THERMAL SURGERY SAFETY APPARATUS AND METHOD

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Appl. No.: 12/135,971
Filed: Jun. 9, 2008

Related U.S. Application Data

Provisional application No. 60/933,736, filed on Jun. 8, 2007, provisional application No. 60/987,596, filed on Nov. 13, 2007, provisional application No. 60/987,617, filed on Nov. 13, 2007, provisional application No. 60/987,819, filed on Nov. 14, 2007, provisional application No. 60/987,821, filed on Nov. 14, 2007, provisional application No. 61/018,729, filed on Jan. 3, 2008, provisional application No. 61/018,727, filed on Jan. 3, 2008.

Publication Classification

Int. Cl. A61B 18/22 (2006.01)
U.S. Cl. ............................... 606/15; 606/14

ABSTRACT

A laser surgical method is disclosed including: providing a laser surgical device including a handpiece including: an optical delivery component that transmits laser energy from a source to a treatment volume; and an accelerometer configured to provide information indicative of the position of the handpiece. The method includes using the handpiece to transmit laser energy from the source to a plurality of positions within the treatment volume; using the accelerometer, providing information indicative of the position of the handpiece; determining information indicative of an amount of energy delivered at each of the plurality of positions within the treatment volume based on the information indicative of the position of the handpiece, and displaying a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.
HIGH PASS 5Hz FILTER & INPUT BUFFER AMP

SPEED INTEGRATOR

ACCELERATION INPUT

\[ \text{FIG. 4} \]
**FIG. 6A**

- **FWD TRAVEL = 67% PWR FOR EACH SHOT**

- **REV TRAVEL = 33% PWR FOR EACH SHOT**

**FIG. 6B**

- **COOLDOWN + THERMAL DISPERSION**

- **TIME**

- **△T FAT OR TISSUE**

- **615 LASER SHOT 67% PWR**

- **610 LASER SHOT 33% PWR**

- **FIBER**

- **PWR IN**

- **PWR STROKE**

- **FWD STROKE**

- **REV STROKE**
MIN SPEED vs POWER CURVE

20J/cm^2

10J/cm^2

PWR OUT

HAND-PIECE SPEED (cm/sec)

0.5

1.0

1Hz Rep RATE

2Hz Rep RATE

FIG. 7
POWER vs SPEED SLOPES (IN LIEU OF A TABLE)

FIG. 8
Min SPEED vs POWER CURVE WITH OFFSET TERM

NEGATIVE OFFSET ALLOWS MORE PWR MORE PWR VS SPD

POSITIVE OFFSET ALLOWS LESS PWR VS SPD

FIG. 9
FIG. 10
ADIABATIC TEMPERATURE RISE IN FAT 1064 nm SOURCE

ADIABATIC TEMPERATURE RISE PRODUCED WITH 100 mJ PULSE, DELIVERED FROM 600 μm FIBER

FIG. 13A
ADIABATIC TEMPERATURE RISE PRODUCED WITH 100mJ PULSE, DELIVERED FROM 600\mu m FIBER

FIG. 13B
ADIABATIC TEMPERATURE RISE IN FAT 1400nm SOURCE

ADIABATIC TEMPERATURE RISE PRODUCED WITH 100mJ PULSE, DELIVERED FROM 600μm FIBER

FIG. 13C
CARTESIAN POINT THERMAL APPROXIMATION vs $\lambda$ MODEL

MAGNITUDE vs DISTANCE CONTAINER MODEL FOR EACH $\lambda$ TISSUE TYPE

+1+2+3

-3-2-1

THE ORIGIN FROM ALIGNMENT $\bar{x}, \bar{y}, \bar{z}$

FIG 14
**Fig. 21**

CLOSED LOOP TEMPERATURE CONTROL

- LASER PWR/REP RATE SETPOINT
- TEMPERATURE COMMAND
- LIMIT BLOCK
- REPITION RATE CMD
- TEMPERATURE FEEDBACK

**Fig. 22**

CLOSED LOOP TEMP + PWR vs SPD CONTROL

- TEMP CMD
- GAIN + COMP
- LIMIT PWR vs SPD
- REP RATE CMD
- SPD OR ACCELERATION FEEDBACK
- TEMPERATURE FEEDBACK
635/532 DOPED TREATMENT FIBER WITH COLOR REMITTANCE/REFLECTION SENSE FIBER

FIG. 29
DUAL FIBER TISSUE TYPING COLOR DETECTOR

FIG. 30
5. CHARACTERISTIC CURVE

FIGURE 33

TYPICAL RELATIVE SENSITIVITY (XYZ) OF THE COLOR SENSOR (MTCSI), SCANNED BY WIDTH BROADBAND LIGHT

TYPICAL SPECTRAL SENSITIVITY AND STANDARD OBSERVER FUNCTION

FIGURE: TYPICAL (RELATIVE) SENSITIVITY (XYZ) OF THE COLOR SENSOR (MTCSI), SCANNED BY NARROW-BAND LIGHT
THERMAL SURGERY SAFETY APPARATUS AND METHOD

RELATED APPLICATION(S)


BACKGROUND

[0002] To improve one's health or shape, patients have resorted to surgical methods for removing undesirable tissue from areas of their body. For example, to remove fat tissue, some patients have preferred liposuction, a procedure in which fat is removed by suction mechanism because despite strenuous dieting and exercise, some of the patients cannot lose fat, particularly in certain areas. Alternatively, laser or other light sources has been applied for heating, removal, destruction (for example, killing), photoacoagulation, eradication or otherwise treating (hereinafter collectively referred as "treating" or "treatment") the tissue.

[0003] Because the treatment mechanism are implemented beneath the skin of the patient, a clinician cannot assess the extent of the treatment or the condition of the treated portions of the treatment area by, for example, a type of visual aid. As such, the clinician has no other means to determine the extent of the treatment or to guide the instrument(s) to the untreated portions of the treatment area except by the means of feel. In turn, it is not uncommon during the procedure to result uneven removal of the undesired tissue which may leave an esthetically unattractive patterning on the patient's skin.

[0004] Further, in typical applications, there is no direct method to ascertain the tissue type in front of the laser delivery fiber during procedures such as laser lipolysis. The physician relies on his knowledge of anatomy and human physiology to position the fiber tip in the unwanted fat layer. The physician is aided by a visible aiming beam carrying a single or multitude of wavelengths through the delivery fiber. A skilful physician can correlate the aiming beam visibility with the fiber tip position and depth under the skin. However, even for a skilful physician is very hard (nearly impossible) to determine the type of tissue in front of the fiber tip.

[0005] Furthermore, while the tissue can be treated using laser or light energy source as a result of absorption in the tissue of the energy source, the surgical instruments lack a mechanism that accounts the amount of power absorbed by the treated portions of the treatment area. As such, the clinician can under-treat or over-treat, resulting an incomplete removal of the tissue or charring thereof due to overexposure.

SUMMARY OF THE INVENTION

[0006] The inventors have realized that by providing one or more sensors for use in a medical environment where energy is directed to target tissue (e.g. laser surgical procedure), increased safety and ease of use may be obtained. By combining different types of sensor inputs, a wealth of information can be provided characterizing an ongoing medical procedure.

[0007] For example, the inventors describe herein methods and devices that include mechanisms to detect the motion of a surgical device used during a procedure for removing undesired tissue or body parts.

[0008] Application of power into tissue results in a local temperature rise according to absorbtance of constituent tissues. Propagation distance is dependent to, for example, wavelength/tissue type. Further, each tissue type has an associated time constant and thermal conductivity. Thus, in principle, tissue temperature rise in vivo can be determined from knowledge of the constituent tissues, the wavelength and power directed thereto as long as the position of the energy delivery component of the device, which is inserted into the treatment area is known.

[0009] According to one aspect of the present invention, the position of the energy delivery component can be determined by processing the acceleration of the device, which is integrated to provide a speed feedback. Accounting the speed feedback, the device can control the amount of the power directed to a treatment area in relation to the value of the speed feedback. For example, the device can stop emitting the energy directed to the treatment area when the device is not moving or moving at a speed below a predetermined value to prevent excessive in vivo thermal effect. The speed feedback may also be used to control the applied dose of energy, e.g. to maintain a fixed energy deposited in the tissue per unit traveled.

[0010] According to another aspect of the present invention, the position of the energy delivery component can be determined by taking the first integration of speed (or the 2nd integration of acceleration) to provide a position feedback of the energy delivery component within the treatment area. Power controlling for the position feedback application is done with a power vs. difference-in-position algorithm. For example, each energy discharge/shot into tissue in the treatment area is assigned a 3-D Cartesian point on an 8 quadrant plane. Each point on the Cartesian reference plane represents a "heat container". The heat containers contain's temperature value increments and decrements according to energy applied or energy-in (E_{in}), absorbtance vs. propagation distance, baseline temperature, and the time constant and conductivity associated with the tissue type. Additional sensor inputs such as tissue type measurements or direct or indirect temperature measurement can be used in conjunction with the positional information to augment or confirm the spatial energy distribution information.

[0011] In one aspect, a laser surgical apparatus is disclosed including: a handpiece including an optical delivery component that transmits laser energy from a source to a treatment volume; and an accelerometer configured to provide information indicative of the position of the handpiece. The apparatus includes a processor coupled to the accelerometer and the source and controlling the laser energy transmitted to the treatment volume; and a display. The processor is configured to determine information indicative of an amount of energy delivered at each of a plurality of positions within the treatment volume based on the information indicative of the position of the handpiece. The display is configured to display a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.
In some embodiments, the processor is configured to control the amount of energy delivered to the treatment volume based on feedback from the accelerometer.

In some embodiments, the accelerometer measures acceleration along three axes.

In some embodiments, the accelerometer is a gyro compensated accelerometer.

In some embodiments, the graphical representation includes a map of the treatment volume, where a plurality of points on the map correspond to the plurality of positions within the treatment volume, and where the a graphical quality of each of the points depends on the amount of energy delivered at the position within the treatment volume.

In some embodiments, the graphical representation is a three dimensional representation.

In some embodiments, the handpiece further includes a temperature sensor configured to provide information indicative of the temperature of tissue at positions within the treatment volume. The processor is coupled to the temperature sensor and is configured to determine information indicative of the temperature of each of a plurality of positions within the treatment volume based on the information indicative of the position of the handpiece and the information indicative of the temperature of tissue at positions within the treatment volume.

The display is configured to display a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

In one aspect, a laser surgical method is disclosed including: providing a laser surgical device including a handpiece including: an optical delivery component that transmits laser energy from a source to a treatment volume; an accelerometer configured to provide information indicative of the position of the handpiece. The method includes using the handpiece to transmit laser energy from the source to a plurality of positions within the treatment volume; using the accelerometer, providing information indicative of the position of the handpiece; determining information indicative of an amount of energy delivered at each of the plurality of positions within the treatment volume based on the information indicative of the position of the handpiece, and displaying a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

In some embodiments, the temperature sensor. Such embodiments include using the temperature sensor, determining information indicative of the temperature of each of a plurality of positions within the treatment volume based on the information indicative of the position of the handpiece and the information indicative of the temperature of tissue at positions within the treatment volume, and displaying a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

In another aspect, a laser surgical apparatus is disclosed including: a handpiece including: an optical delivery component that transmits laser energy from a source to a treatment volume; and an accelerometer configured to provide information indicative of acceleration of the handpiece along three axes. The apparatus includes a processor coupled to the accelerometer and the source and controlling the laser energy transmitted to the treatment volume based on feedback from the accelerometer.

Some embodiments include a gyroscope configured to provide information indicative of the spatial orientation of the handpiece, and where the processor is coupled to the gyroscope and is configured to control the laser energy transmitted to the treatment volume based on feedback from the accelerometer and the gyroscope.

In some embodiments, the processor is configured to determine information indicative of an absolute position of the handpiece based on the information indicative of acceleration of the handpiece along three axes, and the information indicative of the spatial orientation of the handpiece.

In some embodiments, the processor is configured to determine information indicative of a speed of the handpiece based on the information indicative of acceleration of the handpiece along three axes; and control the laser energy transmitted to the treatment volume based on feedback using the information indicative of the speed of the handpiece.

In some embodiments, the information indicative of acceleration of the handpiece along three axes includes, for at least one axis, a signal having an amplitude which depends on the acceleration of the handpiece along the axis.

