, but not gender, had a significant influence on the increase of the angle (OR, 1.13; 95 percent CI, 1.09 to 1.18). When comparing the various decades, the greatest increase in the orbital floor angle was noted between ages 60 and 69 years, with 7.01 degrees (Table 1 and Fig. 1).

The mean maxillary angle was 60.52 ± 7.28 degrees, 57.70 ± 7.82 degrees, and 57.00 ± 7.14 degrees in the young, middle, and old age groups, respectively ($p = 0.035$) with no statistically significant difference between genders ($p = 0.239$). Adjusted models revealed age, but not gender, to significantly influence the decrease of the angle (OR, 0.94; 95 percent CI, 0.89 to 0.98). When comparing the various decades, the greatest decrease was noted between ages 40 and 49 years, with −1.76 degrees (Table 1 and Fig. 2).

The mean midfacial angle was 77.52 ± 4.83 degrees, 79.18 ± 4.15 degrees, and 79.33 ± 4.44 degrees in the young, middle, and old age groups without a statistically significant difference between groups ($p = 0.070$) or genders ($p = 0.672$) (Table 1). The inclination of the palate was 11.30 ± 3.18 degrees, 12.56 ± 4.59 degrees, and 16.19 ± 6.34 degrees in the young, middle, and old age groups, with $p < 0.001$, but without a statistically significant difference between genders ($p = 0.896$). Adjusted models revealed age, but not gender, to influence the increase of the angle (OR, 1.10; 95 percent CI, 1.06 to 1.13). When comparing the various decades, the greatest increase was noted between ages 50 and 59 years, with 2.66 degrees (Table 1 and Fig. 3).

The posterior margin of the vomer formed an angle with the sella-nasion line of 51.36 ± 10.40 degrees in the young, 50.49 ± 9.79 degrees in the middle, and 55.77 ± 10.44 degrees in the old age group ($p = 0.022$), with no statistical difference between genders ($p = 0.129$). Using adjusted models, age was identified as having a significant influence, whereas gender did not (OR, 1.08; 95 percent CI, 1.01 to 1.16). When comparing the various decades, the greatest increase was noted between ages 30 and 39 years, with 10.36 degrees (Table 1).

Table 1. Age-Related Absolute Values of Facial Angles

	Age Group*			*p*†		
Angles	Young (deg)	Middle (deg)	Old (deg)	Difference across Groups (ANOVA)	Difference between Genders (*t* test)	Decade with Greatest Change (yr)
Orbital floor	24.55 ± 5.02	27.30 ± 5.10	31.16 ± 6.69	<0.001	0.285	60–69
Maxillary	60.52 ± 7.28	57.70 ± 7.82	57.00 ± 7.14	0.035	0.239	40–49
Midfacial	77.52 ± 4.83	79.18 ± 4.15	79.33 ± 4.44	0.070	0.672	70–79
Palate	11.30 ± 3.18	12.56 ± 4.59	16.19 ± 6.34	<0.001	0.896	50–59
Vomer	51.36 ± 10.40	50.49 ± 9.79	55.77 ± 10.44	0.022	0.129	30–39
Pterygoid	89.83 ± 6.15	87.46 ± 11.32	84.17 ± 6.32	0.002	0.735	80–89

ANOVA, analysis of variance.
*Young, 20–46 yr ($n = 56$); middle, 47–72 yr ($n = 50$); and old, 73–98 yr ($n = 51$) individuals. Values are given in mean value ± SD in degrees.
†Probability values are given for testing across the three age groups using ANOVA and for comparing men vs. women using the independent *t* test.

The pterygoid angle was measured to be 89.83 ± 6.15 degrees in the young, 87.46 ± 11.32 degrees in the middle, and 84.17 ± 6.32 degrees in the old age group (p = 0.002), with no statistical difference between genders (p = 0.735). Using adjusted models, age was identified as having a significant influence, whereas gender did not (OR, 0.90; 95 percent CI, 0.86 to 0.94). When comparing the various decades, the greatest decrease was noted in those aged 80 to 89 years with −10.49 degrees (Table 1 and Fig. 4).

