

Noninvasive Selective Cryolipolysis and Reperfusion Recovery for Localized Natural Fat Reduction and Contouring

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Abstract

Background: Cryolipolysis is a contemporary method of reducing fat by controlled extraction of heat from adipocytes.

Objectives: The authors recorded temperature profiles during a single cryolipolysis treatment/recovery cycle (with and without massage) and report on the clinical safety and efficacy of this procedure.

Methods: In the pilot study group (PSG), the abdomens of 6 patients were treated with cryolipolysis and subdermal temperatures were recorded. In the clinical treatment group (CTG), 112 patients were treated without temperature recordings and results were evaluated through matched comparison of standardized photographs, caliper measurements, ultrasound imaging, and global assessments.

Results: Thirty minutes into the cooling phase, subdermal temperatures of patients in the PSG declined precipitously from pretreatment levels and remained low until the end of treatment. During recovery, subdermal temperatures of the only subject who received massage returned faster and to higher levels than the temperatures of subjects who did not receive massage. Patients in the CTG who were available for follow-up measurements at 6 months ($n = 85$) demonstrated an average fat reduction of 21.5% by caliper measurements; 6 random patients from this group also showed an average of 19.6% fat reduction by ultrasound imaging at 6 months. Global assessments were highest for the abdomen, hip, and brassiere rolls. Minimal side effects were observed, and patients experienced no significant downtime.

Conclusions: Noninvasive cryolipolysis results in a predictable and noticeable fat reduction within 6 months and does not cause skin damage. Profiling of subdermal temperatures may provide additional insights for improving clinical effectiveness and safety.

Level of Evidence: 3

Keywords

liposuction, cryolipolysis, temperature profile, reperfusion-injury, fat removal, body contouring



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Although liposuction¹⁻¹⁰ remains the most effective procedure for face and body contouring, patients continue to search for noninvasive methods of fat reduction that have lower morbidity rates and shorter recovery times. Current nonsurgical procedures¹¹⁻¹⁹ employ mechanical vacuum-massage, lasers, radio frequency, ultrasound, or low-level energy infrared light and are not intended for the removal of larger volumes of fat. Although these tools produce individual benefits, their long-term value remains in question because they provide less dramatic and predictable results and require multiple treatments.

Cryolipolysis²⁰⁻²⁷ is a contemporary method for localized natural fat reduction that employs controlled, selective

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extraction of heat from adipocytes while sparing injury to skin and other structures. The proposed mechanisms, which result in immediate fat cell demise and gradual apoptosis, are associated with lipid-ice crystallization, inflammatory panniculitis, phagocytic process, and then gradual clearance. The principles of cryolipolysis were established during the 1960s—the modern era of cryobiology and cryosurgery—and consisted of rapid freezing, concurrent ischemia, slow thawing, reperfusion-injury, and, in certain circumstances, repetition of the freeze-thaw cycle. Since then, numerous investigations in animal models²⁰ and cell culture systems²¹ have attempted to define appropriate temperature/time dosimetries, the dynamic significance of cold-induced vascular stasis and reperfusion, and, recently, the emerging role(s) of released reactive oxygen species (ROS) during the hypothermic-reperfusion injury.²⁸⁻³²

The purposes of this study were to record temperature profiles during a single treatment-recovery cycle in a pilot study group (PSG) for temperature/time dosimetries and to report on the safety and efficacy of identical treatments—without temperature recordings—in a larger clinical treatment group (CTG) of consecutive patients.

METHODS

Cryolipolysis System

The cryolipolysis system used in this study (Zeltiq Aesthetics, Pleasanton, California) is composed of a control console with 1 of 2 applicators attached via an umbilical cable. The console contains a thermoelectric cooling element that maintains a variable, preset temperature below 0°C during the entire cooling cycle using sensors embedded within the cooling plates, which are located on each side of the cup-shaped applicator. The control unit regulates the temperature, duration, and rate of energy extraction, which is expressed as milliwatts per centimeter squared (mW/cm²) and referred to as the cooling intensity factor (CIF).

Patient Selection

Candidates for both the PSG and CTG were recruited from the study site's patient base. They were men and women aged 18 years or older who were in good health and had localized fat bulges that were not easily reduced by diet or exercise.

All candidates in both the PSG and the CTG had to demonstrate that they had not experienced significant weight gain or loss (5 pounds or more) during the previous 6 months. Patients with a history of viral infections were given prophylactic antivirals 2 days before the procedure's commencement through 6 days after its completion. Patients who had sensitive scars or who had recently

undergone procedures in the treatment area were cautioned about the possibility of increased discomfort during or after treatment. Patients with a history of cold-induced conditions such as cryoglobulinemia, cold urticaria, and paroxysmal cold hemoglobinuria were contraindicated for treatment. Patients who had undergone surgery or received noninvasive subcutaneous fat treatments within the preceding year were also excluded.

Of more than 25 adults recruited in 6 months for the PSG, only 6 qualified and provided written informed consent that included compliance guidelines established by the International Organization for Standardization, US Food and Drug Administration (FDA), and institutional review board practices. Of more than 175 adults recruited for the CTG, only 112 were qualified and provided informed consent to be treated by the FDA-cleared cryolipolysis system.

Treatment Protocol

Prior to treatment, each patient's weight, height, body mass index (BMI), and body fat percentage were measured. Body fat was assessed with the Futrex-600/XL (Futrex, Inc, Gaithersburg, Maryland). The use of near-infrared optometry at 2 wavelengths (940 nm and 950 nm) at a single body site (the bicep) is a well-established technique³³ for providing accurate measurements of body fat, with a correlation of 0.82 and a standard error of 2.8%—approximately the same standard error observed in the commonly accepted gold standard of underwater weighing or the ether extraction method. On the day of the procedure, the treatment site was washed with a mild cleanser. All metal jewelry was removed from the treatment area. The 6 subjects in the PSG were treated with a large (7.5 × 16.2 cm) or small (5.0 × 9.4 cm) applicator on the basis of the anatomical dimensions of fat collection in the lower abdomen. The large applicator was used across the entire lower half of the abdomen. The small applicator covered half of the abdomen; the other half was treated at the same procedure or at a separate session to balance outcomes. For accurate placement of the applicator, the ovoid area of localized fat was outlined with a marking pen in the standing, sitting, and supine positions.

