Liposuction is considered the gold-standard procedure for body sculpting and contouring. The introduction of the tumescent technique has reduced the risk of bleeding, which has thereby reduced the need for general anesthesia and hospitalization and diminished postoperative ecchymoses associated with liposuction. Other advances include the refinement of body site-specific cannulas and the manual syringe suction for autologous fat transfer and fine contouring. More recently, ultrasound-assisted liposuction (UAL), power-assisted liposuction (PAL), vibroliposuction, and laser-assisted liposuction (LAL) have shown promise in facilitating fat removal and in reducing procedure duration, surgeon strain, patient recovery time, and postoperative pain.

Described first in a multicenter study with a Nd:YAG laser, LAL was designed to enhance outcomes of standard liposuction. An updated technique with a 1064-nm Nd:YAG laser was described in detail by Goldman and colleagues, showing histological evidence of coagulation of small blood vessels, rupture of adipocytes, reorganization of the reticular dermis, and coagulation of collagen in fat tissue. In this and in a later study, Goldman and colleagues delivered the laser energy directly to the adipose tissue transcutaneously through a 300-µm-diameter fiber, with its distal end extending 2 to 3 mm beyond the distal end of a 1-mm stainless steel cannula. Badin et al., with a technique and laser similar to that of Goldman et al., described first in a multicenter study with a Nd:YAG laser.
showed rupture of adipocyte cell membranes, coagulation of small blood vessels in fat tissue, coagulation of collagen in adipose and dermal tissue, and reticular dermal reorganization. Subsequent histological studies showed that irradiation of freshly excised human skin and subcutaneous fat with 1064-nm laser energy resulted in greater vaporization, liquefaction, and cell membrane destruction than in nonirradiated controls. The authors also presented evidence of laser-induced coagulation of collagen fibers, which should stimulate collagen remodeling and tissue tightening. The effects on adipocytes and collagen fibers were dose dependent. Kim and Geronemus showed that LAL with the Nd:YAG laser was well tolerated and associated with dermal tightening, rapid recovery, and magnetic resonance imaging (MRI)—proven reduction in fat volume.

A detailed study described the physics, quantification, and safety of subdermal laser heat treatment. Later, the same authors presented a preliminary report on skin shrinkage and increased elasticity as a result of multilength laser application. Although the aforementioned study showed promising results, it did not directly compare the effects of the LAL to those of an internally controlled traditional liposuction alone. The aim of the present study was to obtain quantitative, objective data for comparing tissue shrinkage and skin tightening achieved by LAL versus liposuction alone. Skin shrinkage was quantified by changes in surface area and skin tightening was quantified by changes in the skin stiffness index.

**METHODS**

Ten female subjects ages 31 to 57 years (median, 38) with unwanted abdominal adiposity and mild to moderate skin laxity without structural ptosis enrolled in the study through the author’s private clinic. Pregnancy, recent abdominal surgery, disorders of the lower abdomen, thrombophlebitis, acute infection, heart failure, and previous liposuction or liposculpture in the study area were grounds for exclusion. The study was approved by the independent institutional review board in Plantation, Florida, and all subjects provided signed informed consent prior to participation.

The study was designed as a “split abdomen” study, in which one side of each subject was treated with LAL (SmartLipo MPX, Cynosure, Inc., Westford, Massachusetts) followed by aspiration and the contralateral side was treated with the laser cannula and fiber without delivery of laser energy followed by liposuction. Subjects and staff were required to wear laser eye protection during the laser portion of the procedure. The selection of treatment for each side was randomized. Prior to treatment, the entire treatment area was divided into 5 × 5-cm squares drawn with a surgical marker. The corners of each square were tattooed with India ink, delivered by dermal puncture with a 20-gauge needle. Subsequent to marking the area with tattoos, the subjects were photographed with the Vectra system (Canfield Scientific, Fairfield, New Jersey) to establish a surface topography measurement baseline. Skin laxity baseline was measured with a suction cup probe (DermaLab Suction Cup, CyberDerm, Media, Pennsylvania) positioned at the center of each tattooed region.

Subjects were given tumescent anesthesia as per the Hunstad formula (lidocaine, 1 g per L of ringer’s lactate; epinephrine, 1 mg per L of ringer’s lactate; and sodium bicarbonate, 10 meq/L in normal saline) five to 20 minutes before laser treatment by infiltration via a cannula into the subcutaneous fat of the premarked areas. This tumescent fluid was given to both the LAL and liposuction-alone sides in a similar fashion, approximately 50 to 100 mL per 5 × 5-cm² sector. In addition, patients were given two oral diazepam (10 mg each) and two acetaminophen/oxycodeone (325 mg/5 mg) approximately 20 to 30 minutes before tumescent fluid application.

