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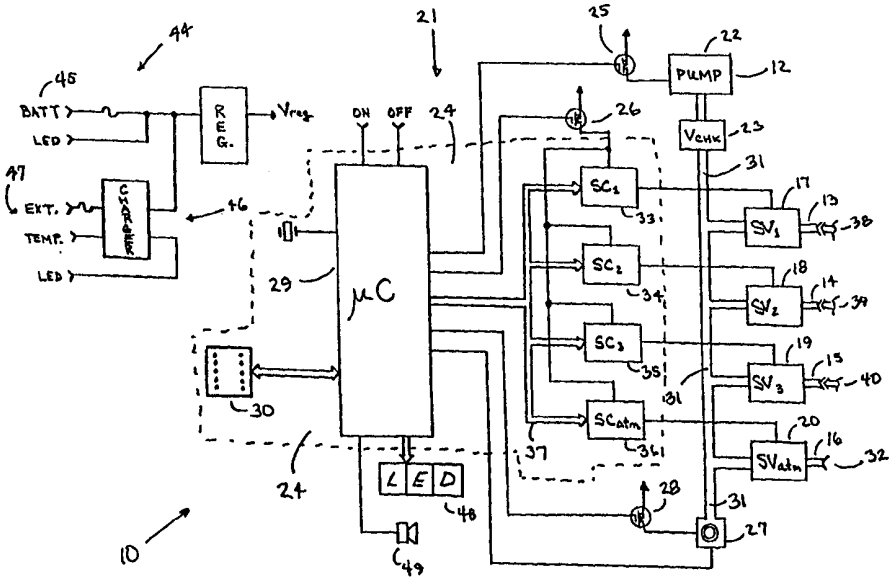
(54) Title: PORTABLE PUMP FOR USE WITH GRADIENT COMPRESSION BANDAGE

(57) Abstract

A portable pump for use with a gradient compression bandage generally comprises a selectively actuable source of pressurized fluid in communication with a plurality of outlets; a plurality of selectively actuable latching valves interposed between the fluid source and each outlet; and a controller for controlling electrical power supplied to the fluid source and the latching valves; thereby selectively actuating the fluid source and the latching valves. Portability is achieved through battery power conservation means such as utilization of latching valves having an open state and a closed state and adapted to require electrical power only in transition between states and utilization of an electrical controller adapted to selectively switch power to the air compressor and the latching valves as required. The fluid source may also comprise a one-way check valve for preventing back flow and leakage of the pressurized fluid through the air compressor. A pressure sensor for obtaining a pressure measurement at each fluid outlet is also selectively powered by the controller. A power supply system allows full battery operation of the portable pump. This system comprises a battery recharge circuit adapted to permit recharge of the system battery even while the pump is in operation. Patient safety is maximized by providing the recharge circuit with an overcharge prevention circuit adapted to automatically discontinue battery charging upon reaching of a three-hour time limit for charging, detection of a negative battery charge voltage curve or measurement of an excessive battery temperature.



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PORTABLE PUMP FOR USE WITH GRADIENT COMPRESSION BANDAGE

RELATED APPLICATION:

This application claims priority to United States patent application Serial No. 09/259,040 entitled PORTABLE PUMP FOR USE WITH GRADIENT COMPRESSION BANDAGE filed February 26, 1999. By this reference, the full disclosure, including the drawings, of U.S. patent application Serial No. 09/259,040 is incorporated herein.

TECHNICAL FIELD:

The present invention relates generally to wound healing. More specifically, the present invention relates to a portable pump for use with a gradient pressure compression bandage as used for treating ulcers and the like in mammalian extremities, particularly venous stasis ulcers and edema.

BACKGROUND ART:

An ulcer is commonly defined as a lesion on the surface of the skin, or on a mucous surface, manifested through a superficial loss of tissue. Ulcers are usually accompanied by inflammation and often become chronic with the formation of fibrous scar tissue in the floor region. Chronic ulcers are difficult to heal; they almost always require medical intervention and, in many cases, lead to amputation of the limb upon which they occur.

In general, ulcers may be attributed to any of a variety of factors reducing superficial blood flow in the affected region. Leg ulcers, in particular, are attributable to congenital disorders, external injury, infections, metabolic disorders, inflammatory diseases, ischaemia, neoplastic disorders and, most commonly, arterial disease, neuropathic disorders and venous insufficiency. Although certainly not exhaustive, the table entitled Common Etiology of Leg Ulcers, highlights the frequency at which patients are placed at risk for the formation of this potentially devastating disease.

