

Superior Lipolytic Effect of the 1,444 nm Nd:YAG Laser: Comparison With the 1,064 nm Nd:YAG Laser

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Background and Objectives: Recently developed laser lipolysis systems have been disappointing because they require more time to remove the same amount of fat than other liposuction methods. A new Nd:YAG laser has been introduced that uses the 1,444 nm wavelength, better absorbed by fat.

Study Design/Materials and Methods: This study consisted of two protocols. The first protocol was an in vivo minipig model. Four 10×10 cm² areas were treated on the back of the first minipig. Using the same total energy and power settings (5,000 J, 8 W), both the 1,064 nm and 1,444 nm lasers were used to irradiate the two cephalic areas. The two caudal areas were irradiated with both lasers, using the maximum power settings (12 W with the 1,064 nm laser, 8 W with the 1,444 nm laser). Another minipig was administered a preoperative injection of tumescent solution and treated with the same condition. Measurements of fat volume with computed tomography and histologic exams were conducted. The second experiment involved in vitro human fat. Equal amounts of human fat, harvested by liposuction, were put into test tubes and irradiated with 1,064 nm and 1,444 nm lasers. Oil production was measured from each test tube.

Results: A marked reduction in fat volume and more oil vacuoles and giant cells in histology were identified with the 1,444 nm wavelength compared to the 1,064 nm wavelength. Human fat in the in vitro experiments also revealed more oil production following the use of the 1,444 nm laser.

Conclusion: The 1,444 nm Nd:YAG laser showed a greater lipolytic effect compared to the 1,064 nm Nd:YAG laser in in vivo minipig and in vitro human fat experiments. To achieve a full understanding of the effects of 1,444 nm Nd:YAG laser lipolysis on the human body, in vivo experimentation will be necessary. *Lasers Surg. Med.* 41:721–727, 2009. © 2009 Wiley-Liss, Inc.

Key words: laser lipolysis; lipoplasty; 1,444 nm; in vivo; Nd:YAG

INTRODUCTION

Body contouring is a major area in the field of dermatologic and plastic surgery. Operative methods, including surgical lipectomy, and less invasive methods, including various liposuction techniques, are mainly used for the purpose of reducing fat. Liposuction can be accomplished using various methods. Widely used methods are suction-assisted liposuction (SAL), ultrasound-assisted liposuc-

tion (UAL), power-assisted liposuction (PAL), and laser-assisted liposuction (LAL) [1].

Laser lipolysis was first introduced in the early 1990s [2]. The 1,064 nm neodymium:yttrium-aluminum-garnet (Nd:YAG) laser has since been the primary wavelength used for lipolytic purposes. Numerous studies have proven the usefulness of 1,064 nm Nd:YAG laser lipolysis [3–6], which has been reported to be associated with less bleeding, dermal tightening, and earlier recovery time [5,7,8] compared to other methods, which has contributed to its popularity.

Several clinicians have tried to use laser lipolysis in various body areas. Kim and Geronemus [7] and Goldman [4] used lipolytic lasers for submental fat reduction. Prado et al. [9] used laser lipolysis for abdominal fat reduction. However, a major problem with using laser lipolysis is that the procedure is labor intensive and requires more time than other methods. As a result, laser lipolysis is not as popular as other methods. Understandably, practitioners want improved and refined laser instrumentation that is more effective than traditional methods [9].

Each laser targets different chromophores with different levels of affinity. The lipolytic effect of the laser is manifested by its photoacoustic and photothermal effects on fat and water [10,11]. Anderson et al. [12] reported that some lasers that use other wavelengths have much more affinity in fat than the 1,064 nm laser (Fig. 1). For example, the 1,400-nm wavelength laser has more than 10 times the fat absorption rate than the 1,064 nm wavelength laser. Until recently, these instruments were not commercialized because of technologic limitations. In recent years, 1,440 nm Nd:YAG fractional lasers were only used for the treatment of photoaging, scars, and nevi of Ota [13,14]. There have been no other clinical applications of Nd:YAG lasers in the 1,400 nm wavelength vicinity in the medical field.

We certify that we have no affiliation with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the manuscript.

