COOLING DEVICE HAVING A PLURALITY OF CONTROLLABLE COOLING ELEMENTS TO PROVIDE A PREDETERMINED COOLING PROFILE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Patent Application No. 11/528,225, filed September 26, 2006, and entitled "COOLING DEVICE HAVING A PLURALITY OF CONTROLLABLE COOLING ELEMENTS TO PROVIDE A PREDETERMINED COOLING PROFILE," which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present application relates generally to cooling devices, systems, and methods for removing heat from subcutaneous lipid-rich cells, and more particularly, but not exclusively, to a cooling device having a plurality of controllable cooling elements to create a spatial cooling profile and/or a time-varying cooling profile in order to more efficiently affect subcutaneous lipid-rich cells.

BACKGROUND

[0003] Excess body fat increases the likelihood of developing various types of diseases such as heart disease, high blood pressure, osteoarthrosis, bronchitis, hypertension, diabetes, deep-vein thrombosis, pulmonary emboli, varicose veins, gallstones, hernias, and several other conditions.

[0004] In addition to being a serious health risk, excess body fat can also detract from personal appearance and athletic performance. For example, excess body fat can form cellulite, which causes an "orange peel" effect at the surface of the skin. Cellulite forms when subcutaneous fat protrudes into the dermis and creates dimples where the skin is attached to underlying structural fibrous strands. Cellulite and excessive amounts of fat are often considered to be unappealing. Thus, in light of the serious health risks and aesthetic concerns associated with excess fat, an effective way of controlling excess accumulation of body fat is urgently needed.

[0005] Liposuction is a method for selectively removing body fat to sculpt a person's body. Liposuction is typically performed by plastic surgeons and dermatologists using specialized surgical equipment that mechanically removes subcutaneous fat cells via suction. One drawback of liposuction is that it is a serious surgical procedure, and the recovery may be painful. Liposuction can have serious and occasionally even fatal complications. In addition, the cost for liposuction is usually substantial.

[0006] Conventional non-invasive treatments for removing excess body fat typically include topical agents, weight-loss drugs, regular exercise, dieting, or a combination of these treatments. One drawback of these treatments is that they may not be effective or even possible under certain circumstances. For example, when a person is physically injured or ill, regular exercise may not be an option. Similarly, weight-loss drugs or topical agents are not an option when they cause an allergic or negative reaction. Furthermore, fat loss in selective areas of a person's body cannot be achieved using general or systemic weight-loss methods.

[0007] Other non-invasive treatment methods include applying heat to a zone of subcutaneous lipid-rich cells. U.S. Patent No. 5,948,011 discloses altering subcutaneous body fat and/or collagen by heating the subcutaneous fat layer with radiant energy while cooling the surface of the skin. The applied heat denatures fibrous septae made of collagen tissue and may destroy fat cells below the skin, and the cooling protects the epidermis from thermal damage. This method is less invasive than liposuction, but it still can cause thermal damage to adjacent tissue, and may be painful for the patient.

[0008] Another method of reducing subcutaneous fat cells is to cool the target cells as disclosed in U.S. Patent Publication No. 2003/0220674, the entire disclosure of which is incorporated herein. This publication discloses, among other things, reducing the temperature of lipid-rich subcutaneous fat cells to selectively affect the fat cells without damaging the cells in the epidermis. Although this publication provides promising methods and devices, several improvements for enhancing the implementation of these methods and devices would be desirable, including providing a plurality of controllable cooling elements to create a spatial cooling profile and/or a

time-varying cooling profile in order to more efficiently affect subcutaneous lipid-rich cells.

[0009] U.S. Patent Publication No. 2003/0220674 also discloses methods for selective removal of lipid-rich cells and avoidance of damage to other structures including dermal and epidermal cells. A method for more efficiently and precisely controlling these effects is desirable. Therefore, a method for spatially cooling lipid-rich cells over a predetermined time-varying cooling profile, selected spatial cooling profile, or maintaining constant process parameters is also needed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not drawn to scale, and some of these elements are arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn are not intended to convey any information regarding the actual shape of the particular elements, and have been solely selected for ease of recognition in the drawings.

[0011] Figure 1 is an isometric view of a system for removing heat from subcutaneous lipid-rich cells in accordance with an embodiment of the invention.

[0012] Figures 2A, 2B, 2C, and 2D are isometric views of a cooling device for removing heat from subcutaneous lipid-rich cells in accordance with embodiments of the invention.

[0013] Figure 3 is an exploded isometric view of the cooling device of Figure 2A for removing heat from subcutaneous lipid-rich cells in accordance with an embodiment of the invention.

[0014] Figure 4 is a further exploded isometric view of the cooling device of Figure 3 illustrating additional components of the cooling device in accordance with another embodiment of the invention.

[0015] Figure 5A is an isometric view of a plurality of heat exchangers connected in series in accordance with another embodiment of the invention. Figure 5B is an isometric top view of a plurality of heat exchangers connected in series in accordance

with yet another embodiment of the invention. Figure 5C is an isometric bottom view of the heat exchangers in Figure 5B.

[0016] Figure 6A is an exploded isometric view of one of the heat exchangers shown in Figure 5A. Figure 6B is an isometric view of an alternative configuration of a cooling element of a heat exchanger in accordance with an embodiment of the invention.

[0017] Figure 7 is a cross-sectional view of one of the cooling elements along line 7-7 of Figure 5A.

[0018] Figure 8 is an isometric top view of an alternative cooling device for removing heat from subcutaneous lipid-rich cells in accordance with an embodiment of the invention.

[0019] Figure 9 is an isometric bottom view of the alternative cooling device of Figure 8.

[0020] Figure 10 is an exemplary sectional view of a lateral cooling pattern in the dermis of the skin in accordance with another embodiment of the invention.

[0021] Figure 11 is a block diagram showing computing system software modules for removing heat from subcutaneous lipid-rich cells in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

A. Overview

[0022] The present disclosure describes devices, systems, and methods for cooling subcutaneous lipid-rich cells. The term "subcutaneous tissue" means tissue lying underneath the dermis and includes adipocytes (fat cells) and subcutaneous fat. It will be appreciated that several of the details set forth below are provided to describe the following embodiments in a manner sufficient to enable a person skilled in the relevant art to make and use the disclosed embodiments. Several of the details and advantages described below, however, may not be necessary to practice certain embodiments of the invention. Additionally, the invention can include other embodiments that are within the scope of the claims but are not described in detail with respect to Figures 1-11.

[0023] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the occurrences of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0024] The headings provided herein are for convenience only and do not interpret the scope or meaning of the claimed invention.

[0025] The present invention is directed toward a cooling device for removing heat from subcutaneous lipid-rich cells of a subject. The cooling device includes a plurality of cooling elements movable relative to each other so as to be conformable to the skin of the subject.

[0026] One aspect is directed toward a cooling device for removing heat from subcutaneous lipid-rich cells. The cooling device includes a plurality of cooling elements contained within interconnected frame members rotatable about at least one axis, a plurality of heat exchanging elements, and a housing. Alternatively, the cooling device includes a plurality of cooling elements contained on a flexible substrate. The cooling elements can use a number of cooling technologies including, for example, thermoelectric coolers, recirculating chilled fluid, vapor compression elements, or phase change cryogenic devices. One skilled in the art will recognize that there are a number of other cooling technologies that could be used and that the cooling elements need not be limited to those described here.

[0027] Another aspect is directed toward a cooling device having a plurality of cooling members using thermoelectric Peltier principles or other cooling technologies. The cooling device also includes a heat dissipating member in thermal communication with the cooling members and a plurality of interface members having heat exchanging surfaces configured to contact a subject's skin. The cooling members can be capable of reducing a temperature of a region such that lipid-rich cells in the region are affected while non-lipid-rich cells are not generally affected.