Common Etiology of Leg Ulcers

Congenital:	Absence of valves, chromosomal disorders, Klinefelter's syndrome, connective tissue defects affecting collagen and elastic fibers, arteriovenous aneurysms, prolidase deficiency.
External Injury:	Laceration, contact dermatitis, decubitus, inoculation (drug addiction), burns, cold, irradiation.

Infections:	Viral, bacterial, fungal.
Metabolic Disorders:	Diabetes mellitus, colonic stasis from sugar/fats.
Inflammatory Diseases:	Vasculitus, pyoderma gangrenosum, rheumatoid arthritis, panniculitus.
Ischaemia:	Peripheral vascular disease, embolus, scleroderma hypertension, sickle-cell anemia.
Neoplastic Disorders:	Skin neoplasms, leukemia.
Neuropathic Disorders:	Spina bifida, leprosy, diabetes mellitus, neoropathy syringomyelia.
Venous Insufficiency:	Posture (prolonged standing, legs crossed, long legs), abdominal pressure (tumor, pregnancy), employment, physical activity (apathy, paralysis, osteoarthritis), effort (weight lifting), deep vein thrombosis (50% tibial fractures, 25% abdominal surgery, 25% myocardial thrombosis, 50% strokes), blood stasis, hemolytic anemias.

Perhaps as striking as the incidence of this disease, is the magnitude of the resources dedicated to the combat of their occurrence. It is estimated that leg ulcers cost the U.S. healthcare industry in excess of $1 billion annually in addition to being responsible for over 2 million annual missed workdays. Unfortunately, the price exacted by ulcers is not merely financial. Leg ulcers are painful and odorous open wounds, noted for their recurrence. Most tragic, diabetic ulcers alone are responsible for over 50,000 amputations per year. As alarming as are these consequences, however, the basic treatment regimen has remained largely unchanged for the last 200 years. In 1797, Thomas Baynton of Bristol, England introduced the use of strips of support bandages, applied from the base of the toes to just below the knee, and wetting of the ulcer from the outside. As discussed in more detail herein, versions of this therapy remain the mainstay treatment to this day and, clearly, any improvement is of critical importance.

As noted above, the most common causes of leg ulcers are venous insufficiency, arterial disease, neuropathy, or a combination of these problems. Venous ulcers, in particular, are associated with abnormal function of the calf pump, the natural mechanism for return to the heart of venous blood from the lower leg. This condition, generally referred to as venous insufficiency or venous hypertension, may occur due to any of a variety of reasons, including damage to the valves, congenital abnormalities, arteriovenous fistulas, neuromuscular dysfunction, or a combination of these factors. Although venous ulcers tend to be in the gaiter area, usually situated over the medial and lateral malleoli, in severe cases the entire

lower leg can be affected, resembling an inverted champagne bottle. While the exact pathologic relationship between venous insufficiency and venous ulcers remains largely unknown, distinct modalities for both prevention and treatment have nonetheless been developed.

Clinical modalities for prevention of venous ulcers generally focus on the return of venous blood from the lower extremities to the heart. Mechanical prophylaxes are widespread in the art of prevention and are often referred to as foot pumps or wraps, leg pumps or wraps and sequential compression devices, all of which function to prevent deep vein thrombosis ("DVT"), a common precursor to venous stasis ulcers. An exemplary foot pump is commercially available from Kinetic Concepts, Inc. of San Antonio, Texas under the trademark "PLEXIPULSE." An exemplary sequential compression device is described in U.S. Patent No. 5,031,604 issued July 16, 1991 to Dye ("Dye").

As generally described in Dye, mechanical prophylaxes for DVT prevention are directed toward the improvement of venous return. To this end, devices like that of Dye are adapted to take advantage of the naturally occurring valvular structure of the veins to squeeze the blood from a patient's limb. For instance, the trademark "PLEXIPULSE" device is adapted to intermittently compress the patient's plantar venous plexus, promoting the return of blood from the patient's foot upward and through the calf region. Likewise, and as generally described at column 2, lines 33 *et seq.* of Dye, leg compression devices are usually adapted to squeeze the patient's leg first near the ankle and then sequentially upward toward the knee. This milking-type sequence may or may not be performed on a decreasing pressure gradient, but is always designed to move blood from the extremity toward the heart.

Treatment of venous ulcers, on the other hand, is predominately centered about gradient compression, through bandaging, and leg elevation. Although it is not precisely known how or why they improve venous ulcer healing, compression therapies, specifically including compression bandaging techniques, are now the well-established mainstay for the treatment of venous stasis and other ulcers. In fact, it is generally undisputed that compression bandaging is the most efficacious method for wound healing, often resulting in overall improvement of the patient's quality of life.

