

QCW Pulsed Nd:YAG 1064 nm Laser Lipolysis

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ABSTRACT:

The aim of this study was to compare the Nd:YAG 1064 nm laser wavelength with other wavelengths used for laser lipolysis in terms of safety and efficacy. The wavelength dependence of laser lipolysis was simulated using a Monte Carlo computer simulation. The results show that the Nd:YAG 1064 nm wavelength is the optimal wavelength for laser lipolysis in terms of safety and efficacy. Compared with other wavelengths, the 1064 nm wavelength exhibits the largest directly heated volume of subcutaneous tissue and has the smallest undesirable thermal effect on neighboring dermal tissue. The pulsed QCW mode of operation of the Nd:YAG laser also has a significantly higher ability to coagulate blood vessels when compared to continuous wave (CW) diode lasers. The high performance and versatility of the latest technology Nd:YAG 1064 nm laser lipolysis systems, combined with their optimal safety and efficacy, make these lasers the medical devices of choice.

Key words: Laser lipolysis, Nd:YAG laser, 1064 nm, subcutaneous tissue, human fat, dermis.

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I. INTRODUCTION

Liposuction is one of the most common cosmetic surgical procedures. Liposuction is the No. 2 cosmetic surgical procedure in the USA, following just 4% behind the most popular procedure (breast augmentation), and is within the top five in the UK. The American Society for Aesthetic Plastic Surgery states that 341,144 procedures were performed in 2008 [1,2,3].

There are, however, several drawbacks associated with traditional liposuction [4]. These drawbacks include increased blood loss, ecchymoses, long recovery times, increased postoperative discomfort, skin laxity, pulmonary emboli, seromas and visceral perforations. For this reason, physicians continue to investigate ways to optimize the final results, and minimize trauma, risks, and down-time for their patients.

Laser lipolysis (LL) is an exciting procedure that provides improved patient tolerability, shorter recovery times, and optimal skin tightening [4-7]. LL procedures are safe, have short recovery times, and provide a good option for patients reluctant to undergo more invasive procedures (Fig.1).

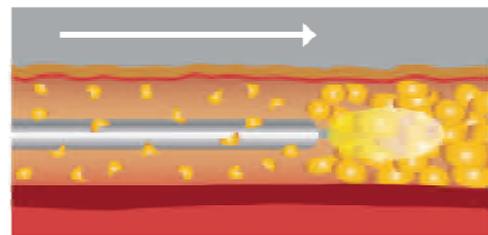


Fig.1: Laser lipolysis is a fat reduction treatment in which laser light energy is used to cause the swelling and rupture of adipocytes. Laser energy is delivered through an optical fiber inserted into a thin cannula, and interstitially introduced into fatty tissue in the hypodermis.

Localized subcutaneous fat deposits that are disproportionately large and are unresponsive to exercise and diet should be considered for laser lipolysis. Locations amenable to treatment with laser lipolysis include the submental area, upper arms, abdomen, hips, flanks, inner thighs, outer thighs, knees, and ankles. Nd:YAG laser lipolysis is particularly good at treating sites that tend to exhibit greater laxity after the removal of adipose tissue, such as the neck/jowls, upper arms, abdomen, inner thighs, and knees; at these sites Nd:YAG laser light can mediate tightening of the overlying skin in addition to adipocyte destruction.

Laser-assisted lipolysis has several advantages over traditional lipolysis [4]. The laser lipolysis effect improves the removal of adipose tissue: by liquefying the adipose tissue, larger volumes can be removed more easily. There is less trauma in a laser lipolysis procedure because, due to the small cannula size and the light mediated lipolysis effect, mechanical destruction of skin structures by the cannula is minimized. The result is faster recovery times and diminished ecchymosis. The third advantage of laser-assisted lipolysis is coagulation of small blood vessels by the laser light, resulting in less blood loss during the procedure. The fourth positive attribute is skin retraction or skin tightening. Disruption and coagulation of collagen can lead to the creation of a new, thicker and more organized reticular dermis, the end clinical result being tightened skin. This attribute makes laser lipolysis particularly attractive for areas of localized adiposity or localized laxity following liposuction. The skin tightens over a period of time that may last up to 8 months, with tightening becoming progressively more evident over time due to collagen regrowth.

Laser-assisted lipolysis is a minimally invasive surgical procedure. The procedure is performed through tiny incisions that do not require sutures, allow drainage, prevent infection and heal within weeks of the procedure. Despite these benefits, adverse effects are still possible. Although laser-assisted lipolysis minimizes trauma it cannot eliminate it. Approximately 1/3 of the trauma sustained during a procedure is caused by the direct mechanical destruction of cells by the cannula (Fig. 3). As a result patients still exhibit edema and mild ecchymosis as in traditional liposuction. However, these effects are less severe and last for a shorter amount of time than following standard liposuction.

The Nd:YAG 1064 nm was the pioneer wavelength for laser lipolysis (Fig. 2). It has been on the world market for almost 10 years during which it has been evaluated in many clinical studies [5-9, 35-43]. Many thousands of satisfied patients have undergone 1064 nm laser lipolysis.



