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Comparison of Effectiveness of Silicone Gel Sheeting With Microporous Paper Tape in the Prevention of Hypertrophic Scarring in a Rabbit Model

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Objective: To determine the effectiveness of treating scars with microporous paper tape or silicone gel sheeting (SGS) in preventing hypertrophic scarring

Methods: Forty hypertrophic scars were induced in a validated rabbit ear model. Wounds were randomized and bandaged for 30 days with either SGS (20 wounds), paper tape (20 wounds), or untreated controls (40 wounds). Two outcome measures of hypertrophic scarring included (1) histologic measurement of scar elevation index (SEI) and (2) blinded photograph analysis using a visual analog scale.

Results: In histologic comparison, no difference in mean (SE) SEI between treatment groups was seen (paper tape group, 1.32 [0.2]; SGS group, 1.41 [0.18]; control, 1.35

[0.23]; $P = .51$). In photographic analysis, both treatment groups were superior to the control group ($P < .01$), whereas no difference was seen between the SGS and paper tape groups ($P = .88$).

Conclusions: Paper tape and SGS demonstrated equal effectiveness in the prevention of hypertrophic scarring on visual analysis, whereas histologic analysis demonstrated no difference in treatment groups from controls. The effectiveness of paper tape in preventing hypertrophic scarring in humans will require further laboratory and clinical investigation.

Arch Facial Plast Surg. 2012;14(1):45-51.
Published online August 15, 2011.
doi:10.1001/archfacial.2011.62

POSTOPERATIVE SCAR MANAGEMENT greatly influences cosmetic outcomes. After suture removal, scars are susceptible to tension, which may be the trigger for hypertrophic scarring. Efficacy of silicone gel sheeting (SGS) in prevention of hypertrophic scarring has been shown in multiple studies. A Cochrane Review¹ of 19 studies demonstrated that the overall results were equivocal as to the usefulness of SGS; however, SGS continue to be used. Microporous paper tape (3M Health Care, St Paul, Minnesota) has also been shown to be efficacious in decreasing scar depth.² Microporous paper tape is much more cost-effective than SGS, and if the 2 methods have equal efficacy, then microporous paper tape would be the preferred choice. There has not been a study looking directly at the effects of SGS compared with microporous paper tape.

In 1997, a rabbit model of hypertrophic scarring was introduced.³ The dermal ulcer rabbit model is attributed to Joseph and Dyson⁴ in 1968; however, in several studies^{2,3,5-7} the model has been improved by creating a protocol for a repro-

ducible and controlled hypertrophic scar model. This unique animal model of hypertrophic scarring in the rabbit ear has been shown to be similar to the human condition by histologic characteristics and visual appearance, with respect to larger wounds, response to steroids, and improvement in degree of scarring with advanced age.³ Treatment of scars with steroids, silicone gel, and onion extract have also been compared using the scar elevation index (SEI), which is a measure of the height of the raised, hypertrophic scar measured as a ratio of the central-most scar area to the same area of normal surrounding skin⁸ (Figure 1). This model will now allow us to analyze the histologic components of scar formation that are reduced by the application of SGS or microporous paper tape.

METHODS

HYPERTROPHIC SCARS

Hypertrophic scarring is a frequent and undesirable complication of surgical incision. It can occur after thermal injury, surgical incision, or other traumatic injury.¹⁰ The lesions are raised,

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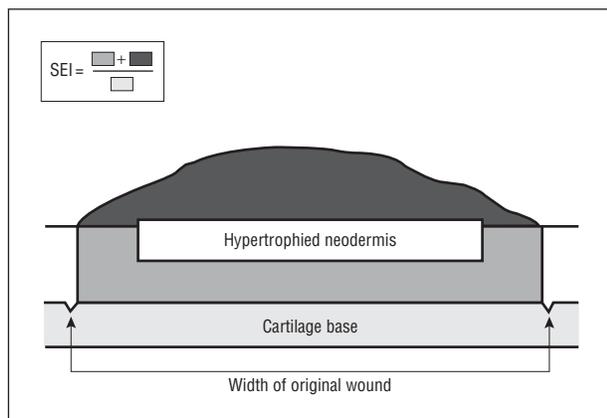


Figure 1. The scar elevation index (SEI) as described by Mustoe⁹ is a histologic measure of the height of the scar compared with the normal scar. The degree of hypertrophy of each scar is the ratio of tissue height of the total wound area to the area of normal tissue below the hypertrophic scar, with an SEI of 1 suggesting no raised height of the scar. (Figure used with permission from Kloeters et al.⁸)

pruritic, erythematous scars that may widen but remain within the confines of the original wound. On histologic examination, hypertrophic scars appear hyperplastic and manifest a thickened epidermis, a dermis lacking dermal papillae, and the presence of collagen nodules in an abnormally increased vascular wound matrix. The etiology of this abnormal scarring process is, for the most part, unknown. Predisposing conditions seem to be related to prolonged inflammation, such as repeated trauma, continued irritation from foreign body inclusions, excessive wound tension, infection, or delayed reepithelialization.

