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Penetration of Laser Light at 808 and 980 nm in Bovine Tissue Samples

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Abstract

Objective: The purpose of this study was to compare the penetration of 808 and 980 nm laser light through bovine tissue samples 18–95 mm thick. ***Background data:*** Low-level laser therapy (LLLT) is frequently used to treat musculoskeletal pathologies. Some of the therapeutic targets are several centimeters deep. ***Methods:*** Laser light at 808 and 980 nm (1 W/cm^2) was projected through bovine tissue samples ranging in thickness from 18 to 95 mm. Power density measurements were taken for each wavelength at the various depths. ***Results:*** For 808 nm, 1 mW/cm^2 was achieved at 3.4 cm, but for 980 nm, 1 mW/cm^2 was achieved at only 2.2 cm depth of tissue. ***Conclusions:*** It was determined that 808 nm of light penetrates as much as 54% deeper than 980 nm light in bovine tissue.

Introduction

Low-level laser therapy (LLLT) is a light therapy frequently used to treat musculoskeletal pathologies. Some of the therapeutic targets can be several centimeters deep, such as the piriformis and psoas muscles, hip joints, intervertebral discs, and the spinal cord. Byrnes et al.[i] found that near infrared light in the range 770–850 nm penetrates deeper through Sprague–Dawley rat tissue than red light or longer infrared wavelengths, up to 1200 nm. They projected Broadband Light transcutaneously through the dorsal skin over thoracic vertebrae, and utilized an optical fiber probe attached to a spectrophotometer to collect data at various layers of tissue. They found that depth of penetration is wavelength dependent, with maximum penetration achieved between 770 and 850 nm. They subsequently chose 808 nm to conduct their spinal cord injury experiments, because that was the peak penetrating wavelength in their study. The purpose of this study was to compare the penetration of 808 and 980 nm laser light through bovine tissue samples 18–95 mm thick.

Materials and Methods

Tissue samples

We chose lean bovine tissue samples for this study. According to Cilesiz and Welch,[ii] "Unavoidable deformation and handling of the tissue such as drying, freezing and dehydration especially leads to a gross effect on the optical properties of tissue." To minimize these effects, only fresh bovine tissue samples were used for each wavelength we tested, and the tests were made as quickly as possible with a minimum of handling. Sample thicknesses ranging from 18 to 95 mm thick were measured with metric calipers. After the bovine tissue samples reached ambient temperature, tests on them were conducted within 4–5 min.

Light sources

A summary of beam parameters is shown in Table 1. The laser sources were coupled to 200 μm fiberoptic cable, and lenses were used to expand the beam and convert from Gaussian to flat top distribution and then projected onto the bovine tissue to produce a 1 cm^2 beam (see Fig. 1).

Measurement instruments and software

The beam parameters were measured using the following instruments: a 45° polka-dot patterned 50/50 beam splitter, a PD3000 photodiode power sensor (Ophir-Spiricon, Inc.), neutral density filters, a SP620U CCD camera, a laptop computer running Beam Gage© (Ophir-Spiricon, Inc.) laser beam analyzer software, and LabStar© power measurement software. The Beam Gage laser beam analyzer software interfaces with the Ophir power sensor and CCD camera, collects real-time power results, and integrates them. This system is as accurate as a National Institute of Standards and Technology-referenced power head. It eliminates the need to

Respond Systems, Inc., Branford, Connecticut.

Table 1. Summary of Beam Parameters

Wavelength (nm)	808 nm	980 nm
Output (W)	1 W	1 W
Illuminated area (cm^2)	1 cm^2	1 cm^2
Irradiance (W/cm^2)	1 W/cm^2	1 W/cm^2
Beam profile	Top-hat	Top-hat
Manufacturer	Respond Systems, Inc.	Respond Systems, Inc.

manually calibrate Beam Gage based on ever changing setup conditions.

Setup

The splitter, which is wavelength independent, divides the light into two equal beams, each half the intensity of the original, after a manual correction. One of these beams was directed to the power sensor, and the other was directed to the CCD camera. Neutral filters inserted between the beam splitter and the camera prevented the beam from saturating the receiver in the camera. The software compensated for the attenuation caused by the filters.

