Age- and Gravity-Related Changes in Facial Morphology: 3-Dimensional Analysis of Facial Morphology in Mother-Daughter Pairs

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Purpose: There is increasing focus on the effects of gravity and age on facial appearance. Understanding these effects on facial morphology requires an accurate means of measuring surface topography. We present a preliminary study on the changes in facial topographic landmarks in a cohort of mothers and their daughters.

Materials and Methods: The faces of mother-daughter pairs (N = 15, aged 13 to 61 years) were imaged by stereophotogrammetry in the upright and supine positions. Twenty anthropometric surface landmarks were placed, and the corresponding x, y, and z coordinates were generated with custom software. The relative excursion of each landmark from the upright to the supine position was calculated.

Results: Movement of up to 7.3 mm occurred in the horizontal (x) plane, 5.7 mm in the vertical (y) plane, and 7.6 mm in the dorsoventral (z) plane. Significant movement ($P < .05$) in the vertical plane occurred in the upper lip, lateral canthi, labial commissures, and gonia. There was no significant movement in the dorsoventral plane. Maximal movement occurred in the lower third of the face in both groups but was more marked in the mothers.

Conclusions: Age- and gravity-related effects on the face can be accurately measured and documented with 3-dimensional imaging. This technique will allow comparison of rejuvenation techniques and a better understanding of the mechanisms of facial aging.

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Facial assessment is a fundamental aspect in the practice of plastic surgery. It is required in the monitoring of therapeutic response, to compare treatment modalities, be they surgical or nonsurgical, and to enable research into new therapies. Although many attempts have been made to quantify the process of aging, these attempts have been subjective,[1,2] and the changes that were documented could not be quantified. Furthermore, there has yet to be any study into the effects of posture on the soft tissues of the face.

The objectives of the study are to develop reliable landmarks for esthetic facial assessment and to show the changes in facial morphology by use of these landmarks with age and gravity.

Materials and Methods

DEVICE

The device used in this study is the VECTRA-3D dual module system for full face imaging (Canfield Scientific, Fairfield, NJ).

The VECTRA-3D system uses the concept of stereophotogrammetry, which generates 3-dimensional images by use of the technique of triangulation—that is, 2 cameras are configured as a stereo pair and used to determine the distance of a point on a 3-dimensional surface, provided that the surface (the face in this context) is within the focal distance of all of the

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FIGURE 1. VECTRA-3D dual module system for full face imaging. (LCD, liquid crystal display.)

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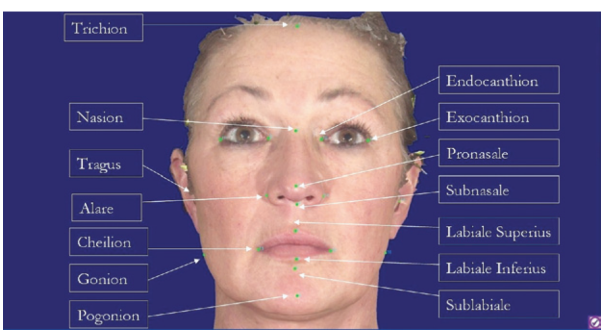

FIGURE 2. Facial landmarks used.

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cameras. This is similar to how the human eye works. The number of points on the surface to be analyzed can be increased by increasing the number of camera stereo pairs to generate a facial model.

The VECTRA-3D system features 2 pods held together by a central bracket that mounts onto a tripod or stand (Fig 1). Each camera pod contains 3 high-resolution digital cameras and a speckle texture flash projector. The camera positions, orientations, and imaging characteristics, such as the lens distortions, are predetermined by the calibration system. The calibration process takes 2 to 3 minutes to perform and is usually carried out once a day.

The capture process begins with the camera projecting a fine pattern onto the surface being studied via the speckle texture flash projector. High-resolution stereo images of the surface and the pattern it displays are then captured within 0.75 milliseconds. Immediately after this, a color surface image is taken. To eliminate the potential for mismatches resulting from subject movement, the individual cameras are synchronized to capture the data simultaneously.

