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United States Patent	12383300
Kind Code	B2
Date of Patent	August 12, 2025
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System and method for fluid ingress control for a skin grafting system

Abstract

A skin grafting system having a handheld device, a cartridge, and a device shield. The handheld device includes a device housing forming an interior that secures a drive system. The cartridge includes a plurality of hollow microneedles surrounded by a peripheral housing and is configured to be operated by the drive system to extend and retract past the peripheral housing into a subject to harvest tissue during a skin grafting process. The device shield is formed of a polymer extending from an interior opening to an exterior edge, the interior opening sized to extend about the peripheral housing to position the exterior edge over the device housing to control ingress of fluids into the interior of the device housing from fluid about the peripheral housing of the cartridge during the skin grafting process performed using the skin grafting system.

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Appl. No.: 17/825431

Filed: May 26, 2022

Prior Publication Data

Document Identifier	Publication Date
US 20220280180 A1	Sep. 08, 2022

Related U.S. Application Data

continuation parent-doc US 16592312 20191003 US 11369409 child-doc US 17825431

Publication Classification

Int. Cl.: A61B17/322 (20060101); A61B17/00 (20060101); A61M37/00 (20060101)

U.S. Cl.:

CPC A61B17/322 (20130101); A61M37/0015 (20130101); A61B2017/00942 (20130101); A61B2017/00969 (20130101); A61B2017/3225 (20130101); A61M2037/003 (20130101); A61M2205/12 (20130101)

Field of Classification Search

CPC: A61B (17/322); A61B (2017/3225); A61M (37/0015); A61M (2037/003); A61M (2037/0061)

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 16/592,312 filed Oct. 3, 2019, the contents of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

(1) The subject matter disclosed herein generally relates to a skin grafting system and, more particularly, to a system that may include a device for harvesting and scattering skin microcolumns.

(2) An autograft can refer to tissue transplanted from one part of an individual's body (e.g., a "donor site") to another part (e.g., a "recipient site"). Autografts can be used, for example, to replace missing skin and other tissue and/or to accelerate healing resulting from trauma, wounds, burns, surgery and birth defects. Availability of tissue for autografting can be limited by characteristics of candidate donor sites, including a number and/or total area of tissue grafts, healing behavior of the donor site, similarity of the donor and recipient sites, aesthetic considerations, and the like.

(3) Skin grafting can be performed surgically. For example, a conventional autograft procedure may include excision or surgical removal of burn injured tissue, choosing a donor site, which may be an area from which healthy skin is removed to be used as cover for the cleaned burned area, and harvesting, where the graft may be removed from the donor site (e.g., using an instrument similar to an electric shaver). Such instrument (e.g., a dermatome) can be structured to gently shave a thin piece of tissue (e.g., about 10/1000 of an inch thick for a split-thickness graft) from the skin at the undamaged donor site to use as a skin graft. The skin graft can then be placed over the cleaned wound to heal. Donor skin tissue can be removed to such a depth that the donor site can heal on its own, in a process similar to that of healing of a second-degree burn.

(4) Traditionally, sheet grafts and meshed grafts are the two types of autografts often used for a permanent wound coverage. A sheet graft can refer to a piece of skin tissue removed from an undamaged donor site of the body, in a process that may be referred to as harvesting. The size of the donor skin piece that is used may be about the same size as the damaged area. The sheet graft can be applied over the excised wound and stapled or otherwise fastened in place. The donor skin tissue used in sheet grafts may not stretch significantly, and a sheet graft can be obtained that is slightly larger than the damaged area to be covered because there may often be a slight shrinkage of the graft tissue after harvesting.

(5) Sheet grafts can provide an improved appearance of the repaired tissue site. For example, sheet grafts may be used on large areas of the face, neck, and hands if they are damaged, so that these more visible parts of the body can appear less scarred after healing. A sheet graft may be used to cover an entire burned or damaged region of skin. Small areas of a sheet graft can be lost after placement because a buildup of fluid (e.g., a hematoma) can occur under the sheet graft following placement of the sheet graft.