Ambient room temperature was maintained at 23°C throughout the cooling and recovery periods. Participants' body temperatures were measured every 15 minutes with an oral thermometer. Continuous skin temperatures were measured by the Omega 450 Thermistor Thermometer (Omega Engineering, Inc, Stamford, Connecticut), which was attached to the midportion of the treated abdominal skin. Skin temperatures were recorded at the baseline and at every degree of change during the 60-minute cooling and 60-minute reperfusion-recovery phases.

After the administration of local anesthesia, a thermocouple at the tip of a 1.6-mm cannula (ThermaGuide,

Cynosure, Inc, Westford, Massachusetts) was inserted under sterile conditions through a dot access incision at the lateral abdomen and threaded through the subcutaneous fat to a marked point indicating the fullest portion of the inner mid-abdomen. An ultrasound device—the DermaScan C, 20-MHz transducer, 10 to 15 mm penetration (Cortex Technology, Hadsund, Denmark)—localized and maintained the tip of the thermocouple at a depth of 1.5 cm below the dermal-fat junction, centralized between the side walls of the applicator, to ensure accurate and consistent temperature recordings. A proprietary saturated gel pad was placed on the marked skin to ensure complete coupling between the applicator's opposing plates. A gentle but moderate vacuum pressure of up to 80 mm Hg was used to pull the tissue between the cooling panels of the applicator. Vacuum pressure of 80 mm Hg was used on the 2 subjects being treated with the small applicator on each side of their abdomens. Their temperature profiles were recorded at different sessions during each cooling phase. Vacuum pressure of 50 mm Hg was used on 4 subjects being treated with the large applicator in a single session. Their temperature readings were recorded during each cooling phase.

All sites were treated to CIF 42 for a 60-minute cycle of cooling followed by an integrated preset 5-minute period of mechanical tissue massage. At the termination of the cooling phase, the applicator was removed. The chilled and indurated sites, treated with the small or large applicator, received no manual massaging. Temperature changes were recorded continually until the surface skin and subdermal temperatures returned to pretreatment values on their own.

One subject received continuous abdominal massage for 1 hour after the cooling phase ended or until the skin and subdermal temperatures returned to baseline. This technique was employed to determine whether vigorous massage would accelerate the return of temperatures—and, by extension, oxygenated blood—to pretreatment levels. The restoration of oxygenated blood is believed to produce an array of free oxygen radicals, which could potentially add to tissue loss.

Candidates in the CTG were treated at 1 or more sites for a total of up to 4 treatment areas in a single session. Sites were treated with either the small or large applicator, based on the size of the problem area and the anatomical limitations of applicator placement. Treatment was applied at CIF 42 for a 60-minute cycle, accompanied by an integrated preset 5-minute period of mechanical tissue massage at the end of the cooling phase. Patients were encouraged to receive the highest levels of negative suction to recruit more tissue between the treatment plates. Any discomfort caused by the initial pull of the vacuum pressure resolved within a few minutes because of the tissue cooling. Once the applicator was attached to the treatment area, no further operator involvement was required.

Patients decided whether to receive the treatment in a sitting or reclined position and were provided with pagers to call the operator with any concerns. If necessary, the operator could remove the applicator from the patient by releasing the vacuum pressure. A 5-minute period of manual massage at the firm, cold treatment site completed the reperfusion-recovery phase of treatment.

Photographic and Statistical Analysis

Participants in both the PSG and CTG were photographed at baseline and at 6 months follow-up with a custom-designed Canfield VISIA Analysis and Photographic System (Canfield Scientific, Inc, Fairfield, New Jersey). Consistent positioning (0°, 45°, and 90° views) was ensured for this photography. A photographer used the Nikon D90 camera system (Nikon Corporation, Tokyo, Japan) in a dedicated room with fixed direct and indirect lighting placed at standardized distances from a marked positioning mat. The matched-orientation function of the Mirror software (Canfield Scientific, Inc) assisted with comparison of baseline and posttreatment images between reference points. Each photographic image was automatically tagged with a label that could not be edited.

A Harpenden skinfold caliper (Baty International, West Sussex, UK) was used to measure the site of greatest thickness within the treatment area for patients who were available for follow-up measurements at baseline and 6 months posttreatment. The author (G.H.S.), aware that differences in technique can cause variations in ultrasonic measurements, selected this particular system based on performance validations provided by the manufacturer and on the inclusion of standardized computer control and analysis programs, which minimize human bias and inconsistency during measurements. DermaScan C (20-MHz) ultrasound imaging was used to measure the extent of fat loss for patients who were available at the baseline and again at a 6-month follow-up. The ultrasound probe was placed lightly on a targeted skin marking (pigmented or vascular lesion) within the treatment zone to localize probe placement at the baseline and follow-up evaluations. An image-analysis program calculated the average depth from the dermis to Scarpa's fascia using 3 repeated measurements taken by an experienced third-party blinded operator.

Two independent investigators evaluated and scored the clinical results on standardized photographs at 6 months, utilizing the Investigator Global Aesthetic Improvement Scale (IGAIS), in which 0 = no change, 1 = mild improvement, 2 = moderate improvement, and 3 = significant improvement. Patients assessed their results 6 months posttreatment using the Subject Global Aesthetic Improvement Scale (SGAIS), in which 0 = no change, 1 = mild change, 2 = moderate change, and 3 = significant change.