[0028] Further aspects include that the cooling device can include a plurality of interconnected hinged segments for rotating to conform to a body portion.

Alternatively, the cooling elements may also be disposed on a flexible substrate and movable relative to each other.

[0029] Another aspect is directed toward a cooling device having a plurality of cooling members individually controlled to provide a spatial cooling profile and/or a time-varying cooling profile. The cooling profile can, for example, be configured to provide cooling members along a perimeter of the cooling device at a lower or a higher temperature than cooling members at an interior of the cooling device. Alternatively, the cooling profile can be configured to provide cooling members in regions of the cooling device at a lower or a higher temperature than cooling members in adjacent regions of the cooling device. Further aspects include that the cooling profile can vary over time to provide a decreasing or an increasing temperature profile during treatment.

[0030] Another aspect is directed toward a method of applying a cooling device having a plurality of cooling elements contained on a plurality of interconnected hinged segments, each adjacent pair of hinged cooling elements being rotatable about at least one axis. The cooling elements can have a plurality of heat exchanging surfaces capable of removing heat from the subject's skin. The method includes rotating hinged segments containing the cooling elements to achieve a desired configuration of the cooling device, cooling the heat exchanging surfaces of the plurality of cooling elements to a desired temperature, placing the plurality of cooled heat exchanging surfaces proximate to the subject's skin, and reducing the temperature of a region such that lipid-rich cells in the region are affected while non-lipid-rich cells in the region are not generally affected. Alternatively, the cooling elements may be disposed on a flexible substrate and movable relative to each other.

[0031] Further aspects include a method for applying and maintaining pressure on the contact region. Further aspects include securing the cooling device in position with a retention device. Further aspects include providing a time-varying profile to increase or decrease the temperature of the cooling elements over a selected time period. Further aspects include spatially varying the temperature of each cooling element of the cooling device to provide discrete cooling regions in the cooling device.

[0032] Another aspect is directed toward a system for removing heat from subcutaneous lipid-rich cells. The system includes a cooling device having a plurality of frame segments containing cooling elements movable relative to each other, the

frame segments capable of achieving a desired orientation between each other, and a heat sink coupled to the cooling device to dissipate heat generated by the cooling device. In one embodiment, the frame segments are hinged. When placed proximate to a subject's skin, the plurality of cooling elements can be capable of reducing a temperature of a region such that lipid-rich cells in the region are affected while non-lipid-rich cells in the epidermis and/or dermis are not generally affected.

[0033] Further aspects include the cooling device being configured to follow the contours of the body. Further aspects include that the cooling device includes a handle and/or can include a strap or other retention device for holding the cooling device in a selected position. Further aspects include a control system for individually controlling the temperature of the cooling elements in a predetermined pattern. Further aspects include a processing unit for controlling a time-varying cooling profile of the cooling device.

B. System for Selectively Reducing Lipid-Rich Cells

[0034] Figure 1 is an isometric view of a system 100 for removing heat from subcutaneous lipid-rich cells of a subject 101 in accordance with an embodiment of the invention. The system 100 can include a cooling device 104 placed at an abdominal area 102 of the subject 101 or another suitable area for removing heat from the subcutaneous lipid-rich cells of the subject 101. Various embodiments of the cooling device 104 are described in more detail below with reference to Figures 2-11.

[0035] The system 100 can further include a cooling unit 106 and supply and return fluid lines 108a-b connecting the cooling device 104 to the cooling unit 106. The cooling unit 106 can remove heat from a coolant to a heat sink and provide a chilled coolant to the cooling device 104 via the fluid lines 108a-b. Examples of the circulating coolant include water, glycol, synthetic heat transfer fluid, oil, a refrigerant, and any other suitable heat conducting fluid. The fluid lines 108a-b can be hoses or other conduits constructed from polyethylene, polyvinyl chloride, polyurethane, and other materials that can accommodate the particular circulating coolant. The cooling unit 106 can be a refrigeration unit, a cooling tower, a thermoelectric chiller, or any other device capable of removing heat from a coolant. Alternatively, a municipal water supply (i.e., tap water) can be used in place of the cooling unit.

[0036] As explained in more detail below, the cooling device 104 includes a plurality of thermoelectric cooling elements, such as Peltier-type thermoelectric elements, which can be individually controlled to create a custom spatial cooling profile and/or a time-varying cooling profile. The system 100 can further include a power supply 110 and a processing unit 114 operatively coupled to the cooling device 104. In one embodiment, the power supply 110 can provide a direct current voltage to the thermoelectric cooling device 104 to effectuate a heat removal rate from the subject 101. The processing unit 114 can monitor process parameters via sensors (not shown) placed proximate to the cooling device 104 through power line 116 to adjust the heat removal rate based on the process parameters. The heat transfer rate can be adjusted to maintain constant process parameters. Alternately, the process parameters can vary either spatially or temporally. The processing unit 114 can be in direct electrical communication through line 112, or alternatively, may be connected via a wireless communication. Alternatively, the processing unit 114 can be preprogrammed to provide a spatially distributed cooling profile and/or a time-varying cooling profile. The processing unit 114 can include any processor, Programmable Logic Controller, Distributed Control System, and the like.

[0037] In another aspect, the processing unit 114 can be in electrical communication with an input device 118, an output device 120, and/or a control panel 122. The input device 118 can include a keyboard, a mouse, a touch screen, a push button, a switch, a potentiometer, and any other device suitable for accepting user input. The output device 120 can include a display screen, a printer, a medium reader, an audio device, and any other device suitable for providing user feedback. The control panel 122 can include indicator lights, numerical displays, and audio devices. In alternative embodiments, the control panel 122 can be contained on the cooling device 104. In the embodiment shown in Figure 1, the processing unit 114, power supply 110, control panel 122, cooling unit 106, input device 118, and output device 120 are carried by a rack 124 with wheels 126 for portability. In alternative embodiments, the processing unit 114 can be contained on the cooling device 104. In another embodiment, the various components can be fixedly installed at a treatment site.

C. Cooling Device Having a Plurality of Cooling Elements

[0038] Figures 2A, 2B, and 2C are isometric views of a cooling device 104 in accordance with embodiments of the invention suitable for use in the system 100. In this embodiment, the cooling device 104 includes a control system housing 202 and cooling element housings 204a-g. The control system housing 202 includes a sleeve 308 (Figure 3) that may slide into collar 310 and/or may mechanically attach to the cooling element housings. The cooling element housings 204a-g are connected to the heat exchanging elements (not shown) by attachment means 206. The attachment means can be any mechanical attachment device such as a screw or pin as is known in the art. The plurality of cooling element housings 204a-g can have many similar features. As such, the features of the first cooling element housing 204a are described below with reference symbols followed by an "a," corresponding features of the second cooling element housing 204b are shown and noted by the same reference symbol followed by a "b," and so forth. The cooling element housing 204a can be constructed from polymeric materials, metals, ceramics, woods, and/or other suitable materials. The example of the cooling element housing 204a shown in Figure 2A-C is generally rectangular, but it can have any other desired shape.

[0039] The cooling device 104 is shown in a first relatively flat configuration in Figure 2A; in a second slightly curved configuration in Figure 2B; and in a third curved configuration in Figure 2C. As shown in Figures 2B and 2C, each segment of the cooling element housings 204a-g are rotatably connected to adjacent segments and moveable about connection 207a-f to allow the cooling device 104 to curve. The connection 207a-f, for example, can be a pin, a ball joint, a bearing, or other type of rotatable joints. The connection 207 can accordingly be configured to rotatably couple the first cooling element housing 204a to the second cooling element housing 204b. According to aspects of the invention, the first cooling element housing 204a can rotate relative to the second cooling element housing 204b (indicated by arrow A), each adjacent moveable pair of cooling elements being such that, for example, the angle between the first and second cooling element housings 204a and 204b can be adjusted up to 45°. In this way, the cooling device is articulated such that it can assume a curved configuration as shown in Figure 2B or 2C, conformable to the skin of a subject.

