Biomechanical Properties of Superficial Musculoaponeurotic System Tissue With vs Without Reinforcement With Poly-4-hydroxybutyric Acid Absorbable Mesh

Patrick C. Angelos, MD; Tara E. Brennan, MD; Dean M. Toriumi, MD

IMPORANCE It is unknown whether poly-4-hydroxybutyric acid (P4HB)-reinforced superficial musculoaponeurotic system tissue (SMAS) plication techniques will support SMAS imbrication and plication and potentially improve outcomes in rhytidectomy.

OBJECTIVES To evaluate the biomechanical properties (tissue breaking strength, suture tearing force, and stress relaxation) of the SMAS with vs without reinforcement with P4HB absorbable mesh and to correlate these results with potential clinical applications.

DESIGN, SETTING, AND SAMPLES In a cadaver study at an academic setting, 12 fresh frozen cadaver heads were used. Rhytidectomy incisions were made, and the SMAS was harvested and prepared for strength and stress testing using an Instron device.

MAIN OUTCOMES AND MEASURES Tissue breaking strength and suture tearing force were analyzed. Stress relaxation test results were also assessed. The results of the SMAS samples alone were compared with those reinforced with P4HB absorbable mesh.

RESULTS Overall, there were significant differences noted in tissue breaking strength and suture tearing force between the 2 groups. When the SMAS was reinforced with absorbable mesh, significant improvements were observed in tissue breaking strength (P < .001) and suture tearing force (P < .003). In addition, less variability was demonstrated in the maximum tensile load-bearing quality of the SMAS when the repair was reinforced with P4HB.

CONCLUSIONS AND RELEVANCE Reinforcement with P4HB absorbable mesh improves tissue breaking strength and suture tearing force in cadaveric SMAS. It also reduces the variability in load vs displacement seen among samples tested. These data suggest that P4HB-reinforced SMAS imbrication would support higher loads and provide more consistent, long-lasting SMAS support among patients undergoing rhytidectomy. Further studies are needed to correlate these data with clinical outcomes in rhytidectomy.

LEVEL OF EVIDENCE NA.
Rhytidectomy is one of the most common procedures performed in cosmetic surgery. Various methods have been used to achieve common goals in face-lifting, which include removing redundant skin, reducing jowls, improving the jawline, and restoring the cervicomental angle in the neck. The procedure historically consisted of limited subcutaneous dissection and trimming of excess skin. This technique was compromised by excess tension being placed on the skin closure, often leading to unfavorable scarring and short-term results. Since Skoog introduced the concept of subfascial dissection in face-lifting, followed by a description by Mitz and Peyronie of the superficial musculoaponeurotic system tissue (SMAS) in the 1970s, many benefits of dissection in the subfascial plane have been realized. These benefits include relieving tension placed on the skin flaps, and previous studies have shown that deeper tissue support in the form of the SMAS layer produces a significant decrease in skin-closing tension. This dual-layer procedure allows for bidirectional manipulation and pull in various vectors with different degrees of tension.

The SMAS is a continuous, organized fibrous network of fascia that envelops the facial muscles and connects them to the overlying dermis. It is contiguous with the temporoparietal fascia superiorly, with the occipitofrontalis muscle and galea, and inferiorly with the platysma muscle in the neck. The SMAS consists of a 3-dimensional scaffold of collagen fibers, elastic fibers, and fat cells. Imbrication and plication of the SMAS contribute to the tensile strength and long-term results achieved in rhytidectomy.

In the past decade, many surgeons have become proponents of SMAS imbrication and plication to stabilize the deep layers in rhytidectomy. In an effort to further support the SMAS imbrication and plication technique in rhytidectomy, some surgeons (including D.M.T.) have used absorbable mesh to strengthen the SMAS fixation. This absorbable mesh reinforcement may help prevent early postoperative looseness and rupture of the SMAS imbrication and may prevent “cheese wiring,” the tearing of the sutures through the SMAS that can occur during healing as the skin and subcutaneous tissues swell.

The biopolymer poly-4-hydroxybutyric acid (P4HB) is a homopolymer of 4-hydroxybutyrate and belongs to a diverse class of materials called polyhydroxalkanoates, which are produced naturally by microorganisms. The P4HB absorbable mesh has a high burst strength and prolonged tissue retention to allow for healing. It is approved by the Food and Drug Administration for soft-tissue reinforcement in plastic and reconstructive surgery, temporary wound support, and hernia repairs. Once implanted, P4HB degrades in the body primarily by hydrolysis to produce 4-hydroxybutyrate. This monomer is a normal constituent of the mammalian body and is found within various tissues, including brain, heart, kidney, liver, lung, muscle, and brown fat. The body quickly metabolizes 4-hydroxybutyrate, and it is then eliminated from the body primarily by metabolism via the Krebs cycle and secondarily by beta oxidation ultimately to carbon dioxide and water. The time to complete degradation and resorption varies with processing (ie, orientation of the polymer and size), but in general complete resorption occurs within 12 to 18 months.