It has been suggested that the common initiating factor for hypertrophic scarring is increased skin tension.^{5,11-13} With sutures in place, there is little tension across a scar, and collagen is laid down along it longitudinally.¹³ However, these initial collagen bonds are thought to be mechanically weak.¹³ A gradual gain in a scar's tensile strength occurs with increased production and remodeling of type I collagen and an alteration in the type of cross-links formed.^{14,15} This gain in wound tensile strength is slow, with only 20% of a scar's final strength evident by the third week.¹⁴ The maximum strength of a scar is not achieved until approximately 12 weeks after wounding. Therefore, once the sutures are removed, the scar is susceptible to skin tension forces.¹³

SCAR PREVENTION

In a perfect world, there would be no scar formation postoperatively, similar to fetal wound healing. In the future, scar prevention methods may explore this concept of "scarless" healing through the presence of growth factors or manipulation of gene expression of such growth factors.¹⁶ So far, a variety of scar prevention methods have been studied, such as compressive dressings,¹⁷ silicone gel pads,¹⁸ steroid injections,¹⁷ laser treatment,¹⁷ botulinum toxin,¹⁹ chemotherapeutic agents,¹⁷ and irradiation.¹⁷ The optimal prevention and treatment of these lesions has not been discovered.

Currently there is a wide variety of over-the-counter products that claim to improve hypertrophic scarring. Objective testing of many of these products in controlled studies has been limited over the years. Several clinical trials have tried to show the efficacy of such products, but the mechanisms of these products are still unknown, partly owing to the paucity of an animal model of hypertrophic scarring. Silicone gel sheeting is the most widely used over-the-counter product to prevent hypertrophic scarring.¹ Microporous paper tape is an inexpensive, readily available product that has also been used to prevent hypertrophic scarring.^{2,17}

SILICONE GEL SHEETING

Silicone, a soft, semioclusive scar cover, is composed of cross-linked polydimethylsiloxane polymer that has extensibility similar to that of skin.¹⁰ The potential usefulness of SGS for the treatment of burn scars and contractures was first observed in the early 1980s.⁵ Although the exact mechanism of scar reduction of SGS remains unknown, numerous postulate theories include compressive factors,¹⁸ oxygen tension,²⁰ temperature,^{20,21} formation of a static electric field,²² and direct silicone absorption.¹⁸ The following studies suggest that the compressive, occlusion, and hydration theories are the primary basis of silicone's therapeutic action on scars.

A growing body of evidence suggests that the beneficial effects of all silicone-based products on scars are mediated by occlusion, which increases hydration. Keratinocytes that are dehydrated are thought to signal fibroblasts to produce collagen.¹⁸ Therefore, the hydration effects of SGS may include decreased (1) vascular proliferation, (2) collagen deposition, and (3) fibroblast proliferation.²³

The semioclusive nature of SGS provides less hydration than plastic film.²⁴ Suetake et al²⁴ studied the dehydrated state of early scar healing by measuring the transepidermal water loss (TEWL). Up to 1 year of healing is required to return to baseline TEWL levels. In addition, the TEWL levels were greatly increased in hypertrophic scars and keloids. The stratum corneum of hypertrophic scars and keloids absorbs water more readily than normal skin. This supports the theory that the reservoir of water that normally hydrates keratinocytes may be depleted in hypertrophic scars.¹⁸ Dehydrated keratinocytes may also produce cytokines that stimulate changes in the dermis and increased collagen production by fibroblasts.²⁵

Silicone cream is another over-the-counter scar treatment. Sawada and Sone²⁶ found a significantly greater improvement in scar quality with silicone cream occlusive dressing compared with silicone cream covered only with gauze. In a subsequent study by the same investigators, silicone-free cream occluded with a water-impermeable plastic film was significantly more effective than a petroleum jelly control in improving hypertrophic scars and keloids.²⁷

MICROPOROUS PAPER TAPE

Microporous paper tape is gaining attention in scar prevention.² However, in current standard practice, paper tape is used for only a few weeks to support surgical scars after suture removal.¹⁷ It is proposed that long-term use of paper tape, until approximately 12 weeks after wounding, would allow maximum strength of scar, which would be beneficial in preventing hypertrophic scarring. In a study by Atkinson et al,² the development of hypertrophic and stretched scars in the treatment group occurred only after the tape was removed. Implicating mechanical tension as a stimulus for hypertrophic scarring and confirming that the use of paper tape for at least 12 weeks is essential for maximizing treatment outcome.

