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A morphometric study of age- and sex-dependent changes in eyebrow height and shape☆

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Summary *Background:* Rejuvenation procedures of the periorbital region and the forehead, with the eyebrow as a key structure, are often performed in plastic surgery. There is no common consent on the changes of aging in this region and the consecutive treatment options. This study was designed to support the body of literature with a broader data basis about the natural changes of eyebrow position and its shape.

Methods: The brow shape, the lid axis, and the distance between both medial canthi (DMC) were analyzed retrospectively on randomly selected standardized photographs of healthy Caucasian females and males. Six defined heights of the upper brow border, including the position and height of the highest brow point (HBP) and the angle of the upper brow line, were measured.

Results: A total of 244 Caucasian females and males in two groups (<34 years and >55 years) were analyzed. The data showed a difference between brow shapes of young females and males, especially relating to the HBP, which is located medially in young females. The brow shape of females assimilates toward a male shape with aging. The eyebrow moves upward, the DMC widens, and the lid axis drops laterally in both sexes with aging.

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Conclusions: Our data suggest that rejuvenation procedures should focus on not only lifting the brow but also reshaping and stabilizing the brow, especially the HBP, which plays an important role in defining the upper brow line. Our findings can explain why lifting the brow can create not only an undesired surprise but also an older look.

Introduction

Rejuvenation procedures have ever since relied on trying to reverse the changes in facial anatomy, which are caused by facial aging and, in turn, are described by theories of facial aging. To achieve a natural result, the performed changes have to move the individual back to a point earlier in time. Thus, the correct description of the exact changes that occur over time is of paramount importance in facial plastic surgery. Yet, the precise description of these changes with aging has proven to be challenging.[1,2] This is due to the complex anatomy, a high degree of interindividual and ethnical variations, and a varying understanding of facial harmony or beauty.[2] In the upper face, it is particularly difficult to define changes with aging.[1] There is a constant presence of dynamic alterations that take place as part of the mimic and compensation processes for static changes of facial structures over time,[3] the latter being the main reason for compensatory elevation of the eyebrow position by frontalis muscle activation to antagonize the ptotic brow during aging.[3] This process makes the static evaluation of the upper facial third particularly difficult and leads to differing results of studies trying to observe the exact changes of this facial area.[4-7]

Although the main concept of most rejuvenation procedures of the upper face relies on an elevation ("lifting") of the respective facial structures and several groups including our own have shown that different surgical procedures succeed in achieving this goal,[8-15] the underlying aging process is yet to be fully understood. The fact that some studies show the opposite effect during upper facial aging – the rising of the eyebrows – may be an explanation why the sometimes possibly overaggressively applied forehead lifting has led to unsatisfactory results, which present as an unnatural appearance or transport an unintended mimic expression (e.g., surprise).[8] The resulting lifted and surprised look might be the main reason for an observable decrease in popularity of these procedures and a more critical approach to upper facial rejuvenation. Again, the media and beauty industry seem to transport a changing ideal in recent years rather than the overly high and arching eyebrow with a maximum of distance between upper lid border and brow.[16]

To better understand the physiological "behavior" and age-dependent changes of the upper face, this study was designed to support the literature body with a broader data basis about the natural changes of eyebrow position and its shape in a large study cohort of Caucasian subjects. To our knowledge, thus far, there is no such study evaluating the age-dependent changes in the eyebrow height and shape in a comparably sized study group in both sexes.

Patients and methods

From a database, all eligible patient photographs from the Department of Plastic and Hand Surgery Department, University Medical Center Freiburg, Germany, were selected for evaluation. Pictures were taken from July 1996 to November 2014. Inclusion criteria were defined as Caucasian subjects, male and female, age between 15 and 82 years, a standardized full-frontal photograph with fully opened eyes, a straightforward gaze, and a relaxed facial expression. Exclusion criteria were injuries, scars, and Botox injections or surgeries of the upper facial half as well as syndromic and congenital abnormalities, facial paralysis, and all other known conditions, which might interfere with the measurements. All patients provided informed consent for the participation, and the principles outlined in the Declaration of Helsinki have been followed in this study.