In some embodiments, the processor is configured to selectively block low frequency components of the signal prior to integrating the signal to determine information indicative of a speed of the handpiece along the respective axis. In some embodiments, the processor is configured to determine the speed of the handpiece along each of the three axes based on the information indicative of acceleration of the handpiece along three axes; determine a weighted average speed of the handpiece by calculating a weighted average of the speeds of the handpiece along each of the three axes; and control the laser energy transmitted to the treatment volume based on feedback using the weighted average speed of the handpiece.

In some embodiments, the handpiece includes a probe member for insertion into the treatment volume, the probe member extending along a probe member axis, the accelerometer is configured to provide information indicative of acceleration along each of the three axes, one of the three axes being substantially parallel to the probe member axis; and the processor is configured to determined the weighted average speed of the handpiece by calculating a weighted average of the speeds of the handpiece along each of the three axes, where the axis substantially parallel to the probe member axis is given greater weight that the other axes.
In another aspect, a laser surgical method is disclosed including: providing a handpiece including: an optical delivery component that transmits laser energy from a source to a treatment volume; and an accelerometer configured to provide information indicative of acceleration of the handpiece along three axes; using the handpiece to transmit laser energy from the source to the treatment volume; using the accelerometer, providing information indicative of acceleration of the handpiece along three axes; and controlling the laser energy transmitted to the treatment volume based on feedback from the accelerometer.

In some embodiments, the handpiece further includes a gyroscope, and the method includes using the gyroscope, providing information indicative of the spatial orientation of the handpiece, and further including; and controlling the laser energy transmitted to the treatment volume based on feedback from the accelerometer and the gyroscope.

Some embodiments include: determining information indicative of an absolute position of the handpiece based on the information indicative of acceleration of the handpiece along three axes, and the information indicative of the spatial orientation of the handpiece.

Some embodiments include: determining information indicative of a speed of the handpiece based on the information indicative of acceleration of the handpiece along three axes; and controlling the laser energy transmitted to the treatment volume using the information indicative of the speed of the handpiece.

Some embodiments include determining the speed of the handpiece along each of the three axes based on information indicative of the handpiece along three axes; determining a weighted average speed of the handpiece by calculating a weighted average of the speeds of the handpiece along each of the three axes; and controlling the laser energy transmitted to the treatment volume based on feedback using the weighted average speed of the handpiece.

In some embodiments, the handpiece includes a probe member extending along a probe member axis. The method further includes:

inserting the probe member into the treatment volume; repetitively advancing and withdrawing the probe member within the treatment volume; using the accelerometer to provide information indicative of acceleration along each of the three axes, one of the three axes being substantially parallel to the probe member axis; and determining the weighted average speed of the handpiece by calculating a weighted average of the speeds of the handpiece along each of the three axes, where the axis substantially parallel to the probe member axis is given greater weight that the other axes.

In another aspect, a laser surgical apparatus is disclosed including: a handpiece including: a probe member including an optical delivery component that transmits laser energy from a source to a treatment volume; the probe member adapted for insertion into a treatment volume through an incision in a patient; and an accelerometer configured to provide information indicative of the position of the handpiece relative to the incision; a processor coupled to the accelerometer and the source and controlling the laser energy transmitted to the treatment volume based on the information indicative of the position of the handpiece relative to the incision.

In some embodiments, the accelerometer is configured to provide information indicative of a speed of the handpiece and the processor is configured to controlling the laser energy transmitted to the treatment volume based on the information indicative of the speed of the handpiece.

In another aspect, a method is disclosed including providing a handpiece including: a probe member including an optical delivery component that transmits laser energy from a source to a treatment volume, the probe member adapted for insertion into a treatment volume through an incision in a patient; and an accelerometer configured to provide information indicative of the position of the handpiece relative to the incision. The method includes inserting the probe member into the treatment volume through the incision; repetitively advancing and withdrawing the probe member within the treatment volume; transmitting laser energy to the treatment volume; using the accelerometer to provide information indicative of the position of the handpiece relative to the incision; and controlling the laser energy transmitted to the treatment volume based on the information indicative of the position of the handpiece relative to the incision.

Some embodiments include: using the accelerometer to provide information indicative of a speed of the handpiece; and controlling the laser energy transmitted to the treatment volume based on the information indicative of the speed of the handpiece.

In another aspect, a laser surgical apparatus is disclosed including: a handpiece including: an optical delivery component that transmits laser energy from a source to a treatment volume; an accelerometer configured to provide information indicative of an acceleration of the handpiece and a temperature sensor configured to provide temperature information indicative of a temperature of tissue within the treatment volume. The apparatus includes a processor coupled to the accelerometer, the temperature sensor, and the source and configured to control the laser energy transmitted to the treatment volume based on the acceleration information and the temperature information.

In some embodiments, the handpiece includes a probe member adapted for insertion into the treatment volume through an incision in a patient, the probe member including at least a portion of the optical delivery component.

In some embodiments, the processor is configured to determine speed information indicative of the speed of the handpiece based on the acceleration information; and control the laser energy transmitted to the treatment volume based on the speed information and the temperature information.

In some embodiments, the processor is configured to determine position information indicative of the position of the handpiece based on the acceleration information; and control the laser energy transmitted to the treatment volume based on the position information and the temperature information.

In some embodiments, the temperature sensor includes at least one selected from the group consisting of: a thermocouple and a thermometer.

In some embodiments, the temperature sensor includes an infrared sensor.

In some embodiments, the handpiece includes a optical sensing element configured to transmit infrared light from the treatment volume to the infrared sensor.

In some embodiments, the processor is configured to compare the speed of the handpiece to a threshold value, and inhibit the transmission of laser energy to the treatment volume when the speed is below the threshold value.
In some embodiments, the temperature sensor is configured to measure the temperature of the tissue when the processor inhibits the transmittal of laser energy to the treatment volume or when the processor determines that the speed of the handpiece is below a measurement threshold speed.

In some embodiments, the processor is configured to compare the temperature of the tissue to a threshold value, and inhibit the transmittal of laser energy to the treatment volume when the temperature is above a threshold value.

In some embodiments, the processor is configured to repetitively, at a first repetition rate, compare the speed of the handpiece to a speed threshold value, and inhibit the transmittal of laser energy to the treatment volume when the speed is below the speed threshold value; and repetitively, at a second repetition rate, compare the temperature of the tissue to a temperature threshold value, and inhibit the transmittal of laser energy to the treatment volume when the temperature is above the temperature threshold value.

In some embodiments, the first repetition rate is greater than the second repetition rate.

In some embodiments, the processor is configured to determine information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

In some embodiments, the processor is configured to control the laser energy transmitted to the treatment volume based on information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

Some embodiments including a display configured to show a graphical depiction indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

In some embodiments, the information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume includes, for each position, a series of temperatures measured at a plurality of times.

In some embodiments, the processor is configured to, for each of the positions, calculate a running average of the series of temperatures.

In some embodiments, the display is configured to display, in real time, a graphical representation of the running averages at each of the positions.

In some embodiments, the accelerometer includes a MEMs device.

In some embodiments, the accelerometer measures accelerations along three axes.

In some embodiments, the accelerometer is a gyro compensated accelerometer.

In some embodiments, controlling the laser energy includes controlling at least one selected from the group consisting of: wavelength, pulse rate, pulse duty cycle, intensity, and fluence.

In another aspect, a laser surgical method is disclosed including: providing a handpiece including: an optical delivery component that transmits laser energy from a source to a treatment volume; an accelerometer configured to provide acceleration information indicative of an acceleration of the handpiece; and a temperature sensor configured to provide temperature information indicative of a temperature of tissue within the treatment volume. The method includes transmitting laser energy to the treatment volume; using the accelerometer to provide acceleration information indicative of an acceleration of the handpiece; using the temperature sensor to provide temperature information indicative of a temperature of tissue within the treatment volume; and controlling the laser energy transmitted to the treatment volume based on the acceleration information and the temperature information.

In some embodiments, the handpiece includes a probe member and the method includes: inserting the probe member through an incision in a patient into the treatment volume; and delivering laser energy to the treatment area from the probe member.

Some embodiments include: determining speed information indicative of the speed of the handpiece based on the acceleration information; and controlling the laser energy transmitted to the treatment volume based on the speed information and the temperature information.

In some embodiments, the processor is configured to determine position information indicative of the position of the handpiece based on the acceleration information; and control the laser energy transmitted to the treatment volume based on the position information and the temperature information.

Some embodiments include: comparing the speed of the handpiece to a threshold value, and inhibiting the transmittal of laser energy to the treatment volume when the speed is below the threshold value.

Some embodiments include: using the temperature sensor to measure the temperature of the tissue when the processor inhibits the transmittal of laser energy to the treatment volume or when the processor determines that the speed of the handpiece is below a measurement threshold speed.

Some embodiments include: comparing the temperature of the tissue to a threshold value, and inhibit the transmittal of laser energy to the treatment volume when the temperature is above a threshold value.

Some embodiments include: determining information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume; and controlling the laser energy transmitted to the treatment volume based on information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

Some embodiments include displaying a graphical depiction indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

Some embodiments include: determining information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume; and controlling the laser energy transmitted to the treatment volume based on information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

Some embodiments include: displaying a graphical representation of the running averages at each of the positions.

Various embodiments may include any of the features described above, alone or in combination.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing will be apparent from the following more particular description of example embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments of the present invention.

FIG. 1 is a schematic of a laser surgical system

FIG. 1A is an exploded view an embodiment of the accelerometer in a device of the present invention.
[0079] FIG. 2 illustrates a device of the present invention applied to a treatment area during a treatment;
[0080] FIG. 3A shows a feature in an embodiment of the device translating acceleration in one, two, or three axes and FIG. 3B shows an embodiment of the accelerometer mounted on to a device of the present invention;
[0081] FIG. 4 is a schematic illustration of a filter and an input amplifier in an embodiment of a translator processing circuit in the present invention;
[0082] FIG. 5 is a schematic diagram for total speed estimation in the speed vs. power application;
[0083] FIGS. 6A and 6B illustrate a mode of power output to reduce thermal shock to a portion of the treatment area and to provide a more even energy deposition throughout the treatment area;
[0084] FIG. 7 is a graph illustrating minimum speed vs. power curve;
[0085] FIG. 8 is a graph illustrating the speed of the device in terms of power output and repetition rate of pulses by the device;
[0086] FIG. 9 is a graph illustrating offset speed vs. power curve;
[0087] FIG. 10 illustrates a mode of plotting three-axis positions in a three-dimensional Cartesian plane in the power vs. difference-in-position application;
[0088] FIG. 11 illustrates a two-dimensional map of a treatment area that represents the treated and untreated portions thereof;
[0089] FIGS. 12A-12D illustrate overlapping pulses and the mode of accounting such overlapping pulses for the map of the treatment area;
[0090] FIGS. 13A-13C graphs illustrating adiabatic temperature rise in the treatment area by 1064 nm, 1320 nm, and 1400 nm sources, respectively;
[0091] FIG. 14 illustrates a three-dimensional coordinate including a physical node within an interstitial target and a plot of $E_{air}$ vs. propagation distance.
[0092] FIG. 15 illustrates an embodiment of a surgical system that includes embodiments of a device and a photodetector sensor pad;
[0093] FIG. 16 is a graph illustrating multiple wavelengths used in the doping beam; and
[0094] FIG. 17 illustrates an embodiment of a user interface display that is in communication with a photodetector sensor pad.
[0095] FIG. 18 shows a surgical device featuring a thermal sensor.
[0096] FIG. 19 shows a surgical device featuring a thermal sensor.
[0097] FIG. 20 shows embodiments of surgical devices featuring a thermal sensor.
[0098] FIG. 21 shows a feedback loop for controlling a surgical device.
[0099] FIG. 22 shows a feedback loop for controlling a surgical device.
[0100] FIG. 23 shows a schematic illustrating temperature-position mapping for a surgical device.
[0101] FIG. 24 shows a surgical device featuring an IR thermal sensor.
[0102] FIG. 25 shows a surgical device featuring an IR thermal sensor.
[0103] FIG. 26 shows a graph of transmission properties of anti-reflection coated ZnSe.
[0104] FIG. 27 shows a tissue type sensor.
[0105] FIG. 28 shows a tissue type sensor.
[0106] FIG. 29 shows a tissue type sensor featuring a sense waveguide.
[0107] FIG. 30 shows a dual color tissue type sensor.
[0108] FIG. 31 shows an electronic circuit for use in a tissue type sensor.
[0109] FIG. 32 shows an electronic circuit for use in a tissue type sensor.
[0110] FIG. 33 shows a response curve for a color photodetector.