Paper tape is microporous and is thought to mimic the stratum corneum and accelerate healing without creating the bacterial growth seen with more occlusive media.²⁸ A moist environment has been shown to be required to downregulate fibroblast, collagen, and glycosaminoglycan production.²⁹ The use of an adhesive, microporous product that mimics the function of the stratum corneum in reducing evaporative water loss is therefore thought to return homeostasis to the scar, thus shortening the period to scar maturation.^{7,30,31}

The advantages of paper tape for hypertrophic scar prevention include durability, ease of use, and cost-effectiveness. Paper tape is inflexible and provides good scar support. It is easier to apply than silicone cream or other modalities and can be worn

for 4 to 7 days continuously, even when bathing or swimming. It is cost-effectiveness is obvious as most scars may be treated with only a single roll of 2.5-cm paper tape for treatment, costing less than \$1.²

OBJECTIVES

To our knowledge, this is the first comparative study to assess the effectiveness of SGS and paper tape directly in an animal model. The objective was to compare the 2 treatment modalities (SGS vs paper tape) in preventing hypertrophic scarring compared with controls. The extent of hypertrophic scar formation in these 3 groups was analyzed with 2 outcome measures: (1) an objective histologic assessment of scar hypertrophy, SEI,³ and (2) a blinded, photographic scar analysis using a visual analog scale (VAS).^{6,7} We hypothesized that the scars treated with topical SGS or paper tape, when compared with controls, would demonstrate less hypertrophic scar formation both histologically and photographically.

The paucity of an animal model for hypertrophic scars had been an obstacle in this area of research. Morris et al⁵ and Saulis et al⁶ established a reproducible rabbit model to create hypertrophic scars. We designed this study based directly on these reports. Ten female New Zealand white rabbits were used, each weighing 2.5 to 3.5 kg (Charles River Laboratories, West Brookfield, Massachusetts). They were reared on a 12-hour light/dark cycle, with temperature maintained at 68°F to 76°F, and were given Ralston Purina Co Rabbit Chow (St Louis, Missouri) and water ad libitum. All procedures were performed in accordance with the US Public Health Service Policy on Humane Care and Use of Laboratory Animals, the National Institutes of Health Guide for the Care and Use of Laboratory Animals, and the Animal Care and the Animal Welfare Act (7 USC § 2131-59). The specific animal use protocol was approved by the Institutional Animal Care and Use Committee of the University of California, Davis. The rabbits were anesthetized with ketamine hydrochloride (60 mg/kg) and xylazine hydrochloride (5 mg/kg). Surgical punch biopsies were performed on day 0, which included 3 full-thickness 6-mm-diameter punch biopsies per ear. Meticulous dissection down to cartilage using microsurgical technique was required to create the cartilage nick that is used to identify the width of the scar during histologic analysis. The perichondrium overlying the ear cartilage was carefully removed, which delays epithelialization of the defect, supporting hypertrophic scar formation.

All wounds were initially covered with occlusive polyurethane dressing (Tegaderm; 3M Healthcare) to facilitate healing. Hypertrophic scars were induced by postprocedure day 14. A protective shield was placed on the rabbit's neck. The animals were monitored for 14 days for healing of their wounds or until the wound had grossly reepithelialized (**Figure 2**). Each wound was then bandaged with the appropriate dressing as specified by the randomized assigned treatment group daily from day 14 to day 44. The animals tolerated the bandage changes well and allowed the bandages to stay in place. On day 44, all wounds were digitally photographed, and the animals were humanely killed. After death, the scars were harvested, and standardized photographs were taken of all the wounds.

PHOTOGRAPHIC EVALUATION

Standardized photographs of the rabbit ear scars were obtained at the time of death using a digital single-lens reflex camera (Nikon D70; Nikon Corp, Tokyo, Japan). Photographs were taken uniformly for all scars immediately after death. Three independent surgeons evaluated the treated and nontreated scars photographically. They rated the scars based on contour and overall severity using a modified VAS.³² The suitability of com-

