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ORIGINAL RESEARCH REPORT

Quantification of adipose volume reduction with a prospective study analyzing the application of external radiofrequency energy and high voltage ultrashort pulse duration electrical fields

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ABSTRACT

To date, there have been no objective measurements of subcutaneous volume loss following treatments with a noninvasive radiofrequency (RF)-based device. Twenty female patients were treated with a suction-coupled bipolar RF device using external RF energy combined with pulsed electromagnetic RF energy for subcutaneous fat reduction. Parameters followed included weight, Vectra measurements of abdominal circumference and torso volume, and high-definition ultrasound measurements of fat thickness. Measurements were taken before treatment and three times following treatment. Analysis of the measured parameters showed that mean circumference reduction of 2.30 cm was noted at three months post-treatment. Independent volumetric analysis showed a mean subcutaneous volume reduction of 428 cc three months following RF treatment. High-resolution ultrasound fat thickness was reduced by a mean of 39.6% three months following the final BodyFX treatment. Independent and paired-sample *t*-tests showed a *p* value of < 0.05. Repeated measures of analysis of covariance (ANCOVA) adjusted for differences in age, as well as height and weight (proxy for body mass index) to minimize individual differences and control for extraneous variables that may affect the pre- and post-treatment results were analyzed. No confounding variables were found. All analyses were conducted using IBM SPSS 21.0.

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Adipocyte; adipocytolysis; apoptosis; body contouring; fat reduction; noninvasive; radiofrequency

Introduction

While many noninvasive devices using varied energy sources claim to cause permanent subcutaneous fat loss, few have peer-reviewed studies substantiating objectively measured volumetric loss combined with serial observation of the adipolytic mechanism. This study was designed to follow multiple non-human-generated measurement parameters during the course of treatment and for three months following cessation of treatment. The limitations of a handheld measuring tape, especially without postural or breathing control, are obvious. There are difficulties in reproducibly measuring subcutaneous fat thickness, even with a high-resolution ultrasound device and a stencil created for each patient and re-used at each time point. A computerized volumetric 3D measurement of subcutaneous fat changes was developed for this study, using serial measurements taken with the Canfield Vectra system prior to study inception, and again at four weeks and eight weeks into the study. These posture and breathing cycle controlled measurements were taken again one month and three months following cessation of bipolar abdominal radiofrequency (RF) treatments. Patient weight was tightly controlled; two patients were discontinued from the study for weight variances of over 5 pounds. One patient failed to show up for her final evaluation.

Materials and methods

Twenty consecutive female patients ranging in age from 19 to 66 were recruited for this noninvasive study after meeting inclusion criteria. These included a previously untreated region of localized periumbilical fat, a BMI ranging from 18 to 31, a nonpregnant and nonlactating status, the ability and willingness to receive eight weekly treatments, and a stable weight, not deviating more than five pounds from their initial unclothed weight. Exclusion criteria included a sore in the treatment region, serious ongoing medical illness or infection, unrealistic expectations, and a chronic disease such as diabetes that might impair the ability to heal. Mean patient age was 41.71. Average height was 166.47 cm, and mean weight pre-treatment was 151.53. At one-month post-treatment, the average weight was 150.2 lb, and at 3 months following treatment it was 152.54 lb. Average BMI before treatment was 24.62. Our cohort's mean BMI was 3.48 points lower than the average American woman's at 28.1. Three months following the final treatment, mean BMI was 24.67. Patients were counseled not to change any current diet or exercise plans in an effort to eliminate these as variables.

The treatment device used was the InMode BodyFX, which combines two forms of bipolar RF energy in order to generate irreversible electroporation-based adipocytolysis. First, the

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patient was marked in an upright position so that serially protuberant regions of the lower abdomen could be demarcated in an area measuring 10 × 15 centimeters. The patient was then placed upon a stable surface in the supine position. No topical anesthetic or conducting gel was used. The handpiece was placed perpendicular to the recipient's skin, and initial settings used are 40 watts of energy, a maximum temperature of 41°C, and a pulse width of 2–5. The suction coupled vacuum was initiated by a footswitch. During this study, the device was programmed to only heat tissue initially, so a 50% overlap was patterned in order to generate subcutaneous heating in the demarcated segment. Once the tissue reached target temperature as measured by the external thermistor, the electromagnetic pulses were initiated. A rotating pattern of treatment pulses was performed within the diagrammed segment. Once the target temperature was initiated and high-voltage pulses were begun, the treatment continued in the demarcated area for a period of ten minutes. In addition to time, the clinical treatment conclusion parameters included palpable warmth and erythema throughout the treated tissue and a change in palpable resistance to a soft pinch. Once the lower abdominal region, including the periumbilical area, was treated, a second treatment region covering the epigastrium was initiated. Since the periumbilical region is traditionally a "trouble spot," 50% overlap over the initial treatment area was utilized. Following treatment, no dressings or topical agents were used. Expected sequelae included palpable warmth and erythema lasting up to an hour, mild bruising, and mild swelling. Complications could have included arc burns, pain or discomfort requiring analgesic medication, peripheral margins of demarcation, and less than hoped for subcutaneous fat reduction. None of these were experienced in the treatment population.