Table 1. Demographics and Measurements, Pilot Study Group

	Subject No.	Age, y	Sex	Ethnicity	Height, m	Weight, kg		BMI		Body Fat, %	
						Pretreatment	Posttreatment	Pretreatment	Posttreatment	Pretreatment	Posttreatment
Large applicator	1	26	F	White	1.7	70.3	72.6	24.3	25.1	37.9	33.4
	2	29	M	Hispanic	1.7	95.3	94.8	31.8	30.1	31.1	31.0
	3	31	M	Asian	1.8	77.1	78.0	25.2	25.5	22.8	22.8
	4	51	F	Hispanic	1.6	56.4	56.7	22.8	23.0	36.4	35.7
Small applicator	5	43	F	Hispanic	1.6	81.0	81.7	32.7	32.8	45.4	45.4
	6	25	F	Hispanic	1.5	55.3	55.0	24.6	24.2	33.6	33.5

RESULTS

Pilot Study Group

Six patients (4 Hispanic, 1 Asian, and 1 white) ranging in age from 26 to 51 years (mean age, 34.2 years) were enrolled in the PSG temperature studies and received treatment with either the large (group 1) or small (group 2) applicator (Table 1). All subjects were permitted to recover without manual massage after the applicator was removed, except for subject 4, who was manually massaged until the subnormal temperatures within the subcutaneous fat returned to pretreatment levels.

At a constant ambient room temperature (23.0°C-24.0°C), average oral temperatures in group 1 (35.3°C) and group 2 (36.0°C) remained consistent, varying 1 to 2 degrees, throughout the treatment phases: baseline, cooling, and reperfusion-recovery (Table 2, Figure 1). In contrast, each subject's skin temperature (Table 2) and the profile curve of average values (Figure 1) characteristically declined during the cooling phase and recovered gradually throughout the reperfusion-recovery phase to pretreatment levels. The average pretreatment skin temperatures were similar in group 1 (26.8°C) and group 2 (26.5°C). During the 60-minute cooling phase, average skin temperatures declined more gradually in group 1 than in group 2 (Table 2), but the difference was not statistically significant. During the 60-minute reperfusion-recovery phase, the average skin temperatures of subjects 1, 2, and 3 from group 1 rose higher than those of subjects from group 2 (Table 2), but the difference was not statistically significant. The skin temperature of subject 4 from group 1 (the subject who received continuous massage from the time the large applicator was removed until her temperatures returned to pretreatment levels) attained slightly higher, but not statistically significant, levels of recovery at each 15-minute interval than other subjects from groups 1 and 2. At the 60-minute mark in the reperfusion-recovery phase, the

recorded skin temperatures of all subjects had rebounded to levels higher than pretreatment.

Each subject's subdermal temperature (Table 3) and profile curve of average values (Figure 2) exhibited similar patterns of gradual temperature decline to its lowest level at 45 to 60 minutes in the cooling phase and then a gradual elevation and restoration of temperatures to baseline levels at 60 minutes during the reperfusion phase. However, each subject's rate and temperature readings at each time point were different from other subjects' readings during the phases of cryolipolysis and reperfusion. The average pretreatment subdermal temperatures (34.0°C) were identical in groups 1 and 2. During the 60-minute cooling phase, average subdermal temperatures fell by the same amount and at the same rate in groups 1 and 2 (Table 3). During the 60-minute reperfusion-recovery period, however, the average subdermal temperatures of subjects 1, 2, and 3 from group 1 climbed to higher temperatures at a faster rate than those of group 2 (Figure 2). These differences were statistically significant ($P < .05$). The subdermal temperature of subject 4 from group 1 (the subject who received massage) rose at a statistically significant higher rate and to a statistically significant higher level than that of all other subjects in groups 1 and 2 (Figure 2). At the 60-minute interval in the recovery phase, the recorded subdermal temperatures of all subjects had returned to pretreatment levels.

Clinical Treatment Group

From July 2009 through January 2011, a total of 112 patients, whose demographic data are listed in Table 4, were treated with the large applicator on the entire lower abdomen and the small applicator on the upper/lower abdomen and other body sites. The treatment sites (Table 5) included any roll of fat that could be safely pulled into the applicator. Of the 112 patients, 85 were available for follow-up caliper evaluations

Table 2. Oral and Skin Temperatures, Pilot Study Group

	Time, min	Large Applicator				Small Applicator			
		Subject 1	Subject 2	Subject 3	Subject 4	Subject 5		Subject 6	
						L	R	L	R
Oral temperature, °C									
Cryolipolysis	0	33.0	35.9	36.8	35.7	36.3	35.8	36.0	36.2
	15	33.0	35.9	35.8	35.1	36.3	36.2	35.6	36.1
	30	34.0	35.9	35.8	35.7	36.3	36.2	35.6	36.6
	45	35.8	35.9	35.8	35.7	36.3	36.2	36.2	36.6
	60	35.8	35.9	35.8	36.0	36.3	36.1	36.1	36.6
Reperfusion recovery	15	36.0	36.2	36.4	36.4	36.3	36.8	36.0	36.6
	30	34.1	36.2	36.5	36.4	35.5	35.7	36.4	36.6
	45	34.1	36.7	36.4	35.2	35.5	36.3	36.4	36.4
	60	35.2	36.7	36.7	35.2	35.5	36.3	36.2	36.4
Skin temperature, °C									
Cryolipolysis	0	26.9	26.9	26.7	26.0	26.1	26.6	26.5	25.7
	15	27.6	25.5	20.4	24.9	18.7	20.7	24.0	25.8
	30	25.2	24.8	17.0	23.7	13.9	16.9	23.6	25.8
	45	15.2	14.3	19.8	15.2	12.3	13.5	14.2	13.4
	60	17.3	12.8	12.7	12.7	12.7	11.3	7.6	11.3
Reperfusion recovery	15	21.9	15.0	24.8	21.2	19.0	19.1	17.4	21.9
	30	24.0	22.0	26.4	25.7	21.2	24.0	20.4	25.0
	45	25.4	25.2	29.0	26.7	22.9	27.1	23.4	25.2
	60	27.2	27.5	29.3	27.8	27.0	28.9	27.3	27.1

L, left; R, right.

