Analysis of the Effects of Deep Mechanical Massage in the Porcine Model

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Deep mechanical massage has been advocated as an alternative or adjunctive therapy for the contouring of subcutaneous fat and as a treatment for cellulite. We evaluated the effects of deep mechanical massage using two pig models. Yucatan pigs were divided into three groups ($n = 4$). One side of each body received 4, 10, or 20 treatments and the other side served as a control. Full-thickness tissue sections, including the underlying muscle, were harvested from identical treated and untreated regions. Examination of these regionally matched samples revealed an accumulation of dense, longitudinal collagen bands in the middle dermal and deep subdermal regions, which progressively increased with the number of treatments. Distortion and disruption of adipocytes was noted. In Yorkshire pigs, force-transducing balloon catheters were surgically placed between the deep subcutaneous tissue and muscle fascia. Catheters were inserted into two regions with different skin and subcutaneous tissue characteristics, the midflank and the hip. Standardized maneuvers were performed at suction settings 3, 5, 7, and 9 to record baseline tissue forces. Each maneuver carried a unique force signature. The measurement of tissue forces was repeated on the opposite side after 10 standardized treatment sessions. Analysis showed a significant reduction of measured forces at the midflank after the treatments. The actual force measured with each particular maneuver varied between different operators but not with different suction settings, suggesting that the technique of administering the treatments is the primary factor in creating the force within the tissue. This leads to the conclusion that deep mechanical massage is highly dependent on the individual operator of the device. (*Plast. Reconstr. Surg.* 108: 233, 2001.)

Deep mechanical massage is a technique that makes use of a machine to lift and manipulate the skin and subcutaneous tissue using suction and powered rollers. The technique is designed to simulate the knead-and-roll method of manual massage widely used by massage and physical therapists. Benefits of deep mechanical massage reportedly include the resolution and softening of burn scars (unpublished study, Prof. Costagliola, Department of Plastic and Reconstructive Surgery, C.H.U. Rangueil-Toulouse-France), improved recovery from muscle fatigue (unpublished study, Portero, P., et al., An electromyographical and biomechanical approach to muscular fatigability: Application impact of a technique called "LPG Technique," 1996), and reduction or correction of cellulite.[1–3] Other effects that have been attributed to deep mechanical massage include enhanced blood and lymphatic flow to the skin,[4] increased cutaneous oxygenation, increased skin tone, improved cellular nutrition and elimination of waste products, softening and restructuring of connective tissue, and modulation of estradiol.[5] In addition, this therapy has also been used, either alone or with liposuction, for the purposes of body contouring.[3,6–8] To date, few scientific reports have appeared in the literature to evaluate the systemic and histologic effects of deep mechanical massage or similar procedures.[5,9,10]

The present study was designed to (1) examine the dermis and superficial fascia for injurious effects and subsequent wound healing responses, and (2) measure and analyze the forces generated in tissues by deep mechanical massage treatment.

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MATERIALS AND METHODS

Mechanical Massage Device

The mechanical massage device used in this study was the ES1 Therapeutic Massager (LPG USA, Fort Lauderdale, Fla.). Treatments were performed by an operator trained by a representative of the manufacturer. The device was maintained in accordance with the recommendations of the manufacturer throughout the course of the study.

Animal Care

Twelve age-matched (4-month-old) Yucatan Miniature Swine (Harlan Sprague-Dawley, Columbus, Mo.) were randomly assigned to three experimental groups, with four animals in each group. An additional three age-matched (6-month-old) Yorkshire Cross pigs were used to measure the forces generated in untreated and treated (after 10 treatment sessions) tissues. During the course of the study, the animals were housed and fed in accordance with the guidelines of the Animal Care Committee of Vanderbilt University Medical Center, Nashville, Tennessee.

Treatment Sessions

The Yucatan pigs underwent massage treatments once or twice a week for a total of 4, 10, or 20 treatments, each session lasting exactly 10 minutes. Standardized maneuvers were performed during each session and were selected as representative of the current clinical practice of Endermologie. One side was randomly chosen as the treatment side, and the opposite side was left untreated during the study and used as the control. Power settings for the maneuvers were gradually increased as the study progressed, mimicking current clinical practice. The subjects received light inhalational anesthesia during each session using 1.0 to 1.5% Aerrane (isoflurane; Fort Dodge Animal Health, Fort Dodge, Iowa), so they exhibited muscle tone and limb movement during the deep mechanical massage. Body weight was measured weekly throughout the study. Skin temperature was measured using an infrared temperature scanner (Exergen Corporation, model DT-1001, Newton, Mass.) at the point midway between the posterior scapula and the hind limb trochanter on the treated side, and on the midspine (untreated area), immediately before and after each treatment.