Among the predominant theories for explaining the effects of compression bandaging, edema reduction and control for the improvement of venous hemodynamic abnormality concomitant prolonged venous hypertension from valvular incompetency or dysfunction stands out. It is thought that the reduction and control of edema improves capillary microcirculation, in turn resulting in the elimination of venous ulcers. Another popular theory holds that reactive hyperemia is responsible for the success of compression

bandaging. According to this theory, the arrest and subsequent restoration of blood flow to the affected region, known as Bier's method, results in an ultimately increased presence of blood in the region. Regardless of the theory adopted, however, it is important to note that it is universally understood that a proper gradient must be established in order to derive the benefits of compression bandaging. This gradient is generally accepted as being from about 35 to 45 mm Hg at the ankle and reducing to about 15 to 20 mm Hg at just below the knee. Often stated in the literature as a prerequisite to good bandaging technique, the maintenance of graduated compression is critical to effective treatment of ulcers. Failure to initially obtain, and thereafter maintain, the desired sub-bandage pressures is fatal to the treatment regimen.

The criticality of establishing and maintaining the desired sub-bandage pressure directly results in significant disadvantages, associated with the application of compression bandaging in general, and serious hazards to the patient, associated with the misapplication of bandaging specifically. In particular, proper bandaging under the presently known methods requires a highly skilled caregiver in order to establish the desired sub-bandage pressures. Once established, however, the pressure gradient is difficult to monitor. In fact, the sub-bandage pressure is usually only monitored to the extent that the caregiver either observes or fails to observe a reduction in edema. This is particularly disturbing when one considers that it is to be expected that as properly applied bandaging performs its intended function edema will be reduced causing, in effect, the bandage to become loosened to a state of improper application where after edema will probably increase. More disturbing is the fact that over tightening of the bandage places the patient at direct risk for skin necrosis and gangrene, especially if the patient has arterially compromised limbs.

Unfortunately, there has been surprisingly little development in treatment protocols directed toward better achieving desired sub-bandage pressures. Even though the foregoing discussion highlights the necessity for frequent reapplication of the bandaging, the presently available treatment modalities are very difficult to apply. One common type of bandaging comprises four layers, including an orthopedic wool layer, a crepe bandage layer and two compression layers. The compression layer bandages are often provided with imprinted rectangles that become square upon achieving the correct tension. Although helpful, only two sets of markings are typically provided – one for normal size ankles and one for larger, and no provision is made for adaptation to changes in the level of edema. Another common treatment modality is the compression dressing – an elastic support stocking providing a compression of about 30 to 40 mm Hg. These stockings, however, are often impractical for elderly patients or patients with arthritis who may find them difficult to put on the leg and for

the patient with large or exudative ulcers, which require frequent dressing changes, compression stockings are thought to be prohibitively impractical.

As this discussion makes apparent, the need for treatment modalities beyond the presently known compression bandaging techniques is great. Unfortunately, the mechanical prophylaxes utilized in prevention therapies are not generally extendable to wound healing. Although, recent reports have indicated that achieving sustained sub-bandage pressures near 40 mm Hg may be more efficacious in providing timely wound healing than lower pressure levels and the present Applicant has found that mechanical prophylaxes are generally better able to deliver higher pressures, caution is warranted. Because some 20 percent or more of patients with venous ulcers may also have some degree of co-existing lower extremity arterial disease, it is important to clarify the possible impact of higher levels of compression bandaging on lower extremity skin circulation. Studies show that mechanically produced compression levels may produce ischaemic effects not noted at similar compression levels obtained through bandaging. The reductions in leg pulsatile blood flow associated with mechanical prophylaxes often occur at compression levels below that necessary for good bandaging effects. This result, sometimes called cuffing, has resulted in most mechanical prevention prophylaxes being contraindicated for patients exhibiting DVT. Consequently, those of ordinary skill in the art have until very recently steadfastly avoided mechanical prophylaxes for the treatment of venous stasis and other ulcers or edema of the extremities.