Photographs were analyzed using Photoshop (©Adobe Systems, Inc., San Jose, California), and all anatomical points were selected manually. A line between both medial canthi was drawn, and the distance between both medial canthi (DMC) and the projection of the distance between the medial and lateral canthus on the DMC plane (ICD) was measured. Furthermore, for both eyes, distances from the DMC-plane to the upper border of the brow were measured at defined positions (H1: 1/4 ICD, H2: 1/3 ICD, H3: 2/3 ICD, H4: ICD, H5: 6/5). The highest brow point in reference to the DMC-plane was defined on the arch of the upper eyebrow border. Its distance from DMC was measured and recorded as HBP. Again, the horizontal deviation laterally from the medial canthus (Ax) was measured on the DMC. As this was a retrospective study, no markers for calibration could be placed on the original photographs. Therefore, all measured distances were standardized in relation to the white-to-white distance (WTW), which can be normalized by age as described by Rüfer et al.[17] (see Figure 1).

In addition, two angles were measured: the angle between the DMC plane and the intercanthal plane (angle α) and the angle that is formed by the upper border of the eyebrow ascending to the HBP point and the upper border of the brow that descends from HBP laterally (angle β). (See Figure 2)

Four groups were defined: female young "f(y)", male young "m(y)", female old "f(o)", and male old "m(o)", see Table 1. Statistical evaluation was performed using Student's t-test or if the normality test failed Mann-Whitney-White rank-sum test (Past 3 Statistics Software package, University of Oslo, Hammer, Ø., Harper, DAT, Ryan, PD 2001). As there was no statistically significant difference between the data of the left and right eyes, the data were merged and analyzed together. Statistical evaluation was

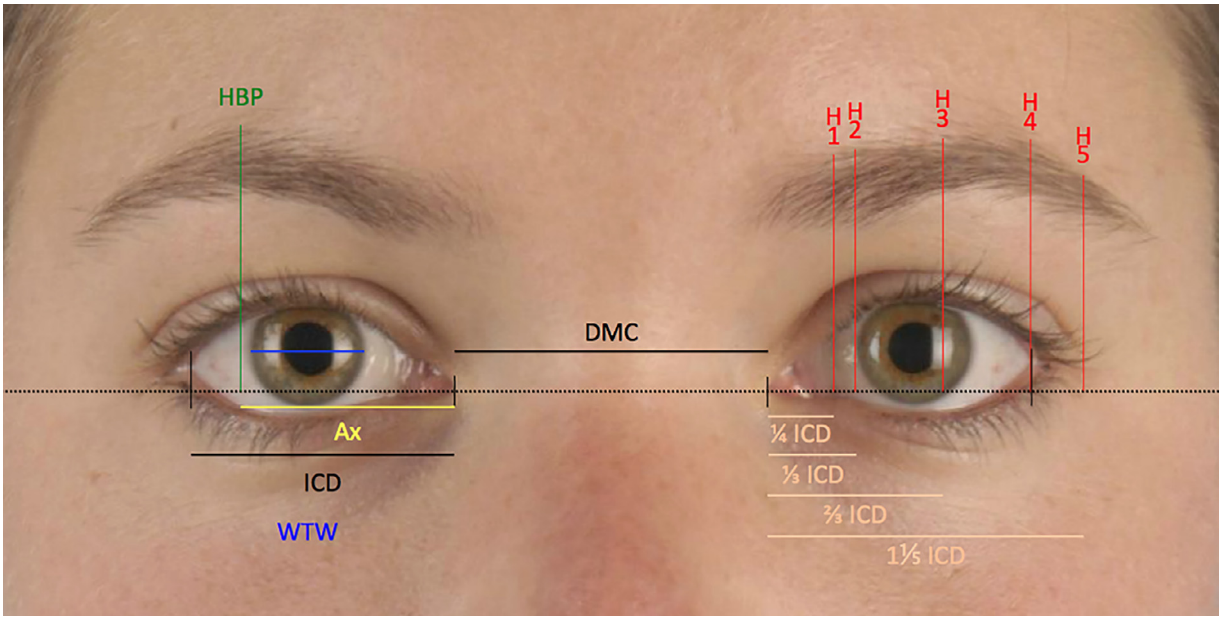

Figure 1 Measured dimensions. The dotted line marks the plane through both medial canthi and is the base of all height measurements (=DMC plane). DMC is the distance between both medial canthi, and ICD is the distance on the DMC plane between medial and lateral canthus. WTW means the horizontal diameter of the cornea, called as white-to-white distance. Five heights of the upper brow border were measured on defined distances lateral to the medial canthus (H1: 1/4 ICD, H2: 1/3 ICD, H3: 2/3 ICD, H4: ICD, H5: 6/5). HBP stands for the height of the highest brow point as seen from the DMC plane. Furthermore, the distance of the base of the HBP to the medial canthus on the DMC plane was measured (Ax).

