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(54) **APPARATUS AND METHOD FOR WOUND TREATMENT EMPLOYING PERIODIC SUB-ATMOSPHERIC PRESSURE**

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(57) **ABSTRACT**

A tissue treatment apparatus and method are provided for treating tissue by the application of the time-varying sub-atmospheric pressure. The apparatus includes a cover adapted to cover a wound and adapted to maintain sub-atmospheric pressure the site of the wound. The apparatus further includes a source of suction configured to generate a time-varying sub-atmospheric pressure having a periodic waveform comprising a gradual change in pressure. The suction source cooperates with the cover to supply the time-varying sub-atmospheric pressure under the cover to the wound. The time-varying sub-atmospheric pressure may vary between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue.

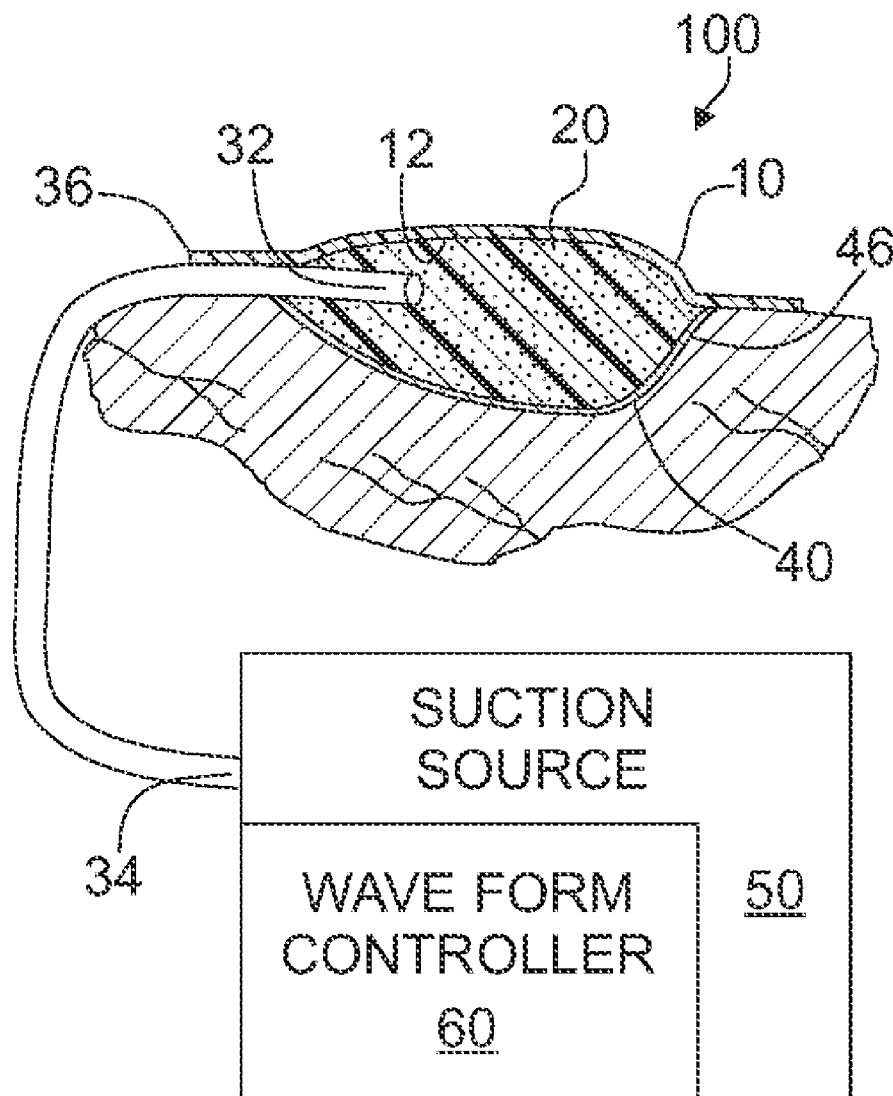
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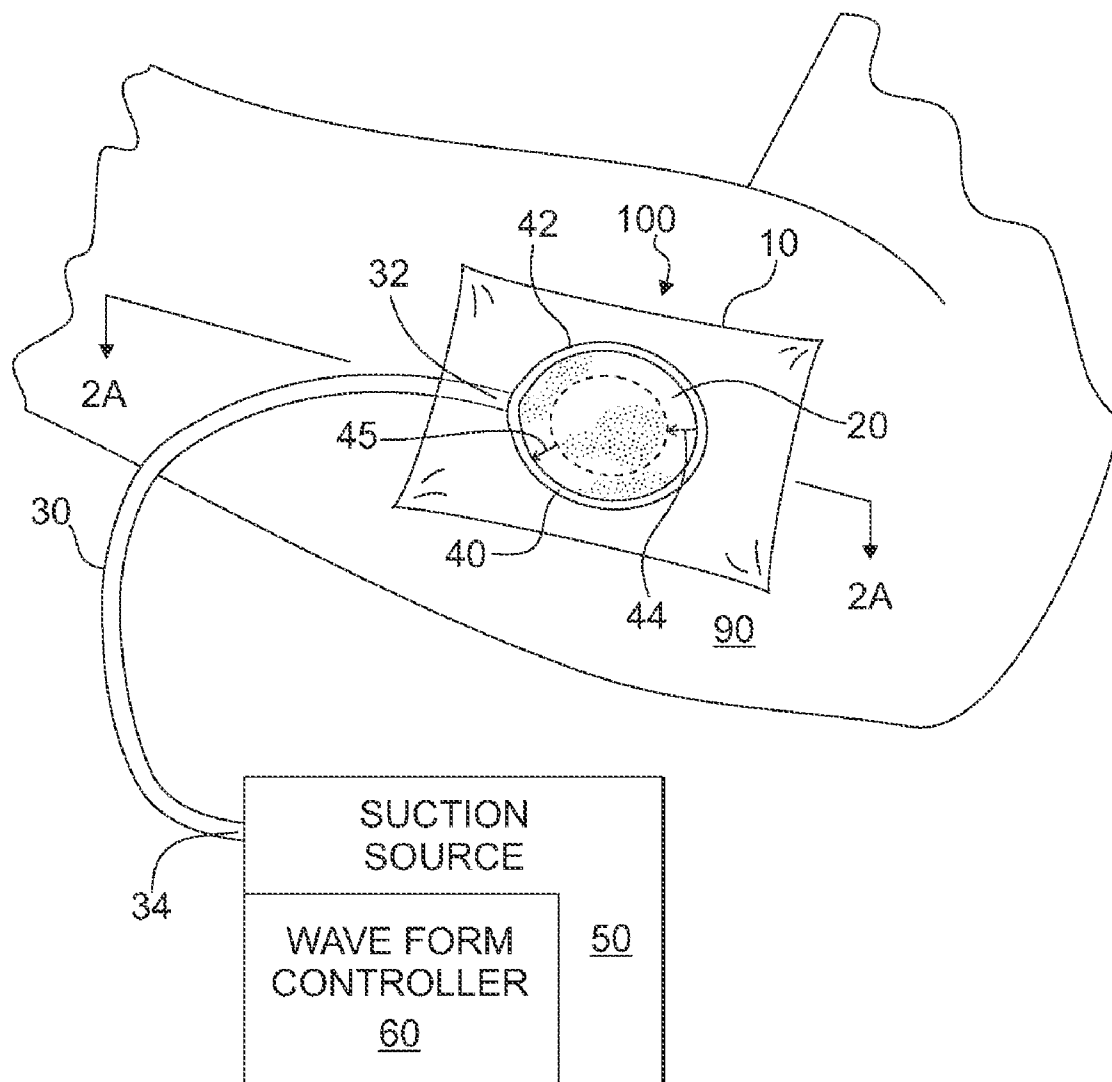


