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# Viscoelastic Properties of the Superficial Musculoaponeurotic System (SMAS): A Microscopic and Mechanical Study

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**Abstract.** A study was undertaken to determine the physical properties and microscopic structure of the superficial musculoaponeurotic system (SMAS) tissue. Forty virginal specimens and eight reoperated specimens were examined. The following findings were discovered. 1) *Microscopic appearance* shows the SMAS to consist of collagen fibers, a relatively high concentration of elastic fibers interspersed with fat cells. 2) *On scanning electron microscopy,* the virginal SMAS shows the collagen fibers to have a similar convoluted appearance as in the dermis. There is some evidence of parallelization of the collagen fibers in the reexcised SMAS specimens. 3) *Mechanical testing (Instron)* demonstrates that both the SMAS and preauricular skin were subjected to a series of loading/unloading tests at various rates, amplitudes, and stress relaxation tests. Both sets of specimens indicated definite viscoelastic properties. Although the mechanical behavior of both tissues was somewhat similar, the viscoelastic effect of the SMAS was less pronounced. A slackening effect of the SMAS indicated a gradual expansion of the SMAS postoperatively. These results could provide some indication of the long-term effects of SMAS surgery.

**Key words:** SMAS—Microscopy—Mechanical testing—Viscoelasticity

Tightening of the superficial musculoaponeurotic system (SMAS) in one form or another has virtually become an integral part of facelift surgery as it is currently performed. However, the long-term efficacy of SMAS surgery is little understood as insufficient scientific data is available to make this evaluation.

The SMAS is a composite fibro-fatty layer comprising collagen and elastic fibers and fat cells. Controversy still persists as to whether the SMAS represents the superficial fascia of the face or whether it is the parotid or platysma fascia [1–4].

In this article, both the microstructure and mechanical properties of the SMAS are extensively examined for the purpose of determining whether the SMAS possesses some degree of viscoelasticity. These findings could help in understanding better the value of SMAS surgery for improving and sustaining the results of facelifting over the long-term.

Three different, but complementary studies were performed in order to investigate the viscoelastic properties of the SMAS. They were as follows:

1. Light Microscopy
2. Scanning Electron Microscopy (SEM)
3. Mechanical (Tensile) Testing (Instron System)

SMAS preparations were taken from primary and redo (4–9 months postsurgery) facelifting procedures in order to examine their collagen and elastic fiber configuration. For comparison of the mechanical properties preauricular skin was also garnered from these patients.

In all, 40 virginal and eight redo SMAS preparations were examined microscopically. The latter were of almost identical size and shape to those excised in the initial operations.

The technique for harnessing the SMAS was through the usual preauricular incision and following the undermining of the cheek skin, a triangular-shaped SMAS segment of 4 × 3 cm was removed. It was partly cut into two smaller segments. These were fixed immediately for light microscopy and scanning electron microscopy in

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1% formaldehyde and 1% glutaraldehyde in phosphate-buffered saline (pH 7.4), respectively. The collagen, elastic fibers, and fat cell components were then examined by light microscopy. Hematoxylin and eosin, and Masson's Trichrome staining were used for collagen fiber demonstration and Verhoeff's Stain for elastic fiber demonstration.

The 1% buffered glutaraldehyde specimens were post-fixed in 1% $O_sO_4$ solution and dehydrated in a series of graded alcohols. Following coating with gold, the specimens were examined with a scanning electron microscope Model JEOL JSM 840 (20 kV). The mechanical testing was performed on the fresh larger remaining segment of the SMAS as well as on the excised preauricular skin using an Instron Floor Model TTC Machine at room temperature of about 20°C and open to observation. The tests were performed about 2 h subsequent to obtaining the specimens, which were kept in a moist environment until that time; drying of the specimens prior to testing was minimal. Specimen strips, ranging from 3 to 4 cm in length, 6 to 8 mm in width, and 2–3 mm thickness were placed between the gripping devices. The relative displacement of the specimen ends was controlled, and the force was measured by a load cell in series with the specimen. In some cases, video recordings of the specimens under loading were obtained.