(6) A meshed skin graft can be used to cover larger areas of open wounds that may be difficult to cover using sheet grafts. Meshing of a skin graft can facilitate skin tissue from a donor site to be expanded to cover a larger area. It also can facilitate draining of blood and body fluids from under the skin grafts when they are placed on a wound, which may help prevent graft loss. The expansion ratio (e.g., a ratio of the unstretched graft area to the stretched graft area) of a meshed graft may typically be between about 1:1 to 1:4. For example, donor skin can be meshed at a ratio of about 1:1 or 1:2 ratio, whereas larger expansion ratios may lead to a more fragile graft, scarring of the meshed graft as it heals, and/or extended healing times.

(7) A conventional graft meshing procedure can include running the donor skin tissue through a machine that cuts slits through the tissue, which can facilitate the expansion in a pattern similar to that of fish netting or a chain-link fence. Healing can occur as the spaces between the mesh of the stretched graft, which may be referred to as gaps or interstices, fill in with new epithelial skin growth. However, meshed grafts may be less durable graft than sheet grafts, and a large mesh can lead to permanent scarring after the graft heals.

(8) As an alternative to autografting, skin tissue obtained from recently deceased people (which may be referred to, e.g. as a homograft, an allograft, or cadaver skin) can be used as a temporary cover for a wound area that has been cleaned. Unmeshed cadaver skin can be put over the excised wound and stapled in place. Post-operatively, the cadaver skin may be covered with a dressing. Wound coverage using cadaveric allograft can then be removed prior to permanent autografting.

(9) A xenograft or heterograft can refer to skin taken from one of a variety of animals, for example,

a pig. Heterograft skin tissue can also be used for temporary coverage of an excised wound prior to placement of a more permanent autograft and may be used because of a limited availability and/or high expense of human skin tissue. In some cases religious, financial, or cultural objections to the use of human cadaver skin may also be factors leading to use of a heterograft. Wound coverage using a xenograft or an allograft is generally a temporary procedure which may be used until harvesting and placement of an autograft is feasible.

(10) Harvesting of the graft tissue from the donor site can generally generate undesirable large-scale tissue damage to the donor site. On the other hand, small areas of skin wounding adjacent to healthy tissue can be well-tolerated and may heal quickly. Such healing of small wounds can occur in techniques such as “fractional photothermolysis” or “fractional resurfacing,” in which patterns of damage having a small dimension can be created in skin tissue. These exemplary techniques are described, for example, in U.S. Pat. No. 6,997,923. Small-scale damage patterns can heal quickly by regrowth of healthy tissue and can further provide desirable effects such as skin tightening without visible scarring.

(11) The mechanism of tissue grafting presents the opportunity for grafting tools to be exposed to clinical “soil” (e.g., blood, tissue, hair, etc.) from the patient. In split-thickness and full-thickness skin grafting (both of which harvest tissue that extends below the epidermis), localized damage to capillaries and/or blood vessels often leads to bleeding. The degree of bleeding can be influenced by patient factors, such as, for example, anticoagulant medications.

(12) Therefore, it would be advantageous to have further systems and methods to shield reusable clinical tools from clinical soil, without sacrificing functionality of the skin harvesting process.

BRIEF DESCRIPTION OF THE DISCLOSURE

(13) In one aspect, the present disclosure provides a skin grafting system having a handheld device, a cartridge, and a disposable device shield. The handheld device includes a device housing forming an interior that secures a drive system. The cartridge includes a plurality of hollow microneedles surrounded by a peripheral housing and is configured to be operated by the drive system to extend and retract past the peripheral housing into a subject to harvest tissue during a skin grafting process. The device shield is formed of a polymer extending from an interior opening to an exterior edge, the interior opening sized to extend about the peripheral housing to position the exterior edge over the device housing to inhibit ingress of fluids into the interior of the device housing from fluid about the peripheral housing of the cartridge during the skin grafting process performed using the skin grafting system.