Fig. 1

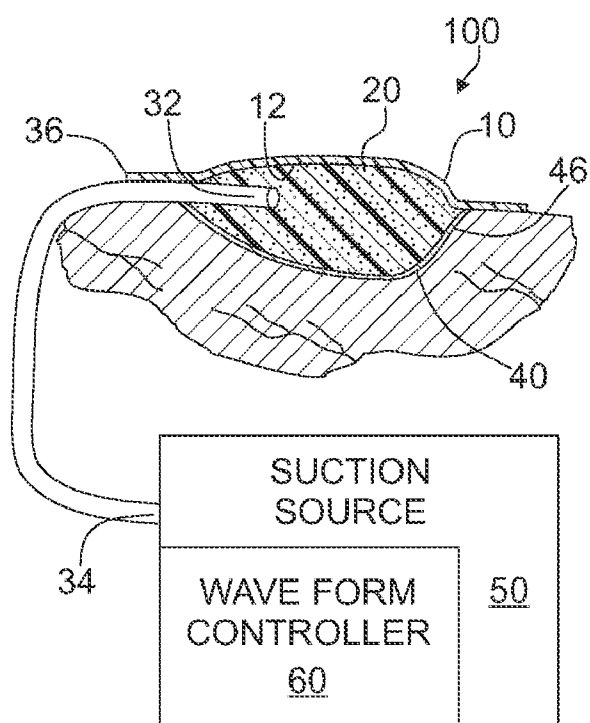


Fig. 2A

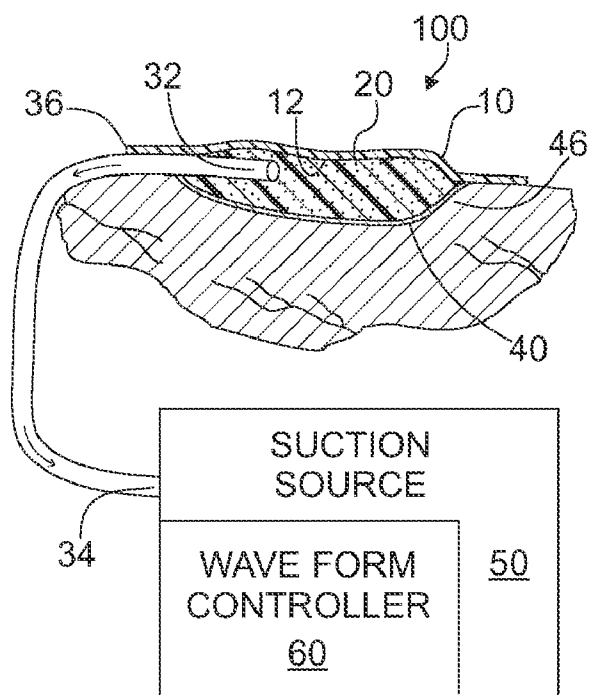


Fig. 2B

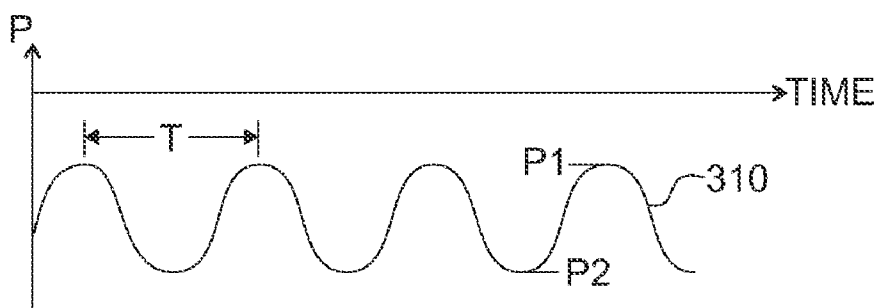


Fig. 3A

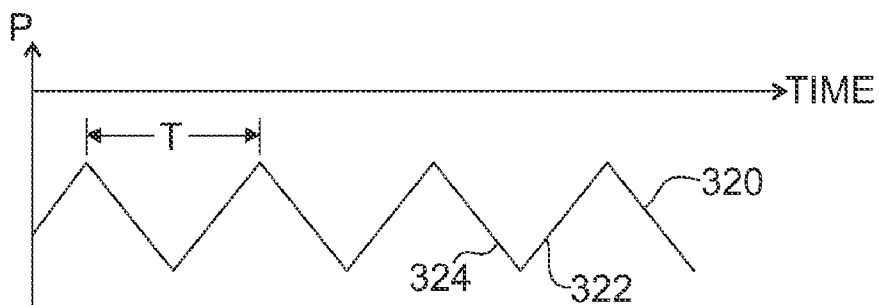


Fig. 3B

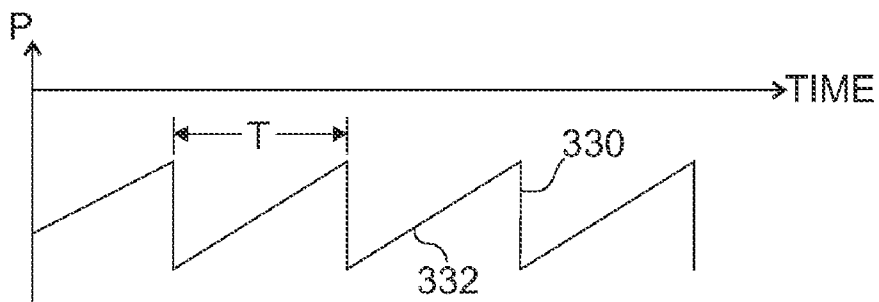


Fig. 3C

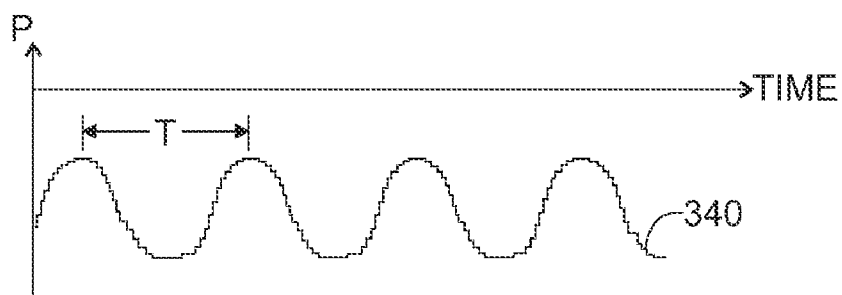


Fig. 3D

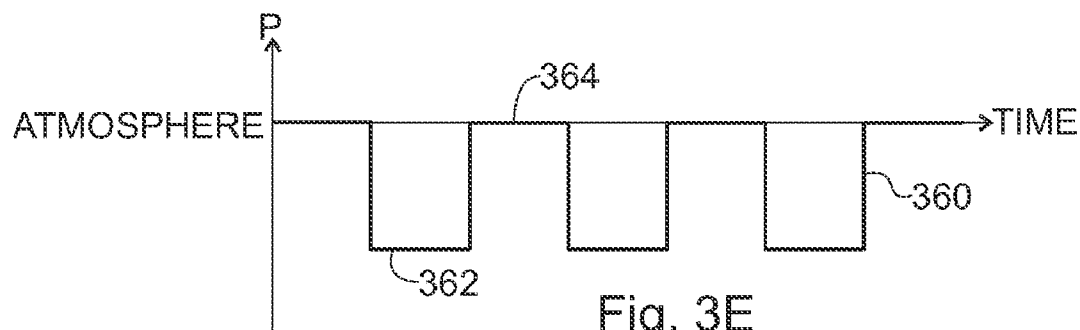


Fig. 3E

APPARATUS AND METHOD FOR WOUND TREATMENT EMPLOYING PERIODIC SUB-ATMOSPHERIC PRESSURE

FIELD OF THE INVENTION

[0001] The present invention relates generally to an apparatus and method for treating tissue using time-varying sub-atmospheric pressure, and more particularly, but not exclusively, to an apparatus and method for treating wounds using sinusoidally varying sub-atmospheric pressure.

BACKGROUND OF THE INVENTION

[0002] The field of medicine has long been concerned with healing tissue damage such as that which may be brought on by disease or trauma. Numerous treatment modalities have been introduced over the years, including more recently the development of wound treatment through the use of negative (or sub-atmospheric) pressure, pioneered by Drs. Argenta and Morykwas and set forth in U.S. Pat. Nos. 5,645,081 and 5,636,643, as well as US Published Application Nos. 2003/0225347, 2004/0039391, and 2004/0122434, the contents of which are incorporated herein by reference. Although the application of either continuous or intermittent negative pressure wound therapy as specified in the aforementioned patents demonstrates an increased rate of healing as compared to traditional methods, an enduring goal of medical treatment remains healing of wounded or damaged tissue as quickly as possible. Consequently, there remains a need in the field of medicine for devices and techniques that expedite the healing of injured or wounded tissue.

SUMMARY OF THE INVENTION

[0003] In accordance with the present invention, a tissue treatment apparatus is provided for treating tissue by application of time-varying sub-atmospheric pressure. Tissues that may be treated by the apparatus of the present invention include wounded tissues, such as those present in chronic wounds, acute wounds, open wounds, closed wounds, and so forth, for example. Such wounds may be created by a variety of causes, such as trauma, disease, thermal injury (e.g., burns or hypothermia), surgical complications, and other factors.

[0004] In order to administer sub-atmospheric pressure treatment to damaged or wounded tissue, the apparatus of the present invention includes a cover adapted to cover a wound and adapted to maintain sub-atmospheric pressure at the site of the wound. The cover may be conveniently provided in the form of a flexible sheet or drape capable of conforming to tissue surrounding the wound. Alternatively, the cover may be provided in the form of a rigid or semi-rigid structure capable of supporting itself out of contact with the tissue to be treated. The apparatus also includes a seal configured to seal the cover to tissue surrounding the wound, so that the sealed cover provides an enclosure above the wound in which sub-atmospheric pressure may be maintained. Optionally, the