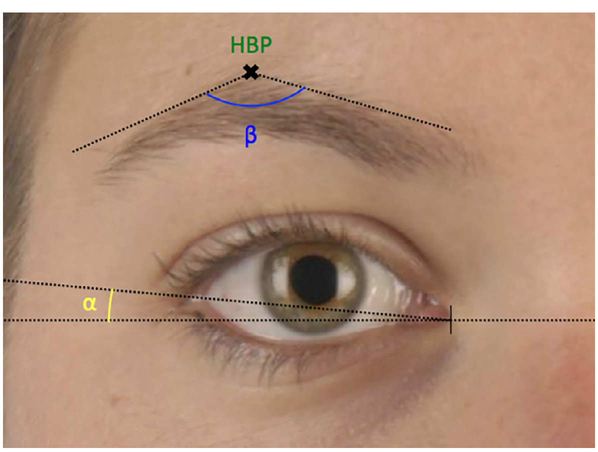

Figure 2 Measured angles. The angle between the DMC plane and the intercanthal plane (angle α) and the angle of the upper brow border lateral and medial of the HBP (angle β) were measured.

Table 1 Overview groups.

	Size (n)	Mean (years)	Minimum (years)	Maximum (years)	Range (years)	Median (years)
f (y)	74	23.6	16	31	15	24
m (y)	62	24.6	15	34	19	25
f (o)	56	64.8	55	80	25	64
m (o)	52	67.4	56	82	26	67
total	244					

completed by a linear regression analysis, which was performed for each distance and angle (Past 3) using age as a variable. To illustrate the results of the linear regression in a compressed manner, the y-values for H1-H5, HBP, and Ax on the regression line for ages 20 and 70 years are presented. Differences with a p-value smaller than 0.05 were considered as statistically significant and values lower than 0.001 as highly significant.

Results

Seventy-four young females (mean age between 16 and 31 years), 62 young males (mean age 15 to 34 years), 56 old females (mean age 55–80 years), and 52 old males (mean age 53 to 82 years) were included in this study. In total, the periorbital regions of 244 patients were analyzed, resulting in data of 488 periorbital regions. Descriptive statistics are shown in Table 1.

Figure 3 shows the results of the linear regression analysis for the DMC standardized to the WTW. The DMC in our cohort were statistically significantly longer with aging in males and females. There was no statistically significant difference between males and females whether young or old.

When comparing young females and males, there was no difference in the upper brow line medial of the HBP. The HBP of young females was significantly located more medial ($p < 0.001$) and lower ($p = 0.02$) than that of young males. The lateral upper brow line of young males was higher (H4: $p = 0.01$, H5: $p = 0.017$) than that in young females (Figure 4).

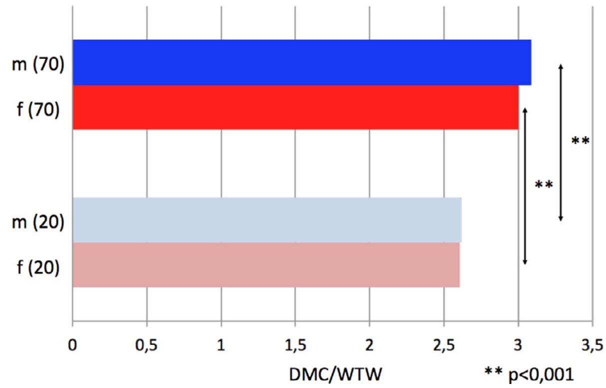

Figure 3 Linear regression analysis DMC/WTW. Calculated values for average male and female patients of age 20 or 70 years are shown here. Calculation was performed using the linear regression analysis data of our cohort. There is a statistically highly significant ($p < 0.001$) lengthening of the DMC standardized to the WTW in both genders in our cohort.