(14) In another aspect, the present disclosure provides a skin grafting system having a handheld device, a cartridge, and a device shield. The handheld device includes a device housing having an engagement slot formed therein and creating an interior that secures a drive system. The cartridge is removably engaged with the handheld device through the engagement slot and includes a plurality of hollow microneedles surrounded by a peripheral housing and configured to be operated by the drive system to extend and retract past the peripheral housing into a subject to harvest tissue during a skin grafting process. The device shield is formed of a flexible membrane extending from an interior opening to an exterior edge, the interior opening sized to extend about and be moved along the peripheral housing to form a barrier over the engagement slot when the exterior edge is arranged to extend over the device housing.

(15) The following description and the accompanying drawings set forth in detail certain illustrative embodiments of the present disclosure. However, these embodiments are indicative of but a few of the various ways in which the principles of the disclosure can be employed. Other embodiments and features will become apparent from the following detailed description of the present disclosure when considered in conjunction with the drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The descriptions hereafter are provided with reference to the accompanying drawings, wherein like reference numerals denote like elements.

(2) FIG. 1 is a top perspective view of a skin grafting system, including a cartridge, in accordance with some implementations of the present disclosure.

(3) FIG. 2A is a front perspective view of the system of FIG. 1.

(4) FIG. 2B is a top view of a user interface that may be included in the system of FIG. 2A, in accordance with some implementations of the present disclosure.

(5) FIG. 3A is a cutaway view of the handheld device of FIG. 2A, in accordance with some implementations of the present disclosure.

(6) FIG. 3B is a cutaway view of a housing corresponding to the handheld device of FIG. 2A, in accordance with some implementations of the present disclosure.

(7) FIG. 4A is a rear perspective view of an internal drive assembly and related elements corresponding to the handheld device of FIG. 2A, in accordance with some implementations of the present disclosure.

(8) FIG. 4B is a right perspective view of a left frame assembly corresponding to the internal assembly of FIG. 4A, in accordance with some implementations of the present disclosure.

(9) FIG. 4C is a right perspective view of a right frame assembly corresponding to the internal assembly of FIG. 4A, in accordance with some implementations of the present disclosure.

(10) FIG. 4D is a rear perspective view of a horizontal component assembly corresponding to the internal assembly of FIG. 4A, in accordance with some implementations of the present disclosure.

(11) FIG. 4E is a rear perspective view of a vertical component assembly corresponding to the internal assembly of FIG. 4A, in accordance with some implementations of the present disclosure.

(12) FIG. 5A is a perspective view of a cartridge assembly including a removable cover, in accordance with some implementations of the present disclosure.

(13) FIG. 5B is a perspective view of a cartridge corresponding to the cartridge of FIG. 5A, in accordance with some implementations of the present disclosure.

(14) FIG. 6A is an example of a microneedle and pin assembly that can harvest tissue, in accordance with some implementations of the present disclosure.

(15) FIG. 6B is a perspective view of a microneedle and pin assembly that can harvest tissue, in accordance with some implementations of the present disclosure.

(16) FIG. 6C is a plan view of a microneedle array, in accordance with some implementations of the present disclosure.

(17) FIG. 7 is a procedural flowchart illustrating a method of harvesting and scattering tissue, in accordance with some implementations of the present disclosure.

(18) FIG. 8 is a front view of a device shield applied to a cartridge, in accordance with some implementations of the present disclosure.

(19) FIG. 9 is a perspective view of the device shield of FIG. 8, as applied to a skin grafting system, in accordance with some implementations of the present disclosure.