[0040] One advantage of the plurality of rotatable heat exchanging surfaces is that the arcuate shape of the cooling device may concentrate the heat transfer in the subcutaneous region. For example, when heat exchanging surfaces are rotated about a body contour of a subject, the arcuate shape can concentrate heat removal from the skin.

[0041] The control system housing 202 can house a processing unit for controlling the cooling device 104 and/or fluid lines 108a-b and/or electrical power and communication lines. The control system housing 202 includes a harness port 210 for electrical and supply fluid lines (not shown for purposes of clarity). The control system housing 202 can further be configured to serve as a handle for a user of the cooling device 104. Alternatively, the processing unit may be contained at a location other than on the cooling device.

[0042] As shown in Figures 2A, 2B, and 2C, the cooling device 104 can further include at each end of the cooling device 104 retention devices 208a and 208b coupled to a frame 304. The retention devices 208a and 208b are rotatably connected to the frame by retention device coupling elements 212a-b. The retention device coupling elements 212a-b, for example, can be a pin, a ball joint, a bearing, or other type of rotatable joints. Alternatively, the retention devices 208a and 208b can be rigidly affixed to the end portions of the cooling element housings 204a and 204g. Alternately, the retention device can attach to control system housing 202.

[0043] The retention devices 208a and 208b are each shown as tabs 214, each having a slot 216 therein for receiving a band or elastomeric strap (not shown for purposes of clarity) to retain the cooling device 104 in place on a subject 101 during treatment. Alternatively, the cooling device may not contain any attached retention device and may be held in place by hand, may be held in place by gravity, or may be held in place with a band, elastomeric strap, or non-elastic fabric (e.g., nylon webbing) wrapped around the cooling device 104 and the subject 101.

[0044] As shown in Figures 2A-2C, the cooling element housings 204a-g have a first edge 218 and an adjacent second edge 220 of a reciprocal shape to allow the cooling device 104 to mate and, thus, configure in a flat configuration. The first edge 218 and the second edge 220 are generally angular in the Figures; however, the shape could be curved, straight, or a combination of angles, curves, and straight edges that

provide a reciprocal shape between adjacent segments of the cooling element housings 204a-g.

[0045] Figure 2D shows an isometric view of an alternative cooling device 104 in accordance with embodiments of the invention suitable for use in the system 100. In this embodiment, the cooling device 104 includes a plurality of heat exchanging elements 300a-g contained within a flexible substrate 350. As described with respect to Figures 2A-2C, adjacent heat exchanging elements 300a-g are fluidicly coupled in series by fluid lines 328.

[0046] According to aspects of the embodiment, the cooling elements 302a-g may be affixed to the flexible substrate 350, or may be embedded in the flexible substrate 350. The flexible substrate 350 can be constructed from polymeric materials, elastomeric materials, and/or other suitable materials. The flexible substrate 350 can further be an elastomer such as silicone or urethane or can be a fabric, such as nylon. The flexible substrate 350 can also be a thin polymer such as polypropylene or ABS. The example of the flexible substrate 350 shown in Figure 2D is generally rectangular, but can have any other desired shape, including a matrix configuration or an anatomy specific shape. According to aspects of this embodiment, the flexible substrate 350 acts as a living hinge between cooling elements 302a-g to allow the cooling elements 302a-g to conform to the skin of a subject.

[0047] Figure 3 is an exploded isometric view of a cooling device 104 in accordance with one embodiment of the invention suitable for use in the system 100. In this embodiment, the cooling device 104 includes a frame 304 having a plurality of rotatably connected segments 305a-g. The rotatably connected segments 305a-g are connected by hinges 306a-g. Alternatively, the rotatably connected segments 305a-g of the frame 304 could be connected by a connection that allows rotation, such as a pin, living hinge, flexible substrate, such as webbing or fabric, or the like. According to one aspect of the invention, the links or hinges are made of plastic to insulate the cooling elements from each other.

[0048] A plurality of heat exchanging elements 300a-g are contained on the frame 304. The heat exchanging elements 300a-g include cooling elements 302a-g having covers 301a-g. The covers 301a-g are affixed on a top side of the cooling elements 302a-g. The covers 301a-g may be affixed by various mechanical means as described

further herein and as are known in the art. According to aspects of the invention, the covers 301a-g are fluidicly sealed to the cooling elements 302a-g. According to further aspects of the invention, the hinges 306a-g are configured so as to be adjacent to the subject's skin, in use, to maintain close proximity between the heat exchanging elements 300a-g when the heat exchanging elements 300a-g are in a rotated position.

[0049] The cooling elements 302a-g are attached by cooling element attachment means 307 to the frame 304 such that the first heat exchanging element 300a is located at the first segment 305a of the frame 304 and the second heat exchanging element 300b is located at the second segment 305b of the frame 304. The cooling element attachment means 307 are shown as a tab 313 extending from the frame 304 and a screw 315 fixedly attaching the tab 313 of the frame 304 to the cooling elements 302a-g. Alternatively, mechanical fixation devices as are known in the art may be used.

[0050] The cooling elements 302a-g of the cooling device 104 are generally configured to rotate to allow the cooling device 104 to conform to an arcuate portion of a subject 101. Once positioned on a subject 101, the cooling device 104 can further be strapped to or otherwise configured to be releasably attached to the subject 101. The cooling elements 302a-g can be configured to move relative to each other or rotate to position the cooling elements 302a-g for applying pressure to the treatment area during operation. Cooling elements 302a-g are movable or rotatable relative to each other such that cooling device 104 is conformable to the skin of the subject. These features are described in more detail below with reference to specific examples of the cooling devices.

[0051] The first cooling element 302a can include the cooling element housing 204a, a fluid inlet port 310 and a fluid outlet port 316a. The fluid inlet port 310 is fluidicly coupled to the supply fluid line 108a. As shown in Figure 3, adjacent cooling elements are fluidicly coupled in series by fluid lines 328 at fluid inlet ports 314a-f and fluid outlet ports 316a-f. The cooling element 302g further includes a fluid outlet port 312 fluidicly coupled to the return fluid line 108b.

[0052] One expected advantage of providing cooling elements fluidicly coupled in series is a uniform flow rate through each cooling element 302a-g to provide more consistent cooling of the cooling device. Another expected advantage of providing

cooling elements 302a-g fluidicly coupled in series is fewer supply lines into the cooling device to provide a more reliable, less cumbersome and easier to house fluid flow configuration for the cooling device.

[0053] Figure 4 is a further exploded isometric view of the cooling device of Figure 3 in accordance with one example of the invention for use in the system 100. This further exploded view is substantially similar to previously described examples, and common acts and structures are identified by the same reference numbers. Only significant differences in operation and structure are described below. The cooling device 104 includes cooling elements 302a-g having a plurality of thermoelectric coolers 402 configured to reduce the temperature of a subcutaneous region of the subject 101 for selectively affecting lipid-rich cells in the region. The plurality of thermoelectric coolers 402, also known as a Peltier-type element, has a first side 404 and a second side 406. The first side 404 is in thermal communication with the cooling element 302, and the second side 406 is in thermal communication with an interface member 418. The thermoelectric coolers 402 can be connected to an external power supply (not shown) to transfer heat between the first side 404 and the second side 406. One suitable thermoelectric cooler is a Peltier-type cooling element (model # CP-2895) produced by TE Technologies, Inc. in Traverse City, Michigan.

[0054] The thermoelectric coolers 402 are contained within the segments 305a-g of the frame 304. According to aspects of the invention, the frame 304 may contain individual guides for each thermoelectric cooler 402. Alternatively, the thermoelectric coolers 402 may be retained on the cooling elements 302a-g, for example, by thermal epoxy or by a combination of solder, mechanical compression and thermal grease.