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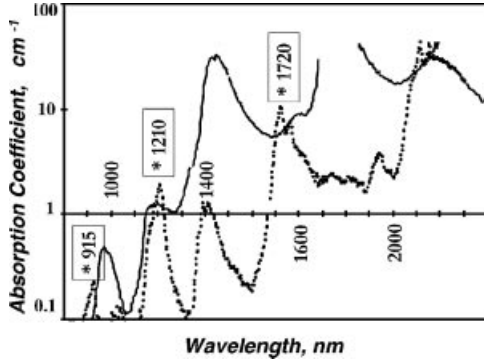


Fig. 1. Infrared absorption spectra of water (solid line) and human fat (dotted line). The 1,400 nm wavelength laser has more than 10 times the fat absorption rate than the 1,064 nm wavelength laser.

The newly developed and introduced 1,444 nm Nd:YAG laser might provide a much higher affinity in fat than the 1,064 nm Nd:YAG laser. Studies can assess the lipolytic effect by comparing the two wavelengths.

MATERIALS AND METHODS

Comparing 1,444 nm and 1,064 nm Nd:YAG Laser Lipolysis in In Vivo Minipig Models

After permission was granted from the ethics committee at the Yonsei University Institutional Animal Care and Use Committee, the following protocol was performed.

Two male minipigs, aged 14–15 months, were used in this protocol. General anesthesia was induced by means of an intramuscular bolus injection of Telazol[®] (Wyeth, Madison, NJ; 6 mg/kg) and atropine (0.05 mg/kg). Endotracheal intubation was performed, and a ventilator was connected using enflurane (2.5%, 420 ml/min) and oxygen (2 L/min). Intravenous hydration with normal saline was maintained through a superficial auricular vein (25 ml/hour). The minipigs' hair were cut with an electrical cutter, and sterilization of the operative field was accomplished with 20% Betadine[®] solution.

Using the spinous process as midline, four 10×10 cm² rectangular operative fields, or areas, were designed. Each operative area was at least 4 cm apart to minimize thermal effect on the other operative areas. A prototype 1,064 nm Nd:YAG laser (Lutronic Corporation, Seoul, Republic of Korea) and 1,444 nm Nd:YAG laser (AccuSculpt[™], Lutronic Corporation) were used for this study. The operative areas on the left side were treated with the 1,064 nm Nd:YAG laser and operative areas on the right side were treated with the 1,444 nm Nd:YAG laser. The cephalic row was treated using all of the same parameters (total energy 5,000 J, polyimide-coated, 600 μm optic fiber diameter, 200 mJ, pulse width 200 μseconds, 40 Hz), with the exception of the wavelength (left: 1,064 nm, right: 1,444 nm). The caudal row was treated with the maximum energy of each wavelength (12 W, 300 mJ with the 1,064 nm laser; 8 W, 200 mJ with the 1,444 nm laser) and using the same parameters as the cephalic row. The endpoint of irradiation was determined by the total energy (5,000 J) delivered to the cephalic row and by the total treatment time (7 minutes) for treatment of the caudal row.

row. In the caudal row, the total treatment time was the same (7 minutes), but the left operative areas were treated with the 1,064 nm laser (total energy 5,040 J), and the right operative areas were treated with the 1,444 nm laser (total energy 3,360 J) (Fig. 2). The endpoint of irradiation was determined by the total energy (5,000 J) delivered to the cephalic row and by the total treatment time (7 minutes) for treatment of the caudal row.

One of the two minipigs was injected with tumescent solution comprised of 10 ml of 4% lidocaine and 1 ml of 1:1,000 epinephrine in 1 L of lactated Ringer's solution (100 ml per treatment area); all other experimental parameters were identical. This particular experiment was designed with consideration of the practical use of lipolytic lasers in the clinical setting, because numerous practitioners perform laser lipolysis after tumescent injection.

After the operative fields were marked, each area was irradiated using the planned settings. The cannula was introduced into the area after a stab incision was made. The velocity of the cannula was 2 cm/second. Determination of cannula speed was based on a previous study using the



Fig. 2. Experimental designs of minipig experimental model. Operative areas on the left side were treated with the 1,064 nm Nd:YAG laser, and operative areas on the right side were treated with the 1,444 nm Nd:YAG laser. The cephalic row was treated using all of the same parameters (total energy 5,000 J, polyimide-coated, 600 μm optic fiber diameter, 200 mJ, pulse width 200 μseconds, 40 Hz), with the exception of the wavelength (left: 1,064 nm, right: 1,444 nm). The caudal row was treated with the maximum energy of each wavelength (12 W, 300 mJ with the 1,064 nm laser; 8 W, 200 mJ with the 1,444 nm laser) and using the same parameters as the cephalic row. The endpoint of irradiation was determined by the total energy (5,000 J) delivered to the cephalic row and by the total treatment time (7 minutes) for treatment of the caudal row.