The laser system employed in this study permits individual as well as sequential emission of 1064-nm and 1320-nm wavelengths. Energy is delivered to the subdermal tissue through a 600-µm fiber threaded through a 1-mm microcannula and extending 2 to 3 mm beyond the distal end of the microcannula. When the microcannula is inserted in tissue, the laser is activated, and the microcannula is moved slowly and evenly through the deep or superficial subdermal layer.

Sequential emission of both wavelengths provides a spatially uniform laser energy profile for treating both superficial and deep subdermal layers. An accelerometer delivery system (SmartSense, Cynosure, Inc., Westford, Massachusetts) attached to the laser handpiece helped to minimize the occurrence of localized thermal damage during treatment. If, during treatment, the surgeon slowed the motion of the handpiece, the delivered laser power dropped accordingly. If the handpiece stopped, energy delivery ceased within 0.2 seconds.

The tissue was treated with a two-layer/two-step technique. The first step on the laser-treated side was to address the deep fat layers (1-3 cm below the epidermis) within the premarked squares. Two to four incisions of 1 mm each were made with a number 11 blade in each treated area for insertion of the microcannula. The deep fat areas were treated with Multiplex Mode 1 (20 W of 1064-nm wavelength source and 10 W of 1320-nm wavelength source). Subsequently, in the second step, the superficial subdermal layer (0.5 cm below the epidermis) was treated with Multiplex Mode 3 (8 W of 1064-nm wavelength source and 8 W of 1320-nm wavelength source). Epidermal temperature was monitored during treatment with a handheld infrared thermal camera (FLIR ThermaCAM E45, Niceville, Florida). The fiber was moved back and forth in a fan-like pattern, moving deeper into the 5 × 5-cm² region and generating lipolysis in the medium and deep layers of adipose tissue until sufficient energy was supplied to cause cell wall disruption and coagulation of small vessels. (This amount of energy is believed to be in the range of 1000 to 2000 joules per 5 × 5-cm² region for every centimeter of pinched skin thickness in the overlying area.) In the superficial layer, the microcannula was moved continually in a fan-like pattern within each premarked square, and energy delivery was
stopped when the epidermal temperature observed with
the thermal camera reached a nearly uniform 40°C to
42°C. This temperature range was shown in previous stud-
ies to be safe to induce skin tightening and shrinkage. A
red aiming beam from a HeNe laser source, better seen
with most of the room lights out, permitted the surgeon to
visualize the tip of the fiber during treatment. For the con-
trol liposuction-alone side, a similar microcannula was
inserted into the same depths as described above and
moved about for a similar duration to mechanically dis-
rupt the fat at the same depths. This was done to eliminate
the possibility that skin shrinkage and tightening on the
LAL side were caused by mechanical damage alone. The
entire abdomen was then aspirated with a standard 3-mm
suction cannula to remove any remaining fat, disrupted
cells, and free fat oils.

When aspiration was complete, standard firm-pressure
dressings were applied to the wounds and subjects were
instructed to wear a compression garment for the follow-
ing three to four weeks. Oral antibiotic prophylaxis began
one day before treatment and continued for seven days
after treatment. Subjects were evaluated for skin shrinkage
and skin tightening one month and three months after
treatment. Skin shrinkage was evaluated by measuring
changes in the dimensions of the regions marked with tat-
tooing. Tattooed regions were photographed at baseline, one month, and three months with the
same camera under standardized conditions of lighting,
magnification, and background. Dimensions (horizontal,
vertical, and diagonal) and the perimeter of each tattoo
were measured with the Vectra System at each time point
and formed a basis for calculating surface areas. All meas-
urements were reviewed and calculated by an unrelated
third party blinded with respect to the treatment modality.

Shrinkage and tightening on the laser-assisted side ver-
sus the liposuction-alone side were compared at one
month and three months. Differences were tested for sig-
ificance through a paired \( t \) test, with \( P < .05 \) as the cutoff
value. Skin shrinkage was evaluated by calculating the
surface area shrinkage ratio (Equation (1)) for each region
on each subject.

\[
R_{\text{SkinShrinkage}} = \frac{SA_{\text{postTx}} - SA_{\text{preTx}}}{SA_{\text{preTx}}}, \tag{1}
\]

where

\( R_{\text{SkinShrinkage}} \) is the skin area shrinkage ratio,
Tx indicates treatment, and
SA indicates surface area (mm\(^2\)).