(20) FIG. 10 is a cross-sectional view of the device shield of FIG. 8, as applied to a skin grafting system, in accordance with some implementations of the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

(21) The following discussion is presented to enable a person skilled in the art to make and use the systems and methods of the present disclosure. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the high-level principles herein can be applied to other embodiments and applications without departing from embodiments of the present disclosure. Thus, embodiments of the present disclosure are not intended to be limited to embodiments shown but are to be accorded the widest scope consistent with the principles and features disclosed herein.

(22) The detailed description is to be read with reference to the figures. The figures depict selected embodiments and are not intended to limit the scope of embodiments of the present disclosure. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of embodiments of the present disclosure. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of “including,” “comprising,” or “having” and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

(23) Unless specified or limited otherwise, the terms “mounted,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, “connected” and “coupled” are not restricted to physical or mechanical connections or couplings. As used herein, unless expressly stated otherwise, “connected” means that one element/feature is directly or indirectly connected to another element/feature, and not necessarily electrically or mechanically. Likewise, unless expressly stated otherwise, “coupled” means that one element/feature is directly or indirectly coupled to another element/feature, and not necessarily electrically or mechanically.

(24) Embodiments of the present disclosure may be described herein in terms of functional and/or logical block components and various processing steps. It should be appreciated that such block components may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. For example, an embodiment may employ various integrated circuit components, e.g., digital signal processing elements, logic elements, diodes, etc., which may carry out a variety of functions under the control of one or more processors or other control devices. Other embodiments may employ program code, or code in combination with other circuit components.

(25) As described above, the present disclosure generally relates to a skin grafting system and, more particularly, to a system that may include a device for harvesting and scattering skin microcolumns. In some situations, the process of harvesting the skin microcolumns can include penetrating donor site tissue. Although generally minimal, harvesting the microcolumns often causes localized bleeding. Blood quantity from the donor site can depend on a variety of factors, such as, for example, number of tissue punctures/penetrations, number of harvesting processes conducted on a single tissue area, number of harvesting processes conducted with a single cartridge (as described below), patient blood pressure, platelet count, medication, donor site treatments, and/or comorbidities. In some situations, it may be advantageous to prevent blood contact and/or ingress into portions of the skin grafting system. In particular, it may be advantageous to prevent blood ingress to reusable elements of the skin grafting system.

(26) As an example, healthcare facilities often have standard cleaning, disinfecting, and/or sterilization procedures that must be performed when an instrument is reusable between patients. Specifically, to minimize the risk of spread of infection, all blood and body substances should be treated as potentially infectious. With complex instruments, blood ingress into an instrument housing can result in procedure delays, lengthy sterilization processes, and/or instrument replacement (and associated cost), among other things. Accordingly, the present disclosure includes systems for preventing blood ingress into a handheld device (e.g., a reusable handheld device) corresponding to a skin grafting system.

(27) Referring now to FIG. 1, a skin grafting system **3000** is shown, in accordance with some implementations of the present disclosure. In some configurations, the skin grafting system **3000** can be configured to harvest and scatter donor tissue. As shown, the skin grafting system **3000** can include a handheld device **1000** (which can be reusable) and a cartridge assembly **2000**. As will be described in greater detail below, the cartridge assembly **2000** can include a cartridge **2002** and a cartridge cover **2004**. The cartridge **2002** can include a microneedle and pin array **2006**, according to some configurations. Notably, the cartridge **2002** can include a simplified microneedle array

2006 (i.e., without pins).

(28) As shown by FIGS. **1-2B**, the handheld device **1000** can include an engagement slot **1002** configured to receive the cartridge assembly **2000**. A loading door **1004** can move between an “open” position (see, e.g., FIG. **1**) and a “closed” position (see, e.g., FIGS. **2A-2B**). In some configurations, the loading door **1004** can be hinged and further configured to open and close over a loading aperture **1006**. The handheld device **1000** can include a door sensor, which can determine the position of the loading door **1004**. The loading aperture **1006** can be sized such that the cartridge assembly **2000** can slide in and out of the engagement slot **1002**, as desired by the user. Advantageously, the cartridge assembly **2000** can be single-use and/or disposable (including, for example, multiple uses for a single patient), while the handheld device **1000** can be designed to be multi-use. As shown by FIG. **2A**, the handheld device **1000** can further include a trigger **1014**. The trigger **1014** can be configured to activate a harvesting process and/or a scattering process in response to selection via a user interface **1008** and/or trigger inputs by a user. In some configurations, the handheld device **1000** can include an indicator light **1016**. The indicator light **1016** can be positioned such that a user can readily view the indicator light **1016** during harvesting and/or scattering.