The configuration of equipment shown in Fig. 2 enables us to acquire two or three dimensional light patterns of the power density. The data provided by the Beam Gage system are accurate to four significant figures and they also provide colored images that can be related to power density.

The two-dimensional pattern in Fig. 3 shows laser light at a wavelength of 808 nm, 1 W power, projected through a 6.4 cm sample of fresh bovine tissue. The beam pattern is generally circular in shape as expected. The center is bright red and indicates the highest value of power density, followed by yellow, which is slightly lower in power density, and then green, and finally blue, a very low value. The white irregular spots in the center of the pattern are spots of camera sensor saturation, and adjustments are made to the Beam Gage profile to minimize these spots.

The same piece of fresh bovine tissue is shown in a three-dimensional view in Fig. 4. All of the three-dimensional light patterns are viewed as if one is looking down at a section of tissue. The camera has been focused on the bovine tissue sample where the laser light is exiting the meat sample; that is why the camera is placed 11.625 cm from the sample. Some portion of the energy emitted into the tissue is being absorbed within the bovine tissue sample; the camera is recording scattered laser light that is exiting the surface.

Many details not obvious in the two-dimensional view can be seen in the three-dimensional view. The vertical scale

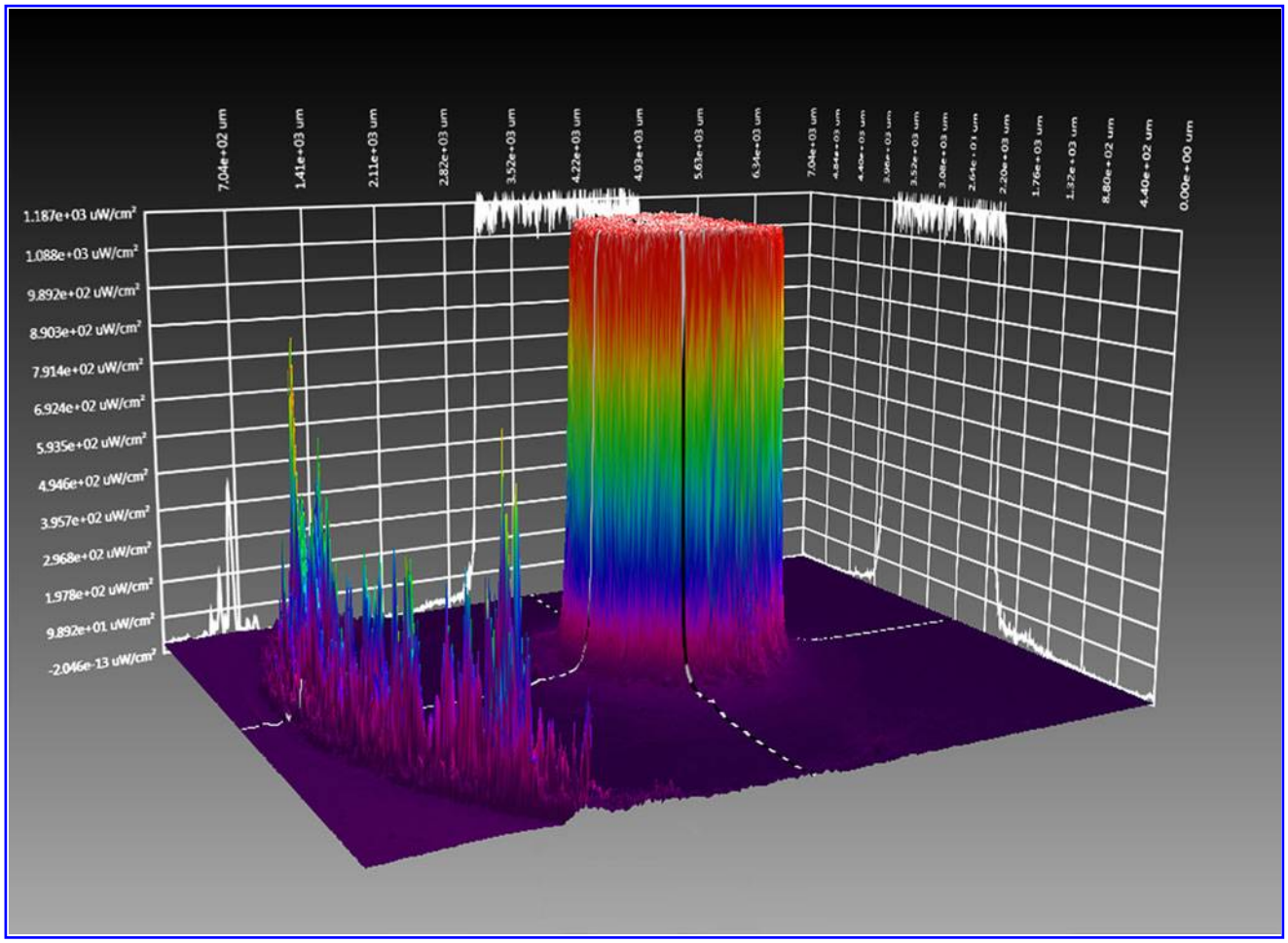

FIG. 1. Top-hat light pattern before entering tissue sample.

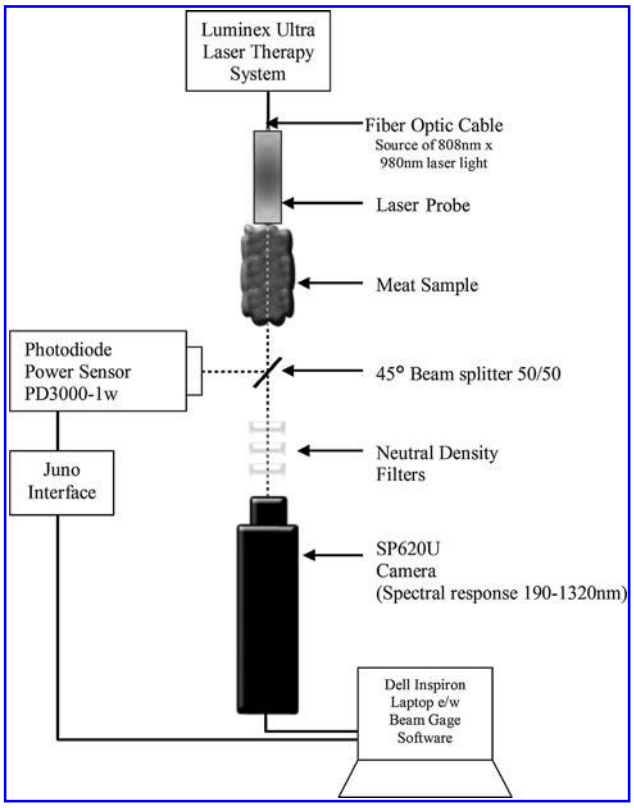

FIG. 2. Configuration for components for two- and three-dimensional pictures of laser light exiting meat sample.

provides a measure of the power density (chosen as $\mu W/cm^2$), and the scale on the horizontal axis was selected to provide data on the width of the pattern in micrometers.

Many of the three-dimensional patterns generated in tests show marked change in the power density over the surface of the tissue. In some local spots, the transmission of laser light is much higher than in other spots. Niemz[iii] summarized the research work of many scientists relative to the optical properties of human tissue *in vitro*. The evidence reveals a wide range of absorption coefficients as well as scatter coefficients for bone, skin, blood, and muscle, depending upon wavelength. Consequently, it is not surprising that three-dimensional laser light patterns would display power density areas of high or low absorption of laser energy depending upon the type of tissue encountered.

