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Laser Lipolysis Using a 1064/1319-nm Blended Wavelength Laser and Internal Temperature Monitoring

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Lasers, both in single and multiple wavelength designs, have recently been introduced to enhance the results of liposuction. Safe parameters of fluence and temperature have not yet been described. In this study, I describe a series of laser lipolysis patients treated with a dual wavelength (1064/1319 nm) laser where internal and external temperatures have been measured. From this series of 36 patients treated with a 1064/1319-nm wavelength laser for laser lipolysis, we calculated the specific heat of the fat and tumescent fluid combination to be 4.7 J/(g°C). The average increase in temperature measured in the subcutaneous space was 16°C.
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KEYWORDS laser lipolysis, specific heat, internal temperature monitoring, external temperature monitoring, dual wavelength laser

Laser lipolysis is a relative newcomer to the armamentarium of the cosmetic surgeon dealing with body contour dysmorphisms. Fischer and Fischer[1] in 1976 first elucidated the idea that sharp suction could be used for fat removal. Frictional negative pressure aspiration of underlying fat by the use of hollow blunt cannulas was first introduced to modern plastic surgery by Illouz.[2] During the following 2 decades numerous innovations in suction-assisted lipolysis were introduced to enhance the result, lessen the amount of blood loss, decrease physician fatigue, and shorten the recovery period for the patient. Klein[3] first described lipoaspiration under a tumescent local anesthetic, which allowed for the avoidance of a general anesthetic, a prolonged anesthetic effect, a decrease in blood loss, and improved esthetic outcome secondary to the small size of the cannulas used. Klein[4] further introduced the concept that the conventional accepted maximum safe dose of lidocaine with epinephrine, 7 mg/kg, could be expanded to a maximum of 35 mg/kg by diluting it with saline.

Ultrasound-assisted liposuction (UAL) was first described by Zocchi[5] in the 1980s. Ultrasonic energy at 20-30 MHz was delivered through a solid cannula to the fat, causing cell wall disruption through cavitation with eventual liquefaction of the fat. Standard hollow liposuction cannulas were then used to remove the liquified fat and cellular debris. Second-generation UAL devices (Lysonix, Mentor, Santa Barbara, CA) were subsequently introduced to allow for simultaneous ultrasound application and negative pressure evacuation. The large cannula diameters and necessary skin heat protectors left more visible access incisions. Seromas, skin burns, skin necrosis, and neurogenic pain limited UAL's acceptance as the preferred method of liposuction for the majority of liposuction practitioners in the United States.[6,7] External UAL was championed by Silberg[8] in 1998. High-frequency ultrasonic energy was applied through the skin after a wetting solution was introduced into the interstitial subcutaneous space. Although more harmonious dispersion of the wetting solution before negative-pressure frictional aspiration may have allowed for better intraoperative assessment of the true contour of the eventual result, good evidence for actual lipolysis and increase in efficacy over standard aspiration alone could not be demonstrated.[9,10] Power-assisted liposuction devices were introduced in the late 1990s. Either powered by compressed gas or electric motors, the cannula would reciprocate in a to-and-fro movement, facilitating its passage through the tissues. It was believed to be helpful in thick fibrous areas, such as the male flank, gynecomastia, or in cases of scarring from earlier liposuction. Although power assist in liposuction is thought to reduce physician fatigue and allow for more volume of fat removal per unit time, multiple authors have failed to show a statistical difference in an improvement in the esthetic result.[11,12]

Apfelberg[13,14] published a series of articles, beginning in 1992 first describing the use of a laser as an adjunct to liposuction. He treated 51 patients with a hollow single-hole

