

Selective Laser Induced “Melting”

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The Structure of Adipose Tissue

Adipose tissue is a unique type of connective tissue comprised of adipocytes, blood vessels and fibrous septa and approximately 75-85% lipids and 15 -25% water and proteins. The unilocular white or yellow adipose tissue (WAT) is the most common type in adult humans and is composed mostly of mature adipocytes that contain one large droplet of lipids (triglycerides).

The adipocyte's cytoplasm is divided from the surrounding interstitial spaces by the external lamina, a glycoprotein envelope that superficially resembles the basal lamina of epithelia. In addition, the lipid droplet within the cell is not surrounded by a membrane but its interface with the cytoplasm contains a 5 - 10 nm condensed layer of lipid reinforced by parallel microfilaments 5 nm in diameter. We term this interface Lipid Cytoplasm Interface (LCI, see Figure 1).

Adipocytes are surrounded by a loose network of fine reticular fibers containing collagen fibrils, fibroblasts, lymphoid cells, eosinophils and some mast cells (Figs. 1 and 2). Adipocytes are well supplied by blood and lymphatic capillaries and appear polyhedral or oval with the nucleus flattened and pushed to the periphery when adipocytes are grouped together in adipose tissue. An adipocyte's mean diameter depends on the volume of accumulated lipid in the adipocyte cells and ranges from 25 to 125 microns. The volume ratio of lipid to surrounding cytoplasm appears to be high as the cytoplasm is not visible in some areas.

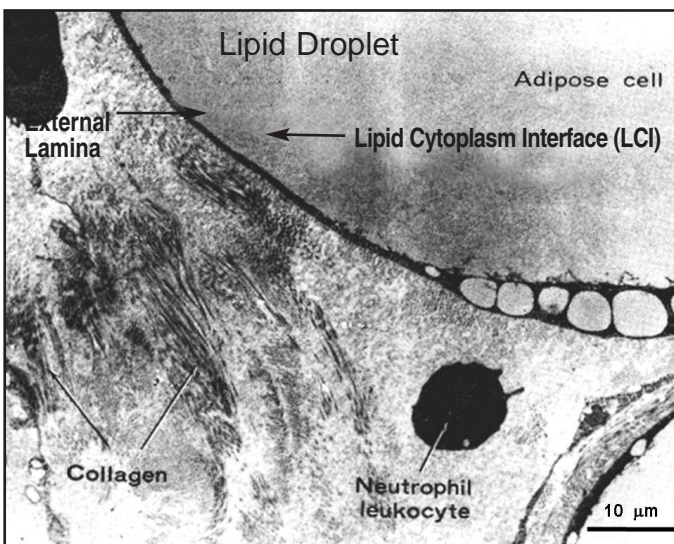


Fig. 1 Electron micrograph of adipocyte and surrounding tissue.

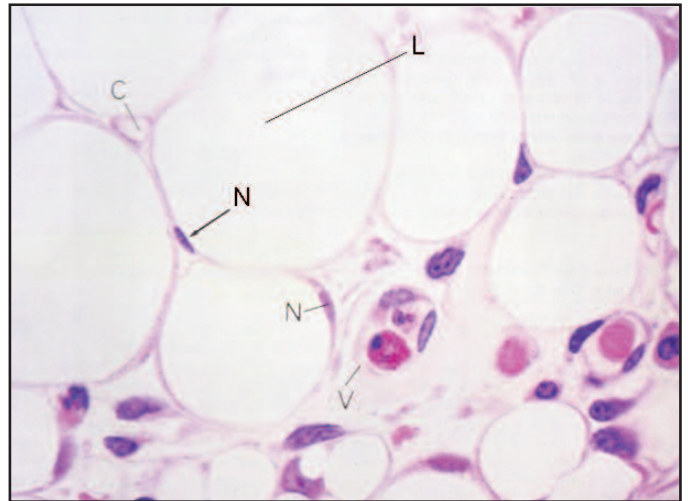


Fig. 2 Photomicrograph of unilocular adipose tissue (WAT) showing lipid (L) within the adipocytes. The cytoplasm is visible in some areas and the nucleus (N) is seen along the periphery of the cell. Also visible is a capillary (C) and venule (V).