[0055] As shown in Figure 4, the plurality of cooling elements 302a-g can further include a plurality of interface members 418 in thermal communication with the thermoelectric cooler 402 having heat exchanging surfaces 420 for transferring heat to/from the subject 101. In one example, the interface members 418 are generally planar, but in other examples, the interface members 418 are non-planar (e.g., curved, faceted, etc.) The interface members 418 can be constructed from any suitable material with a thermal conductivity greater than 0.05 Watts/Meter Kelvin, and in many examples, the thermal conductivity is more than 0.1 Watts/Meter Kelvin. Examples of

suitable materials include aluminum, other metals, metal alloys, graphite, ceramics, some polymeric materials, composites, or fluids contained in a flexible membrane.

[0056] By applying power to the thermoelectric coolers 402, heat can be effectively removed from the subject's skin to a circulating fluid in cooling elements 302a-g. For example, applying a current to the thermoelectric coolers 402 can achieve a temperature generally below 37°C on the first side 404 of the thermoelectric coolers 402 to remove heat from the subject 101 via the interface members 418. The thermoelectric coolers 402 pull heat from the second side 406 to the first side 404 where the heat is then transferred to the circulating fluid. The cooling unit 106 then removes the heat from the circulating fluid.

[0057] The thermoelectric coolers 402 can be configured to withdraw a sufficient amount of heat quickly from the subject 101 without using a high-current power supply for the cooling unit 106. In order to facilitate thermal transfer, the interface members 418 can be an aluminum plate configured generally the same dimensions at the thermoelectric coolers 402. According to aspects of the invention, the thermoelectric coolers 402 can be Peltier-type thermoelectric elements rated at about 160 watts. As such, the cooling device 104 can cool a portion of the subject's skin from a temperature of about 37°C to about -20°C quickly and effectively. The cooling unit 106 can use a normal voltage power supply (e.g., 120 VAC) because the power consumption is not excessive. This enables the system to be used in hospitals, clinics, and small offices without more costly high voltage electrical systems.

[0058] Figure 5A is an isometric view of a plurality of heat exchanging elements 300a-g connected in series with the housing removed to better show the plurality of heat exchanging elements 300a-g and interconnected fluid lines. According to aspects of the invention, the heat exchanging elements 300a-g are rotatably contained on linked segments of the frame 304 to provide a cooling device that is wider than it is tall. Thus, the cooling device is compliant and will form to follow contours. According to aspects of the invention, the cooling device is dimensionally small in a first dimension so that curvature of the treatment area in a second dimension does not significantly impact the amount of surface area in contact between the skin and the cooling device.

[0059] According to further embodiments of the invention, Figure 5B is an isometric top view of a plurality of heat exchangers connected in series by a hinge

350a, 350b, wherein the hinge connection is connected directly to the heat exchanger 302a, 302b. The hinge 350a, 350b as shown in Figure 5B is a piano hinge that extends along adjacent edges of the heat exchanger 300a, 300b for the length of the heat exchanger 300a, 300b, alternatively, the hinge 350a, 350b may extend a portion of the length of the adjacent sides of the heat exchanger 300a, 300b or the hinged connection may include a plurality of hinges 350a 350b. Unlike in Figure 5A, no frame is employed to connect the heat exchangers 300a, 300b or provide support for the hinged connection between heat exchangers 300a, 300b. Figure 5C is an isometric bottom view of the heat exchangers in Figure 5B. According to further aspects of the invention, alternative hinged mechanical connections as is known in the art may be used alone or in combination; or, alternative chemical connections such as flexible adhesives or a living hinge as is known in the art may be used in the hinged connections; or, electromechanical connections such as magnets may be used between heat exchangers to connect the heat exchangers.

[0060] Figure 6A is an exploded isometric side elevation view of the heat exchanging element 300a shown in Figure 5A to further show the flow of fluid in the heat exchanging element 300a. Like reference symbols refer to like features and components in the Figures. As shown in Figure 6A, the heat exchanging element 300a can include a fluid chamber 610 having a serpentine shape within the cooling element 302a. As shown in Figure 6B, the heat exchanging element 300a can include fins 612 to direct fluid flow through the fluid chamber 610. The fluid chamber 610 can be in fluid communication with the associated fluid ports such that fluid can circulate through the fluid chamber 610. The fluid chamber 610 can be configured to accept fluid coolants, such as water, glycol, a synthetic heat transfer fluid, oil, refrigerants, air, carbon dioxide, nitrogen, and argon. According to further aspects of the invention, the fluid chamber 610 may be configured in a variety of configurations as is known in the art in order to distribute the fluid throughout the cooling element 302a.

[0061] Figure 7 is a cross-sectional view of one cooling element 302a. The cooling element 302a is fluidicly sealed by cover 301a containing an o-ring seal 722, held in place by an attachment means 326. According to aspects of the invention, the cooling element 302a can further include at least one sensing element 710 proximate to the heat exchanging surface 420 (Figure 4). The sensing element 710, for example,

can be generally flush with the heat exchanging surface 420. Alternatively, it may be recessed or protrude from the surface. The sensing element 710 can include a temperature sensor, a pressure sensor, a transmissivity sensor, a bio-resistance sensor, an ultrasound sensor, an optical sensor, an infrared sensor, a heat flux sensor, or any other desired sensor as described further herein.

[0062] In one example, the sensing element 710 can be a temperature sensor configured to measure the temperature of the first heat exchanging surface 420 and/or the temperature of the skin of the subject 101. For example, the temperature sensor can be configured as a probe or as a needle that penetrates the skin during measurement. Examples of suitable temperature sensors include thermocouples, resistance temperature devices, thermistors (e.g., neutron-transmutation-doped germanium thermistors), and infrared radiation temperature sensors. In another example, the sensing element 710 can be an ultrasound sensor configured to measure crystallization or change in viscosity of subcutaneous fat in the treatment region of a subject. In yet another example, the sensing element 710 can be an optical or infrared sensor configured to monitor an image of the treatment region to detect, for example, epidermal physiological reactions to the treatment. The sensing element 710 can be in electrical communication with the processing unit 114 via, for example, a direct wired connection, a networked connection and/or a wireless connection.

[0063] Accordingly, the cooling device 104 can be in electrical communication with the processing unit 114, and the cooling temperature can be automatically adjusted by the processing unit 114. According to further aspects of the invention, the temperature of the interface member 418 can be sensed by the sensing element 710 and the sensed electrical signal can be converted by the processing unit 114 into a process value for the temperature. In one embodiment, the processing unit 114 can include a Proportional, Integral and Derivative controller, which can adjust the power output to the thermoelectric coolers 402 to achieve and/or maintain the desired temperature.

[0064] According to further aspects of the invention, the sensing element 710 can alternatively be a pressure sensor to sense the pressure exerted by the cooling element 302a against the subject 101. In one embodiment, the interface member 418 can be attached to the frame 304 such that pressure applied against the heat exchanging element 300a is transferred via the housing 204a to the pressure sensor.

The pressure sensor can alternatively be configured to sense the pressure in the fluid chamber 610 for monitoring pressure variations in the fluid chamber 610. Alternatively, the pressure could be inferred from force and the known contact area of the cooling elements. For example, the sensing element 710 can be any type of load-sensitive pressure sensing element such as a load cell (model #LC201-25) produced by OMEGA Engineering, Inc. in Stamford, Connecticut. Direct pressure measurement could also be performed by placing a pressure measurement membrane directly at the interface between the cooling element and the skin.

[0065] The cooling elements 302a-g can have many additional embodiments with different and/or additional features without detracting from the operation of the elements. For example, an adjacent cooling element may or may not have a sensing element proximate to the heat exchanging surface. Alternatively, the cooling elements can be constructed from a material that is different from that of the adjacent cooling element.