Fig.2: Nd:YAG surgical laser [10]

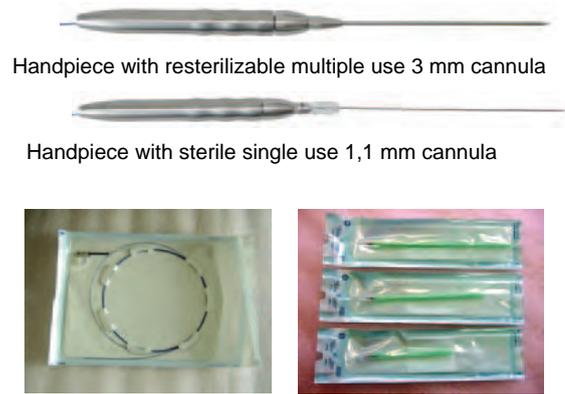


Fig. 3: Accessories for laser lipolysis. To keep up with new in-demand procedures, manufacturers offer an ever increasing range of compatible, re-useable surgical sets eliminating the need to continuously invest in expensive technologies and upgrades. [10]

Since the introduction of the Nd:YAG laser, several other wavelengths have been tried and tested for Laser Lipolysis. [11-15, 28]

Optics of Lipolysis

The basic mechanism of laser-tissue interaction in laser lipolysis is photo thermal [16-18, 27]. The conversion of laser light energy into heat is achieved by the absorption of light in target tissue. The thermal effects of a laser beam incident upon the human tissue can be predicted if the time dependent temperature distribution within the tissue is known. When the laser is fired a small fraction of tissue, V1 is directly heated by energy conversion through mechanisms of absorption and scattering (Fig. 4). Due to tissue thermal conductivity, heat from V1 is dissipated, forming a larger volume, V2.



Fig. 4: Thermal images of the development of thermal zones V1 and V2 during Nd:YAG Laser Lipolysis. [19]

Dissipation into V2 is a considerably slower process than direct heating in V1. Thus, in a standard laser lipolysis procedure, in which the cannula is moved faster than dissipation occurs, the primary thermal volume (V1) plays the major role in the thermal dissolution of fat. Our analysis focuses on the direct heating of the tissue within the volume V1.

Based on the above, calculating the temperature distribution during lipolysis requires modeling the light propagation through the tissue. [20-22] Within

the tissue the light photons undergo two processes: absorption and scattering. The absorption in biological tissues is mainly caused by water molecules, proteins and pigments. Due to absorption, light intensity I , decreases with depth z , according to Beer-Lambert law:

$$I(z;\lambda) = I_0 \exp(-\mu_a(\lambda) z)$$

Here, $\mu_a(\lambda)$ is the wavelength dependent absorption coefficient. Water strongly absorbs above 2 μm with the strongest peak at 3 μm , proteins have a peak absorption in UV (280 nm), leaving pigments dominating the visual and NIR (400 - 2000 nm).

Human tissue is also a heavy scatterer: its scattering coefficient $\mu_s(\lambda)$ being somewhere between 50 and 1000 cm^{-1} . Scattered parts of the laser beam are internally refracted from cell membranes, cell nuclei, etc, until they are finally absorbed. Note that only the absorbed laser radiation is transformed into heat. Scattering broadens the final volume of tissue in which absorption takes place (Fig. 5). It also reduces the penetration depth of the laser beam as the intensity of the incident beam decreases with depth z according to:

$$I(z;\lambda) = I_0 \exp(-(\mu_a(\lambda) + \mu'_s(\lambda)) z)$$

where $\mu'_s(\lambda)$ is the reduced scattering coefficient that takes into account how much of the laser light is scattered away from the original direction. For the tissues in this study, this represents 10% of the incident beam ($\mu'_s(\lambda) = \mu_s(\lambda)/10$).

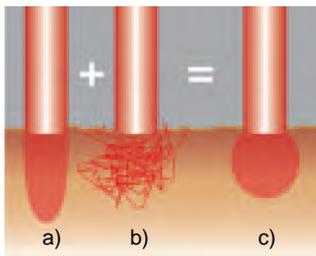


Fig. 5 Combined effects of absorption (a) and scattering (b) lead to the reduced penetration depth and broadening of the directly heated volume V_1 (c).

Optical Properties of Subcutaneous Fat

In order to account for the photon propagation during Lipolysis, both laser beam and tissue optical properties must be known. The subcutaneous layer is composed of proteins and adipose tissue (fat). Above this layer lie inner dermis and epidermis (Fig. 6).