DETAILED DESCRIPTION

[0111] A description of example embodiments of the invention follows.

[0112] FIG. 1 shows a laser surgical system 10 featuring several safety and control features of the type described herein. System includes a handpiece 12 adapted to be held by a clinician or other operator, and to deliver therapeutic laser energy from laser source 14 to a treatment area (e.g., via an optical fiber). Controller 15 operates to control the delivery of therapeutic laser energy, e.g., by allowing or inhibiting the transmit bit of light from source 14 to the treatment area or by controlling one or more laser parameters such as intensity, wavelength, pulse rate, etc. Handpiece 12 includes multiple sensors 16a, 16b, and 16c of differing types. For example, in the embodiment shown sensor 16a is an accelerometer, sensor 16b is a temperature sensor, and sensor 16c is a tissue type sensor.

[0113] Sensors 16a-c are coupled to controller 15, which can process the outputs of the signals to determine information about the ongoing treatment. Controller 15 can process information measured by the sensors 16a-c and control laser 15 based on the processed information. Information from each of the sensors 16a-c may be used separately, or combined to provide a wealth of real-time information about the area undergoing treatment. This information can be displayed to the clinician, or used to automatically control laser 15 to, for example, provide a desired dose profile across the treatment area or to inhibit laser 15 in the event that a dangerous condition (e.g., overheating of a portion of the treatment area) is detected. In some embodiments, information from the sensors 16a-c may be used to confirm each other, thereby providing enhanced reliability and safety.

[0114] In some embodiments, an additional sensor 17, located external to handpiece 12 also provides information about the area of tissue undergoing treatment. For example, sensor 17 may be an infrared camera or other type or IR sensor which measures the temperature of the tissue undergoing treatment, or adjacent/related tissue (e.g., the outer surface of the skin overlaying the tissue undergoing treatment.).

[0115] FIG. 1A describes the device 100 for in vivo surgical applications. The device 100 comprises an apparatus 115. The apparatus 115 can be adapted to be held by a clinician (e.g., a surgeon) and includes an energy source 105. An energy delivery component 110 can be coupled to the energy source 105 and the apparatus 115 to deliver energy to a treatment area (not shown). The term “treatment area” can include any portion of a patient’s body. Examples of a treatment area can include interstitial targets situated within a patient’s body but also portions of the skin surface. In one embodiment, the energy delivery component 110 is an optical fiber. The energy delivery component 115 is threaded through the apparatus 115 and a sleeve 130, reaching to the tip 135. During a procedure, the portion of the energy delivery
component 110 covered by the sleeve 130 is applied to the treatment area. The device 100 can further include an accelerometer 120 that is coupled to the apparatus 115 for measuring inertial acceleration. In one embodiment, the energy delivery component 110 can be an optical fiber.

[0116] The energy source 105 can be configured to provide at least one of a suction energy, a light energy, a radiofrequency energy, sonic 9 c.g. ultrasound) energy and an electromagnetic radiation. In one embodiment, the energy source comprises a laser light. The laser light can comprise laser radiation. Yet in another embodiment, the laser radiation comprises a laser pulse (e.g., Nd:YAG laser). In this embodiment, the energy source comprises a laser. In one embodiment, the radiofrequency energy can comprise a radiofrequency (RF) pulse. Yet in another embodiment, the electromagnetic radiation comprises ultraviolet (UV) light.

[0117] When a pulse is delivered to the treatment area, the wavelength of a pulse also plays a factor to the amount of power applied to the target. For example, a 1440 nm wavelength pulse is more highly absorbed by, for example, fat tissue than an equivalent power 1320 nm wavelength pulse.

[0118] In certain embodiments, the device 100 can include an accelerometer 120 secured to the energy delivery component 110. The accelerometer 120 can be mounted to or within the apparatus 115 in fixed relation with respect to the energy delivery component 110. The accelerometer 120 generates an electrical signal indicative of the motion of the energy delivery component 110 in at least one direction and as many as three orthogonal directions. The electrical signal from the accelerometer 120 can be sent to a processor 125 for controlling the energy source 105, such that the operation of the energy source 105 is controlled, at least in part, by the movement of the apparatus 115.

[0119] In certain embodiments, the processor 125 can be programmed such that the energy delivery component 110 only operates when the apparatus 115 (and thus the energy delivery component 110) is in motion. When the accelerometer 120 indicates that the apparatus 115 and the energy delivery component 110 are stationary, the output of the energy source 105 ceases. This provides a safety function because it would prevent the energy delivery component 110 from delivering more than the optimal amount of the energy in rapid succession to the same portion of the treatment area, thereby preventing undesirable thermal damage. Furthermore, in one embodiment, the safety function of the device 100 can include at least a control that provides a warning feedback when the apparatus 115 is moving below a critical minimum speed. Alternatively or in combination with the safety function, the device 100 can include a control for stopping the function of the energy source 105 when the energy delivery component 110 is moving below a critical minimum speed.

[0120] In certain embodiments, the energy source emits a beam, which can be pulsed. For example, if the energy source delivers a laser light, the energy source is enabled to control the rate of a laser pulse. The energy source is configured to manipulate one or more parameters to control the amount of the total energy directed to the treatment area. In one embodiment, the energy source can control a power per pulse, a pulse duration, a pulse repetition rate, or a combination thereof. While keeping the total power directed to the treatment area constant in a time duration, the energy source is configured to increase or decrease the power per pulse, the pulse duration, the pulse rate or a combination thereof. In one embodiment, the energy source further includes a control system that is configured to control the rate at which the energy source generates pulses of each energy pulse in response to the feedback provided by the accelerometer. Thus, a device (and thus an energy delivery component) moving at a slow speed would deliver less energy directed to the treatment area. Conversely, a device moving at a higher speed would deliver more power. In one embodiment, the control system can be configured to emit energy pulses only when the device is in motion, and at a power that is modulated in accordance with the device motion in all three axes. In another embodiment, the energy source is enabled to control the rate of the energy pulse in relation to: the wavelength of a pulse, a speed of the energy delivery component, a tissue of the treatment area, fluence setting, propagation distance, or a combination thereof.

[0121] In certain embodiments, the device comprises a detector that is coupled to the energy delivery component for detecting the reaction by the treatment area in response to the treatment. In one embodiment, a sensor can be coupled to the energy delivery component to measure the physical change of the treatment area, in response to the energy directed thereto. In another embodiment, a detector can be coupled to the energy delivery component for detecting radiation transmitted back through the energy delivery component from the treatment area. For example, the detector detects near infrared radiation that travels down the energy delivery component from the treatment area, in the reverse direction of the energy pulses. The detected near infrared radiation can be used to monitor the temperature of the tissue in the treatment area and to regulate the operation of the energy source. Yet in another embodiment, the device can be programmed to provide a warning when the detected radiation indicates that the temperature of the tissue exceeds a pre-determined temperature. The device can further be programmed to prohibit operation of the energy source when the detected radiation indicates that the temperature of the tissue exceeds a predetermined temperature. For example, the energy source operates in a pulsed mode, and the near infrared radiation from the treatment area is detected during the delay period between successive treatment pulses. Even for a continuous wave source, the treatment beam and diagnostic beam could be modulated, such that the duty cycle of the continuous wave treatment beam was close to unity.

[0122] FIG. 2 shows a method how a device of the present invention can be applied. The device 200 is inserted into a treatment area 205 (e.g., fat tissue) through an incision 210 made on the skin of a patient. As the energy delivery component 215 is inserted and moved further into the treatment area 205, the energy delivery component 215 is configured to direct one or more sequential pulses in a predetermined rate to the treatment area 205. During the procedure, much of the absorption and heating occurs in tissue immediately adjacent to the tip 220 of the energy delivery component 215. As the clinician moves back and forth, the device 200, and, thus, the energy delivery component device 215 in the treatment area 205, the energy source (not shown) provides the energy by emitting the one or more sequential pulses, distributing and breaking up tissue cells (e.g., fat cells).

[0123] In certain embodiments, the energy source is configured to modulate the amount of the energy directed to the treatment area 205 in relation to the position of the energy delivery component 215. In another embodiment, the energy source is configured to modulate the amount of the energy directed to the treatment area 205 in relation to a feedback
provided by the accelerometer 230 regarding the amount of the energy delivered to a physical location within the treatment area 205.

[0124] In one embodiment, as shown in FIGS. 3A and 3B, the device 300 includes a three-axis accelerometer 305 located in the laser/surgical hand piece 310 and a translator processing circuit 315, which translates acceleration into speed and/or position feedback to the operator, configured with algorithms for manipulating power or the amount of the energy output to be directed to the treatment area. The processing circuit 315 is coupled to the accelerometer 305 and determines dosimetry of the energy directed to the treatment area (not shown). The term “dosimetry” refers to the calculation of the energy dose in matter or tissue resulting from the exposure to the energy. As such, in relation to the speed and/or position feedback, the device 300 can control the power, and the amount of the energy directed to the treatment area.

[0125] In certain embodiments, the device of the present invention includes a processor coupled to an accelerometer for processing a feedback from the accelerometer and for controlling the amount of energy directed to the treatment area. In one embodiment, the device includes a power vs. speed application. In this application, the power directed to the treatment area is controlled in relation to the speed feedback. The accelerometer provides outputs, which are filtered, scaled and integrated to obtain one, two or three axes speed feedback. When the speed feedback is provided for two or three axes, the direct current (DC) component of the accelerometer 305 output can be filtered such that static acceleration is blocked and only dynamic acceleration signals are sensed by the energy delivery component. As such, when the DC component of the accelerometer 305 is blocked, the processing circuit 315 accumulates dynamic accelerations to provide overall value for the speed, including either + or - magnitude of the speed.

[0126] The translator processing circuit 315 includes both analog and digital elements. The three channels of the speed feedback by the accelerometer 305 are provided to the translator processing circuit 315 via a filter such as a DC blocking high pass filter (with, for example, 0.25 Hz cutoff) followed by an adjustable gain input amplifier as shown in FIG. 4. The input amplifier can be also offset the filtered acceleration signals to allow for bi-polar bi-directional acceleration feedback. Through these means, the constant or static DC acceleration due to the gravity is blocked, and dynamic or changing accelerations are passed to the accelerometer to be scaled and integrated to obtain the speed feedback. Furthermore, changes in orientation of the device such as the one indicated as 300 in FIG. 3 or angles will cause the static gravity acceleration vector to be re-distributed amongst all three axes and thus to the acceleration signals because the signals are dependent on the angles of the three axis reference frame with respect to gravity.

[0127] In certain embodiments of the power vs. speed application, the accelerometer is configured to provide a combined three-axis composite speed feedback. Based on the combined speed feedback, the power output directed to the treatment area can be then throttled or adjusted. Because each speed signal represents velocity along a different axis, it is not possible to simply sum the speed values from the three axes. For example, a negative speed value in the X-axis direction would subtract from a positive speed value in the Y-axis or in the Z-axis. As such, to simplify processing the accelerometers of the present invention can be configured to provide a quasi-

speed total value by taking the absolute speed value in each axis independently and then summing the absolute values from all the axes as shown in FIG. 5. FIG. 5 demonstrates one example how the devices of the present invention can provide the combined three-axis composite speed feedback. In step 505, X, Y, Z, the acceleration signal from each axis is measured. In steps 510 X, Y, Z and 515 X, Y, Z, the input amplifier and the acceleration signals are offset and subsequently integrated, generating speed values. The speed values from each axis are then converted to absolute values in step 520 X, Y, Z. In step 525 X, Y, Z, each of the absolute values for the speed is then weighted and summed to provide the combined three axis composite speed feedback, respectively. For example, the absolute value for the speed value for the X-axis is given the most weight, contributing 85% to the combined three axis composite speed feedback while the values of the Y and Z axes are weighted 15% and 5%, respectively. Each axis may be amplified differently to bias or emphasize the primary axis of movement for the device in the given procedure. Thus, in one embodiment, the X-axis tracks the main stroke of a procedure such as lipolysis while lateral and depth acceleration from Y and Z axis sensors by the accelerometer contribute less to the combined three axis composite speed feedback. For lipolysis, the speed in the X axis can contribute up to 80%, the Y axis up to 15%, and the Z axis up to 5% of the combined three axis composite speed feedback. To achieve 100% of the selected fluence (power out), the absolute value of the speed in all three axes are added together, the sum then must exceed the 100% fluence vs. speed threshold. If the combined three-axis composite speed feedback is less than the 100% threshold, the power out is reduced linearly in relation to the speed.