The end result has been that the patient once suffering from leg ulcers was left at the mercy of an extraordinarily high recurrence rate and in many cases is still thought to be at severe risk for eventual amputation. This leads to emotional complication of the treatment process. Because preventing recurrence is as great a challenge as healing the ulcer, new and improved methods and apparatus for treatment of leg ulcers continue to be desperately needed. In particular, because careful skin care and compression therapy must continue throughout the patient's lifetime, it is imperative to the patient's long-term health care to provide a low-cost, easily applied solution with which the patient may be assured of receiving effective therapy. In addition, it is imperative that the implemented solution go as far as possible toward allowing the patient to regain a relatively normal lifestyle. To this end, it is a primary object of the present invention to overcome many of the shortcomings of the prior art to provide a mechanical prophylaxis for the administration of gradient compression therapy whereby the patient may return to a relatively normal regimen. In particular, the present invention strives to maximize patient mobility by reducing the need for the patient to be located at any particular place in order to receive therapy. It is yet another object of the present invention to provide such a prophylaxis in a lightweight, readily transportable and

non-intrusive package. In this manner, the present invention is directed toward improved patient compliance, ultimately resulting in improved long-term outcome – both physically and emotionally.

Additionally, many other problems, obstacles and challenges present in existing modalities for the treatment of leg ulcers will be evident to caregivers and others of ordinary skill in the art. Many of these will be readily recognized as being overcome by the teachings set forth herein.

DISCLOSURE OF THE INVENTION:

In accordance with the foregoing objects, the present invention – a portable pump for use with a gradient pressure compression bandage – generally comprises a selectively actuable source of pressurized fluid in communication with a plurality of outlets; a plurality of selectively actuable latching valves interposed between the fluid source and each outlet; and a controller for controlling electrical power supplied to the fluid source and the latching valves, thereby selectively actuating the fluid source and the latching valves.

Each latching valve has an open state and a closed state and is adapted to require electrical power only in transition between these states. The fluid source preferably comprises a miniature diaphragm air compressor. In the preferred embodiment, the controller comprises an electrical circuit adapted to selectively switch power, through a low power, transistor-based switching circuit, to the air compressor and the latching valves as required. In this manner, power is conserved thereby making possible the portable use of the present invention.

In at least one embodiment, the fluid source further comprises a one-way check valve. This check valve is interposed between the air compressor and the latching valves for substantially preventing back flow and leakage of the pressurized fluid through the air compressor. Although this provision contributes to the ability to operate the present invention as a portable pump, due to the decreased need to use power for compressor operation, it is to be understood that in many implementations this feature is only optional. For example, many compressors have built in check valves and others function in a manner inherently preclusive of back flows.

In at least one particular embodiment, the fluid outlets comprise a plurality of bandage ports. These bandage ports are designated to deliver at least a three-tier pressure gradient to the gradient compression bandage. In addition, one fluid outlet preferably comprises a vent adapted to discharge the pressurized fluid to atmosphere. Because the electrical circuit is adapted to switch power to the latching valves, through an integrated

valve controller, independently of the air compressor, baseline atmospheric pressure values may be obtained and a soft power down feature may be implemented. This soft power down feature is adapted to discharge the pressurized fluid from each bandage port through the vent prior to an interruption of the pump's operation, thereby ensuring patient safety by facilitating pressure relief prior to power down.

In the preferred embodiment of the present invention, the portable pump further comprises a pressure sensor for obtaining a pressure measurement at each fluid outlet. This pressure sensor is in electrical communication with the controller for conveyance to the controller of each obtained pressure measurement. Again, in order to facilitate maximum power conservation, the controller is preferably adapted to selectively power the pressure sensor. The controller is adapted to selectively actuate the air compressor and the latching valves in response to pressure measurements obtained by the pressure sensor and, in particular, in response to comparisons of those pressure measurements with predetermined pressure values.

The portable pump also preferably comprises a battery power supply system adapted to allow full operation of the portable pump with all power provided by a battery. This battery power supply system comprises a battery recharge circuit, preferably adapted to permit recharge of the battery even while the portable pump is in operation. To ensure maximum patient safety in the often unattended portable environment, the battery recharge circuit is provided with an overcharge prevention circuit adapted to automatically discontinue battery charging upon reaching of a three-hour time limit for charging, detection of a negative battery charge voltage curve or measurement of an excessive battery temperature.

Many other features, objects and advantages of the present invention will be apparent to those of ordinary skill in the relevant arts, especially in light of the foregoing discussions and the following drawings, exemplary detailed description and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS:

Although the scope of the present invention is much broader than any particular embodiment, a detailed description of the preferred embodiment follows together with illustrative figures, wherein like reference numerals refer to like components, and wherein:

Figure 1 shows a functional block diagram, detailing the major components, of the portable pump of the present invention; and

Figure 2 shows, in perspective view, an exemplary pneumatically operated gradient pressure compression bandage as appropriate for use with the pump of Figure 1 and as applied to a patient's lower leg.