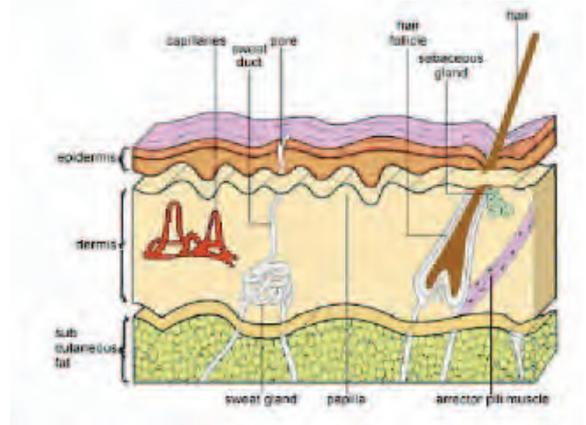
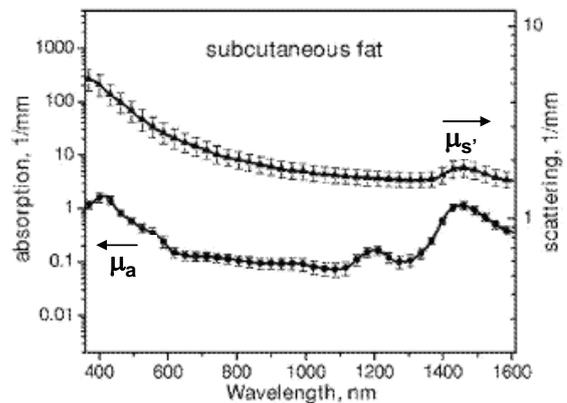


Fig. 6 Structure of human skin and subcutaneous layer.

The optical properties of the subcutaneous layer, the nearby dermis, and epidermis are not the same but they are all strongly dependent on the laser wavelength [22-26]. In human skin and fat tissues for the wavelengths between 450 nm and 1800 nm scattering predominates over direct absorption [16,44]. Fig. 7 shows the absorption and scattering coefficients for the subcutaneous fat and dermis in the 400 to 1600 nm laser wavelength range [23]. The optical properties of the dermis are important in laser lipolysis because some of the laser light may propagate through the directly illuminated fat into the neighboring dermis. In what follows we shall presume that the tissue optical parameters do not change appreciably as a result of heating during laser irradiation.



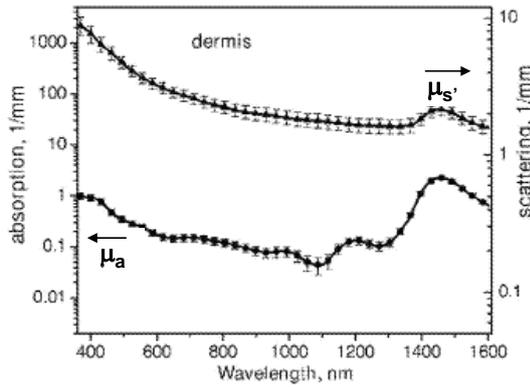


Fig. 7: Measured absorption coefficient μ_a and the reduced scattering coefficient $\mu_{s'}$ of subcutaneous fat and dermis as a function of laser wavelength. For both tissues there are two peaks of higher absorption around 1210 and 1450 nm. [23]

For safe execution of laser lipolysis, it is important to work with appropriate temperatures – clinical endpoints that are high enough to achieve thermal lysis effects, but not so high as to produce unwanted side effects. During standard LL procedure the thermal process of adipocytes destruction happens inside the heated volume V1 with approximate temperatures between 50°C and 65°C (Fig. 8) [16].



Fig. 8: Heat induced destruction of adipocytes

Most researchers agree that this temperatures represent the clinical endpoint for the LL procedure. [11,16,31]. Higher temperatures are not desired; they cause unwanted side effects (like tissue necrosis and scarring). Temperatures under 50°C do not result in the destruction of adipocytes.

The goal of our study was a comparison of the Nd:YAG 1064 nm wavelength and other wavelength devices in terms of their safety and efficacy for laser lipolysis procedures.

II. MATERIALS AND METHODS

Photon Transport model of Laser Lipolysis

The distribution of light and of the resulting temperature distribution can be effectively modeled by the so called photon transport theory [17].

The irradiative transport equation is difficult to solve directly and many approximations exist, among others the Kubelka-Munk inverse adding-doubling and the diffusion approximation. [21] Since the mean free path of the light propagating in human fat and skin is much smaller than the typical dimensions involved, propagation quickly becomes effectively random. The Monte-Carlo simulation is then the preferred method for numerically solving the irradiative transport problem. [16-18]

In the Monte-Carlo simulation the laser beam is represented as a stream of a large number of laser "photons", each having a coordinate, direction and energy weight E.

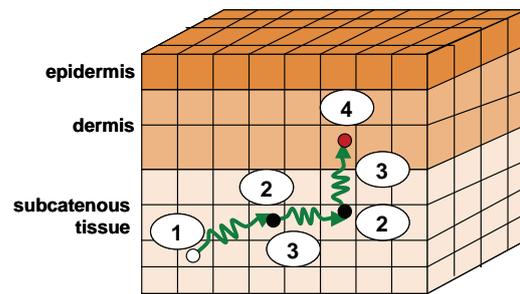


Fig. 9: Schematic representation of Monte-Carlo simulation steps of laser beam propagation during lipolysis. It consists of five steps (see text below): 1- photon generation at the position of the inserted laser cannula, 2- scattered pathway generation, 3-absorption, 4-elimination and detector count. The white dot represents photon generation, black dots represent scattering and absorption events and red dot represents photon elimination.