## Results

### *Light Microscopy Examination*

Histological examination of the virginal SMAS specimens showed a fibro-fatty tissue in which lobules of fat cells are surrounded by fibrous septae. These consist of wavy, regularly oriented collagen fibers with few fibrocytes (Fig. 1).

The collagen fibers are oriented in a compact parallel configuration in the redo SMAS specimens, with a similar parallel direction of the scattered fibrocytes. In spite of the stretching, the wavy pattern of the collagen is partially preserved (Fig. 2). The fat cells have retained their lobular pattern.

The density of elastic fibers selectively stained with Verhoeff's Stain appears to be higher in SMAS than in skin. However, we were unable to estimate the percentage of elastic fibers [5].

### *SEM Appearance*

*Virgin SMAS tissue.* The fibrous elements of collagen and elastin form a network in which lobules of fat cells are embedded and in which all the components are randomly intermingled. As in skin, the collagen fibers are convoluted and are irregularly and loosely arranged in a multidirectional pattern (Figs. 3 and 4).

*Redo specimens.* Parallelization and higher density of the collagen fibers was found with a persistence of the wavy form. This is in contrast to the appearance of stretched dermis in which the collagen fibers are highly compacted, without a wavy convoluted pattern [6–8]. The normal shape of the fat cells in these specimens was retained (Fig. 5).

### *Mechanical Properties of SMAS as Compared to Those of the Dermis*

> Both dermis and SMAS consist of interwoven coiled collagen fibers and elastin densely packed to form a fiber mat which is generally not isotropic, but has directional variations or a ''grain'' effect. The fibers are lubricated by a mucopolysaccharide viscous extracellular matrix. This reduces dry friction effects during relative movements of separate fibers but imparts a viscous resistance to relative motion. In view of this, the mechanical response of dermis and SMAS to loading is time dependent, indicating ''viscoelastic'' behavior.
>
> Due to the stiffening effects of stress-induced orientation of the coiled interwoven fibers, the elastic fully reversible response behavior is highly nonlinear.

Some nonreversible inelastic effects generally occur at initial loadings due to consolidation of fibers but the response of the fiber mat by itself after repeated cycling is primarily nonlinearly elastic.

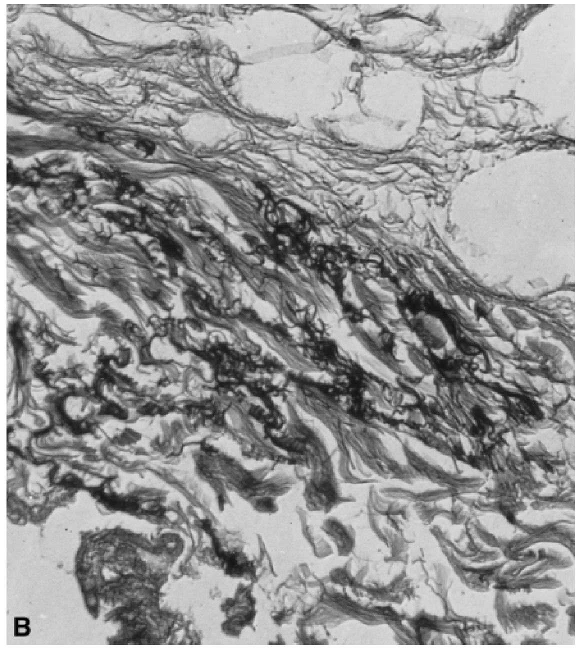
Both skin and SMAS being viscoelastic substances indicate the typical phenomena of *creep*—skin in tension will gradually stretch—and *stress relaxation*—if skin is stretched to a given length which remains constant, the tensile force would gradually decrease with time. In addition, *hysteresis,* that is, energy loss, upon a loading and unloading cycle (Fig. 6), is also exhibited. The mechanical behavior of skin and SMAS will depend on the proportion and geometry of constituent fibers, the proportion of viscous fluid to fiber mat, and in the SMAS, the presence of fat cells.