1,064 nm Nd:YAG laser [15]. A total of 20 stab incisions were made in a lattice-shaped pattern, and a transverse $1 \times 10 \text{ cm}^2$ row was treated each time.

Measuring changes in fat volume. Changes in fat volume were measured by computed tomography (CT) preoperatively, and at 8 and 29 days postoperatively, using an Aquarius WorkstationTM (Ver. 3.6.3.0, TeraRecon, Inc., San Mateo, CA). The same method was used for measuring fat volume in a previous study [16]. Each $10 \times 10 \text{ cm}^2$ area was divided into 10 transverse $10 \times 1 \text{ cm}^2$ fragments. Fat volume was measured per each fragment and 10 measurements were collected in each treatment area. Results of each laser treatment were evaluated by average volume of $10 \times 1 \text{ cm}^2$ fragments of each area. The serial volume change was measured and analyzed (cm^3 , Hounsfield unit = -490 to -50) (Fig. 3).

Histologic comparisons. The minipigs were sacrificed by potassium chloride injection 32 days postoperatively. Four tissues were harvested in full depth from each $10 \times 10 \text{ cm}^2$ area and stained with hematoxylin and eosin stains. Histologic findings for each sample were compared by a pathologist in a blinded study setting.

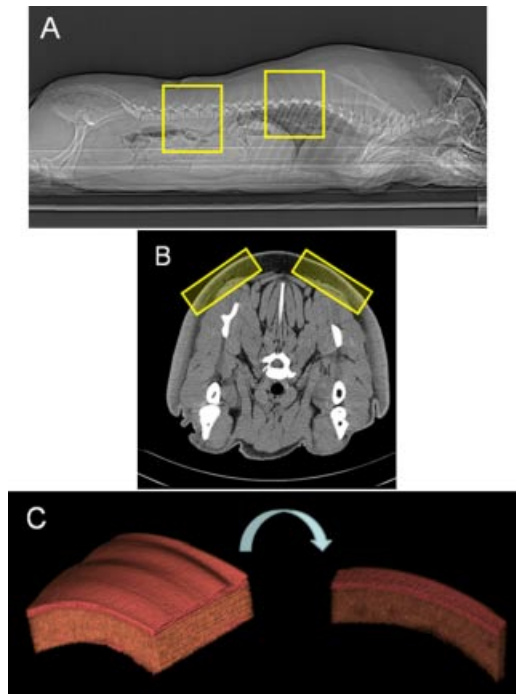


Fig. 3. Measuring changes in the volume of fat. Experiment areas were drawn in lateral view (A). Experiment areas were drawn in anteroposterior view (B). Three dimensional volume analysis of fat volume. Area ($10 \times 10 \text{ cm}^2$) was divided into 10 transverse $10 \times 1 \text{ cm}^2$ fragments. Fat volume was measured per each fragment. So, 10 measurements data were collected in each treatment area. Results of each laser treatment were evaluated by average volume of $10 \times 1 \text{ cm}^2$ fragments of each area (C).

Comparing 1,444 nm and 1,064 nm Nd:YAG Laser Lipolysis in an In Vitro Human Fat Model

With the consent of the patient, human fat was harvested from the abdomen during abdominoplasty by PAL (LipoKit, Seoul, Korea). The harvested fat was washed twice with phosphate-buffered saline (PBS) solution, and water was removed with cotton sponges. A total of 10 test tubes were filled with 9.5 g of fat each. Five of the tubes were used for 1,064 nm laser lipolysis, and the other five tubes were used for 1,444 nm laser lipolysis. Laser treatments were carried out by introducing a cannula into the test tubes, with a tip velocity of 2 cm/second for 30 seconds. The 1,064 nm and 1,444 nm Nd:YAG lasers were set identically at 8 W, 200 mJ/second, and 40 Hz, with a total energy output of 240 J. The cannula diameter was $600 \mu\text{m}$ in both lasers. After lipolysis, each test tube was treated with collagenase and was centrifuged for 10 minutes at 1,200g. Lipolysis comparison was accomplished by measuring the weight of the layer of oil resulting from centrifugation.

