RF/Microwave-Aided Tumescent Liposuction

Arye Rosen, *Fellow, IEEE*, Danielle Rosen, Gary A. Tuma, and Louis P. Bucky

***Abstract*—Liposuction is the most popular method of body contouring, and constitutes a major part of reconstructive and cosmetic-surgery procedures performed today. New methods have been developed to reduce the risk of discomfort and recovery time for patients, while increasing ease and efficiency for surgeons. These advances are in response to the increased demand for the procedure. The application of RF/microwave-aided liposuction (MAL) may reduce some problems associated with standard mechanical liposuction, specifically removing fibrous tissues or secondarily scarred tissues and thus reducing perioperative bleeding. Preliminary results of *ex-vivo* studies using surgically excised human fat tissue utilizing an RF/MAL system have shown encouraging results.**

***Index Terms*—Cannula, fatty tumors, gynecomastia, lidocaine, neurovascular, suction lipectomy, tumescent liposuction.**

I. Introduction

LIPOSUCTION, a technique for removing blocks of fatty tissue, is considered by many to be cosmetic surgery. However, in the last few years, the liposuction technique has been incorporated into many facets of reconstructive surgery. Several noncosmetic uses for liposuction include: 1) undermining large flaps for reconstruction while preserving neurovascular attachments; 2) removal of lipomas; 3) treatment of gynecomastia; 4) contouring tissues after breast reconstruction; and 5) liposuction for improvement of axillary hyperhidrosis [1]–[6]. The technique of RF/microwave-aided liposuction (MAL) [7], the topic of this paper, reduced some of the current problems associated with mechanical liposuction. RF/MAL has the potential to be a low-cost safe procedure performed on an outpatient basis.

Suction lipectomy, or liposuction, is the term used by plastic surgeons to describe the surgical disruption and removal of subcutaneous adipose tissue by means of a vacuum assisted cannula. A cannula is a narrow cylindrical tube with a blunted end and a suction port that is attached to a vacuum device that is hand held. It is selected by its maximum diameter, ability to dissect through tissue, and the ease of fat removal, thus avoiding large surgical incisions. In addition to the negative pressure suction, the movement of the cannula facilitates fat removal by curettage of the fat aided by the manual squeezing of the fat into the cannula. The movement of the cannula removes fat through the opening and can potentially cause trauma and hemorrhage to surrounding tissues.

Several adaptations to the basic concept of liposuction have been advocated to improve results, minimize complications, and enhance the removal of adipose tissue. These adaptations include injections of low-dose epinephrine and local anesthetic to minimize bleeding and discomfort. Additionally, more efficient and less traumatic suction cannulas were developed.

The "tumescent technique" of liposuction was introduced in 1986 [2], [8]–[10]. The use of a multihole infiltration needle has allowed the anesthetic solution to be rapidly injected through the same incision used for liposuction. This has permitted the surgeon to efficiently anesthetize large subcutaneous areas while diminishing the need and risks of general anesthesia. Injection of a large volume of dilute lidocaine produces a swelling and firmness to the site that greatly facilitates fat removal. Over time, much larger volumes of lidocaine were administered, resulting in the capability of aspirating significantly greater volumes of tissue. All this was achieved with serum lidocaine levels that tests revealed were well below the toxicity range. More efficient and less traumatic cannulas were engineered, which resulted in decreased blood loss, bruising, and discomfort for the patient. We had anticipated [11] that using microwave volume heating would further enhance and benefit the tumescent technique because the absorption of microwave energy by the adipose tissue would result in fat liquefaction, thus easing its extraction. This should also assist in the removal of more fibrous tissue from certain anatomic areas such as the back, flanks, and breasts.

II. Microwave System

RF/microwave liposuction research involves two distinct areas: 1) the development of the apparatus, including a new cannula system, which allows for the insertion of the microwave heating element (a coaxial cable terminated by an antenna) and 2) the investigation of the MAL technique, including variations in power delivery, temperatures reached, and length of time for RF/microwave energy delivery.