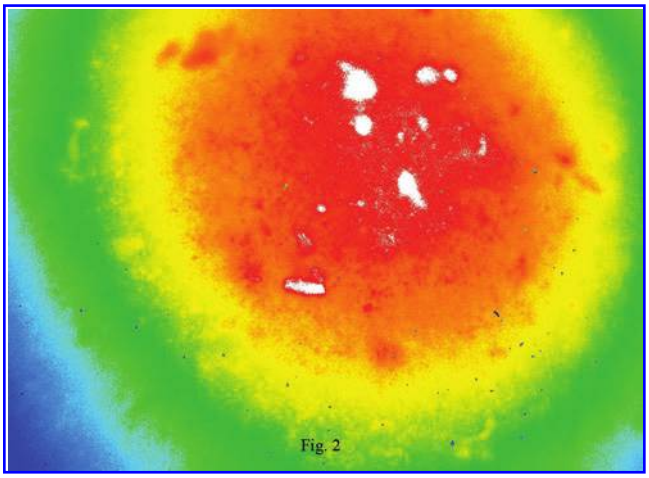

FIG. 3. Laser light two-dimensional pattern.

Results

Power and power density measurements were made with 10 different thicknesses of sample tissue in order to plot a line of best fit on a graph, generated using Microsoft Office Excel 2010. The lines were generated using the exponential trend lines setting in Excel. This setting also produced equations that were used to predict additional data points in the graph. The power and power density measurements are shown in Table 2. Using the exponential best fit equation, data points were calculated for thicknesses of 0.1–10 cm, shown in Table 3. The trend lines plotting the measured and calculated power density data points from Tables 2 and 3 are shown in Fig. 5. The "Y" axis (labeled "Meat Thickness cm") is a linear scale and the "X" axis (labeled "Power Density W/cm^2") is a logarithmic scale.

Discussion

Because the slopes of the measured power versus thickness line for 808 and 980 nm are different, the penetration we see with 808 and 980 nm laser light varied at different power density levels. For example, at a measured power of 1 mW/cm^2, the depth of penetration is 3.4 cm for 808 nm, and at the same measured power density level, the depth of penetration for 980 nm is 2.2 cm. The penetration at that power level improved > 54% at 808 nm. At a power level of 1000 nW/cm^2, the depth of penetration for 808 nm laser is 8.4 cm, as opposed to 5.9 cm for 980 nm laser light. At this power level, penetration improved by 42% with the 808 nm laser.

Two- and three-dimensional pictures of laser light penetrating a tissue sample display absorption and scatter of light in tissue at different wavelengths, and illustrate the data we obtained. In our study, we used a laser light source with a *top-hat pattern*, shown in Fig. 1, meaning that the laser light exited the laser probe with the same power density across the lens of the probe. It looks like an old fashioned top hat. The advantage of a top-hat laser pattern is that there are no spots in the laser pattern with uneven power densities that could burn or irritate the tissue. This pattern was evident just before the laser light entered the tissue sample.

We compared that top-hat pattern of laser light entering the tissue sample with the laser light pattern at 808 nm that leaves the sample after 3.3 cm of tissue thickness, shown in Fig. 6. Laser light is now spread over a much larger area; the top-hat pattern disappears and is replaced by a Gaussian light pattern of various shapes. We used the term "various shapes" to call attention to the fact that in tests of laser light with a wavelength of 808 nm, the Gaussian pattern formed in the thinner sections of the sample was close to a normal distribution (bell shaped curve). As the thickness increased, fat tails began to appear in the Gaussian pattern and it became flatter.