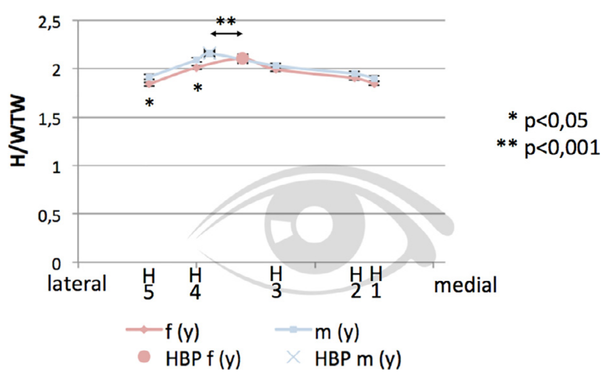

Figure 4 Comparison of mean values of H1-H5, HBP, and Ax between f (y) and m (y) standardized to WTW. This graph compares the mean values of all measured heights, the HBP, and Ax of the groups of young females (light red) and males (light blue) projected on a right eye. The error bars show the standard error of mean. H4, H5, and HBP are significantly higher ($p < 0.05$) in the group with young males than in the group with young females. The HBP is located more laterally in the group with young males than in the group with young females ($p < 0.001$).

There was no statistically significant difference related to the upper brow line between the group of old females and males in our cohort (see Figure 5). With aging, the HBP was located higher and more laterally in both genders. In females, all the measured points of the upper brow border were higher, whereas in males, only H3 and H4 moved upward (see Figures 6 and 7). Linear regression analysis results supported these findings in our cohort (see Figures 8 and 9).

Regarding the measured angles α and β (see Tables 2 and 3), our data showed that there was a statistically significant flattening of the intercanthal plane in aging in both genders, with no difference between f(y)/m(y) and f(o)/m(o). Angle β was smaller in young males than in young females (difference 7.26°, $p < 0.001$). This angle became smaller with aging in both genders (linear regression difference f(20), f(70): 20.18°, $p < 0.001$; m(20), m(70): 13.26°, $p < 0.001$).

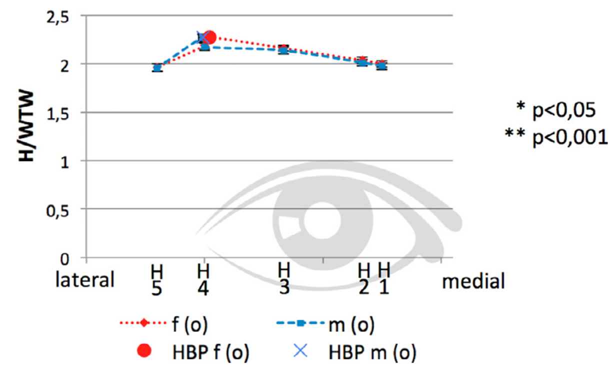

Figure 5 Comparison of mean values of H1-H5, HBP, and Ax between f (o) and m (o) standardized to WTW. This graph compares the mean values of all measured heights, the HBP, and Ax of the groups of old females (dark red) and males (dark blue) projected on a right eye. The error bars show the standard error of mean. There is no statistically significant difference in the mean values of the two groups.

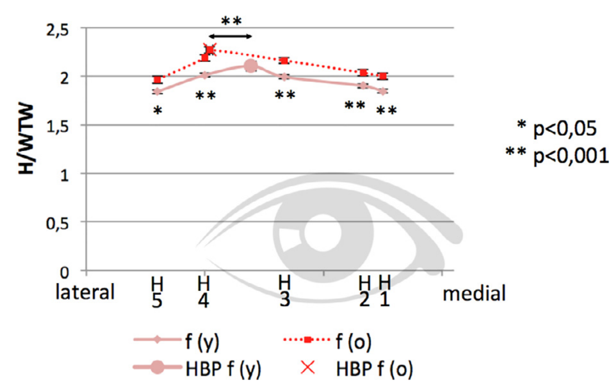

Figure 6 Comparison of mean values of H1-H5, HBP, and Ax between f (y) and f (o) standardized to WTW. This graph compares the mean values of all measured heights, the HBP, and Ax of the groups of young (light red) and old (dark red) females projected on a right eye. The error bars show the standard error of mean. All measured mean heights are statistically significantly higher in the group of old females, and the HBP is located more medially in the group of young females.

Table 2 Angle α.

α	mean	SEM		linear regression	
f (y/20)	4.27°	0.23°	n.s.	4.3°	
m (y/20)	3.81°	0.24°	**	3.99°	**
f (o/70)	2.78°	0.29°	**	2.68°	**
m (o/70)	2.12°	0.36°	n.s.	2.02°	

n.s.: not significant; **: $p > 0.001$.

Table 3 Angle β.