[0128] In certain embodiments, the power vs. speed feedback application can include a processor that control an energy source (e.g., the component labeled as 215 in FIG. 2) to deliver the energy to the treatment area with a direction-based power output routine. With the direction-based power output routine implemented, the energy source emits varied amounts of the energy in relation to the direction which a device of the present invention moves. Such a processor is applied to evenly deliver the energy to portions of the treatment area. For example, during the forward stroke 605, 67% of the total stroke energy is deposited as shown in FIG. 6A. In FIG. 6B, the return stroke 610 deposits the remaining 33% of the total power. The idea is that some cooling/thermal dispersion time is allowed before a subsequent shot. The result is to reduce the thermal shock (fast ΔT) to the treatment area 615 while providing a more even energy deposition throughout the portion of the treatment area. Furthermore, the direction-based power output routine can be applied to side-to-side strokes.

[0129] With a power vs. speed application, the clinician can know whether and how fast the energy delivery component is moving but the clinician cannot know where the energy delivery component is moving exactly. For example, the clinician may return to the treated portion of the treatment area repeatedly (e.g., moving along the X-axis back and forth only with no speed in the Y- and Z-axes). In such case, the speed feedback allows maximum power output as long as the X-axis speed exceeds the minimum speed vs. 100% fluence limit. In one embodiment of the processor or the translator processing circuit, the processor or the translator processing is configured with an algorithm that limits the power directed to the treatment area in relation to the speed of the energy delivery component. With such algorithm, safety is greatly enhanced.
Injuries due to excessive dwell time are easily prevented, and ease of learning by the operator for the optimum tempo by the device of the present invention with the power vs. speed application is enhanced. In another embodiment for safety measures, the devices of the present invention can be configured with audio feedbacks that indicate various conditions of the device and/or the treatment area. The audio feedbacks can indicate, for example: out of power, excessive temperature increase at a portion of the treatment area, proximity detection of un-targeted tissues (e.g., as determined by probe/doping beam remittance & or reflectance photo-detector) and adverse conditions (e.g., bleeding, charring).

[0130] In certain embodiments, the power vs. speed application further includes a processor that implements a power limiting algorithm. The algorithm can limit or throttle power output such that the energy/unit volume of the treatment area does not exceed safe thermal limits. Variables for determining how much power is safe in relation to at least one of the following: wavelength, power setting, tissue type (e.g., absorbance by the tissue), propagation distance and repetition rate. For example, as described in FIG. 6, a basic curve would require twice the minimum speed for a 2 Hz setting as compared to a 1 Hz setting because a power output is doubled at the 2 Hz setting. A different slope for each repetition rate is indicated in FIG. 8. FIG. 8 illustrates that the power directed to the treatment area and/or the repetition rate of pulses is adjusted in relation to the speed of the device. The minimum speed curve is to prevent excessive tissue temperature rise based on estimates of at least one of the following: applied energy, tissue absorbance, cool down time, and hand piece travel speed. Furthermore, a slope correction factor can be derived from each wavelength and/or each tissue type.

[0131] In one embodiment of the power limiting algorithm, the device can include an energy source that is configured to modulate the amount of energy emitted when the energy delivery component is within a predetermined distance from the point of entry into the treatment area. Referring back to FIG. 2, when the tip 220 revisits the physical location that has been already treated, the energy source (not shown) is configured to modulate the amount of the energy delivered to the respective portions of the treatment area so that the already treated portions are not burned but optimally treated with an appropriate amount of the energy. For example, the tip 220 comes in contact with the portions at the physical location 235 near the incision 210 more frequently than the ones in the physical location 240, which are relatively far from the incision 210. Therefore, if the portions of the physical location 235 get pulsed with the same amount of the energy every time the tip 220 makes contact, these portions would be burned or otherwise overtreated in time. To prevent this type of undesired overexposure of the energy to the portions near the incision 210, the energy source is configured to modulate the amount of the energy delivered to the portions within a predetermined distance from the incision 210 and put a limit on the amount of the energy directed thereto.

[0132] In certain embodiments of the power vs. speed application, the devices of the present invention can further include an offset mechanism, as illustrated in FIG. 7. In one embodiment, the device includes a laser light and the laser light can be throttled directly by the speed of the travel of the device. The offset mechanism allows some deviation from the speed vs. power graph provided in FIG. 9. For example, this provides the clinician the ability to fine tune the energy vs. speed slope within hard-coded safe limits to suit the specific procedure. For example, the devices can be configured to apply a negative offset to increasing power in the power vs. speed application for a 1 Hz repetition rate setting as indicated by the curve 905. Conversely, when a positive offsetting is applied, the devices are configured to emit less power as indicated by the curve 910. The laser then reduces power in relation to the speed so that the speed of travel still determines the percentage of the selected power to be allowed. Obviously, the selected power would never be exceeded regardless of the device’s travel speed.

[0133] An alternative to the power vs. speed power limiting algorithm is a power vs. difference-in-position” (A-position) application. In this case, translation vectors are calculated from the difference-in-position in all three axes. These translation vectors defines the distance and absolute speed through three-dimensional space.

[0134] The power vs. difference-in-position power application allows a more precise control and true energy/unit volume temperature rise limitation. Specifically, by tracking the absolute position of the device and simultaneously the wavelength and power out (e.g., fat tissue absorbance) a very good estimate of local temperature rise can be made.

[0135] By plotting three separate position tracks, acceleration independently measured in all three axes using an accelerometer is twice integrated to yield the precise position in three-dimensional space of the interstitial target as shown in FIG. 10. The position tracks in the three axes are plotted and placed on a three-dimensional Cartesian plane 1000. The three axes converges on one point, and the plotting of the convergence of the three axes yields the actual position 1005 of the energy delivery component of the device in the present invention in the target area.

[0136] Location of each shot locked to an absolute position can be recorded throughout the procedure by creating a map of the treatment area. A simple pixel darkening display to the operator allows quick identification of missed or untreated areas. This feedback allows for a more evenly distributed energy treatment.

[0137] In certain embodiments of the power vs. difference-in-position application, the treatment area is surface portions of the patient’s skin (e.g., face). Similar to a three-dimensional map of the interstitial target shown in FIG. 10, a three-dimensional topographical map displaying peaks and valleys of skin surface portions. Prior to the treatment, the three-dimensional topographical map is produced using a two-dimension-to-three-dimension algorithm based on photos of the skin surface portions. Each point on the topographical map represents an accumulation that accounts at least one of the energy applied or $E_{abs}$ absorbance vs. or propagation distance and the time constant and continuity associated with the tissue type. During the treatment, the three dimensional topographical map is configured to indicate: the position of the energy delivery component; the amount of the energy directed to the respective portion; and/or the amount of the energy absorbed by the respective portion.

[0138] In certain embodiments of the power vs. difference-in-position application, the power directed to the treatment area is controlled in relation to the position feedback where translation is calculated from the difference in position in all three axes. This translation vector defines the distance and absolute speed in three-dimensional space. The translator processing circuit that is coupled to the accelerometer for the difference-in-position feedback application differs from the speed feedback in that gravity can no longer be disregarded.
Rather, the direction of the gravity vector must be determined either mathematically or by use of a gyro (e.g., the component labeled as 320 in FIG. 3) coupled to the accelerometer in the device. The advantage of the gyro is that once aligned, at the start of a procedure, the gyro can provide precise inclination feedback, which allows the translator to subtract gravity and independently account the accelerations from each of the axis to derive speed and position. The gyro also allows for other accelerometer drift and offset compensation.

In one embodiment of the power vs. difference-in-position application, these position feedback values can be charted on a three-dimensional coordinate plane and any change in position of the energy delivery component in the three-axis coordinates. This accounting of the position allows computation of a translation vector of that position between points in a three-dimensional coordinate plane, travel time between points or other relevant positional data and provides absolute position as well as actual three-dimensional speed total. Another advantage of a three-dimensional coordinate plane is simplifying complex operations such as allowing for an offset vector and distance, rotation about any axis or mirror image management of position data. An example of the need for mirror image translation is such component as the apparatus 105 in FIG. 1A. The component moves in mirror image coordinate plane relative to such component as the energy delivery component 110, which is within the body.

The algorithm configured with a power vs. difference-in-position application can also limit or prevent the discharge of excessive energy into an already treated spot/position. Thus, the clinician can pass over the same tissue sector multiple times while the laser throttles back the power on a pulse by pulse or millisecond basis to prevent excessive thermal rise. The less time the clinician allows for cooling of a previously treated area, correspondingly less energy is then subsequently allowed. This embodiment is illustrated in FIG. 11. While the present invention can operate two- or three-dimensionally, for the sake of explanation, FIG. 11 shows only a two-dimensional sectional map illustrating a treatment area 1100. As the clinician maneuvers within the treatment area 1100, the map records all the portions that are treated with the device 1140 and provide the clinician a view of the treatment area similar to the one shown in FIG. 11. The treatment area 1100 can be charted and divided into different sections 1110, 1115, 1120, 1125, and 1130 representing internal body cavities or treatment areas. The spots/positions 1105, 1106, 1107 are the ones that are already treated with, for example, a laser pulse and the portion 1135, 1136, 1137 are yet to be treated. As the treatment proceeds, the clinician, observing from the position based on the power vs. Δ-position application, can readily discern the treated portions 1105, 1106, 1107 of the treatment area 1100 from the untreated ones 1135, 1136, 1137. Thus, the clinician would then maneuver the device 1140 and move onto to treat the untreated portions 1135, 1136, 1137 of the treatment area 1100. In addition to the locations of the treated portions 1105, 1106, 1107, the map of the treatment area 1100 also shows the amount of the energy/area directed thereto and/or the amount of the energy absorbed. For example, the section 1130 being treated with, for example, more laser pulses than other sections, the map would provide an indication indicating that the section 1130 are treated with more power/area for than other sections and that certain portions are already treated optimally. In one embodiment, the map of the treatment area can include color coding. The color coding can indicate the effects of the treatments such as the magnitude of absorbance by the portions of the treatment area. The color coding can also indicate intensity of the emitted pulses, for example, a solid red dot for many shots of pulses at certain wavelength, and a weak red dot for few shots of pulses at another wavelength.

In certain embodiments, the devices configured with a power vs. difference-in-position application discussed herein can include the safety features similar to ones discussed earlier with the speed vs. power application.

In certain embodiments, the devices configured with a power vs. difference-in-position application discussed herein can include one or more of the processors and/or power limiting algorithms that were discussed with respect to the power vs. speed applications, including one for evenly distributing the energy within treatment area, analogous to the speed feedback application as previously discussed.

In certain embodiments, the device of the present invention further includes a processor that accounts for overlapping pulses. Each pulse propagates different distances and difference absorbance depending on the wavelength of the pulse. When the series of pulses are emitted, the wavelength absorbance and propagation distance can be overlapped as illustrated in FIGS. 12A-12D. FIG. 12A shows an energy delivery component 1201 inserted under a treatment area 1205 and delivered to an energy (e.g., a laser pulse) 1210. FIG. 12B shows the radial temperature rise from the delivered energy 1210, bringing the nearest circle to the origin of the energy 1210 being hottest to approximately 70°C. and the farthest circle at approximately 50°C. FIG. 12C shows hotspots 1220, 1221 resulted from a series of overlapping pulses 1225, 1226, 1227. For the purpose of accounting the amount of power delivered to a hot spot, the resultant thermal energy absorbed at the hot spot 1220 can be simply added together. When the series of the pulses are emitted in different wavelengths, the total energy absorbed vs. distance of all constituent wavelengths of the pulses allows precise prediction of tissue temperature rise. FIG. 12D depicts two sequential and closely placed or overlapping shots (laser pulses) with the corresponding temperature rise vs distance. Change in temperature or ΔT for individual shots can be estimated by the adiabatic calculations, wherein the wavelength, power, target tissue absorbance and scattering effects allow calculation of ΔT with respect to distance and direction in the target tissue. Closely placed shot's wherein the resulting tissue ΔT zones overlap, have an additional accumulation of temperature due to preheating from adjacently delivered shots. Further, the ratio between the maximum ΔT and minimum ΔT with respect to distance can be defined as the “differential ΔTmax”. For example, to deposit energy and cause a very even tissue heating the “differential ΔTmax” should be minimized to provide more consistent tissue heating.

