

Longitudinal Analysis of Superficial Midfacial Fat Volumes Over a 10-Year Period

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Abstract

Background Volumetric changes to facial fat that occur with aging remain poorly understood. The aim of this study was to evaluate for longitudinal changes to midfacial fat volumes in a group of individuals.

Methods We conducted a retrospective longitudinal study of adult subjects who underwent multiple facial computed tomographic (CT) scans timed at least 8 years apart. Subjects who underwent facial surgery or suffered facial trauma were excluded. Facial CT scans were analyzed, and superficial cheek fat volumes were measured and compared to track changes that occurred with aging.

Results Fourteen subjects were included in our analysis of facial aging (5 male, 9 female; mean initial age 50.9 years; mean final age 60.4 years). In the right superficial cheek there was an increase in mean (SD) superficial fat volume from 10.33 (2.01) to 10.50 (1.80) cc, which was not statistically significant ($P = 0.75$). Similar results were observed in the left cheek. There were no statistically significant longitudinal changes to caudal, middle, or cephalad subdivisions of bilateral superficial cheek fat. A simple linear regression was performed to predict superficial cheek fat pad volume based on age which did not reach statistical significance ($P = 0.31$), with an R^2 of 0.039.

Conclusions This study is the first to quantitatively assess for longitudinal changes to midfacial fat in a group of individuals. Superficial cheek fat remained stable as subjects aged from approximately 50 to 60 years old, with no change in total volume or redistribution within a radiographically defined compartment.

Level of Evidence IV This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine ratings, please refer to the Table of Contents or the online Instructions to Authors www.springer.com/00266.

Keywords Aging · Cheek · Fat · Face · Facial rejuvenation · Computed tomography

Introduction

For a surgeon to adequately address the issue of facial aging, they must endeavor to understand its causes. Changes to skin, fat, muscle, and bone over time are each known to contribute to the aging process, but the relative importance of each continues to be debated.

The volumetric theory of facial aging is based on the premise that a primary driver of aging-related changes is compartmentalized losses and gains of fat in neighboring regions [1, 2]. Following the logic of this position, the model promotes a role for soft-tissue fillers and fat transfer to correct the areas of the face that are sunken or hollowed by the presupposed fat loss [3]. However, to our knowledge there is no study that demonstrates definitive evidence of the postulated facial fat loss during the aging process.

On a yearly basis, millions of facial rejuvenation procedures are performed in the USA to remove rhytids, and smooth the contours of the aging face. The propensity for

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patients to undergo these procedures increases dramatically in the fifth and sixth decades of life. According to the American Society of Plastic Surgeons, in 2016 only 2% of rhytidectomies and 11% of facial filler procedures were performed in the 30–39-year-old age group, whereas 33% and 49% were performed in the 40–54-year-old age group. The fact that this older age group is pursuing facial cosmetic procedures at such a high rate makes it an attractive population to study for volume change in the facial fat compartments. Multiple investigators have noted that an ideal method of trending how fat pads change with age would be a longitudinal study of live subjects, but thus far no such study has been conducted [1, 4].

The vast majority of rejuvenation procedures are non-surgical in nature, including botulinum toxin injections as the most popular method, followed closely by injectable fillers. Filler techniques nicely complement the volume model of facial aging; however, they have aesthetic limitations which may be related to the inadequacy of the volume model to account for alternative drivers of aging aside from facial fat loss. If the goal of a facial rejuvenation procedure is to restore the face to a more youthful state, it logically follows that we must strive to understand the severity and timeframe of changes in fat volume related to aging.

The goal of this study was to use imaging techniques to understand whether an observable population trend of facial fat loss, gain, or redistribution is occurring during the aging process. Because there are substantial differences among individuals' facial fat content (volume and distribution), it was necessary to identify individuals for whom accurate longitudinal measurements of facial fat could be obtained. The present study is the first to track individual changes in facial fat content longitudinally. In this observational study based on radiographical data, we find mature adult subjects to have stable superficial cheek fat pads over a 10-year period.

Materials and Methods

A retrospective query of our institution's radiology report database (Montage Healthcare Solutions) was performed to identify adult patients initially aged 40–60 years with repeated CT studies at least 8 years apart that included the entire midface. This study was approved by the Yale School of Medicine IRB, and a waiver for informed consent was granted due to its retrospective nature and use of deidentified patient information.