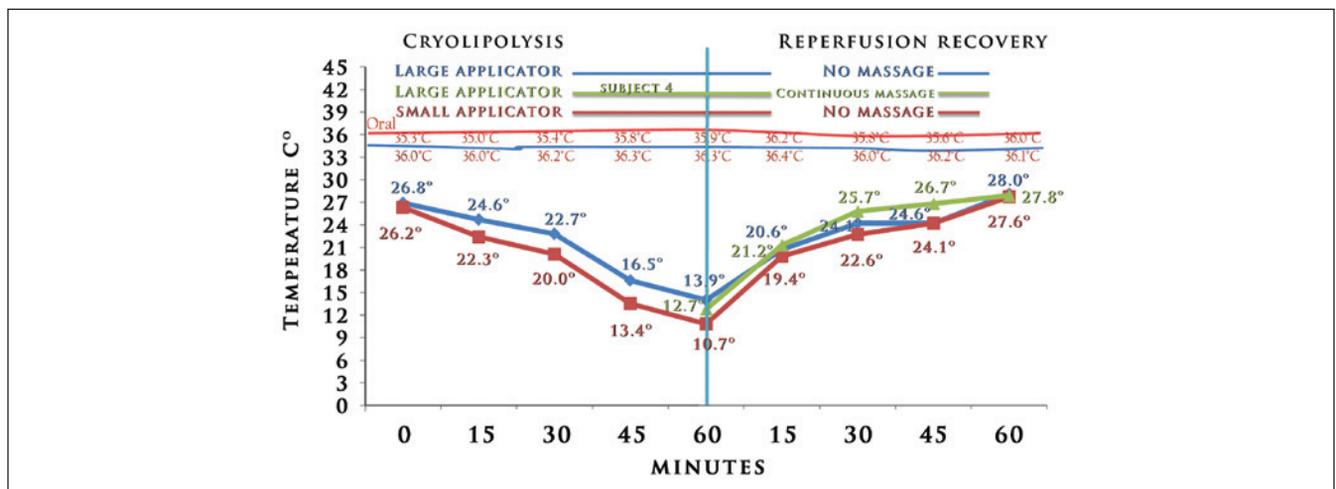


Figure 1. Average oral and skin temperature profiles during cryolipolysis and reperfusion-recovery phases for the abdomens of subjects 1 through 5.

Table 3. Subdermal Temperatures, Pilot Study Group

Subdermal temperature, °C	Time, min	Large Applicator Group 1					Small Applicator Group 2				
		Subject 1	Subject 2	Subject 3	Subject 4	Average	Subject 5		Subject 6		Average
							L	R	L	R	
Cryolipolysis	0	35.0	33.0	35.0	33.0	34.0	34.0	35.0	33.0	34.0	34.0
	15	18.0	17.0	30.0	21.0	21.5	18.0	21.0	21.0	25.0	21.2
	30	10.0	11.0	23.0	12.0	14.0	11.0	12.0	13.0	13.0	12.2
	45	9.0	10.0	18.0	10.0	11.8	9.0	11.0	10.0	11.0	10.2
	60	8.0	12.0	17.0	7.0	11.0	8.0	10.0	10.0	10.0	9.5
Reperfusion recovery	15	16.0	20.1	23.4	19.8	25.0	16.0	16.0	14.0	15.0	15.2
	30	23.0	25.0	27.0	25.0	32.0	22.0	26.0	18.0	23.0	22.2
	45	26.0	33.4	34.0	31.1	34.0	27.0	32.0	21.0	24.0	26.0
	60	34.0	34.0	36.0	34.7	36.0	33.0	35.0	34.0	34.0	34.0

L, left; R, right.

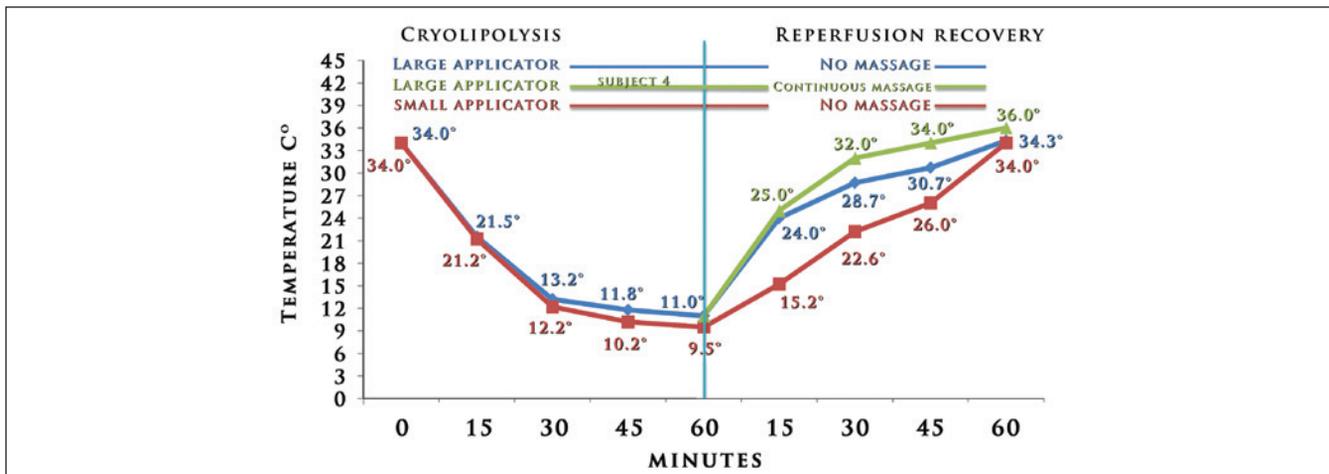


Figure 2. Average subdermal temperature profiles during cryolipolysis and reperfusion-recovery phases for the abdomens of subjects 1 through 5.

of their abdomens, brassiere rolls, lumbar rolls, hip rolls, inner thighs, and medial knees at 6 months posttreatment. The average reduction at follow-up was 21.5% (Table 6). Five patients did not demonstrate significant reductions (anterior thighs, banana rolls, and saddle bags) by caliper measurements. DermaScan C ultrasound measurements, taken 6 months after the baseline assessments in a random subset of 6 patients from the CTG, demonstrated an average fat reduction of 19.6% in the abdomen.