Each photon is statistically ray-traced through tissue following five steps depicted in Fig. 9 above:

1. Photon generation: initial location and direction of propagation are randomly determined according to the original beam output of the laser cannula.
2. Pathway generation: the path to the next event is determined: the direction of propagation is determined according to the scattering characteristics of the tissue.
3. Absorption: the photon energy weight E is decreased after each event according to the absorption and scattering coefficients.
4. Elimination: when the photon energy weight falls below some predetermined threshold, its propagation is terminated and a new photon is generated.
5. Detection: the absorbed energy ΔE is registered at the event coordinates after each event.

We used an optical ray-tracing program Zemax, which features a highly efficient Monte-Carlo implementation, to obtain the distributions of absorbed light. Simulation consisted of two layers, subcutaneous tissue and dermis illuminated by the Nd:YAG ($\lambda = 1064$ nm) and, for comparison other wavelength lasers. Distributions of absorbed light were calculated for 0.6 mm spot sizes of square (or "top-hat") collimated beams that represented the output out of a typical laser lipolysis fiber.

A typical calculated distribution of laser "photons" is shown in Fig. 10a. Scattering of photons after they exit the laser fiber can be clearly seen. For comparison, the light distribution, as measured in [19], is shown in Fig. 10b, and the resulting measured temperature distribution is shown in Fig. 10c.

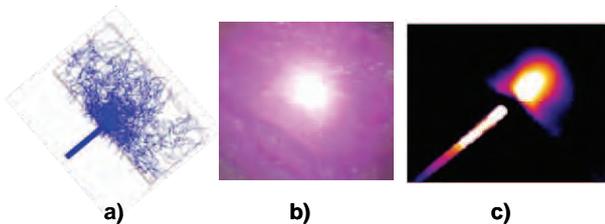


Fig. 10: a) Monte Carlo numerical model of hemispheric 1064 nm scattering in human fat; b) Measured video image of a full sphere 1064 nm laser light scattering inside the human fat; c) Measured temperature image of a hemispheric 1064 nm laser irradiation of human fat. [19]

III. RESULTS

Analysis of LL Efficacy

During standard LL procedures, a cannula containing a fiber is moved back and forth, criss-crossing certain regions many times, until all the fat in the region is melted (Fig. 11)

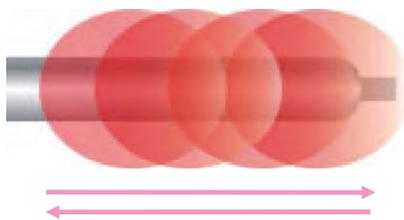


Fig. 11: Movements of thermal volume inside the fat tissue during laser lipolysis procedure

A bigger thermal volume allows the fat in the region to be melted in a shorter time (fewer passes of cannula), and with a minimal mechanical damage to the tissue. Thus, one measure of laser lipolysis efficacy is the volume of the directly heated subcutaneous tissue, i.e. the thermal volume V1 (Fig. 12).

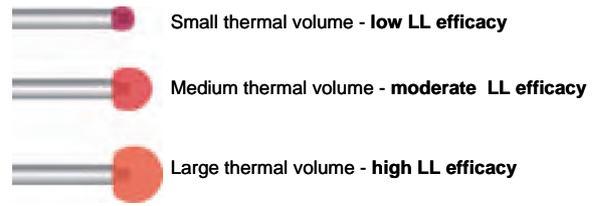


Fig. 12: One measure of the efficacy of laser lipolysis is the size of the thermal volume, V1.

The combination of wavelength dependent absorption and scattering coefficients plays an important role in the maximization of thermal volumes and thus in the optimization of the LL efficacy (Fig. 13).

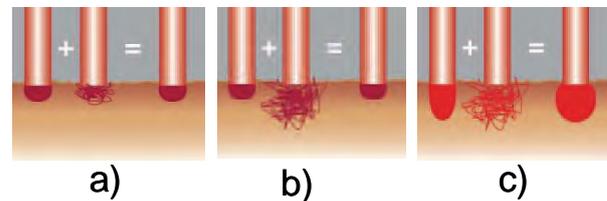


Fig. 13: Some of the possible wavelength dependent combinations of absorption and scattering: a) strong absorption and weak scattering lead to a small thermal volume V1; b) strong absorption and strong scattering also lead to a small V1; c) medium absorption and medium scattering results in optimal thermal volume conditions.

Scattering phenomena broaden the diameter of the thermal volume beyond the laser beam cross-section. As a consequence the operator can use a smaller diameter cannula or fiber; using a small diameter instrument causes less mechanical damage to the tissue. However, while scattering increases the diameter of the thermal volume, it also reduces its depth.