β	mean	SEM		linear regression	
f (y/20)	151.72°	0.74°	**	152.94°	
m (y/20)	144.46°	0.94°	**	145.16°	**
f (o/70)	134.60°	1.22°	**	132.76°	**
m (o/70)	132.00°	1.44°	n.s.	131.90°	

n.s.: not significant; **: $p > 0.001$.

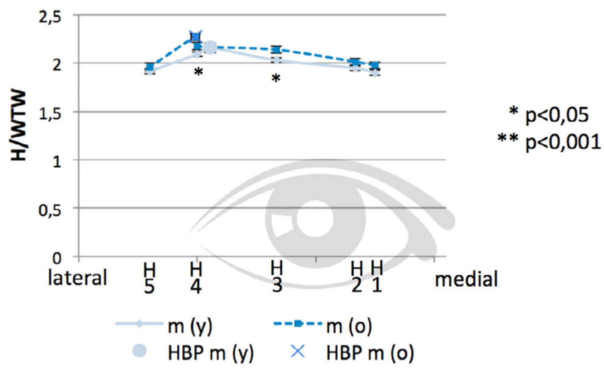

Figure 7 Comparison of mean values of H1-H5, HBP, and Ax between m (y) and m (o) standardized to WTW. This graph compares the mean values of all measured heights, the HBP, and Ax of the groups of young (light blue) and old males (dark blue) projected on a right eye. The error bars show the standard error of mean. H3, H4, and HBP are statistically significantly lower ($p < 0.05$) in the group of young males. There is no statistically significant difference in the position of the HBP on the DMC plane (Ax).

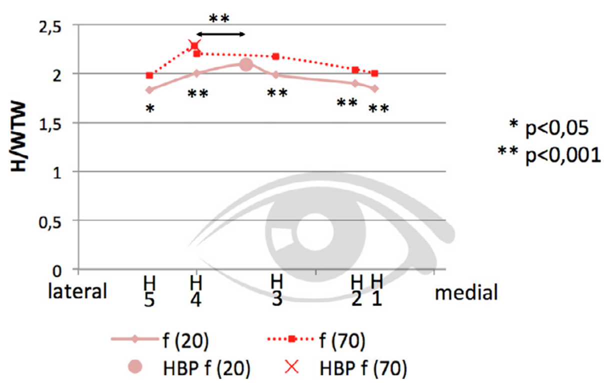

Figure 8 Linear regression analysis of H1-H5, HBP, and Ax standardized to WTW for females. The shown values are calculated for average individuals of age 20 (light red) and 70 (dark red) years using linear regression analysis data. All values are statistically significant lower in the average female at the age of 20 years.

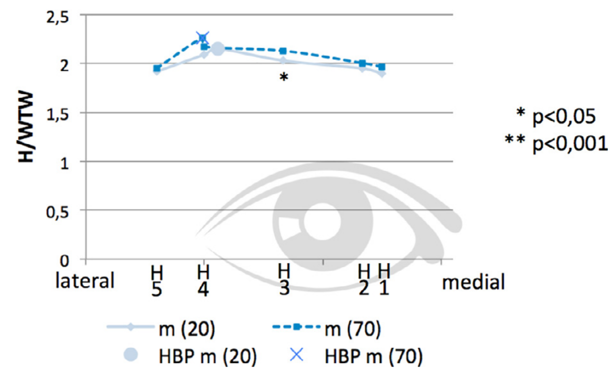

Figure 9 Linear regression analysis of H1-H5, HBP, and Ax standardized to WTW for males. The shown values are calculated for average individuals of the age of 20 (light blue) and 70 (dark blue) years using linear regression analysis data. H3 and HBP are statistically significantly lower in the average male at the age of 20 years.

Descriptive statistics for linear regression analysis are available as supplemental digital content (see Table, Supplemental Digital Content 1).

Figure 10 shows exemplary photographs of patients of all four groups.

Discussion

The fact that there are many different approaches for the evaluation of the periorbital region and the forehead with various, incommensurable, and sometimes opposed results [4-7,18,16,19,20] leads to a lack of a common consent on the changes of aging in this region and the consecutive treatment options. To propose clear algorithms, we believe that esthetic surgery of specifically treated anatomical regions needs to undergo systematic and reproducible evidence-based evaluation. Because of the high mobility of the anatomic landmarks, it is difficult to systematically evaluate the dynamic periorbital and forehead region. With the action of the frontalis muscle being not completely under voluntary control, a systematic evaluation is even more difficult. In this study, we aimed to establish a simple evaluation tool for interindividual comparison of the height of the upper border of the eyebrow and to describe and quantify the changes to the upper border of the eyebrow, the DMC, and the lid axis with aging.