As shown in FIGS. 13A-13C, adiabatic temperature rises when a portion of the treatment area when exposed to 1064 nm, 1320 nm, and 1400 nm energy delivery components (e.g., a 600 μm fiber) delivering 100 mJ or 0.2°C, 0.8°C, and 20°C, respectively, at a 300 μm radial coordinate.

In certain embodiments of the power vs. difference-in-position application, the treatment area is an interstitial target. Using the accelerometer that is coupled to a device of the present invention, an area internal to the body can be mapped, and, thereby enabling the device to navigate the interstitial target. In one embodiment of the three-dimensional map, the point at which the alignment is done is defined
as the origin the origin \((0,0,0)\) \((1405)\), as shown in FIG. 14. Each physical point of the three dimensional map includes an accumulator that measures combined effect of absorbed energy within the range of the physical node represented by the accumulator when the energy in \((E_{in})\), for example, a laser pulse, is directed to the physical node \((1410)\). The arrows \((1415, 1416, 1417, 1418, 1419\) and \((1420)\) show the propagation distance of \((E_{in})\) to the interstitial target (the vectors of \((E_{in})\) propagation are indicated in three axes to simplify math and translation). Each point on the three dimensional map represents an accumulation that accounts at least one of the energy applied or \((E_{out})\) absorbance vs. or propagation distance and the time constant and continuity associated with the tissue type. The graph shadowing the arrows are a plot \((1425)\) of magnitude energy vs. distance. The numbers \(+1, +2, +3, -1, -2,\) and \(-3\) indicate an arbitrary distance from the physical node \((1410)\) and \(-1\) being the nearest. As such, the area under \(+1\) and \(-1\) near the physical node \((1410)\) provided with or absorbed the most energy, indicated by the highest peak temperature rise \((1430)\). Conversely, the area further from the physical node \((1410)\), for example \(+3\) or \(-3\) show the lowest peak temperature rise \((1435)\).

[0146] In certain embodiments, as discussed in more detail below, implanting doping beams or other techniques could be used to determine tissue type. For example, using 2 different wavelength low power light-emitting diode (such as in oximetry devices) allows us to distinguish color specific reflectivity or remittance. The main treatment wavelength may even be one of the doping or probing beams multiplexed into the energy delivery component. Because tissues reflect different wavelengths based on the type, the type of the tissue made up the physical node \((1410)\) can be ascertained by a doping beam during the treatment. As the device of the present invention maneuvers within the interstitial target, the energy source can be adjusted automatically in accordance with the tissue type to provide a predetermined amount of the energy that is suitable for an optimal treatment. Furthermore, in another embodiment, the accumulator also tracks the rate of cooling at the physical node \((1410)\) after one or more shots of the energy. As such, when the device returns to the physical node \((1410)\), the energy source can be adjusted based on the rate of cooling to determine whether any more treatment is necessary and by how much.

[0147] The tissue discriminator or doping beam can also ascertain the location of the device in relation to the skin. If fiber approaches too close to the skin (from beneath), a suitable change in reflectivity vs. color is observed thus allowing the algorithm to shut down the laser before causing a burn, or providing a warning to the operator. In one embodiment, the doping beam is located at the tip of an energy delivery component and emits a beam which is then reflected by the tissue and detected by a sensor.

[0148] The embodiment of the device described herein are provided with an energy source that related to laser or light energy. However, these energy sources can be substituted with suction energy, as commonly used in lipolysis. In the embodiments with suction energy, an accelerometer is in communication with the suction energy source, and thus, the suction energy source can modulate an amount of the suction energy directed to the treatment area. Instead of having an energy delivery component (i.e., the component \((110)\) in FIG. 1) that threads the apparatus \((115)\) in FIG. 1) and the cannula \((130)\) in FIG. 1), the cannula by itself would be applied to remove tissue or undesired bodily parts from the treatment area.

[0149] In certain embodiments of the present invention, a surgical system \((1500)\) includes a device \((1510)\), which is analogous to the apparatus indicated as \((100, 200, 300)\), or the one with suction energy, and a visual display that is in communication with the device. In one embodiment, the visual display indicates the position of the visual element that is analogous to the energy delivery component such as ones indicated as \((315)\) in FIG. 3, and/or the amount of energy absorbed by a physical point of the treatment area. An example of the visual display is a photodetector sensor pad \((1505)\) as illustrated in FIG. 14. The trans detector sensor pad \((1505)\) is a thin sheet containing a matrix of photodetector elements that is placed on the patient over the treatment area. In one embodiment, the sensor pad \((1505)\) comprises a matrix of dye-based solar cells \((1520)\) (DBSC) that can be fabricated using any known means, such as conventional silk-screen printing processes. In another embodiment, the sensor pad \((1505)\) comprises of a matrix of DBSVCs (e.g., \(-100\) cm by \(1\) cm matrix). The DBSCs are fabricated on a flexible plastic material having metalized electrodes printed onto the plastic material to carry signals back to detection circuitry \((1520)\). As shown in FIG. 15, the sensor pad \((1505)\) is placed on the patient over the area to be treated, and detects the physical point \((1535)\) of the tip \((1530)\) and laser shots fired on a shot-by-shot basis. The sensor pad \((1505)\) communicates the physical point \((1535)\) of the tip \((1530)\) and where shots are fired back to the laser via a data connector \((1540)\), such as a USB connector. This information can then be displayed on a touch-screen display to aide the doctor during the procedure, and can also be used by the laser control system to disable the laser if too many shots have been fired in any one position.

[0150] As shown in FIG. 15, as the laser is fired, the location that the laser is fired will be detected by one or a small number of the photodetectors \((1535)\) which then send x, y coordinates back to the laser control system for display. The laser beam could also be doped with one or several low power constant light sources, such as light-emitting diodes, to convey the tip position back to the clinician for proper location of the tip during treatment. As shown in FIG. 16, the doping wavelengths could be, for example, 550 nm or 660 nm, or a combination of both. When multiple wavelengths are used in the doping beam, the depth of the laser hand piece tip can be determined by detecting changes in the amplitude, e.g. due to the differential scattering of the two wavelengths, of the doping beams.

[0151] The sensor pad \((1505)\) can be a disposable component that is removed from the position translation circuitry \((1525)\) after use and discarded. The translation circuitry \((1525)\) can then be attached to a new sensor pad (not shown) for use in a subsequent lipolysis treatment.

[0152] The laser lipolysis system can include a user interface display \((1700)\) as shown in FIG. 17. This display \((1700)\) includes basic laser interface controls \((1705)\), such as pulse width control \((1710)\), fluence display \((1715)\) and controls, etc. In addition, a laser shot location display \((1700)\) can display the current location of the tip (e.g., the component \((1530)\) in FIG. 15) as well as where on the sensor pad (e.g., the component \((1505)\) in FIG. 15) shots have been recorded. The shot location display preferably also indicates the level of treatment that has occurred throughout the grid, such as by a color-coding of the grid. This display can be used to aide the doctor in posi-
toning the device for the next shot and to prevent overtreatment in any one location of the treatment area.

[0153] Thermal Sensing

[0154] The following describes in greater detail thermal sensing techniques of the type described above, used alone, or in conjunction with other sensor information.

[0155] Temperature sensors may be mounted on surgical devices in any suitable fashion. For example, FIG. 18 shows a surgical probe 1800 for laser liposuction which includes an optical fiber 1810 in a fiber cannula 1820. The optical fiber 1810 delivers treatment light to tissue (e.g., fat tissue). The probe also includes a suction cannula 1830 for removal of treatment by-product. A feature of this probe is a temperature sensor 1840 integral to the suction cannula. The temperature sensor 1840 is set back from the laser fiber tip. In typical embodiments, this configuration avoids localized heating of the tip of fiber 1810 and cannula 1820 leading to false readings of tissue temperature.

[0156] During a surgical procedure, tissue temperature can be read while holding the probe stationary (a short pause) within the laser field. Based on the reading, more laser energy or cooling effort can be applied to reach the desired internal tissue temperature. In typical applications, temperature readings will fluctuate (e.g., if the probe is being rapidly reciprocated into and out of the tissue). In such cases, the temperature readings may be averaged to indicate a meaningful temperature.

[0157] In various embodiments, any suitable temperature sensor may be included with any of a variety of surgical probe types. For example, FIG. 19 shows a surgical probe for laser liposuction featuring a separate stainless steel cannula 1910 for the temperature sensor 1920. The temperature sensor 1920 resides in the tip of the cannula 1910, and one or more wires 1930 run up through the cannula 1910, into a hand piece 1940. The wires 1930 extend from the end of the hand piece 1940 and can be connected to a monitor or processing unit.

[0158] FIG. 20 shows an embodiment of a laser surgical probe 2000 which, unlike the embodiments shown immediately above, does not include a suction cannula. The probe includes 2000 an optical fiber 2010 for delivering treatment light placed in an inner cannula 2020 (e.g., a standard 600 μm cannula). A larger outer cannula 2030 surrounds the inner cannula 2020. A temperature sensor 2040 (e.g., a thermocouple junction) is located near the tip of the outer cannula 2030. The sensor 2040 and connecting wires extending therefrom are thermally and electrically isolated from the inner cannula 2020. For example, as shown in the lower portion of the figure, the sensor 2040 and wires may be surrounded by a thermally and electrically insulating material jacket 2050. In some embodiments, the sensor tip, wires, and insulating jacket may be autoclavable. In one embodiment, the thermistor is bonded and housed to the cannula’s outer surface by being blanket waving in a (autoclavable, biocompatible) heat shrink.

[0159] In various embodiments, the use of a thermistor or thermocouple located within or adjacent to the cannula tip provides tissue temperature feedback to the laser. Tissue temperature feedback allows the possibility of closed loop tissue temperature control wherein the laser output (power, pulse rate, wavelength etc.) may be controlled (e.g. modulated) to effect a desired tissue temperature profile for a given procedure. For example, deep “fat basting” procedures typically place the cannula tip well out of range of surface temperature feedback techniques such as an IR camera. It is easy to unintentionally overheat deep tissue layers (e.g., beyond the temperature required for optimum safe lipo disruption). Excessive deep heating is associated with various deleterious side effects such as necrosis of blood vessels, or even thermal damage to adjacent tissue layers (muscle, fascia, etc.). By employing a closed loop temperature management system, optimum tissue temperatures can be maintained, simplifying the procedure for the clinician and providing improved efficacy with enhanced safety.

[0160] Another example of closed loop temperature management benefits is in skin tightening procedures where the cannula tip is placed proximal to the subdermal layer. In essence the laser heats fat adjacent to these deeper dermal areas and said heat acts on the entire dermis to affect so called collagen remodeling (skin tightening). In some applications, a difficulty is that thermal conduction through dermal layers (to effect skin tightening) varies greatly based on skin type and thickness. Thermal gradients from deep dermis to epidermal layers may vary considerably. Thus it is possible to over heat deeper sub-dermal areas while affecting optimum surface temperatures. This may cause vascular damage and other side effects. With closed loop thermal control of deeper or subdermal layers, a compromise between optimum epidermal temperature and subdermal temperatures can be made.

[0161] For various applications, the optimum time constant (response rate) of any tissue contact temperature measuring device may vary. A faster response time has the advantage of actively measuring tissue temperature throughout the surgeon’s treatment stroke. To accomplish this, the thermal mass of the thermistor or thermocouple should be reduced or minimized. Another possibility is to measure the treatment stroke length (e.g., using an accelerometer to measure a sign change in the velocity of the probe), divide the treatment stroke into near, mid and far “ranges” and then sample average temperature for the period the cannula tip is present in each range. This allows a slower response time thermal couple to generate a relatively precise average temperature feedback signal for each of the near, mid and far range areas. Said feedback can then be used by the laser to adjust or even out temperature accumulation through each “range” of the cannula stroke. This approach compensates for poor clinician technique.

[0162] As shown in FIG. 21, in some embodiments, the closed loop control consists of a temperature control loop where a temperature error signal is derived by a summation block/difference amplifier and laser average power (or, equivalently, for pulsed lasers, variable repetition rate) acts as a limit value. Desired final tissue temperature is selected as “temperature command”. When summed with the temperature feedback from the cannula thermistor a temperature error term results. This error is then gained (amplified) and compensated, the result of which is then clamped by the laser power/repetition rate setpoint limiter. The resulting output acts as a laser power, or laser repetition rate command. Operation is such that once the tissue temperature reaches the temperature command, laser output is inhibited. Regardless of temperature, the laser will not exceed the laser power/rep rate limit value.