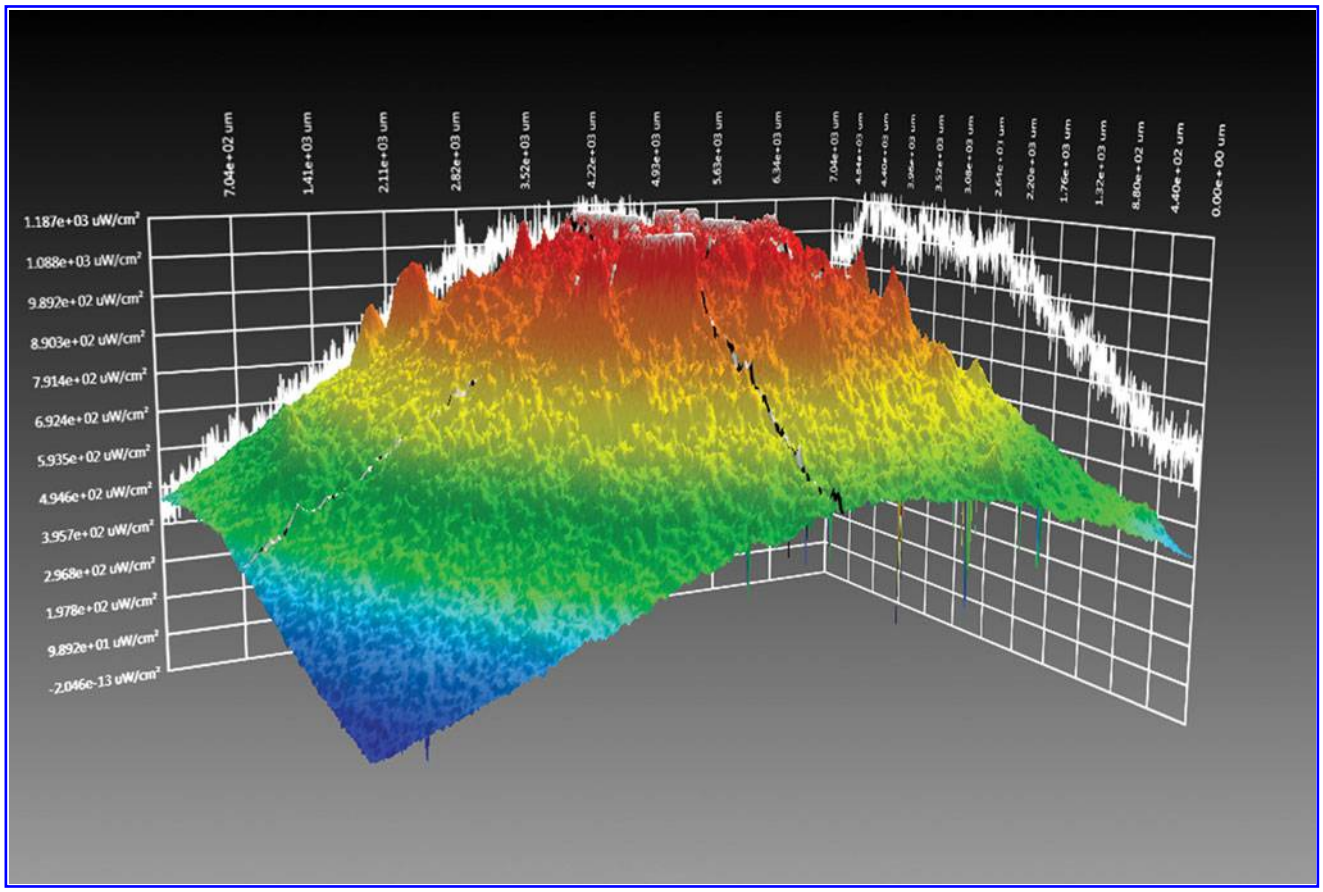

FIG. 4. Laser light three-dimensional pattern.

Beam Gage permits the calculation of a factor called *Roughness of Fit* for these patterns, thereby providing a method for comparing a laser light pattern generated against a standard. Note the irregular surface of the three-dimensional laser light pattern. These peaks and valleys are the result of laser light passing through different types of tissue with different values of absorption and scatter coefficients.

Laboratory tests using a wavelength of 980 nm gave very different exit light patterns after 2.8 cm of tissue, shown in Fig. 7. In general, the patterns formed were noticeably flatter. The colors shown in Figure 6 at 808 nm maintain the more intense orange and yellow, whereas the 980 nm pattern in Fig. 7 has much less intensity, with corresponding blue and purple, even though the 808 light had exited a 17% thicker sample of tissue.