A total of 14 patients meeting criteria were selected for further review, with the majority having undergone CT angiography surveillance for intracranial aneurysm growth. Patients were excluded from study participation for

evidence of prior significant facial surgery, noted current or previous facial trauma, abnormal appearing soft-tissue or bony structures consistent with pathologic disease processes. Scans with slice thickness of 0.63 mm were selected for use.

CT scans were analyzed in the axial plane to obtain two-dimensional measurements of superficial cheek fat (Fig. 1). The axial slice that contained the most prominent projection of the nasal spine was used as a reference point. The superficial cheek fat was identified at this level and measured cross-sectionally. The deep boundary of the superficial cheek fat zone was delineated by a linear plane between the zygomaticus major muscle and levator labii superioris. The superficial boundary was the skin. The anteromedial boundary was defined by the meeting point of the levator labii superioris and skin where the deep and superficial boundaries converged. The posterolateral boundary was defined by the posterior border of zygomaticus major.

Using the method described above, cross-sectional measurements of superficial cheek fat were taken at every third axial cut (1.89 mm apart) from 9.45 mm caudal to the reference slice to 11.34 mm cephalad to the reference slice for a total of 12 measured slices over a vertical distance of 20.79 mm. Volumetric measurements were obtained with the following formula where V is volume, and A is the cross-sectional area of axial slice number i :

$$V = \sum_{i=1}^{12} A_i \times 0.63 \text{ mm} \times 3$$

For further analysis, the total superficial cheek fat volumes were subdivided into caudal, middle and cephalad portions by simply summing only the caudal, middle or cephalad 4 slices when applying the same volume equation as shown above. Three-dimensional reconstructions were performed on select subjects using Vitrea software (Vital Images Inc, Minnetonka, MN, USA).

Statistical analysis was performed using Microsoft Excel. For each patient, the total volumes of the superficial cheek fat were calculated bilaterally. Changes in superficial cheek volume area over time were then calculated for each patient. Paired two-tailed t tests and linear regression analysis were performed to evaluate for statistical significance. $P < .05$ was considered statistically significant.

Results

Fourteen subjects were included in our analysis of facial aging. There were 5 male subjects and 9 female subjects. The mean (SD) age at initial imaging was 50.9 (5.0) years, and the mean (SD) age at final imaging was 60.4 (4.2)

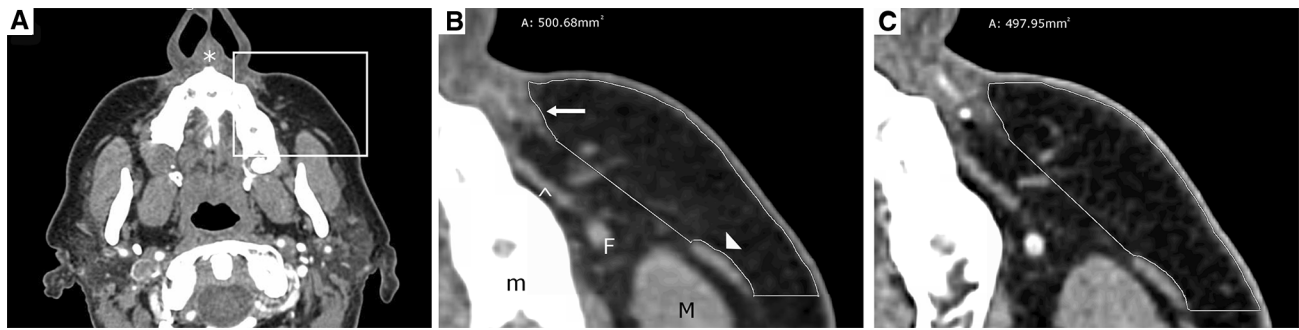


Fig. 1 Example of cross-sectional measurements (Subject 2) through axial reference slices from initial (a and b) and final (c) imaging timepoints. a Asterisk indicates nasal spine. b Outlined area circumscribes superficial medial cheek fat ($A = 500.68 \text{ mm}^2$); M ,

masseter; m , maxilla; F , facial vein; arrow, levator labii superioris; arrowhead, zygomaticus major; caret, levator anguli oris. c Outlined area circumscribes superficial medial cheek fat ($A = 497.95 \text{ mm}^2$; 8 years elapsed)

years old. The mean (SD) elapsed time between initial and final imaging was 9.5 (1.7) years (Table 1).