To ensure the safety of P4HB, the biological effects of the polymer and devices made from it have been extensively evaluated in vitro and in vivo.

The objective of this study was to evaluate the biomechanical properties of the SMAS with vs without reinforcement with P4HB absorbable mesh. Based on clinical experience, the hypothesis was that reinforcing the SMAS with absorbable mesh improves tissue breaking strength and suture tearing force. Clinically, this would correlate with a more durable SMAS imbrication and plication and prevent tissue rupture or tearing of the sutures through the SMAS.

Methods

Institutional review board approval and informed consent were not obtained because this is a cadaver study. Twelve fresh frozen cadaver heads were used for the study. Once the heads were appropriately thawed, a line was marked 1 cm lateral to the melolabial fold. Using sharp dissection, a subcutaneous flap was raised from the temporal region to the neck and anteriorly to the line as noted. Next, careful SMAS dissection was performed to raise the SMAS from the underlying parotid fascia and surrounding tissues. The SMAS flaps were dissected on each side to just over 1 cm from the melolabial folds. The SMAS was then trimmed of excess fat without compromising the integrity of the SMAS (Figure 1).

The elevated SMAS flaps were then cut into 1 × 2-cm samples (Figure 1). Because of the known variability of the SMAS across different facial regions within a single cadaver, as well as in a given facial region between cadavers, each sample was kept in its original orientation (as if for a posterior or superior vector of pull used in rhytidectomy) and labeled based on the cadaver from which it was harvested. Future testing with vs without reinforced absorbable mesh would attempt to eliminate intercadaver variability by pairing mesh and nonmesh samples harvested from the same cadaver.

In total, 72 samples were prepared, and 36 of the samples were reinforced with P4HB absorbable mesh. The mesh was sutured to the SMAS samples in a uniform fashion, consisting of 6 total mattress sutures of 5-0 polydioxanone suture (PDS), all tied with 5 knots per suture, and all knots placed 5 mm from the leading edge of the sample (Figure 1). Four groups contained 18 samples each. These included 2 groups of 18 samples each for tissue breaking strength (SMAS only and SMAS with absorbable mesh) and suture tearing force testing.

Between preparation and testing, the SMAS samples were wrapped in gauze and placed in cups of saline to prevent dehydration. All excised SMAS was tested within 12 hours of harvest from the fresh cadaver heads and kept moist with saline.

An Instron biomechanical testing device (Teplha Medical Devices), pulling at a constant rate of 2.5 mm/min, was used to measure tissue breaking strength and suture tearing force of the SMAS with vs without absorbable mesh reinforcement. To facilitate loading of the tissue in the testing device grips and to limit slippage of the tissue samples, sandpaper was attached to the grips.

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For the tissue breaking strength testing, 5 mm of tissue was placed into each of the Instron biomechanical testing device grips, with 1 cm between available for observation of tissue bursting. Samples were excluded if the tissue broke at the grips or if significant slippage was noted (Figure 2). For the suture tearing force testing, 1 cm of tissue was placed in the superior grip, a 5-0 PDS was placed 5 mm from the other end and tied with 5 knots, and its suture tail was placed across the full length of the inferior grip. The tissue was pulled at the previously noted constant rate until the suture tore through the tissue or ruptured. Data were collected and stored with the manufacturer’s software (TM). A third party, using a mixed-effects model, performed the statistical analysis. P < .05 was considered statistically significant.

The second part of the study used 2 × 3-cm prepared SMAS samples. Two vertically oriented samples were overlapped by...
1 cm and sutured together using 3 sutures of 5-0 PDS. This procedure was performed with all available samples, leaving several SMAS dyads for study. Each SMAS dyad measured 2 × 5 cm in vertical orientation after suturing (Figure 3). Care was taken to pair SMAS samples harvested from the same cadaver to minimize the variability between samples.

Next, half of the dyads were reinforced with absorbable mesh. This involved suturing the 2 × 3-cm pieces of absorbable mesh to the SMAS dyads, which overlapped by 1 cm and were in a vertically oriented direction to mimic the orientation of mesh reinforcement of SMAS imbrication in vivo during a rhytidectomy. The absorbable mesh was sutured to the SMAS samples in a uniform fashion, consisting of 6 total mattress sutures of 5-0 PDS (3 on each side of the 2-cm edge of the mesh), all tied with 5 knots per suture (Figure 3). Four groups contained 18 samples each. These included 2 groups of 18 samples each for tissue breaking strength (SMAS only and SMAS with absorbable mesh) and stress relaxation testing.