[0066] Figure 8 shows an isometric view of a plurality of thermoelectric coolers contained in a matrix design. Figure 8 and 9 are isometric views of an alternative cooling device for removing heat from subcutaneous lipid-rich cells in accordance with an embodiment of the invention. As shown in Figures 8 and 9, the cooling device 810 includes a cooling element 804 configured in a planar matrix. The cooling device 810 can include a band 812 for retaining the cooling element 804 in place during use. The cooling device can further include a handle 814, a wiring harness 818 and a flap 816 for releasably securing the band 812 to the cooling element 804. The cooling element 804 can further include a sleeve 822 as described further above.

[0067] As shown in Figure 9, the cooling element 804 includes a planar matrix 824 including a plurality of thermoelectric coolers 826. The thermoelectric coolers 826 are contained on a flexible substrate 830. The flexible substrate 830 can be an elastomer such as silicone or urethane or can be a fabric, such as nylon. According to further aspects, the flexible substrate 830 can be a thin polymer such as polypropylene or ABS. As described in greater detail herein, the thermoelectric coolers 826 can have small protective interface plates (not shown) glued to the cold surface of the thermoelectric coolers 826 with a thermal epoxy. According to alternative embodiments of the invention, additional mechanical restraints can further be included

in the flexible substrate 830 to capture the thermoelectric coolers 826. As described in greater detail herein, the thermoelectric coolers 826 can include a heat exchanger (shown and described with respect to Figures 3-7) on the hot side to cool the hot side. According to aspects of this embodiment, each thermoelectric cooler 826 can have a corresponding heat exchanger to provide increased flexibility to the planar matrix. Alternately, a single flexible heat exchanger can be coupled to the hot side of the thermoelectric coolers (e.g., a bladder or other flexible membrane that water can be circulated through).

[0068] According to alternative aspects of the embodiment, the planar matrix 824 can further include temperature or other sensors (not shown) captured between the interface plate and the thermoelectric coolers and/or can have a separate sleeve that houses temperature sensors as further discussed herein.

D. Operation of the Cooling Device

[0069] Figure 10 is an exemplary sectional view of a lateral cooling pattern in the dermis of the skin. The cooling pattern radiates from the cooling elements 302a-f through the epidermis and dermis of the skin such that when it affects the targeted dermis layer containing the lipid-rich cells, the cooling pattern forms a uniform cooling layer and any gaps between the segments of the frame are mitigated. One expected advantage of this cooling pattern is that the cooling of the dermis layer is uniform during treatment. Figure 10 discloses cooling device 104 applied to a generally flat portion of a subject's body. Cooling elements 302a-f of the cooling device are movable relative to each other (as shown in Figures 2B, C and D), to conform to the contours of the subject's skin.

[0070] Without being bound by theory, it is believed that, in operation, effective cooling from the cooling device 104, which cools through conduction, depends on a number of factors. Two exemplary factors that impact heat removal from the skin area are the surface area of the cooling element and the temperature of the interface member. When conduction is between two materials that are placed in physical contact, i.e., the skin and the cooling element, there is a certain amount of thermal resistance known as contact resistance. The contact resistance takes the form of a temperature differential between the two materials. Higher contact resistance means

less effective cooling; therefore, in the cooling device it is desirable to minimize contact resistance.

[0071] One means to minimize contact resistance and maximize the contact surface area is with an interface member that is flexible and will conform to the natural body contours. According to alternative aspects, contact pressure can be reduced by increasing the pressure of the applicator on the skin. Surface pressure has an additional benefit in a skin cooling application. Sufficient pressure on the skin can cause internal capillaries to constrict, temporarily reducing the flow of blood into the treatment region. Reduced blood flow into the treatment area allows the area being cooled to cool more efficiently and improves the effectiveness of the treatment.

[0072] Thus, according to aspects of the invention, the cooling device also incorporates a flexible strapping material or belt that wraps around the subject following the curvature of the cooling device. By tightening the strapping, pressure is applied and can be maintained between the subject and the cooling device. According to aspects of the invention, the strap can incorporate a hoop or d-ring through which the strapping can be looped to provide mechanical advantage in tightening the strap. According to further aspects of the invention, the strap also incorporates Velcro or a latch or buckle to hold the pressure once the strap has been tightened.

[0073] In operation, an operator can hold the cooling device 104 in one hand by grasping the control system housing 202 or another type of suitable handle (not shown). Then the cooling elements 302a-g can be moved or rotated to achieve a desired orientation. The operator can place the cooling device 104 having the cooling elements 302a-g in the desired orientation proximate to the subject's skin to remove heat from a subcutaneous region of the subject 101. In one embodiment, the operator tightens retention devices 208a-b affixed to the cooling device 104 to apply pressure to the subject's skin. In another embodiment, the operator can manually press the cooling device 104 against the subject's skin. The operator can also monitor and control the treatment process by collecting measurements, such as skin temperatures, from the sensing element 710. By cooling the subcutaneous tissues to a temperature lower than 37°C, more preferably lower than 25°C, subcutaneous lipid-rich cells can be selectively affected. The affected cells are then resorbed into the patient through natural processes.

[0074] According to aspects of the invention, interface members 418, for example thin aluminum plates, are mounted to the bottom of the thermoelectric coolers in a manner to ensure good thermal contact between the thermoelectric coolers and the interface members. The interface members can be coupled to the cooling element by a variety of mechanical fixation means such as are known in the art. For example, the coupling means can include using thermally conductive epoxy or using thermal grease such as zinc oxide.

[0075] In operation, cooling is efficiently distributed through the heat exchanging elements 300a-g. For example, the cooling device includes a series of interface members 418 approximately 1mm in thickness. The interface members 418 are in thermal communication with the cooling elements 302a-g by mechanical fixation such as thermal epoxy. The cooling elements 302a-g are cooled by a plurality of thermoelectric coolers to provide a more efficient cooling system to the treatment region. The cooling elements 302a-g are contained on segments that are movable relative to each other to conform to the contours of the subject's skin. Alternatively, the cooling elements are rotatable relative to each other, similar to the joined segments of a metal watch band, thus allowing the assembly to curve.

[0076] As designed, the interface members and cooling elements protect the thermoelectric coolers while maintaining good heat transfer between the thermoelectric coolers and the skin. The interface members are sized such that they do not present a significant thermal mass. In one design, each thermoelectric cooler could be 1" x 1.5". The interface member or aluminum plate could also be 1" x 1.5" with a thickness of 0.04". If the thermoelectric coolers' cooling power is approximately 10W, which is appropriate based on the heat flux expected to conduct from the skin, then the aluminum plate would cool from an ambient temperature of 20°C to a treatment temperature of -10°C in about 7 seconds. The change in internal energy of the plate is described by the following equation:

$$\Delta E = \rho \cdot V \cdot C \cdot \Delta T$$

where ΔE is the change in internal energy, ρ is the material density, V is the material volume, $C°$ is the heat capacity of the material, and ΔT is the temperature change. In the problem described above, the volume of the aluminum plate is V = 1in x 1.5in x

.04in or .06 in^3 (9.8 x 10-7m3). For a typical grade of aluminum, C° = 875 J/kg*°C and ρ = 2770 kg/m3. Solving the equation using these constants:

$$\Delta E = 2770 \text{ kg/m3*9.8 x 10-7m3*875 J/kg*°C*30°C} = 71.3\text{J}$$

[0077] If the thermoelectric coolers have a cooling power of 10 W, then 71.3 J could be removed from the aluminum plate in 7.1 seconds, as is shown in the calculation below:

$$71.3 \text{ J} / (10 \text{ J/second}) = 7.13 \text{ seconds}$$

[0078] A small gap or recess in the frame at the skin surface may be included in one embodiment. Prior to applying the cooling device to the skin, a thermally conducting fluid or coupling agent can be applied to the device and to the skin to minimize contact resistance and increase heat transfer between the cooling device and the skin. This coupling agent will fill the gap in the cooling device and allow for limited lateral conduction between the thermoelectric coolers' plates. This will create a more uniform temperature gradient across the surface area of the skin when the cooling is applied to the skin.