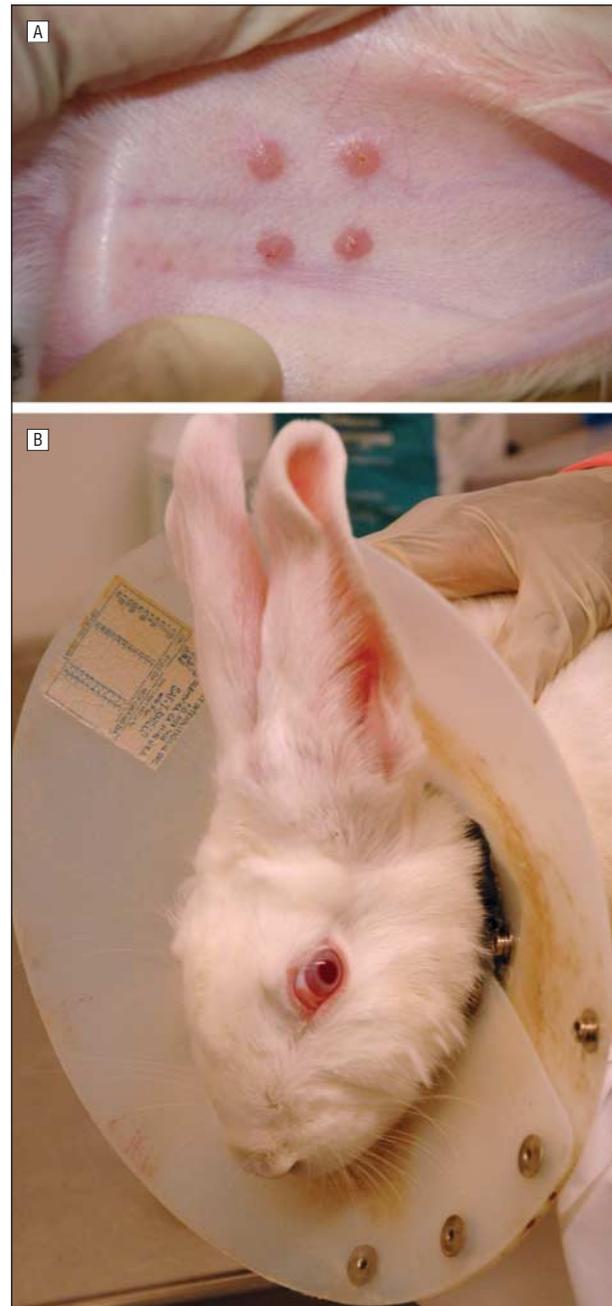


Figure 2. The hypertrophic scar formation began with 4 punch biopsy specimens through the skin that were allowed to epithelialize. A, Photograph of a rabbit ear on day 7 demonstrating 4 wounds that were healing with hypertrophic scars. Treatment was begun after all wounds demonstrated complete epithelialization on day 14. B, Photograph of the plastic shield placed on the rabbit to protect the wounds from manipulation.

paring scar outcomes between treatment groups using VAS scoring and ranking has been well established.^{32,33} The scars were rated on contour (mild: flush with surrounding skin; moderate: slightly raised or indented; severe: hypertrophic scar), and an overall severity (mild, moderate, severe).^{32,33}

HISTOLOGIC EVALUATION

The techniques described by Mustoe⁹ were also used for the histologic analysis of the specimens. The scars were bisected through the point of maximum height of hypertrophic scar determined by palpation. A 0.5-cm margin of surrounding un wounded tis-

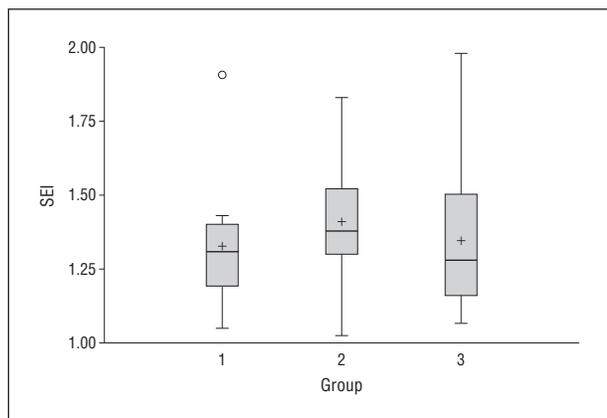


Figure 3. Box plot of scar elevation Index (SEI) between treatment groups. The mean (SD) SEI between treatment groups (group 1: paper tape, 1.32 [0.2]; group 2: silicone gel sheeting, 1.41 [0.18]; group 3: control, 1.35 [0.23]) showed no difference ($P=.51$, $F=0.69$).

sue was harvested with each wound. One-half of each wound was fixed in 4% neutral-buffered formaldehyde, dehydrated, embedded in paraffin, sectioned, and stained with the Masson trichrome stain. Slides were coded in a random double-blind manner and assessed by light microscopy. Each region was digitally captured as a calibrated image and stored electronically using a PixelFly digital camera (Cooke Corp, Auburn Hills, Michigan) and at 10 times the objective magnification. The degree of hypertrophy of each scar was expressed as the SEI, the ratio of tissue height of the total wound area to the area of normal tissue below the hypertrophic scar, with an SEI of 1 suggesting no raised height of the scar. These measurements were made from trichrome-stained tissue sections at 40 times the original magnification. Each scar was measured twice, on 2 separate occasions, and the values were averaged.