Physiologically, the adipose tissue is classified into primary microlobules (~1 mm) and secondary microlobules (~1 cm), which are enclosed within a sheet of connective tissue called fibrous septa composed of collagen and elastic fibers. Each primary microlobule is composed of grouped adipocytes with a capillary network. Each secondary microlobule is composed of a group of primary microlobules with larger networks of arterioles and venules located within connective fibrous septa that are visible to the naked eye (Fig. 3).

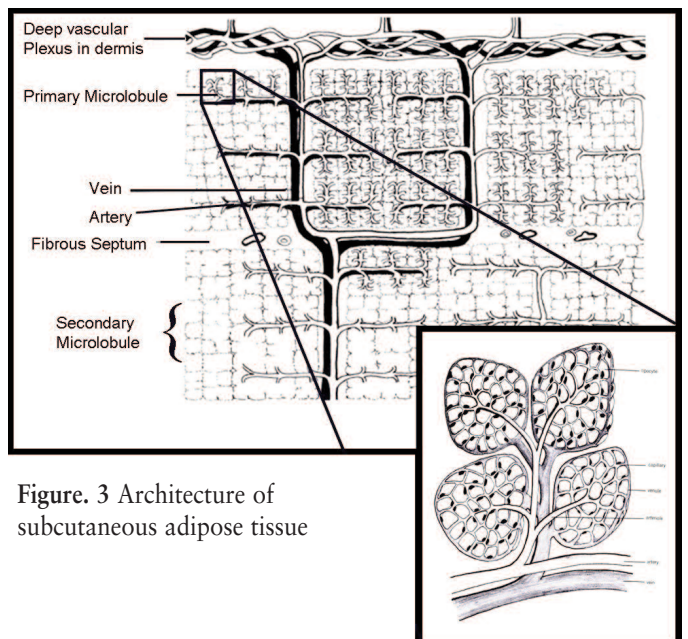


Figure. 3 Architecture of subcutaneous adipose tissue

Laser Thermolysis of Fat

The objectives of the SlimLipo™ are to provide all the benefits of laser-assisted liposuction in an efficient, easy-to-use hand-held laser fiber delivery assembly. With optimized selection of wavelengths and power levels and a superior treatment tip design, laser thermolysis treatment with the SlimLipo™ results in significant hemostasis and tissue shrinkage, easier penetration and heating of adipose tissue. SlimLipo™ enables use of a smaller suctioning device than is used for traditional liposuction (e.g., a needle, a toomey syringe, and/or a relatively small cannula can be employed). The benefits of SlimLipo™ when compared to traditional liposuction include:

- easy removal of lipids
- improved skin retraction
- immediate skin tightening effect
- smoother skin
- reduced tissue trauma
- reduced patient post-treatment discomfort and bruising
- reduced patient downtime
- reduced physician effort and fatigue

Through laser-assisted lipolysis the desired clinical endpoints of tissue retraction and tightening are accomplished via lipid removal and controlled tissue coagulation. With these endpoints in mind, the primary goals in designing a system for effective laser thermolysis of fat are choosing the optimal wavelengths, power levels and pulse durations that will compliment a specific beam and tip geometry. The SlimLipo™ treatment tip selectively heats adipose tissue to release the intra-cellular lipid from the adipocytes and to coagulate, not tear, the immediate surrounding fibrous support structures. As the lipid temperature rises above a threshold value (> 43°C), the cells' LCI are irreversibly damaged allowing the lipid to flow into the extracellular compartments, (a process we call lipid liberation or "LL"), for easy suctioning of the fat. Temperatures adjacent to the treatment tip are between 60 – 70°C leading to coagulation of local collagenous septa, the network of collagen fibrils surrounding adipocytes, capillaries and blood vessels. A clinically beneficial shrinkage effect arises with coagulation of the collagenous tissue. The result is the creation of a channel through the adipose tissue of free-flowing lipid surrounded by a wall of shrunken coagulated fibrous tissue.

The manner by which the tissue surrounding the treatment tip is heated is crucial. Power levels sufficient to vaporize lipids or water are significantly greater than the power levels needed for lipid liberation and coagulation of surrounding cells and collagenous tissue. When operating at the high vaporization levels, excess energy deposition can occur that not only lowers efficiency but is highly unsafe particularly in regions proximal to the dermis. To most effectively and safely disrupt the adipocytes, free the entrapped lipid and coagulate the surrounding cells and collagenous structures, it is best to perform smooth heating with CW (continuous wattage) or long pulses without overheating to the point of bubble formation or mechanical shock wave generation. In this way, tissue retraction and tightening can most effectively and safely be reached.