Statistics

Standard *t*-test was used to compare the two groups. Normally distributed continuous variables were described by mean \pm standard deviation (SD). All reported *P* values were two-sided and an alpha level of <0.05 was considered statistically significant. SPSS (ver 10.0, SPSS, Inc., Chicago, IL) software was used for the statistical evaluations.

RESULTS

Comparing 1,444 nm and 1,064 nm Nd:YAG Laser Lipolysis in In Vivo Minipig Models

Measuring changes in fat volume. The body weight of the first minipig was 52.2 kg (preoperatively), 52.8 kg (8 days postoperatively), and 53.9 kg (29 days postoperatively). Except for the two different wavelengths, the parameters used to treat the two areas in the cephalic row on the first minipig were the same (total 5,000 J, 8 W, 200 mJ/s, 40 Hz, $600\text{-}\mu\text{m}$ cannula) for both lasers. Fat volume (cm^3) in the $1 \times 10 \text{ cm}^2$ area treated with the 1,064 nm laser was 25.9 ± 3.0 (preoperatively), 24.6 ± 2.2 (8 days postoperatively), and 25.9 ± 2.3 (29 days postoperatively), compared with 25.3 ± 2.3 (preoperatively), 21.5 ± 2.3 (8 days postoperatively), and 21.7 ± 2.5 (29 days postoperatively) in the $1 \times 10 \text{ cm}^2$ area treated with the 1,444 nm laser.

The two areas in the caudal row on the first minipig were treated with maximum power for each wavelength (12 W with the 1,064 nm laser, and 8 W with the 1,444 nm laser), with the same duration of treatment (7 minutes). Fat volume (cm^3) in the $1 \times 10 \text{ cm}^2$ area treated with the 1,064 nm laser were 26.3 ± 1.5 (preoperatively), 24.3 ± 1.6 (8 days postoperatively), and 26.1 ± 2.0 (29 days postoperatively), compared with 25.3 ± 1.4 (preoperatively), 22.7 ± 1.9 (8 days postoperatively), and 23.5 ± 1.9 (29 days postoperatively) in the $1 \times 10 \text{ cm}^2$ area treated with the 1,444 nm laser.

The body weight of the second minipig was 42.3 kg (preoperatively), 43.8 kg (8 days postoperatively), and 49.4 kg (29 days postoperatively). This minipig was the

TABLE 1. In Vivo Minipig Experiments Without Tumescence (Fat Volume, cm³)

Postoperative days	Same total energy (5,000 J)			Maximal power (12 W in 1,064 nm vs. 8 W 1,444 nm)		
	1,064 nm	1,444 nm	<i>P</i>	1,064 nm	1,444 nm	<i>P</i>
0	25.9 ± 3.0	25.3 ± 2.3	0.668	26.3 ± 1.5	25.3 ± 1.4	0.13
8	24.6 ± 2.2	21.5 ± 2.3 ^a	0.005	24.3 ± 1.6	22.7 ± 1.9 ^a	0.001
29	25.9 ± 2.3	21.7 ± 2.5 ^a	0.043	26.1 ± 2.0	23.5 ± 1.9 ^a	0.007

^a*P* < 0.05.

same experimental model as the first minipig except that the second minipig was injected with tumescent solution (100 cc per area). Cephalic row volume (cm³) in the 1×10 cm area treated with the 1,064 nm laser was 23.8 ± 2.0 (preoperatively), 23.0 ± 2.0 (8 days postoperatively), and 24.4 ± 2.0 (29 days postoperatively), compared to 24.4 ± 2.1 (preoperatively), 20.9 ± 2.0 (8 days postoperatively), and 22.3 ± 2.2 (29 days postoperative) in the 1×10 cm area treated with the 1,444 nm laser.

Fat volume (cm³) in the 1×10 cm² area in the caudal row treated with the 1,064 nm laser were 25.4 ± 1.9 (preoperatively), 24.5 ± 2.1 (8 days postoperatively), and 26.1 ± 1.8 (29 days postoperatively), compared with 25.9 ± 2.3 (preoperatively), 23.0 ± 1.9 (8 days postoperatively), and 24.3 ± 1.8 (29 days postoperative) in the 1×10 cm² area treated with the 1,444 nm laser. These data are also shown in Tables 1 and 2.