The resultant stereo images are then processed to find dense sets of corresponding points in each image. The process is performed by use of a highly accurate least squares correlation matching algorithm,[3,4] which is guided by a region-growing search algorithm.[5] The process continues until all of the corresponding points in the stereo images have been identified and analyzed. This information and previously determined camera characteristics are then processed to determine the surface shape. The color image information is then projected onto the calculated surface model, therefore providing shape, color,

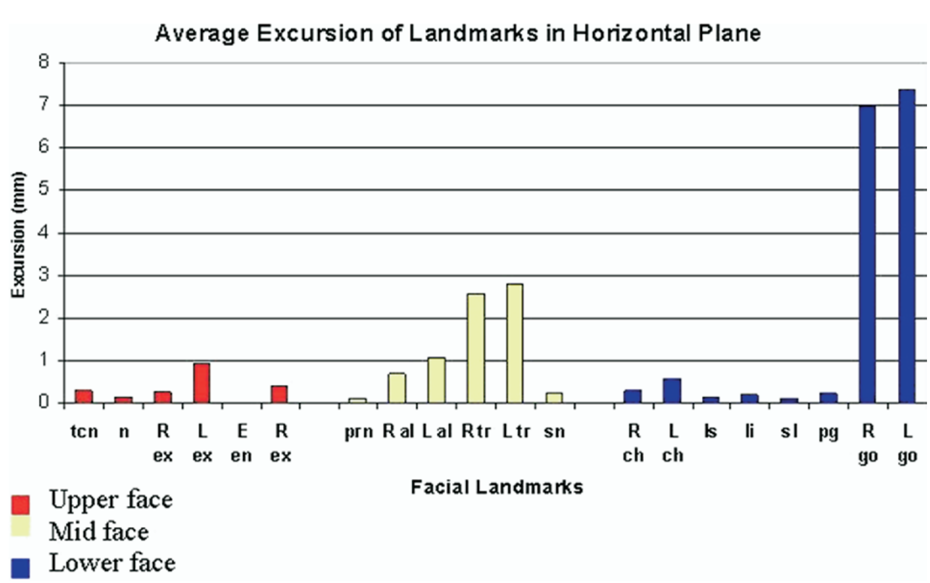

FIGURE 3. Histogram showing average excursion of facial landmarks from upright to supine in the horizontal (x) plane in the daughter group.

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Table 1. ABBREVIATIONS FOR FACIAL LANDMARKS

al	Alare
ch	Cheilion
en	Endocanthion
ex	Exocanthion
go	Gonion
li	Labiale inferius
ls	Labiale superius
n	Nasion
pg	Pogonion
prn	Pronasale
sl	Sublabiale
sn	Subnasale
tcn	Trichion
tr	Tragus

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and texture information for all visible parts of the surface. The total capture time is less than 1.5 milliseconds.

IMAGE ANALYSIS SOFTWARE

The 3-dimensional facial model that is generated can be analyzed by use of VAM (visualization, analysis, measurement) application software. Because it is a digital facial model, one is able to rotate, pan, or zoom into the images, as well as view multiple surfaces simultaneously to facilitate analysis. Measurements that can be carried out on the images include volumetric analysis, surface and caliper measurements, and measurement of angles.

SUBJECTS

Mother-daughter pairs were recruited for this study. By use of the VECTRA-3D camera, they were imaged by stereophotogrammetry in repose, in the upright and supine positions. We applied 20 facial landmarks, 8 in the midline and 6 bilaterally (Fig 2), onto each image, and the corresponding x, y, and z coordinates of these landmarks were generated by VAM software. The excursion of each landmark from the upright to the supine position was calculated for each person. Differences in the excursion of the landmarks in the "mother" (older) and "daughter" (younger) groups were compared.

Ethical committee approval for this study was granted by the Joint University College London/University College London Hospital Committees on the Ethics of Human Research (Committee A).

STATISTICAL ANALYSIS

The Wilcoxon signed rank test was used for the statistical analysis. *P* values less than .05 were considered significant. All statistical analyses were performed with SPSS software, version 13.0 (SPSS, Chicago, IL).

Results

A total of 6 mothers and their 9 daughters were recruited for this study. The mothers were aged between 44 and 61 years. The daughters were aged between 13 and 25 years. The median age for the mothers was 53.5 years (interquartile range 11), whereas the daughters had a median age of 20 years (interquartile range 3).

To facilitate analysis, each facial image was divided into 3 parts to form the upper, middle, and lower face.

For all subjects, movement of up to 7.3 mm occurred in the horizontal (x) plane, 5.7 mm in the vertical (y) plane, and 7.6 mm in the dorsoventral (z) plane. Significant movement ($P < .05$) in the vertical plane occurred in the upper lip (labiale superius), lateral canthi (exocanthi), labial commissures (cheilion), and gonia. Maximal movement occurred in the middle and lower third of the face in both groups but was more marked in the mothers.