The patient's unclothed weight was taken on a calibrated digital scale immediately prior to each treatment. Other monitored variables included Canfield Vectra 3D photograph generated circumference and volumetric measurements of the epigastrium, mid, and lower abdomen utilizing a breathing cycle and postural control. A Phillips ultrasound device using a 15/2-mm high-resolution linear array was used to measure subcutaneous fat thickness at the 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock position 1 cm from the umbilical verge. These measurements were taken before treatment initiation, immediately following the fourth and eighth/final treatment, and again one month and three months following treatment cessation.

Results

Seventeen out of twenty patients completed the study during a five-month period. One excluded patient gained over five pounds, and one lost over five pounds. One patient failed to appear for her final evaluation.

Instead of measuring only periumbilical circumference, the Canfield Vectra system (Figure 1) measures torso circumference at the umbilical reference point, and each 20 millimeters above and below the umbilical reference point. Table 1 shows the mean change in torso circumference per zone, with "0" being the umbilical reference point, "+ 20" being 20 mm above the umbilicus, and "− 40" being 40 mm below the umbilicus.

Figure 1. The Canfield scientific photographic station.

Table 2 shows mean ultrasound thickness change by location, as measured by a single technician at one centimeter distal to the umbilical verge at 12 o'clock, 3 o'clock, 6 o'clock, and 9 o'clock using a stencil pattern.

Volumetric change (Table 3) was calculated by an uninvolved Canfield technician. Each 20-mm segment of the patient's measured torso (Figure 2)—for example, 0 to –20 mm—was subjected to a computer-based algorithm which calculated volume based on circumference and the measured cross section surface area. Table 3 shows the mean change in volume at each segment.

Figures 5–8 show the progression of cellular change over time under scanning electron microscopy performed at Colorado State University.

Statistical analysis

Frequencies, means, and standard deviations for each characteristic were reported. A paired-sample t-test was computed for pre- and post-treatment effects. BMI group differences in pre-treatment volumetric fat measurement, post-treatment volumetric fat measurement, and total volumetric fat loss were analyzed using independent t-test. A repeated-measures ANCOVA was computed for pre- and post-treatment effects at five different time points adjusting for the following covariates: age and BMI at baseline. Two-tail significance level of 0.05 was used. All analyses were conducted using IBM SPSS 21.0.

Table 1. Overall group mean change of circumference measurement of the abdomen at each plane—before treatment and after treatment at 1 month and at 3 months ($N = 17$ females).

Plane	Before treatment Mean ± SD	After 1 month Mean ± SD	After 3 months Mean ± SD	ΔCHANGE 1 month	ΔCHANGE 3 months
+ 60	85.53 ± 12.21	84.86 ± 11.86	81.18 ± 11.04*	0.67	1.42
+ 50	86.91 ± 12.36	85.90 ± 12.40	82.07 ± 11.60*	1.01	1.89
+ 40	88.53 ± 12.26	87.24 ± 12.64*	83.40 ± 12.02*	1.30	2.32
+ 30	90.25 ± 12.06	88.83 ± 12.71*	85.08 ± 12.26*	1.43	2.61
+ 20	91.95 ± 11.79	90.56 ± 12.65*	86.90 ± 12.37*	1.38	2.73
+ 10	93.53 ± 11.44	92.28 ± 12.50*	88.78 ± 12.36*	1.25	2.71
+ 0	95.24 ± 11.21	94.17 ± 12.45	90.94 ± 12.43*	1.07	2.52
− 10	96.47 ± 10.93	95.56 ± 12.26	92.36 ± 12.30*	0.90	2.39
− 20	97.55 ± 10.93	96.73 ± 12.28	93.51 ± 12.30*	0.82	2.27
− 30	98.69 ± 11.01	97.91 ± 12.29	94.66 ± 12.31*	0.77	2.16
− 40	99.69 ± 11.07	98.99 ± 12.31	95.66 ± 12.33	0.70	2.08
− 50	101.02 ± 12.14	100.43 ± 13.51	97.24 ± 14.15	0.60	1.34
− 60	99.46 ± 12.62	98.75 ± 14.35	97.43 ± 15.20	0.71	1.81
− 70	97.92 ± 10.26	97.16 ± 12.13	94.07 ± 11.52	0.76	2.23
Sum of change				14.76 cm at 14 sites	32.30 cm at 14 sites