BEST MODE FOR CARRYING OUT THE INVENTION:

Although those of ordinary skill in the art will readily recognize many alternative embodiments, especially in light of the illustrations provided herein, this detailed description is exemplary of the preferred embodiment of the present invention – a portable pump for use with a gradient compression bandage, the scope of which is limited only by the claims appended hereto.

Referring to the Figures, and Figure 1 in particular, a portable pump 10 for use with a gradient pressure compression bandage 11 , as shown in Figure 2, is detailed. The portable pump 10 generally comprises a selectively actuable source 12 of pressurized fluid in communication with a plurality of fluid outlets 13, 14, 15, 16; a plurality of selectively actuable latching valves 17, 18, 19, 20 interposed between the fluid source 12 and each fluid outlet 13, 14, 15, 16; and a controller 21 for controlling electrical power supplied to the fluid source 12 and the latching valves 17, 18, 19, 20, thereby selectively actuating the fluid source 12 and the latching valves 17, 18, 19, 20. As will be detailed herein, the pump 10 further comprises many power saving and size reducing features, all serving to enable portable operation thereof.

Each latching valve 17, 18, 19, 20 has an open state and a closed state and is adapted to require electrical power only in transition between these states. Suitable latching valves 17, 18, 19, 20 are commercially available from sources such as MAC Valves of Wixom, Michigan. The fluid source 12 preferably comprises a miniature diaphragm air compressor 22, such as is readily available from Thomas Compressors and Vacuum Pumps of Sheboygan, Wisconsin under the 3004 Series trade designation. Although other compressor pumps 22 may be readily substituted by those of ordinary skill in the art, it is critical to maintaining the portable features of the present invention that a small, lightweight and yet relatively high airflow compressor 22 be utilized. The 3004 Series, for example, is capable of delivering a continuous pressure of 500 mbar, but weighs only 51 grams.

In order to ensure minimum operation of the compressor 22, thereby again conserving power, the fluid source 12 of the preferred embodiment of the present invention further comprises a one-way check valve 23. This check valve 23 is interposed between the air compressor 22 and the latching valves 17, 18, 19, 20 for substantially preventing back flow and leakage of the pressurized fluid through the air compressor 22. This provision greatly contributes to the ability to operate the present invention as a portable pump 10 due to the decreased need to use power for compressor operation.

The controller 21 comprises an electrical circuit 24 adapted to selectively switch power, through low power MOSFET switching circuits 25, 26, to the air compressor 22 and

the latching valves 17, 18, 19, 20, respectively, as required. As will be better understood further herein, this configuration greatly contributes to power conservation, thereby enabling the portable use of the present invention. As also will be better understood further herein, the portable pump 10 further comprises a pressure sensor 27 for obtaining a pressure measurement at each fluid outlet 13, 14, 15, 16. This pressure sensor 27 is in electrical communication with the controller 21 for conveyance to the controller 21 of each obtained pressure measurement. Again, in order to facilitate maximum power conservation, the controller 21 is preferably adapted to selectively power the pressure sensor 27 and does so through a third MOSFET switching circuit 28.

In the preferred embodiment of the present invention, the electrical control circuit 24 is microcontroller based, built about a trademark "ATMEL" high performance, low power RISC microontroller 29. In particular, the AT90S4434 is chosen for its integrated sleep mode and in-circuit programmability 30. As with many other features of the present invention detailed herein, the sleep mode is implemented in order to conserve power, thereby further adapting the present invention for portable operation. In-circuit programmability 30 allows features to be added or removed without requiring pre-positioned permanent structure. This also serves to promote portability as it contributes to size reduction.

The preferred embodiment of the present invention comprises a single trademark "MOTOROLA" MXP-5000 series piezoresistive pressure sensor 27 in fluid communication with a manifold 31 extending between the one-way check valve 23 and each latching valve 17, 18, 19, 20. In this manner, pressure readings may be obtained from each fluid outlet 13, 14, 15, 16, including a vent 32 to atmosphere, without requiring multiple sensors. As shown in Figure 1, a plurality of solenoid controllers 33, 34, 35, 36 are implemented for actuating each latching valve 17, 18, 19, 20. In the preferred embodiment, the Temic Semiconductor Si9986CY buffered H-bridge is utilized for this function. In operation, each solenoid controller 33, 34, 35, 36 delivers either a positive or negative pulse of power to its respective latching valve 17, 18, 19, 20, based upon instruction received over a common bus 37 from the microcontroller, whenever power is delivered from the MOSFET switching circuit 26 to the solenoid controllers 33, 34, 35, 36. This overall configuration results in an architecture wherein power may be selectively applied to the pressure sensor 27, solenoid controllers 33, 34, 35, 36 and compressor 22 in order to provide a desired pressure at each fluid outlet 13, 14, 15, 16 with minimum power consumption.