Mechanical Massage Force Measurements

In preparation for the collection of force measurements, the subjects were anesthetized with 15 mg/kg ketamine (Phoenix Pharmaceutical, St. Joseph, Mo.) and administered 2.5% isoflurane inhalational vapor. After surgical skin preparation with povidone iodine solution, a 2-cm skin incision was made 10 cm distant from the region where force measurements were to be collected (Fig. 1). Minimal blunt dissection was performed to create a pocket between the deep subcutaneous tissue and the underlying muscle fascia, into which a 1.5-cc volume balloon catheter was advanced. The catheter was connected to a transducer (Gould P23XL Transducer; Gould Electronics, Norcross, Ga.) with noncompressible 210-cm pressure tubing, and the incision was closed by suturing. After inflation of the catheter with 1.5 cc of sterile water, five standardized Endermologie maneuvers (smoothing, kneading, figure-eight, popping, and bouncing) were performed by an Endermologie technician at suction settings 3, 5, 7, and 9. The forces generated within the tissue by the maneuvers were recorded (Gould RS 3200 two-channel recorder, 500 mmHg scale at tape speed 5 mm/sec). The resonant frequency of the P23XL with 210-cm pressure tubing and needle with balloon was 23 Hz. After these measurements the balloon was removed, the incision was closed, and the procedure was repeated over the hip region of the subject. Over the next 3 weeks, the subjects underwent a series of 10 treatment sessions on the opposite side of the body. After completion of the 10 sessions, force measurements at both the flank and hip regions were collected to assess possible differences in the tissues after repeated deep mechanical massage therapy. Force tracings were analyzed using Zeiss Image Pro-Plus software

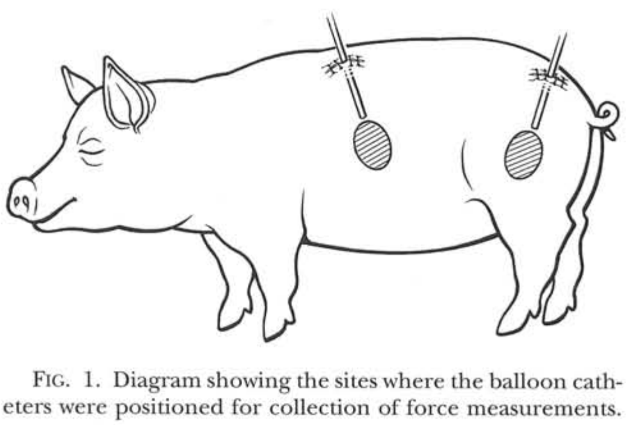

FIG. 1. Diagram showing the sites where the balloon catheters were positioned for collection of force measurements.

and measured in mmHg per second. Measurement of the suction forces generated by the ES1 Therapeutic Massager at its various settings was provided by LPG USA. Analysis of force measurement data was performed using the Student's t test. Significance was assumed for a value of $p = 0.05$ or less.

Tissue Fixation and Staining

The subjects were humanely killed with an intramuscular injection of 25 mg/kg ketamine (Phoenix Pharmaceutical, St. Joseph, Mo.) and 0.7 mg/kg acepromazine (Vedco, St. Joseph, Mo.), and administration of 2.5% isoflurane inhalational vapor. The right carotid artery and jugular vein were exposed and cannulated, heparin sulfate (125 U/kg intravenous) was administered, and normal saline (100 ml/kg) was perfused through the carotid artery and allowed to drain through the jugular vein. This was followed by perfusion with 4% paraformaldehyde (125 ml/kg), and the intact carcass was placed in cold storage for 24 hours of in situ tissue fixation. Full-thickness sections (10 cm in diameter), including the underlying skeletal muscle, were excised en bloc from matched sites of treated and untreated regions of the flank and hip region (Fig. 1). Paraffin-embedded sections were examined using Gomori one-step trichrome stain for collagen.