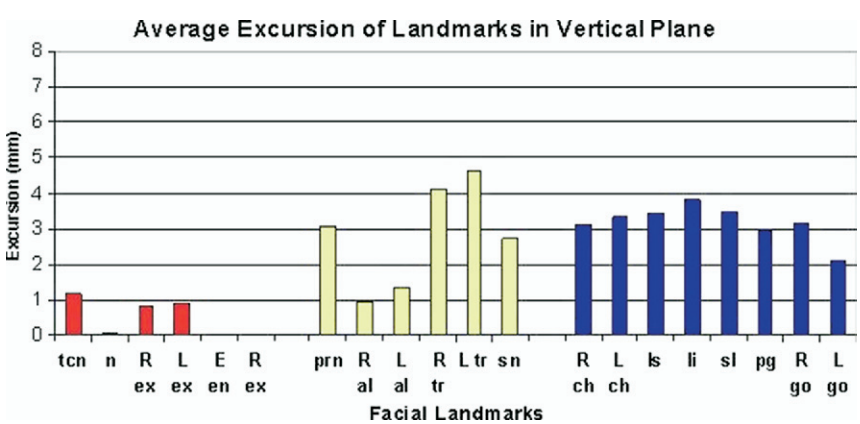

FIGURE 4. Histogram showing average excursion of facial landmarks from upright to supine in the vertical (y) plane in the daughter group.

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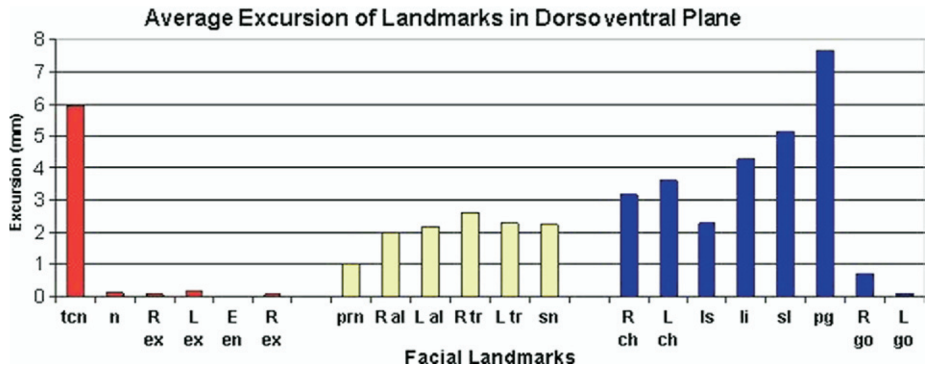

FIGURE 5. Histogram showing average excursion of facial landmarks from upright to supine in dorsoventral (z) plane in daughter group.

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In the younger (daughter) group, in the horizontal plane (x coordinates), maximal movement occurred in the tragi and gonia on moving from the upright to the supine position (Fig 3, Table 1). In the vertical plane and dorsoventral planes, maximal excursion occurred at the landmarks of the midface and lower face (Figs 4, 5). In the dorsoventral plane, the trichion also had a large excursion.

In the horizontal plane for the older (mother) group, maximal movement occurred at the cheilion and the gonia from the upright to the supine position (Fig 6). In the vertical plane, most movement occurred in the landmarks of the midface and lower face. In the upper face, the anterior hairline or trichion was the landmark that had the greatest excursion (Fig 7). In the dorsoventral plane, a pattern sim-

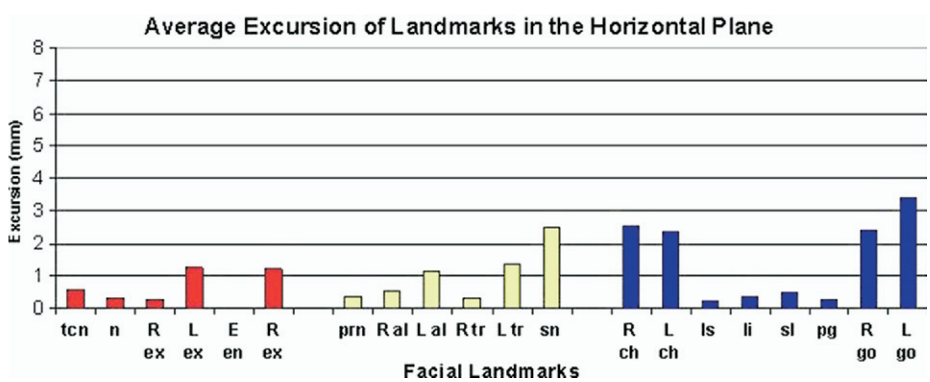

FIGURE 6. Histogram showing average excursion of facial landmarks from upright to supine in horizontal (x) plane in mother group.