The tattooed regions were also assessed for skin tighten-
ing with an elasticity device. A suction cup probe (Derma
Lab Suction Cup, cyberDerm, Media, Pennsylvania) 20,21

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**Figure 1.** (A) The suction cup houses a space into which the skin stretches as vacuum is applied to the skin. The negative
pressure (vacuum) exerts a force per unit area (stress) on the skin. This stretching is an elastic deformation of the skin. Elevation
detectors with light beams are positioned at two heights within the space. As vacuum is applied, the skin stretches into the
space. (B) When the skin reaches the lower detector, it obstructs the light beam at this lower level, and the (negative) pressure
is recorded. As the vacuum (negative pressure) increases, the skin continues to stretch (C) and eventually reaches the upper
detector where it obstructs the light beam (D). The negative pressure at this upper level is also recorded. Since the positions of
the light beams are fixed, the strain on the skin (the magnitude of the deformation \( \Delta x \) in Equation (2) caused by the vacuum)
at each of the two levels is known. The (negative) pressure that lifted the skin to the lower level is a measure of the stress at
that level. The same relationship holds as the skin stretches to the upper level. The greater the negative pressure \( \Delta p \) in Equation
(2)) required to stretch the skin to a given level, the lesser the elasticity of the skin. Reproduced with permission from Grove GL,
Figure 2. Individual skin area shrinkage ratios one month posttreatment, calculated from Equation (1).

Figure 3. Individual skin area shrinkage ratios three months posttreatment, calculated from Equation (1).
was positioned at the center of each tattooed region. When suction was applied, the skin was drawn up to a lower level first and then to an upper level (Figure 1). As the skin was pulled toward each level, it was subjected to tensile mechanical stress. The (negative) pressure difference between the upper and lower levels at each time point was a measure of skin elasticity at that time point.

In the present study, skin tightening was determined by measuring the skin stiffness index at baseline, one month, and three months and then comparing the stiffness index at one month and three months with the stiffness index at baseline. If the skin had a higher stiffness index at one month or three months than at baseline, the skin had been tightened. The skin stiffness indexes were calculated from a stress-strain relationship (Equation (2)).

\[ Y_{\text{SkinStiffness}} = \alpha \frac{\Delta p}{\Delta x}, \quad (2) \]

where

- \( Y_{\text{SkinStiffness}} \) is the skin stiffness index,
- \( \alpha = 0.3125 \) is a fixed system constant based on the geometry of the detecting suction probe,
- \( \Delta p \) is the difference in negative pressure (mm Hg) between the upper and lower level, and
- \( \Delta x \) is the distance between the upper and lower detectors (mm).

The \( \Delta x \) value is fixed by the geometry of the probe, so \( \Delta p \) is a direct measurement of the skin stiffness index. If the skin stiffness index was greater at three months than at baseline, the skin had tightened during the three-month period.

**RESULTS**

All subjects tolerated the procedure well. Adverse events were limited to minor swelling and bruising in the treated areas. The average volume of the aspirate was 936 mL.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Laser One Month (%)</th>
<th>Suction One Month (%)</th>
<th>Laser Three Months (%)</th>
<th>Suction Three Months (%)</th>
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</table>

Percentage shrinkage calculation based on Equation (1).

Figure 4. Mean skin shrinkage improvement ratio at one month and three months posttreatment. Individual skin shrinkage improvement ratios, calculated from Equation (3).
Skin shrinkage data are tabulated in Table 1. At one month, the reduction in surface areas was greater in the laser side than in the suction side for nine of the 10 subjects. After that time, one subject, Patient 9, was lost to follow-up due to pregnancy. At three months, the same was true for eight of the nine remaining subjects. Patient 6 had a weight gain of over 15 pounds through the course of the study, contributing to results that were not consistent with the other patients.

Area shrinkage ratios at one month and three months are shown in Figures 2 and 3, respectively. A two-tailed paired t test showed that the mean shrinkage ratios were significantly higher \( (P = .018) \) on the laser side than on the suction side in nine of 10 subjects at one month and in eight of nine subjects at three months \( (P = .014) \). (Again, one subject was lost to follow-up at three months.) Among subjects with excess flaccidity, improvement was greater on the laser-treated side.