[0163] As shown in FIG. 22, in some embodiments, control loop includes an outer tissue temperature loop combined with an inner laser power vs. speed (or velocity) laser control loop. Using the techniques described in detail above, speed feedback is provided by an accelerometer, e.g. mounted to the cannula hand piece or otherwise integrated with the surgical probe. The inner speed vs. power loop acts to limit
laser power during instantaneous hand piece dwell (motion stoppage) thereby providing a convenient method to inhibit the laser when the hand piece stops moving, such that a more precise tissue temperature measurement may be made by the cannula thermistor. Additionally, the speed vs. power or inner control loop prevents very rapid buildup of localized tissue temperature proximal to the fiber tip which could otherwise occur during a dwell period.

[0164] In some embodiments, this technique also allows flexibility in the placement of the thermistor (relative to the tip and distance to heated tissue), and further reduces the fast time constant thermistor requirement. In essence the power vs. speed loop controls very rapid tissue temperature increases (e.g. due to probe dwell), while the thermistor more precisely controls the average tissue temperature increases which occur during the treatment process. In some embodiments, the thermistor/thermocouple may be triggered to take a temperature measurement when the accelerometer data indicates that the handpiece is moving sufficiently slowly compared to the time constant of the thermistor/thermocouple to allow for an accurate measurement.

[0165] The adjustable temperature command may be selected based on the type of procedure being performed (skin tightening vs deep lipo disruption), or it may be selected based on the body location being treated (neck/face vs abdomen).

[0166] In some embodiments, handpiece position information derived from the accelerometer outputs may be combined with temperature information from the temperature sensor to provide, for example, a temperature map (e.g. a 2D or 3D map) of the treatment area. For example, referring to FIG. 23 A temporary 2D temperature map can be created from the combined data of the accelerometer and the temperature within tissue along a cannula reciprocal stroke path along a given surgical track. This is based on the fact that the reciprocal axis of the handpiece may be fixed in space for several seconds, or strokes. For example, in the embodiment shown, 1 see/stroke a typical cycle, before a new surgical track is selected. During each one second one second, the temperature can be sampled more than 10 times and the information of probe position and temperature linked (t=0-3 s below) as shown in plots 2301. In typical applications, the information will be too transient and perhaps noisy to be useful. A running average of at least three stroke cycles will create a coarse time/temperature map 2302 of the temperature profile within the current surgical track. In the example shown, a quick glance by the clinician would indicate more accumulated energy/temperature 2303 near the right, incision side of the surgical track.

[0167] The change in direction of the handpiece can be sampled since the speed goes to zero. This concept works if the strokes only stop on the extreme ends and not within the stroke.

[0168] In some embodiments, the thermistor or thermocouple may be replaced by other types of temperature sensors. For example, FIG. 24 shows an embodiment of a surgical laser waveguide 2400 which incorporates IR temperature sensing of tissue adjacent to the treatment waveguide/fiber tip 2410. An infrared waveguide 2420 (e.g. a ZnSe IR fiber) is bundled with the surgical waveguide 2430 in an over-jacket 2440. In the example shown, a two sensor IR photodetector assembly 2450 is located in the hand piece 2460 adjacent to the treatment beam focus assembly 2470. Portions of light from the IR waveguide at two distinct wavelengths are separated and directed respectively to the two IR sensors using, for example, a dichroic beamsplitter 2480. Signals from the detectors are compared differentially to increase sensitivity and reject errors due to the "sense waveguide" transmission variables or characteristics.

[0169] The signals from the IR sensors are processed to obtain temperature information about the tissue under treatment. IR temperature monitoring provides tissue temperature feedback to the laser (which would adjust energy deposition based on observed tissue temperatures). In various embodiments, this could include a simple maximum temperature safety limit, or feedback could allow closed loop temperature control of tissues. In either case the laser takes feedback from the IR sensor and then adjusts laser output power (closed loop) to achieve the selected tissue temperature.

[0170] In some embodiments, the surgical waveguide itself can collect IR light from the treatment area during treatment to provide IR tissue temperature sensing. However, for some applications, such a waveguide or fiber would be required to pass high energy lasers in the 532 to 1550 nm wavelengths (treatment wavelengths) and also IR wavelengths of 3-14 μm, e.g. 3-5 μm or 8-12 μm (for temperature sensing and feedback). In some embodiments, this may be an unwanted requirement. FIG. 25 shows an example of a device 2500 which avoids this requirement by employing a dual fiber approach. As with the systems described above, light at a treatment wavelength is delivered via a waveguide 2510 (e.g. a stiffened fiber) suitable for surgical use without a cannula. The treatment waveguide 2510 is surrounded by and coaxial with an IR waveguide 2520 (e.g. a ZnSe cylinder or tube). As described above, the treatment waveguide 2510 is coupled to a treatment fiber 2530 which delivers light from a treatment source. The coupling is accomplished using a focus assembly 2540 in a connector 2550 connected to the back of a hand piece. As shown, the connector also includes and IR pass filter ring 2560 (to filter out stray treatment light) and IR detector ring 2570 (e.g., an annular array of IR photodetectors), aligned with the IR waveguide tube 2520. The IR sensor ring produces electrical signals in response to incident IR light. These signals are passed to a processor, which operates to determine tissue temperature information and provide feedback to the treatment laser, as described above.

[0171] As described above, in various embodiments, IR light from a treatment area is propagated to an IR detector assembly via optics suitable for in vivo temperature monitoring. These optics may include, for example, coated ZnSe or Germanium rods or tubes, or certain IR transmissive plastics or even photonic waveguides (the IR transmission characteristics of AR coated ZnSe are shown in FIG. 26). Although several examples of IR optics are presented, it is to be understood that other suitable materials, geometries, and configurations may be used.

[0172] The temperature information acquired using the above described IR sensing techniques may be used in place of the thermistor/thermocouple derived information in any of the techniques described above.

[0173] In some embodiments, a surgical probe is disclosed with a temperature sensor attached to cannula tip for purpose of measuring cannula temperature and shutting down laser should cannula become overheated. In various embodiments, the temperature sensor may include a negative temperature coefficient NTC or positive temperature coefficient PTC thermistor or even IR photodetectors.
Some embodiments employ control method or algorithm where a temperature feedback signal from a temperature sensor is used to adjust laser output power by means of an error amplifier and compensation circuits.

Some embodiments employ a method or control algorithm that limits the temperature measured at the cannula tip for purpose of limiting laser output based on combined tissue and cannula tip temperature rise.

Some embodiments employ a method or control algorithm that, based on the temperature measured at a cannula tip of a laser surgical probe, limits laser output based on combined tissue and cannula tip temperature rise.

Some embodiments employ a method or control algorithm which adjusts the relative power of independent wavelengths of a multiplexed laser treatment pulse to effect a change in tissue temperature rise or treatment area to improve the homogenous deposition of energy and also temperature rise. Since penetrating depths vary for different laser wavelengths, simply adjusting the ratio of composite wavelengths adjusts the dimensions of the treatment space or treatment area.

Tissue Type Discrimination

An exemplary probe beam injector 2700 with reflectivity and remittance color sensor is shown in FIGS. 27 and 28. A tissue treatment beam (in this example, with a wavelength of 1064 nm) is propagated from the output coupler (OC) of a treatment beam resonator cavity to a focus assembly 2720 via a polarized beam splitter 2730. The polarizer/beamsplitters are transparent to the 1064 nm treatment beam and act as polarizers to one or more probe/doping beams. Accordingly, the probe beam sources at one or more wavelengths are coupled into the path of the treatment beam, directed to the focus assembly 2720, propagated down a fiber 2740 or waveguide to an output tip 2750, and directed to tissue of interest. Similarly, reflected/remitted probe light from the tissue is collected and propagates back along the fiber 2740 or waveguide from the output tip 2750 and back through the focus assembly 2720 and is separated out from the path of the treatment beam and directed to one or more color photodetectors 2760. The photodetectors may include filters for filtering out stray treatment light and/or to distinguish between multiple probe light wavelengths (i.e., colors). Signals from the photodetectors (e.g., color and intensity), are processed, e.g., as described below, to characterize tissue and determine treatment (e.g., treatment beam intensity, pulse duration, etc.). For example, in laser lipolysis applications, if hidden vascular tissue, or other tissue unsuited for treatment is identified, the treatment laser is directed not to fire.

FIGS. 29 and 30 show examples of laser systems with tissue type determination featuring dual waveguides. As in the system described above, doping/probe light at multiple wavelengths/colors (as shown, 532 nm green and 635 nm red light) are coupled into the path of a treatment beam (e.g., using dichroic elements 2710 such as mirrors and/or beam combiners/splitters), and propagated down a treatment waveguide or fiber 2720 to a treatment area 2730. However, unlike the systems above, a second “sense” waveguide or fiber 2740 is included with the treatment fiber, e.g., in a cannula 2750 or catheter inserted into the patient. The sense fiber 2740 collects reflected/remitted light from tissue of interest, and propagates it back to a focus assembly 2760 and on to a color photodetector 2770 (e.g., an RGB photodetector). As with the systems above, signals from the photodetector are processed using processing electronics 2780 (e.g., differential amplifiers, analog to digital converters, microprocessors, etc., see below) for tissue determination. The results of the tissue determination are fed back to the treatments laser source 2780 (or laser source controller 2790) to control (e.g., provide or halt) treatment based on the determined tissue type. In some embodiments, the sense fiber tip 2795 can be offset from the treatment fiber tip 2796, as shown.

In various embodiments, visible or invisible wavelengths can be used for tissue type discrimination. (As mentioned above, in some embodiments the diagnostic and treatment beams are a single beam.) In some embodiments, at least 2 diagnostic wavelengths are used, although more wavelengths will improve precision and resolution. For example, aim-beam style low power visible lasers (e.g., lasers with power outputs in the range of about 1-50 mW) are readily available, low cost, and suitable for discrimination of the major tissues of interest common to laser lipolysis. For example human fat is yellow, fascia is white, and skin contains large amounts of darker pigments including red, etc. In some embodiments, the diagnostic “doping” or probe beams may be continuous wave (CW). In some embodiments, a time multiplexed or pulsed combination of different wavelengths may also be used.

In some embodiments, it is possible to build a tissue type determination system based on a single wavelength diagnostic beam. The single wavelength is chosen so that there is a large difference in the absorption coefficient of the targeted lipids and all the other tissues that are not targeted. However, such system heavily relies on a predetermined backscatter coupling efficiency. That is the total efficiency of delivering the diagnostic beam to the tissue in front of the tip, collecting the backscattered signal, and delivering the backscattered signal to a sensor in the laser system. Any changes in the fiber delivery system (like fiber tip contamination) would change the backscatter coupling efficiency and decrease the reliability of a single wavelength diagnostic system.

The reliability of the tissue type diagnostic can be greatly improved by using a multiple wavelength diagnostic beam. Increasing the number of wavelengths will increase the precision of the diagnostic system and allow it, for example, to distinguish between multiple chromophores.

An example as a two wavelength diagnostic system will be considered. In the example the system will be assumed to distinguish between fat (liposomes) and water. Most tissues in the body other than fat contain over 80% water. Therefore a diagnostic system that distinguishes between fat and water can be used to deliver energy when the fiber tip is pointing towards fat and not to deliver energy when the tip is pointing at any other tissue.