Two independent evaluators evaluated pre- and post-treatment photographs and observed that fewer than 5% of patients demonstrated mild improvements by IGAIS grading as early as 6 weeks after treatment. Six months after

treatment, improvement was deemed significant, especially to the abdomen (IGAIS score = 3) and hip rolls (IGAIS score = 3) (Table 7 and Figures 3-6). In most cases, subject ratings for the abdomen (SGAIS = 2) and hip rolls (SGAIS = 3) mirrored the ratings of the independent evaluators. Patient ratings showed high satisfaction with the procedure's results for the abdomen, brassiere rolls, and hip rolls. Eighteen of 91 patients, who experienced a moderate to significant reduction in fat on their abdomens and hip rolls, chose to undergo repeat treatments about 9 months to a year after the first procedure.

All subjects tolerated the procedure after experiencing the initial tugging sensation caused by tissue being drawn

Table 4. Demographic Data, Clinical Treatment Group

Characteristic	Value
Total No. of patients	112
Average age, y	55.8
Age range, y	15-75
Average BMI	24.7
BMI range	19.5-31.8
Ethnicity, No.	
White	67
Asian	23
Hispanic	22
Sex, No.	
Female	80
Male	32

BMI, body mass index.

Table 5. Distribution of Treatment Sites, Clinical Treatment Group

Site (No. of Patients)	Large Applicator, No.	Small Applicator, No.
Abdomen (68)		
Upper abdomen	0	25
Lower abdomen	37	40
Hip rolls (27)	0	41
Brassiere rolls (5)	0	10
Interior thighs (4)	0	8
Anterior thighs (3)	0	4
Lumbar rolls (2)	0	4
Banana rolls (1)	0	2
Medial knees (1)	0	2
Saddle bags (1)	0	2

into the applicator. Once tissue temperatures were lowered by the initiation of the cooling cycle, all subjects were comfortable throughout the procedure, engaging in reading, sleeping, and other relaxing activities. Erythema, lasting up to a few days, developed on all treatment sites. The majority of patients observed bruising that dissipated within 2 weeks after cryolipolysis. The treated tissue was transiently cold and firm upon removal of the applicator, remained firm during the 5 minutes of posttreatment massage, and gradually returned to normalcy within 60 minutes. For almost all patients, the treated area returned to normal sensation within a week. Three patients reported

Table 6. Caliper Evaluations, Clinical Treatment Group

Site (No. of Patients)	Caliper Measurements, Average Change From Baseline to 6-Month Follow-up, cm	Percent Reduction
Lower abdomen (55)	1.0	27.0
Brassiere rolls (4)	0.5	20.0
Lumbar rolls (2)	0.8	22.0
Hip rolls (20)	1.0	25.0
Inner thighs (3)	0.5	17.0
Medial knees (1)	0.5	18.0
Average (85)	0.7	21.5

Table 7. IGAIS and SGAIS Assessments, Clinical Treatment Group

Site	IGAIS Rating, 6 Months After Baseline	SGAIS Rating, 6 Months After Baseline
Abdomen	3	2
Brassiere rolls	2	1
Lumbar rolls	1	1
Hip rolls	3	3
Inner thighs	1	1
Anterior thighs	1	1
Banana rolls	1	1
Saddle bags	2	2
Medial knees	1	1

IGAIS, Investigator Global Aesthetic Improvement Scale; SGAIS, Subject Global Aesthetic Improvement Scale.

dysesthesia and increased sensitivity of the treated skin for to 2 to 3 weeks. No ulcerations, scarring, or infections were observed in the CTG.

DISCUSSION

Current clinical cryolipolysis procedures are performed with either small or large vacuum-pressure applicators capable of extracting heat from both sides of a fold and reducing blood flow via tissue compression and cold-induced vasoconstriction. Preliminary results from our PSG indicated that the entrapped fold of skin and subcutaneous fat, held between two -7°C cooling plates on each side of a small (80 mm Hg) or large (50 mm Hg) applicator, can be cooled gradually with almost identical slopes of decline after 30 minutes into the procedure to hypothermic levels. The low temperatures within the subcutaneous fat surrounding the thermocouple probe, which was buried at