The scope of this research work does not include a study of the thermal effects at a microscopic level for 808 and

Table 2. Power and Power Density Measurements

Thickness of tissue sample in cm	*Source wavelength*	*Power in mW*	*Average power density in mW/cm²*
1.8	808	4.0	10.8
3.3	808	0.36	0.99
6.2	808	0.010	0.0272
7.5	808	0.00125	0.0032
9.53	808	0.000098	0.000216
1.92	980	0.85	2.64
2.8	980	0.1	0.311
3.9	980	0.0095	0.0262
5.65	980	0.000620	0.001640
7.0	980	0.000070	0.000185

Table 3. Predictive Data

808 nm data Avg. power density (W/cm²)	*Best fit (cm) y = −0.72ln(x) - 1.5288*	*980 nm data Avg. power density (W/cm²)*	*Best fit (cm) y = −0.535ln(x) - 1.4556*
0.100000	0.129061267	0.100000	−0.223716975
0.030000	0.995921686	0.030000	0.420408475
0.010000	1.786922534	0.010000	1.00816605
0.003000	2.653782953	0.003000	1.6522915
0.001000	3.444783801	0.001000	2.240049074
0.000300	4.31164422	0.000300	2.884174525
0.000100	5.102645068	0.000100	3.471932099
0.000030	5.969505487	0.000030	4.116057549
0.000010	6.760506335	0.000010	4.703815124
0.000003	7.627366754	0.000003	5.347940574
0.000001	8.418367602	0.000001	5.935698149
0.0000003	9.285228021	0.0000003	6.579823599
0.0000001	10.07622887	0.0000001	7.167581173
0.00000003	10.94308929	0.00000003	7.811706624
0.00000001	11.73409014	0.00000001	8.399464198

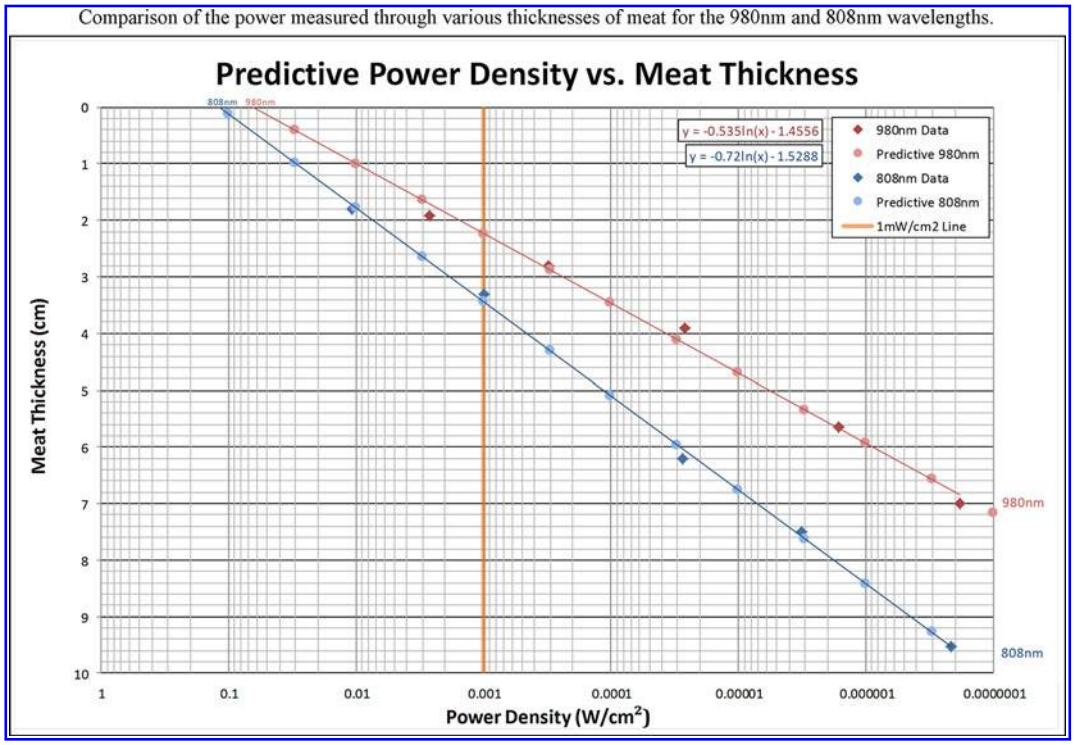

FIG. 5. Actual and predictive power dentisty measurements of 808 and 980 nm light.