Care was taken to minimize the variability of the SMAS samples tested within groups; that is, bulkier SMAS samples reinforced with absorbable mesh were tested against bulkier SMAS samples not reinforced with absorbable mesh. This was typically accomplished simply by pairing mesh and nonmesh samples harvested from the same cadaveric specimen. The Instron device, at a constant rate of 2.5 mm/min, was used to measure tissue breaking strength and stress relaxation of the SMAS with vs without absorbable mesh reinforcement. To facilitate loading of the tissue in the Instron device grips and to limit slippage of the tissue samples, sandpaper was attached to the grips as in the first experiment (Figure 4).

Results

For the mechanical testing, the mean (SD) breaking force of the SMAS without absorbable mesh was 2.22 (1.74) kilogram force (kgf), with a minimum of 0.27 kgf and a maximum of 4.76 kgf. The mean (SD) tissue breaking strength of the SMAS with P4HB absorbable mesh reinforcement was 3.78 (1.86) kgf, with a minimum of 0.78 kgf and a maximum of 7.09 kgf. These differences were statistically significant at $P < .001$ (Figure 5).

For the suture tearing force testing, the mean (SD) force to tear the suture out of the SMAS without absorbable mesh was 0.73 (0.30) kgf, with a minimum of 0.20 kgf and a maximum of 1.23 kgf. The mean (SD) force to tear the suture out of the SMAS with P4HB absorbable mesh reinforcement was 0.98 (0.28) kgf, with a minimum of 0.37 kgf and a maximum of 1.39 kgf. These differences were statistically significant at $P < .003$ (Figure 6).
The results of the second portion of the study involving the 2 × 3-cm overlapping SMAS dyads with vs without absorbable mesh reinforcement revealed a mean (SD) maximum load for the nonmesh repair of 22.64 (10.06) N, while that for the mesh repair was 38.76 (7.66) N. This difference was statistically significant at $P = .003$ (Figure 7).

The early portions of the load vs displacement curves were similar between the mesh and nonmesh groups (eFigure 1 and eFigure 2 in the Supplement). This shows that the relative stiffness of each repair was similar. However, the SMAS mesh dyads demonstrated more consistent load vs displacement curves, with less variability between samples than their nonmesh counterparts. The mean load vs displacement curves for the SMAS dyads with vs without mesh reinforcement are shown in Figure 8. At 25-mm displacement, the difference between the groups was statistically significant ($P = .001$ by $t$ test). At 20-mm displacement, the difference was not statistically significant ($P = .07$).

Discussion

The results of this study indicate that, under controlled Instron device biomechanical testing, the SMAS that is reinforced with P4HB absorbable mesh demonstrates significant improvements in tissue breaking strength. The addition of absorbable mesh also increased the force required to tear a 5-0 PDS through the tissue (also known as cheese wiring). The SMAS mesh dyads demonstrated more consistent load vs displacement curves, with less variability between samples than their nonmesh counterparts. Specifically, the nonmesh dyads failed at consistently lower loads than their mesh counterparts (mean [SD], 22.64 [10.06] vs 38.76 [7.66] N). Notably, some of the nonmesh dyads failed at loads between 15 and 20 N, which is only slightly higher than the 10-N estimated requirement to achieve a desirable surgical outcome. The mesh dyads did not begin to fail until higher loads (30-40 N) were applied. This finding is a significant point to consider because the repair site may experience high loads after surgery even during normal facial movements.

A moderate amount of variability was seen among the samples, especially those used for tissue breaking strength testing. This effect was thought to occur because of intercadaver variability in SMAS bulk and strength as well as inter-SMAS specimen variability in the facial location harvested. As noted in the Methods section, this effect was controlled for as much as possible by specifically assigning an equal number of SMAS samples per anatomic area and per cadaver head evenly across all 4 groups in an attempt to control for the variability among tissue samples. Because of this, it is understandable that the standard deviations are high across the samples, but overall we do not believe that this detracts from the significant differences seen between SMAS samples tested with vs without P4HB absorbable mesh reinforcement.
Recently, face-lift surgery has seen a pendulum shift in popularity from more invasive, extensive dissection procedures to less invasive procedures with more limited dissection. The goal and balance that surgeons and patients try to achieve with these procedures are to gain the most improvement and lasting benefit from surgery with the least associated morbidity, risk, and recovery time. The dissection and suspension of the SMAS seem to represent a common goal among various contemporary rhytidectomy procedures.

It is thought that the SMAS aids in the elevation of the facial soft tissue and that SMAS plication can overcome the resistive forces of the undissected SMAS, which maintains its attachments to the underlying structures. With the SMAS suspension by imbrication and plication, sutures are placed under tension that may be close to or at the breaking strength of the SMAS. Also of concern is that postoperative swelling may lead to early failure of the SMAS suspension. It has been shown in an animal model that suspension sutures are of limited long-term effectiveness and have an early failure rate. Early failures are frustrating for surgeons and patients, especially when early revision surgery is required. Revision procedures are potentially more problematic because these patients are at increased risk for soft-tissue fibrosis, increased SMAS attenuation, and secondary skin deformities.