The average means of $N = 17$ patients who underwent noninvasive fat reduction procedure is shown. The numbers were derived from Canfield Vectra M4–360 Body Imaging System, which measures circumference (mm) of abdomen at different planes. The change scores are derived from three time points: before treatment, after treatment at 1 month, and after treatment at 3 months. The overall group mean indicates that on average, there was a total of 14.76-mm circumference reduction at 1 month and 32.30-mm circumference reduction at 3 months following the final BodyFX treatment. Mean change per measurement site was 1.05 cm at 1 month and 2.36 cm per site at 3 months post-treatment.
*$p < 0.05$.

Complications

Expected sequelae included temporary erythema or discomfort, bruising, or minor swelling. Three patients noted the sensation of uncomfortable heat in the treatment region, which was immediately improved with the application of cool compresses.

An unexpected sequela—a temporary problem which would resolve without further treatment—was experienced by one patient. She had mild petechiae in the treatment region lasting 48 hours after one treatment session.

Complications—unexpected side effects that might require further intervention—were not noted. Risks of treatment reviewed with each patient prior to treatment included little to no improvement in fat thickness, asymmetry or unevenness, prolonged bruising or swelling, prolonged erythema, a burn, skin discoloration, less than hoped for fat loss, or a pattern ledge. Three patients noted they would like to have lost more fat volume. No patients had any other complications.

Histology was performed by evaluating serial biopsies from four volunteers over time using scanning electron microscopy at Colorado State University, due to the known variables in performing traditional histologic evaluation of adipose tissue unattached to any stabilizing structures. Fractional adipose tissue death over time was described as poroptosis, generated by progressive poration and lipid droplet egress over time.

Table 2. Overall study participants' fat reduction treatment results: Vectra 3D ultrasound abdomen thickness measurement (cm).

Bivariate analysis	Before treatment Mean ± SD	After 1 month Mean ± SD	After 3 months Mean ± SD
US at 12 o'clock	2.72 ± .892	1.84 ± .667**	1.73 ± .714**
US at 3 o'clock	2.90 ± .563	1.64 ± .533**	1.56 ± .658**
US at 6 o'clock	2.68 ± .853	1.83 ± .661**	1.84 ± .779**
US at 9 o'clock	2.81 ± .727	1.55 ± .503**	1.58 ± .702**
Repeated-measures ANCOVA	**Before treatment Mean ± SE**	**After 1 month Mean ± SD**	**After 3 months Mean ± SD**
US at 12 o'clock	2.63 ± .283	1.74 ± .202**	1.68 ± .218**
US at 3 o'clock	2.83 ± .160	1.57 ± .164**	1.55 ± .188**
US at 6 o'clock	2.60 ± .249	1.71 ± .184**	1.76 ± .204**
US at 9 o'clock	2.82 ± .237	1.49 ± .150**	1.57 ± .179**

The repeated-measures ANCOVA has been adjusted for the following variables: age (years) and height (cm). Overall group means of abdominal subcutaneous thickness as measured from the basal dermis to Scarpa's fascia at the same locations, measured at 1 cm from the umbilical verge at 12 o'clock, 3 o'clock, 6 o'clock, and 9 o'clock, after adjusting for age (in years) and height (in cm) are shown.
*$p < .05$; **$p < .001$.

Discussion

Many noninvasive devices claim subcutaneous fat reduction (1–8), but few studies show totally objective measurements of outcome. Accurate quantification of volumetric fat reduction is difficult (9,10). Auh and Alum (11) note that while magnetic resonance imaging (MRI) is the current "gold standard," it is costly and may not be readily available. Two dimensional photographs are commonly used as "proof" of outcome, but patient position, lighting, change in patient weight, clothing, and a difference in camera operator personnel are noted confounding variables. Image editing is fairly easy to do and may be difficult to detect.

The authors note that handheld circumference measurements are the most common basis of claims for fat reduction (12–15). Variables in taking waist circumference measurements include more than one person taking the measurements, the use of a tension-controlled versus handheld measuring tape, the location at which the measuring tape is placed, the subjective tightness or looseness of the tape due to chosen outcome bias, lack of postural controls, and lack of breathing cycle controls.

Table 3. Overall group mean change of sectional volume measurement of the abdomen at each plane—before treatment, after treatment at 1 month and at 3 months ($N = 17$ females).