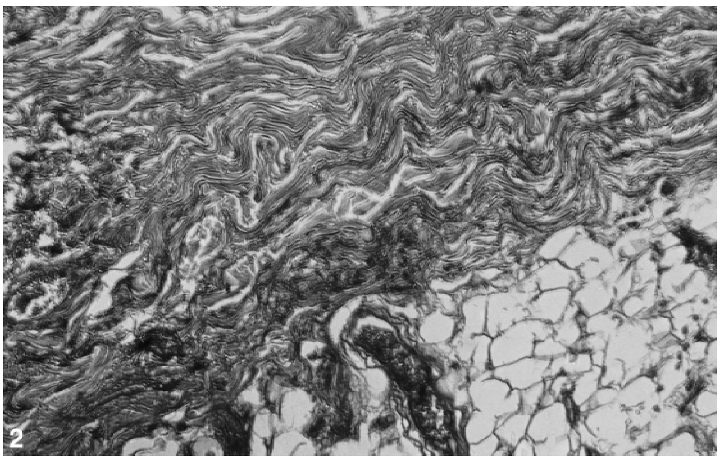
Three successive cycles of loading and unloading an SMAS specimen to the same maximum stress (force per unit area) were performed in one set of tests. Stiffness increased with strain which is the measure of deformation measured by the change in length compared to the original length. Hysteresis upon unloading was also observed (Fig. 6). A similar exercise was conducted for skin (Fig. 7).

In another tensile test, the elongation strain of the specimen (strain) was held constant for a period of 5 min for stress relaxation to occur, after which it was unloaded to zero stress. Thereafter, the sequence was repeated for a higher initial stress value. Following three or four cycles, the first test cycle was repeated.

Figures 8 and 9 for SMAS and skin, respectively, show the following test results.

1. With repeated cycling, stiffening of the initial response curve was shown until a saturation condition was reached.
2. With repeated cycles of stress relaxation, the relative stress relaxation decreases. Upon stress relaxation cycling at higher initial stress values, stress





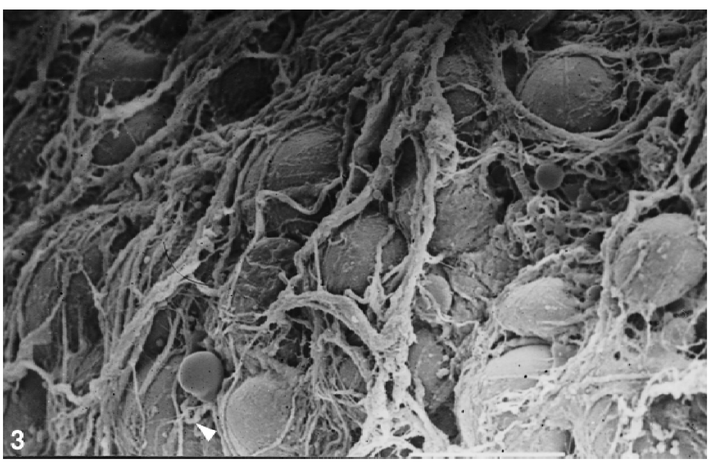


**Fig. 1. (A)** Wavy collagen fibers in a virginal SMAS specimen. The fibers are embedded within the ground substance. Some single fibrocytes are evident. (H&E, ×200). **(B)** Elastic tissue stain in virginal SMAS specimen demonstrates darkly stained irregular distribution of the elastic fibers. These fibers appear in a branching pattern interwoven with collagen fibers. Note the prevalence of the elastic fibers within the section (Verhoeff's elastic stain, ×250).

**Fig. 2.** SMAS specimen taken from a patient during a redo facelift operation performed 4 months after the initial surgery. The collagen fibers demonstrate partially parallel compact configuration. Elastic tissue stain showing stretched parallel darkly stained fibers arranged between compact collagen fibers. The collagen, although oriented in parallel, partially maintains its same wavy form (Verhoeff's elastic stain, ×180).

**Fig. 3.** A SEM view of virginal SMAS tissue demonstrates the composite nature of this tissue. Fat cells are interspersed throughout multidirectional wavy collagen fibers. The elastic fibers are exhibited as thin filamentous strands *(arrow)* (×250).

relaxation at a lower initial stress is essentially eliminated indicating fully elastic behavior to that stress level.