The width of the orbit was 37.24 ± 2.89 mm, 37.51 ± 1.92 mm, and 35.78 ± 2.23 mm in men and 35.66 ± 1.33 mm, 35.20 ± 2.78 mm, and 35.76 ± 1.19 mm in women in the young, middle, and old age groups, respectively (gender difference, p < 0.001). A statistical significance was noted in men across age groups (p = 0.022), but not in women (p = 0.538). When including age and gender together into generalized linear models, an overall statistically significant decrease in orbital width was observed (OR, 0.99; 95 percent CI, 0.97 to 0.99) with significant influence of age (p = 0.033) and gender (p < 0.001). The greatest decrease in men was detected to occur between ages 80 and 89 years, with −1.99 mm, and in women between ages 60 to 69, with −1.92 mm (Table 2).

The width of the pyriform aperture was measured to be 22.56 ± 2.49 mm in the young age group, 23.87 ± 2.85 mm in the middle age group, and 23.77 ± 2.40 mm in the old age group (p = 0.015), without statistically significant differences between genders (p = 0.546). Using adjusted models, age was identified to have a significant influence, whereas gender did not (OR, 1.03; 95 percent CI, 1.01 to 1.04). When comparing the various decades, the greatest increase occurred between ages 60 and 69 years, with 1.31 mm (Table 2).

The height of the midface was 51.70 ± 3.62 mm, 51.26 ± 3.94 mm, and 46.99 ± 3.86 mm in men and 47.33 ± 3.86 mm, 46.42 ± 3.38 mm, and 44.14 ± 4.02 in women in the young, middle, and old age groups, respectively (gender difference, p < 0.001). There was a statistically significant difference across age groups for both men (p < 0.001) and women (p = 0.010). Using adjusted models, age and gender were identified to significantly influence the decrease in midfacial height (both p < 0.001; OR, 0.92; 95 percent CI, 0.90 to 0.94). The greatest decrease was found to occur in men aged 80 to 89 years, with −2.62 mm, and in women aged 80 to 89 years, with −5.03 mm (Table 2).

DISCUSSION

The results of this large sampled (n = 157) and gender-balanced (78 men and 79 women) investigation revealed a change in facial angles that can be summarized as a clockwise rotation of the midfacial skeleton (when viewed from the right side): an increase in the orbital floor angle (p < 0.001), a decrease in the maxillary angle (p = 0.035), an increase in the palate angle (p < 0.001), and an increase in vomer angle (p = 0.022). These changes occurred similarly in men and women. We were able to identify, however, that the pterygoid angle decreases with increasing age (p = 0.002, independent of gender); this represents a counterclockwise rotation of the bony structures posterior to the maxilla (when viewed from the right side) (Fig. 5). In addition, we were able to show that anthropometric measures such as the width of the orbit and the height of the midface (but not the width of the pyriform aperture) were significantly smaller in women compared with men, but, independent of gender, underwent an age-related decrease (orbital width, p = 0.033; pyriform width, p = 0.015; and midfacial height, p < 0.001).

A strength of the present study is the large sample size (n = 157), which is larger than any

Table 2. Age-Related Absolute Values of Facial Widths

	Age Group*			p†		
Distances	Young (mm)	Middle (mm)	Old (mm)	Difference across Groups (ANOVA)	Difference between Genders (t test)	Decade with Greatest Change (yr)
Orbital width	36.40 ± 2.31	36.36 ± 2.64	35.77 ± 1.80	Men, 0.022; women, 0.538	<0.001	60–69
Width pyriform aperture	22.56 ± 2.49	23.87 ± 2.85	23.77 ± 2.40	0.015	0.546	60–69
Midfacial height	49.36 ± 4.32	48.84 ± 4.38	45.65 ± 4.16	Men/women, <0.001	<0.001	60–69

ANOVA, analysis of variance.
*Young, 20–46 yr (n = 56); middle, 47–72 yr (n = 50); and old, 73–98 yr (n = 51) individuals. Values are given in mean value ± SD in millimeters.
†Probability values are given for testing across the three age groups using ANOVA and for comparing men vs. women using the independent t test.