RESULTS

All of the pigs remained healthy throughout the study and continued to gain weight as expected because they were still in their young-adult growth phase. Transient hyperemia of the skin was noted during each treatment session but resolved within 30 minutes of treatment. Visual inspection of the skin revealed no noticeable contour differences between treated and untreated areas during the course of the study. Epidermal pigmentation remained unaltered after 10 treatments. Earlier, we and others had confirmed that no abnormalities were detectable in serum electrolytes, proteins, triglycerides, or cholesterol after repeated treatments with deep mechanical massage.[5,10] In addition, the urinalysis workup showed no evidence of urine lipids or tissue breakdown products.[10]

Histologic Examination of Skin, Subcutaneous Tissues, and Muscle

Examination of the skin and muscle revealed no gross or microscopic evidence of trauma or injury. However, examination of subcutaneous tissue revealed significant changes of tissue architecture. Specifically, adipocyte cell membrane distortion and cell deformity were observed at the deep subcutaneous level of the Yucatan pigs that underwent 10 treatment sessions, designated as the intermediate-term group (Fig. 2, *center, left* and *right*), when compared with untreated tissue (Fig. 2, *above, left* and *right*). Longitudinal collagen bands accumulated in the deep subcutaneous tissues, beginning at the muscle fascia and gradually decreasing in the more superficial subcutaneous layer. The degree of adipocyte distortion also seemed to diminish as the more superficial areas were examined. These changes were considerably more pronounced in the long-term treatment group (20 treatment sessions) (Fig. 2, *below, left* and *right*). In this group, the collagen bands were more dense and extended into the midsubcutaneous level. In places, the muscle fascia was elevated from off of the muscle and thickened, without evidence of muscle injury, distortion, or hypertrophy. Adipocyte distortion was more frequent and more pronounced in tissues that received 10 or 20 treatments as compared with untreated regions. None of the changes noted here were seen to any degree in the short-term treatment group (four treatments; data not shown). Our histologic findings were seen consistently in all Yucatan pigs in each treatment group. Increased subcutaneous collagen accumulation was significant only in the pigs that underwent either 10 or 20 treatment sessions (Student's t test, $p = 0.05$ or less).

Forces Applied to Subcutaneous Tissues by Deep Mechanical Massage

Three comparisons were made between the forces generated in the tissues. Initially, a comparison was made between forces using the same maneuver at the same site but at different suction settings. Although in most cases there was a trend of increasing force as the suction setting was increased, this was not statistically significant. Second, a comparison was made between matched areas undergoing identical maneuvers at the same suction settings, looking for differences between pretreatment and