To analyze the periorbital region using standardized photographs is a common and easily applicable procedure,[6,18,2,16,21] although the measured distances are just projections on the two-dimensional (2D) plane of photographs and may not represent the complex three-dimensional (3D) shape of the anatomical structures. When comparing measurements on different photographs, a standardized setting has to be guaranteed because a small change in the shooting angle can have a significant influence on the measured projections. Furthermore, when talking about the consistency of 2D photograph analysis of the periorbital region, the photo effect has to be discussed. Some individuals tend to activate the frontalis muscle while a photograph is taken. Particularly, when there is concomitant dermatochalasis or relevant brow ptosis, this induces reflective frontalis hyperactivity. To minimize these possible errors, all photographs used in this study were taken in a standardized setting with fully opened eyes, a straightforward gaze, and a relaxed facial expression.

There are different approaches of measuring the periorbital region and particularly the brow shape.[4-7,18,16,19,20] As described in the often cited method by Westmore,[22] it is common to use only a few measuring points, by giving just vague data about the entire brow line. Our study included six points along the upper brow line to get a more detailed description, even though we did not measure the lateral and medial ends of the upper brow border. 3D imaging is capable of producing even more precise and detailed data but is not yet commonly available, costly, time consuming, and sometimes difficult to evaluate when applying it for standard preoperative and postoperative documentations. The fact that the resolution is extremely

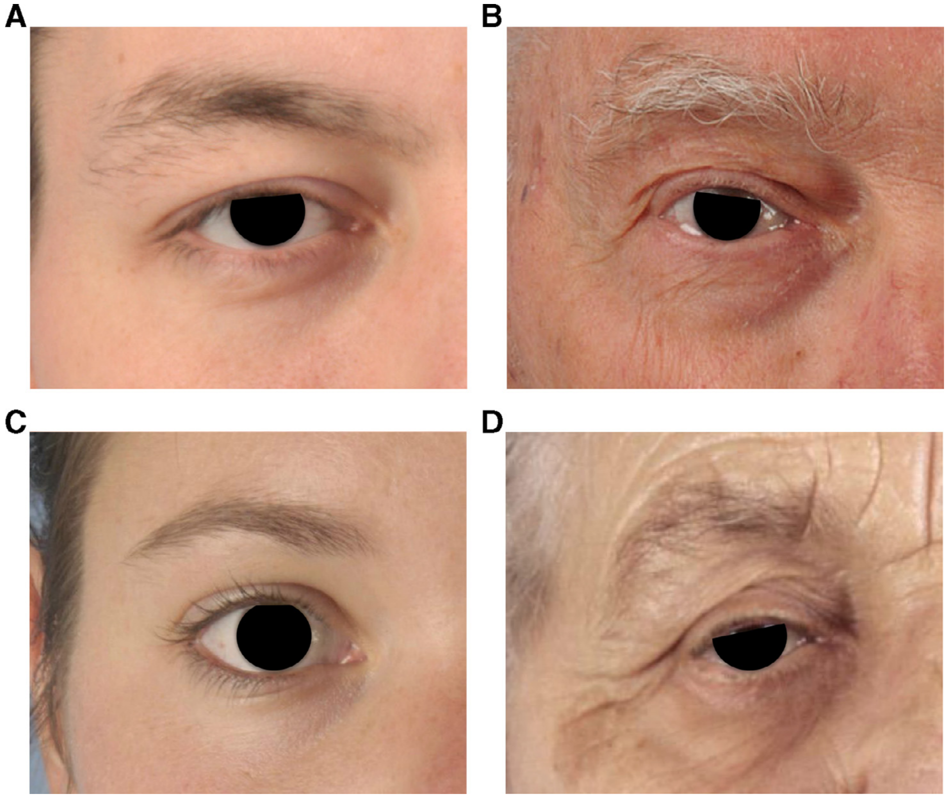

Figure 10 Individuals of all four groups. A: male 25 y, B: male 80 y, C: female 24 y, D: female 80 y.

high does not solve measurement errors caused by mimical movements, positional changes, or imprecise measurement methods. Coombes et al.[23] proved that analyzing standardized photographs using computer software is comparable and offers advantages over traditional, manual measuring methods. In this study, computer software was used for the performed measurements, but the anatomical reference points were selected manually. The selection error was tried to minimize by using defined anatomical points with sharp borders and only one author did perform the measurements.