STATISTICAL ANALYSIS

Statistical analysis was completed using SAS software (version 9.2; SAS Institute Inc, Cary, North Carolina). The 80 scars were divided into the SGS-treated group (20 scars), the paper tape-treated group (20 scars), and a control group (40 scars). There were 20 wounds for each treatment, each wound having a control. Analysis of variance was used for both SEI and photograph VAS. Interrater and intrarater variability for both outcomes was assessed as described in the following subsection.

SCAR ELEVATION INDEX

The effect of treatment on score was estimated using a linear mixed-effects model incorporating random effects for the observer (O) and the scar (S). A score from a scar on rabbit i measured by observer j is modeled as $Y_{ijk} = S_i + O_j + e_{ijk}$, where

- S_i , $k = 1, \dots, 10$ is a random scar effect assumed to be normally distributed with mean 0 and variance σ_s^2
- O_j , $j = 1, 2$ is a random observer effect assumed to be normally distributed with mean 0 and variance σ_o^2
- e_{ijk} is a residual error terms assumed to be normally distributed with mean 0 and variance σ^2 .

The total variance of a score, based on this model, is $\sigma_o^2 + \sigma_s^2 + \sigma^2$. The proportion of the total variability attributable to variation between observers is $\sigma_o^2 / (\sigma_o^2 + \sigma_s^2 + \sigma^2)$. The correlation between 2 scores on the same scar but measured by different observers is $(\sigma_s^2 + \sigma^2) / (\sigma_o^2 + \sigma_s^2 + \sigma^2)$. If the variance of the observer effect is small relative to the total variabil-

ity, the correlation between 2 scores on the same scar but measured by different observers will be close to 1.

PHOTOGRAPHIC ANALYSIS

The effect of treatment on score was estimated using a linear mixed-effects model incorporating random effects for observer and scar and a fixed effect for treatment. The structure of the model is as for SEI, with the addition of a term for treatment.

An F test was conducted to test for any differences between groups; following a significant F test, P values for comparisons between groups were calculated using Tukey-Kramer post hoc tests.

RESULTS

MEASUREMENT OF SEI

First, the measurement of the SEI by 2 independent observers was tested for consistency with a linear mixed model. Interrater, intrarater, and consistent rates per scar were excellent. Based on the following estimated variance components

Variance Component	Estimate
Scar, σ_s^2	0.0909
Observer, σ_o^2	2.33×10^{-10}
Residual, σ^2	0.0084

the proportion of variability attributable to variation between observers is effectively 0. The correlation between 2 scores on the same scar measured by different observers is effectively 1.

The SEI could not be performed in 16 of the 80 specimens (paper tape group, 2 specimens; SGS group, 4 specimens; and control group, 10 specimens) owing to an artifact during histologic sectioning. **Figure 3** demonstrates the comparison of mean (SD) SEIs that were evaluated with a general linear model. Treatment groups were not significantly different (paper tape group, 1.32 [0.2]; SGS group, 1.41 [0.18]; control group, 1.35 [0.23]; $P=.51$, $F=0.69$). **Figure 4** shows examples of the histologic cross sections of scars in each group.

EVALUATION OF PHOTOGRAPHIC ANALYSIS

Hypertrophic scars as shown in **Figure 5** were evaluated on the treated and nontreated controls based on contour and overall severity using a VAS. In scar photographic analysis with VAS, both treatment groups (paper tape group, 1.52, and SGS group, 1.61) were superior to the control group (2.19; $P < .01$). **Figure 6** shows that no difference was seen between the SGS and paper tape groups ($P=.88$). The 95% confidence interval for the difference in mean score between treatment groups is -0.46 to 0.28 . The mean score in each treatment group is summarized as follows:

Group	Estimated Mean (SE)
Paper tape	1.52 (0.19)
SGS	1.61 (0.19)
Control	2.10 (0.16)

Testing the consistency between the observers demonstrated excellent correlation. Based on the following