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cannula with a 600-μm laser-fiber oriented just proximal to the distal hole. He used a 40-W YAG laser with a 0.2 second pulse width. Standard frictional aspiration with continuous cooling of an infusion port was added. In theory, as the fat would be drawn into the single hole by negative pressure, the laser would help lessen the amount of bleeding by coagulation of the small vessel attachments before it being avulsed into the cannula. Some of the patients had a control side done without the adjunctive laser application. No statistical difference in blood loss, ecchymosis, or clinical outcome was observed. In 1996, the same author expanded the study to include several sites. He subsequently published his observations of a trend toward less edema, ecchymosis, and pain in the laser-treated patients compared with the control side.[15] Goldman,[16] in 2002, published a series of 1734 patients treated under a tumescent anesthesia with a 6-W 1064-nm Nd-YAG laser and a 300-μm fiber. Negative-pressure fine cannula aspiration was then done and specimens sent for histologic analysis. He reported histologic evidence of coagulation of small vessels, rupture of adipocytes, as well a reticular dermal injury. Neira[17] surmised that low-level laser application to fat, in the absence of a heating effect, could promote lipolysis. He treated abdominoplasty fat with a 635-nm, 10-mW diode laser and evaluated the specimens using electron microscopy. At 6 minutes of laser exposure, 99% of the fat was released into the interstitial space. The mechanism of effect was thought to be the formation of a transitory pore in the fat cell wall that would allow the migration of the intracellular fatty acid into the interstitial space. Several authors have published clinical series of laser lipolysis patients in which a 1064-nm, Nd-YAG laser (SmartLipo, Deka, Florence, Italy) was used under a tumescent anesthetic both with and without subsequent negative pressure aspiration. In each of the series, both reduction in fat and overlying skin tightening were observed.[18,19]

Materials and Methods

From March 2009 to July 2009, a total of 36 patients, of which 3 were male and 33 female, underwent laser lipolysis of 47 areas, all done under a tumescent local anesthesia in an office setting. Both internal and external measurements of temperatures during the procedure were recorded. The most common area treated was the abdomen at 40% of the total, followed by the hips at 21% and the neck at 11%. All potential liposuction candidates were evaluated for lipodystrophy by the author and considered for various body-contouring procedures, including abdominoplasty, mini-abdominoplasty, power-assisted liposuction, chemical lipolysis (LipoDissolve), or laser-assisted lipolysis. Patients chosen for laser-assisted lipolysis had small to moderate areas of lipodystrophy, were nonobese, devoid of systemic illnesses, American Society of Anesthesiologists class 1, and of the mindset that they could be operated upon without a general anesthetic.

A dual wavelength (1064 and 1319 nm), 30-W laser with a fiber delivery and coaxial 635-nm aiming beam laser for localization was used (ProLipo, Sciton, Palo Alto, CA). The operator chose the proportion of each wavelength (either 1064 or 1319 nm) to be used. The laser wavelengths could be used at 10% increments from 0% to 100% of either wavelength, with the 2 percentages totaling 100%.

All the patients received oral benzodiazapene about 30 minutes before the procedure and no IV was used. The 0.1% tumescent solution composed of 1 L of Ringer's lactate, 50 mL of 2% lidocaine plain (Hospira, Lake Forest, IL), 1 mL of epinephrine 1:1000 (Hospira, Lake Forest, IL), and 10 mL of 8.4% sodium bicarbonate (Hospira, Lake Forest, IL) was used for all patients in which 1 L or lesser amount of solution was used. For multiple sites in the same patient, 50 mL of 1% lidocaine plain was substituted for 2% lidocaine.