The fluid outlets 13, 14, 15, 16 of the preferred embodiment comprise a plurality of bandage ports 38, 39, 40 designated to deliver at least a three-tier pressure gradient to the gradient pressure compression bandage 11. As shown in Figure 2, and known to those of

ordinary skill in the art, such a compression bandage 11 generally comprises a plurality of compression chambers 41, 42, 43, each intended to compress the patient's lower extremity 44 to a slightly greater or lesser degree. Because it is important to deliver only that pressure necessary for proper therapy and to do so for only the required time period, one fluid outlet 16 also preferably comprises a vent 32 adapted to discharge the pressurized fluid to atmosphere. Because the electrical circuit 24 is adapted to switch power to the latching valves 17, 18, 19, 20, through an integrated valve controller 33, 34, 35, 36, independently of the air compressor 22, baseline atmospheric pressure values may be obtained and a soft power down feature may be implemented. This soft power down feature is adapted to discharge the pressurized fluid from each bandage port 38, 39, 40 through the vent 32 prior to an interruption of the pump's operation, thereby ensuring patient safety by facilitating pressure relief prior to power down.

Upon power up, all valves 17, 18, 19, 20 are opened and a baseline atmospheric pressure value is obtained. In particular, the microcontroller 29 operates to deliver power to the solenoid controllers 33, 34, 35, 36, by switching on the appropriate MOSFET 26, and to shuttle open each latching valve 17, 18, 19, 20, by placing the appropriate instruction on the bus 37 to the solenoid controllers 33, 34, 35, 36. As with every operation of the present invention, power is then immediately disengaged by switching off the MOSFET 26. With each bandage port 38, 39, 40 now vented to atmosphere 32, power is provided to the pressure sensor, again by switching on the appropriate MOSFET 26, whereafter a baseline pressure measurement is obtained by the microcontroller 29. Again, the microcontroller 29 then switches off the MOSFET 28 to the pressure sensor 27. This operation serves to ensure residual pressure is removed from each compression chamber 41, 42, 43 and also provides a baseline from which the desired compression gradient may be determined, as is understood by those of ordinary skill in the art.

In operation of the portable pump 10 of the present invention, the controller 21 is adapted to selectively actuate the air compressor 22 and the latching valves 17, 18, 19, 20 in response to pressure measurements obtained by the pressure sensor 27 and, in particular, in response to comparisons of those pressure measurements with predetermined pressure values and according to a predetermined timing regimen. In general, the pump 10 is designed to deliver a 20 minute pressurize and hold cycle alternately with a 5 minute release and hold cycle. In the pressurization cycle, power is switched on to the pressure sensor 27 and the solenoid controllers 33, 34, 35, 36 with appropriate instruction on the bus 37 to open a first latching valve 17 to a first chamber 41. Power is then switched on, through the appropriate MOSFET 25 to the compressor 22 until the desired pressure is measured by the pressure

sensor 27 as communicated to the microcontroller 29, which then places appropriate instruction on the bus 37 to close the first valve 17. Power is then switched off to the solenoid controllers 33, 34, 35, 36, compressor 22 and sensor 27. As will be apparent to those of ordinary skill in the art, this routine is repeated for each chamber 41, 42, 43, 44 to be pressurized.

In the preferred operation of the present invention, the pressure is measured at each bandage port 38, 39, 40 at least once every five minutes during the pressurize and hold cycle. It at any time the pressure is found to be below desired, the pressurization cycle as described above is repeated for that port 38, 39, 40. If, on the other hand, pressure is found to exceed the desired level, a similar operation is implemented to vent the violating port 38, 39, 40 to atmosphere 32 for 0.2 second. Upon termination of the pressurize and hold cycle, each port 38, 39, 40 is vented to atmosphere 32 for a five minute period.

Although the presently preferred embodiment of the portable pump 10 described herein utilizes a 20 minute pressurize cycle alternately with a five minute release cycle, it is well understood by those of ordinary skill in the art that the particular timing is a clinical matter. It is only critical to the present invention that the portable pump 10 be adapted to operate within the ranges of timing values as may be expected in practice, these ranges being understood in the relevant arts.