Absorption mitigates the effects of scattering. As absorption increases the "free-path" of the photons is reduced, limiting the thermal volume. Very weak absorption would result in a large amount of scattering and, consequently, a very large thermal volume; eventually the thermal volume would become so large that it would require an impractically large amount of laser power to heat it to a clinically significant end-point.

Because of the complex interrelation of scattering, absorption, and laser power, the optimal choice of wavelength for laser lipolysis is one that is moderately scattered and absorbed in subcutaneous tissue. In general as the wavelength increases from 800 nm to 1500 nm the absorption coefficient increases and the scattering coefficient decreases.

Based on the considerations presented above the optimal thermal volume V_1 occurs around 1100 nm.

This is in line with the results of our Monte Carlo simulation in which we compared the relative rate of heat generation versus the depth of thermal volume for five different relevant wavelengths ($\lambda = 920$ nm, 980 nm, 1064 nm, 1320 nm, and 1440 nm). The greatest amount of heat is generated at the surface of the fiber, but the heat generation is dramatically increased as the absorption coefficient is increased. At equivalent laser power the 1440 nm wavelength results in the highest temperature at the surface and the smallest depth of the thermal volume, whereas the 1064 nm wavelength results in the lowest temperature at the surface and the largest depth of the thermal volume.

Some interpret the high surface peak temperature of the 1440 nm wavelength as its advantage. [28] However, since the surface temperature must not exceed the clinical end-point of 65°C, this interpretation is incorrect. In order to perform safe lipolysis, the laser power must be adjusted in such a way that the temperature at all wavelengths does not exceed this clinical end-point. It is true that for the medium absorbed 1064 nm a slightly higher power is required to reach the clinical end-point but the important benefit is a larger thermal volume. In addition, the 1064 nm Nd:YAG laser is one of the most efficient lasers, and in spite of slightly higher working powers, the electrical efficiency and longevity of the 1064 nm Nd:YAG far exceeds those of the 1320 and 1440 nm lasers. Note, however, that lower heat generation could become an issue for less efficient lasers with weakly absorbed wavelengths.

Figure 14 presents our results from the Monte Carlo simulations in the subcutaneous fat. In the simulation, the light was assumed to propagate out of a fiber into an infinite scattering medium. With the same surface temperature of 65°C, the thermal penetration depth, and consequently the thermal volume are the largest for the 1064 nm wavelength.

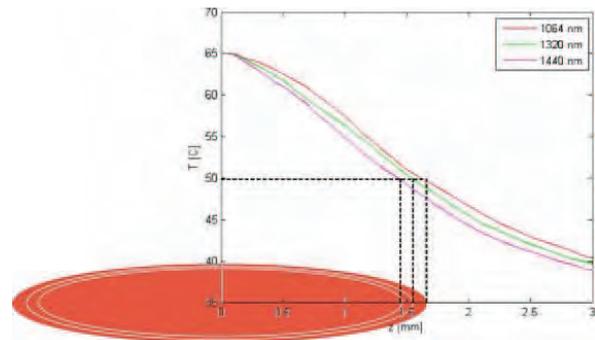


Fig. 14: Comparison of wavelengths, generating the same maximal safe temperature of 65°C. Out of all studied wavelengths (920 nm, 980 nm, 1064 nm, 1320 nm, 1440 nm), the largest thermal volume is generated with the 1064 nm (for clarity, volumes for 1064nm, 1320 nm and 1440 nm are shown). This enables the highest LL efficacy of this wavelength at a given safe temperature endpoint.

While the differences in the radii for these wavelengths do not seem large, the final differences in the thermal volumes are appreciable. This has been studied also by Wassmer et al.[32]. Figure 15 shows a graphical representation of the calculated thermal volumes from their study for various lipolysis wavelengths. The difference in the thermal volumes for the analyzed wavelengths can be clearly observed, with the 1064 nm wavelength resulting in the largest thermal volume.

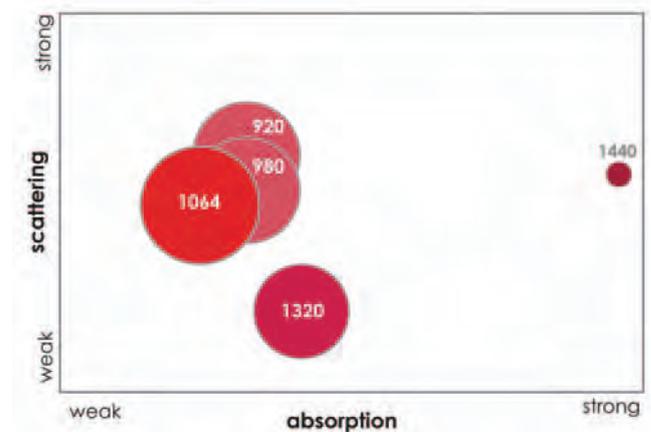


Fig. 15: Graphical representation of calculated thermal volumes for different laser wavelengths as obtained from a previously published study). [32]. The size of the circles is proportional to the size of the thermal volume. The 1064 nm exhibits the largest thermal volume, the thermal volumes of 980 nm and 920 nm are only slightly smaller, while the 1320 nm, and particularly the 1440 nm wavelengths result in significantly smaller thermal volumes.