The MAL system employed an approach used previously in our microwave balloon angioplasty. It is similar to the system now in use in human trials for treatment of benign prostatic hyperplasia (BPH). Thus, the MAL system used similar components.

III. Coaxial Cable/Antenna at 2.45 GHz

The coaxial cable/antenna at 2.45 GHz (bio-compatible/sterile) is shown in Table I.

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TABLE I
COAXIAL CABLE/ANTENNA AT 2.45 GHz

Semi-rigid Coaxial Cable diameter:	Ohm	Rated power at 2.45 GHz	Attenuation at 2.5 GHz	Dielectric constant between inner and outer conductor	Antenna Configuration
0.037"	50	50 W	1.0 dB/ft	Below 1.2	Whip type: helical

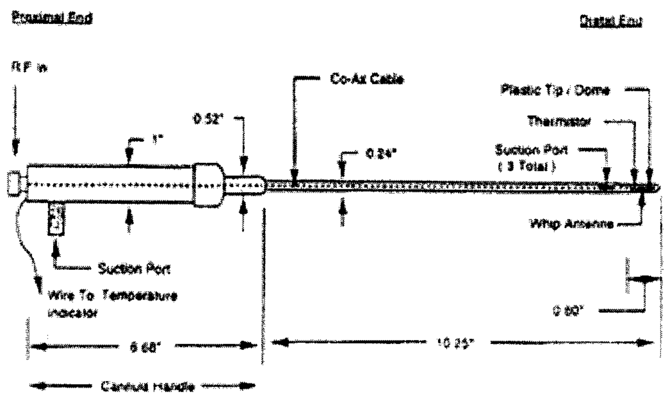
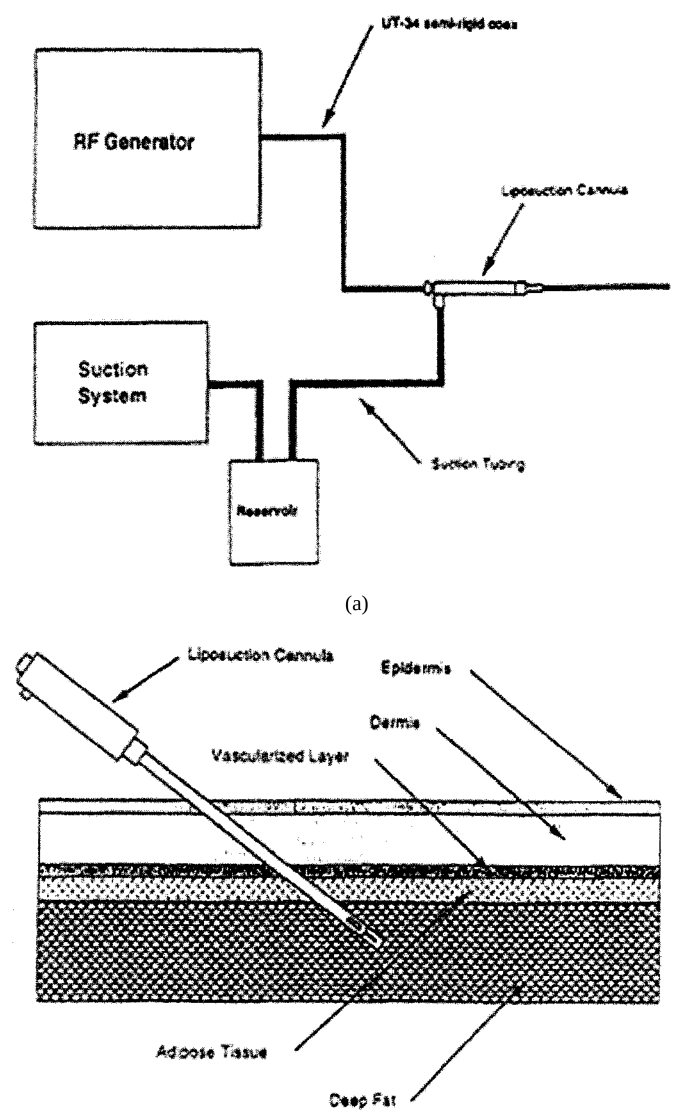


Fig. 1. MAL cannula.



