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A Novel Prospective Three-Dimensional Analysis of Nasolabial Fold Augmentation

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Abstract

Background: There are many products approved for aesthetic soft tissue augmentation. Despite this abundance, there is limited objective data regarding safety, longevity, and complication rates. Instead, most reports rely on subjective measures to report volume changes and outcomes, making product comparison difficult.

Objectives: The authors developed and validated a mathematical model to prospectively calculate and analyze three-dimensional (3D) volumetric changes associated with nasolabial fold augmentation based on human acellular dermis.

Methods: Seven consecutive patients were included in this prospective review. The patients underwent nasolabial fold treatment with BellaDerm (Musculoskeletal Transplant Foundation, Edison, NJ), administered by a single surgeon. 3D photographs were obtained and analyzed with a novel mathematical model to determine absolute volumetric changes and objective longevity.

Results: Mean preoperative nasolabial fold volume was 0.17 mL. The mean one-, three-, and six-month postoperative fill volumes were 0.35, 0.19, and 0.07 mL, respectively. Fill volumes and contour changes returned to baseline by 24 weeks postoperatively in the majority of patients.

Conclusions: The mathematical model utilized in this study provided prospective and objective data regarding longevity and volumetric changes associated with nasolabial fold augmentation. The analysis demonstrated minimal objective filler permanence beyond six months, with peak volume enhancement between one and three months. Adoption of objective 3D mathematical metrics into the assessment of soft tissue filler outcomes is critical to obtaining more accurate product-to-product comparisons.

Keywords

soft tissue augmentation, fillers, facial filler, outcomes, volumetric analysis

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Today, more than ever, patients are seeking alternatives to surgical correction for facial aging. It is well established that facial soft tissue augmentation can effectively restore the youthful, harmonious contours of the face, at least temporarily. The suggested primary indications for facial fillers are signs of aging associated with rhytids and areas with noticeable facial lipoatrophy.[1-2] The number of patients seeking facial soft tissue augmentation has increased exponentially. Thanks in large part to the convenience of office-based injections, short recovery time, and predictable results, almost four million soft tissue injections were performed in 2010, which is a nearly-10-fold increase since 1997.[3]

The number of available filler options is extensive, with these products typically classified into one of four categories: autologous fat, collagens, hyaluronic acids (HA), and biosynthetic polymers. Each category of filler has varying degrees of postinjection permanence and side-effect profiles.[2,4-10] The search for the ideal filler has been underway for much of the past decade. Scientists, surgeons, and patients in search of this "Holy Grail" have looked for a filler that is nonimmunogenic, practical, and long-term in efficacy, while looking and feeling natural.[5] Unfortunately, the search continues, as the current medical literature lacks

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Figure 1. BellaDerm prehydrated acellular dermis material (Musculoskeletal Transplant Foundation, Edison, NJ) is shown prior to insertion into the nasolabial fold. The dermal strip was rolled and secured with 3-0 chromic gut sutures and tethered to 3-0 Vicryl sutures (both Ethicon, Inc., Somerville, NJ).

any standard of measure or significant objective support for any particular product over another.[2,5]

In an attempt to fill this critical assessment gap, we utilized a novel mathematical model to prospectively determine objective three-dimensional (3D) volumetric changes associated with nasolabial fold augmentation.

METHODS

This study is a prospective review of all consecutive patients who presented to the senior author (JYSK) for nasolabial fold augmentation with BellaDerm (Musculoskeletal Transplant Foundation, Edison, NJ) from May 2010 to August 2010. In total, informed consent was obtained from seven patients who participated in the study, which was approved by the Institutional Review Board at Northwestern University.

Filler Preparation

One sheet of BellaDerm acellular dermal matrix (2 × 4 cm) was cut longitudinally into two strips (1 × 4 cm). Each strip was then folded in half, dermal side out, and sutured with 4-0 chromic gut (Ethicon, Inc., Somerville, NJ) to create a hollow cylindrical shape. A separate 3-0 Vicryl (Ethicon) suture, approximately 5 cm in length, was secured to one end of each cylinder (Figure 1). The prepared BellaDerm cylinders were submerged in sterile saline to maintain hydration prior to insertion.