Analysis of LL Safety

Laser lipolysis is performed by inserting a cannula into the fat under the skin. It is possible to damage the skin when the cannula is moved close to the skin (Fig. 16), and the laser light penetrates into the dermis.

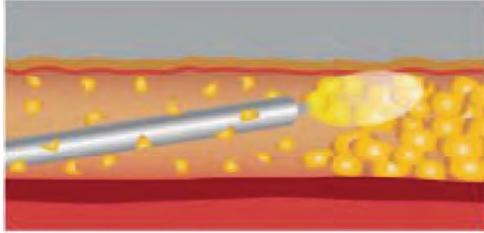


Fig. 16: If, during the procedure the laser lipolysis cannula is positioned closer to the dermis the laser light may penetrate and thermally damage the dermis.

The effect that laser light of a certain wavelength will have on the dermis will depend on the difference between the optical coefficients of subcutaneous tissue and the dermis at that wavelength. To demonstrate this we calculated the temperature distribution during laser lipolysis with various wavelengths under the three geometries depicted in Fig. 17.

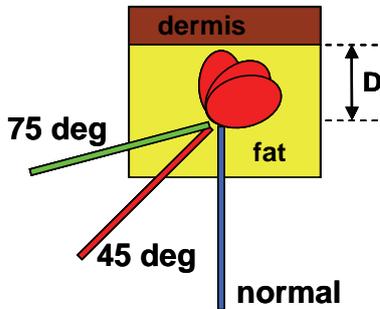


Fig. 17: Three geometries were used to evaluate the influence of dermis vicinity to temperature distribution in the two tissues model

Figure 18 shows the calculated temperature distributions ($\lambda = 920 \text{ nm}, 980 \text{ nm}, 1064 \text{ nm}, 1320 \text{ nm}, \text{ and } 1440 \text{ nm}$) when the end of the cannula is positioned at a distance of $D = 0.5 \text{ mm}$ from the fat-dermis boundary. For all three wavelengths, it was assumed that the procedure was performed up to the temperature clinical end-point of 65°C in the subcutaneous tissue. In the calculation, we used the most commonly accepted values for the absorption coefficient μ_a and the reduced scattering coefficient μ'_s , as shown in Table 1.

Table 1: The values of the absorption coefficients (μ_a) and scattering coefficients (μ_s) in fat and dermis for different wavelengths that were used in the Monte Carlo simulation. Numbers in the brackets represent the corresponding references.

| Wavelength | λ (nm) | 920 | 890 | 1064 | 1320 | 1440 |
|------------|------------------------------|--------------|--------------|----------------|----------------|----------------|
| Fat | μ_a (cm^{-1}) | 1,65 [23] | 1,65 [23] | 1,5 [16,29] | 2 [16,29] | 2,5 [16,29] |
| | μ_s (cm^{-1}) | 120 [23] | 110 [23] | 110 [16,29] | 105 [16,29] | 110 [16,29] |
| Dermis | μ_a (cm^{-1}) | 2 [23] | 2 [23] | 1 [16,29] | 2 [16,29] | 4 [16,29] |
| | μ_s (cm^{-1}) | 250 [23] | 250 [23] | 250 [16,29] | 250 [16,29] | 250 [16,29] |

The results of the Monte Carlo simulation show that the injury to the dermis can be appreciable when working with sub-optimal wavelengths. The temperature increase in the dermis is particularly high at the 1440 nm wavelength where the temperature reaches over 80°C . With the 1064 nm, the effect on the dermis is negligible. This explains partially why certain manufacturers of higher wavelength laser lipolysis devices have started offering additional thermal imaging accessories for monitoring skin temperature during the procedures. At higher wavelengths, and especially if they are positioned on the absorption peaks, the risks of damaging the skin are much higher.