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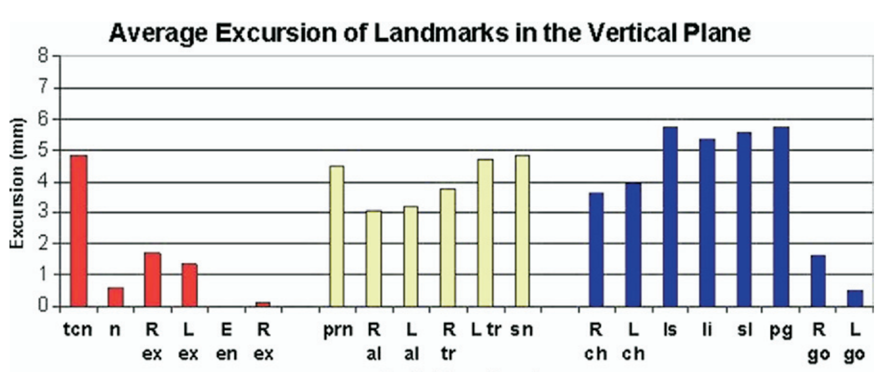

FIGURE 7. Histogram showing average excursion of facial landmarks from upright to supine in vertical (y) plane in mother group.

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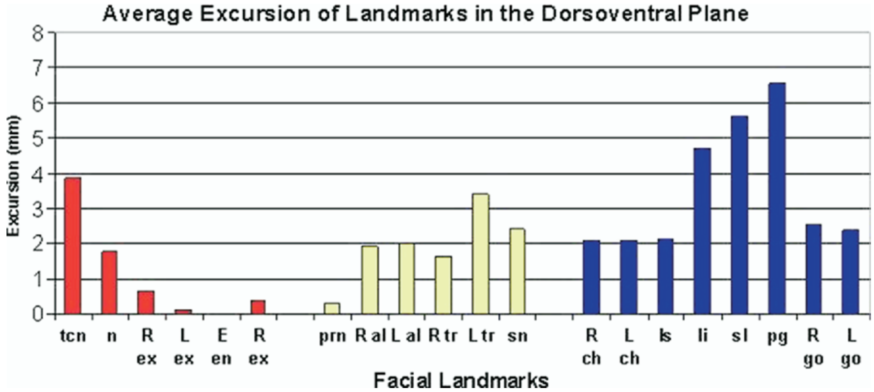

FIGURE 8. Histogram showing average excursion of facial landmarks from upright to supine in the dorsoventral (z) plane in the mother group.

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ilar to that for the vertical plane was noted—that is, landmarks in the midface and lower face had the greatest excursion from the upright to the supine position (Fig 8).

As shown in Figure 9, by use of custom software, it was possible to superimpose each upright image onto the supine one and then calculate the distance between the surfaces. The distance between the surfaces represents the movement of the tissues with posture. Whereas the daughters did not show much tissue movement, as seen from the uniformly green image, the mothers' images show that maximal movement occurred around the lower face, in particular around the nasolabial fold and marionette lines.