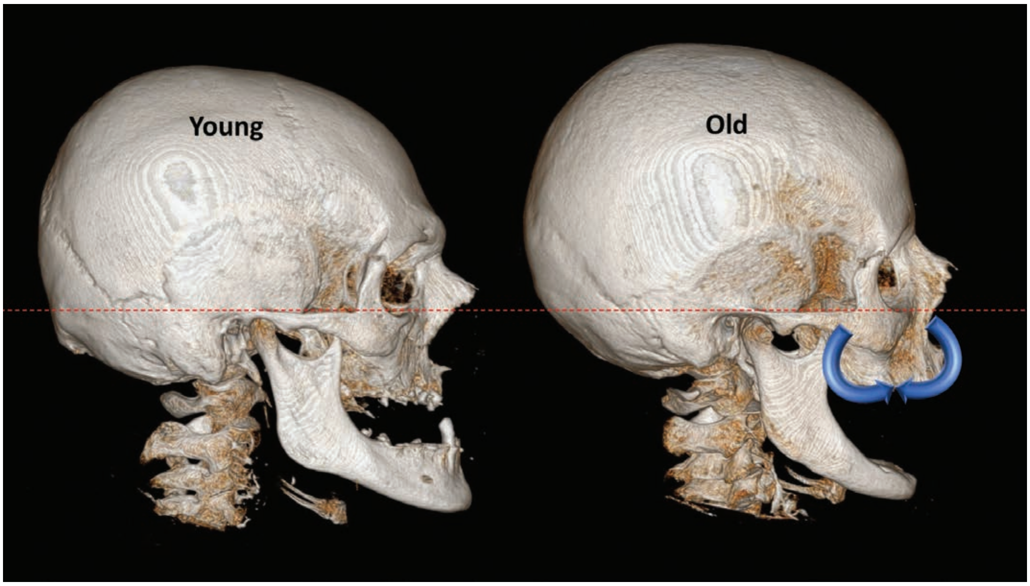

Fig. 5. Comparison of the three-dimensional volume-rendered cranial computed tomographic scans of a young man versus an old man. The changes occurring in the midface of the old individual are summarized by the *blue arrows*. The *red dotted line* is used to compare the level of the upper margin of the zygomatic arch between individuals. Note the age-related loss in mandibular height.

previously conducted investigation in a Caucasian population.[4,5,14] This enables one to potentially measure true changes of age-related bone morphology rather than interindividual or gender-dependent variability.

Another strength of the present investigation is the balanced distribution of men and women. This unique sample with 10 men and 10 women per decade facilitates valid comparisons between genders to estimate distinct gender-dependent differences in facial bone aging. This can help to guide therapeutic options for better and longer-lasting effects. Our results reveal that changes in facial angles take place independent of gender; this indicates that the process of aging in the bony facial skeleton is an event that occurs similarly in both men and women. However, the width of the orbit ($p = 0.033$) and the height of the midface ($p < 0.001$), but not the width of the pyriform aperture ($p = 0.546$), were significantly smaller in women compared with men. These findings are plausible as, in general, women have smaller heads than men.[10]

We found that the width of the orbit, when measured in the (horizontal) midpupillary line, significantly decreased with aging ($p = 0.033$). Previous studies[3,4,8] reported conclusively that the diagonal diameter of the orbital aperture increases with aging caused by bony changes in the superomedial and inferolateral aspects. These changes did not seem to occur in the (vertical) midpupillary line or did not seem to affect the orbital width.[2,7,10] A recent study by Karunanayake et al.[7] compared computed tomographic scans of the same individual at different time points and reported findings similar to ours relative to a decrease in orbital width. Their study design[7] allowed longitudinal measurements—even if conducted in a small sample size—and the variability reported could have been the result of true change rather than that of interindividual variability.