apparatus may include a screen disposed between the cover and the wound for promoting the distribution of sub-atmospheric pressure under the cover and/or stimulating growth of tissue at the wound site. The apparatus further includes a source of suction configured to generate a time-varying sub-atmospheric pressure having a periodic or other variable increasing and/or decreasing waveform comprising a gradual change in pressure. The suction source cooperates with the cover to supply the time-varying sub-atmospheric pressure under the

cover to the wound. The cooperation between the cover and the suction source may be provided in the form of a tube that communicates via a port in the cover to deliver the periodic time-varying sub-atmospheric pressure under the cover.

[0005] In an additional aspect of the present invention, the time-varying sub-atmospheric pressure may desirably vary between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue. Such a variation can provide gross deformation of the wound margin, which may accelerate tissue growth. For example, the time-varying sub-atmospheric pressure may have a minimum value of 25 mm Hg below atmospheric pressure and a maximum value of 100 mm Hg below atmospheric pressure.

[0006] In addition, the present invention provides a method for administering sub-atmospheric pressure to a wound. The method includes covering a wound with a wound cover configured to maintain sub-atmospheric pressure at the site of the wound. The cover is then sealed to tissue surrounding the wound to provide an enclosure for maintaining sub-atmospheric pressure under the cover about the wound. A time-varying sub-atmospheric pressure is then applied under the cover to the wound, where the sub-atmospheric pressure has a periodic or other variable increasing and/or decreasing waveform comprising a gradual change in pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The foregoing summary and the following detailed description of the preferred embodiments of the present invention will be further understood when read in conjunction with the appended drawings, in which:

[0008] FIG. 1 schematically illustrates a top view of an apparatus in accordance with the present invention, showing the apparatus in situ on wound tissue to be treated prior to the application of sub-atmospheric pressure to the apparatus;

[0009] FIG. 2A schematically illustrates a side elevational view of the apparatus of FIG. 1, shown in partial section, taken along the sectioning line 2A-2A of FIG. 1;

[0010] FIG. 2B schematically illustrates the apparatus of FIG. 2A with the wound surface and surrounding tissue drawn inward towards the center of the wound after the application of sub-atmospheric pressure to the wound tissue sufficient to overcome the inherent tissue tension of the wound tissue;

[0011] FIGS. 3A-3D schematically illustrate waveforms of cyclically varying sub-atmospheric pressures of the present invention having a gradual change in pressure, with FIG. 3A showing a sinusoidal waveform, FIG. 3B showing a triangular waveform, FIG. 3C showing a sawtooth waveform, and FIG. 3D showing a digitized sinusoidal waveform; and