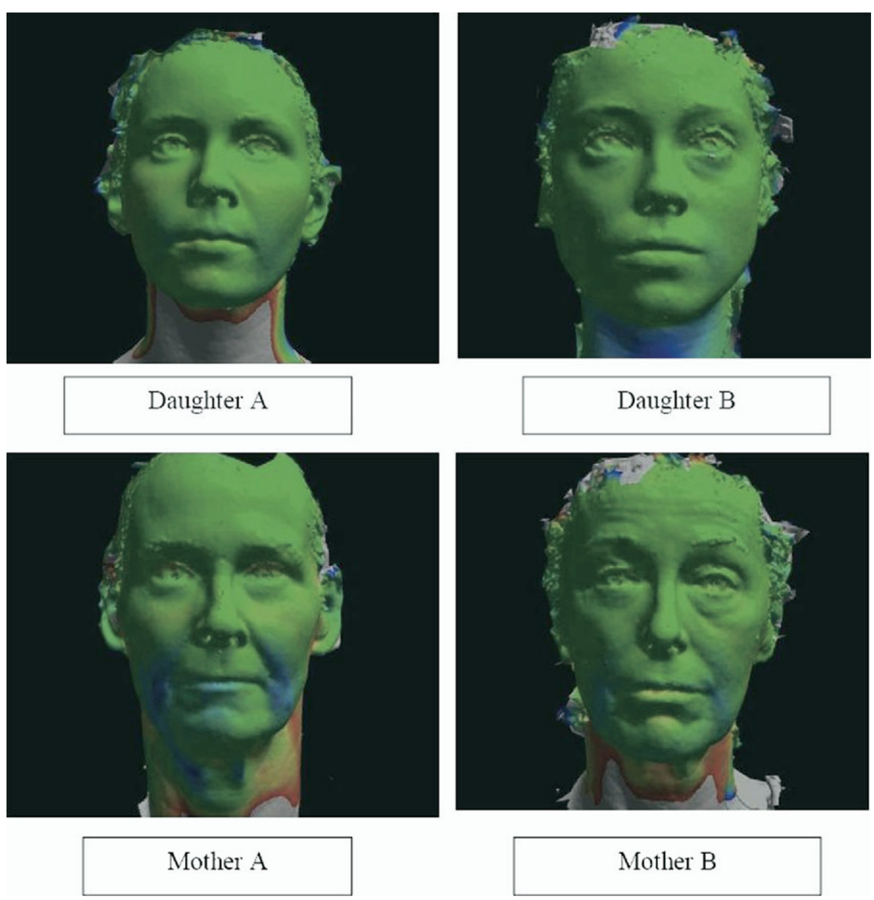

FIGURE 9. Figures of mothers and their daughters. Each figure is generated as a result of the upright and supine images superimposed onto each other.

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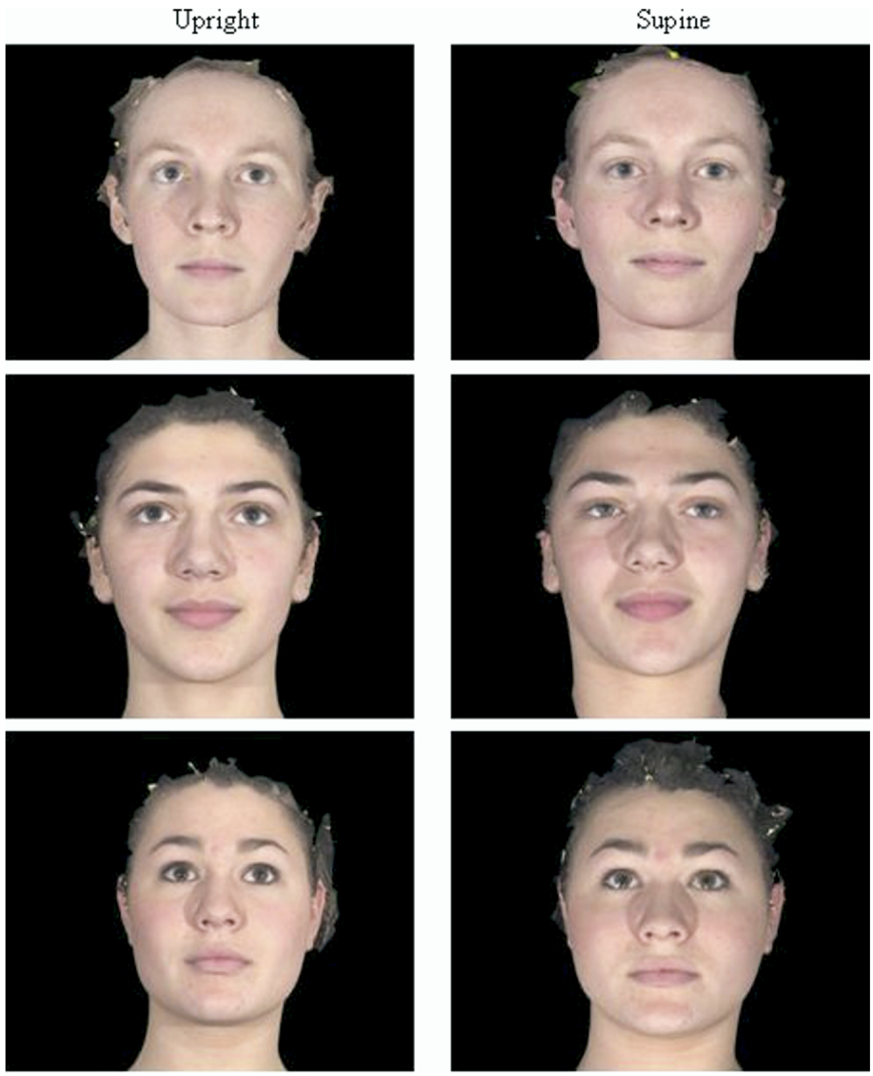