Changes of the facial skeleton were observed to begin independent of gender between age 20 and 29 years and to continue throughout one's lifetime. However, we were able to identify decades that were more prone to bony change compared with others (Table 1); this indicates that the pace of age-related changes is inhomogeneously distributed across various facial regions. Whereas the maxillary angle displayed the greatest change between 40 and 49 years, the orbital floor was measured to have the greatest change between 60 and 69 years (Fig. 6). The vomer showed the greatest change in the decade between 30 and 39 years and the midfacial angle between 70 and 79 years; this highlights the spatial differences of bony change (Tables 1 and 2 and Fig. 6). From a clinical perspective, treatment options could be initiated before these changes occur in anticipation of the future aging of the facial skeleton.

Bony changes cannot be modified per se, but the resulting changes affecting the anchoring

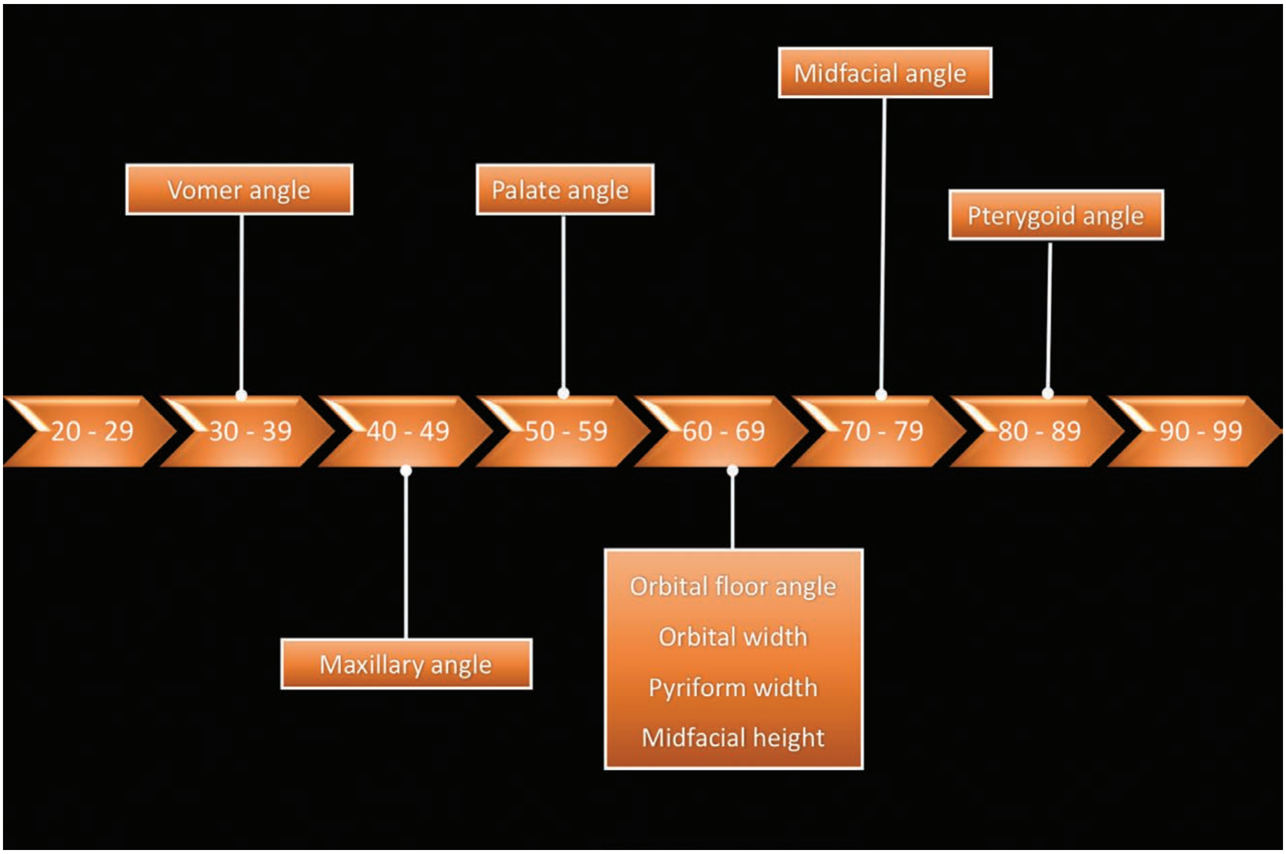

Fig. 6. Timeline of the greatest bony changes in midfacial angles and widths.

ligaments and the overlying fat, muscles, and skin, such as descent of superficial and deep fat compartments and laxity of the overlying soft tissue and skin, can be approached more methodically with a better understanding of the age-related alterations that occur in the facial bones. When looking at the 2016 procedure statistics of the American Society of Plastic Surgeons, our results provide a reasonable explanation for why the age group between 40 and 54 years received the highest number of minimally invasive treatments (7.0 million in the United States) compared with other age groups.[15] In this age group, the greatest change occurred in the maxillary angle, which contributes significantly to the shape of the (superficial) midfacial skeleton and thus to the appearance of the midface.

The changes in facial angles have been previously summarized by Pessa[2] as a clockwise rotation of the midface relative to the cranial base and inappropriately termed "Lambros' theory."[14] If the postulated rotation of the viscerocranium occurred, the structures posterior to the maxilla (i.e., structures in the pharyngeal and pterygopalatine region such as the pharynx, auditory tube, contents of the pterygopalatine fossa, and so forth) would be at risk for compression and loss of function during the aging process. As this does not occur, it is questionable whether Lambros' theory holds true and whether the viscerocranium does, in fact, move against the cranial base. Our results were able to identify that, with increasing age, the slope of the orbital floor, inclination of the hard palate, and