[0012] FIG. 3E schematically illustrates intermittent sub-atmospheric pressure having a square waveform.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Referring now to the figures, wherein like elements are numbered alike throughout, a sub-atmospheric treatment apparatus, generally designated **100**, is provided for applying a sub-atmospheric pressure comprising a gradual change in pressure to a tissue to be treated, FIG. 1. As used herein, a "gradual" change in pressure is defined to be a change between two pressure values that is quasi-continuous or continuous, i.e., not instantaneous. In particular, sub-atmospheric pressure waveforms of the present invention compris-

ing a gradual change in pressure desirably have a periodic, or cyclically-varying, waveform. For example, a gradual change in sub-atmospheric pressure in accordance with the present invention may be provided in the form of a sinusoidal waveform **310**, FIG. 3A. Other exemplary waveforms of the present invention having a gradual or continuous change in pressure include a triangular waveform **320** and sawtooth waveform **330**, each of which include a ramp-up **322**, **332** and/or ramp-down **324** in pressure, FIGS. 3B and 3C. (To be continuous, a waveform need not be continuous with respect to its first and/or higher order derivatives, e.g., FIGS. 3B and 3C, though it may be, e.g., FIG. 3A.) In addition, as used herein, the definition of a gradual change in pressure also includes a quasi-continuous waveform, e.g., a digitized form of a waveform having a continuous gradual change in pressure, such as, a digitized sine wave **340**, FIG. 3D. For a digitized waveform to comprise a gradual change in pressure, the digitization must comprise at least two (and preferably more) steps between the minimum and maximum value of the waveform. A gradual change in pressure does not include a pressure waveform that contains only an instantaneous change between the minimum and maximum pressures of the waveform, e.g., does not include a square or rectangular waveform **360**, FIG. 3E. The term “intermittent” pressure as used herein refers to a square or rectangular waveform **360** in which the sub-atmospheric pressure is applied in alternating periods of application **362** and non-application **364**, i.e., “on/off” pressure. Intermittent pressure, by definition, does not include a gradual change in pressure. Sub-atmospheric pressure having a gradual change in pressure, e.g., a sinusoidal waveform **310**, provides an increased rate of healing when compared with either continuous sub-atmospheric pressure or intermittent sub-atmospheric pressure **360**.

[0014] To administer a gradually changing sub-atmospheric pressure **310**, **320**, **330**, **340** to tissue to be treated, such as a wound **40**, the apparatus of the present invention includes a cover **10** for placement over the wound **40** to provide an environment about the wound **40** in which sub-atmospheric pressure may be maintained. An optional screen **20** may be provided under the cover **10** over the wound **40** to assist in the healing of the wound tissue. Sub-atmospheric pressure may be delivered under the cover **10** via a tube **30**, which communicates at one end with the space under the cover **10** and at the other end with a suction source **50**. The suction source **50** generates a sub-atmospheric pressure having a gradual change in pressure, which desirably has a periodic waveform. In this regard, the suction source **50** may comprise a waveform controller **60** for generating a sub-atmospheric pressure waveform.

[0015] Turning now to the figures in more detail, FIG. 1 schematically illustrates a top view of an exemplary configuration of an apparatus **100** in accordance with the present invention applied to a treatment location **90**, and FIG. 2A schematically illustrates a side elevational view in partial cross-section of the apparatus of FIG. 1 taken along the sectioning lines 2A-2A. The apparatus **100** includes a cover **10** sealed over tissue to be treated, such as a wound **40**. A suitable cover **10** is one which is appropriate for medical application and capable of maintaining a sub-atmospheric pressure about the wound **40** under the cover **10**. The cover **10** may be conveniently provided in the form of a self-adhesive (or non-adhesive) cover **10**, such as a flexible polymer sheet or surgical drape, for example. Exemplary self-adhesive drapes include Ioban® drape (3M Corporation, St. Paul, Minn.),

OpSite® drape (Smith & Nephew, Largo, Fla.), and so forth. Providing the cover **10** in the form of a flexible sheet or surgical drape may be particularly desirable for use in applications where the cover **10** should conform to the treatment site **90**. Further, the use of a flexible sheet or drape may be particularly desirable in weight dependent locations. In addition, providing a self-adhesive cover **10** may simplify the application of the cover **10** to the tissue surrounding the wound **40** and may conveniently permit the cover **10** to be attached to and/or immobilize other components of the apparatus **100** which the cover adhesive contacts, such as suction tube **30** or optional screen **20**. Alternatively, the cover **10** may be provided as a self-supporting rigid or semi-rigid material, which may be particularly desirable for configurations of the apparatus **100** which do not include optional screen **20** so that the cover **10** does not come in contact with the wound surface **46**.

[0016] To provide an enclosure under the cover **10** in which sub-atmospheric pressure may be maintained, the cover **10** may be sealed to tissue surrounding the wound using an adhesive. For example, if a self-adhesive flexible sheet or surgical drape is used as the cover **10**, the adhesive backing may be secured to the tissue surrounding the wound **40** to provide a seal about the wound **40**. Instead, if a non-adhesive cover **10** is used, a separately applied adhesive or other suitable material may be used to secure the cover **10** to the treatment site **90** to provide an enclosure about the wound **40** in which sub-atmospheric pressure may be maintained. Still further, for a rigid or semi rigid cover **10**, the seal may be provided by cooperation between an edge of the cover contacting the treatment site **90** and the action of sub-atmospheric pressure under the cover **10** to create sealing contact between the cover edge and the treatment site **90**.

[0017] An optional screen **20** may be provided between the cover **10** and the wound surface **46** to provide various functions, such as preventing the cover **10** from contact in the wound surface **46**, promoting even distribution of sub-atmospheric pressure under the cover **10**, assisting in drawing of liquid away from the wound surface **46**, stimulating growth of tissue (e.g., granulation tissue) at the wound surface **46**, and preventing loculation of the wound **40**, for example. In this regard, the screen may comprise a variety of materials such as a synthetic polymer material, open-cell polymer foam, a non-adherent material, a polymer mesh, and combinations thereof, for example. The composition and structural properties, such as reticulation, for example, are selected with regard to the function(s) to be provided by the screen **20**. For instance, the degree of reticulation (or porosity) of the screen **20** may be selected to deter growth of tissue within the screen **20**. Conversely, the degree of reticulation of the screen **20** may be selected to promote tissue growth therein, which may be particularly desirable if the screen **20** comprises a bio-absorbable material.

[0018] The screen **20** may be provided as a unitary structure or as a composite of separate components assembled upon application to the tissue to be treated. Exemplary materials that may be used for the screen **20**, alone or in combination with other materials, include V.A.C.® GranuFoam® and V.A.C.® WhiteFoam™ dressings (Kinetic Concepts Inc, San Antonio, Tex.), Prolene® Mesh (New Brunswick, N.J.), and the like. Exemplary non-adherent materials that may be used for the screen **20**, alone or in combination with other materials, include Aquaphor® Gauze (Smith & Nephew, Largo, Fla.), Adaptic® Non-Adherent Dressing (New Brunswick,

N.J.), and so forth. In addition, the non-adherent material may be provided as a coating disposed on or throughout the volume of the screen 20, such as an ointment, gel, natural or synthetic polymer, or other suitable materials. For example, the non-adherent material may be provided as part of the foam screen 20, either as a one-piece screen 20, with a non-adherent material integral to the screen 20, or as a two-piece screen 20, with the screen and a non-adherent material as separate pieces. Further, for the rigid or semi rigid cover 10 it may be desirable to draw the screen 20 taut across the opening of the cover 10 above the wound 40 and to optionally attach the screen 20 to the cover 10 to provide a barrier that impedes the growth of tissue into the cavity of the cover 10.