(b)

Fig. 2. (a) System configuration. (b) Artist drawing of the cannula's insertion.

IV. CANNULA DESIGN

The cannulas used were of a design widely established in plastic and reconstructive surgery, such as the Byron Accelerator III type cannula, which had been modified to hold a microwave semirigid coaxial cable having a whip antenna at the distal end (Fig. 1). The tip of each cannula, distal to the suction port, was modified by replacement of its metal tip with a thin-walled plastic dome 2.3 mm in in order to facilitate microwave radiation. By converting the suction port in the cannula handle, it accepted the semirigid coaxial cable/antenna structure. This created a new suction port installed in the cannula handle.

For the preliminary experiments performed on a 500-lb swine, a 6-mm Byron Accelerator III cannula was used. An UT-34 semirigid coaxial cable was adapted to provide the whip antenna at its distal end, and an SMA-50-1-1C connector was attached to the proximal end of the coaxial cable. Stripping a 15.9-mm section of the coaxial cable's outer conductor at its distal end created the whip antenna. This microwave transmission line, complete with connector and antenna, was then inserted into the cannula. The antenna was then secured to the tip of the plastic dome, the distal end of the cannula. In addition, a thermistor was secured near the midpoint of the antenna to provide temperature measurement in the vicinity of the antenna during liposuction procedures.

A whip antenna delivered the microwave energy used to heat the treated volume of fat [see Fig. 2(a) and (b)]. The antenna design controls the size and location of the radiated field, thus controlling the volume of affected tissue. From our previous analysis with the microwave angioplasty system, temperature distribution along the whip antenna has a Gaussian shape with peaks adjacent to the junction in the whip antenna, and a fall of temperature in either direction axially from the junction. Very little temperature rise occurred near the tip of the antenna [11].

To evaluate the design of our microwave-assisted liposuction cannula/antenna and to study the temperature profile, a chamber was developed, similar to that used in our previous study of RF/microwave ablation [12]. A saline solution was introduced to mimic conditions existing during *in-vivo* tumescent liposuction.

For the modified liposuction cannula and antenna that we constructed and tested in a saline solution phantom, we measured a return loss of 23 dB at 2.45 GHz, as shown in Fig. 3.

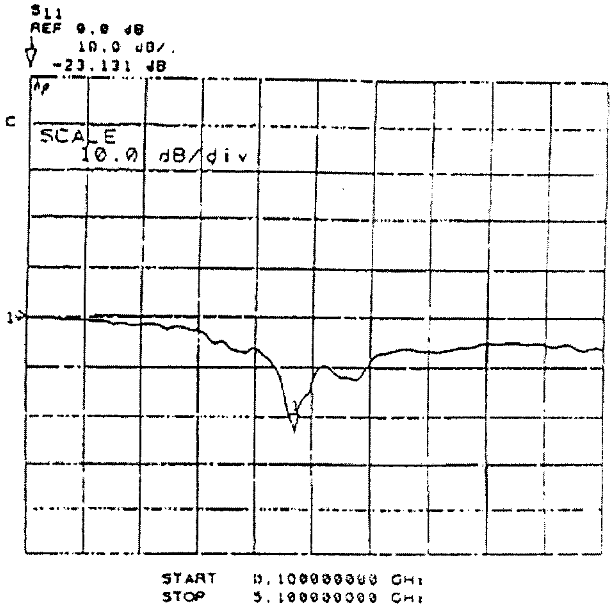


Fig. 3. Return loss for microwave enhanced liposuction cannula at 2.45 GHz in phantom.