The Procedure

Patients were marked with a topographic map, beginning with the smallest circle representing the thickest areas of contour dysmorphism. A measurement of the width, length, and thickness of the area to be treated was recorded. Thickness of the area was measured with a Mentor breast caliper (Mentor, Santa Barbara, CA) and one-half of the measured thickness was used because the area was doubled over or pinched to obtain the measurement. The calculated volume of fat was determined by (length $\times$ width $\times$ 0.5 thickness). Using the experimental specific heat capacity of fat of 2.51 J/(g°C)[20] and 0.9 g/cm^3 for the density of fat, an estimate of the total number of joules of laser energy can be calculated for any anticipated delta of temperature. For example, a 20 cm by 20 cm abdomen that measures 40 mm with a skin caliper would have a calculated volume of 800 cm^3. If we want to see an internal temperature of 45°C after laser application and accept a starting temperature of 30°C, we would need (800 cm^3 $\times$ 2.51 J/(g°C) $\times$0.9 g/cm^3 $\times$ 15°C) or 27,108 J of laser energy to heat that amount of fat to 45°C. This value we describe as calculated energy necessity.

The patients were prepped and draped in the usual sterile fashion and best positioned on the table for adequate access to the area to be treated. The tumescent formula described above is first delivered to the area to be treated with a Hunstadt Handle (Byron, Tucson, AZ) and a Variable Speed Auto-Fuse Pump (Byron, Tucson, AZ) through a 22-gauge spinal needle. About 20% of the anticipated volume to be placed was done in that fashion to make the introduction of a Klein multihole infusion cannula (Byron, Tucson, AZ) less uncomfortable. With the Klein cannula, through a 2-mm 11-blade incision, the remainder of the tumescent fluid was introduced into the area in a total volume of about 1.5-2 times the amount of fat that I wanted to remove based on my past experience with standard negative-pressure cannula liposuction of similar areas. I waited several minutes for the epinephrine to promote hemostasis, although in my experience, starting the laser application just after infiltration does not seem to cause the eventual aspirate to be more bloody.

The 1064/1319-nm laser was applied to the area through either a 600-μm fiber for small areas such as the neck or anterior axillary fold, or a 1000-μm fiber for the larger areas, such as the abdomen or thighs. The laser fiber was positioned in the attached cannula with 2 mm of fiber exposed beyond the confines of the metal cannula. Laser power is set to reflect the thickness of the fatty layer. Typical power levels were 12-15 W for the neck and 22-28 W for the abdomen, hips, and thighs. The laser was applied in a short methodical slow fanlike fashion beginning deep and working more superficial. Before the advent of internal temperature monitoring, I would deliver about 60% of the calculated energy necessary before negative pressure cannula evacuation and the other 40% in a skin tightening fashion after lipoaspiration. The end point of laser delivery had previously been described as lack of resistance of the cannula passing through the tissue or the feeling on the skin overlying the treat area as gloved hand warmth.[19] I split the energy of the dual wavelength laser to optimize the photothermalytic properties of each wavelength. When treating during the lipolysis phase, with the chromophore of oxyhemoglobin in vascularized fat, I would treat at 70% of 1064 nm and 30% of 1319 nm. After the fat had been aspirated, I would flip the percentages around using 70% of 1319 nm. The target chromophore for 1319 nm is water. For the lipolysis after aspiration, I favored the 1319 nm in an attempt to heat the fibrous stroma now devoid of fat and the subcutaneous skin surface to elicit skin tightening. In the postevacuation phase of laser delivery, I liked to see direct contact of the laser fiber just under the skin surface. This is visualized by a brighter and larger diameter circle of the red aiming light. When the procedure is complete, the small 2-mm incision for access is closed with cyanoacrylate glue (Skinstitch, Progressive Medical, St. Louis, MO) and an occlusive dressing is placed.

Temperature monitoring of the skin surface was accomplished using an infrared thermometer (Sperry IRT 100, Sperry Instruments, Hauppauge, NY). Internal temperatures were recorded by a prototype of the TempAssure (Sciton, Palo Alto, CA), which has a small thermocouple embedded a few millimeters proximal to the distal end of the cannulas for both the 600- and 1000-μm fibers. The thermocouple cannula was wire-attached to a computerized monitor that read the temperatures at 2.5-second intervals and provided feedback with both voice and tones. Both internal and external temperature readings were recorded at specified intervals: before tumescent infiltration, after tumescent infiltration, after lipolysis delivery of blended laser, after syringe liposuction evacuation, and, finally, after the second blended laser delivery to the area. The delta temperature was calculated from the difference between the baseline measured before tumescent infiltration and the highest sustained 12-second average temperature achieved during the first laser delivery.