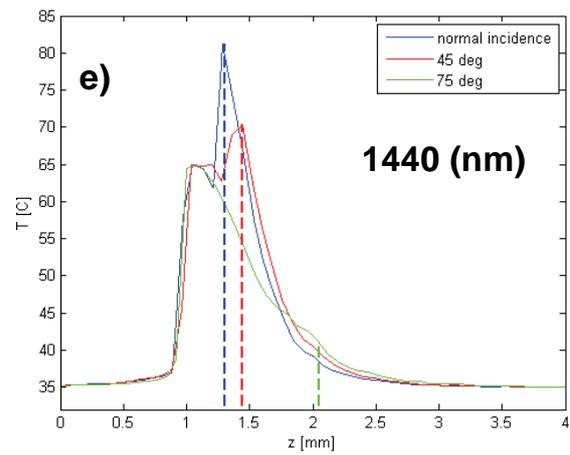
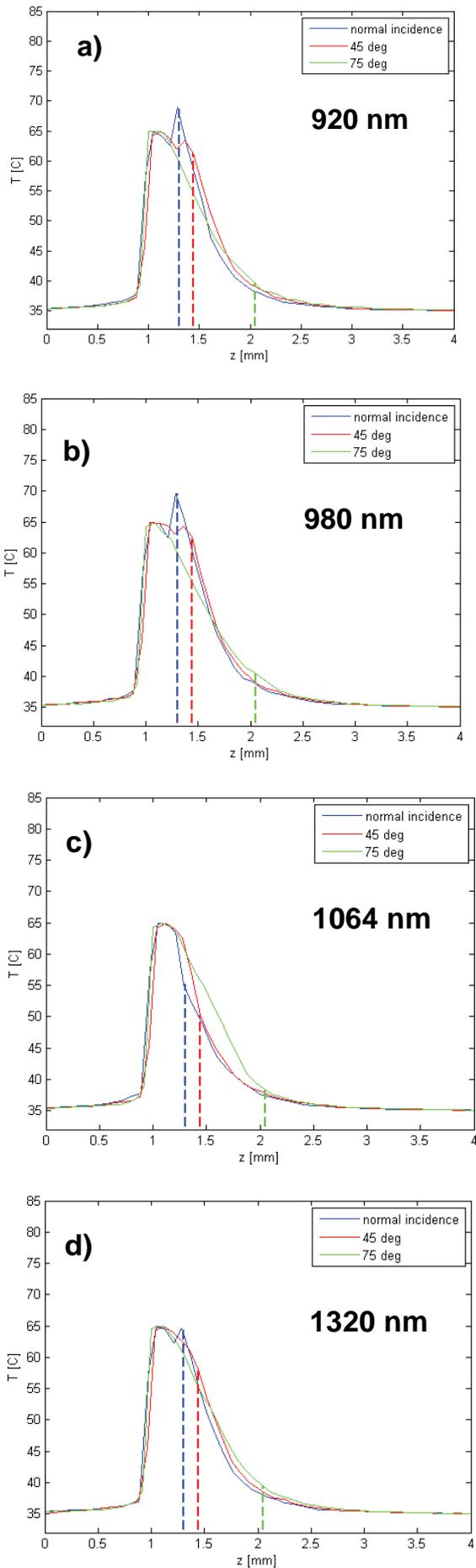
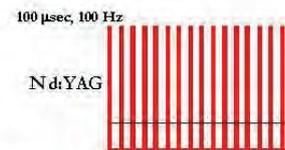


Fig. 18: Analysis of the fat/dermis border on thermal effects. At close distance ($D = 0.5 \text{ mm}$) of the lipolysis cannula to the fat/dermis border, the thermal effect in the dermis is smallest with the 1064 nm laser. At other wavelengths, the thermal effects are more expressed and can exceed the maximal allowed temperatures. The largest undesired thermal effect in the dermis is with the 1440nm.

Pulsed vs. CW Operation

There are two types of lasers for lipolysis. Quasi continuous wave (QCW) lasers, such as the 1064 nm Nd:YAG, deliver the power in a fast sequence of high peak power (several kilowatts) laser pulses, while the continuous wave (CW) lasers, such as 980 nm diode laser deliver the power (in the range of only ten watts) in a non-pulsed or in a pulse gated manner. (Fig. 19)

QCW = Quasi Continuous Waves Mode



CW = Continuous Waves Mode



Pulsed Diode (Gated) Mode



Fig. 19.: The QCW crystal pulsed lasers are capable of delivering laser radiation in a fast sequence of high peak power pulses, while CW lasers are capable of only low power gated pulsing.

As explained below, the pulsed QCW operation of lipolysis lasers is of extreme importance when considering the ability of lasers to coagulate blood vessels [6].

If the clinical objective was only to coagulate blood vessels the optimal laser wavelength would have the highest absorption in hemoglobin relative to surrounding tissue. However, the wavelengths that are highly absorbed in blood vessels (such as $\lambda = 530$ nm) do not reach deeper lying tissue, and can result in excessive damage to the surrounding tissue structures. For this reason, the QCW lipolysis lasers operate at a laser wavelength of 1064 nm that penetrates optimally into the subcutaneous tissue, and achieves selective vessel coagulation by adjusting the laser pulse duration to the thermal relaxation time of the targeted vessels [33]. Namely, during a lengthy laser exposure, most of the deposited heat may diffuse away from the vessels, resulting in a non-specific thermal effect on the adjacent subcutaneous tissue. Conversely, a suitably short laser pulse confines the heating effect to the target vessel structure, resulting in a temporary local temperature increase of the vessels without overheating the surrounding subcutaneous tissue [34].

The thermal relaxation time of the vascular targets can be estimated from the relaxation time of an infinite cylinder:

$$\tau = d^2/16 \alpha$$

giving thermal relaxation time for different blood vessel diameters as shown in Table 2. The Nd:YAG QCW treatment modality with pulse durations between 0.1 and 0.6 ms can coagulate vessels with diameters under 50 μm . A good representative of a “coagulating” Nd:YAG laser for lipolysis is the XP-2 Focus Nd:YAG laser system (Fotona d.d.) that has an adjustable high peak power pulse duration range starting as low as 0.2 msec.