Surgical Procedure

Patients were prepped and draped in standard sterile fashion. The nasolabial fold was marked along the deepest point of the visible deformity, extending 5 to 10 mm past its end. A guide mark was then drawn 5 to 10 mm medial to the fold line. These markings acted as borders, outlining the eventual location where the BellaDerm would be tunneled. These markings were critical to preventing accidental insertion of the filler on the lateral portion of the fold, leading to displacement into the cheek and/or deepening of the fold. After the marking, the patients were anesthetized with topical lidocaine along the nasolabial folds and via infraorbital nerve block with 1% lidocaine with epinephrine solution. At this point, the visible deformity was effaced by the local anesthetic, indicating again the importance of proper preoperative marking. Two stab incisions were made bilaterally with a No. 15 blade scalpel—the first approximately 2 to 5 mm lateral to the alar along the superior portion of the fold and the second approximately 2 to 5 mm lateral to the intersection between the commissure and the inferior aspect of the fold. A subdermal pocket was dissected bluntly along the fold, situated between the preoperative markings. The BellaDerm cylinder was threaded into the superior incision and pulled through the pocket with the 3-0 Vicryl suture as a guide. Once inserted, excess graft was trimmed to allow for proper fit within the defect. The incisions were closed with interrupted 6-0 Prolene sutures (Ethicon). Steri-strips were placed along the length of the fold. Sutures were removed at seven days, and patients were instructed to begin performing gentle massage daily.

Data Analysis

Three-dimensional photographs were obtained with the Canfield Vectra-CR 3-D camera system (Canfield Imaging Systems, Fairfield, NJ). The photographs were taken preoperatively and then at one, four, 12, and 24 weeks postoperatively (Figure 2). The images were analyzed with the Canfield Mirror Vectra Viewing and Analysis modules and Matlab (Mathworks, Natick, MA) software. 3D stereophotogrammetry has been validated in the literature for the objective evaluation of facial soft tissue analysis.[11-15]

Pre- and postoperative photograph surfaces were registered to each other with the Analysis software module. Nasolabial folds were defined in the preoperative photograph by marking a perimeter line horizontally equidistant from the midline of the fold defect, where the lateral perimeter was delimited by the apex of the cheek. The preoperative perimeter line was projected onto postoperative 3D models to standardize the measurable surface area of the nasolabial fold for analysis. The fold areas were then exported for analysis with both Matlab and the Analysis software module.

Baseline fold defect volume was first established with a novel calculation to geometrically "flatten" the selected defect area. This algorithm was developed at the Engineering Sciences and Applied Mathematics Institute, Northwestern University, Evanston, Illinois. The algorithm is based on solving the following equation:

$$\Delta_s \vec{x} = 0, \qquad \vec{x} \in \Omega$$
$$\vec{x}\,|_{\delta\Omega} \qquad \text{fixed},$$