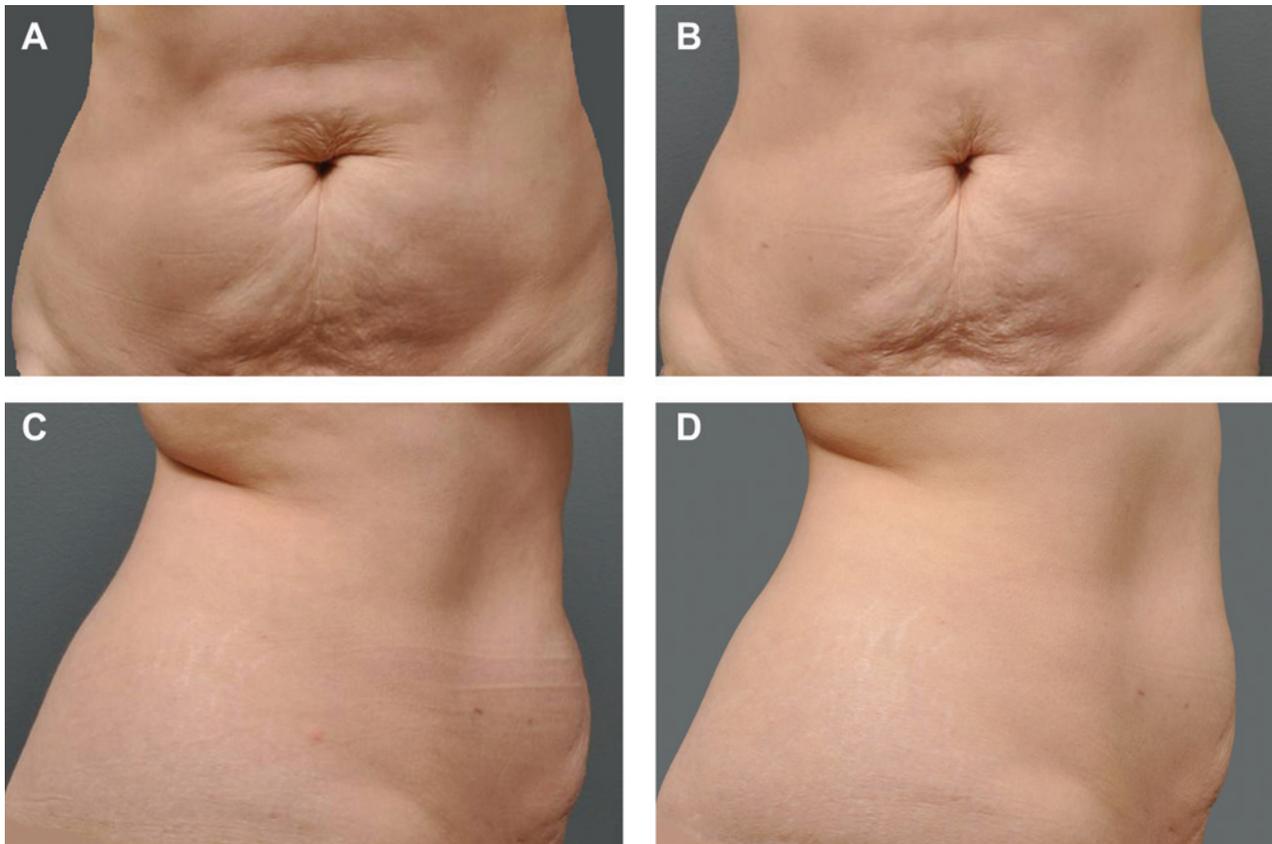


Figure 3. (A, C) This 51-year-old woman (subject 4 from the Pilot Study Group) presented for fat reduction and abdominal contouring. The patient's pretreatment weight was 56.4 kg, her body mass index (BMI) was 22.8, and her body fat was 36.4%. (B, D) Six months after cryolipolysis treatment of her entire lower abdomen with a large applicator in a single session, the patient showed a clinical reduction of fat (weight, 56.7 kg; BMI, 23.0; body fat, 35.7%).

a depth of 1.5 cm, were maintained at 11.0°C to 13.2°C (with the large applicator) and 9.5°C to 12.2°C (with the small applicator) for 30 minutes.

Six participants in the PSG were evaluated to determine the simultaneous temperatures of the skin and subdermal fat during the active cooling and recovery phases. There was no need for controls, as the study's objective was to record temperatures throughout a clinical cycle of treatment. This pilot study, the first clinical study of temperature changes associated with cryolipolysis, will aid clinicians in understanding temperature events during treatment. Three subjects in the PSG presented with body fat percentages in the obese range despite normal BMIs; this conflict is believed to have been caused by the patients' abnormally high levels of subcutaneous and intramuscular body fat relative to their weight, an occurrence frequently observed among individuals who do not engage in vigorous exercise.

Previous studies have demonstrated that fat cells are more susceptible to cold than other types of cells^{34,35} and that controlled cold exposure of adipocytes causes apoptosis and the eventual demise of fat cells without affecting

surrounding structures.^{20,22,25,36,37} A tissue culture study²¹ indicated that porcine adipocytes cooled to -2°C, 0°C, and 2°C were all necrotically injured (LDH cytotoxicity) regardless of recovery time. Most adipocytes cooled to 7°C demonstrated necrotic injury and some apoptotic injury (caspase-3). Adipocytes cooled to temperatures of 14°C, 21°C, and 28°C resulted in no necrotic injury but had the same degree of apoptotic injury after 48 hours as those cooled to 7°C. Relative to controls at 20°C, the first in vivo dosimetric study²⁰ on Black Yucatan pigs demonstrated—by histological grading and assessments performed immediately after cold exposure or between 1 and 28 days postexposure—a direct correlation of adipocyte damage when temperatures of -1°C, -3°C, -5°C, or -7°C were applied for 10 minutes with a flat-plate applicator. In the same study,²⁰ in vivo temperature profiles were monitored by thin thermocouples placed on the skin surface and below the dermal-fat junction during cold exposure of -7°C, which was applied for 10 minutes with a flat plate. Skin temperatures plummeted to -5°C within the first minute of exposure, remained at that level until the plate was removed at 10 minutes, and then rose to about 20°C at 6.7