[0019] The screen 20 is desirably cut and shaped to fit into and fill the wound 40. As the wound 40 heals and becomes smaller in size, the size of the screen 20 may be decreased accordingly. The screen 20 may be held in place by contacting an adhesive coated under surface 12 of the cover 10 to assist in securing the screen 20 in a fixed position and to assist in the removal of the screen 20 when the cover 10 is removed. One particularly convenient configuration of cover 10 and screen 20 is the combination of a flexible self-adhesive polymer sheet or drape used in conjunction with an open-cell polymer foam.

[0020] Delivery of sub-atmospheric pressure to wound 40 may be provided via a tube 30, or other suitable structure, that gaseously communicates with the enclosure under the cover 10 via a port 36. The port 36 may comprise an edge of the cover 10 under which the tube 30 passes, such as a mesentery, for example, to communicate with the space under the cover 10. Alternatively, the port 36 may be provided as an opening, or a nipple, disposed at the surface of the cover 10, or other suitable structure. The distal end of the tube 32 disposed under the cover 10 may be located above or below the optional screen 20 or may be embedded within the screen 20. In addition to having an opening at the distal end 32, the tube 30 may be fenestrated along the portion of the tube 30 in communication with the enclosure under the cover 10 to deliver sub-atmospheric pressure along the fenestrated portion of the tube 30. For example, the tube 30 may comprise a Jackson-Pratt drain.

[0021] Sub-atmospheric pressure is provided to the wound 40 by a suction source 50 via the tube 30, which is in gaseous communication with the suction source 50 at the tube's proximal end 34. The suction source 50, which may comprise a vacuum pump, includes a waveform controller 60 for controlling the time-varying properties of the pressure waveform created by the suction source 50, so that the suction source 50 produces a time-varying sub-atmospheric pressure having a gradual change in pressure (a gradually changing sub-atmospheric pressure). Sub-atmospheric pressure having a gradual change in pressure is desirably provided in the form of a periodic, or cyclically-varying, waveform that is continuous over at least a portion of the period, T, of the waveform. For example, the gradually varying sub-atmospheric pressure may take the form of a sinusoidal waveform 310, a triangular waveform 320, a sawtooth waveform 330, or a digitized waveform, such as a digitized sinusoid 340, as illustrated in FIGS. 3A-3D, respectively.

[0022] In particular applications, it may be desirable that the maximum sub-atmospheric pressure, P2, and minimum sub-atmospheric pressure, P1, be selected to induce gross tissue deformation (e.g., radial inward and outward movement 44, 45 of the wound margin 42 as illustrated in FIG. 1).

The minimum sub-atmospheric pressure P1 is defined to be the pressure closest to atmospheric pressure, and the maximum sub-atmospheric pressure P2 is defined to be the pressure furthest from atmospheric pressure (i.e., stronger suction or vacuum). As the sub-atmospheric pressure varies between its maximum and minimum values P2, P1 the wound margin 42 may contract and relax, respectively. Such gross contraction and relaxation may lead to an increased rate of tissue formation as compared to application of sub-atmospheric pressure that does not provide gross deformation and relaxation. For example, gross deformation of the wound tissue may not occur if the maximum sub-atmospheric pressure P2 is large enough to cause wound margin contraction. Similarly, gross relaxation of the wound tissue may not occur if the minimum sub-atmospheric pressure P1 is not sufficiently low to permit the wound margin 42 to relax.

[0023] One such choice of minimum and maximum sub-atmospheric pressures P1, P2 for inducing gross tissue deformation are pressures that span the inherent tissue tension of the tissue or wound 40 to be treated. (Tissues have an inherent tension—if an incision is made the wound gapes open. Inherent tissue tension may be observed by the deformation of a circular defect into an elliptical shape after the tissue is removed. A mapping of these lines in humans is often referred to as 'Langer Lines'.) If the maximum sub-atmospheric pressure P2 is sufficiently large, the maximum sub-atmospheric pressure P2 can provide a radial inwardly directed force that creates radially inward movement 44 of the wound margin 42. When such radially inward movement 44 is achieved, the value of the sub-atmospheric pressure is above the inherent tissue of the wound tissue. After the wound margin 42 has contracted inwardly due to the application of sub-atmospheric pressure, the wound margin 42 can relax and approach its original rest position if the minimum sub-atmospheric pressure P1 is sufficiently small (close to atmospheric pressure). In such a case, the time-varying sub-atmospheric pressure is said to vary between a first (minimum) pressure value P1 below the inherent tissue tension of the wound tissue and a second (maximum) pressure value P2 above the inherent tissue tension of the wound tissue. Thus, the cyclic variation in the sub-atmospheric pressure can create an accompanying cyclic radial inward and outward movement 44, 45 of the wound margin 42.

[0024] In addition to an apparatus as described above, the present invention provides a method for administering sub-atmospheric pressure to a wound 40. The method includes covering a wound 40 with a wound cover 10 configured to maintain sub-atmospheric pressure at the site of the wound 40, and sealing the cover 10 to tissue surrounding the wound 40 to provide an enclosure for maintaining sub-atmospheric pressure under the cover 10 about the wound 40. The method continues with the application of time-varying sub-atmospheric pressure under the cover 10 to the wound 40, where the sub-atmospheric pressure has a periodic waveform comprising a gradual change in pressure. The gradual change in pressure may extend over a portion of the period of the periodic waveform, or may extend over the full period of the periodic waveform. In addition, the time-varying sub-atmospheric pressure may vary between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue.

EXAMPLE 1

[0025] A pilot study was performed on two pigs to compare the effects of sine wave application of sub-atmospheric pres-

sure to continuous sub-atmospheric pressure, intermittent sub-atmospheric pressure, and wet-to-moist gauze dressings. The pigs were procured and allowed to acclimate to the new housing conditions for one week. The animals were transported to the operating room and the backs of the animals shaved and prepped for surgery. On the first animal four full thickness wounds, 5 cm in diameter and extending to the fascia covering the spine and deep back muscles, were created over the spine (midline). On the second animal, two pairs of wounds were created lateral to the spine, two on each side of the spine. One treatment was applied to each wound: 1) sine wave sub-atmospheric pressure varying from 50 mm Hg below atmospheric pressure to 150 mm Hg below atmospheric pressure; 2) continuous sub-atmospheric pressure at 125 mm Hg below atmospheric pressure; 3) intermittent sub-atmospheric pressure on for 5 minutes at 125 mm Hg below atmospheric pressure and off for 2 minutes (i.e., no sub-atmospheric pressure applied); and 4) wet-to-moist gauze dressings. The volume of the wounds was measured by taking alginate impressions, then submersing the cast impression into a water filled graduated cylinder. The volume of fluid displacement equaled the volume of the defect.