These results were at least partly due to the loss of part of the viscous fluid during the test. As a consequence, there was less lubrication between the fibers and a reduction of the time-dependent effect. A jerky, irregular behavior of the stress relaxation curve, indicative of ''slip-stick'' dry friction motion conditions was seen on repeated cycling.

In all, the SMAS specimens showed response characteristics to mechanical testing similar to that of skin but with a reduction in the relative stress relaxation effect. The mechanical behavior of virginal and reoperated SMAS tissue revealed no essential differences.

## Discussion

Since the milestone paper of Mitz and Peyronie [9] was published outlining the anatomy of the superficial mus-

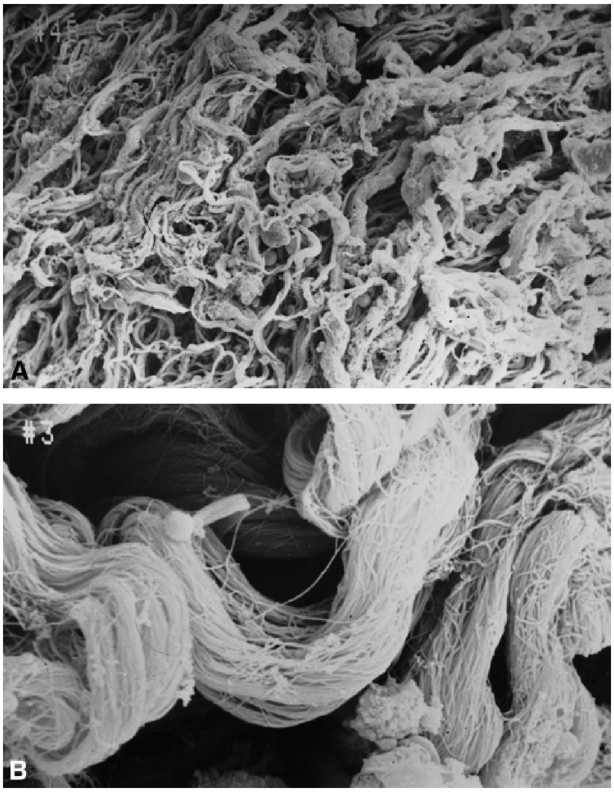


**Fig. 4.** **(A)** SEM view of virginal SMAS illustrating the wavy irregular loosely scattered multidirectional collagen. (×500). **(B)** High magnification of virginal SMAS demonstrating collagen in a loose coil array (×2500).

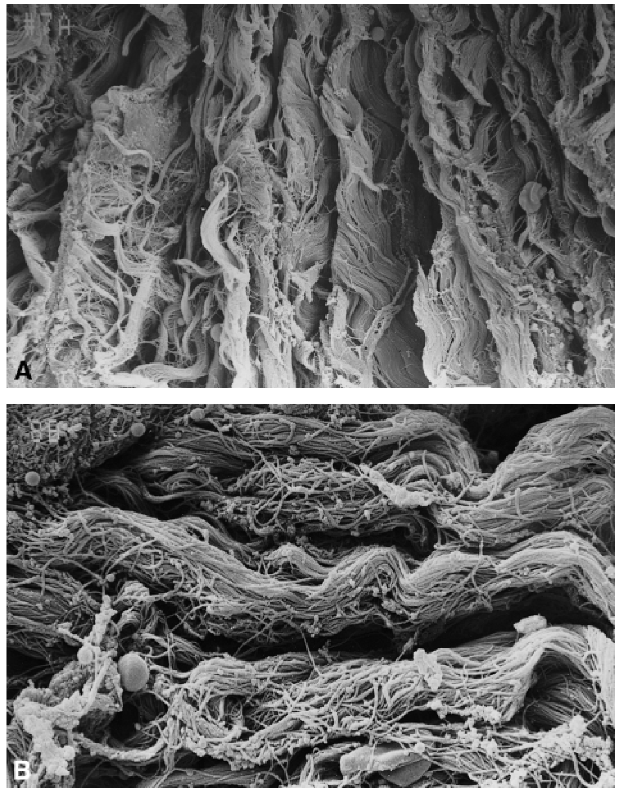


**Fig. 5.** **(A)** SEM view of an SMAS specimen taken from a patient during a redo facelift operation performed 5 months after the initial surgery. Parallel compact configuration of the collagen fibers is evident (×700). **(B)** High magnification of reoperated SMAS specimen with an area of stretched, compact collagen fibers (×2500).

culoaponeurotic system, numerous articles have appeared [10–19] describing individual preferences in technique with SMAS surgery. All have reported on the value of SMAS tightening as part of the standard facelifting operation.