[0079] The coupling agent may be applied to the skin or to the interface member to provide improved thermal conductivity. The coupling agent may include polypropylene glycol, polyethylene glycol, propylene glycol, and/or glycol. Glycols, glycerols, and other deicing chemicals are efficient freezing-point depressants and act as a solute to lower the freezing point of the coupling agent. Propylene glycol (CH3CHOHCH2OH) is one exemplary component of deicer or non-freezing coupling agents. Other components include polypropylene glycol (PPG), polyethylene glycol (PEG), polyglycols, glycols, ethylene glycol, dimethyl sulfoxide, polyvinyl pyridine, calcium magnesium acetate, sodium acetate, and/or sodium formate. The coupling agent preferably has a freezing point in the range of -40°C to 0°C, more preferably below -10°C as further described in U.S. Provisional Application 60/795,799, entitled Coupling Agent For Use With a Cooling Device For Improved Removal of Heat From Subcutaneous Lipid-Rich Cells, filed on April 28, 2006, herein incorporated in its entirety by reference.

[0080] One expected advantage of using the cooling device 104 is that subcutaneous lipid-rich cells can be reduced generally without collateral damage to non-lipid-rich cells in the same region. In general, lipid-rich cells can be affected at low temperatures that do not affect non-lipid-rich cells. As a result, lipid-rich cells, such as subcutaneous adipose tissue, can be affected while other cells in the same region are generally not damaged even though the non-lipid-rich cells at the surface are subject to even lower temperatures. Another expected advantage of the cooling device 104 is that it is relatively compact because the cooling device 104 can be configured as a handheld device. Yet another advantage is that the cooling device can be applied to various regions of the subject's body because the cooling elements 302a-g can be adjusted to conform to any body contour. Another expected advantage is that by pressing the cooling device 104 against the subject's skin, blood flow through the treatment region can be reduced to achieve efficient cooling. Yet another expected advantage is the use of pressure by constriction of the band to restrict blood flow to the treatment region and thereby reduce heat transfer (by mass transport). Thus, the band can not only provide a means for holding the cooling element in place, but also ensures good thermal contact between the cooling device and the skin, and further constricts the flow of blood in the treatment region. Still another expected advantage is that the plurality of the cooling elements 302a-g more efficiently remove heat from the skin compared to a single cooling element.

E. Spatially Controlled Cooling Element Profile

[0081] Many skin cooling devices rely on a relatively thick piece of aluminum or other conductive material between a thermoelectric cooler or other cooling source and the skin. When a cooling device is applied to a relatively insulating material, such as skin tissue, the aluminum plate becomes isothermal and maintains a constant temperature profile across the skin's surface. The drawback of this design is that when the device initially cools, or during thermal cycling, the thermal mass presented by the aluminum plate requires a large cooling power. This either translates into increased cooling time or increased power required from the cooling device or both.

[0082] According to aspects of the invention, the cooling device has a low thermal mass that will still maintain a constant temperature profile across the skin's surface. Further, according to aspects of the invention, a plurality of cooling elements are

provided to allow different regions of the skin to be treated at different temperatures during one treatment session. There are some circumstances where it may be desirable to cool different regions of the skin to different temperatures or for different time periods. According to aspects of the invention, each thermoelectric cooler can be individually controlled to cool different regions of the skin to different temperatures and/or for different time periods and/or to ensure uniform temperature throughout the treatment region. One reason this may be desirable is that the composition of tissue is different in different locations of the body. Some regions have thicker layers of adipose tissue than others, which influence the thermal response of the skin. In other regions, the presence of bone or other organs will affect the heat transfer to the skin.

[0083] According to aspects of the invention, a spatially controlled temperature profile can provide more efficient cooling to the treatment region. The plurality of thermoelectric coolers allows the cooling device to accommodate spatial cooling. For example, thermoelectric coolers contained at the perimeter of the cooling device may have a lower or higher temperature or duration than thermoelectric coolers contained at the interior of the cooling device because of different boundary conditions in the different areas of the treatment zone. According to aspects of the invention, the cooling device will quickly and efficiently cool skin to a prescribed temperature. In addition, the cooling device described here has the additional ability to treat a large area in a single treatment while cooling different regions to different temperatures and/or for different durations.

[0084] This variation in localized cooling could alternatively be achieved using a cooling device that is relatively small such that many treatments are performed, cooling to different temperatures in different regions. However, this type of cooling device would require many treatments, thereby increasing the overall treatment time and the opportunity for operator error. In addition, a cooling device with a large thermal mass would require a longer cooling time during each treatment.

[0085] According to aspects of the invention, the device can accommodate spatially controlled cooling temperature profiles which may provide at least the following advantages: (1) increased efficiency; (2) decreased power consumption with comparable efficacy; (3) increased patient comfort; or (4) decreased treatment time. For example, according to aspects of the invention, the plurality of thermoelectric

coolers will allow adjustment for anatomical differences between patients by selectively enabling or disabling portions of the apparatus based on anatomical differences of the patient. One example includes disabling the thermoelectric coolers around bony anatomy for patient comfort or for power conservation.

[0086] Alternatively, a particular pattern of controlled cooling may be customized to match an individual patient's pattern of cellulite, thus increasing the efficacy of the treatment. Similarly, treatment regions requiring a higher intensity of treatment may be pre-identified by ultrasound or other devices. The device can then be spatially controlled to provide higher intensity treatment to pre-identified areas. Further advantages include increased patient comfort and safety by allowing spatial control of cooling to accommodate unnatural anatomy (e.g. lumps, blemishes, nipples, hairy areas, scars, wounds, presence of implants, jewelry, or areas of heightened sensitivity.)

[0087] A further advantage of spatial control of the device includes utilizing only a subset of the cooling elements in order to treat only the region requiring treatment. It is advantageous to use one device that can accommodate small and large treatment regions without over treating (e.g. a large device that cannot be spatially controlled) or having to move the device multiple times thus extending the treatment time (e.g. a treatment device smaller than the treatment region). Thus, according to aspects of the invention, a selected region of thermoelectric coolers can be controlled to a few degrees warmer than another region of thermoelectric coolers. Alternatively, a first region of the cooling device can be turned off while a second region of the cooling device is activated, such that only a selected region of the subject is treated, thus limiting the treatment region. Other advantageous spatially controlled patterns include treating areas within the treatment region more intensely, conserving power by alternating thermoelectric coolers, increasing cooling at a perimeter in order to provide a uniform cooling pattern across the treatment area, and a combination of these spatially controlled patterns in order to increase treatment efficacy, reduce treatment time, decrease power consumption and provide for patient comfort and safety.

F. Time-Varying Cooling Profiles

[0088] In certain embodiments, once a desired temperature is achieved, the temperature of the region can be maintained for a predetermined period of time. The cooling cycle can be terminated by separating the heat exchanging surfaces 420a-g from the skin. After a certain period of time, if desired, the cooling device 104 can be reapplied to the same portion of the skin as described above until the lipid-rich cells are affected an amount sufficient to produce a desired reduction in lipid-rich cells. In another embodiment, the cooling device 104 can be applied to a different portion of the skin as described above to selectively affect lipid-rich cells in a different subcutaneous target region.