[0026] The first animal was euthanized after seven days as all wounds became infected. The second animal was treated for 10 days. It was noted for the first animal, prior to becoming infected, that the sine wave sub-atmospheric pressure treated wound appeared 'grayish' in color, perhaps due to the sub-atmospheric pressure level being too high (i.e., too far below atmospheric pressure). The sine wave sub-atmospheric pressure treated wounds produced new granulation tissue faster than the continuously treated wounds, but less rapidly than the intermittent sub-atmospheric pressure treated wounds. All three sub-atmospheric pressure applications caused formation of granulation tissue faster than wet-to-moist gauze dressing changes. It was also noted during the study that the wound edges of the intermittent sub-atmospheric pressure treated wounds grossly moved with each cycle of sub-atmospheric pressure application and cessation. The edges of the sine wave and continuous sub-atmospheric pressure treated wounds grossly moved only on initial application of the sub-atmospheric pressure. It was determined that the amplitude of the sine wave, even at the low end (i.e., end closest to atmospheric pressure, was too great (greater than the inherent tissue tension). It was concluded from this pilot study that a further study needed to be undertaken in which the level of sub-atmospheric pressure of the sine wave application should oscillate above and below the inherent tissue tension of full thickness pig skin.

[0027] In preparation for the second study, a test was conducted to determine the correlation between vacuum level and force. A 10 ml syringe was fixed vertically with the tip up and the plunger down. A tube was connected to the tip of the syringe, with the other end of the tube connected to a vacuum pump. The plunger was withdrawn. A predetermined sub-atmospheric pressure level was applied, which resulted in the

TABLE 1-continued

Animal	Pressure Type	Initial Wound Volume (cc)	Final Wound Volume (cc)	Days from initial to final	Fill Rate (cc/day)
2	None (gauze)	9	4	10	0.5
	Continuous	8.5	2	10	0.65
	Intermittent	11	2	10	0.9
	Sine-wave	9	2	10	0.7

plunger being drawn into the barrel of the syringe. Weights were applied to the plunger until the plunger stopped moving. (Increased weight would have drawn the plunger back out of the barrel of the syringe.) A linear response was determined for sub-atmospheric pressure versus applied force ($F=ma$). The static friction of the system was measured by having the plunger fully inserted into the barrel of the syringe, then applying weights until the plunger started to move down. The static friction was subtracted from the measurements to determine the relationship between sub-atmospheric pressure and force. The resulting relationship between force in Newtons, F , and sub-atmospheric pressure in mm Hg, P , was found to be $F=0.0214 P-0.1372$. According to an article by Ksander, et al. (Plastic and Reconstructive Surgery, 59(3): 398-406, 1977), wounds created on the back (dorsal surface) of young swine require approximately 50 grams of force to grossly displace the edges of the wound (Ksander, FIG. 1). Thus, we concluded that 30 mm Hg below atmospheric pressure would create a force equal to 50 grams, which should be the level above and below which sub-atmospheric pressure should oscillate to cause gross tissue (and hence cellular) deformation.

EXAMPLE 2

[0028] Six 25 kg white feeder swine were used as the animal models in this study. Each pig was acclimated to the environment for a full week before the study began. At the outset, each animal was sedated via intramuscular injection of a 10 ml ketamine, 2 ml acepromazine and 1 ml xylazine cocktail. Once sedated, the pig was transferred to the animal surgery suite, shaved, prepped for surgery and anesthetized with halothane and oxygen. Under sterile conditions two 5 cm diameter, circular, full-thickness wounds were created, 5 cm apart, on the animal's dorsal midline, extending down to the deep postural back muscles. A GranuFoam® sponge (Kinetic Concepts Inc, San Antonio, Tex.) was then cut into two circles of 5 cm diameter to fit the two wounds. Evacuation tubes were connected to each sponge and the whole area was draped with an Ioban® drape (3M Corporation, St. Paul, Minn.). A heavy plastic harness was then placed over the dressing, and two stockinette t-shirts were positioned over the harness, to stabilize dressings and tubing. The pig was then returned to its housing and one evacuation tube was connected to a V.A.C.® pump delivering 5 minute on/2 minute off intermittent square wave application of 100 mm Hg below atmospheric pressure and the other evacuation tube was connected to a vacuum pump delivering a sine wave application varying between 25 and 100 mm Hg below atmospheric pressure with a 60 second periodicity. The subjects were staggered such that if the square wave was applied to the front wound and sine wave applied to the back wound, then the next subject would have opposite application, to control for the influence of the wound's anatomic position on wound healing.

TABLE 1

Animal	Pressure Type	Initial Wound Volume (cc)	Final Wound Volume (cc)	Days from initial to final	Fill Rate (cc/day)
1	None (gauze)	12	8	7	0.57
	Continuous	14	9	7	0.71
	Intermittent	18	7	7	1.57
	Sine-wave	27	19	7	1.14

[0029] Daily dressing changes and volume measurements were made by making impressions of the wounds using Jeltrate® Alginate (DENTSPLY International, York, Pa.) impression material. The volume was measured by water displacement in a 100 ml graduated cylinder.

[0030] Data from six 25 kg white feeder swine demonstrate a 19% increase in the rate of granulation tissue formation in the sine wave sub-atmospheric pressure (mean rate 1.354 cc/day) when compared with square wave intermittent sub-atmospheric pressure (mean rate 1.141 cc/day) ($p=0.12$). If this data were extrapolated and compared with prior studies, then sine wave sub-atmospheric pressure demonstrates roughly 122% acceleration in granulation tissue formation when compared with standard moist gauze application to the wound bed. In addition to providing for an increased rate of healing as compared to intermittent sub-atmospheric pressure, sine wave sub-atmospheric pressure appears to reduce problems associated with air leaks. Sine wave sub-atmospheric pressure is thought to prevent air leaks, because the sub-atmospheric pressure is applied and removed more gradually. Further, unlike intermittent sub-atmospheric pressure, leaks may be deterred by providing a gradually varying pressure that does not return to atmospheric pressure during the pressure variation cycle.

TABLE 2

Animal	Pressure Type	Initial Wound Volume (cc)	Final Wound Volume (cc)	Days from initial to final	Fill Rate (cc/day)
1	Intermittent	10	0	10	1
	Sine-wave	10	0	10	1
2	Intermittent	12	6	8	0.75
	Sine-wave	12	1	8	1.375
3	Intermittent	10	0	8	1.25
	Sine-wave	11	0	8	1.375
4	Intermittent	17	4	9	1.444
	Sine-wave	13	2	9	1.222
5	Intermittent	13	0	10	1.3
	Sine-wave	16	0	9	1.778
6	Intermittent	10	1.5	8	1.1
	Sine-wave	11	0	8	1.375
Mean	Intermittent				1.141
	Sine-wave				1.354

[0031] These and other advantages of the present invention will be apparent to those skilled in the art from the foregoing specification. Accordingly, it will be recognized by those skilled in the art that changes or modifications may be made to the above-described embodiments without departing from the broad inventive concepts of the invention. It should therefore be understood that this invention is not limited to the particular embodiments described herein, but is intended to include all changes and modifications that are within the scope and spirit of the invention as set forth in the claims.

What is claimed is:

1. An apparatus for administering sub-atmospheric pressure to a wound, comprising:

- (a) a cover adapted to cover a wound and adapted to maintain sub-atmospheric pressure at the site of the wound;
- (b) a seal configured to seal the cover to tissue surrounding the wound; and
- (c) a source of suction configured to generate a time-varying sub-atmospheric pressure having a periodic waveform comprising a gradual change in pressure, the suc-

tion source cooperating with the cover to supply the time-varying sub-atmospheric pressure under the cover to the wound.