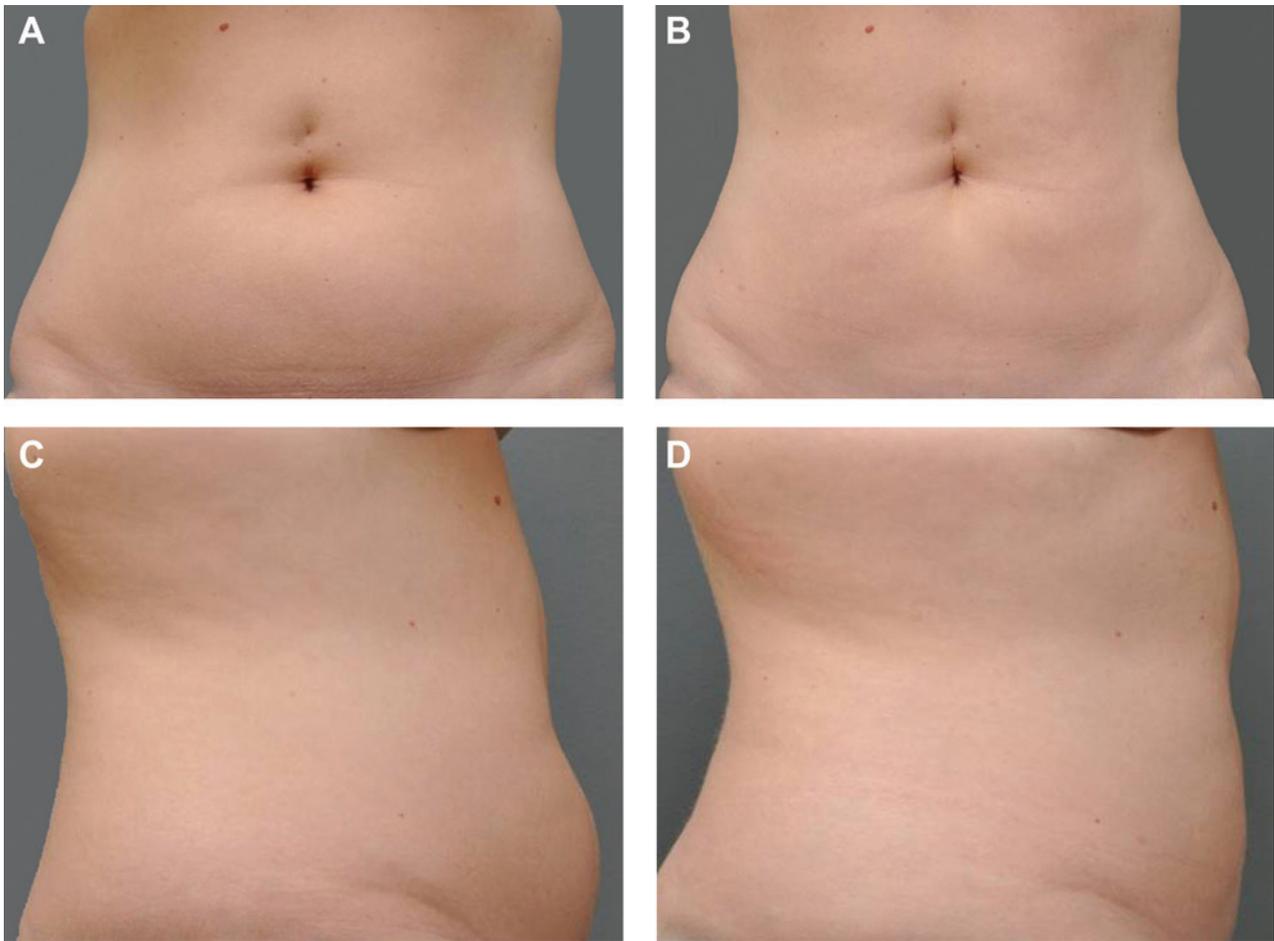


Figure 4. (A, C) This 27-year-old woman presented for fat reduction and abdominal contouring. The patient's pretreatment weight was 70.3 kg, her body mass index (BMI) was 24.3, and her body fat was 37.9%. (B, D) One year after cryolipolysis treatment of her entire lower abdomen with a large applicator in a single session, the patient showed a clinical reduction of fat and skin accommodation (weight, 73.0 kg; BMI, 26.4; body fat, 36.4%) and a weight increase of 2.7 kg (5.9 lb).

minutes into the reperfusion-recovery period. By comparison, subdermal temperatures fell gradually to levels between 12°C at 3.3 minutes and 5°C at 10 minutes into the cooling phase and then ascended to 18°C at 6.7 minutes into the reperfusion-recovery phase.

There is supportive evidence^{20,28,29} that intracellular “lipid ice” is formed at around 10.0°C (compared to water ice at 0°C). The presence of lipid ice may contribute to the immediate death or delayed apoptosis of fat cells. During cold ischemic injury, other known mechanisms that promote cell death are related to perturbations in osmoregulation (cell edema), reduced Na-K-ATPase activity and adenosine triphosphate levels, and intracellular lactic acidosis.³⁸ Additional studies^{39,40} have suggested that free radicals, released from mitochondria during the cooling phase, facilitated further cellular injury, even in the presence of reduced cellular metabolism and enzymatic activity in the cold.

Rewarming cooled adipose tissue after cryolipolysis may promote additional fat cell injury by ischemic reperfusion

during the recovery period. Previous studies⁴¹⁻⁴³ have suggested that the apoptotic form of cell death occurred only after the reperfusion of cooled transplanted organs. The process of reperfusing cooled tissue is believed to generate an increase in reactive oxygen species and cytosolic calcium and to activate several calcium-dependent and calcium-independent proteolytic enzymes, including caspases that caused a significant proportion of sublethally injured cells to undergo apoptosis.⁴⁴⁻⁴⁶

The results from our PSG demonstrated that, without massage, the subdermal temperatures of subjects treated with large applicators returned to higher temperatures at a faster rate than those treated with small applicators. It is unclear why a larger amount of fat treated with large applicators exhibited a faster return to pretreatment temperatures than a lesser quantity of fat treated with small applicators, but it may be that the fat within the larger applicator did not cool to the same temperature as the fat within the small applicator due to the greater distance

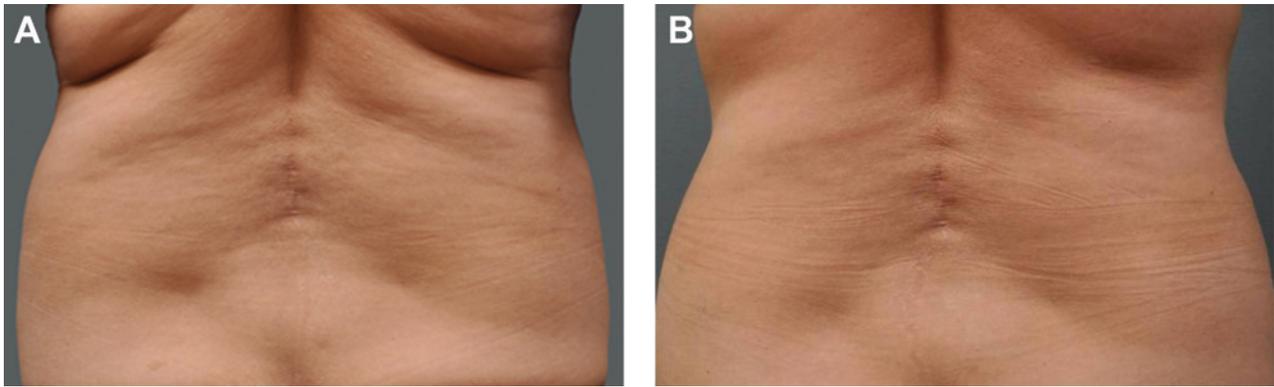


Figure 5. (A) This 55-year-old woman presented for treatment of her brassiere rolls. The patient's pretreatment weight was 62.6 kg, her body mass index (BMI) was 26.1, and her body fat was 41.1%. (B) Six months after a single cryolipolysis treatment with a small applicator to each of her brassiere rolls, the patient's rolls were significantly reduced (weight, 62.6 kg; BMI, 26.1; body fat, 41.6%). The patient demonstrated no change in weight at the 6-month evaluation period.