[0089] Alternatively, the cooling elements 302a-g can be controlled according to a predetermined time-varying cooling profile to cool, heat, re-cool, and/or cool in a stepped temperature pattern over time. In particular, according to aspects of the invention, patterns of controlled cooling over time provide at least the following advantages: (1) increased efficiency; (2) decreased power consumption with comparable efficacy; (3) increased patient comfort; or (4) decreased treatment time. One exemplary cooling pattern includes cooling to -5° for 15 minutes, warming to 30° for 5 minutes, cooling to -3° for 10 minutes. According to aspects of the present invention, any desired time-varying cooling profile can be programmed into the device. For example, a gradual or stepped cooling rate may decrease power requirements. Alternatively, a rapid cooling rate may be used in order to supercool the treatment region. Exemplary cooling rates include 5 to 1000 degrees per minute, more preferably 30 to 120 degrees per minute, and most preferably 35 to 100 degrees per minute.

[0090] One expected advantage of controlling the time-temperature profile of the device is that in practice, tissue is sensitive to cooling rates and thus tissue damage can be controlled by controlling the rate of cooling of the treatment region. Further, cooling the treatment region down over an extended period of time, or in phases, will increase patient comfort.

[0091] Another expected advantage of several of the embodiments described above is that the cooling device 104 can selectively reduce subcutaneous lipid-rich cells without unacceptably affecting the dermis, epidermis, and/or other tissues. Another expected advantage is that the cooling device 104 can simultaneously

selectively reduce subcutaneous lipid-rich cells while providing beneficial effects to the dermis and/or epidermis. These effects may include: fibroplasia, neocollagenesis, collagen contraction, collagen compaction, collagen density increase, collagen remodeling, and acanthosis (epidermal thickening). In the treatment of cellulite, it is expected that dermal thickening above the herniating superficial fat lobules will help reduce the appearance of cellulite and improve the longevity of the effect. Another expected advantage is that the cooling device 104 can conform to various body contours of a subject by rotating or moving the cooling elements 302a-g to achieve a desired orientation. Yet another expected advantage is that the cooling device 104 can be configured as a handheld device for ease of operation. Furthermore, another expected advantage is that the system 100 with the handheld cooling device 104 and the rack-mounted processing unit 114 and cooling unit 106 are compact and efficient such that the method described above can be administered in an outpatient clinic or a doctor's office instead of in a hospital. Yet another expected advantage is that the cooling device 104 can be strapped in place to free the clinician's hands and allow the clinician to do other tasks with the treatment is in process.

G. Method of Applying Cooling Devices with a Plurality of Rotatable or Movable Cooling Elements

[0092] In operation, the angle between the heat exchanging surfaces 420 is selected by rotating or moving the cooling elements 302a-g. The angle between the cooling elements 320a-g is often selected to conform the heat exchanging surfaces 320a-g to various body contours of the subject 101 and/or a desired clamping arrangement. In the embodiment shown in Figure 2A, the angle between the heat exchanging surfaces 320a-g can be generally 180°, i.e., the heat exchanging surfaces 320a-g are generally coplanar for applying the cooling device to a treatment region. In the embodiment shown in Figure 2B, the angle can be less than 180° to allow the cooling device to curve about a subject's body. In the embodiment shown in Figure 2C, the cooling device is further curved to conform to a subject's body. In other embodiments, the angle can be any angle to conform to a subject's body, as would be recognized by one skilled in the art.

[0093] After configuring the cooling elements 302a-g, an operator places the cooling device 104 proximate to the skin of the subject 101. In the embodiment shown

in Figure 2A (where the angle is in a generally flat configuration), the cooling elements 302a-g are initially placed flat against a subject's skin. The operator then rotates or moves the cooling device to conform to a subject's body. The cooling device can be tightened by a strap, and a pressure can be increased by tightening the strap further. Optionally, the pressure sensor can be used to sense the clamping pressure applied via the interface members 418, and the sensed clamping force can be processed by the processing unit 114 and displayed on the output device 120. The pressure can then be adjusted based on the displayed values. Depending on the location of the cooling device, the pressure, for example, can be higher than the systolic pressure in the skin to impede or block the blood flow into the treatment region. Applying such pressure enables more effective cooling of the target region because there is less blood flow to transfer core body heat to the treatment region.

[0094] Applying the cooling device with pressure to the subject's skin or pressing against the skin can be advantageous to achieve efficient cooling. In general, the subject 101 has a body temperature of about 37°C, and the blood circulation is one mechanism for maintaining a constant body temperature. As a result, blood flow through the dermis and subcutaneous layer of the region is a heat source that counteracts the cooling of the subdermal fat. As such, if the blood flow is not reduced, cooling the subcutaneous tissues would require not only removing the specific heat of the tissues but also that of the blood circulating through the tissues. Thus, reducing or eliminating blood flow through the treatment region can improve the efficiency of cooling and avoid excessive heat loss from the dermis and epidermis.

[0095] By cooling the subcutaneous tissues to a temperature lower than 37°C, subcutaneous lipid-rich cells can be selectively affected. In general, the epidermis and dermis of the subject 101 have lower amounts of unsaturated fatty acids compared to the underlying lipid-rich cells forming the subcutaneous tissues. Because non-lipid-rich cells usually can withstand colder temperatures better than lipid-rich cells, the subcutaneous lipid-rich cells can be selectively affected while maintaining the non-lipid-rich cells in the dermis and epidermis. An exemplary range for the cooling elements 302a-g can be from about -20°C to about 20°C, preferably from about -20°C to about 10°C, more preferably from about -15°C to about 5°C, more preferably from about -10°C to about 0°C.

[0096] The lipid-rich cells can be affected by disrupting, shrinking, disabling, destroying, removing, killing, or otherwise being altered. Without being bound by theory, selectively affecting lipid-rich cells is believed to result from localized crystallization of highly saturated fatty acids at temperatures that do not induce crystallization in non-lipid-rich cells. The crystals can rupture the bi-layer membrane of lipid-rich cells to selectively necrose these cells. Thus, damage of non-lipid-rich cells, such as dermal cells, can be avoided at temperatures that induce crystal formation in lipid-rich cells. Cooling is also believed to induce lipolysis (e.g., fat metabolism) of lipid-rich cells to further enhance the reduction in subcutaneous lipid-rich cells. Lipolysis may be enhanced by local cold exposure, inducing stimulation of the sympathetic nervous system.

H. Computing System Software Modules

[0097] Figure 11 is a functional diagram showing exemplary software modules 940 suitable for use in the processing unit 114. Each component can be a computer program, procedure, or process written as source code in a conventional programming language, such as the C++ programming language, and can be presented for execution by the CPU of processor 942. The various implementations of the source code and object and byte codes can be stored on a computer-readable storage medium or embodied on a transmission medium in a carrier wave. The modules of processor 942 can include an input module 944, a database module 946, a process module 948, an output module 950, and, optionally, a display module 951. In another embodiment, the software modules 940 can be presented for execution by the CPU of a network server in a distributed computing scheme.

[0098] In operation, the input module 944 accepts an operator input, such as process setpoint and control selections, and communicates the accepted information or selections to other components for further processing. The database module 946 organizes records, including operating parameters 954, operator activities 956, and alarms 958, and facilitates storing and retrieving of these records to and from a database 952. Any type of database organization can be utilized, including a flat file system, hierarchical database, relational database, or distributed database, such as provided by a database vendor such as Oracle Corporation, Redwood Shores, California.

[0099] The process module 948 generates control variables based on sensor readings 960, and the output module 950 generates output signals 962 based on the control variables. For example, the output module 950 can convert the generated control variables from the process module 948 into 4-20 mA output signals 962 suitable for a direct current voltage modulator. The processor 942 optionally can include the display module 951 for displaying, printing, or downloading the sensor readings 960 and output signals 962 via devices such as the output device 120. A suitable display module 951 can be a video driver that enables the processor 942 to display the sensor readings 960 on the output device 120.