Emphasis has been placed on the benefits accruing from SMAS surgery on wound healing and scar formation. The deep-tissue support that this provides has been shown by both Burgess et al. [20] and Forrest et al. [21] to significantly reduce closing skin tension. As an example, the preauricular incision can be sutured without tension, which is generally considered advisable.

The dermis, which consists mainly of Type I and III collagen is in a constant state of stretch and relaxation and these coiled collagen fibers play an important role in this dynamic viscous state. By the same token, the facial features are also in a state of semiflux during talking, smiling, and eating, etc., and it would be reasonable to suppose that the deeper facial structures likewise possess viscoelastic properties. This supposition would appear to be validated since the microstructure and mechanical properties of the skin and the SMAS are fairly similar.

There are in all 16 varieties of collagen in the body, with variations in the shape and arrangement of the collagen molecules, depending on the function that the collagen serves. It is not within the scope of this article to compare the molecular makeup of the SMAS with that of skin as this falls within the province of molecular biology.

There does appear to be a decided difference between the response to stretching of the SMAS to that of skin. Intraoperative stretching of the facial skin during facelifting, over a 40- to 45-min period [22], does cause some slackening. When the tightened SMAS after excision and suturing is subjected to a similar stretching force to that applied to the overlying skin, it does not show any evidence of slackening intraoperatively. However, following a lapse of some 4–9 months postoperative, an equal amount of SMAS tissue to that originally excised, can be reexcised. This was seen in four of our patients—two female and two male. They were dissatisfied with their postoperative results because of persistence of the nasolabial folds and recurrence of jowl sagging and vertical neck folds, and were subsequently reoperated on (redo facelifting [23]). This gradual expansion of the SMAS postoperatively has been termed *the slackening effect.*

There may be two contributing factors to this slackening effect. First, the observation that, with Verhoeff's elastic stain, the density of elastic fibers in the SMAS on light microscopy seems to be higher than that in the skin. A function of the elastic fibers, which are interwoven with the collagen fibers, is to limit the distensibility of

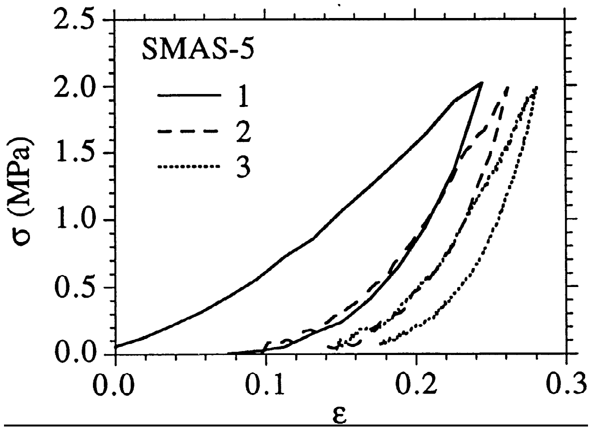



**Fig. 6.** Successive loading and unloading cycles on tensile specimen of excised SMAS tissue, showing an increase in stiffening and decrease in hysteresis (energy loss due to viscoelasticity) with continued cycling.

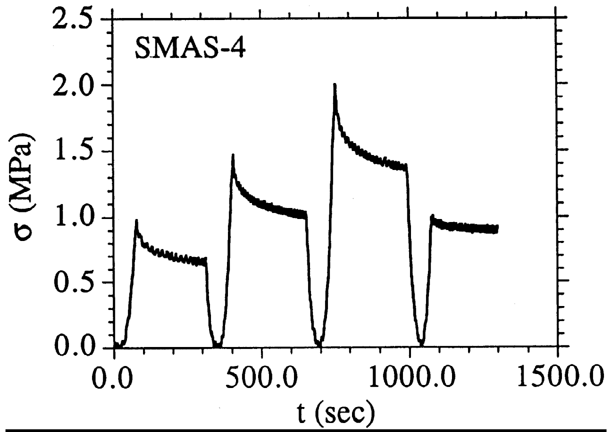



**Fig. 8.** Successive stress relaxation tests on tensile specimen of excised SMAS tissue, showing an increase in stiffening and decrease in relative stress relaxation (viscoelasticity) with continued testing under stress; also, the presence of stress oscillations during relaxation.