Cross-sectional areas of superficial cheek fat were summed to obtain total volumetric measurements for all subjects (Fig. 1). Individual longitudinal changes in superficial cheek fat volume are detailed in Table 1. In the right superficial cheek there was an increase in mean (SD) total fat volume from 10.33 (2.01) to 10.50 (1.80) cc, which was not statistically significant ($P = 0.75$).

Likewise, the increase in mean (SD) total fat volume in the left superficial cheek from 10.67 (1.93) to 10.79 (1.40) cc was not statistically significant ($P = 0.82$).

Among the 14 subjects, there were two significant outliers in the volumetric data set. Subject 7 had a substantial bilateral gain of volume over a period of 9.1 years. On the right side, her superficial cheek fat volume increased by 4.54 cc (44.6%) from 10.19 to 14.73 cc. The corresponding left sided volume increased by 3.64 cc (35.4%) from 10.30

Table 1 Individual changes in right and left total superficial cheek volumes

Subject	Sex	Age, years			Right cheek			Left cheek		
		Initial	Final	Difference	Initial	Final	Difference (%)	Initial	Final	Difference (%)
1	F	56.1	63.6	7.5	13.79	11.75	- 2.04 (- 14.8)	13.39	11.75	- 1.64 (- 12.2)
2	F	57.3	65.0	7.7	8.81	9.32	0.51 (5.8)	11.97	11.97	0.00 (0.0)
3	M	59.8	67.5	7.7	7.83	7.70	- 0.13 (- 1.7)	7.95	8.30	0.35 (4.5)
4	M	49.3	57.1	7.8	8.70	8.72	0.02 (0.2)	9.60	9.56	- 0.04 (- 0.4)
5	F	45.2	53.3	8.1	10.35	10.72	0.37 (3.6)	10.34	11.67	1.33 (12.9)
6	F	54.7	63.7	9	9.23	9.38	0.15 (1.6)	9.84	10.03	0.19 (1.9)
7	F	46.7	55.8	9.1	10.19	14.73	4.54 (44.6)	10.30	13.94	3.64 (35.4)
8	M	56.1	65.5	9.4	9.08	10.08	1.00 (11.0)	9.90	10.10	0.20 (2.1)
9	F	48.6	58.3	9.7	10.54	12.10	1.56 (14.8)	10.34	11.65	1.31 (12.7)
10	F	50.1	60.8	10.7	10.59	10.87	0.28 (2.6)	9.80	10.60	0.80 (8.1)
11	F	48.3	59.1	10.8	9.25	9.28	0.03 (0.3)	9.49	9.52	0.03 (0.3)
12	M	49.4	60.7	11.3	12.28	12.43	0.15 (1.2)	11.13	11.39	0.26 (2.3)
13	M	45.8	57.4	11.6	14.79	10.31	- 4.48 (- 30.3)	15.73	10.77	- 4.96 (- 31.5)
14	F	44.5	57.1	12.6	9.17	9.57	0.40 (4.4)	9.66	9.82	0.16 (1.6)
Mean [SD]		50.9 [5.0]	60.4 [4.2]	9.5 [1.7]	10.33 [2.01]	10.50 [1.80]	0.17 (3.1) [1.93]	10.67 [1.93]	10.79 [1.40]	0.12 (2.7) [1.86]
<i>P</i> value (initial vs. final)					0.75			0.82		

to 13.94 cc total. In contrast, Subject 13 had a substantial loss of superficial cheek fat volume. Over a period of 11.6 years, this subject lost 4.48 cc (30.3%) of superficial cheek fat volume from the right cheek, and 4.96 (31.5%) of corresponding volume from the left superficial cheek. In order to gain an aesthetic appreciation of these changes, three-dimensional reconstructions were created from the source CT scans (Fig. 2). Subject 7 has accentuated jowl, nasolabial and nasojugal folds as a result of midfacial fat gain (Fig. 2, panels a and b). By comparison, Subject 13's nasojugal and nasolabial folds become effaced as a result of volume loss (Fig. 2, panels c and d). These visual representations appear to confirm the quantitative results from our volumetric measurements.