Results

Results for the data collection of these 36 patients are presented in Table 1. The calculated volume was derived from a product of the measured length, width, and half of the caliper thickness of the area. The tumescent volume was the amount of tumescent fluid placed into the area. The volume we removed with frictional aspiration is shown as SAL volume. The sum of the tumescent volume and sal volume are represented by the total volume. The deep Joules indicated the energy delivered during the lipolysis phase using a blended 1064/1319-nm wavelength before the aspiration was done. The superficial joules were the blended laser delivered after frictional aspiration was completed. The total joules were the sum of the superficial and deep joules. The average delta of temperature measured internally was 16°C, while the average delta as measured at the skin level was 4°C. The average number of joules of laser energy delivered per cubic centimetre of eventual fat removal with frictional negative pressure syringe aspiration was 57 J/cm^3. We also calculated the specific heat of the fat and tumescent anesthetic combination by the following formula: Observed specific heat = (Total joules/observed Delta T $\times$0.9 g/cm^3 $\times$ sal volume.) The average observed specific heat of the series was 4.7 joules/(g°C). No blisters or overt burns were observed. No bleeding, infections or wound healing complications were noted in any of the patients. Photographic evidence of skin tightening as well as reduction in volume can be seen in Figures 1 and 2.

Discussion

Laser lipolysis is a relative newcomer into the possible modalities in consideration for body contouring. At its inception, no definitive endpoints for laser delivery have been demonstrated. Although lack of resistance of passage of the cannula fiber combined with gloved hand warmth has been described as endpoints to laser energy delivery,[19] these are subjective criteria and may vary greatly between different consistencies of fat (ie, fibrous areas, such as gynecomastia or male flanks) or with varying thickness of the fatty layer. Dibernardo[20] using abdominoplasty patients, treated areas of 3 $\times$ 3-cm^2 with the 1064-nm laser, 1320-nm laser, as well as the combined multiplex 1064/1320 nm (Cynosure, Westford, MA) wavelengths at laser doses of 8.3-333 J/cm^2. He showed evidence of histologic epidermal and dermal injury at temperatures exceeding 47°C measured 5 mm under the skin surface. Blistering was observed at 58°C. He calculated that laser doses between 4.5 J/cm^2 for 1319 nm and 7.5 J/cm^2 for 1064/1320 nm were necessary for a 1°C increase in temperature measured at the skin surface. Before the advent of internal temperature monitoring equipment, some estimation of the required amount of laser energy to be delivered was needed. A measured formula calculation of required joules was first used to best predict the amount of energy needed to heat the fat of the operated area from a baseline temperature to a desired average temperature. Optimal internal temperatures during laser delivery had not yet been described when this series of patients were treated. Several assumptions employing the use of this formula may over or underestimate those required number of joules. First, while the measurement of length and width of the area may be accurate, the thickness, usually measured at the thickest area, certainly does not take into account the fact that the thickness of the fatty layer is not homogenous across the surface area of the treated location. Some feathering into adjacent areas is usually done as well to smooth the result. This added energy