To eliminate any possible damage to surrounding tissue, Lele's [13] study suggests that the temperature not exceed 50 °C if the microwave exposure is between 10–60 min continuously. Our preliminary measurements have indicated that the skin above or the muscle below the fat would never see this temperature. Even if the total procedure lasts 30 min, the cannula is moved constantly and in many directions. No one area is exposed for more than a few minutes, and the microwave penetration is limited to a few millimeters. This was verified by *in-vitro* measurements of the saline phantom solution environment.

V. Antenna Considerations

The antenna design for MAL presents some interesting challenges. The antenna must deliver microwave energy to heat the treated volume of fat. Unlike traditional biological antenna designs, the MAL antenna radiates in close proximity to a metallic cannula. The cannula serves two primary functions. First, the openings in the end of the cannula are sharp to facilitate fat removal via curettage. Second, removed fat is suctioned through the cannula with the assistance of a vacuum. Clearly, the cannula imposes more complex antenna geometry than exists for traditional biological antennas. Furthermore, as opposed to microwave hyperthermia applications, for example, it may actually be desirable to allow heating to occur along the transmission line since that heating will prevent the coagulation of fat being suctioned through the cannula. Analytical antenna design approaches become increasingly difficult under these design constraints. Therefore, it is appealing to consider the use of accurate simulation tools to design the antenna and to analyze the antenna performance. This approach was used by Labonte *et al.*, who implemented a finite-element method (FEM) in the frequency domain to compare the near-field radiation patterns of several types of antennas, including the dielectric-tip monopole, open-tip monopole, and metal-tip monopole [15], [16]. In our future work, we propose to use finite-element time domain (FDTD) code to model the MAL antenna. This code will allow the computation of input impedance, near-field values, and specific absorption rate (SAR).

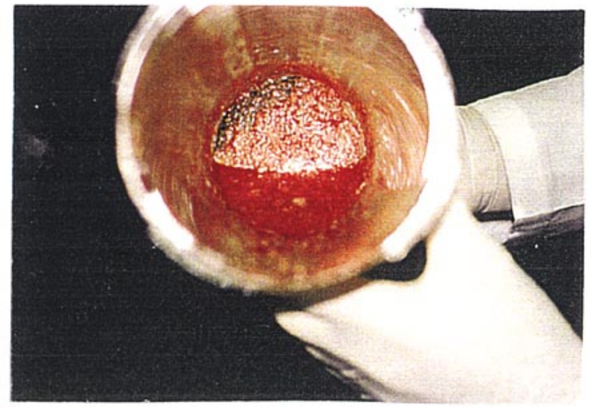


Fig. 4. Specimen using the dry technique and non-microwave liposuction: fat mixed with blood.