In standard liposuction, significant force is needed to cut through the septa and other supporting structures. This force can be transmitted through the septa to distant parts of the adipose tissue and has the potential to cause additional trauma. However, in laser-assisted liposuction with SlimLipo™ the required mechanical force is greatly reduced both by the treatment tip design and by the easy penetration of the coagulated septa and collagen fibrils. The distant infrastructure of the tissue is left intact and undisturbed to support faster healing. An additional benefit of SlimLipo™-assisted liposuction is that smaller cannulae may be used for suctioning as the detached tissue includes freed lipids that have been heated.

Optimal Wavelengths

Figure 4a shows several candidate wavelengths at the peaks of the absorption profile for human fat. Palomar selected the 924 nm wavelength corresponding to an absorption peak of lipid – the dominate chromophore in subcutaneous fat – as the best wavelength for targeting normal adipose tissue. This wavelength provides the maximum selectivity for fat while simultaneously providing sufficient optical penetration into the fat for maximal volume heating of the adipose tissue surrounding the treatment tip. A second wavelength at 975 nm was chosen because it corresponds to a peak in dermal absorption where water is the primary chromophore (Fig. 4b). This wavelength targets the dermis for soft tissue coagulation, which has been shown to provide skin tightening results and, when combined with 924 nm in mixed mode, optimizes the treatment tip's performance in fat tissue with 30% water, which can represent the fat tissue following tumescence. Note, however, that the dominant mecha-

nism for heating the surrounding collagen structures in the adipose tissue is thermal conduction from the neighboring lipid droplets heated by the laser light.

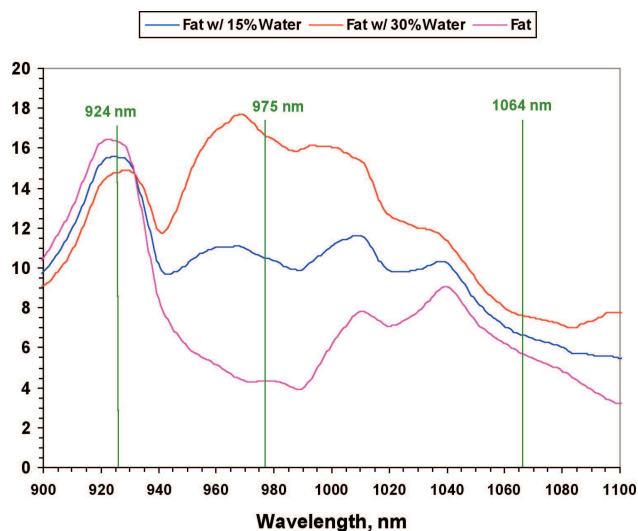


Figure 4a. Absorption spectrum of human fat with physiologic conditions (magenta curve), absorption spectrum of human fat with 15% water (blue curve) and absorption spectrum of human fat with 30% water, which can represent fat tissue after tumescence (red curve).

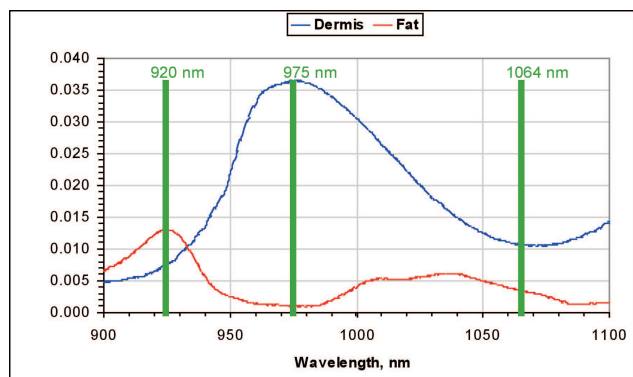


Figure 4b. Absorption spectrum of dermis with 70% water (blue curve) and fat under physiologic conditions (red curve).