Plane	Before treatment Mean ± SD	After 1 month Mean ± SD	After 3 months Mean ± SD	ΔCHANGE 1 month	ΔCHANGE 3 months
+ 60	563.11 ± 161.51	551.83 ± 159.85	501.91 ± 144.51*	11.29	20.21
+ 50	582.24 ± 165.26	567.47 ± 166.26	515.27 ± 151.47*	14.77	24.96
+ 40	603.55 ± 166.63	586.77 ± 170.48	533.35 ± 157.22*	16.78	29.37
+ 30	625.74 ± 167.00	608.45 ± 173.68*	554.57 ± 162.09*	17.29	32.65
+ 20	646.98 ± 165.09	629.95 ± 175.47*	576.84 ± 165.78*	17.03	35.14
+ 10	665.90 ± 162.95	649.73 ± 175.24*	598.35 ± 168.41*	16.17	36.45
+ 0	684.28 ± 161.13	669.86 ± 176.28	619.70 ± 171.11*	14.42	36.01
− 10	705.69 ± 162.52	693.06 ± 179.71	642.68 ± 174.41*	12.63	34.99
− 20	726.46 ± 165.19	714.89 ± 183.12	663.56 ± 177.50*	11.57	34.05
− 30	744.74 ± 168.27	733.99 ± 186.84	680.95 ± 180.13*	10.75	33.10
− 40	767.52 ± 187.38	757.12 ± 208.38	705.36 ± 206.90	10.41	20.01
− 50	744.94 ± 198.47	733.58 ± 225.93	710.90 ± 225.38	11.36	26.21
− 60	720.53 ± 162.29	707.74 ± 192.07	655.52 ± 155.35	12.79	33.88
− 70	727.03 ± 126.12	701.93 ± 147.65	687.93 ± 160.39	25.10	31.43
Sum of change				202.36 cc	428.46 cc

The average means of $N = 17$ patients who underwent noninvasive fat reduction procedure are shown. The numbers were derived from Canfield Vectra M4–360 Body Imaging System, which measures sectional volume (cc) of abdomen at different planes. The change scores are derived from three time points: before treatment, after treatment at 1 month, and after treatment at 3 months. The overall group mean indicates that on average, there was a total of 202.36-cc volume reduction at 1 month, and 428.46-cc volume reduction from abdomen at 3 months following the final BodyFX treatment.
$^{*}p < 0.05$.

The Likert patient satisfaction scale is another commonly used method of rating procedure outcomes (16–18). This scale assumes a linear progression of "strongly agree" to "strongly disagree." Some studies quote a percentage of patient satisfaction; these are frequently quite subjective and are often assessed directly by involved study members (19).

Skinfold caliper measurements are also noted as an index of fat reduction or gain (20–22). Variables of this method include a lack of consistent positioning of the measured location, a change in the amount of skin and fat grasped, and variation in the pressure of the pinch, as well as inconsistent device types. Different people performing the measurement will certainly use different techniques.

Ultrasound fat thickness has become more common as a measurement of localized fat reduction (23–27), especially when a noninvasive device is used. However, AA notes that outcome is highly dependent on operator expertise. Variables in measuring fat thickness include the level of tissue hydration (28), the pressure with which the operator places the transducer, the variations in actual location of the transducer from