angle of the posterior bony margin of the vomer all increase, whereas the anterior wall of the maxilla regresses (all statistically significant and independent of gender). These changes confirm the previously reported superficial changes[5,6,14] and further expand our understanding of other bony changes that occur, specifically related to the depth of the maxilla. However, we also identified that the pterygoid angle—the anterior margin of the pterygoid process—undergoes a counterclockwise movement (when viewed from the right side; $p = 0.002$), contrary to the movement performed by the maxilla. As this structure lies posterior to the maxilla, it is plausible that the total process is attributable to bone resorption of the posterior maxilla than to bone rotation. Based on the results of our investigation, it might be more appropriate to describe the facial bony changes as an age-related event caused by bone remodeling with consequent changes in facial angles and widths independent of gender in the Caucasian population (Fig. 5).

The change in midfacial vectors can be observed clinically with laxity and inferior displacement of the overlying soft tissues: ligaments, muscles, fat compartments, and skin. Treatments designed to reverse the signs of facial aging aim, therefore, to generate superior or superolateral vectors to counteract and offset the effects of the bony changes and those of gravity. With advancing age, the changing inclination of the orbital floor angle increases the likelihood of pseudoherniation of intraorbital fat and the formation of palpebral bags. It can be assumed that the greater incline enables the intraorbital fat pads to slide anteriorly and inferiorly, contributing to the formation of palpebral bags. As the greatest change in orbital floor inclination is observed between age 60 and 69 years, it is understandable that this event is a sign of more advanced aging and can be observed, in general, later than midfacial sagging (Fig. 6). Other factors may be involved, but the bony changes in the orbital floor certainly facilitate this process.

CONCLUSIONS

Age-related changes of the facial skeleton occur independently of gender but at different ages in different locations. Therapeutic options should be planned accordingly, and the results of our investigation may help establish a time sequence for the performance of such procedures. More importantly, our study points to the conclusion that the changes in angles and width seem to be driven by a bone resorption center located in the posterior maxilla, rather than the previous postulated rotational movement of the facial skeleton against the cranial base.

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