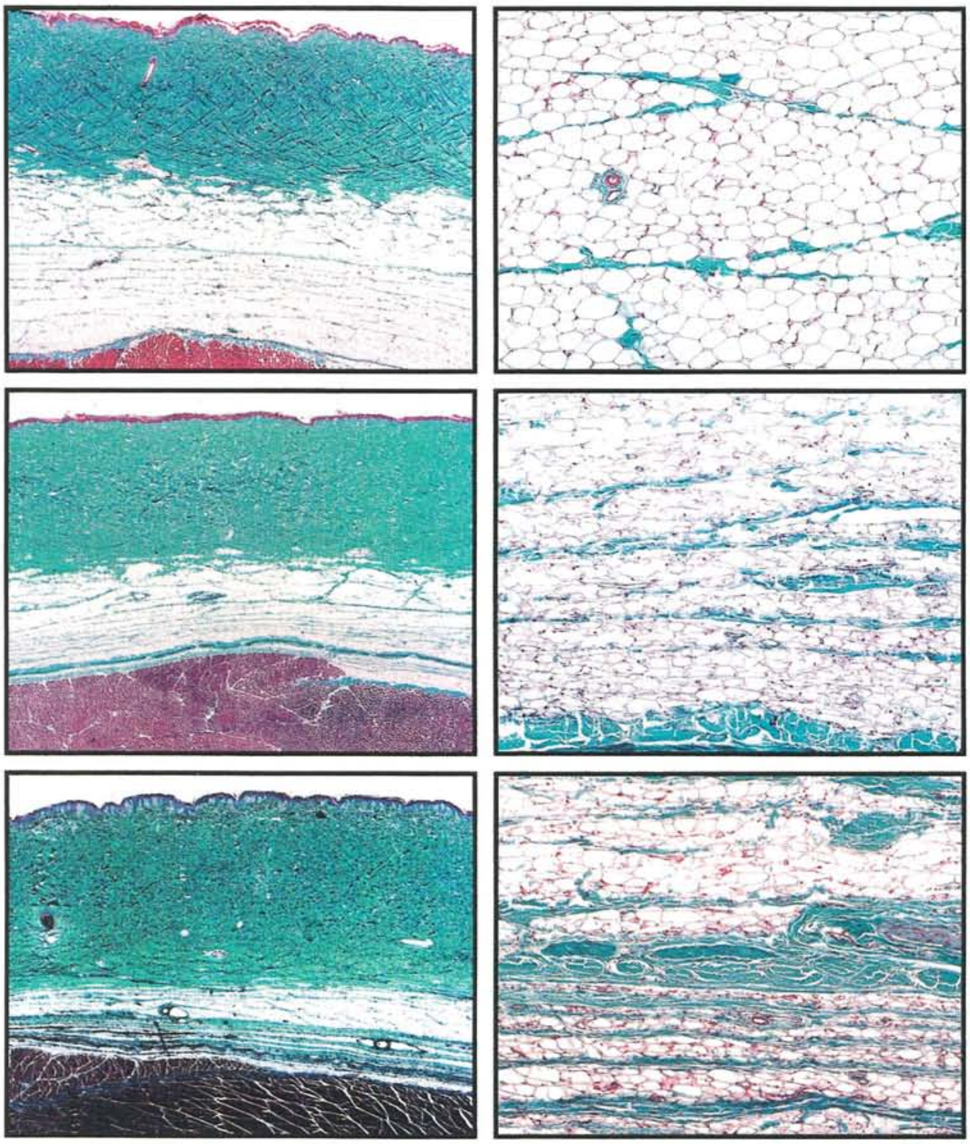

FIG. 2. Low and high magnifications of porcine skin stained with Gomori one-step trichrome. (*Above, left* and *right*) Tissue was removed from a nontreated flank region. Scant collagen bundles are evident and adipocytes are robust and intact. (*Center, left* and *right*) This tissue received an intermediate number of treatments (10 sessions). Collagen bundles are increased in number, especially in the deepest regions of the subcutaneous region, and many adipocytes appear deformed or shrunken. (*Below, left* and *right*) This tissue received 20 treatments. The volume of collagen bundles is greatly increased compared with the control tissue and the tissue that received the intermediate treatments. The deepest areas of the subcutaneous layer (*bottom portion*) show more collagen deposition than the more superficial areas nearest the dermis (*upper portion*).

posttreatment forces. Significant changes in forces were measured after 10 treatments (paired Student's t test). Specifically, at the suction settings 3, 5, and 7, significantly lower forces were generated in the thicker tissues (flank) after they had undergone 10 treatment sessions. By contrast, diminishing force was not observed in the tissues that were thinner (hip region) or when the mechanical massage device was turned up to the highest suction settings. Third, a comparison of forces was made between the flank region, where the subcutaneous tissue is thicker (Fig. 3), and the hip, where this tissue is thinner (Fig. 4). The forces were consistently higher in the flank than in the hip region tissue before treatment. However, after undergoing 10 treatment sessions, the forces in the thicker flank tissue diminished and were not significantly different from those in the thinner hip tissue (paired Stu-