Mainly in women, plucking is a widespread procedure to change the brow shape. By choosing the upper brow line as the measured landmark, one can reduce the error of plucking, as this procedure is usually used only to change the contour of the lower brow border.[16]

As this study is retrospective, there was no calibration mark on the photographs. Therefore, we used the age-adapted WTW distance for standardization. This method is often used and reliable,[6,24-26] as there is just small interindividual variation[17] although a direct calibration, as used in the work of Milbratz et al.,[27] would be more accurate.

In conclusion, our data showed that there is barely any difference in the height of the upper brow border comparing both genders in the same age group, while the position and the height of the HBP differ particularly between young females and males. The HBP in young males is located higher and more laterally than that in young females. This suggests that the brow is more angled in young males, whereas it is more round in young females. These findings are supported by the results of our measurement of angle β, which is statistically significantly smaller in young males than in young females.

Gunter and Androbus described an attractive eye including the eyebrow, and interestingly, the shown shape resembles our findings of an average eyebrow in young females.[2] Price et al.[6] found the position of HBP statistically significant more laterally in men than in women when comparing young people, but in contrast to our data, the HBP in old men was located more laterally than in old women. Their cohort “white women” of all ages had a significantly higher brow height across all ages, yet they did use the lower brow margin as a reference, measured the brow height with eyes closed, and used smaller groups.

Literature verifies the importance of the HBP, or more commonly described as the brow apex, in analyzing and reshaping the brow, as this point is a key structure of periorbital beauty and its placement has to be well considered when reshaping a brow.[6,2,28]

Comparing the changes in aging in our cohort, it can be concluded that the contour of the upper brow border and the height, as well as the position of the HBP, becomes more similar in both genders as they grow older. Our data suggest that the upper brow line of females and males converge during aging (see Figure 5). This means that the more round brow shape of young females assimilates with the more angled one of males, as shown by our data of angle β as well. Furthermore and very interestingly, the upper brow line moves upward with increasing age, especially in females. This may be due to more widespread frontalis hyperactivity. In our cohort, the intercanthal plane (angel α) flattens with aging.

There is no consistent concept of the age-dependent changes to the eyebrow in literature. On the one hand, some studies describe a lowering of the eyebrow in aging, especially in the lateral part, often defined as the lateral third.[29,3] On the other hand, there are data that the eyebrow is rising with aging[5,1] or that there is no change.[6] This discrepancy could be explained by the fact that there is a wide interindividual variation in age-dependent changes and groups of young and old individuals, as well as the term "aging" is not defined equally in different studies.

The position of the brow above the eye determines the visual size of the eye by creating the impression of a bigger eye with the brow being lower.[28] Therefore, the measured increase in brow height in elderly, especially in women, means that the eye itself appears visually smaller.

It has been frequently described[3,30,31] that aging in the periorbital region includes brow ptosis, and therefore, rejuvenation procedures should focus on lifting the brow. In the presented large cohort of Caucasians, we could not measure lowering but, in contrast, a rise of the upper brow line with aging, especially in women. This could be due to frontalis muscle hyperactivity as a compensatory mechanism. It is well known that age-related changes in the periorbital region include blepharochalasis, leading to a restriction of the field of vision.[32-34] An automatic and unconscious reflex is frontalis muscle activation to lift the eyebrow and the upper lid skin and thereby clear the field of vision. Further studies could shed more light on the dynamics of brow position by comparing the measurements with fully opened and fully closed eyes.

The fact that eyebrows of young individuals show significant differences between both genders is supported by our data.[6,35-38] As there is an increasing demand for rejuvenation procedures of the periorbital region in men,[39] this study can help to refine different approaches for each gender. It has already been reported that there are gender-specific differences in choosing a specific rejuvenation procedure, e.g., that endoscopic brow lifts are preferred in males.[37,40]

Our data suggest that regarding the upper brow line, rejuvenation procedures should not exclusively focus on lifting the brow but should rather also consider to reshape and stabilize, especially the highest brow point, which plays an important role in defining the upper brow line.[6,2,28] Furthermore, our findings can explain why lifting the brow in rejuvenation procedures of the periorbital region can sometimes create not only an undesired surprised but also an older look.[6]

Conflict of interest

The authors have no financial interest to declare in relation to the content of this article. No outside funding was received.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.01.011.

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