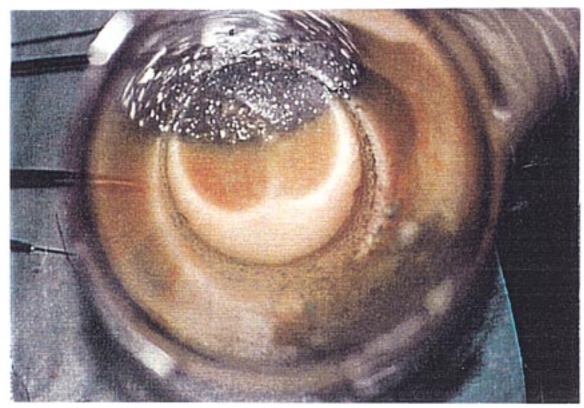


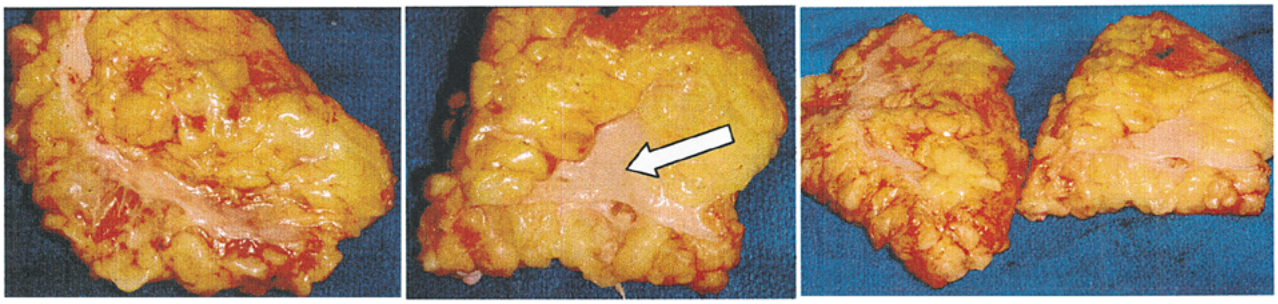
Fig. 5. Specimen using the dry technique and microwave liposuction: fat is fused into an opaque amorphous melted state.

VI. Preliminary Studies

Using the MAL system outlined, two studies were performed prior to the human *ex-vivo* experiments. Both of these experiments were performed on an anesthetized full-grown 500-lb swine. We utilized a standard liposuction cannula measuring 26 cm in length connected to a suction machine (Byron Medical, Tucson, AZ). The cannula was adapted for MAL as described previously. The same cannula could perform non-microwave-aided liposuction (non-MAL) as well as MAL for these experiments.

The first study compared nontumescent liposuction (dry) with and without MAL. The second study compared non-MAL versus MAL with the use of a tumescent solution. The tumescent solution consisted of 1000 cc of normal saline, 50 cc of 1% lidocaine, and one ampule of epinephrine. Although the dry liposuction method is not commonly utilized, the comparison is of value, as seen in Figs. 4 and 5.[1]

[1]In collaboration with Dr. D. Debias *et al.*, Department of Physiology, Philadelphia School of Osteopathic Medicine, Philadelphia, PA.



(a) (b) (c)

Fig. 6. (a) Non-microwave-aided tumescent liposuction: smaller amount of fat removed with normal adjacent tissue. (b) Microwave-aided tumescent liposuction: Arrow: intact fascia and more fat removed with normal adjacent tissue. (c) Both specimens side by side.

Results: Utilizing the dry technique, the MAL specimens grossly revealed less blood in the aspirate. In addition, the fat was also more liquefied in the MAL specimens. This is depicted in Figs. 4 and 5.

In the second experiment, approximately 250 cc of tumescent solution was infiltrated into four sites on the flank fat pad of the pig prior to liposuction. Non-MAL was performed at the two cephalad sites and MAL was performed at the caudal sites. The non-MAL yielded a more particulate substance consisting of fat globules mixed with blood. The MAL was performed at a power between 30–40 W. The suctioned fat solution was creamier, grossly less bloody, and more liquefied, as compared to the non-MAL fat solution. In addition, it was physically easier to pass the cannula through the tissues using the MAL cannula. In the animal studies, it appears that tumescent liposuction combined with microwave power between 30–40 W yields less blood in the suctioned fat while improving the ease of passing the cannula.

VII. *Ex-Vivo* Studies

The *ex-vivo* studies were conducted at the University of Pennsylvania Medical Center, Philadelphia. Fresh human abdominal-wall specimens were utilized to compare the changes in microstructure of the subcutaneous fat and surrounding tissues after the use of MAL. Specimens were obtained from patients who were undergoing elective surgical excision of abdominal-wall tissue. Each specimen was relatively equal in size and weight, approximately 30 $\times$ 15 cm, and consisted of full thickness tissue from fascia to skin. Once excised, the tissue was immediately infiltrated with tumescent solution as previously described. All studies were performed on warm human tissues prior to cooling. The effects on the abdominal specimens were assessed after undergoing tumescent techniques of MAL and non-MAL.