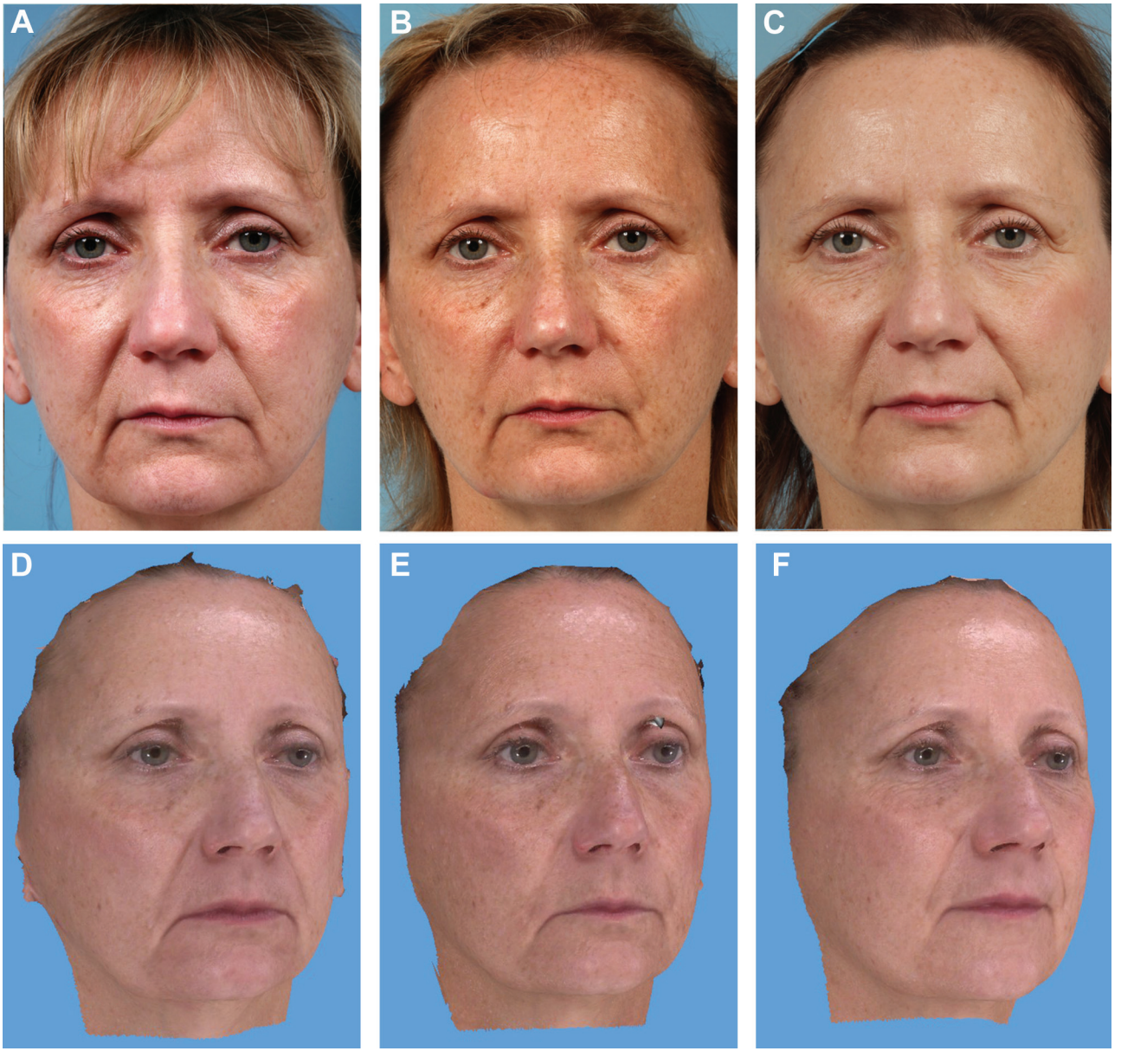

Figure 2. This 59-year-old woman is shown preoperatively (A, D) and three (B, E), and six months (C, F) after bilateral nasolabial fold correction with BellaDerm prehydrated acellular dermis.

where Δ_s is the surface Laplacian operator. The equation was approximated with a successive overrelaxation iterative procedure where each node on the boundary of the specified region of the 3D model was assumed fixed. Each node in the interior was moved to the average location of its neighbors as defined by the connectivity map provided by the Canfield Vectra imaging software. The process was repeated until the motion of any node reached a minimum, indicating a solution to the equation. The resulting surface was an approximation of the minimal spanning surface, which represented a theoretical repair of the facial defect. Once the new surface was computed, the volume difference between the old and new surfaces could be computed (Figure 3). The magnitude of change for each node was color-coded so that nodes that did not move were colored blue and nodes that moved the most distance were colored red. Other colors were linearly scaled between these two extremes, indicating the severity of the defect. The process was repeated on postoperative folds to determine the remainder of any defect still mathematically visible; this defined the defect contour volume, or the ideal amount of fill necessary to completely repair the current defect at any given time. Contour angles were also measured and defined as the average obtuse angle formed by the nasolabial fold trough, determined from an average of nine data points. The contour angles were used

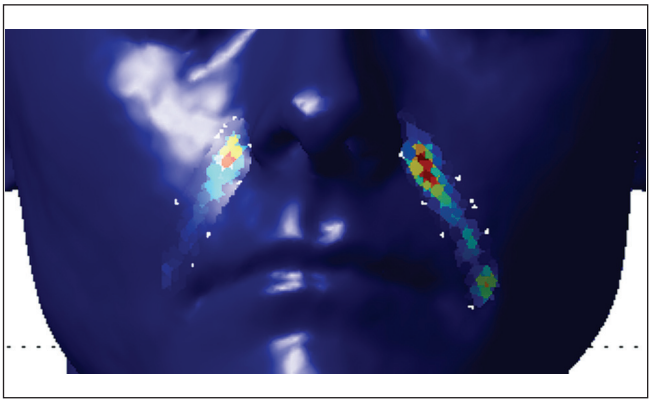

Figure 3. Calculation of preoperative fold depth and volume with our mathematical fill model. Nodes with no movement during calculation of the minimal spanning surface were colored blue. Nodes that moved the most distance were colored red. Other colors were scaled linearly between extremes.

to internally verify the computer model by comparing the theoretical fill volumes with the effacement of the contour angle. Finally, the volume between the pre- and postoperative fold surfaces was calculated by parallel projection of the surfaces with the Canfield Vectra Analysis Module.