Histologic comparisons. Histology was evaluated 32 days postoperatively by a pathologist. In the first minipig, which was not injected with tumescent solution, the tissue that was treated with the 1,064 nm laser showed no specific findings except for a few slight fibrotic changes. However, tissue treated with the 1,444 nm laser showed an abundance of large fat vacuoles (spaces filled with oil produced after adipocyte rupture), inflammatory cells, and fibrotic changes. Giant cells were also seen in abundance around the large fat vacuoles (Fig. 4).

Histologic findings for the second minipig, which was injected with tumescent solution, were similar to those of the first minipig (Fig. 5). Tissue treated with the 1,064 nm laser with 5,000 J of total energy (Fig. 5A) showed histologic findings similar to those associated with tissue treated with the 1,444 nm laser. It is important, however, to keep in mind that in this study, the findings for the most severe portions of injured tissue are presented and, on the whole, histologic changes in tissue treated with the 1,444 nm laser

were more extensive than the histologic changes seen in tissue treated with the 1,064 nm laser.

The cephalic rows showed more prominent changes in comparison to the caudal rows. In this experimental setting, the use of tumescent solution did not make much difference in the microscopic view.

Comparing the 1,444 nm and 1,064 nm Nd:YAG Laser Lipolysis in an In Vitro Human Fat Model

In this protocol, oil production resulting from the rupture of adipocytes was more prominent in the group treated with the 1,444 nm laser. The oil weight (g) was 0.51 ± 0.17 in the 1,064 nm laser group and 0.83 ± 0.12 (*P* = 0.01) in the 1,444 nm laser group (Table 3 and Fig. 6).

DISCUSSION

Fatty tissue reduction is an essential part of body contouring, with surgical lipectomy and liposuction the two main procedures. Liposuction is more popular than surgical lipectomy because it is less invasive and more effective.

Some authors advocated that laser lipolysis offers several advantages: less bleeding, less pain, dermal tightening, no need for an incision and repair, minimal tissue damage, and early recovery compared to other liposuction methods [3,6,9,15]. Despite the fact that their study is somewhat controversial, Katz et al. [5] found that highly vascularized areas and areas where skin laxity might worsen after conventional liposuction may now be successfully treated with laser lipoplasty.

The Nd:YAG and diode lasers are the lipolytic lasers currently being clinically used. Nd:YAG laser lipolysis was first described in 1994 and was mainly used in Europe and South America [2]. Today, it has become one of the most popular laser lipoplasty methods in the world. The mechanism of action of laser lipolysis is not clear [9].

TABLE 2. In Vivo Minipig Experiments With Tumescence (Fat Volume, cm³)

Postoperative days	Same total energy (5,000 J)			Maximal power (12 W in 1,064 nm vs. 8 W 1,444 nm)		
	1,064 nm	1,444 nm	<i>P</i>	1,064 nm	1,444 nm	<i>P</i>
0	23.8 ± 2.0	24.4 ± 2.1	0.49	25.4 ± 1.9	25.9 ± 2.3	0.55
8	23.0 ± 2.0	20.9 ± 2.0 ^a	0.026	24.5 ± 2.1	23.0 ± 1.9	0.122
29	24.4 ± 2.0	22.3 ± 2.2 ^a	0.038	26.1 ± 1.8	24.3 ± 1.8 ^a	0.046

^a*P* < 0.05.

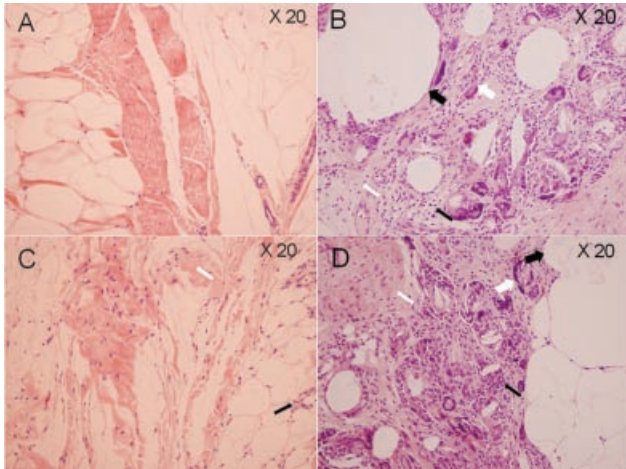


Fig. 4. Histology of 32 postoperative days in minipig experimental model (without tumescent). 1,064 nm laser (5,000 J) (A); 1,444 nm laser (5,000 J) (B); 1,064 nm laser (12 W) (C); lower right, 1,444 nm laser (8 W) (D). Tissues treated with 1,444 nm Nd:YAG laser showed an abundance of large fat vacuoles (black thick arrows), inflammatory cells (black thin arrows) and fibrotic changes (white thin arrows). Giant cells (white thick arrows) were also seen in abundance around the large fat vacuoles.