Table 1 Laser Lipolysis Results

Patient	Area	Calculated Volume	Tumescent Volume	SAL Volume	Total Volume	Deep Laser	Superficial Laser	Total Joules	Delta Internal T	Delta External T	Experimental Specific Heat
1	Neck	41	120	55	175	1208	280	1488	13	0	2.31
2	Neck	50	130	36	166	2240	875	3115	14	4	6.87
3	Neck	60	150	17	167	1403	472	1875	18	9	11.27
4	Neck	60	125	22	147	2040	816	2856	14	8	10.30
5	Axilla	65	150	50	200	1240	512	1752	15	5	2.60
6	Axilla	79	100	50	150	3023	1517	4540	35	14	2.88
7	Axilla	101	100	55	155	3133	1526	4659	35	14	2.69
8	Neck	134	150	68	218	3414	1325	4739	14	8	5.53
9	Axilla	155	120	55	175	3057	1258	4315	14	3	6.23
10	Hip	180	325	200	525	5468	1393	6861	20	2	1.91
11	Hip	185	359	210	569	4985	1358	6343	17	3	1.97
12	Hip	187	200	115	315	5000	2150	7150	16	3	4.32
13	Buttock	252	250	36	286	5006	1542	6548	16	2	12.63
14	Flank	266	450	350	800	6950	2066	9016	22	3	1.30
15	Arm	280	110	50	160	1828	1173	3001	14	4	4.76
16	Hip	306	200	125	325	5088	756	5844	18	11	2.89
17	Hip	314	250	48	298	3506	1041	4547	15	5	7.02
18	Bra	342	275	115	390	8058	3169	11,227	10	0	10.85
19	Hip	390	325	140	465	5308	678	5986	20	1	2.38
20	Outer thigh	470	325	230	555	8069	6076	14,145	10	1	6.83
21	Hip	515	400	165	565	8546	2009	10,555	11	4	6.46
22	Medial thigh	531	125	110	235	1968	1550	3518	14	3	2.54
23	Arm	546	275	240	515	8039	4312	12,351	18	2	3.18
24	Abdomen	595	1000	595	1595	20,522	6161	26,683	8	6	6.23
25	Abdomen	640	775	470	1245	18,139	7859	25,998	15	3	4.10
26	Abdomen	643	525	410	935	11,777	3100	14,877	10	3	4.03
27	Abdomen	660	1000	710	1710	21,797	8023	29,820	10	5	4.67
28	Abdomen	756	550	500	1050	7465	3505	10,970	14	2	1.74
29	Abdomen	760	500	420	920	5056	2056	7112	15	2	1.25
30	Inner thigh	782	300	90	390	6056	4560	10,616	10	5	13.11
31	Back	790	750	430	1180	10,989	2685	13,674	17	0	2.08
32	Back	794	750	430	1180	12,609	1740	14,349	6	6	6.18
33	Abdomen	794	900	545	1445	20,090	10,075	30,165	15	6	4.10
34	Hip	801	800	395	1195	15,053	7979	23,032	15	3	4.32
35	Hip	873	550	195	745	8109	4065	12,174	14	5	4.95
36	Hip	897	375	165	540	9099	4194	13,293	19	3	4.71
37	Abdomen	980	1800	1495	3295	31,979	12,249	44,228	14	6	2.35
38	Abdomen	1008	950	760	1710	20,698	4348	25,046	14	2	2.62
39	Abdomen	1049	1050	510	1560	14,149	14,021	28,170	14	3	4.38
40	Abdomen	1063	1000	745	1745	20,142	8804	28,946	18	2	2.40
41	Abdomen	1185	1275	720	1995	26,843	8521	35,364	12	2	4.55
42	Abdomen	1187	825	570	1395	2528	14,496	17,024	22	6	1.51
43	Abdomen	1200	950	890	1840	20,065	10,096	30,161	5	3	7.53
44	Abdomen	1248	1050	250	1300	12,174	4079	16,253	14	4	5.16
45	Abdomen	1253	1010	555	1565	16,174	10,333	26,507	14	6	3.79
46	Abdomen	1380	900	650	1550	21,399	7414	28,813	19	3	2.59
47	Abdomen	1544	1075	900	1975	28,446	11,506	39,952	30	0	1.64
								Average	15.7	4.1	4.7

as well as the added volume might not be included in the measurement. If the chromophore for 1319 nm is water, then we should include the tumescent volume as volume that is exposed to laser, as it may be the water that is preferentially heated and transfers that heat to the fat. The addition of a water-based tumescent infiltration into the fat to be treated with laser lipolysis may change the specific heat of that mixture from what is seen in fat alone. We calculated this specific heat for the fat and tumescent fluid to be 4.7 J/(g°C) on average for our series. By using the specific heat capacity described above and measuring the length, width, and thickness of the area to be treated, some estimate of the amount of total energy for effective treatment can be ascertained that will safely increase the internal temperature to 46°C.