The total cheek fat was separated into caudal, middle and cephalad subdivisions to assess for vertical redistribution of fat over time (Table 2). At the caudal level,

representing the inferior third of the fat compartment, there were non-statistically significant increases in mean (SD) fat volumes from 2.56 (0.82) to 2.61 (0.74) cc on the right side and from 2.82 (0.72) to 2.83 (0.53) cc on the left side ($P = 0.74$ and $P = 0.92$, respectively). Similarly, there were no significant changes in fat volume over time within the middle or cephalad subdivisions. At the initial and final imaging time points we also observed no statistically significant volume differences between the right and left side at all levels.

A simple linear regression was performed to predict superficial cheek fat volume based on age. Each subject was included twice, and their right-sided cheek volumes at the initial and final imaging timepoints were plotted against age (see Fig. 3). A regression equation was calculated which did not reach statistical significance ($F(1, 26) = 1.063$, $P = 0.31$), with an R^2 of 0.039.

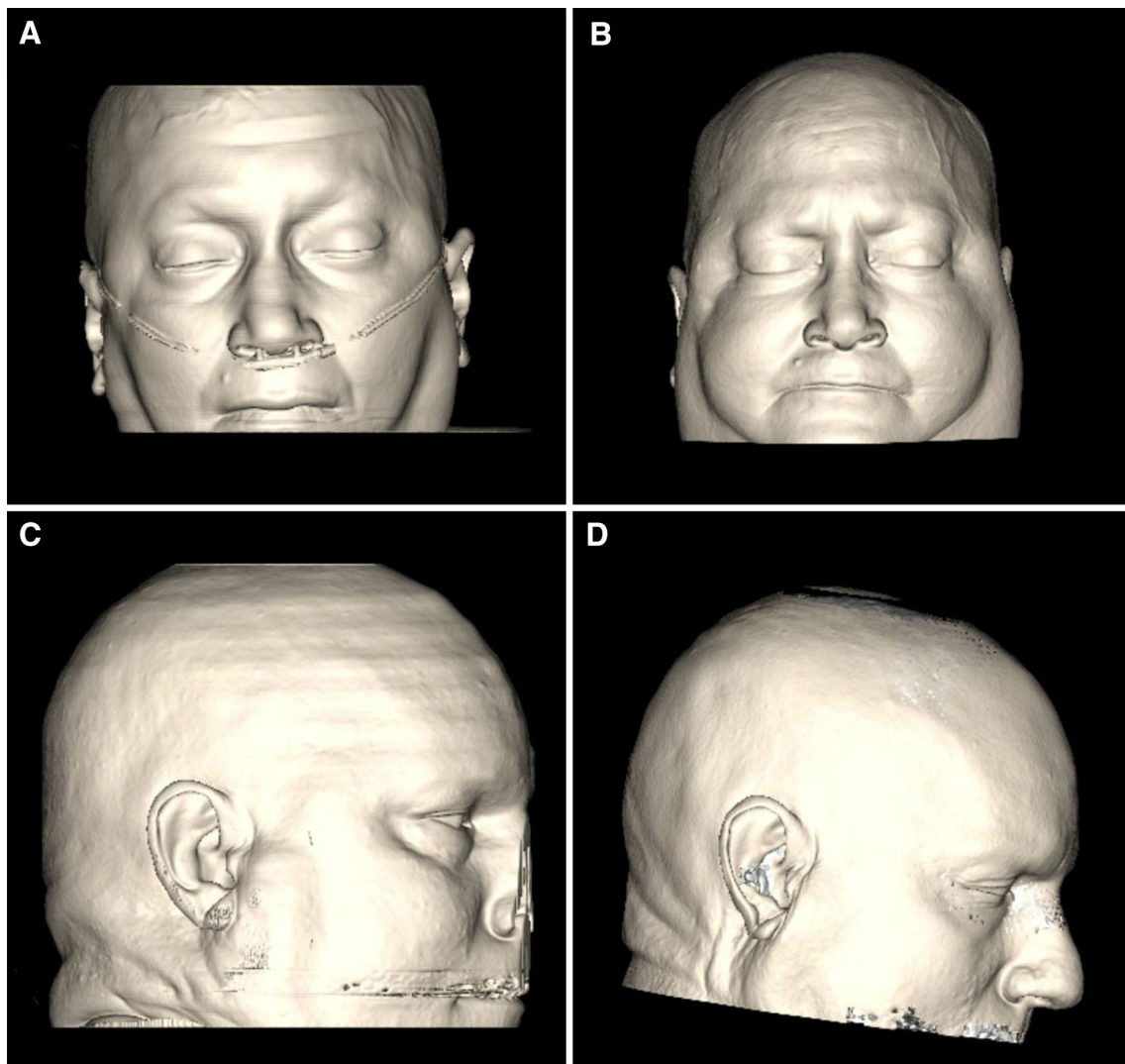
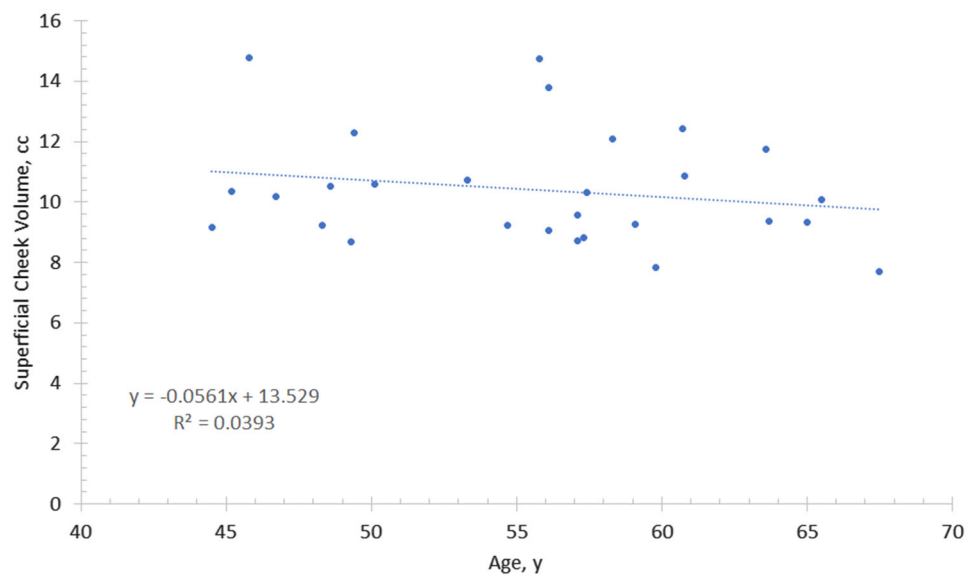