RESULTS

All patients in the study were women 35 to 61 years of age, with a mean age of 50 years. Based on 3D photographs, the mean preoperative fold contour volume was calculated at 0.17 mL. The mean postoperative acellular dermal matrix fill volumes calculated at one, three, and six months were 0.35, 0.19, and 0.07 mL, respectively (Figure 4). The mean postoperative fold contour volumes at one, three, and six months were 0.07, 0.12, and 0.17 mL, respectively. These volume changes represent a 205% and 109% increase from baseline fold volume at one and three months, respectively. The implanted acellular dermal matrix resulted in a flattening of the fold contour by 61% at one month and 28% at three months. Flattening was defined as the ratio of the postoperative fold volume to the preoperative fold volume.

Globally, a decrease in overall fill volumes and contour effects was observed over time, with a return to preoperative baseline by the 24-week visit (Table 1). Secondary calculated outcomes of fill percentage and fold flattening also indicated a return to baseline (Table 2). These results are closely correlated with results from other authors who utilized similar 3D facial analysis techniques.[14,15] Additionally, the contour angles used to internally verify the mathematical model generally correlated with fill volume loss (Figure 5). One patient reported interval nodularity at the injection site. This resolved without surgical intervention.

Table 1. Fill Characteristics Over Time

	Week				
	0	1	4	12	24
Fill volume, mL	NA	0.56	0.35	0.19	0.07
Contour volume, mL	0.17	0.06	0.07	0.12	0.17
Contour angle	20.6°	10.2°	13.0°	17.3°	24.2°

Table 2. Calculated Secondary Endpoints Over Time (in Percentages)

	Week			
	1	4	12	24
Fold fill	325.8	205.2	109.1	40.4
Fold flattening	64.4	60.9	28.4	3.8

DISCUSSION

In this study, we devised a novel 3D mathematical model to objectively determine volumetric changes associated with nasolabial fold augmentation. By incorporating quantitative mathematical calculations from 3D models, we are able to draw more accurate conclusions about the true longevity and effectiveness of nasolabial fill. Current metrics for the evaluation of durability are largely subjective, either determined visually by a treating or blinded physician or by patient-reported satisfaction with the result.[16-20] In addition, the standardization of durability reporting is itself lacking and thus prevents true head-to-head result comparisons. For example, there is a wide range of clinically-reported assessment tools in the literature on facial fillers, including the Five-Point Wrinkle Assessment Scale, the Wrinkle Severity Rating Scale, the Global Aesthetic Improvement Scale, and physician-generated Likert scales.[16-20] Three-dimensional stereophotogrammetry, with the aforementioned mathematical model, permits an objective evaluation of volume correction that is more meaningful than previously reported.

To construct a reproducible and reliable mathematical model, we based the model on the geometric fill of a trough defined by internally-consistent points of a patient's anatomy. Since the calculation of the minimal spanning surface is by definition the smoothest possible geometric solution to a "defect," this model is universally applicable and can be globally transposed for other soft tissue defects (for instance, lower lid tear trough deformities). Moreover, the geometric model can be extrapolated in a predictive fashion and provide the surgeon with the ideal amount of injectable needed to fill a given space.

These predictive models can further enhance our understanding of fillers by allowing calculation of secondary