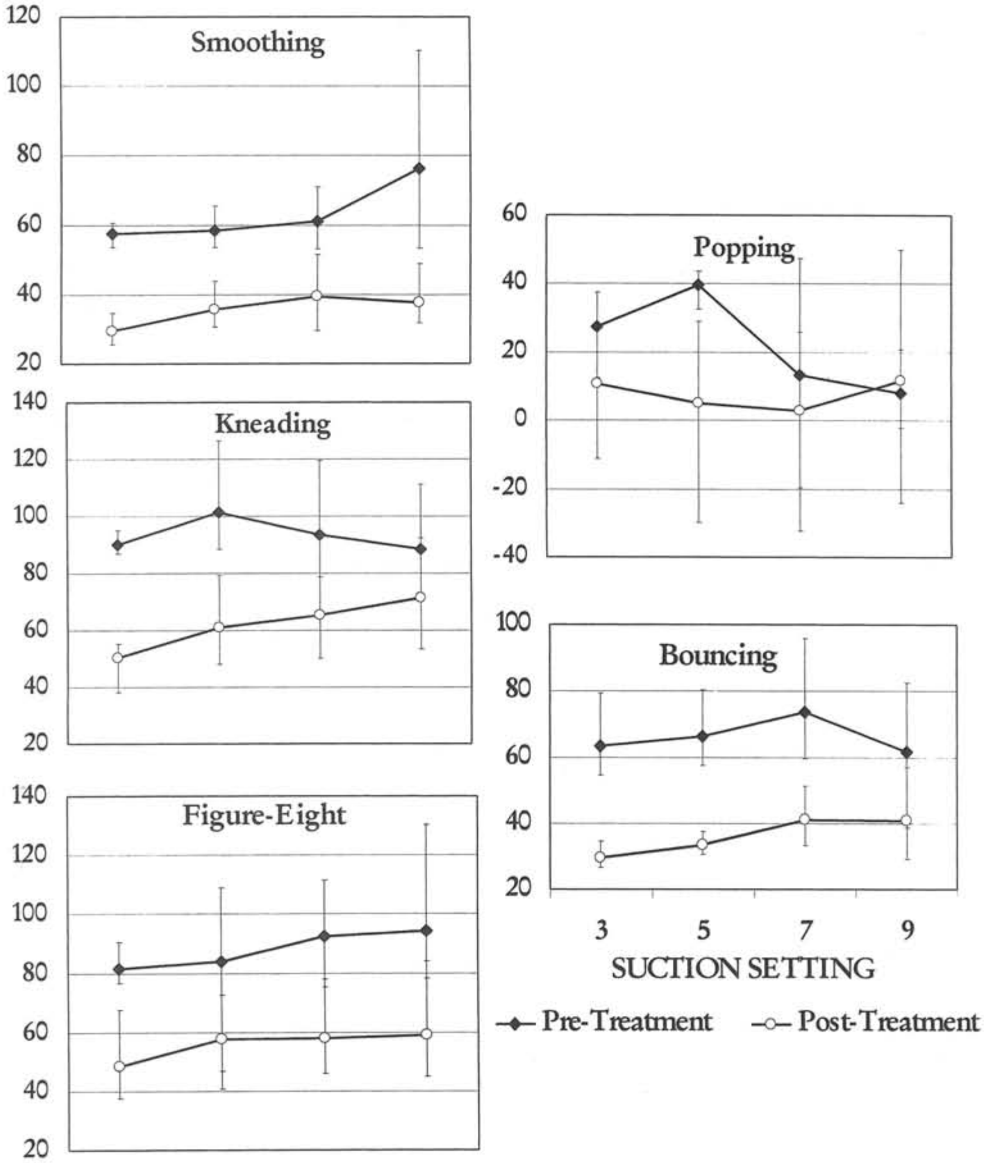

FIG. 3. Pressure measurements from the flank region collected before and after 10 deep mechanical massage treatments.

dent's *t* test). Finally, we were able to measure the relative contributions that suction, roller tension, and individual maneuvers made to the total force in the tissue. Suction contributed from 2 to 8 mmHg to the total force, roller tension 1 to 2 mmHg, and the remaining majority of the force was from each maneuver. Suction and roller tension were essentially continuous forces that changed only as the suction setting was increased (Fig. 5), whereas the maneuver force fluctuated widely as the maneuver was being performed (Figs. 3 and 4). Negative forces were encountered only with the Endermologie popping maneuver, mainly at the higher suction settings 7 and 9.