Internal temperature monitoring using a device, such as the TempAssure (Sciton, Palo Alto, CA) will allow for harmonious distribution of the laser energy across the surface area and depth of the treated site. The external temperature increase does not seem to be relevant or helpful in understanding the actual temperature that exists where the energy is being applied. The increase in skin temperature is delayed from the actual internal temperature and varies relative to the thickness of the fat layer. In the neck or anterior axillary fold, for instance, the temperature increase internally is rapid due to the small volume of fat and tumescent in the area. We observed that the appearance of a temperature increase at the skin level is delayed from that observed internally and the delay is shorter in the thinner areas such as the neck and anterior axillary fold. In the thicker areas, such as the abdomen and thighs, the cutaneous skin temperature measure-

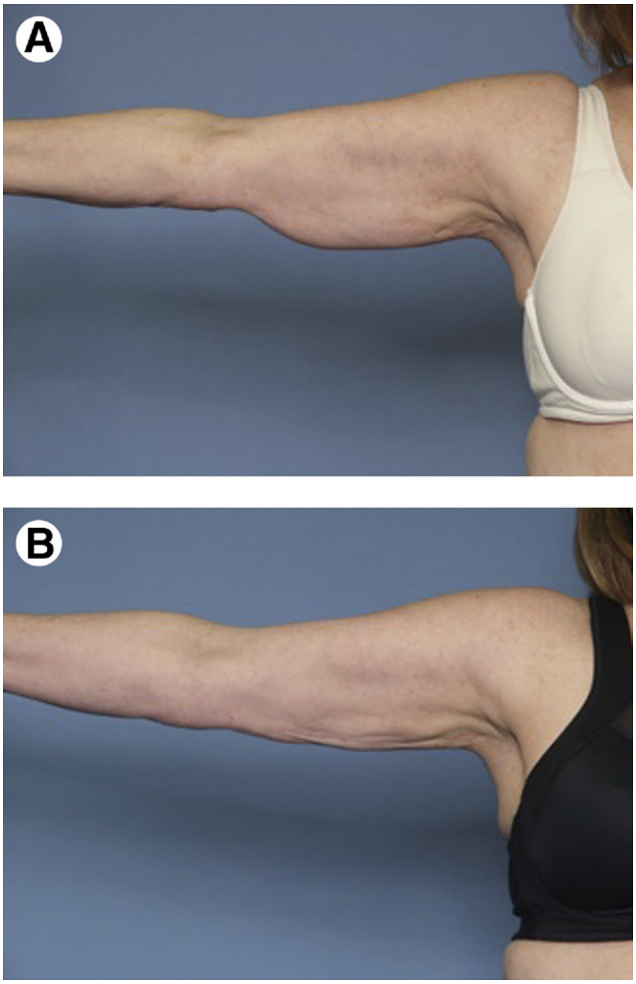

Figure 1 (A) A 59-year-old women before laser lipolysis and aspiration liposuction of the arms. (B) Six-week postoperative laser lipolysis and aspiration liposuction of the arms.

ment changed very little from baseline. The external temperature measurement may also not be the temperature that is important in the overall effect. By measuring the temperatures of multiple areas and depths and averaging those over a specified unit of time, the resulting temperature may be more predictive of the actual Delta T. We observed that while the laser is being fired, the temperature would continue to increase. The rate of increase is rapid if more Watts are used. After the laser stops firing, the measured internal temperature decreases a few degrees then stabilizes. Thus, the true temperature may be that which is measured on average for a few seconds after the laser application and some equilibration has taken effect.