The portable pump 10 also preferably comprises a battery power supply system 44 adapted to allow full operation of the portable pump 10 with all power provided by a system battery 45. This battery power supply system 44 comprises a battery recharge circuit 46, preferably adapted to permit recharge of the system battery 45 even while the portable pump 10 is in operation. To ensure maximum patient safety in the often unattended portable environment, the battery recharge circuit 46 is provided with an overcharge prevention circuit 47 adapted to automatically discontinue battery charging upon reaching of a three-hour time limit for charging, detection of a negative battery charge voltage curve or measurement of an excessive battery temperature. Such a circuit, which is readily within the reach of those of ordinary skill in the art, may be built around the trademark "MAXIM" MAX713 fast-charge controller.

While the foregoing description is exemplary of the preferred embodiment of the present invention, those of ordinary skill in the relevant arts will recognize the many variations, alterations, modifications, substitutions and the like as are readily possible, especially in light of this description, the accompanying drawings and the claims drawn hereto. For example, low power display drivers 48 and the like may be implemented to operate only at power up or while the system is in charge or a warning buzzer 49 may

likewise be implemented to indicate low battery charge and the like. In any case, because the scope of the present invention is much broader than any particular embodiment, the foregoing detailed description should not be construed as a limitation of the present invention, which is limited only by the claims appended hereto.

5

INDUSTRIAL APPLICABILITY:

The present invention is applicable to the medical equipment arts.

CLAIMS:

What is claimed is:

1. A portable pump for use with a gradient compression bandage, said portable pump comprising:

a selectively actuable source of pressurized fluid, said source being in fluid communication with a plurality of fluid outlets;

a plurality of selectively actuable latching valves, at least one said latching valve being interposed between said fluid source and each said fluid outlet, each said latching valve comprising an open state and a closed state and being adapted to require electrical power only in transition between said states; and

a controller for controlling electrical power supplied to said fluid source and to said latching valves, said controller being adapted to selectively supply electrical power to said fluid source and to said latching valves thereby selectively actuating said fluid source and said latching valves.

2. The portable pump as recited in claim 1, wherein said fluid source comprises an air compressor.

3. The portable pump as recited in claim 2, wherein said air compressor comprises a miniature diaphragm compressor pump.

4. The portable pump as recited in claim 2, wherein said fluid source further comprises a one-way check valve, said check valve being interposed between said air compressor and said latching valves for substantially preventing back flow and leakage of said pressurized fluid through said air compressor.

5. The portable pump as recited in claim 2, wherein said fluid outlets further comprise a plurality of bandage ports, said bandage ports being designated to deliver at least a three tier pressure gradient to the gradient compression bandage.

6. The portable pump as recited in claim 5, wherein said fluid outlets comprise a vent, said vent being adapted to discharge said pressurized fluid to atmosphere.

7. The portable pump as recited in claim 5, wherein said controller comprises an electrical circuit, said electrical circuit being adapted to selectively switch power to said air compressor and said latching valves.

8. The portable pump as recited in claim 7, wherein said electrical circuit is further adapted to switch power to said latching valves independently of said air compressor.

9. The portable pump as recited in claim 8, wherein said electrical circuit comprises a low power, transistor-based switching circuit.

10. The portable pump as recited in claim 8, wherein said electrical circuit comprises:

an integrated valve controller, said valve controller being adapted to independently actuate each said latching valve; and

a micro-controller, said micro-controller being adapted to effect the state of each said latching valve by providing substantially simultaneous instruction and power to said valve controller.

11. The portable pump as recited in claim 10, wherein said micro-controller is further adapted to provide a coded output to said valve controller, whereby said valve controller establishes a configuration of states for said latching valves.

12. The portable pump as recited in claim 10, wherein said micro-controller is further adapted to provide power to said valve controller through a low power, transistor-based switching circuit.

13. The portable pump as recited in claim 10, said portable pump further comprising a pressure sensor for obtaining a pressure measurement at each said fluid outlet, said pressure sensor being in electrical communication with said micro-controller for conveyance to said micro-controller of each obtained pressure measurement.

14. The portable pump as recited in claim 13, wherein said micro-controller is further adapted to selectively power said pressure sensor.

15. The portable pump as recited in claim 13, wherein said micro-controller is adapted to selectively actuate said air compressor and said latching valves in response to pressure measurements obtained by said pressure sensor.

16. The portable pump as recited in claim 15, wherein said micro-controller is further adapted to selectively actuate said air compressor and said latching valves in response to a plurality of comparisons of said pressure measurements and predetermined pressure values.

17. The portable pump as recited in claim 13, said portable pump further comprising a battery power supply system, said battery power supply system being adapted to allow full operation of said portable pump with all power provided by a system battery.

18. The portable pump as recited in claim 17, wherein said battery power supply system comprises a battery recharge circuit, said recharge circuit being adapted to permit recharge of the system battery while said portable pump is in operation.