(29) In some configurations, the handheld device **1000** can include a user interface **1008**. As shown, the user interface **1008** can include a stand-by input **1018**, an indicator light **1020**, and/or a scatter input **1022**. In some configurations, the indicator light **1020** can operate the same as, or similar to, the indicator light **1016** (as described above). The stand-by input **1018**, the indicator lights **1016**, **1020**, and the scatter input **1022** can provide visual feedback to a user that correspond to current operation of the skin grafting system **3000** as the skin grafting system **3000** is utilized according to a skin grafting process, such as will be described.

(30) Referring now to FIGS. **3A-3B**, cutaway views of the handheld device **1000** are shown, according to configurations of the present disclosure. The handheld device **1000** is shown to include various internal controllers. In some configurations, the handheld device **1000** can include a power module **1028**, a solenoid controller **1030**, and/or a main controller **1032**. The power module **1028** can be in electrical communication with a power input **1038**. In some configurations, a drive system can include a solenoid in communication with the solenoid controller **1030**.

(31) Still referring to FIGS. **3A-3B**, in some configurations, the handheld device **1000** can include a housing **1036**. The housing **1036** can include a left enclosure half and a right enclosure half. In some configurations, each of the left enclosure half, the right enclosure half, the loading door **1004** and the enclosure mount cover can be individually injection molded. The left and right enclosure halves can be made up of a hard plastic substrate, and in some configurations, a softer elastomeric over-molded section. Similarly, the loading door **1004** and the enclosure mount cover can be made up of hard plastic substrate. In some configurations, the interior of the housing **1036** can interface with internal subassemblies. As an example, ribs can be affixed to the interior of the housing **1036** and can be configured to support various printed circuit boards

(32) (PCBs). The ribs can separate the PCBs (e.g., power module **1028**, solenoid controller **1030**, and main controller **1032**) from internal moving components. Additionally, in some configurations, the housing **1036** can support the internal subassembly **1034** via pins and vibration damping boots. This can dampen the operational impacts of the internal subassembly **1034** (e.g., from a user, from internal moving components), as well as protect the internal subassembly **1034** from damage due to external impacts (e.g., from dropping the handheld device **1000**).

(33) Referring now to FIGS. **4A-4E**, various internal assemblies corresponding to handheld device **1000** are shown, according to some configurations. FIG. **4A** shows the internal subassembly **1034** that can include a left frame assembly **1040a**, a right frame assembly **1040b**, a horizontal component assembly **1044**, and/or a vertical component assembly **1046**. Each of the left and right frame assemblies **1040a**, **1040b** can include a corresponding flipper assembly (e.g., left flipper assembly **1048a**, right flipper assembly **1048b**). In some configurations, the horizontal component

assembly **1044** can include a horizontal motor **1050**. Further, the vertical component assembly **1046** can include a solenoid **1052**.

(34) Still referring to FIGS. **4A-4E**, and in particular FIGS. **4B-4C**, further exemplary details of the left and right frame assemblies **1040a**, **1040b** are shown, according to some configurations. In some configurations, the left frame assembly **1040a** and the right frame assembly **1040b** can be the same or substantially similar (e.g., symmetrical). As shown, the left frame assembly **1040a** can include a left flipper assembly **1048a** affixed to a first side of a left frame. Additionally, the left frame assembly **1040a** can include flag sensors **1060a**, **1060b**, affixed to a second side of the left frame. The flag sensors **1060a**, **1060b** can communicate with a position sensing linear slide **1054**, and a position sensing flag **1062**. In some configurations, the left frame assembly **1040a** can include position sensing springs **1056a**, **1056b**, which can contact a tissue interface **1058a**. The tissue interface **1058a** can be positioned on a third side of the left frame. In some configurations, the left frame assembly **1040a** can attach to a portion of the vertical component assembly **1046** via screws and alignment pins, or other attachment systems.