The amount of tumescent can affect both the rate of increase of the temperature and the total energy necessity for the volume of the water and the fat. We chose to use a superwet amount of wetting solution, which is described as 1.5-2 times the amount of anticipated lipoaspiration. If more water were placed, as is implied in a true tumescent technique in which 3 times as much wetting solution is placed for the volume of lipoaspiration, certainly more energy would be necessary to heat this increased volume to the same goal temperature. Our data demonstrate that a 16°C increase in temperature measured under the skin surface produces safe and effective laser lipolysis. Because the observed baseline temperature was about 30°C, a goal temperature of 46°C measured beneath the skin surface should be adequate in avoiding skin burns yet producing satisfying results. A more moderate 4°C increase at the skin level was observed on average as measured by a laser infrared thermometer. As this external temperature increase can be quite delayed compared with the underlying internal temperature, this may limit its usefulness in delivering the appropriate amount of laser en-

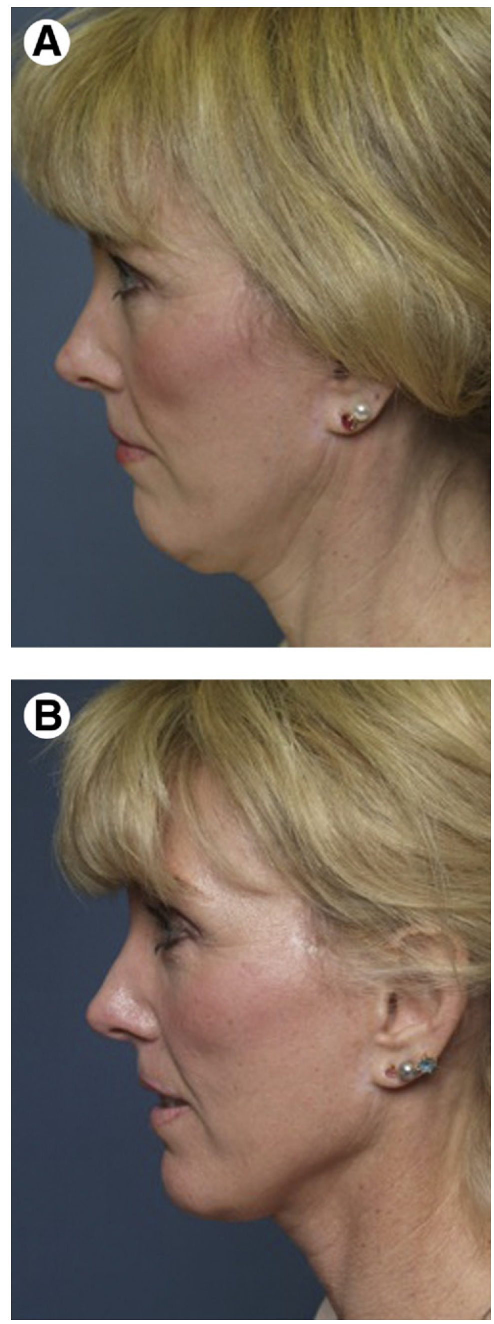

Figure 2 (A) A 56-year-old before laser lipolysis and aspiration liposuction of the neck. (B) Six-week after laser lipolysis and aspiration liposuction of the neck. (Used with permission.)

ergy that will be efficacious yet safe. The goal of using the laser as an adjunct to frictional negative pressure aspiration is to improve the results in liposuction. The addition of heat may reduce bleeding, promote neocollagenesis through the inflammatory cascade, and tighten the overlying skin. These results should have a dose-response curve that can be mediated through temperature modulation. By measuring the internal temperature and avoiding extremes of temperature that could lead to blisters and skin and fat necrosis we hope to improve the results of liposuction for our patients.

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