Table 2: Thermal relaxation time for the range of blood vessel diameters.

| Vessel diameter (μm) | Thermal relaxation time (ms) |
|-----------------------------------|------------------------------|
| 10 | 0.057 |
| 20 | 0.23 |
| 50 | 1.42 |

It has been reported that QCW pulsed lasers have significantly higher ability to coagulate blood vessels when compared to continuous wave, CW diode lasers [6,33,34]. Treatments with QCW pulsed lasers, such as Nd:YAG, thus result in less bruising, swelling and quicker recovery.

IV. DISCUSSION

The 1064 nm Nd:YAG lasers are the most widely used lasers for lipolysis, with the longest clinical record of safety and efficacy.

For example, Goldman has reported on more than 3,000 cases of successful laser lipolysis performed with the 1064 nm Nd:YAG laser in a period lasting from 1999 to 2006, with minimal side effects and high patient satisfaction. [38] Together with Schavelzon and Blugerman, Goldman has also reported on a three center study in which, during a period of 30 months, 1,734 procedures of laser assisted liposuctions with the 1064 nm Nd:YAG were performed. [9] The results showed the procedure to be safe and effective with minimal side effects. Similarly, Katz’s 18 month, 537 treatment study showed that complications from surgery were minimal. [39] During a meeting of the American Society for Laser Medicine and Surgery, Mazzi, reported on his 5 year (2003 – 2008) experience with 1064 nm Nd:YAG laser lipolysis [40] during which he successfully treated 386 patients with a low occurrence of any complications.



Fig. 20: Example of laser lipolysis treatment (Courtesy of Dr. Maletic)



Fig. 21: Example of laser lipolysis results (Courtesy of Dr. Maletic)

Maletic recently reported on a study with 224 patients with 1064 nm Nd:YAG laser during an 18 month period resulting in very successful body shaping and a very low side effects rate.[41] (fig. 20-22) Similarly Steventon, reported more than 300 successful cases of 1064 nm Nd:YAG laser lipolysis treatments [43]. There were no reports of deaths, pulmonary emboli, viscus perforation, thrombophlebitis, hypovolemic shock, seizures or toxic reactions. Minimal side effects were reported: 0.4% infections, 1% skin irregularities, 0.7% hematoma or seroma, 0.02% unacceptable scarring, 0.9% sensory nerve impairments, 0.12% contact dermatitis.

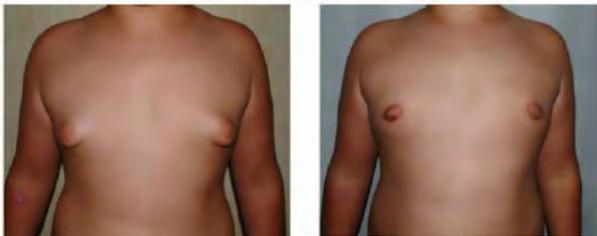


Fig. 22: Example of laser lipolysis results (Courtesy of Prof. Massoud)

There are also other reports, with smaller numbers of patients, all of them presenting positive results in terms of safety and efficacy for the 1064 nm Nd:YAG laser lipolysis treatment [6,35,37,42].

Published clinical studies of laser lipolysis with other wavelengths are much more modest in scope and enrollment. So far, the only study exceeding 100 patients has been done with a 980 nm diode laser in which Reynaud et al. reported about treatment of 534 procedures performed on 334 patients [12]. Results showed successful removal of small volumes of fat, high patient tolerance and quick recovery time.

Initial results with wavelengths 924, 975, 1320 and 1440 nm are, thus far, based on clinical studies in which the number of patients is usually 10-30, and the follow-ups are shorter than one year.

The clinically observed minimal discomfort, exceptional long-term success and short recovery are attributed to Nd:YAG laser's ability to optimally target laser energy into fatty tissue thereby limiting undesirable mechanical and thermal effects in the surrounding tissues.

In addition, the Nd:YAG 1064 nm laser systems have developed significantly since their introduction for laser lipolysis. Nd:YAG lasers with QCW mode power-generating capacity are reaching higher procedure speeds and efficiency while operating at a fraction of their maximum capacity. This ensures system durability, essentially lowering running costs. In conjunction with the VSP (Variable Square Pulse) technology, a wide range of selectable pulse durations are now available in Nd:YAG lasers. This provides better procedure control and extreme versatility. The high performance and versatility of the latest technology solid crystal Nd:YAG 1064 nm laser systems, combined with their optimal efficacy and safety, make these lasers the medical devices of choice when compared with other wavelength devices for laser lipolysis.

V. CONCLUSION

The results of the Monte Carlo statistical simulations are in agreement with clinical reports: a) the Nd:YAG laser wavelength results in the largest thermal volume in the subcutaneous tissue, and is least likely to cause any injury in the neighboring dermis; b) the pulsed QCW mode of operation of the Nd:YAG laser has significantly higher ability to coagulate blood vessels when compared to continuous wave, CW diode lasers.

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