[00100] Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number, respectively. When the claims use the word "or" in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

[00101] The above detailed descriptions of embodiments of the invention are not intended to be exhaustive or to limit the invention to the precise form disclosed above. While specific embodiments of, and examples for, the invention are described above for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. For example, while steps are presented in a given order, alternative embodiments may perform steps in a different order. The various embodiments described herein can be combined to provide further embodiments.

[00102] In general, the terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification, unless the above detailed description explicitly defines such terms. While certain aspects of the invention are presented below in certain claim forms, the inventors contemplate the various aspects of the invention in any number of claim forms. Accordingly, the inventors reserve the right to add additional claims after filing the application to pursue such additional claim forms for other aspects of the invention.

[00103] The various embodiments described above can be combined to provide further embodiments. All of the U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet are incorporated herein by reference, in their entirety. Aspects of the invention can be modified, if necessary, to employ cooling devices with a plurality of cooling elements, thermally conductive devices with various configurations, and concepts of the various patents, applications, and publications to provide yet further embodiments of the invention.

[00104] These and other changes can be made to the invention in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims, but should be construed to include all cooling that operates in accordance with the claims. Accordingly, the invention is not limited by the disclosure, but instead its scope is to be determined entirely by the following claims.

CLAIMS

I/We claim:

1. A cooling device for removing heat from subcutaneous lipid-rich cells of a subject having skin, comprising:

a plurality of cooling elements hinged to each other to allow the elements to rotate relative to each other; and

wherein the cooling elements have a skin interface surface.

2. The cooling device of claim 1, wherein the angle between the cooling elements can be rotated from about 0° to about 45°.

3. The cooling device of claim 1, wherein the cooling device forms an arcuate shape configured to conform to a subject.

4. The cooling device of claim 1, further comprising a retention device to releasably retain the cooling device on a subject.

5. The cooling device of claim 1, wherein the cooling elements further comprise a fluid chamber in thermal communication with the interface members and a plurality of fluid ports in fluid communication with the fluid chamber, and wherein the fluid ports are configured to allow fluid circulation through the fluid chamber.

6. The cooling device of claim 5, wherein the fluid in communication with the fluid chamber is circulated through a device that chills the fluid.

7. The cooling device of claim 5, wherein the fluid chambers are serpentine shaped.

8. The cooling device of claim 5, wherein the cooling elements are fluidicly connected in series.

9. The cooling device of claim 1, further comprising a thermally conductive coupling agent applied to an interface between the cooling device and the skin of the subject to increase thermal conductivity between the cooling device and the skin of the subject.

10. The cooling device of claim 1, wherein each of the plurality of cooling elements has a first side in thermal communication with the corresponding interface member and a second side opposite the first side in thermal communication with the corresponding thermoelectric heat exchanger, wherein the cooling element is configured to reduce a temperature of the target region such that lipid-rich cells in the region are affected while non-lipid-rich cells proximate to the heat exchanging surface are not significantly affected.

11. The cooling device of claim 1, further comprising a sensing element proximate to at least one of the interface members.

12. The cooling device of claim 1, further comprising:

a first temperature sensing element proximate to at least one of the interface members for detecting a temperature of a corresponding interface member; and

a second temperature sensing element proximate to at least one of the interface members for detecting a temperature of the skin of the subject.

13. The cooling device of claim 1 wherein the hinge is a living hinge.

14. A system for removing heat from subcutaneous lipid-rich cells, comprising:

a plurality of rotatable cooling elements moveable relative to one another and thermally coupled to a plurality of thermoelectric cooling devices and a corresponding plurality of heat exchanging elements contained on a segmented frame rotatable and configured to reduce a temperature of a target region under the epidermis of the subject to reduce the temperature of lipid-rich cells in the region such that the lipid-rich cells are substantially affected while non-lipid-rich cells in the epidermis are not substantially affected; and

a fluid chamber fluidicly coupled to the cooling device to dissipate heat generated by the cooling device.

15. The system of claim 14, further comprising a cooling unit in thermal communication with the fluid chamber and configured for providing a coolant to the cooling device.

16. The system of claim 15, further comprising a fluid line between the cooling unit and the cooling device such that the cooling device is in fluid communication with the cooling unit.

17. The system of claim 15, wherein the cooling device further comprises a sensing element proximate to at least one of the heat exchanging surfaces, and wherein the system further comprises:

a processor in electrical communication to the sensing element and configured to convert electrical signals from the sensing element into an operating parameter; and

a database electrically connected to the processor to store the operating parameter.

18. The system of claim 17, wherein the processor includes a control module for controlling the temperature of the region based on the operating parameter, wherein the temperature of the region is controlled based on a selected spatial temperature profile.

19. The system of claim 17, wherein the processor includes a control module for controlling the temperature of the region based on the operating parameter, and wherein the temperature of the region is controlled based on a predetermined time-varying profile.

20. A cooling device for removing heat from subcutaneous lipid-rich cells of a subject having skin, said device comprising:

a flexible substrate having a first surface and a second surface;

a plurality of cooling elements, each cooling element having a thermoelectric cooler and an interface member, wherein the interface member has a heat exchanging surface; and

wherein the plurality of cooling elements are attached to the flexible substrate such that the heat exchange surface of the interface member is at the first surface of the flexible substrate and the thermoelectric cooler is within the flexible substrate;.

21. The cooling device of claim 20 wherein said cooling elements have edges, wherein edges of adjacent cooling elements remain substantially parallel to each other.

22. The cooling device of claim 20 wherein said cooling elements are rotatable with respect to a plane in at least one direction.

23. The cooling device of claim 20 wherein said cooling elements are thermoelectric cooling elements.

24. The cooling device of claim 20 wherein each of said plurality of cooling elements is positioned adjacent to at least one other cooling element and hingedly attached to the adjacent cooling element.

25. The cooling device of claim 20 further comprising a flexible substrate, wherein said plurality of cooling elements are embedded within the substrate.

26. The cooling device of claim 20, wherein the flexible substrate is a polymeric material, elastomeric material, silicone, urethane, fabric, polypropylene or ABS.

27. The cooling device of claim 20, wherein the flexible substrate is an anatomy specific shape.

28. The cooling device of claim 20, wherein the flexible substrate is configured to provide a living hinge between cooling elements.

29. The cooling device of claim 22, wherein an angle between the cooling elements can be rotated from about 0° to about 45°.

30. The cooling device of claim 20 further comprising a retention device to releasably retain the cooling device on a subject.

31. The cooling device of claim 20, wherein the cooling elements further comprise a fluid chamber in thermal communication with interface members and a plurality of fluid ports in fluid communication with the fluid chamber, and wherein the fluid ports are configured to allow fluid circulation through the fluid chamber.

32. The cooling device of claim 31, wherein the fluid in communication with the fluid chamber is circulated through a device that chills the fluid.

33. The cooling device of claim 31, wherein the fluid chamber is serpentine shaped.

34. The cooling device of claim 31, wherein the cooling elements are fluidicly connected in series.

35. The cooling device of claim 20, further comprising a thermally conductive coupling agent applied to an interface between the cooling device and the skin of the subject to increase thermal conductivity between the cooling device and the skin of the subject.

36. The cooling device of claim 20, wherein the interface member has a non-flexible metal surface, wherein the cooling element is configured to reduce a temperature of a target region such that lipid-rich cells in the region are affected while non-lipid-rich cells proximate to a heat exchanging surface are not significantly affected.

37. The cooling device of claim 20, further comprising a sensing element proximate to at least one of an interface members.

38. The cooling device of claim 20, further comprising:

a first temperature sensing element proximate to at least one of an interface members for detecting a temperature of a corresponding interface member; and

a second temperature sensing element proximate to at least one of the interface members for detecting a temperature of the skin of the subject.