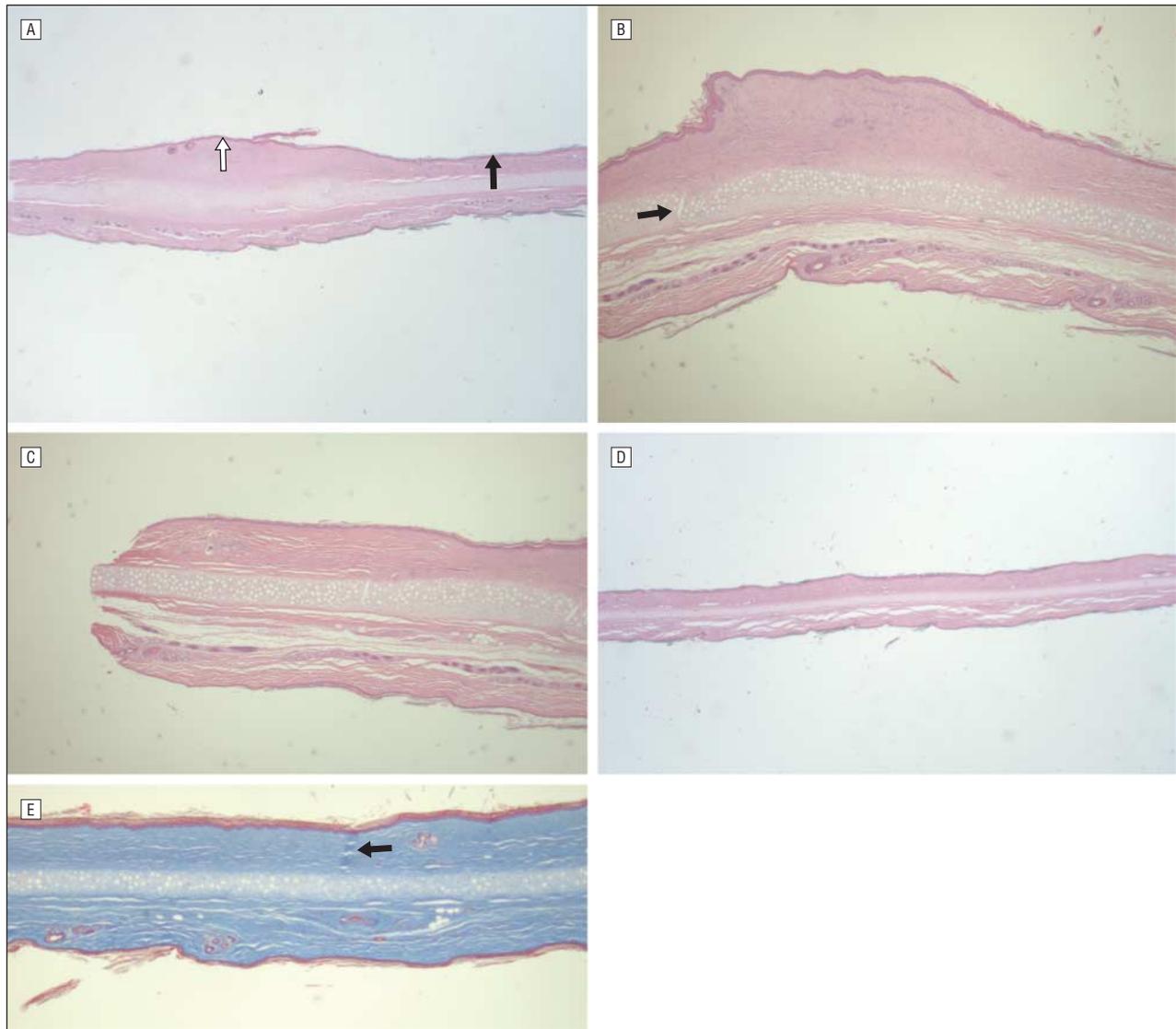


Figure 4. A hematoxylin-eosin–stained cross-section of scars treated topically for 30 days. A, A cross-section of a scar in a rabbit in the control group in which the highest portion of the scar (white arrow) is on the left and the normal, unscarred skin is on the right (black arrow) (original magnification $\times 4$). The scar elevation index (SEI) was 1.90. B and C, An example of a scar treated with silicone gel sheeting (SEI, 1.35) and the normal adjacent skin, respectively, using high-power magnification (original magnification $\times 10$) (the arrow in panel B indicates the notch in the cartilage that was created with the punch biopsy). D, An example of a scar treated with microporous paper tape (original magnification $\times 4$) with a small SEI (1.09). E, The same scar is shown with trichrome stain demonstrating the extensive collagen framework of the scar between the cartilage and epidermis. The notch left by the punch biopsy is visible in the healed scar (arrow).

estimated variance components, the proportion of variability attributable to variation between observers is 0.091, or 9.1%.