FIGURE 10. Comparison of upright and supine images of daughter group.

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Discussion

This system has previously been validated by Ghoddousi et al[6] and was found to be accurate and reliable. As seen from the results, it has been possible to document soft tissue ptosis as shown by changes in the landmarks of the midface and lower face. The greatest excursion occurred in the vertical and dorsoventral planes in both the older (mother) and younger (daughter) groups. However, there was greater excursion of the landmarks in the older group compared with the younger group.

The changes of the soft tissues that occur with age have been well established. In the upper face, brow ptosis and forehead rhytids develop. In the midface, the changes that occur include deepening of the nasolabial fold and descent of the malar fat pad, which moves anteriorly, inferiorly, and laterally, resulting in depression in the infraorbital area and visual lengthening of the lower lid. In contrast, in the lower face, the appearance of the jowls and marionette lines alter the facial contour. This is a result of the attenuation and laxity of retaining ligaments of the midlateral face, as well as ptosis within the fascial-fatty layer and overlying dermis of the cheek mass.[2]

Mother-daughter pairs were recruited to reduce the variation in facial morphology. In the younger age group, gravity has little effect on the soft tissues as a result of muscle tone and greater elasticity. Hence the changes that occur from the upright to the supine position are not obviously demonstrated (Fig 10). In contrast, in the mother group (Fig 11), the

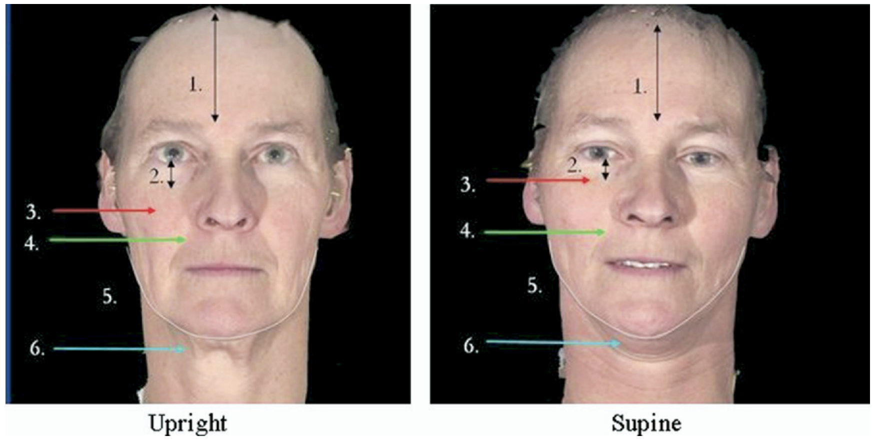

FIGURE 11. Example from the mother group illustrating changes that occur from upright to supine. Refer to text for points 1-6.
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changes that occur in the supine position are as follows:

1. reduction of the vertical dimension of the brow occurs;
2. visual lengthening of the lower lid is reduced;
3. the malar fat pad is located more superiorly;
4. the nasolabial fold is effaced;
5. the shape of the facial contour, which is more square in the upright position, becomes more oval;
6. the platysmal bands disappear.

A limitation of this study is the relatively small number of subjects. The preliminary data obtained provide an indication of how the soft tissues of the face alter with posture and age. However, a larger study would not only provide greater statistical power but also refine the results in terms of the excursion of each landmark in relation to the other landmarks and the different planes.

Nevertheless, the importance of being able to quantify these changes is significant because patients are assessed in the upright position and most procedures are carried out in the supine position. Therefore these changes should be taken into account when planning the extent of the procedure, be it in rejuvenation surgery, injection of intradermal fillers and botulinum toxin, or reanimation surgery for facial palsy.

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