(35) In some configurations, the right frame assembly **1040b** can include flag sensors **1060c**, **1060d**, affixed to a first side of a right frame. The flag sensors **1060c**, **1060d** can communicate with a position sensing linear slide **1054**, and a position sensing flag **1062**. Additionally, as shown, the right frame assembly **1040b** can include a right flipper assembly **1048b** affixed to a second side of the right frame. In some configurations, the right frame assembly **1040b** can include position sensing springs **1056c**, **1056d**, which can contact a tissue interface **1058b**. The tissue interface **1058b** can be positioned on a third side of the right frame. In some configurations, the right frame assembly **1040b** can attach to a portion of the vertical component assembly **1046** via screws and alignment pins.

(36) The flipper assemblies **1048a**, **1048b** can include a flipper mounting block **1066**, and a flipper motor **1068**. In some configurations, the flipper mounting block **1066** can be constructed from a dielectric material. The flipper motor **1068** can be connected to (and control) flipper driver pulleys **1070a**, **1070b**. A bearing (e.g., a thrust bearing) **1072** can support an axial load exerted by the needle top plate (e.g., needle top plate **1112** as described below) on a flipper **1074**. The flipper **1074** can rotate in accordance with motor actuation, and the flipper driver pulleys **1070a**, **1070b** can prevent any downward movement of the flipper **1074** during operation of the handheld device **1000**. In some configurations, the flipper **1074** can include two connected components, such as two brass components that are brazed together. The primary function of the flipper **1074** can be to hold a needle top plate **1112** of FIG. **4E** in place when loading needle retract springs. The flipper **1074** can then move out of the way of the needle top plate **1112** during the remainder of normal operation. In some configurations, the flipper mounting block **1066** can act as a guide for solenoid plunger bar **1106** of FIG. **4E** (e.g., to keep proper alignment).

(37) Still referring to FIGS. **4A-4E**, and in particular FIG. **4D**, further exemplary details of the horizontal component assembly **1044** are shown, according to some configurations. The horizontal component assembly can include sensors, actuators, and/or guides for positioning a horizontal carriage assembly **1082** and, thereby, the hammers **1098a**, **1098b** used to drive microneedles into the tissue (as will be described below). In some configurations, a horizontal flag sensor **1064** can be used to position the horizontal component assembly **1082**. As shown, the horizontal component assembly **1044** can include the horizontal carriage assembly **1082** that can be configured to mount the horizontal motor **1050**. In some configurations, a horizontal chassis **1084** can support the horizontal carriage assembly **1082**. Additionally, the right frame assembly **1040b** and the left frame assembly **1040a** can be affixed to opposing sides of the horizontal chassis **1084**, for example, using rivets. An earth-ground connection **1080** can be attached to the horizontal chassis **1084**, according to some configurations.

(38) In some configurations, the horizontal component assembly **1044** can further include a retractable slide door **1090**. The slide door **1090** can extend across the loading aperture **1006** when

the cartridge **2002** has not been inserted into the engagement slot **1002**. Accordingly, a user can be prevented from placing anything into the handheld device **1000** during the absence of the cartridge **2002**. The sliding door **1090** can be secured to a sliding door mount **1086**, which can be affixed to the horizontal chassis **1084**. Additionally, a sliding door spring **1088** can be secured to the sliding door mount **1086** and biased such that the slide door **1090** remains in a “closed” position (i.e., extended across the loading aperture **1006**) when a cartridge is not loaded.