Figure 5a displays a typical temperature profile at the treatment tip of the SlimLipo™ fiber one second after the SlimLipo™ system was turned on. Two damage zones are outlined surrounding the tip. The larger zone is the volume of “LL” characterized by temperatures exceeding 43° C and the smaller zone depicts the volume of protein (collagen) coagulation with temperatures exceeding 60° C. Figure 5b also displays temperature profiles for two wavelength modes operating in two adipose tissue environments. The upper left quadrant of Fig. 5b depicts treatment with the single wavelength mode 924 nm at 17W output in normal adipose tissue. The upper right quadrant shows treatment at the same wavelength and

power but in hydrated fat, which is fat tissue with 30% water, which can represent fat tissue after tumescence. Similarly, the bottom quadrants depict treatment with the system in mixed mode (924 nm at 17W and 975 nm at 8W) for the two tissue types (the lower left quadrant tissue type is normal adipose tissue and the lower right quadrant tissue type is adipose tissue with approximately 30% water, which can represent fat tissue after tumescence). Note that with tumescence, the mixed mode provides larger LL volumes since water has higher absorption at the 975 nm than 924 nm light. A summary of the LL and coagulation volumes are compared across the specified wavelengths in Fig. 6 for treatment of normal adipose tissue.

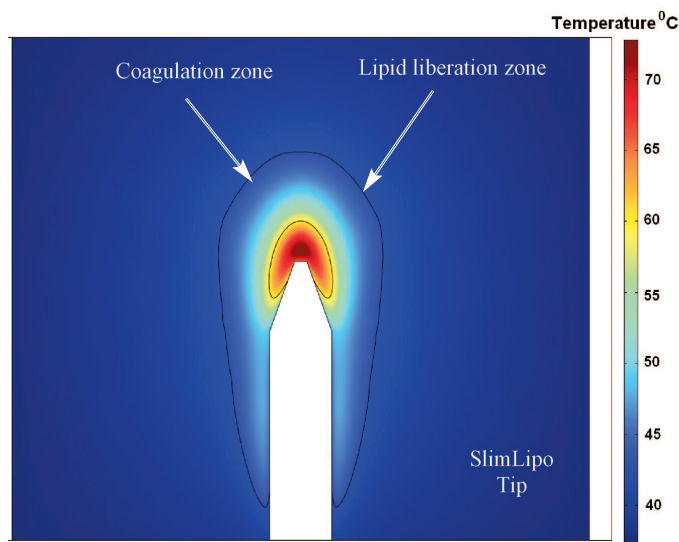


Figure 5a. Temperature profile shown at the end of 1 s around the SlimLipo™ treatment tip operating in mixed mode at 25W. Also shown are the “LL” and coagulation zones demarcated by lines with the “LL” zone being exterior to the coagulation zone.

References for Figures

- (1) Fawcett DW, Raviola E. Bloom and Fawcett - A Textbook of Histology. 12th ed. New York: Chapman and Hall; 1994
- (2) Ross MH, Romrell LJ, Kaye GI. Histology – A Text and Atlas. 3rd Edition. Williams and Wilkins 1995.
- (3) Ackerman, Bernard. Histologic Diagnosis of Inflammatory Skin Diseases: An Algorithmic Method Based On Pattern Analysis. 3rd edition, 2005