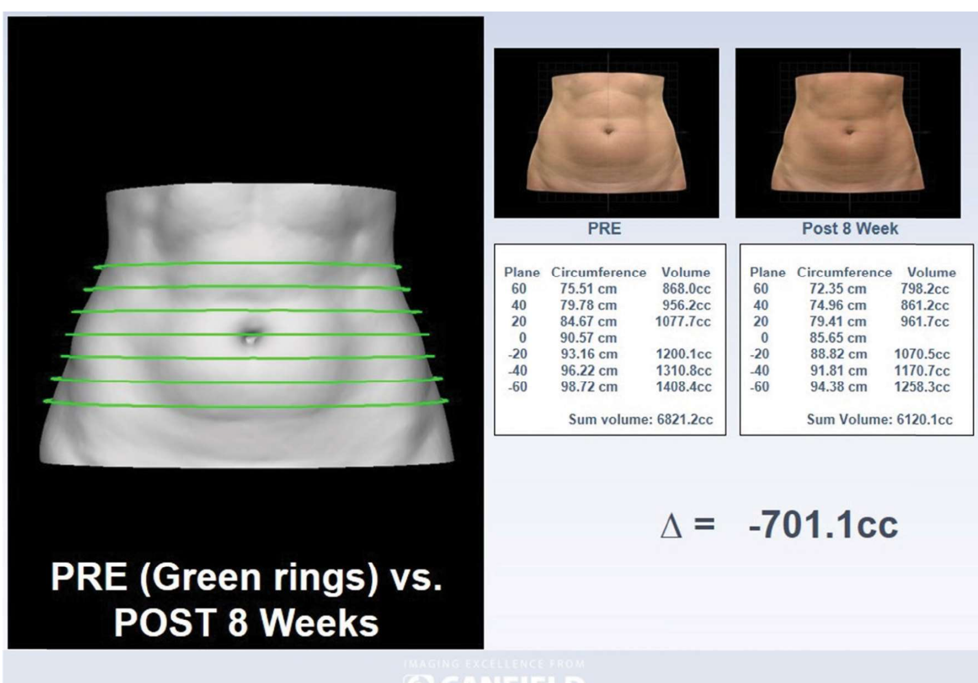

Figure 2. Vectra 3D measurements taken at intervals were evaluated by a computer technician using an algorithm based on serial circumference measurements taken 20 mm apart, as measured above and below the center of the umbilicus. The cylindrical segmental volumes were used to calculate the volume of the total as measured from + 60 to −60 mm. This patient had an abdominal adipose volume reduction of 701 cc.

Figure 3. A 23-year-old woman 3 months following eight BodyFX treatments combining suction coupled external radiofrequency heating with a train of electrical impulses to induce adipocyte poration. Her BMI was 21.2.

Figure 4. A 52-year-old overweight woman 3 months following eight BodyFX treatments. Her weight before treatment was 152 lb; weight after treatment was 153 lb. BMI was 28.5. Estimated volumetric loss was 701 cc.

one time interval to the next, and the posture and position of the patient.

MRI and computerized axial tomography scans are heavily utilized by other specialties in the accurate assessment of fat volume (29–37). However, with aesthetic procedures, medical insurance will not cover the cost of these studies, so the rare aesthetic study utilizing this measurement modality is likely to be funded by a grant (38).

An emerging objective measurement method is 3D imaging (39). In the past, multiple studies have used this method to measure skin surface area contraction (40–42), but few have used the device to measure soft tissue volumetric change (42,43). Variables with this modality include breathing cycle and posture. Patient clothing, and weight gain or loss during treatment intervals can also affect the measurements.

Advantages to the use of 3D photographic analysis include the ability to eliminate the clothing and patient weight variable by incorporating guidelines for this into the study. Both

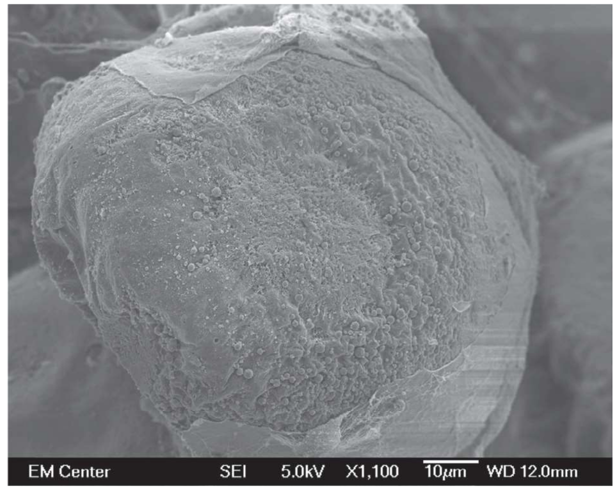

Figure 6. Adipocyte treated with BodyFX immediately following eighth and final treatment: hundreds of lipid droplets egress through pores created by irreversible electroporation.

postural and breathing cycle controls can be tightly controlled. While variability with all measurement modalities is unavoidable, objective measurements best reflect the true outcome of a certain treatment type, especially when the data is analyzed off-site by a disinterested third party (44).

This study utilized both high-resolution ultrasound and Canfield Vectra 3D photography with serial circumference measurements and algorithmically derived volumetric change measurements by an off-site third party in an effort to show real and reproducible outcomes.

Conclusions

Application of temperature-controlled RF bulk heating plus trains of high-voltage, ultrashort pulse duration RF with the BodyFX once weekly for 8 weeks resulted in the following changes to the adipose tissue:

1. As measured by ultrasound, mean subcutaneous fat thickness before treatment was 2.78 cm. The mean

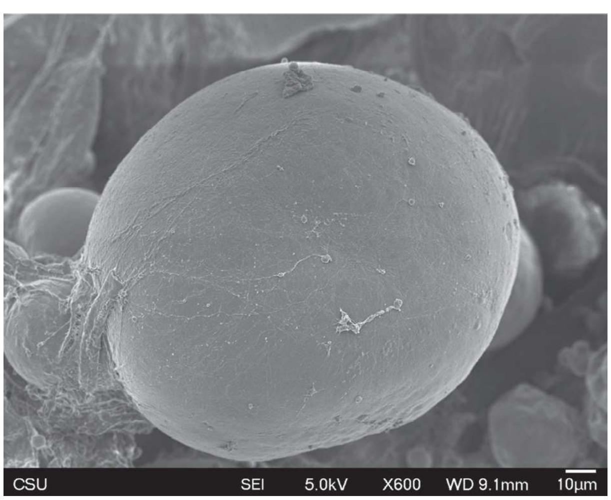

Figure 5. Control adipocyte prior to treatment with BodyFX noninvasive radiofrequency body contouring device.