Variance Component	Estimate
Observer, σ_o^2	0.0491
Scar, σ_s^2	0.2363
Residual, σ^2	0.2565

The correlation between 2 scores on the same scar measured by different observers is 0.909.

For the *F* test of a group effect, $P < .001$. In post hoc pairwise comparisons of mean scores between groups, scores in control group are significantly higher than scores in the paper tape and SGS groups, but both treatment groups did not differ significantly from each other. Results of Tukey-Kramer tests are shown in the **Table**.

COMMENT

Surgeons and patients alike are interested in prevention of hypertrophic scars after surgery. As health care practitioners, we have few objective outcomes to respond to patients as they inquire as to which over-the-counter scar treatments are effective.^{9,17} In this controlled comparative study, photographic analysis of the treated scars supported our hypothesis (and previous reports) that favors the positive effects of SGS and paper tape to improve scar appearance and contour.^{2,5-7}

In contrast to previous reports, examination of cross-sectioned treated scars found no difference in the SEI when compared with controls.^{2,5,8,34} Saulis et al⁶ when comparing silicone gel with occlusive dressing controls also found this lack of a histologic difference, but the authors noted

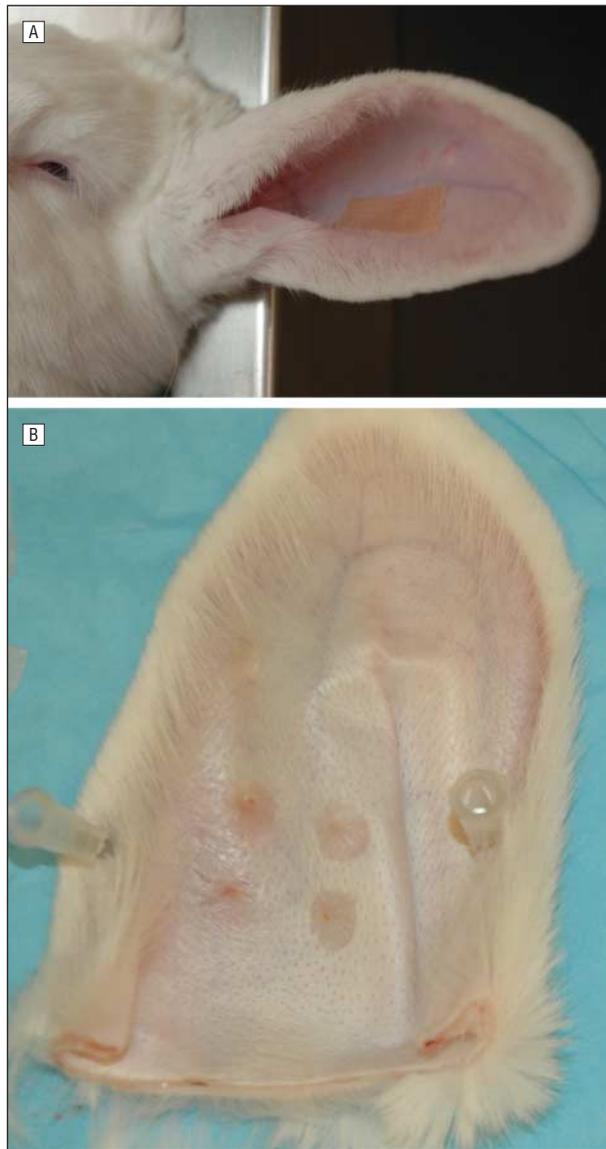


Figure 5. Photograph of a rabbit ear. A, Two raised hypertrophic scars (superiorly) and silicone gel sheeting applied over the 2 inferior scars. B, Rabbit ear during preparation for histologic sectioning showing 2 scars treated with microporous paper tape on the left and untreated controls on right. Note the raised, widened scars on the 2 control scars on the right.

electron microscopic differences in the basal epithelium. We intended to qualitatively examine the histologic differences in between treatment groups using the fibroblast immunohistochemical marker, Ki-67, and vascular in-growth with the endothelial cell marker, CD 31. As noted by other authors, this is not currently possible, owing to a paucity of species-specific rabbit reagents or antibodies.⁸

Factors that may have contributed to the disparity between the VAS and SEI results may include rabbit model consistency, tissue sectioning, SEI measurement, and length of treatment and follow-up. These will be addressed as follows.

