Three-Dimensional Facial Averaging: A Tool for Understanding Facial Aging

Val Lambros, M.D.
Gideon Amos, Ph.D.

Newport Beach, Calif.

Summary: The progression of facial shape with aging is the subject of various theories and assumptions but remains poorly understood. The authors have used the unique capabilities of the three-dimensional camera to average the faces of large numbers of subjects to understand this complex process. What the authors present here is a technique of analysis rather than detailed results. (*Plast. Reconstr. Surg.* 138: 980e, 2016.)

Over the past 10 years, the clinical author (V.L.) has amassed a collection of three-dimensional facial images using a three-dimensional camera system (Vectra; Canfield Scientific, Parsippany, N.J.). Both handheld and stationary cameras were used. This article conforms to the Helsinki Declaration. Dr. Lambros used subjects from his ongoing studies of facial aging and assembled the images. Dr. Amos developed the software used for the facial averaging.

The images were landmarked at the glabella, nasion, nasal tip, subnasale, upper and lower midline lip vermilion, right and left oral commissures, right and left alar bases, right and left endocanthion and exocanthion, and pogonion. Images obtained using a stationary camera had additional landmarks at the right and left incisura tragi (tragal notch). Subjects were Caucasian, and those with a history of cosmetic surgery were excluded. A single exposure with the handheld system has a smaller field of view than the stationary system; thus, only the central face is fully captured when combining images from different systems as in the example we show here.

Faces are averaged using a dense surface model, similar to that described by Hutton et al.[1] and by Hammond et al.[2–4] and applied by others.[5,6] The averaging begins with the set of dense triangular meshes that describes the shape of each subject's face. A template mesh is chosen (i.e., a single mesh with its own set of triangles and vertices). Any mesh of suitable coverage and quality will do, although it helps if the shape of the mesh is close to the mean of the group of faces to be averaged.

Landmarks are used to warp the template mesh to each individual face using a method known as the thin plate spline warp.[7] The result is a close alignment of the template mesh to the subject's face that matches exactly at the landmarks, and approximately elsewhere. The vertices of the template mesh are then projected onto the subject face by finding the closest point on the subject face to the given vertex. Finally, a smoothing procedure is applied to vertices of the template mesh to ensure an even distribution of vertices on the subject face, excluding those directly adjacent to a landmark and those on the boundary of the template mesh. The smoothing procedure consists of a Laplacian smoothing operation,[8] followed by projection to the closest point on the subject face and repeated until the maximum change of combined smoothing plus projection operation is below some threshold.

Once the template mesh is fitted to a set of subject faces, they are aligned using an ordinary Procrustes analysis procedure,[9] which preserves the scale of each face mesh. The mean face mesh emerges as part of the Procrustes procedure.

From private practice and Canfield Scientific, Parsippany N.J.
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Each vertex represents the mean of vertices of the template mesh applied to subject faces, aligned to minimize the sum of squared distances between all vertices.

Registering landmarks and surface contours according to standard protocols, the two averaged images shown were then combined as a gif animation.[10] [**See Animation, Supplemental Digital Content 1**, which shows a gif animation of Figure 1 (courtesy of Val Lambros, M.D.). Note the anteroposterior changes of the columella and nasal base and the tip ptosis. Note that the lid aperture gets smaller vertically and horizontally and that the lower lid border rises. The slight flattening of the mentum is artifactual. The reader is encouraged to let this animation play for some time: with the investment of time, more will be revealed, ***http://links.lww.com/PRS/B922.***]

RESULTS

The reader will recognize the youthful and older contours of the static averaged images; the animation (online) shows the dynamic differences between the averages. We find that the animations are best viewed from approximately 3 to 4 feet away and should not be simply glanced at; the longer one looks, the more one sees. We will point out without further comment the immediately obvious points: the lid aperture gets smaller, vertically and transversely. The average lower lid rises rather than falls with age. Although not intuitive, this finding is constant in men and women in our observations so far. The lid-cheek junction moves slightly.

It has long been known that the upper and lower lip thin and the intersection of the two, the horizontal labial fissure, moves inferiorly and inferoposteriorly, as do the commissures. In the animation, one can see the profound implications this has for nasolabial fold formation. What has not been appreciated is the strong and common tendency of the columellar base to move posteriorly. The splaying and elevation of the alar bases and the ptosis of the nasal tip parallel the thinning of the lip. In other words, the entire lip mass seems to thin and move posteriorly, taking the nasal base along with it. We have seen these findings in a prior photographic study.[11] The ability to rotate three-dimensional captures makes these changes much easier to see. Other images from different angles enlarge on the observations above and show others.

DISCUSSION

Although the data were initially used for a longitudinal study, it soon became clear that subjects were aging too slowly and the author was aging far too quickly for any finality, so the same

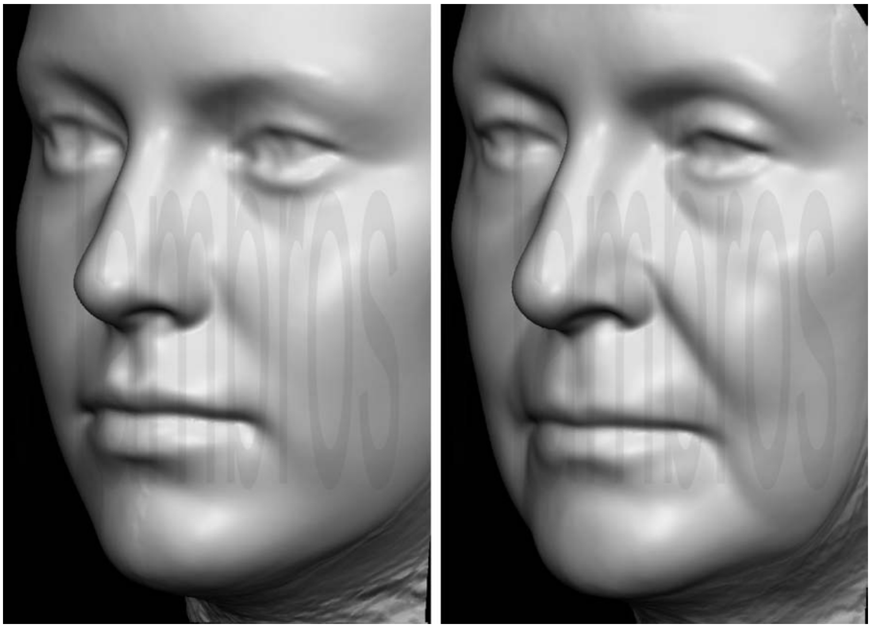

Fig. 1. (*Left*) The average of the facial surfaces of 116 female subjects aged 20 to 30 years. (*Right*) The average of the facial surfaces of 100 female subjects aged 68 to 91 years (average, 76 years). (Photographs courtesy of Val Lambros, M.D.)

data were then redirected for use in a population study. This averaging technique is not new; it has been used successfully to identify childhood facial syndromes[3,12,13] but has not seemed to find its way into the facial aging literature as of yet.

With this technique, an extraordinary amount of numerical data in almost every axis of the face is presented visually. This is an effective way of defining complex changes in curvatures in an accurate, easily understood, and useful way and shows details of aging that have not been well described as of yet.

Val Lambros, M.D.
360 San Miguel Drive, Suite 406
Newport Beach, Calif. 92660
lambrosone@aol.com

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