2. The apparatus of claim 1, wherein the gradual change in pressure extends over at least a portion of the period of the periodic waveform.

3. The apparatus of claim 1, wherein the pressure changes gradually over the full period of the periodic waveform.

4. The apparatus of claim 1, wherein time-varying sub-atmospheric pressure has a minimum value of 25 mm Hg below atmospheric pressure and a maximum value of 100 mm Hg below atmospheric pressure.

5. The apparatus of claim 1, wherein the time-varying sub-atmospheric pressure varies between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue.

6. The apparatus of claim 1, wherein the source of suction is configured to generate a sinusoidal-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

7. The apparatus of claim 6, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

8. The apparatus of claim 6, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

9. The apparatus of claim 1, wherein the source of suction is configured to generate a triangular-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

10. The apparatus of claim 9, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

11. The apparatus of claim 9, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

12. The apparatus of claim 1, wherein the source of suction is configured to generate a sawtooth-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

13. The apparatus of claim 12, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

14. The apparatus of claim 12, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

15. The apparatus of claim 1, wherein the source of suction comprises a vacuum pump.

16. The apparatus of claim 1, wherein the cover comprises a flexible sheet.

17. The apparatus of claim 16, wherein the seal includes an adhesive on a sheet surface facing the wound to attach and seal the sheet to tissue surrounding the wound.

18. The apparatus of claim 16, comprising a screen for placement at the wound between the cover and the wound.

19. The apparatus of claim 1, comprising a screen for placement at the wound between the cover and the wound.

20. The apparatus of claim 19, wherein the screen comprises open-cell foam.

21. The apparatus of claim 19, wherein the screen comprises a synthetic polymer material.

22. The apparatus of claim 19, wherein the screen comprises a non-adherent material.

23. The apparatus of claim 19, wherein the screen comprises a polymer mesh.

24. The apparatus of claim 23, wherein the screen comprises a synthetic polymer material.

25. The apparatus of claim 24, wherein the screen comprises an ointment.

26. The apparatus of claim 19, wherein the screen is configured to promote the formation of tissue of the type with which the screen is in contact.

27. The apparatus of claim 19, wherein the screen is configured to promote the formation of granulation tissue.

28. The apparatus of claim 19, wherein the screen is configured to promote tissue growth therein.

29. The apparatus of claim 19, wherein the screen is configured to deter tissue growth therein.

30. The apparatus of claim 19, wherein the screen comprises a bio-absorbable material.

31. The apparatus of claim 1, comprising a port at the cover configured to deliver the sub-atmospheric pressure under the cover.

32. The apparatus of claim 31, wherein port comprises a tube in gaseous communication with the source of suction.

33. The apparatus of claim 32, wherein the tube extends under an edge of the cover.

34. An apparatus for administering sub-atmospheric pressure to a wound, comprising:

- (a) a self-adhesive cover adapted to cover and form a seal about a wound to maintain sub-atmospheric pressure at the site of the wound;
- (b) port at the cover configured to deliver the sub-atmospheric pressure under the cover; and
- (c) a source of suction for gaseous communication with the port, the source of suction configured to generate a sinusoidally varying sub-atmospheric pressure under the cover to the wound.

35. The apparatus of claim 34, wherein sinusoidally varying sub-atmospheric pressure has a minimum value of 25 mm Hg below atmospheric pressure and a maximum value of 100 mm Hg below atmospheric pressure.

36. The apparatus of claim 34, wherein the sub-atmospheric pressure varies between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue.

37. The apparatus of claim 34, wherein the source of suction comprises a vacuum pump.

38. The apparatus of claim 34, wherein the cover comprises a flexible sheet.

39. The apparatus of claim 38, comprising a screen for placement at the wound between the cover and the wound.

40. The apparatus of claim 34, comprising a screen for placement at the wound between the cover and the wound.

41. The apparatus of claim 40, wherein the screen comprises open-cell foam.

42. The apparatus of claim 40, wherein the screen comprises a synthetic polymer material.

43. The apparatus of claim 40, wherein the screen comprises a non-adherent material.

44. The apparatus of claim 40, wherein the screen comprises a polymer mesh.

45. The apparatus of claim 44, wherein the screen comprises a synthetic polymer material.

46. The apparatus of claim 45, wherein the screen comprises an ointment.

47. The apparatus of claim 40, wherein the screen is configured to promote the formation of tissue of the type with which the screen is in contact.

48. The apparatus of claim 40, wherein the screen is configured to promote the formation of granulation tissue.

49. The apparatus of claim 40, wherein the screen is configured to promote tissue growth therein.

50. The apparatus of claim 40, wherein the screen is configured to deter tissue growth therein.

51. The apparatus of claim 40, wherein the screen comprises a bio-absorbable material.

52. The apparatus of claim 34, wherein the port comprises a tube in gaseous communication with the source of suction.

53. The apparatus of claim 52, wherein the tube extends under an edge of the cover.

54. An apparatus for administering sub-atmospheric pressure to a wound, comprising:

- (a) a cover adapted to cover a wound to provide an enclosure above the wound in which sub-atmospheric pressure may be maintained;
- (b) a screen configured to overlie the wound under the cover; and
- (c) a vacuum means in gaseous communication with the cover to supply sub-atmospheric pressure within the enclosure, the vacuum means configured to generate a cyclically-varying sub-atmospheric pressure comprising a gradual change in pressure.

55. The apparatus of claim 54, wherein the gradual change in pressure extends over at least a portion of the cycle of the cyclically-varying sub-atmospheric pressure.

56. The apparatus of claim 54, wherein the pressure changes gradually over the full cycle of cyclically-varying the sub-atmospheric pressure.

57. The apparatus of claim 54, wherein the cyclically-varying sub-atmospheric pressure has a minimum value of 25 mm Hg below atmospheric pressure and a maximum value of 100 mm Hg below atmospheric pressure.

58. The apparatus of claim 54, wherein the cyclically-varying sub-atmospheric pressure varies between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue.

59. The apparatus of claim 54, wherein the vacuum means is configured to generate a sinusoidal-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

60. The apparatus of claim 59, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

61. The apparatus of claim 59, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

62. The apparatus of claim 54, wherein the vacuum means is configured to generate a triangular-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

63. The apparatus of claim 62, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

64. The apparatus of claim 62, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

65. The apparatus of claim 54, wherein the vacuum means is configured to generate a sawtooth-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

66. The apparatus of claim 65, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

67. The apparatus of claim 65, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

68. The apparatus of claim 54, wherein the vacuum means comprises a vacuum pump.

69. The apparatus of claim 54, wherein the cover comprises a flexible self-adhesive sheet for sealing to tissue about the wound.

70. The apparatus of claim 54, wherein the screen comprises open-cell foam.

71. The apparatus of claim 54, wherein the screen comprises a synthetic polymer material.

72. The apparatus of claim 54, wherein the screen comprises a non-adherent material.

73. The apparatus of claim 54, wherein the screen comprises a polymer mesh.

74. The apparatus of claim 73, wherein the screen comprises a synthetic polymer material.

75. The apparatus of claim 74, wherein the screen comprises an ointment.

76. The apparatus of claim 54, wherein the screen is configured to promote the formation of tissue of the type with which the screen is in contact.