The design of this study was strongly influenced by the published work of Mustoe⁹ and others.^{2,3,5-7} Since the completion of this study, Kloeters and Mustoe⁸ published suggestions to improve the consistency of creating hypertrophic scars by increasing the size of the punch

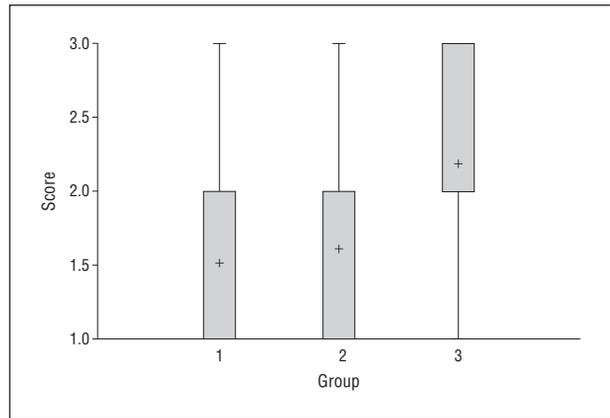


Figure 6. Box plot of visual analog scale scores between treatment groups. Both treatment groups 1 (paper tape group, 1.5185) and group 2 (silicone gel sheeting [SGS] group, 1.6111) were scored higher than group 3 (control group, 2.1852; $P < .01$). No difference was seen between the paper tape group (group 1) and the SGS group (group 2) ($P = .88$).

Table. Tukey-Kramer Tests of Pairwise Differences in the VAS Between Treatment Groups

Treatment Group Comparison	Estimated Difference in Means	P Value
Paper tape vs SGS	-0.09	.88
Paper tape vs control	-0.66	<.001
SGS vs control	-0.57	.001

Abbreviations: SGS, silicone gel sheeting; VAS, visual analog scale.

biopsy specimen from 6 mm to 7 mm. They report that “5 mm punch biopsy wounds fail to generate hypertrophic scars and 6 mm wounds are less hypertrophic due to faster epithelialization.”^{3(p541)} Kryger et al³⁵ have since reported that the SEI at day 28 in a 7-mm wound was 1.67 vs 1.15 when the 5-mm punch biopsy was used. In future studies, we will use the 7-mm punch biopsy to create a wound that is a “critical-sized defect,” allowing delayed epithelialization similar to human hypertrophic scars. This difference may account for a smaller mean SEI in our control group (1.35 [0.23]) than the previously reported SEI control group range of 1.49³⁴ to 1.71.⁶

We encountered a few difficulties while performing the histologic analysis of the scars. Laboratory difficulty with sectioning of the scars precluded further measurement on 14 scars owing to artifact and tissue tearing. Fortunately, these were nearly equally distributed between groups. Excellent consistency was seen in the SEI measurements performed in replicate by 2 blinded observers. The most difficult technical component of the study was creating the nick just deep to the perichondrium during wound creation. Mustoe⁹ reported the importance of balancing the removal of the perichondrium (to prevent early epithelialization) while rabbit ear cartilage is meticulously nicked to allow for proper histologic measurement after the scars have healed.⁸ We did not have difficulty with the daily dressing changes using the adhesive paper tape and SGS.

The duration of our experiment (44 days) was inadequate for definitive assessment of long-term hypertrophic scar prevention. Previous reports by Morris et al³ demonstrated that consistent hypertrophic scar forma-

tion continued for more than 40 days after the procedure, and even persisted until 280 days. Ideally, the rabbit's survival for 1 year would provide insights but was not feasible in this experiment. The sample size may have been too small to identify a histologic difference between the groups; however, the power was chosen based on published protocols.^{2,3,5-8}

The equivocal effectiveness of SGS or paper tape in this study translates to the authors' advocating early application after surgery (during the first 4-6 weeks) to prevent hypertrophic scars. We agree with Atkinson et al,² who recommended "that individuals at greater risk of developing hypertrophic scars should support their scars using paper tape for a long period of time—until the scar matures."^{2(p1655)} Longer-term clinical randomized controlled studies will be necessary to validate this 6-week animal model.

In conclusion, to our knowledge this is the first comparative study to assess the effectiveness of SGS and paper tape directly in an animal model. In this animal model, the 2 treatment modalities were equally effective at improving scar appearance compared with controls; however, no difference was seen at the histologic level. Microporous paper tape is less expensive than SGS, easy to use, and may be effective at preventing poor scars. Paper tape application as a hypertrophic scar prevention in humans will require further laboratory and clinical investigation.

Accepted for Publication: May 17, 2011.

Published Online: August 15, 2011. doi:10.1001/archfacial.2011.62

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Financial Disclosure: None reported.

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