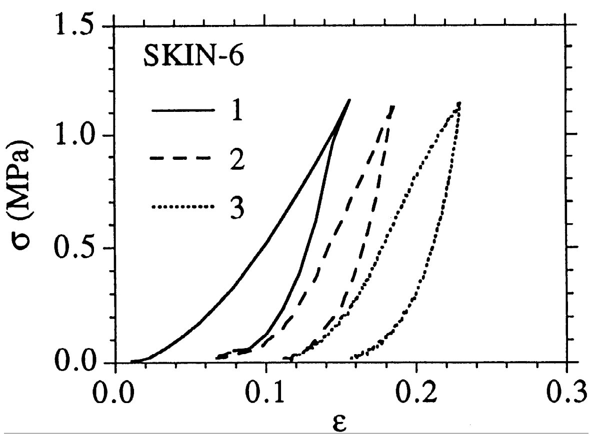



**Fig. 7.** Successive stress relaxation tests on tensile specimen of excised skin, showing an increase in stiffening and decrease in relative stress relaxation (viscoelasticity) with continued testing under stress; also, the increasing amplitude of stress oscillations during relaxation with continued testing.

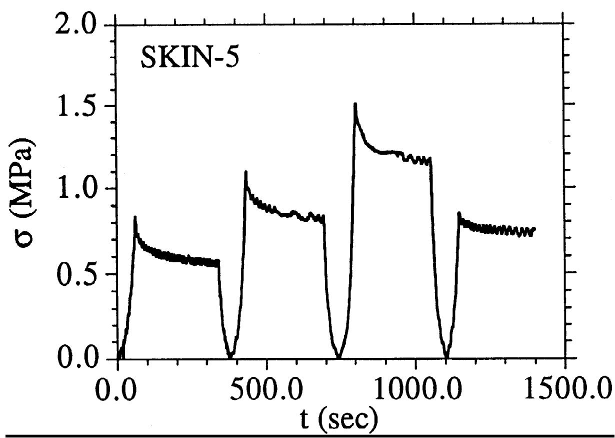



**Fig. 9.** Successive stress relaxation tests on tensile specimen of excised skin of a patient with facial palsy, showing an increase in stiffening and decrease in stress relaxation (viscoelasticity) with continued testing under stress; also, the relatively large stress oscillations during relaxation.

the latter. An unusual polypeptide backbone of the elastin molecule causes its random coiling, which gives the elastic fiber its ability to be stretched and then revert to its original state [24], providing resilience and elasticity to the tissue. Second, the fatty component of the SMAS probably adds some measure of pliability to the SMAS. Both the presumed higher density of the elastic fibers and the presence of fat cells most likely play a significant role in the long-term efficacy of SMAS surgery.

The slackening effect could be applied surgically with the knowledge that some patients may require repeat surgery some months after facelifting and for whom an appreciable amount of skin and SMAS can then be re-excised. Future advances may reveal that patients are candidates for a redo operation and these patients could be prepared in advance for this possibility.

The findings of our study indicate that the cheek has two viscoelastic layers, the skin and the SMAS, which are both intimately attached by fibrous septae.

The muscles of facial expression are, in turn, connected with the SMAS mainly in its medial and inferior aspects. It seems that all these elements make for a functional unit, which enables fine movements of facial expression to be executed.

In conclusion, the SMAS is a composite tissue comprising collagen, elastic fibers, and fat cells in an extracellular viscous matrix. The SMAS does possess viscoelastic properties of creep, stress relaxation, and hysteresis, with relative stress relaxation being reduced for the SMAS. Following tightening of the SMAS, a slackening effect has been observed to take place in some patients over a period of weeks to months. This differs from the behavior of skin with its relatively rapid-stretch relaxation phenomenon, which can begin after the passage of some minutes. What as yet has not been clarified, is whether, after all SMAS tightening procedures, a slackening effect occurs.