The variable skin shrinkage response in individual patients was accounted for by calculating for each patient a skin shrinkage improvement ratio defined in Equation (3).

\[
I_{\text{SkinShrinkage}} = \frac{R_{\text{SkinShrinkage_Laser}}}{R_{\text{SkinShrinkage_Suction}}} - 1
\]  

where

- \( I_{\text{SkinShrinkage}} \) is the skin shrinkage improvement ratio,
- \( R_{\text{SkinShrinkage_Laser}} \) is the skin shrinkage ratio using the laser, and
- \( R_{\text{SkinShrinkage_Suction}} \) is the skin shrinkage ratio using suction alone.

Improvement in shrinkage ratios on the laser side over the suction side at one month and three months was quantified by Equation (3). The mean of the individual skin shrinkage improvement ratios showed 35\% greater shrinkage on the laser side at one month and 54\% greater shrinkage at three months. These results are presented graphically in Figure 4.

To assess improvement in skin tightening, suction cup probe measurements were taken and the skin stiffness indexes were calculated from Equation (2) for both sides of the abdomen at baseline, one month, and three months. The skin stiffness indexes for each subject at baseline, one month, and three months are shown in Figures 5 and 6, respectively.

The variable skin stiffness index at baseline and skin-tightening response in individual patients were accounted for by calculating for each side of the abdomen of each patient a skin-tightening index defined in Equation (4).
where

\[
T_{\text{SkinTightening\_Laser\_or\_Suction}} = \frac{Y_{\text{SkinStiffness\_Laser\_or\_Suction}}}{Y_{\text{SkinStiffness\_Baseline}}} - 1, \quad (4)
\]

At one month (n = 9), the mean skin-tightening indexes of the laser side versus suction side did not differ significantly. Mean improvements in skin stiffness from baseline were −2% for the laser side and −3% for the suction side (Table 2). Based on a paired two-tailed \( t \) test at one month, the difference between the mean skin stiffness after treatment (laser or suction) and baseline was not statistically significant.

At three months (n = 8), all patients had higher skin stiffness on the laser side than on the suction side. Mean skin-tightening improvements were 62% for the laser side and 5% for the suction side (Table 2). One subject was lost to follow-up. Based on a paired two-tailed \( t \) test, the mean skin stiffness index was significantly higher (\( P = .02 \)) on the laser than on the suction side. The difference between the mean skin stiffness after treatment with suction alone and baseline was not statistically significant. On the laser side, the difference between the mean skin stiffness index at three months and baseline was of borderline significance (\( P = .06 \)). Due to the small sample size and large variance over patients, Wilcoxon signed rank tests were used to check for significance. The test showed that the median skin stiffness index at three months was significantly higher on the laser side versus baseline (\( P = .011 \)).

The mean skin-tightening indices for the laser-assisted and the suction side, calculated from Equation (4), are plotted on the graph in Figure 7. A clinical example is shown in Figures 8 and 9.

**DISCUSSION**

Previous studies\(^{17}\) covered the safety and laser physics of laser-assisted liposuction and the specific temperature ranges involved for safe and effective treatment. In addition, a preliminary report\(^{18}\) indicated initial evidence for skin shrinkage and tightening with laser. The present study is the first to provide objective data showing that
LAL with the Smartlipo MPX followed by aspiration provides greater skin shrinkage and skin tightening than liposuction alone. The results support those of earlier studies in which a similar 1064-nm device was employed. The 600-µm fiber in the present study is larger than the 300-µm fiber in previous studies. The larger diameter fiber would allow more energy to be delivered at a faster rate with lower probability for fiber failures. Uncontrolled large energy sources near the skin surface can cause complications if not monitored properly.

Goldman et al. showed that LAL and liposuction did not alter blood levels of hemoglobin, hematocrit, triglycerides, and cholesterol up to one month after treatment. Badin and colleagues showed improvement in tissue flaccidity and in areas that, if treated by liposuction, would potentially become flaccid. Badin and colleagues, employing adipocyte diameter as an indicator of reversible damage (tumefaction) to adipocytes, showed that LAL affected adipocytes both reversibly and irreversibly (lysis) and that the procedure resulted in better wound healing, better hemostasis, less surgical fatigue, improved postoperative recovery, more rapid return to daily activities, and an excellent aesthetic result.