The temperature of the tissue was measured during the application of microwave energy to the specimens by two methods. The first temperature was measured using the thermistor at the distal end of the cannula. This monitored the temperature of the fat at the tip of the cannula as it was being suctioned. The second measurement was taken with a separate probe at 1-cm distances from the area of fat being microwaved in order to determine the temperature of the surrounding tissue.

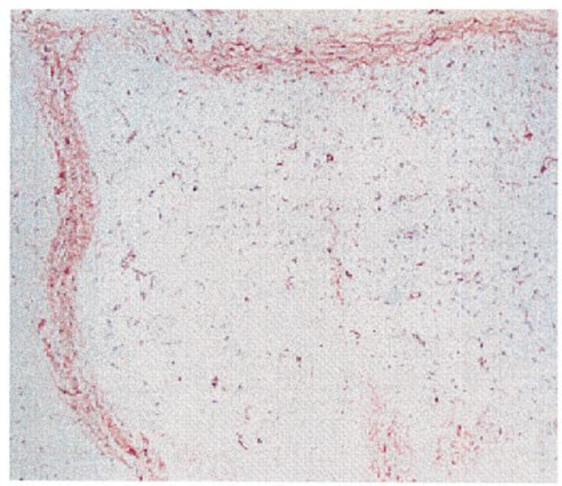
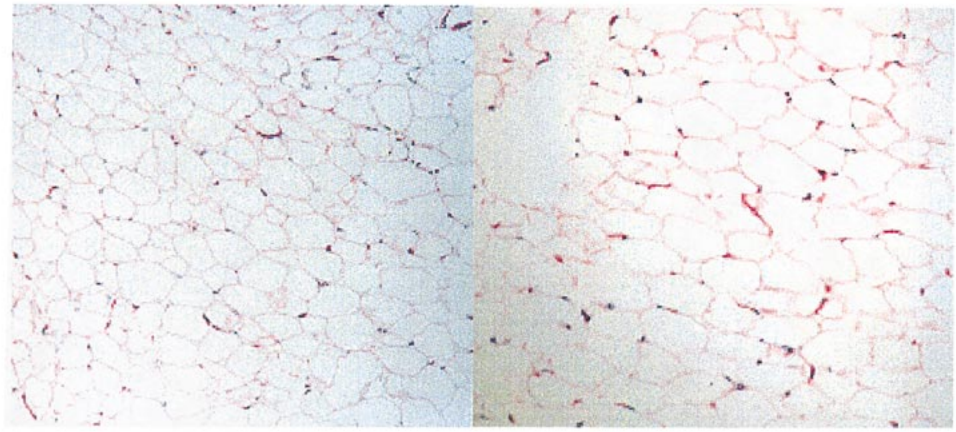


Fig. 7. Normal fat lobule.

Results: Temperatures at the tip of the cannula measured as high as 55 °C with the application of 40 W. This temperature yielded the most liquefaction of the fat. The temperature rise was found to be dependent on the flow rate of the mixture of fat and tumescent solution, which acted as coolants to the coaxial line, which transfers the power to the antenna. Interestingly, the regional temperatures measured 1 cm from the tip of the cannula showed no increase in temperature.

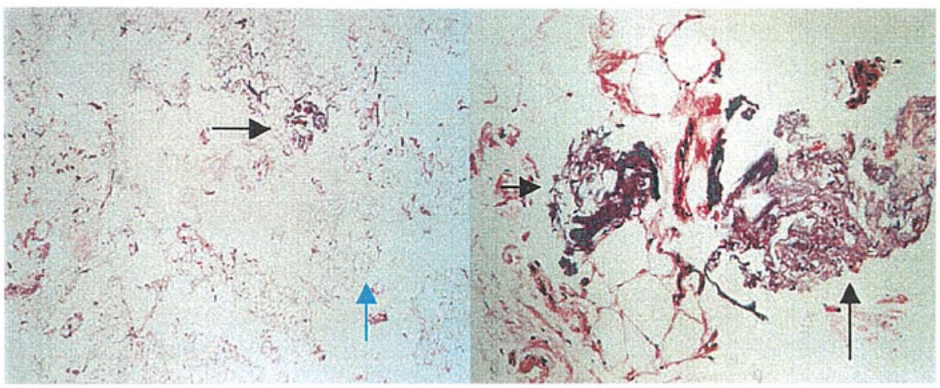
VIII. Physical and Histological Evaluation of *ex-vivo* Fat Specimens