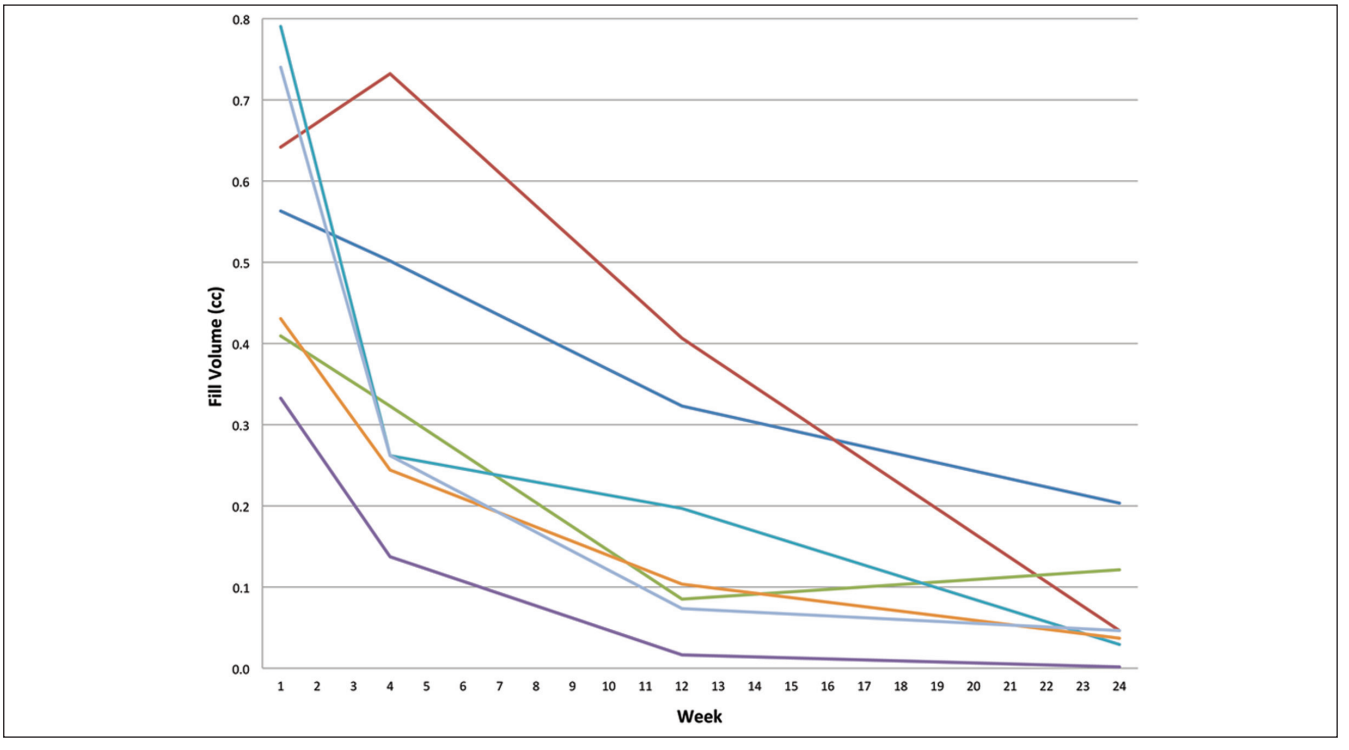

Figure 4. Nasolabial absolute fill volume over 24 weeks for seven patients after bilateral nasolabial fold correction with BellaDerm prehydrated acellular dermis. The initial data point indicates the one week postoperative fill.