Description of Massage Maneuvers

The five maneuvers that were performed during force measurements were smoothing, kneading, figure-eight, popping, and bouncing. Smoothing is performed by moving the handheld massage head of the therapeutic massager across the skin while lifting upward, moving both forward and back across the skin in broad strokes. Kneading consists of rapid, short strokes in succession as one progresses forward across the skin, followed by smoothing strokes back across the skin. The figure-eight maneuver involves lifting and twisting the tissue in a figure-eight motion. Popping is per-

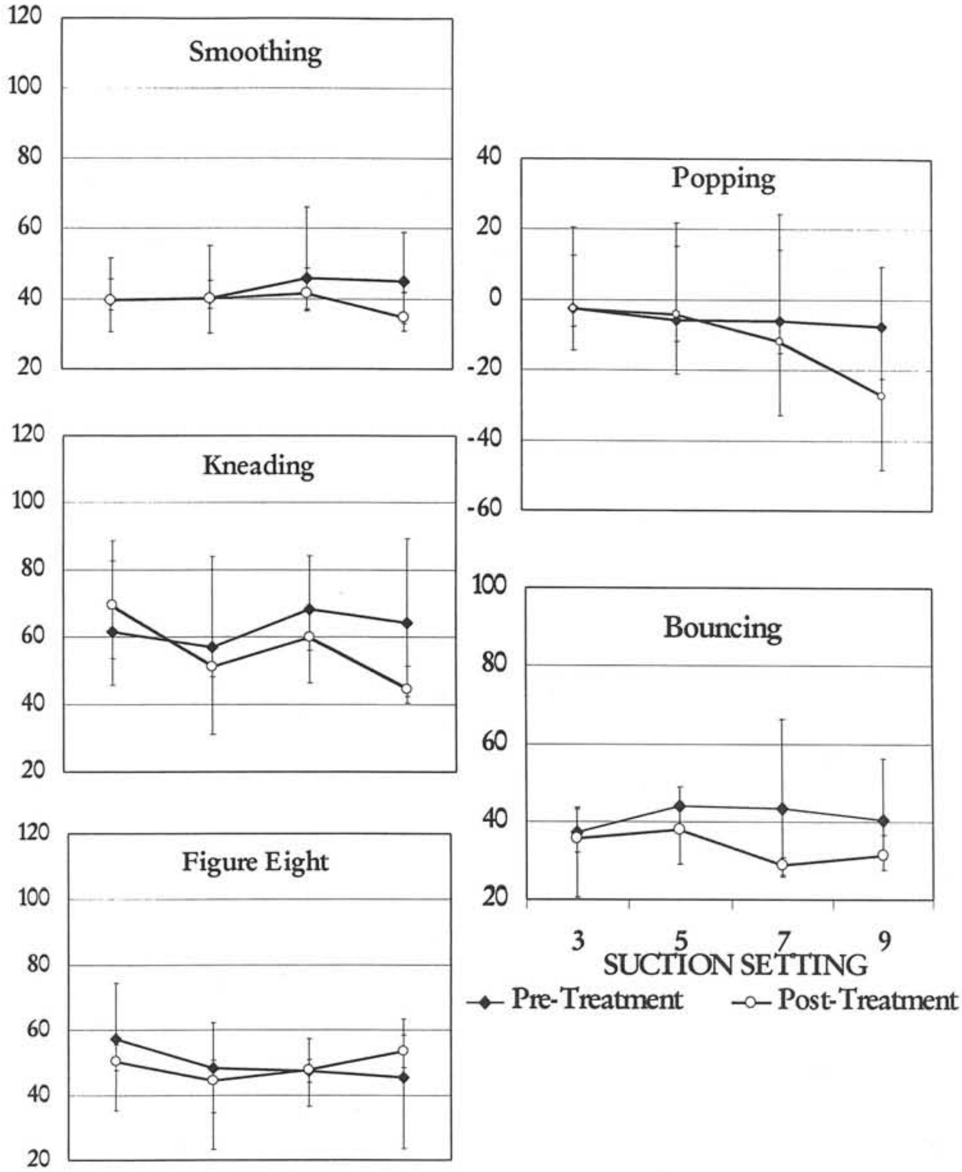

FIG. 4. Pressure measurement from the hip region collected before and after 10 deep mechanical massage treatments.

formed with the power rollers turned off, using the suction to lift the tissue until it springs out of the massage head, then repeating the maneuver. Bouncing is similar to the smoothing maneuver, but with a continuous bouncing of the massage head as it moves across the skin. Each maneuver produced a unique force pattern or signature.