Recently, Khoury et al. [10] suggested that a combination of photoacoustic ablation and selective photothermolysis of fibrous septae was the main mechanism of action of laser lipolysis. However, they also noted that it is

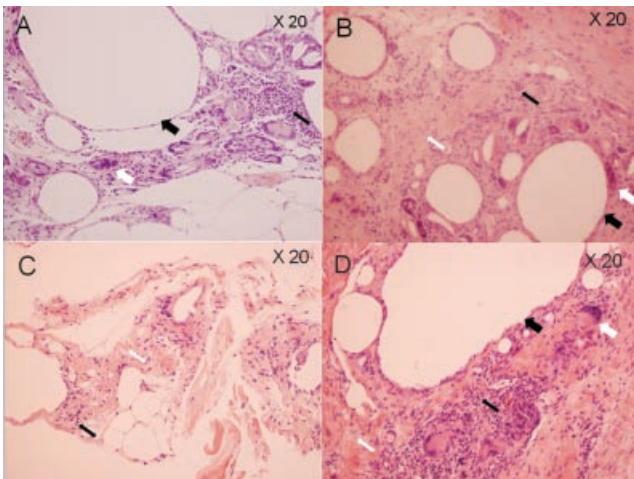


Fig. 5. Histology of 32 postoperative days in minipig experimental model (with tumescent). 1,064 nm laser (5,000 J) (A); 1,444 nm laser (5,000 J) (B); 1,064 nm laser (12 W) (C); 1,444 nm laser (8 W) (D). Tissues treated with 1,444 nm Nd:YAG laser showed an abundance of large fat vacuoles (black thick arrows), inflammatory cells (black thin arrows), fibrotic changes (white thin arrows) and giant cells (white thick arrows). These findings were more extensive in tissues treated with 1,444 nm laser.

TABLE 3. In Vitro Human Fat Experiments

No.	1,064 nm (gram of oil)	1,444 nm (gram of oil)
1	0.4	0.7
2	0.23	1
3	0.62	0.92
4	0.65	0.75
5	0.63	0.8
Mean ± SD	0.506 ± 0.165	0.834 ± 0.123

P-value = 0.01.

difficult to separate the photoacoustic effect from the thermal effect.

As noted in Figure 1, the most widely used 1,064 nm Nd:YAG laser does not have the highest affinity to fat and water compared with lasers of other wavelengths. However, technologic limitations block more efficient wavelength use. Recently, the 1,444 nm Nd:YAG laser was developed. Theoretically, it has been anticipated that more effective laser lipolysis can be done with the 1,444 nm wavelength because its affinity to fat is more than 10 times greater than that associated with the 1,064 nm wavelength.

In addition, fat contains 14% water and collagen contains approximately 60% water [11]. The increased affinity of the 1,444 nm laser to water was much greater than the increased affinity to fat compared with the 1,064 nm laser. Therefore, the favorable effects of laser lipolysis, including dermal tightening and less bleeding, might be augmented by the 1,444 nm laser. This article is one of the first studies of 1,444 nm Nd:YAG laser lipolysis that has shown its quantitative superiority over the 1,064 nm Nd:YAG laser.