In a study similar to ours, Saulis et al evaluated the biomechanical and viscoelastic properties of skin, SMAS, and composite flaps as they pertain to rhytidectomy. The authors found that tissue breaking strength measurements were significantly greater in skin and composite flaps compared with SMAS flaps. They also found that the suture tearing force was stronger for composite flaps than for skin and SMAS flaps. This study also examined stress relaxation and creep and found that skin flaps demonstrated the greatest degree of tissue creep, which was significantly greater than that of SMAS flaps or composite flaps. However, no difference was found in stress relaxation or creep between SMAS flaps and composite grafts. The authors postulated from these findings that, because skin and composite flaps are stronger than SMAS flaps, greater tension that may be close to or at the breaking strength of SMAS may be placed on these flaps.

In contrast, Trussler et al demonstrated that, under increased tension, the SMAS has an inferior viscoelastic profile and shows more tissue deformation under these conditions, including increased stress relaxation and creep. This study evaluated the viscoelastic properties of the SMAS within the biomechanical variables of the high SMAS rhytidectomy. Intraoperative tension at superior and inferior points of SMAS fixation was tested, as well as ex vivo testing of breaking strength, stress relaxation, and creep. The in vivo force applied to the SMAS was found to be only 15% of its total breaking strength. Furthermore, the deformational load of the high SMAS face-lift caused only a 14% creep in the tissue ex vivo. The authors concluded that the focus of rhytidectomy should be centered on soft-tissue suspension at lower tension to improve the ability to reposition the facial soft tissue and increase the longevity of the result.

We tend to agree with the philosophy that the suspension of the SMAS at lower tension decreases the chance for tissue rupture or suture tearing through the imbrication. We also use the high SMAS rhytidectomy technique similar to that described by Trussler et al, which is a limited dissection face-lift in which a sub-SMAS dissection is performed to the area of the attachments of the zygomaticus major. A subcutaneous dissection is used anteriorly to translate the lifting forces on the anterior cheek and nasolabial fold. The suspension of the flap is performed at 2 points: one at the temporal area securing the SMAS to the deep temporal fascia and the other posteriorly at the mastoid region. These are precisely the areas where we have used P4HB absorbable mesh to help distribute and ease tension on the SMAS imbrication. Our clinical theory is that the absorbable mesh helps support the imbrication and prevents early tissue rupture. Placing the imbrication under minimal tension is also paramount to the success of this technique. Most important, we believe that the absorbable mesh also helps prevent cheese wiring, or the tearing of the sutures through the SMAS that may result in early tissue relaxation and reduced support of the face-lift.

Limitations of this study include the ex vivo conditions and the use of cadaver tissue as opposed to living, actively perfused tissues. Other limitations include the variability in the SMAS samples harvested, as previously addressed. Efforts to reduce this inter-SMAS sample variability were also discussed. An additional consideration is the potential for intersample variability in the strength of the union between the absorbable mesh and the SMAS dyads sutured together using PDS. Specifically, any slipping or breaking of sutures between the absorbable mesh and the SMAS to which it is sutured may affect the results of the testing. Again, efforts were made to uniformly secure the SMAS to the absorbable mesh (almost all the samples were sutured together by the same operator [D.M.T.]). Also, the number of sutures used per unit area to secure the absorbable mesh to the SMAS samples mirrored in vivo clinical situations as performed by one of us (D.M.T.).

Conclusions
The reinforcement of the SMAS with P4HB absorbable mesh significantly improves SMAS breaking strength and suture tearing force using 5-0 PDS. Absorbable mesh repairs are also better at withstanding stress relaxation forces and fare better on creep testing. Overall, P4HB absorbable mesh reliably increases the tensile strength and reduces the load vs displacement measures of the SMAS imbrication repair simulated in this cadaver study, which may allow for stronger, longer-lasting, and consistent SMAS imbrication and plication outcomes in rhytidectomy.

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Study concept and design: All authors.
Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: Angelos, Brennan.

Critical revision of the manuscript for important intellectual content: All authors.

Study supervision: All authors.

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Additional Contributions: Kevin O’Grady (University of Illinois at Chicago) assisted in the research laboratory, facilitated cadaver laboratory dissections, and coordinated and helped with Instron device testing and interpretation. David P. Martin, PhD (Tepha Medical Devices) assisted with Instron device testing and data analysis. Nirav Thakkar, MD (University of Illinois at Chicago) helped with processing of the superficial musculoaponeurotic system tissue samples and securing the absorbable mesh to the tissue.

REFERENCES