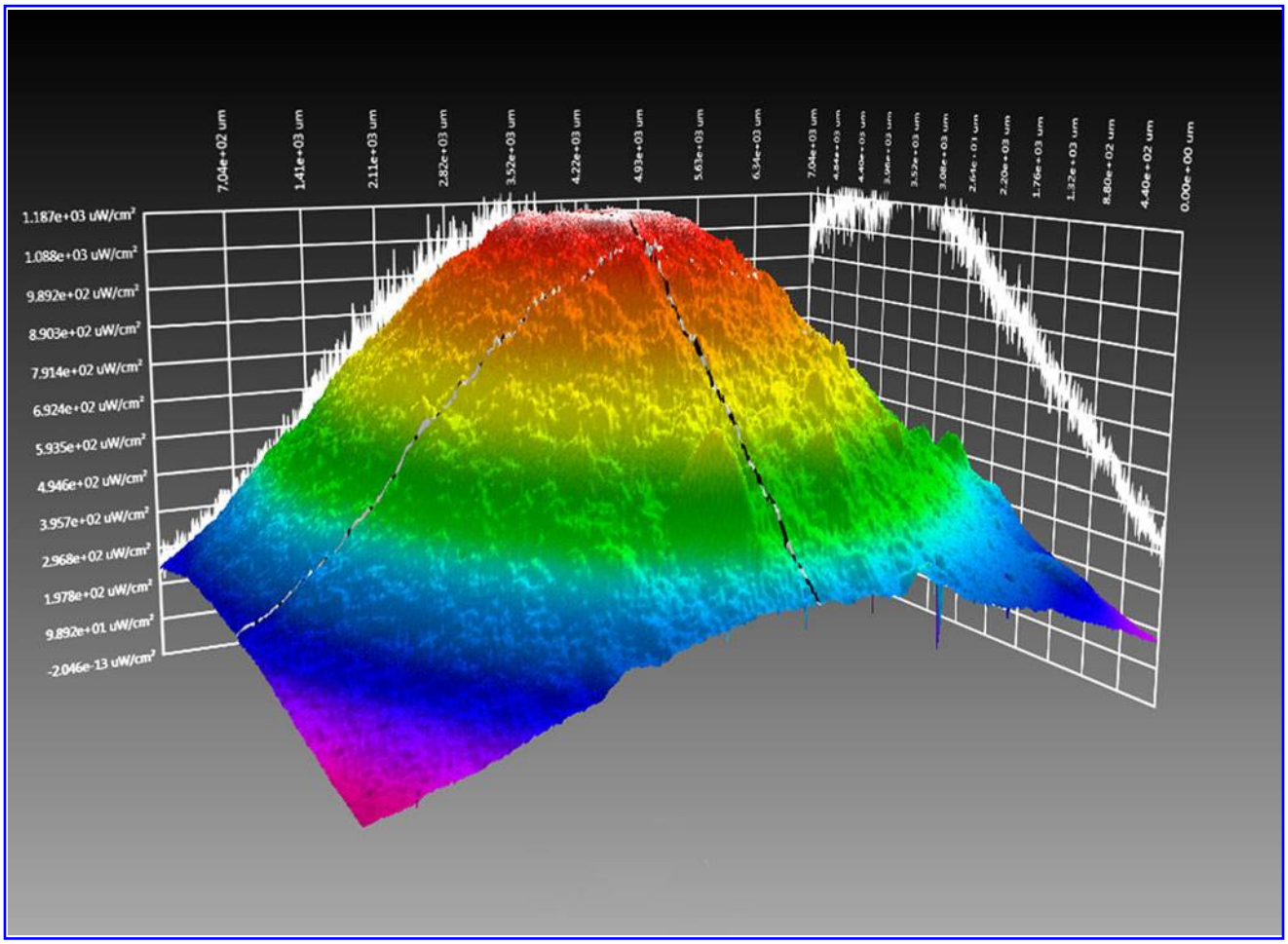

FIG. 6. Laser light pattern 808 nm at 3.3 cm tissue depth.