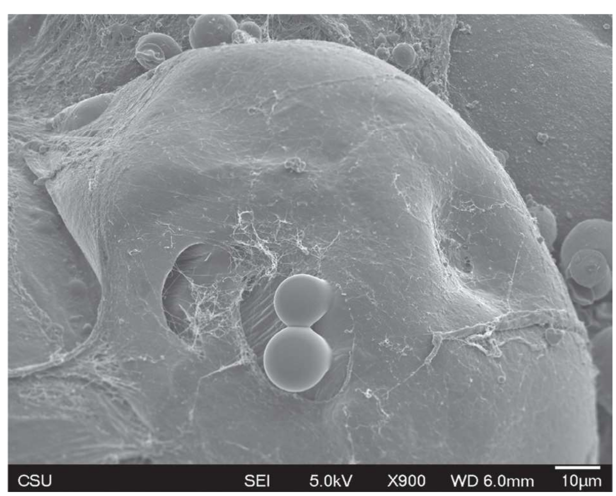

Figure 7. Adipocyte showing giant lipid droplet egress through a large membrane pore 1 month following final radiofrequency treatment with BodyFX. Poration response varies from cell to cell; the process is fractional.

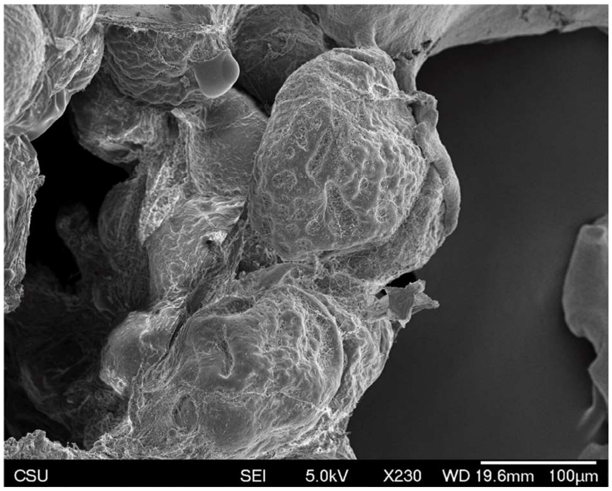

Figure 8. Adipocyte "strawberry" response pattern 3 months following final treatment. This pattern is marked by large pores in the adipocyte which the adipocyte has tried to repair. Some cells survive, and some have completely lost their lipid content.

subcutaneous thickness reduction was 1.10 cm at three months following the final BodyFX treatment. The mean reduction in adipose thickness was 39.6% three months following the final treatment.

2. Vectra 3D measurements showed a mean abdominal circumferential reduction of 2.30 cm three months following the final treatment.
3. Vectra 3D measurements documented a 428.46-cc mean volume loss of fat at the 3-month timepoint.
4. RF-induced fat loss caused by electroporation-induced cell death generated a fractional tissue response with what appears to be a combination of fat loss and soft tissue tightening. However, obese patients and those with severe skin laxity are best treated with more traditional methods.
5. 2D photographs taken before treatment and 3 months post-treatment showed excellent results in thinner patients (Figure 3), and significant improvement in overweight patients (Figure 4).

Disclosures

The device used for the study was loaned to Plastic Surgical Associates by the InMode Corporation for a period of one year for the duration of the study.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the report.