We evaluated the impact of progressive power on the ability to remove fat as well as the histologic changes that were present when using microwave-aided tumescent liposuction. Using microwave-aided tumescent liposuction grossly showed that areas of fat were removed while adjacent fat was left undisturbed [see Fig. 6(a)–(c)]. Standard Hematoxylin & Eosin and Periodic Acid Schiff (PAS) staining were used to evaluate the suctioned fat architecture. This first study revealed that below 40 W of input power, there was no evidence of thermal necrosis. In addition, the control specimens had viable adipocytes with some evidence of mechanical destruction and no thermal necrosis (Fig. 7). Above 40 W, microwave treated



(a) (b)

Fig. 8. (a) PAS stain 10× non-microwaved specimen. Adipocytes adjacent to liposuctioned area: revealing normal architecture and no evidence of destruction. (b) PAS stain 10× microwaved specimen. Adipocytes adjacent to liposuctioned area: revealing normal architecture and no evidence of destruction.



(a) (b)

Fig. 9. (a) PAS stain 2.5× microwaved specimen. Black arrow: region of thermal necrosis. Blue arrow: intact adipocytes. (b) PAS stain 10× microwaved specimen. Arrow: high-power view of thermal necrosis.

specimens had evidence of small areas of thermal fat necrosis [see Fig. 8(a) and (b)]. However, the treated areas also showed viable adipocytes with loss of well-demarcated septa between the fat lobules [see Fig. 8(a)]. PAS staining revealed that the necrotic area included the collagen/connective tissue region surrounding the fat. The specimens that were treated with the highest power showed the most prominent areas of thermal necrosis [see Fig. 9(b)]. Of note, evaluation of the fat adjacent to the microwave treated region revealed normal adipose tissue [see Fig. 8(a) and (b)]. The fact that there is a correlation between the thermal destruction of fat and increasing power indicates a thermal mechanism for this destruction. This may be due to the fact that fat has a lower melting point than its surrounding tissues. Lastly, there was no evidence of damage to tissues that were not in immediate contact with the cannula [see Fig. 8(b)]. There was no histologic evidence of any dermal injury. These findings were supported by direct temperature studies and coincided with the histologic findings.

IX. Conclusion

It appears that microwave-assisted liposuction takes advantage of the differential melting points of various structures. Adipocytes are clearly injured, along with surrounding cellular stroma and immediately adjacent connective tissue, as a function of thermal energy. We have shown that this is a very localized phenomenon, assisting in efficient removal of fat, that it and does not affect peripheral structures. These early histological findings show that no adjacent tissue is damaged and, therefore, selective removal of fat may be possible with MAL. Both the *in-vivo* animal studies and the *ex-vivo* human studies showed that MAL improves the ease of tissue removal by the cannula and decreases trauma to surrounding tissue, which minimizes blood loss. Our future studies will evaluate the melting point of different tissues, as well as the use of the microwave-aided tumescent liposuction cannula in human *in-vivo* trials.

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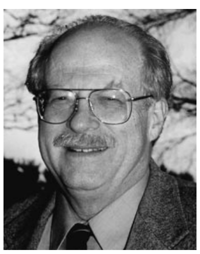

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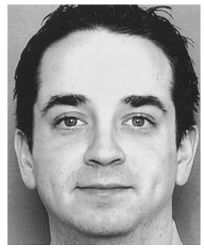

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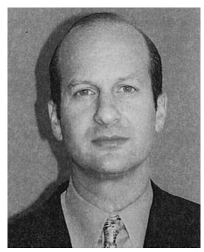

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