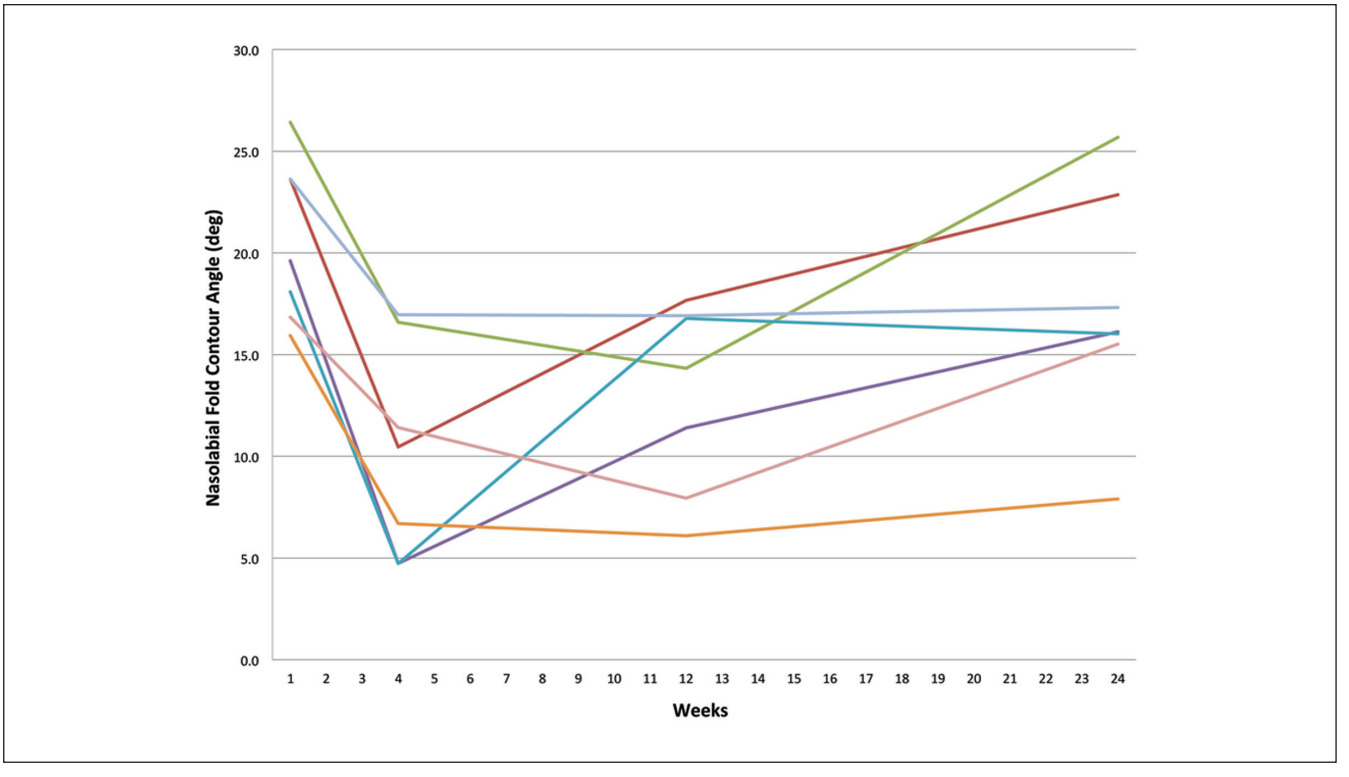

Figure 5. Nasolabial contour angle over 24 weeks for seven patients before and after bilateral nasolabial fold correction with BellaDerm prehydrated acellular dermis. The initial data point indicates the preoperative contour angle.

endpoints. For instance, serial contour volume measurements allow us to calculate the percent reduction in the visible crease of a defect's fold. In larger studies, these outcomes could provide surgeons with "half-life" graphs for the various fillers, similar to Figure 4. Combined with the computation of a patient's theoretical defect volume, this would allow a surgeon to provide the patient with the exact amount of correction or overcorrection to produce the desired result. Table 2 shows two such secondary endpoints, demonstrating that many patients were overcorrected to provide longer-lasting results and that the mathematical model was able to demonstrate that the visible effacement of the defect was 66% effective on average.

With respect to facial rejuvenation, a true dichotomy exists between long-lasting, reproducible surgical procedures and shorter-acting, somewhat unpredictable soft tissue fillers. Currently, an increasing number of patients are selecting the less-invasive, simpler injectable options to reverse the signs of facial aging.[21,22] However, a paucity of quantifiable results on injectable fillers also exists, making the potential benefits of one filler type over another difficult to delineate. Many of the once popular collagen-based products have fallen from favor in lieu of newer, nonimmunogenic fillers.[23,24] Likewise, a shift toward products with longer-lasting effects has occurred.[25] Hyaluronic acid–based fillers are by far the most commonly employed in soft tissue augmentation. However, despite their reportedly-low incidence of immunogenic and adverse events, subjective reports of longevity have varied significantly, with reported results lasting anywhere from three to 12 months.[8,26,27] This kind of subjective variability in longevity and volumetric benefit plagues nearly-all soft tissue fillers and significantly complicates the informed consent process. How can one accurately counsel the patient on expected longevity of results with such wide variability in reported outcomes data?

As a result, an opportunity exists for the development of an innovative augmentation technique that marries the advantages of surgical and injectable rejuvenation, providing longer-lasting, predictable results in a simple, less-invasive way. Preliminary reports have led many to believe that human acellular dermis (HADM) products meet these needs.[28-31] As such, we opted to test HADM for filling of nasolabial defects to prove the concept of our mathematical model. Based on our prospective study, we can infer that HADM fill in the nasolabial fold will last approximately six months, with peak volume enhancement between one to three months. Indeed, this model can now provide prospective, objective comparisons of other fillers applied through the same geometric modeling principle.

CONCLUSIONS

To our knowledge, this is the first mathematical model of nasolabial fold augmentation efficacy. We utilized a class of HADM-based filler material to prospectively validate this model. Future iterations will allow direct prospective comparisons of other filler materials in hopes of producing objective longevity data to better guide clinical practice and improve patient satisfaction.

Disclosures

Dr. Kim receives research funding from and is a consultant for the Musculoskeletal Transplant Foundation, the manufacturer of the product discussed in this article. The remaining authors have nothing to disclose.

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