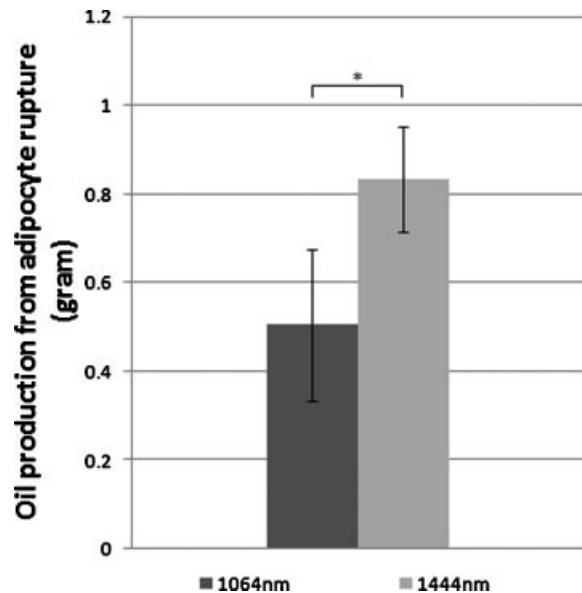


Fig. 6. Graph of human fat in vitro experimental model (*P = 0.01). 1,444 nm Nd:YAG laser showed much more oil reduction than 1,064 nm Nd:YAG laser.

In animal experimental models, all volume measurements results showed statistically superior lipolytic effects resulting from the use of the 1,444 nm Nd:YAG laser, except for the results of the maximum power experiment with tumescent solution on the 8th postoperative day. However, on the 29th postoperative day, the 1,444 nm laser once again showed statistically significant superiority. The reason for this finding is not clear, but considering the high number of remaining oil vacuoles on the 29th postoperative day, excessive adipocyte rupture beyond the lymphatic drainage system can cause oil vacuole accumulation, which may be interpreted as fat on CT. The graphs also showed an initial reduction in fat, but later there was an increase. We thought this might be the result of weight gain (data were showed in the results) of minipigs because all the graphs had such a tendency.

Histologic studies showed an abundance of oil vacuoles and giant cells. Ruptured adipocytes emit oil, and giant cells may phagocytose it. Inflammatory cells and fibrosis may also result and be associated with thermal damage from the laser. Signs of hemorrhage were not seen, probably because the samples were collected 32 days postoperatively. Carbonization of fat tissues was also shown but was rare (data not shown). Carbonization may also have been due to delayed sample collection. Melega [17] reported histologic changes after 1,064 nm Nd:YAG laser irradiation on human tissue that coagulated small vessels and the collagen of the fatty tissue and ruptured adipocytes. Other articles reported char, tumefaction (reversible cell damage), cavitation, cell lysis, coagulation, and hemorrhage on microscopic view after laser lipolysis. Because these findings are based on sampling performed immediately after a laser procedure, comparison with our findings is difficult [3,15].

Owing to the limitations of histologic examination, quantitative analysis was difficult. But on microscopic view, there were clear differences in the number of oil vacuoles, fibrotic changes, and giant cells, and in the size of the thermally damaged area. Considering the association between powerful lipolytic effect and thermal damage, burns could be a complication of the 1,444 nm laser, and caution should be taken so as to avoid overuse. However, in this experimental setting, we did not observe any skin changes in either minipig that might indicate a burn, such as erythema or blisters.

Oil vacuoles can also be a problem. If they exceed the capacity of the lymphatic drainage system, they can become a medium for bacterial contamination. Moreover, any remaining emulsified fat can cause the release of free fatty acids and can theoretically affect renal and hepatic function [9]. If the amount of lipolytic fat is large or hepatic and renal function is compromised, it is possible that the free fatty acids might harm the patient's health. Therefore, suction would be necessary if the amount of lipolytic fat is considerable.

The color of minipig subcutaneous fat is comparatively whiter than that of human subcutaneous fat. Color is a very important factor affecting laser absorption given the role of chromophores. Thus, to achieve a full understanding of the

effect of 1,444 nm Nd:YAG laser lipolysis on human fat, in vivo experimentation will be necessary.

In vitro human fat tissue models also show superior lipolytic effect with the use of the 1,444 nm Nd:YAG laser. In this experimental model, dwelling time in any one area can potentially impact fat destruction, even with same amount of total time delivered. In addition, this would be different from in vivo situation because there were no vessels or fibrous frames. In spite of these problems, we could estimate the lipolytic effect of 1,444 nm Nd:YAG laser in human indirectly with these experiments.

CONCLUSION

This study is one of the first reports on the 1,444 nm Nd:YAG laser, a new tool for performing lipolysis. Its effective lipolytic features promise great advantages over the 1,064 nm Nd:YAG laser. However, burns and oil collection can be serious complications because of the powerful thermal and lipolytic effects of the 1,444 nm laser. Additional in vivo investigation is necessary to determine safety guidelines for its use on human patients and to prevent burns.

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