Fig. 2 Three-dimensional reconstructions of Subject 7 (a and b) and Subject 13 (c and d), representing substantial volume gain and loss, over periods of 9 and 12 years, respectively

Table 2 Population changes in right and left superficial cheek volumes by subdivision

		Mean (SD)			P value
		Initial	Final	Difference	
Caudal, cc	Right	2.56 (0.82)	2.61 (0.74)	0.05	0.74
	Left	2.82 (0.72)	2.83 (0.53)	0.01	0.92
	Difference	0.26	0.22		
	P value	0.23	0.28		
Middle, cc	Right	3.70 (0.75)	3.71 (0.64)	0.01	0.98
	Left	3.81 (0.71)	3.78 (0.48)	− 0.03	0.84
	Difference	0.11	0.07		
	P value	0.18	0.29		
Cephalad, cc	Right	4.07 (0.62)	4.18 (0.67)	0.11	0.58
	Left	4.04 (0.55)	4.18 (0.56)	0.14	0.49
	Difference	− 0.03	0.00		
	P value	0.71	1.00		
Total, cc	Right	10.33 (2.00)	10.50 (1.80)	0.17	0.75
	Left	10.67 (1.93)	10.79 (1.40)	0.12	0.82
	Difference	0.34	0.29		
	P value	0.23	0.24		

Fig. 3 Relationship between superficial cheek fat volume based on age. A regression equation was calculated which did not reach statistical significance ($F(1, 26) = 1.063$, $P = 0.31$), with an R^2 of 0.039

Conclusion

Longitudinal volumetric changes in facial fat compartments can be accurately measured with repetitive computed tomography imaging. Among a population of subjects over a 10-year period, there was no observable trend of volume loss or gain. Further longitudinal studies are needed to determine whether volume changes are occurring as a function of age, and if so, which facial fat compartments are most affected.