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## References

1. Jost G, Levet Y: Parotid fascia and face lifting: A critical evaluation of the SMAS concept. Plast Reconstr Surg **74:**42, 1984
2. Thaller SR, Kim S, Patterson H, Wildman M, Daniller A: The submuscular aponeurotic system (SMAS). A histological and comparative anatomy evaluation. Plast Reconstr Surg **86:**960, 1990
3. Stuzin JM, Baker TJ, Gordon HL: The relationship of the superficial and deep facial fascias: Relevance to rhytidectomy and aging. Plast Reconstr Surg **89:**441–449, 1992
4. Gosain AK, Yousif NJ, Madiedo G, Larson DL, Matloub HS, Sanger JR: Anatomy of the SMAS: A reinvestigation. Plast Reconstr Surg **92:**1254–1263, 1993
5. Weinstein GD, Boucek RJ: Collagen and elastin of human dermis. J Invest Dermatol **35:**227–229, 1960
6. Gibson T: The physical properties of skin. In Plastic and Reconstructive Surgery, 2nd ed. JM Converse (ed.). Philadelphia: W.B. Saunders, pp. 69–77, 1977
7. Brown IA: A scanning electron microscope study of the effects of uniaxial tension on human skin. Br J Dermatol **89:**383–393, 1973
8. Govrin-Yehudain J, Levanon D, Hirshowitz B: Collagen fiber alignment in the human preauricular dermis before and after rhytidectomy. A scanning electron microscopy study. Ann Plast Surg **16:**200–203, 1986
9. Mitz V, Peyronie M: The superficial musculoaponeurotic System (SMAS) in the parotid and cheek area. Plast Reconstr Surg **58:**80–88, 1976
10. Owsley JQ: Platysma-fascial rhytidectomy—A preliminary report. Plast Reconstr Surg **59:**843–850, 1977
11. Rees TD, Aston SJ: A clinical evaluation of the results of musculo-aponeurotic dissection and fixation in face lifts. Plast Reconstr Surg **59:**851–859, 1977
12. Mitz V: Current face lifting procedure: an attempt at evaluation. Ann Plast Surg **17:**184–193, 1986
13. Cardoso de Castro C: The role of the superficial musculo-aponeurotic system in face lift. Ann Plast Surg **16:**279–286, 1986
14. Ruess W, Owsley JQ: The anatomy of the skin and fascial layers of the face in aesthetic surgery. Clinics Plastic Surg **14:**677–682, 1987
15. Turpin JM: The modern rhytidectomy. Clinics Plastic Surgery **19:**383–400, 1992
16. Mendelson BC: Correction of the nasolabial fold: Extended SMAS dissection with periosteal fixation. Plast Reconstr Surg **89:**822–833, 1992
17. Barton FE: The SMAS and the nasolabial fold. Plast Reconstr Surg **89:**1054–1057, 1992
18. Tapia A, Ferreira B, Blanch A: A new approach to the treatment of facial aging: The three flap SMAS. Aesth Plast Surg **17:**247–251, 1993
19. Teimourian B, Delia S, Wahrman A: The multiplane face lift. Plast Reconstr Surg **93:**78–85, 1994
20. Burgess PA, Casler JD, Kryzer TC: Wound tension in rhytidectomy. Effects of skin-flap undermining and superficial musculoaponeurotic system suspension. Arch Otolaryngol Head Neck Surg **119:**173–177, 1993
21. Forrest CR, Phillips JH, Bell TAB, Gruss JS: The biomechanical effects of deep tissue support as related to brow and face-lift procedures. Plast Reconstr Surg **88:**427–432, 1991
22. Hirshowitz B, Jackson IT: An attempt to harness the viscoelastic properties of skin in face lift operations. A preliminary report. Ann Plast Surg **18:**188–198, 1987
23. Hirshowitz B: The two-stage face lift. Br J Plast Surg **31:**159–164, 1978
24. Ross MH, Romrell LJ, Kaye GI: Connective Tissue Histology, 3rd ed. Baltimore: Williams & Wilkins, 1995