Although not intending to be bound by theory, the following example illustrates the operation of a two wavelength diagnostic system designed to determine the fat content in water environment. For each wavelength the signal propagates from the source to the detector. For wavelength λ the source intensity is I. The total optical system and fiber transmission is T. The signal delivered at the end of the fiber is S. Part of that signal is backscattered to the fiber with efficiency B while part of it is absorbed with efficiency A. The signal that arrives back at the fiber end is I S 1 - B 1 - A. The backscattered signal is coupled to the fiber and transmitted to the detector with efficiency C. the detector has efficiency D. The signal arriving at the detector is I S 1 - B 1 - A C D. It will be assumed that if the two diagnostic wavelengths...
are sufficiently close (300 nm in the IR) the backscattering efficiency \( B \) does not depend on the wavelength or the fat content \( f \). Then the only fat content dependent parameter is the absorption efficiency \( A \). If the diagnosed tissue has an unknown fat content \( f \), the detected signals in the two detectors \( V_1 \) and \( V_2 \) for the two wavelengths can be written as

\[
V_1 = s_1 TBCD_1(1-A_1^F)CD_1 + f s_1 TBCD_1(1-A_1^W)CD_1
\]

\[
V_2 = s_2 TBCD_2(1-A_2^F)CD_2 + f s_2 TBCD_2(1-A_2^W)CD_2
\]

where the indices 1 and 2 indicate wavelengths and the superscripts F and W indicate fat and water. The two equations can be rewritten as

\[
V_1 = s_1 TBCD_1(1-A_1^F) + s_1 TBCD_1(A_1^F - A_1^W)
\]

\[
V_2 = s_2 TBCD_2(1-A_2^F) + s_2 TBCD_2(A_2^F - A_2^W)
\]

The parameters independent of tissue absorption can be eliminated by system calibration—that is by measuring the diagnostic signals \( V_{1,d} \) and \( V_{2,d} \) from a known sample with no fat content (\( f = 0 \)). The expressions for the calibration measurements are

\[
V_{1,c} = s_1 TBCD_1(1-A_1^W)
\]

\[
V_{2,c} = s_2 TBCD_2(1-A_2^W)
\]

The ratio of the two calibration measurements \( R_c \) can be defined as

\[
R_c = \frac{V_{2,c}}{V_{1,c}} = \frac{s_2 TBCD_2(1 - A_2^W)}{s_1 TBCD_1(1 - A_1^W)}
\]

The calibration ratio may be obtained from a calibration tissue phantom before the laser lyses procedure begins and stored in the diagnostic system computer to be used in the real-time tissue determination. During the laser treatment the diagnostic system runs the tissue determination procedure interspersed between the treatment pulses (or in parallel with a CW treatment beam) while the operator moves the treatment tip. The real-time diagnostic signals \( V_{1,d} \) and \( V_{2,d} \) can be expressed from (1)

\[
V_{1,d} = s_1 TBCD_1(1-A_1^W) + s_1 TBCD_1(A_1^F - A_1^W)
\]

\[
V_{2,d} = s_2 TBCD_2(1-A_2^W) + s_2 TBCD_2(A_2^F - A_2^W)
\]

Based on the calibration measurement the last expression can be rewritten as

\[
V_{1,d} = s_1 TBCD_1(1-A_1^W) + f s_1 TBCD_1(A_1^F - A_1^W)
\]

\[
V_{2,d} = R_c s_2 TBCD_2(1-A_2^W) + f R_c s_2 TBCD_2(A_2^F - A_2^W)
\]

The product \( s_1 TBCD_1 \) can be expressed from the first equation and substituted in the second

\[
s_1 TBCD_1 = \frac{V_{1,d}}{(1-A_1^W) + f (A_1^F - A_1^W)}
\]

\[
V_{2,d} = R_c \left( \frac{V_{1,d}}{(1-A_1^W) + f (A_1^F - A_1^W)} \right) + \frac{f R_c (A_2^F - A_2^W)}{A_2^W}
\]

The ratio of the two diagnostic measurements \( R_d \) can be defined as

\[
R_d = \frac{V_{2,d}}{V_{1,d}} = \frac{(1-A_1^W)}{(1-A_1^W) + f (A_1^F - A_1^W)}
\]

\[
= \frac{(1-A_1^W)}{(1-A_1^W) + f (A_1^F - A_1^W)}
\]

\[
= \frac{R_c (A_2^F - A_2^W)}{A_2^W}
\]

\[
= \frac{R_c (A_2^F - A_2^W)}{A_2^W}
\]

The last expression can be used to express the unknown fat content fraction

\[
f = \frac{(R_c - R_d)(1-A_1^W)}{R_c(A_1^F - A_1^W) - R_d(1-A_1^W)} = \frac{(R_c - R_d)}{R_c(A_1^F - A_1^W)}
\]

\[
= \frac{(R_c - R_d)}{R_c(A_1^F - A_1^W)} = \frac{(A_2^F - A_2^W)}{(1-A_2^W)}
\]

The expression for the tissue fat content (2) emphasizes the importance of choosing at least one wavelength so that there will be a large difference in the absorbed fractions in fat and water and at least one of the difference terms in the denominator will be large. One such wavelength region is 1300 to 1500 nm. A possible choice for large absorption difference wavelength is 1440 nm. The form of expression (2) would be simplified if the other wavelength is chosen so that the absorbed fractions in fat and water are nearly the same. Such wavelengths are for example around 1190, 1230, 1690 and 1750 nm. If one of the wavelengths (wavelength 1) is chosen so that the absorbed fractions in fat and water are nearly the same, the expression (2) for the fat content \( f \) becomes a linear function of the ratio of the two diagnostic measurements \( R_d \).

\[
f = R_d \left( \frac{1-A_1^W}{A_1^W} \right) = \frac{R_d (A_2^F - A_2^W)}{A_2^W}
\]

The expression (3) can be simplified further if the absorbed fraction in fat is neglected in comparison to the much larger absorbed fraction in water

\[
f = R_d \left( \frac{1-A_1^W}{A_1^W} \right) = \frac{R_d (A_2^F - A_2^W)}{A_2^W}
\]
Expression (4) can be rearranged to express the expected ratio of the diagnostic and calibration ratios (R_d and R_c) as a function of the fat content f

\[ r_c = \frac{R_c}{R_d} = \frac{(1 - A_d^f + \rho d^f)}{(1 - A_d^f)} \]  

(5)

where \( r_c \) can be interpreted as a tissue type ratio. It is clear from equation (5) that for very low fat content \( f = 0 \), the diagnostic ratio is equal to the calibration ratio and the tissue type ratio \( r_c = 1 \). As the fat content increases (and for wavelength 2 fat having much lower absorption than water), the tissue type ratio grows.

[0189] In some embodiments, a diagnostic system or threshold tissue type ratio may be predetermined so that if the tissue type ratio exceeds the threshold, the sampled tissue in front of the tip of the delivery fiber will be considered to be fat. The threshold tissue type ratio can be calculated, for example, using equation (5) and absorbed fraction in water at wavelength 2. In some embodiments, the threshold tissue type ratio can be established by experimental measurements in excised tissue fat from fat reduction surgery.

[0190] In some embodiments, the operation of the tissue type determination can be greatly simplified with some loss of precision by a specific choice of diagnostic wavelengths. One such choice is when wavelength 1 is chosen so that water and fat have the same absorption, for example around 1230 nm. Then wavelength 2 is chosen so that water has nearly the same absorption and fat has a much lower absorption \( A_1 = A_2 = A_2^w \approx A_2^f \). For example wavelength 2 can be chosen around 1290 nm. Other possible combinations of wavelengths 1 and 2 can be 930 nm and 1070 nm, 1730 nm and 1630 nm, 2320 nm and 2100 nm. For these wavelength choices the expressions (1) for the diagnostic signals at the two wavelengths simplify to

\[ V_1 = S_1 \text{TCP} A_1 (1 - A_1^w) \]
\[ V_2 = S_1 \text{TCP} A_1 (1 - A_1^w) + S_2 \text{TCP} A_2 (1 - A_2^w) \]

The source intensity is \( S_1 \) and \( S_2 \) and the detector has efficiencies \( D_1 \) and \( D_2 \) can be adjusted to be the same (for example using electronics). Then the diagnostic ratio of the two signals reduces to

\[ \rho_d = \frac{V_2}{V_1} = \frac{1 - A_1^w + \rho A_2^w}{1 - A_1^w} \]

Then for very low fat content the diagnostic ratio is around 1 and it grows with increasing fat content. A threshold tissue type ratio can be established either by calculations or by experimental measurements in excised tissue fat from fat reduction surgery.

[0191] FIG. 31 shows an exemplary circuit 3100 for use in processing signals detected by a color photodetector. As shown, an MTCSICO Integral True Color Sensor type TO39 is used as the color photodetector. The TO 39 includes three photodiodes which each produce photocurrents in response to light at a different frequency (the spectral response characteristics of the respective photodiodes are shown in FIG. 33). An amplifying circuit features a three op amp package OPA491, configured to convert the respective photocurrents from the TO39 into voltages. Variable resistors are provided to selectively adjust the response of the amplifying circuit to each of the three photocurrent “channels.” As described above, such control of detector response efficiencies can be used to simplify tissue determination.

[0192] FIG. 32 also shows an example of a differential amplifier 3200 for use in tissue type determination using the techniques described above. The differential amplifier produces a voltage difference across its output terminals which is representative of the difference in photocurrent measured by each of two photodiodes corresponding to different detected wavelengths.

[0193] It is to be understood that the light collected for tissue type analysis may include, for example, reflected probe/doping light, scattered or refracted probe/doping light, reflected light, stimulated fluorescence or phosphorescence, or any other light indicative of tissue type.

[0194] Embodiments of the present invention described herein are directed to devices and methods that can be used in a surgical procedures. One example of the surgical procedures is lipolysis.

[0195] While this invention has been particularly shown and described with references to example embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

[0196] One or more or any part thereof of the tissue determination techniques described above can be implemented in computer hardware or software, or a combination of both. The methods can be implemented in computer programs using standard programming techniques following the method and figures described herein. Program code is applied to input data to perform the functions described herein and generate output information. The output information is applied to one or more output devices such as a display monitor. Each program may be implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the programs can be implemented in assembly or machine language, if desired. In any case, the language can be a compiled or interpreted language. Moreover, the program can run on dedicated integrated circuits preprogrammed for that purpose.

[0197] Each such computer program is preferably stored on a storage medium or device (e.g., ROM or magnetic diskette) readable by a general or special purpose programmable computer, for configuring and operating the computer when the storage media or device is read by the computer to perform the procedures described herein. The computer program can also reside in cache or main memory during program execution. The analysis method can also be implemented as a computer-readable storage medium, configured with a computer program, where the storage medium so configured causes a computer to operate in a specific and predefined manner to perform the functions described herein.

What is claimed is:

1. A laser surgical apparatus comprising:
   a handpiece comprising:
   an optical delivery component that transmits laser energy from a source to a treatment volume; and
   an accelerometer configured to provide information indicative of the position of the handpiece;
a processor coupled to the accelerometer and the source and controlling the laser energy transmitted to the treatment volume; and

a display;

wherein the processor is configured to determine information indicative of an amount of energy delivered at each of a plurality of positions within the treatment volume based on the information indicative of the position of the handpiece,

wherein the display is configured to display a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

2. The apparatus of claim 1, wherein the processor is configured to control the amount of energy delivered to the treatment volume based on feedback from the accelerometer.

3. The apparatus of claim 2, wherein the accelerometer measures acceleration along three axes.

4. The apparatus of claim 3, wherein the accelerometer is a gyro compensated accelerometer.

5. The apparatus of claim 1, wherein the graphical representation comprises a map of the treatment volume, wherein a plurality of points on the map correspond to the plurality of positions within the treatment volume, and wherein the graphical quality of each of the points depends on the amount of energy delivered at the position within the treatment volume.

6. The apparatus of claim 5, wherein the graphical representation is a three dimensional representation.

7. The apparatus of claim 1, wherein:

the handpiece further comprises a temperature sensor configured to provide information indicative of the temperature of tissue at positions within the treatment volume, the processor is coupled to the temperature sensor and is configured to determine information indicative of the temperature of each of a plurality of positions within the treatment volume based on the information indicative of the position of the handpiece and the information indicative of the temperature of tissue at positions within the treatment volume, and

wherein the display is configured to display a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

8. A laser surgical method comprising:

providing a laser surgical device comprising:

a handpiece comprising:

an optical delivery component that transmits laser energy from a source to a treatment volume; and

an accelerometer configured to provide information indicative of the position of the handpiece;

using the handpiece to transmit laser energy from the source to a plurality of positions within the treatment volume

using the accelerometer, providing information indicative of the position of the handpiece;

determining information indicative of an amount of energy delivered at each of the plurality of positions within the treatment volume based on the information indicative of the position of the handpiece; and

displaying a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

9. The method of claim 8, further comprising controlling the amount of energy delivered to the plurality of positions within the treatment volume based on feedback from the accelerometer.

10. The method of claim 9, wherein the accelerometer measures acceleration along three axes.

11. The method of claim 10, wherein the accelerometer is a gyro compensated accelerometer.

12. The method of claim 8, wherein the graphical representation comprises a map of the treatment volume, wherein a plurality of points on the map correspond to the plurality of positions within the treatment volume, and wherein the graphical quality of each of the points depends on the amount of energy delivered at the position within the treatment volume.