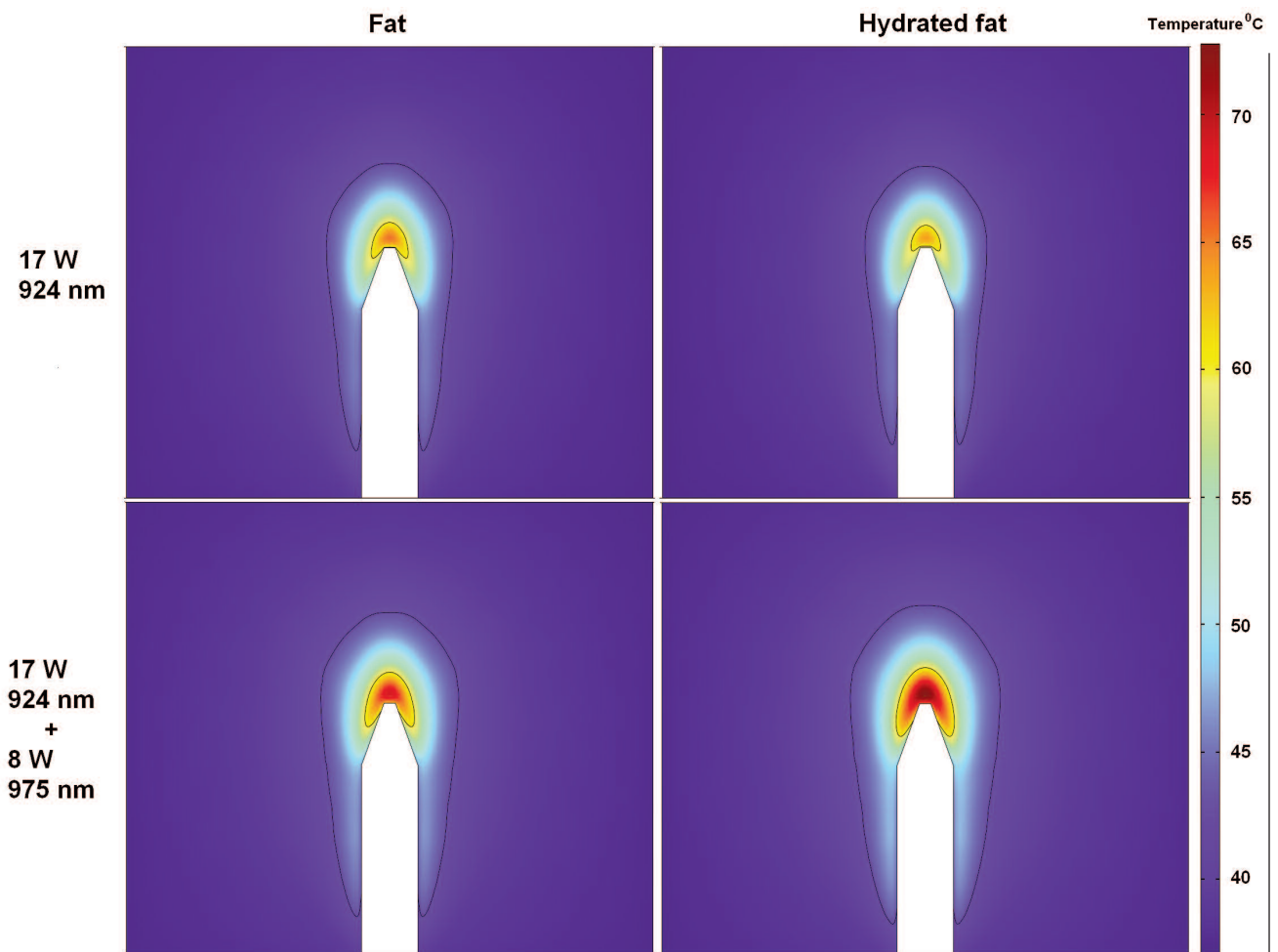


Fig. 5b. Temperature profile comparison of single and mixed wavelengths of the SlimLipo™ treatment tip in normal physiologic adipose tissue (“Fat”) and adipose tissue with 30% water (“Hydrated fat”), which can represent fat tissue after tumescence.

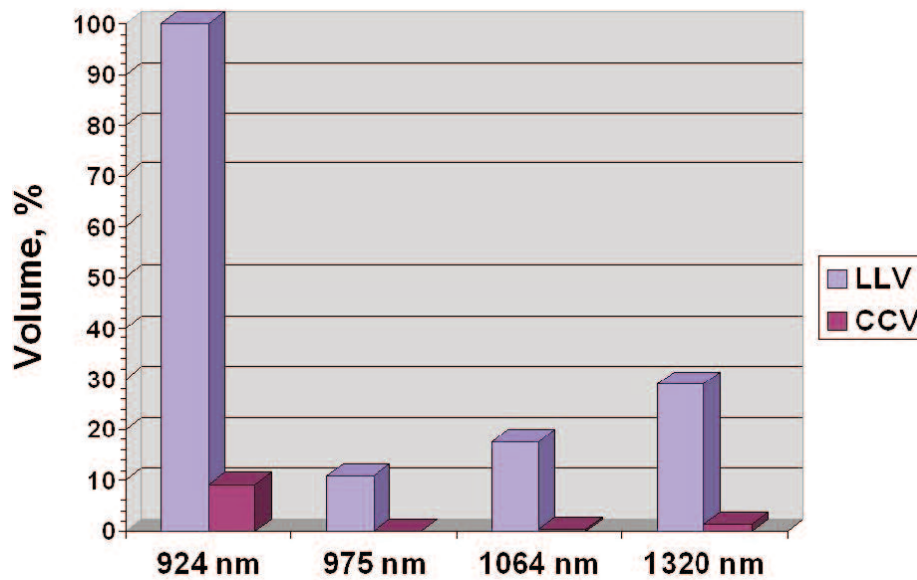


Fig. 6. Liberated lipid volume (LLV) and coagulated collagen volume (CCV) in adipose tissue in normal physiologic condition.