References

1. Ingargiola M, Motakef S, Chung MT, Vasconez HC, Sasaki GH. Cryolipolysis for Fat Reduction and Body Contouring: Safety and Efficacy of Current Treatment Paradigm. Plast Reconstr Surg. 2015;135:1581–1590.
2. Chang SL, Huang YL, Lee MC, Chang CH, Chung WH, Wu EH, Hu S. Combination therapy of focused ultrasound and radio-frequency for noninvasive body contouring in Asians with MRI photographic documentation. Lasers Med Sci. 2014;29(1):165–172.
3. Jewell ML, Baxter RA, Cox SE, Donofrio LM, Dover JS, Glogau RG, et al. Randomized sham-controlled trial to evaluate the safety and effectiveness of a high-intensity focused ultrasounddevice for noninvasive body sculpting. Plast Reconstr Surg. 2011;128:253–262.
4. Fatemi A. High-intensity focused ultrasound effectively reduces adipose tissue. Semin Cutan Med Surg. 2009;28(4):257–262.
5. Barta RJ, Hillard C, Bernstein D, Betker MR, Heinrich CA. Radio Frequency Therapy (Vanquish) Noninvasive Body Sculpting for Reduction of Abdominal Fat. Plast Reconstr Surg. 2015; 136(4 Suppl):130. doi: 10.1097/01.prs.0000472444.62861.68.
6. Weiss RA. Noninvasive radio frequency for skin tightening and body contouring Semin Cutan Med Surg. 2013;32(1):9–17.
7. Avci P, Nyame TT, Gupta GK, Sadasivam M, Hamblin MR. Low-level laser therapy for fat layer reduction: a comprehensive review. Lasers Surg Med. 2013;45(6):349–357.
8. Elm CM, Wallander ID, Endrizzi B, Zelickson BD. Efficacy of a multiple diode laser system for body contouring. Lasers Surg Med. 2011;43(2):114–21.
9. Zachary CB, Saedi N, Allison J. The geometric model and fat reduction. J Drugs Dermatol. 2013;12(1):27–34.
10. Cohen SR, Weiss ET, Brightman LA, Geronemus RG, Locke KW, Maytom MC, Dobak JD. Quantitation of the results of abdominal liposuction. Aesthet Surg J. 2012;32(5):593–600.
11. Auh S, Alam M. Quantification of non-invasive fat reduction: a systematic review. http://www.aslms.org/annualconference/documents/abstract9.pdf accessed 10-25-15.
12. Saedi N, Kaminer M. New waves for fat reduction: high-intensity focused ultrasound Semin Cutan Med Surg. 2013;32(1):26–30.
13. Kennedy J, Verne S, Griffith R, Falto-Aizpurua L, Nouri K. Non-invasive subcutaneous fat reduction: a review. J Eur Acad Dermatol Venereol. 2015;29(9):1679–1688.
14. Ferraro GA, De Francesco F, Cataldo C, Rossano F, Nicoletti G, D'Andrea F. Synergistic effects of cryolipolysis and shock waves for noninvasive body contouring. Aesthetic Plast Surg. 2012;36(3): 666–679.
15. Robinson DM, Kaminer MS, Baumann L, Burns AJ, Brauer JA, Jewell M, et al. High-intensity focused ultrasound for the reduction of subcutaneous adipose tissue using multiple treatment techniques. Lasers Surg Med. 2012;44(2):125–130.
16. Shek SY, Chan NP, Chan HH. Non-invasive cryolipolysis for body contouring in Chinese–a first commercial experience. Lasers Surg Med. 2012;44(2):125–130. Erratum in: Lasers Surg Med. 2012; 44(5):435.
17. Bernstein EF, Bloom JD, Basilavecchio LD, Plugis JM. Non-invasive fat reduction of the flanks using a new cryolipolysis applicator and overlapping, two-cycle treatments. Lasers Surg Med. 2014;46(10): 731–735.
18. Krueger N, Mai SV, Luebberding S, Sadick NS. Cryolipolysis for non-invasive body contouring: clinical efficacy and patient satisfaction. Clin Cosmet Investig Dermatol. 2014;7:201–205.
19. Tonucci LB, Mourão DM, Ribeiro AQ, Bressan J. Noninvasive body contouring: biological and aesthetic effects of low-frequency, low-intensity ultrasound device. Aesthetic Plast Surg. 2014;38(5): 959–967.
20. Lach E. Reduction of subcutaneous fat and improvement in cellulite appearance by dual-wavelength, low-level laser energy combined with vacuum and massage. J Cosmet Laser Ther. 2008;10(4):202–209.
21. Mahmoud ELdesoky MT, Mohamed Abutaleb EE, Mohamed Mousa GS. Ultrasound cavitation versus cryolipolysis for non-invasive body contouring. Australas J Dermatol. 2015 Aug 24. doi: 10.1111/ajd.12386. [Epub ahead of print]
22. Dierickx CC, Mazer JM, Sand M, Koenig S, Arigon V. Safety, tolerance, and patient satisfaction with noninvasive cryolipolysis. Dermatol Surg. 2013;39(8):1209–1216.
23. Boisnic S, Divaris M, Nelson AA, Gharavi NM, Lask GP. A clinical and biological evaluation of a novel, noninvasive radiofrequency device for the long-term reduction of adipose tissue. Lasers Surg Med. 2014;46(2):94–103.
24. Nassar AH, Dorizas AS, Shafai A, Sadick NS. A randomized, controlled clinical study to investigate the safety and efficacy of acoustic wave therapy in body contouring. Dermatol Surg. 2015;41(3):366–370.