To eliminate the possibility that skin shrinkage and tightening were caused by mechanical damage, the side not receiving laser energy was treated with the cannula alone, both subdermally as well as in deep fat. The manual treatment was performed for approximately the same amount of time as the laser cannula was moved manually during LAL. However, the mechanical damage did not lead to the improvement achieved on the side treated with laser energy. It is clear that laser-assisted lipolysis achieved greater skin tightening and skin shrinkage than liposuction alone.

Both the 1064-nm and 1320-nm wavelength energies in the present study are absorbed by adipose tissue and

### Table 2. Skin-Tightening Index for Laser-Assisted Side and Suction-Only Side

<table>
<thead>
<tr>
<th>Subject</th>
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<th>Three Months (%)</th>
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Percentage skin-tightening indexes calculation based on Equation (4).

![Figure 7](https://academic.oup.com/asj/article-abstract/30/4/593/201989/304593201899?69)

**Figure 7.** Mean skin-tightening indices at one and three months posttreatment. Individual skin-tightening indices calculated from Equation (4).

![Figure 8](https://academic.oup.com/asj/article-abstract/30/4/593/201989/304593201899?69)

**Figure 8.** (A) This 40-year-old woman presented for treatment of unwanted abdominal adiposity and skin laxity. (B) Seven months after a single treatment. The right side of the abdomen was treated with the Smartlipo MPX laser (Cynosure, Inc.) and the left side by manual manipulation with the cannula and suction.
converted to heat that causes deformation, volume expansion, and rupture of the fat cells. The laser-induced heating also stimulates activity of dermal and fat cell collagen. The 1064-nm wavelength energy is absorbed by both oxyhemoglobin and methemoglobin, which is responsible for coagulation of small blood vessels in the fat tissue.\(^5\) Since absorption of 1320-nm energy by hemoglobin results in methemoglobin formation and methemoglobin absorbs 1064-nm energy three to five times as strongly as it absorbs 1320-nm energy, the synergistic 1064-nm/1320-nm unit further enhances hemostasis.\(^{22}\) The 1320-nm wavelength energy has a higher water absorption coefficient and is scattered less than the 1064-nm energy, so energy of this wavelength rapidly heats adipose tissue in small regions close to the tip of the optical fiber.\(^5\) Since the 1064-nm energy from the tip of the fiber has good tissue penetration and is scattered more than its 1320-nm counterpart, it is distributed over a broader treatment area, resulting in more controlled increases in temperature, more generalized heating of adipose cells, and more widespread activity in hemoglobin. As for the 1320-nm energy, because its target is water, its effect on dermal collagen is greater than that of the 1064-nm energy and the result is greater collagen shrinkage and skin tightening.\(^5\)

The skin-tightening indexes, plotted on the graph in Figure 7, suggest that one month after treatment, the mean skin stiffness and skin tightening showed no statistically significant difference from baseline both for the laser-assisted and the suction-alone side. That might be accounted for by the fact that at the one-month time point, skin healing is incomplete. Three months after treatment, mean skin stiffness and skin tightening were significantly higher on the laser-treated side.

In summary, the advantages of LAL with aspiration over liposuction alone are that the small-diameter cannula reduces the trauma to the patient and permits the surgeon to treat superficial areas, the face, and other areas in which it is either difficult to remove fat\(^{11,13}\) or in which the trauma of a larger cannula without laser energy in the

**Figure 9.** (A) This 42-year-old woman presented for treatment of unwanted abdominal adiposity and skin laxity. (B) Seven months after a single laser treatment (18,000 J deep and 19,681 J superficial) on the left side and manual manipulation with the cannula on the right side. (C, D) The identical before and after photos with an overlay of the 3D measured tattoo reference squares.
superficial zone would cause skin irregularities after treatment. LAL provides the additional laser energy source, for those difficult-to-treat fibrous areas such as breasts in gynecomastia, upper abdomen, and back rolls. Additional studies with more subjects would be needed to further optimize the parameters for treatment of the abdomen and other anatomical sites with unwanted fat.

CONCLUSIONS

Laser-assisted liposuction has experienced increase usage in clinical practice. Previous work has confirmed safety, efficacy, and temperature parameters to elicit skin tightening. In the present study, the sequential delivery of the 1064- and 1320-nm laser energies, as the only variable parameter in this internally controlled study, has led to data suggesting that the delivery of laser energy prior to liposuction has a statistically significant effect on skin shrinkage and tightening of the skin in the abdominal area.

Disclosures

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REFERENCES