DISCUSSION

The present study was designed to evaluate the forces that produce tissue architectural changes in response to deep mechanical massage. Specifically, we wanted to assess the change in force at the tissue level that occurs at different suction settings, with each different maneuver, following collagen deposition, and between tissues of different character and thickness. It was also important to differentiate the contribution to the total force by suction, roller spring tension, and each maneuver. Even though there is a steady increase in suction with each successive suction setting, this increase does not translate into increased force within the tissue. In some instances, increasing the suction actually diminished the force measured in the tissue. Each treatment maneuver exhibited a unique force pattern or signature, and these patterns were unchanged in relation to location of tissue or whether the maneuver

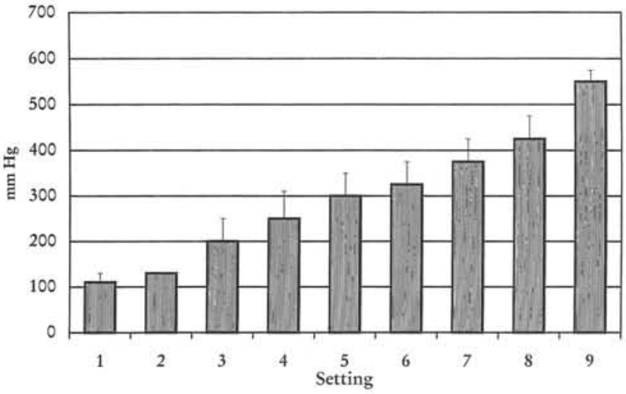

FIG. 5. The stepwise increase in suction force measurements measured as settings on the ES1 Therapeutic Massager (LPG USA) were raised.

was performed on untreated or posttreatment tissue. Significant decreases in force magnitudes were measured at the flank area of the Yorkshire pigs after 10 treatment sessions, but this decrease in force was not observed at the hip area. This change in measured force corresponds to the greater increase of tissue collagen content we observed in thicker tissues, such as the flank region, as opposed to a lower increase in collagen found in thinner tissues, such as the hip. Consequently, the treatments seem to have a greater effect in thicker tissues and a lesser effect in thinner tissues.

Deep massage therapies that make use of mechanical devices, such as Endermologie, have been advocated as treatments for cellulite. The present report provides an objective assessment of the various maneuvers and forces that may be generated when deep mechanical massage therapies are used. The efficacy of these treatment methods for cellulite reduction, tissue toning, and correction of body contour irregularities has previously been based on the use of photogrammetry, which is claimed to show reduction of soft-tissue mass in treated regions. Promotional brochures from device manufacturers typically state that during the performance of the mechanical massage, subcutaneous fatty tissue is broken down and then excreted by the body. Unfortunately, rigorous scientific studies have not yet appeared to substantiate such claims. Our previous systemic evaluation with the Yucatan porcine model seems to refute such metabolic claims.[10] No changes in cholesterol or triglycerides were reported in a human study with 10 subjects.[5] We are aware of only one study in which a reduction of soft-tissue mass was reported when one side of the human subjects was treated; the contralateral side was used as the untreated control.[8]

The Yucatan mini-pig and Yorkshire pig models were chosen for this study because of their histologic and physiologic similarities to humans and our wish to build on our previous data.[10] Younger animals were chosen to avoid the problem of soft-tissue morphologic changes, such as fibrosis and calcification, that occur with porcine aging. The selection of porcine subjects also allowed us to compare the effects of treatment on regions of varying tissue character and thickness, as are found in human subjects. The pig model was selected over the human model because objective force measurements could be readily collected from catheters strategically positioned over areas with different tissue architectural characteristics. The size of the porcine model enabled us to collect baseline data on one side of the pig and later use the opposite side to collect force measurements after 10 treatments. The minimal sedation used on the pigs during treatment sessions allowed them to exhibit muscle tone similar to that of awake humans undergoing treatment.

We first evaluated whether there were differences between the measured forces in tissues of different quality or thickness before the subjects underwent treatment. We noted that forces measured pretreatment in thicker tissues are significantly greater than those measured pretreatment in thinner tissues. However, after 10 treatment sessions, the forces in the thicker tissues diminished, and significant differences were not observed in posttreatment forces between thick and thin tissue. This change in tissue character and behavior is also related to the increase in subcutaneous collagen. The change was not associated with a detectable alteration in subcutaneous tissue thickness, because no thickness changes were observed in this study or in our previously published work.[10]