77. The apparatus of claim 54, wherein the screen is configured to promote the formation of granulation tissue.

78. The apparatus of claim 54, wherein the screen is configured to promote tissue growth therein.

79. The apparatus of claim 54, wherein the screen is configured to deter tissue growth therein.

80. The apparatus of claim 54, wherein the screen comprises a bio-absorbable material.

81. The apparatus of claim 54, comprising a port at the cover configured to deliver the sub-atmospheric pressure under the cover.

82. The apparatus of claim 81, wherein the port comprises a tube in gaseous communication with the vacuum means.

83. The apparatus of claim 82, wherein the tube extends under an edge of the cover.

84. An apparatus for administering sub-atmospheric pressure to a wound, comprising:

(a) a cover adapted to cover a wound to provide an enclosure above the wound in which sub-atmospheric pressure may be maintained;

(b) a port disposed at the cover configured to deliver the sub-atmospheric pressure under the cover; and

(c) a vacuum means in gaseous communication with the port to supply sub-atmospheric pressure within the enclosure, the vacuum means configured to generate a cyclically-varying sub-atmospheric pressure comprising a gradual change in pressure over at least a portion of the cycle, the change ranging from first pressure value below the inherent tissue tension of the wound tissue to a second pressure value above the inherent tissue tension of the wound tissue.

85. The apparatus of claim 84, wherein the pressure changes gradually over the full cycle of cyclically-varying the sub-atmospheric pressure.

86. The apparatus of claim 84, wherein the cyclically-varying sub-atmospheric pressure has a minimum value of 25 mm Hg below atmospheric pressure and a maximum value of 100 mm Hg below atmospheric pressure.

87. The apparatus of claim 84, wherein the vacuum means is configured to generate a sinusoidal-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

88. The apparatus of claim 87, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

89. The apparatus of claim 84, wherein the vacuum means is configured to generate a triangular-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

90. The apparatus of claim 89, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

91. The apparatus of claim 54, wherein the vacuum means is configured to generate a sawtooth-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

92. The apparatus of claim 91, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

93. The apparatus of claim 84, wherein the vacuum means comprises a vacuum pump.

94. The apparatus of claim 84, wherein the cover comprises a flexible self-adhesive sheet for sealing to tissue about the wound.

95. The apparatus of claim 94, comprising a screen for placement at the wound between the cover and the wound.

96. The apparatus of claim 84, comprising a screen for placement at the wound between the cover and the wound.

97. The apparatus of claim 96, wherein the screen comprises open-cell foam.

98. The apparatus of claim 96, wherein the screen comprises a synthetic polymer material.

99. The apparatus of claim 96, wherein the screen comprises a non-adherent material.

100. The apparatus of claim **96**, wherein the screen comprises a polymer mesh.

101. The apparatus of claim **100**, wherein the screen comprises a synthetic polymer material.

102. The apparatus of claim **101**, wherein the screen comprises an ointment.

103. The apparatus of claim **96**, wherein the screen is configured to promote the formation of tissue of the type with which the screen is in contact.

104. The apparatus of claim **96**, wherein the screen is configured to promote the formation of granulation tissue.

105. The apparatus of claim **96**, wherein the screen is configured to promote tissue growth therein.

106. The apparatus of claim **96**, wherein the screen is configured to deter tissue growth therein.

107. The apparatus of claim **96**, wherein the screen comprises a bio-absorbable material.

108. The apparatus of claim **84**, wherein the port comprises a tube in gaseous communication with the vacuum means.

109. The apparatus of claim **108**, wherein the tube extends under an edge of the cover.

110. The apparatus according to any one of claims **3, 5, 19-30, 56, 58, 70-80, 85, or 96-107**, wherein the gradual change in pressure consists of a continuous change in pressure.

111. The apparatus according to any one of claims **3, 5, 19-30, 56, 58, 70-80, 85, or 96-107**, wherein the gradual change in pressure comprises a digitized waveform.

112. A method for administering sub-atmospheric pressure to a wound, comprising the steps of:

- (a) covering a wound with a wound cover configured to maintain sub-atmospheric pressure under the cover at the site of the wound;
- (b) sealing the cover to tissue surrounding the wound to provide an enclosure for maintaining sub-atmospheric pressure under the cover about the wound; and
- (c) applying time-varying sub-atmospheric pressure under the cover to the wound, the sub-atmospheric pressure having a periodic waveform comprising a gradual change in pressure.

113. The apparatus of claim **112**, wherein the gradual change in pressure extends over at least a portion of the period of the periodic waveform.

114. The apparatus of claim **112**, wherein the pressure changes gradually over the full period of the periodic waveform.

115. The method of claim **112**, wherein the time-varying sub-atmospheric pressure has a minimum value of 25 mm Hg below atmospheric pressure and a maximum value of 100 mm Hg below atmospheric pressure.

116. The method of claim **112**, wherein the time-varying sub-atmospheric pressure varies between a first pressure value below the inherent tissue tension of the wound tissue and a second pressure value above the inherent tissue tension of the wound tissue.

117. The method of claim **112**, wherein the time-varying sub-atmospheric pressure comprises a sinusoidal-waveform variation in pressure that varies between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

118. The method of claim **117**, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

119. The method of claim **117**, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

120. The method of claim **112**, wherein the time-varying sub-atmospheric pressure comprises a triangular-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

121. The method of claim **120**, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

122. The method of claim **120**, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

123. The method of claim **112**, wherein the time-varying sub-atmospheric pressure comprises a sawtooth-waveform variation in pressure between a first pressure value below atmospheric pressure and a second pressure value below atmospheric pressure.

124. The method of claim **123**, wherein the first pressure value is 25 mm Hg below atmospheric pressure and the second pressure value is 100 mm Hg below atmospheric pressure.

125. The method of claim **123**, wherein the first pressure value is below the inherent tissue tension of the wound tissue and the second pressure value is above the inherent tissue tension of the wound tissue.

126. The method of claim **112**, comprising placing a screen between the cover and the wound.

127. The method of claim **126**, wherein the screen comprises open-cell foam.

128. The apparatus of claim **126**, wherein the screen comprises a synthetic polymer material.

129. The method of claim **126**, wherein the screen comprises a non-adherent material.

130. The apparatus of claim **126**, wherein the screen comprises a polymer mesh.

131. The method of claim **130**, wherein the screen comprises a synthetic polymer material.

132. The method of claim **131**, wherein the screen comprises an ointment.

133. The method of claim **126**, wherein the screen is configured to promote the formation of tissue of the type with which the screen is in contact.

134. The method of claim **126**, wherein the screen is configured to promote the formation of granulation tissue.

135. The method of claim **126**, wherein the screen is configured to promote tissue growth therein.

136. The apparatus of claim **126**, wherein the screen is configured to deter tissue growth therein.

137. The method of claim **126**, wherein the screen comprises a bio-absorbable material.

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