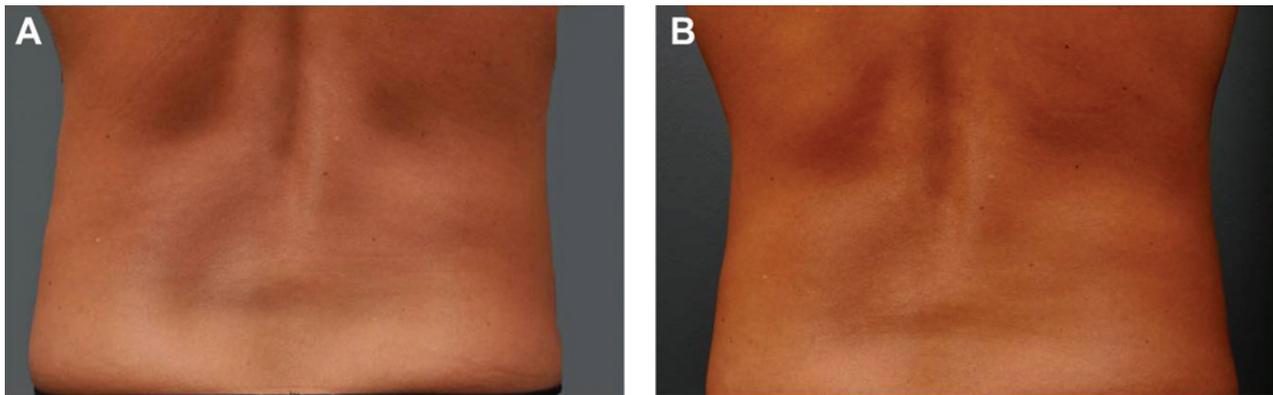


Figure 6. (A) This 35-year-old man presented for contouring of his waist at the lumbar and hip rolls. The patient's pretreatment weight was 75.0 kg, his body mass index (BMI) was 25, and his body fat was 22.9%; his caliper measurements were 2.6 cm on the left and 2.4 cm on the right. (B) One year after a single cryolipolysis treatment with a small applicator to each of his lumbar and hip rolls, the patient showed contouring of the waistline (weight, 72.7 kg; BMI, 24.3; body fat, 22.3%) and a significant reduction in caliper measurements at the waist (left, 1.9 cm; right, 2.0 cm).

between the cooling plates. The 1 subject who received massage 0, 15, 30, and 45 minutes after removal of the large applicator experienced a faster return to pretreatment temperatures than did all other subjects. The contribution of reestablishing pretreatment temperatures and, indirectly, increasing the return of blood flow to the treated site has yet to be defined. Because indirect measurements of blood flow and cold-induced release of reactive oxygen species in hypothermic-induced fat cell injury were not performed in this study, the exact role of blood flow in ischemic reperfusion injury in fatty tissue remains to be determined.³⁰⁻³²

Our CTG demonstrated that the isolated reduction of fat, as reported in previous experimental^{20,22} and clinical studies,²³⁻²⁶ can be safely and effectively performed on almost any area of the body. All patients in that group were treated with identical parameters, including 5 minutes of

manual massage at the completion of the procedure. Successful outcomes were evaluated based on 4 assessment criteria: a matched comparison of photographs from the baseline and 6-month follow-up, caliper measurements of the area of greatest thickness within the treatment zone taken at the baseline and at 6-month follow-up, ultrasound imaging at targeted landmarks (nevus, pigmentation, etc), and IGAIS and SGAIS assessments.

The abdomen and hip rolls were the most common treatment sites. Based on caliper measurements taken at the 6-month follow-ups, these sites averaged about a 27% and 25% reduction, respectively. The IGAIS and SGAIS were most favorable after treatments to the abdomen, hip, and brassiere rolls. Ultrasound imaging of the abdomens of 6 patients demonstrated an average reduction in thickness from the dermis to Camper fascia of about 19.6%, confirming similar findings based on caliper measurements taken

after a single treatment. The author (G.H.S.), aware of the vagaries of ultrasonic measurements as a technique-dependent technology, selected this system from among similar devices based on performance-validations (provided by the manufacturer prior to initiation of the study), standardized computer control, and analysis programs, which minimized human bias and inconsistency during baseline and follow-up measurements. Subjective improvements were observed in less than 5% of participants within 6 weeks of the procedure. The majority of clinical outcomes to the abdomen and hip rolls were realized between 3 and 6 months. Patients who underwent serial treatments gained further reductions from each subsequent cooling session.

All patients tolerated the entire cooling and recovery periods without immediate or delayed effects of any consequence. Cooling of the skin dermis to temperatures of 10.7°C to 16.5°C for the last 15 minutes of treatment did not result in any deleterious effects, such as cold-burns, blisters, or ulcerations. All patients resumed normal activities immediately after treatment or within 1 to 2 days.

CONCLUSIONS

Although the exact mechanisms of cryolipolysis remain unknown, our investigational and clinical results suggest that fat cooling to subnormal temperatures results in adipocyte cell death and apoptosis over time. This selective noninvasive treatment for localized excess fat was associated with a noticeable reduction in subcutaneous fat in most areas of the body in our study and did not cause skin damage. Returning subdermal temperatures to pretreatment levels more rapidly after the procedure by continuous massage may result in additional adipocyte demise by releasing reactive oxygen species and activating other deleterious intracellular events that accompany reperfusion. This clinical investigation may encourage additional studies focusing on greater fat reduction and safer delivery of cryolipolysis.

Disclosures

Dr Sasaki is an unpaid consultant and has no other affiliation or stockholdings with Zeltiq Aesthetics (Pleasanton, California), the manufacturer of the device discussed in this study. He is an unpaid consultant to other industry companies and has no other affiliations or stockholdings with them. Ana Tevez-Ortiz and Natalie Abelev have no conflicts of interest to disclose.

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