13. The method of claim 5, wherein the graphical representation is a three dimensional representation.

14. The apparatus of claim 1, wherein:

the handpiece further comprises a temperature sensor configured to provide information indicative of the temperature of tissue at positions within the treatment volume, and the processor is coupled to the temperature sensor; and

further comprising:

using the temperature sensor, determining information indicative of the temperature of each of a plurality of positions within the treatment volume based on the information indicative of the position of the handpiece and the information indicative of the temperature of tissue at positions within the treatment volume, and displaying a graphical representation indicative of the amount of energy delivered at each of the plurality of positions within the treatment volume.

15. A laser surgical apparatus comprising:

a handpiece comprising:

an optical delivery component that transmits laser energy from a source to a treatment volume; and

an accelerometer configured to provide information indicative of acceleration of the handpiece along three axes; and

a processor coupled to the accelerometer and the source and controlling the laser energy transmitted to the treatment volume based on feedback from the accelerometer.

16. The apparatus of claim 15, further comprising a gyroscope configured to provide information indicative of the spatial orientation of the handpiece, and wherein the processor is coupled to the gyroscope and is configured to control the laser energy transmitted to the treatment volume based on feedback from the accelerometer and the gyroscope.

17. The apparatus of claim 16, wherein the processor is configured to determine information indicative of an absolute position of the handpiece based on the information indicative of acceleration of the handpiece along three axes, and the information indicative of the spatial orientation of the handpiece.

18. The apparatus of claim 17, wherein the processor is configured to:

determine information indicative of a speed of the handpiece based on the information indicative of acceleration of the handpiece along three axes; and

control the laser energy transmitted to the treatment volume based on feedback using the information indicative of the speed of the handpiece.
19. The apparatus of claim 18, wherein
the information indicative of acceleration of the handpiece
along three axes comprises, for at least one axis, a signal
having an amplitude which depends on the acceleration of
the handpiece along the axis, and
the processor is configured to selectively block low fre-
quency components of the signal prior to integrating said
signal to determine information indicative of a speed of
the handpiece along the respective axis.

20. The apparatus of claim 18, wherein the processor is
configured to
determine the speed of the handpiece along each of the
three axes based on information indicative of acceleration
of the handpiece along each of the three axes;

determine a weighted average speed of the handpiece by
calculating a weighted average of the speeds of the hand-
piece along each of the three axes; and

control the laser energy transmitted to the treatment vol-
ume based on feedback using the weighted average
speed of the handpiece.

21. The apparatus of claim 20, wherein
the handpiece comprises a probe member extending into
the treatment volume, said probe member extending
along a probe member axis,
the accelerometer is configured to provide information
indicative of acceleration along each of the three axes,
one of said three axes being substantially parallel to the
probe member axis; and
the processor is configured to determine the weighted
average speed of the handpiece by calculating a
weighted average of the speeds of the handpiece along
each of the three axes, wherein the axis substantially
parallel to the probe member axis is given greater weight
that the other axes.

22. A laser surgical method comprising:
providing a handpiece comprising:

an optical delivery component that transmits laser
energy from a source to a treatment volume; and
an accelerometer configured to provide information
indicative of acceleration of the handpiece along three
axes;

using the handpiece to transmit laser energy from the
source to the treatment volume;

using the accelerometer, providing information indicative
of acceleration of the handpiece along three axes; and
controlling the laser energy transmitted to the treatment
volume based on feedback from the accelerometer.

23. The method of claim 22, wherein the handpiece further
comprises a gyroscope, and further comprising:
using the gyroscope, providing information indicative of
the spatial orientation of the handpiece, and further com-
prising; and
controlling the laser energy transmitted to the treatment
volume based on feedback from the accelerometer and
the gyroscope.

24. The method of claim 23, further comprising:
determining information indicative of an absolute position
of the handpiece based on the information indicative
of acceleration of the handpiece along three axes, and the
information indicative of the spatial orientation of the
handpiece.

25. The method of claim 22, further comprising:
determining information indicative of a speed of the hand-
piece based on the information indicative of acceleration
of the handpiece along three axes; and
controlling the laser energy transmitted to the treatment
volume based on feedback using the information indica-
tive of the speed of the handpiece.

26. The method of claim 25, further comprising:
determining the speed of the handpiece along each of the
three axes based on information indicative of acceleration
of the handpiece along each of the three axes;
determining a weighted average speed of the handpiece by
calculating a weighted average of the speeds of the hand-
piece along each of the three axes; and
controlling the laser energy transmitted to the treatment
volume based on feedback using the weighted average
speed of the handpiece.

27. The method of claim 17, wherein the handpiece com-
prises a probe member extending along a probe member axis,
and further comprising:
inserting the probe member into the treatment volume;
repetitively advancing and withdrawing the probe member
within the treatment volume;
using the accelerometer to provide information indicative
of acceleration along each of the three axes, one of said
three axes being substantially parallel to the probe mem-
ber axis; and
determining the weighted average speed of the handpiece
by calculating a weighted average of the speeds of the hand-
piece along each of the three axes, wherein the axis
substantially parallel to the probe member axis is given
greater weight than the other axes.

28. A laser surgical apparatus comprising:

a handpiece comprising:

a probe member comprising an optical delivery compo-
nent that transmits laser energy from a source to a treat-
ment volume, said probe member adapted for
insertion into a treatment volume through an incision in a
patient; and

an accelerometer configured to provide information
indicative of the position of the handpiece relative to
the incision;

a processor coupled to the accelerometer and the source
and controlling the laser energy transmitted to the treat-
ment volume based on the information indicative of the
position of the handpiece relative to the incision.

29. The apparatus of claim 28, wherein the accelerometer is
configured to provide information indicative of a speed of the
handpiece and the processor is configured to controlling the
laser energy transmitted to the treatment volume based on
the information indicative of the speed of the handpiece.

30. A method comprising
providing a handpiece comprising:

a probe member comprising an optical delivery compo-
nent that transmits laser energy from a source to a treat-
ment volume, said probe member adapted for
insertion into a treatment volume through an incision in a
patient; and

an accelerometer configured to provide information
indicative of the position of the handpiece relative to
the incision; and

inserting the probe member into the treatment volume
through the incision;
repetitively advancing and withdrawing the probe member within the treatment volume; 
transmitting laser energy to the treatment volume; 
using the accelerometer to provide information indicative of the position of the handpiece relative to the incision; and controlling the laser energy transmitted to the treatment volume based on the information indicative of the position of the handpiece relative to the incision.

31. The method of claim 30, further comprising: using the accelerometer to provide information indicative of a speed of the handpiece; and controlling the laser energy transmitted to the treatment volume based on the information indicative of the speed of the handpiece.

32. A laser surgical apparatus comprising: 
a handpiece comprising: 
an optical delivery component that transmits laser energy from a source to a treatment volume; 
an accelerometer configured to provide acceleration information indicative of an acceleration of the handpiece; and 
a temperature sensor configured to provide temperature information indicative of a temperature of tissue within the treatment volume; and 
a processor coupled to the accelerometer, the temperature sensor, and the source and configured to control the laser energy transmitted to the treatment volume based on the acceleration information and the temperature information.

33. The apparatus of claim 32, wherein the handpiece comprises a probe member adapted for insertion into the treatment volume through an incision in a patient, said probe member comprising at least a portion of the optical delivery component.

34. The apparatus of claim 33, wherein the processor is configured to determine speed information indicative of the speed of the handpiece based on the acceleration information; and control the laser energy transmitted to the treatment volume based on the speed information and the temperature information.

35. The apparatus of claim 33, wherein the processor is configured to determine position information indicative of the position of the handpiece based on the acceleration information; and control the laser energy transmitted to the treatment volume based on the position information and the temperature information.

36. The apparatus of claim 33, wherein the temperature sensor comprises at least one selected from the group consisting of: a thermocouple and a thermister.

37. The apparatus of claim 33, wherein the temperature sensor comprises an infrared sensor.

38. The apparatus of claim 37, wherein the handpiece comprises a optical sensing element configured to transmit infrared light from the treatment volume to the infrared sensor.

39. The apparatus of claim 34, wherein the processor is configured to compare the speed of the handpiece to a threshold value, and inhibit the transmission of laser energy to the treatment volume when the speed is below the threshold value.

40. The apparatus of claim 39, wherein the temperature sensor is configured to measure the temperature of the tissue when the processor inhibits the transmission of laser energy to the treatment volume or when the processor determines that the speed of the handpiece is below a measurement threshold speed.

41. The apparatus of claim 39, wherein the processor is configured to compare the temperature of the tissue to a threshold value, and inhibit the transmission of laser energy to the treatment volume when the temperature is above a threshold value.

42. The apparatus of claim 41, wherein the processor is configured to repetitively, at a first repetition rate, compare the speed of the handpiece to a speed threshold value, and inhibit the transmission of laser energy to the treatment volume when the speed is below the speed threshold value; repetitively, at a second repetition rate, compare the temperature of the tissue to a temperature threshold value, and inhibit the transmission of laser energy to the treatment volume when the temperature is above the temperature threshold value.

43. The apparatus of claim 42, wherein the first repetition rate is greater than the second repetition rate.

44. The apparatus of claim 35, wherein the processor is configured to determine information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

45. The apparatus of claim 44, wherein the processor is configured to control the laser energy transmitted to the treatment volume based on information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

46. The apparatus of claim 45, further comprising a display configured to show a graphical depiction indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

47. The apparatus of claim 46, wherein the information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume comprises, for each position, a series of temperatures measured at a plurality of times.

48. The apparatus of claim 47, wherein the processor is configured to, for each of the positions, calculate a running average of the series of temperatures.

49. The apparatus of claim 48, wherein the display is configured to display, in real time, a graphical representation of the running averages at each of the positions.

50. The apparatus of claim 32, wherein the accelerometer comprises a MEMs device.

51. The apparatus of claim 32, wherein the accelerometer measures accelerations along three axes.

52. The apparatus of claim 32, wherein the accelerometer is a gyro compensated accelerometer.

53. The apparatus of claim 32, wherein controlling the laser energy comprises controlling at least one selected from the group consisting of: wavelength, pulse rate, pulse duty cycle, intensity, and fluence.

54. A laser surgical method comprising: 
providing a handpiece comprising: 
an optical delivery component that transmits laser energy from a source to a treatment volume;
an accelerometer configured to provide acceleration information indicative of an acceleration of the handpiece; and
a temperature sensor configured to provide temperature information indicative of a temperature of tissue within the treatment volume;
transmitting laser energy to the treatment volume;
using the accelerometer to provide acceleration information indicative of an acceleration of the handpiece;
using the temperature sensor to provide temperature information indicative of a temperature of tissue within the treatment volume; and
controlling the laser energy transmitted to the treatment volume based on the acceleration information and the temperature information.

55. The method of claim 54, wherein the handpiece comprises a probe member and further comprising:
inserting said probe member through an incision in a patient into the treatment volume; and
delivering laser energy to the treatment area from said probe member.

56. The method of claim 55, further comprising:
determining speed information indicative of the speed of the handpiece based on the acceleration information; and
controlling the laser energy transmitted to the treatment volume based on the speed information and the temperature information.

57. The method of claim 55, wherein the processor is configured to
determine position information indicative of the position of the handpiece based on the acceleration information; control the laser energy transmitted to the treatment volume based on the position information and the temperature information.

58. The method of claim 56, further comprising:
comparing the speed of the handpiece to a threshold value, and
inhibiting the transmission of laser energy to the treatment volume when the speed is below the threshold value.

59. The method of claim 58, further comprising:
using the temperature sensor to measure the temperature of the tissue when the processor inhibits the transmission of laser energy to the treatment volume or when the processor determines that the speed of the handpiece is below a measurement threshold speed.

60. The method of claim 58, further comprising:
comparing the temperature of the tissue to a threshold value, and inhibit the transmission of laser energy to the treatment volume when the temperature is above a threshold value.

61. The method of claim 57, further comprising:
determining information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume; and
control the laser energy transmitted to the treatment volume based on information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

62. The method of claim 61, further comprising:
displaying a graphical depiction indicative of the temperature of tissue at each of a plurality of positions within the treatment volume.

63. The method of claim 62, wherein the information indicative of the temperature of tissue at each of a plurality of positions within the treatment volume comprises, for each position, a series of temperatures measured at a plurality of times, and further comprising:
for each of the positions, calculating a running average of the series of temperatures; and
displaying, in real time, a graphical representation of the running averages at each of the positions.

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