Discussion

The evidence presented in this study shows that midfacial fat can be reliably measured with high-resolution computed tomography scans. By summing cross-sectional measurements to obtain fat volumes, we show that the midfacial fat content of an aging population appears generally stable between approximately 50–60 years old. Based on linear regression analysis, superficial cheek fat does not appear to correlate with age in our population sample. To our knowledge, this is the first study that has assessed for longitudinal changes in the same individuals over time.

There is significant variability of facial fat volume and position among individuals, even within the same age group. This variability poses a difficult challenge when trying to determine whether significant fat loss occurs during the aging process. Prior studies have compared measurements of midfacial fat between separate populations of young and old subjects with mixed conclusions [4, 5]. When volume differences have been observed, they are attributed to the aging process. We believe that our method of tracking changes in fat content is superior because we have repeated measures for individuals over many years, such that each serves as his or her own control.

Measuring fat volume radiographically is inherently challenging because the borders of fat compartments are not as discretely defined as other structures such as muscle or bone. It is known from cadaveric studies that facial fat can be subdivided into anatomical compartments which are separated by septal barriers and ligamentous attachments [6]. Furthermore, the postulated volume changes in facial fat may vary by compartment rather than as a global phenomenon [3]. However, these divisions cannot be identified radiographically with the precision allowed by surgical dissection. Therefore, we relied on using consistent, easily identifiable radiographical landmarks to approximate the divisions among the facial fat compartments. In this study, the unflinching symmetry of the bilateral volumetric measurements serves as additional validation for this novel system of fat measurement.

We identified a superficial layer of fat that could be easily identified in all patients which was the zone of interest for our cross-sectional measurements (Fig. 1). This zone, which we call “superficial cheek fat” is delineated by the skin laterally and a plane between the zygomaticus major and levator labii superioris muscles medially. We believe that this zone of superficial cheek fat correlates with the superficial nasolabial and medial cheek fat, as described in anatomical studies [6–8]. Perforating vessels could sometimes be seen in the expected plane that anatomically divides the nasolabial and medial cheek fat compartments [7]; however, this was not a reliable finding on the CT scans. Therefore, these fat compartments were analyzed as a combined superficial cheek fat unit for the purposes of this study.

The results of our study suggest that the fat contained within the superficial cheek compartments remains generally stable as patients age from approximately 50 to 60 years old with no significant gain or loss of fat in our cohort. There are individuals who lose or gain substantial amounts of fat, but these changes are not part of a trend, and seem more likely related to changes in total body fat and not in specific isolated facial fat compartments. We hope to investigate this hypothetical correlation in future studies using similar methodology.

One interesting finding in our study is related to the outliers in our data. Subject 7, who had substantial volume gain, was noted on 3D reconstructions to have deeper nasolabial folds as a result. This makes sense overall, when one considers the face as a series of hills and valleys. When the hills grow, the valleys deepen, and this is often perceived as facial aging. This is contrary to the volumetric theory, where volume loss is perceived as aging in the midface. Subject 13, who did show significant facial volume loss, demonstrates this contradiction because they lost the prominence of their “hills” but effectively appeared younger on facial 3D reconstruction. We do not disagree with the use of filler products for improving the appearance of the aging face. However, the underlying logic is based on adding volume to an area which may not have incurred loss in the first place—filling the valley between the hills, to use our analogy. We have too often seen patients with fuller faces, continue to get filler, only to appear rounder in general. In our minds, a more natural approach would be to soften the “hills” by repositioning the lateral soft tissues, essentially decreasing the visual prominence of the “valley.”

There are limitations to extrapolating this data with regard to aging. First, although we know that this cohort aged *chronologically* by 10 years, even with 3D reconstruction it is difficult to extrapolate the degree of *aesthetic* aging that took place. Therefore, it is impossible to say whether a lack of change in cross-sectional fat content indicates aesthetic stability. That is to say, changes that can be detected by the trained eye may not be detectable with our measurement system. Second, it is possible that the window of time that we investigated (9.5 years) is too short and our sample size too small to capture significant population trends in facial fat volume. It may take many decades for measurable trends in compartmentalized fat losses or gains to emerge from a population, and we do not know exactly how much fat loss or gain must occur before it becomes aesthetically significant. We did observe individuals who each had a remarkable gain and loss of superficial cheek fat volume, but unfortunately, we lack weight or BMI measurements to investigate a correlation.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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