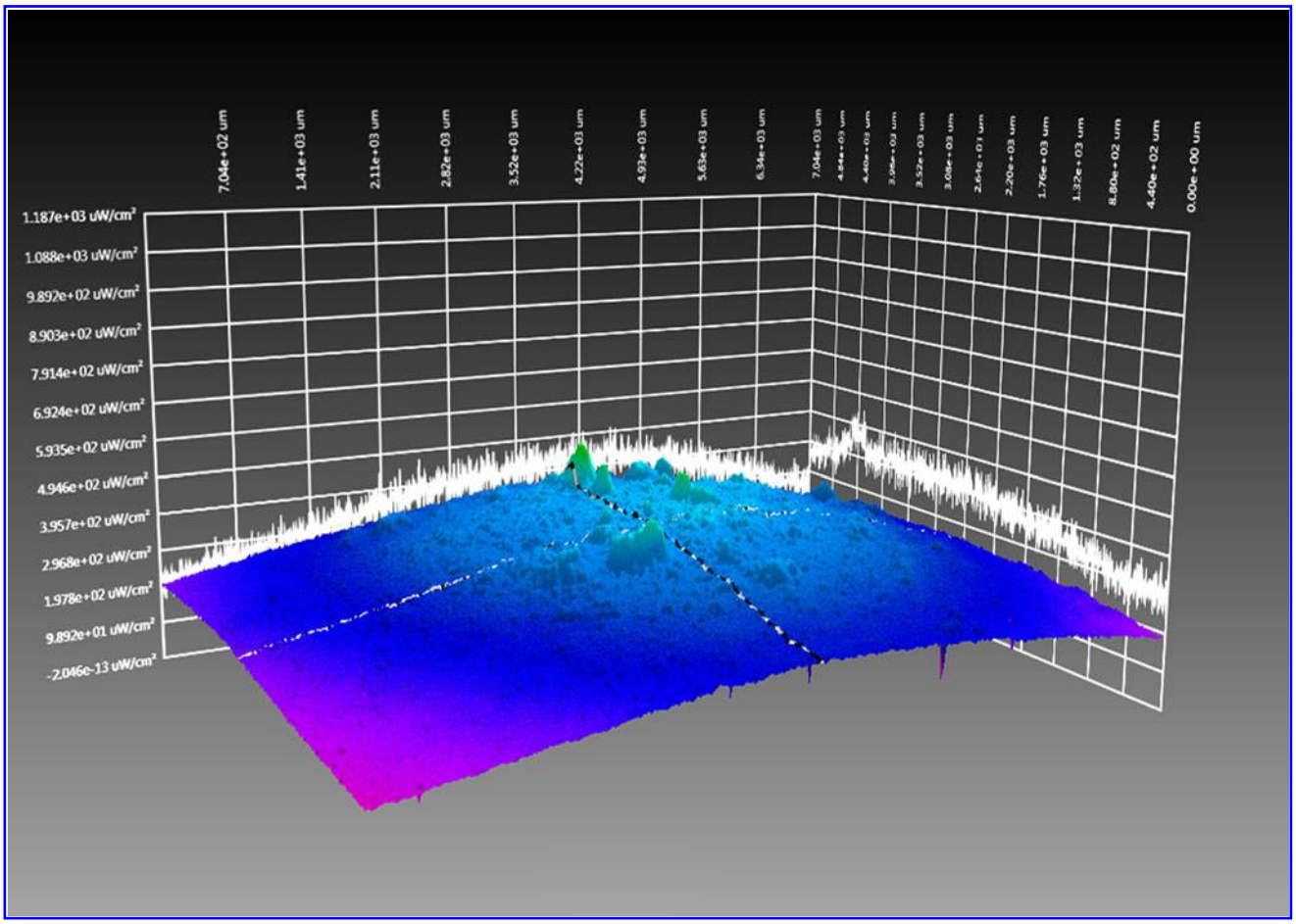

FIG. 7. Laser light pattern 980 nm at 2.8 cm tissue depth.

980 nm laser light. There is a temperature rise from the transfer of photon energy to kinetic energy for the laser therapy process, which should be studied for different wavelengths.

Conclusions

We set out to compare the penetration of 808 versus 980 nm laser light through bovine tissue samples, and found that 808 nm light penetrates as much as 54% deeper than 980 nm.

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