The most striking histologic change that is induced by the application of deep mechanical massage is the accumulation of longitudinal collagen bands in the subcutaneous tissue. This change is accompanied by some deformity of adipocytes. Both of these alterations were most pronounced in the deep subcutaneous tissue and became less noticeable as the more superficial tissue was examined. The location of these tissue architecture changes is consistent with our understanding of how deep mechanical massage applies forces to the tissues. When a treatment maneuver is performed, the tissue is manipulated, lifted, and twisted. The underlying skeletal muscle is relatively fixed in place, whereas the overlying subcutaneous tissue is relatively mobile. The forces applied by suction and roller spring tension are minor in comparison with the forces generated by each maneuver. The result of the force application at this tissue interface is the accumulation of thick, longitudinal collagen bands, which increases with a greater number of treatment sessions. It is significant that these architectural changes occur without detectable evidence of inflammatory or wound repair responses.

We believe that the smoothing effect and appearance of decreased cellulite that have been reported in human subjects is the result of tissue architecture changes and a redirection of forces within subcutaneous tissue. Cellulite has been described as the unsightly dimpling of skin that progressively develops as excessive fat accumulates in the subcutaneous layer. Puckering is caused by vertical tethering of the dermal layer to underlying fascia. The redistribution of the vertical force vector, by deposition of longitudinal collagen bands running parallel to the skin surface, or disruption of the vertical fascial fibers, may account for the skin smoothing and the appearance of decreased cellulite in treated tissues. These tissue architectural changes and subsequent force redistributions are significant primarily in areas of thicker subcutaneous tissue.

CONCLUSIONS

This study demonstrates that significant changes occur in the forces measured within subcutaneous tissues over the course of repeated deep mechanical massage. Coincident with these changes in forces is the accumulation of longitudinal layers of collagen within the subcutaneous layer. The principal force applied to the tissue during therapy depends on the particular type of maneuver performed, with the suction and roller tension being minor forces. Increased suction does not consistently lead to increased force applied to the tissue. Each maneuver carries a unique force signature. The actual force at which a particular maneuver was administered exerts the primary force within the tissue, leading to the conclusion that deep mechanical massage therapy is highly dependent on the individual operator of the device. Deep mechanical massage has its greatest effect on thicker tissues with underlying fixed muscle, which begin to exhibit the force-measurement characteristics of thinner tissues by the completion of 10 treatment sessions. We postulate that the appearance of cellulite reduction will therefore be more noticeable in locations such as the hip and thighs after deep mechanical massage. Future studies should be designed to evaluate whether the changes we observed are transient or long in duration.

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REFERENCES

1. Daver, J. A new instrument for the treatment of cellulite. *Medecine au Feminine* 39: 25, 1991.
2. Ersek, R. A., Mann, G. E., Salisbury, S., and Salisbury, A. V. Noninvasive mechanical body contouring: A preliminary clinical outcome study. *Aesthetic Plast. Surg.* 21: 61, 1997.
3. LaTrenta, G. S. Endermolgie versus liposuction with external ultrasound assist. *Aesthetic Surg. J.* 19: 452, 1999.
4. Watson J., Fodor, P. B., Cutcliffe, B., Sayah, P., and Shaw, W. Physiologic effects of endermologie: A preliminary report. *Aesthetic Surg. J.* 19: 27, 1999.
5. Benelli, L., Berta, J. L., Cannistra, C., Amram, P., and Benhamou, G. Endermologie: Humoral repercussions and estrogen interaction. *Aesthetic Plast. Surg.* 23: 312, 1999.
6. Leduc, A., Leduc, O., Bourgeois, P., Van den Bossche, C., and Snoeck, T. Research report. Brussels: University of Brussels, July 1995.
7. Cumin, J. The utilization of LPG technique during liposuction. *J. Esthet. Med. Surg.* 23: 12, 1996.
8. Fodor, P. B. Endermologie (LPG): Does it work? *Aesthetic Plast. Surg.* 21: 68, 1997.
9. Sasaki, G. Report of a human study using the Silhouette device. Presented at the Annual Meeting of the American Society of Aesthetic Plastic Surgery, Dallas, May 18, 1999.
10. Adcock, D., Paulson, S., Davis, S., Nanney, L., and Shack, R. B. Analysis of the cutaneous and systemic effects of endermolgie in the porcine model. *Aesthetic Surg. J.* 18: 414, 1998.