25. Ingargiola MJ, Motakef S, Chung MT, Vasconez HC, Sasaki GH. Cryolipolysis for fat reduction and body contouring: safety and efficacy of current treatment paradigms. Plast Reconstr Surg. 2015;135(6):1581–1590.
26. Boey GE1, Wasilenchuk JL. Fat reduction in the inner thigh using a prototype cryolipolysis applicator. Dermatol Surg. 2014;40(9):1004–1009.
27. Adatto MA, Adatto-Neilson RM, Morren G. Reduction in adipose tissue volume using a new high-power radiofrequency technology combined with infrared light and mechanical manipulation for body contouring. Lasers Med Sci. 2014;29(5):1627–1631.
28. Sarvazyan A, Tatarinov A, Sarvazyan N.Ultrasonics. Ultrasonic assessment of tissue hydration status. 2005;43(8):661–671.
29. Galanakis CG, Daskalakis M, Manios A, Xyda A, Karantanas AH, Melissas J. Computed tomography-based assessment of abdominal adiposity changes and their impact on metabolic alterations following bariatric surgery. World J Surg. 2015;39(2):417–423.
30. Makrogiannis S, Caturegli G, Davatzikos C, Ferrucci L.Acad Radiol. Computer-aided assessment of regional abdominal fat with food residue removal in CT. 2013;20(11):1413–1421.
31. Onuma T, Kamishima T, Sasaki T, Sakata M. Absolute reliability of adipose tissue volume measurement by computed tomography: application of low-dose scan and minimal detectable change–a phantom study. Radiol Phys Technol. 2015;8(2):312–319.
32. Rossi A, Zoico E, Goodpaster BH, Sepe A, Di Francesco V, Fantin F, et al. Quantification of intermuscular adipose tissue in the erector spinae muscle by MRI: agreement with histological evaluation. Obesity (Silver Spring). 2010;18(12):2379–2384.
33. Ding X, Terzopoulos D, Diaz-Zamudio M, Berman DS, Slomka PJ, Dey D. Automated pericardium delineation and epicardial fat volume quantification from noncontrast CT. Med Phys. 2015;42(9):5015–5026.
34. Tong Y, Udupa JK, Torigian DA. Optimization of abdominal fat quantification on CT imaging through use of standardized anatomic space: a novel approach. Med Phys. 2014;41(6):063501.
35. Holstila M, Virtanen KA, Grönroos TJ, Laine J, Lepomäki V, Saunavaara J, et al. Measurement of brown adipose tissue mass using a novel dual-echo magnetic resonance imaging approach: a validation study. Metabolism. 2013;62(8):1189–1198.
36. Jewell ML, Baxter RA, Cox SE, Donofrio LM, Dover JS, Glogau RG, et al. Randomized sham-controlled trial to evaluate the safety and effectiveness of a high-intensity focused ultrasounddevice for noninvasive body sculpting.Plast Reconstr Surg. 2011;128(1):253–262.
37. Hu HH, Chen J, Shen W. Segmentation and quantification of adipose tissue by magnetic resonance imaging. MAGMA. 2015 Sep 4. [Epub ahead of print]
38. Reeds DN, Mohammed BS, Klein S, Boswell CB, Young VL. Metabolic and structural effects of phosphatidylcholine and deoxycholate injections on subcutaneous fat: a randomized, controlled trial. Aesthet Surg J. 2013;33(3):400–408.
39. Kulick MI. Evaluation of a noninvasive, dual-wavelength laser-suction and massage device for the regional treatment of cellulite. Plast Reconstr Surg. 2010;125(6):1788–1796.
40. Sasaki GH. Quantification of human abdominal tissue tightening and contraction after component treatments with 1064-nm/1320-nm laser-assisted lipolysis: clinical implications. Aesthet Surg J. 2010;30(2):239–245.
41. DiBernardo BE. Randomized, blinded split abdomen study evaluating skin shrinkage and skin tightening in laser-assisted liposuction versus liposuction control. Aesthet Surg J. 2010;30(4):593–602.
42. Duncan DI. Improving outcomes in upper arm liposuction: adding radiofrequency-assisted liposuction to induce skin contraction. Aesthet Surg J. 2012;32(1):84–95.
43. Nelson L, Stewart KJ. Psychological morbidity and facial volume in HIV lipodystrophy: quantification of treatment outcome. J Plast Reconstr Aesthet Surg. 2012;65(4):439–447.
44. Garibyan L, Sipprell WH 3rd, Jalian HR, Sakamoto FH, Avram M, Anderson RR. Three-dimensional volumetric quantification of fat loss following cryolipolysis. Lasers Surg Med. 2014;46(2):75–80.