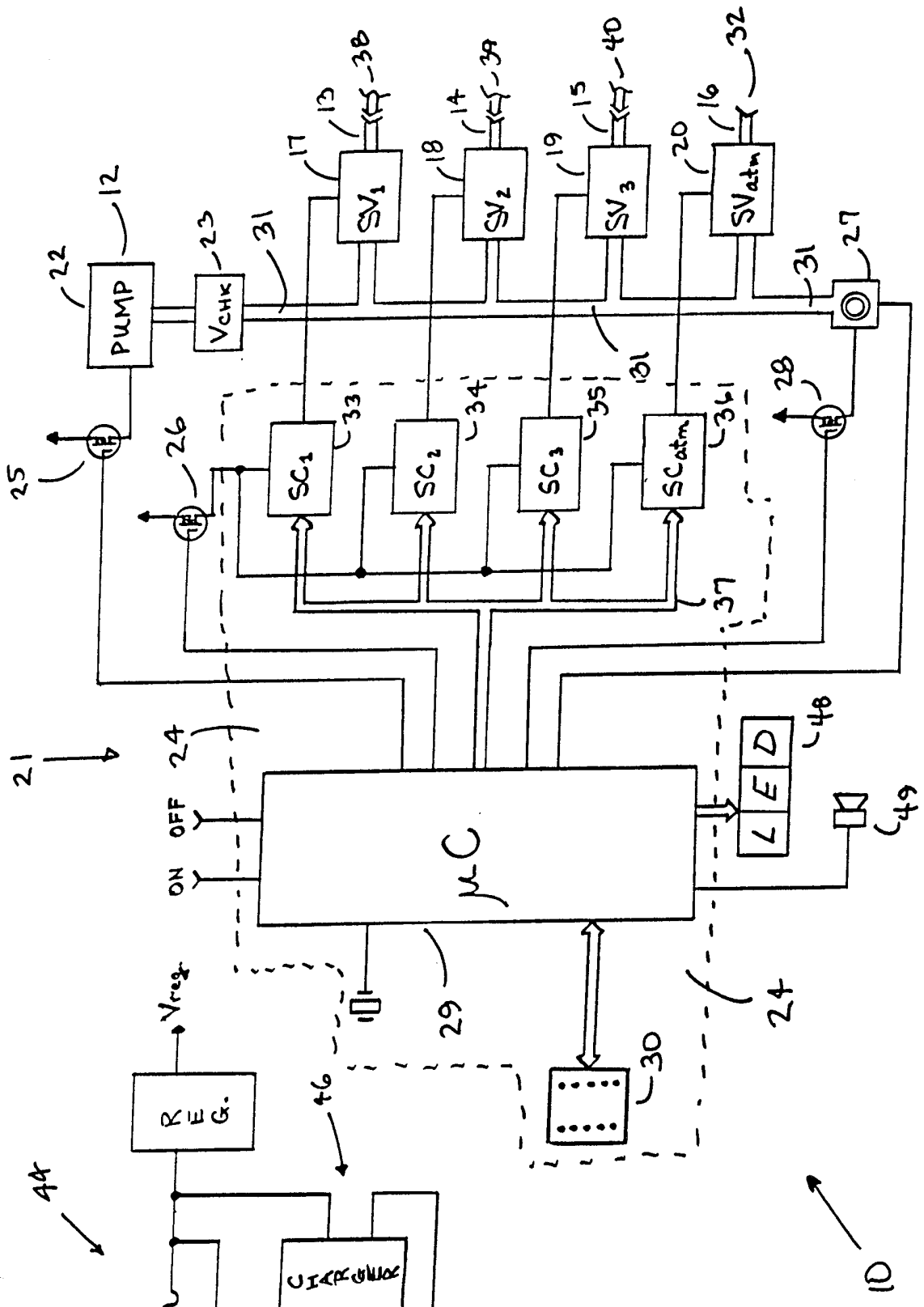
19. The portable pump as recited in claim 18, wherein said battery recharge circuit comprises an overcharge prevention circuit, said circuit being adapted to automatically discontinue battery charging upon satisfaction of a condition selected from the group consisting of:

a three-hour time limit for charging is exceeded;

the slope of the battery charge voltage curve becomes negative; and

the battery temperature exceeds a predetermined limit.

20. The portable pump as recited in claim 13, wherein said controller further comprises a soft power down feature, said power down feature being adapted to discharge said pressurized fluid from each said bandage port through said vent prior to an interruption of said pump's operation.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EXT.
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FIGURE 1

FIGURE 2