(39) As shown, the horizontal carriage assembly **1082** can include hammers **1098a**, **1098b**, corresponding hammer return springs **1092a**, **1092b**, and corresponding hammer guides **1094a**, **1094b**, according to some configurations. Generally, the horizontal carriage assembly **1082** can be configured to position and guide the hammers **1098a**, **1098b** to drive the microneedles into the tissue. In some configurations, the hammer guides **1094a**, **1094b** can be made of bronze, which can help to maintain bearing surfaces throughout many harvesting and scattering cycles. Additionally, in some configurations, the hammers **1098a**, **1098b** can be hardened 17-4 stainless steel, which can provide superior wear characteristics while maintaining anti-corrosion properties. Alternatively, the hammers **1098a**, **1098b** can be a different bearing material. The horizontal carriage assembly **1082** can further include a horizontal leadscrew drive nut **1096**. Additionally, the horizontal leadscrew assembly **1096** can be a Teflon-coated lead screw, and an Acetal drive nut designed to reduce friction. Alternatively, the horizontal leadscrew assembly **1096** can include other material types. The horizontal leadscrew assembly **1096** can provide a pitch adequate for positional resolution and linear force. The horizontal carriage assembly **1082** can additionally use motor stalling to sense whether or not a cartridge is loaded, or if there is a device jam.

(40) Still referring to FIGS. **4A-4E**, and in particular FIG. **4E**, further exemplary details of the vertical component assembly **1046** are shown, according to some configurations. As shown, the vertical component assembly **1046** can include the solenoid **1052** and corresponding solenoid plunger bar **1106**. Additionally, the vertical component assembly **1046** can include a vertical motor **1100**, and associated unlock cams **1102a**, **1102b** and vertical leadscrews **1104a**, **1104b**. In some configurations, the vertical position of the vertical carriage subassembly **1108** can be controlled by traveling up and down on the vertical leadscrews **1104a**, **1104b** (e.g., using the vertical motor **1100**). As will be described, vertical positioning can move each of the microneedles corresponding to the cartridge **2002**. In general, the vertical component assembly **1046** can be configured to interface with and manipulate the cartridge **2002** and its associated components during harvesting and/or scattering of tissue. In some configurations, the vertical motor **1100** can be sized to fit within the vertical component assembly **1046** while still providing the torque and speeds necessary for manipulating the microneedle positions.

(41) In some configurations, the solenoid **1052** can deliver an operating force to the hammers **1098a**, **1098b** during harvesting. The solenoid **1052** can be activated by a half wave of AC current, as one non-limiting example. The force delivered by the solenoid **1052** can increase sharply, towards the end of its stroke. In some configurations, the mass of the solenoid plunger bar **1106** and the solenoid plunger can be selected based on the energy needed to drive the microneedles into the tissue. In some configurations, a stop (e.g., a brass stop) can be integrated into the solenoid **1052**, which can enable extension control of the solenoid plunger bar **1106** and absorption of remaining kinetic energy at the end of the stroke.

(42) In some configurations, the vertical component assembly **1046** can include a vertical carriage assembly **1108**. As shown, the vertical carriage assembly **1108** can include a needle retract slide **1110** with a top plate **1112**. In some configurations, opposite ends of the vertical carriage assembly **1108** can include needle retract slide-latches **1116a**, **1116b** with corresponding latch plates **1122a**, **1122b**. The latch plates **1122a**, **1122b** can define a maximum position of the needle retract slide **1110**. Additionally, needle retract springs **1120** can be integrated into the vertical carriage assembly **1108**, such that efficient retraction of the microneedles can be achieved over the pins. The needle retract slide-latches **1116a**, **1116b** can be used to lock down the needle retract slide **1110** in

preparation for harvesting. The vertical carriage assembly **1108** can also move both the needles and pins (e.g., pins within the microneedles) at the same time.

(43) In some configurations, the vertical carriage assembly **1108** can include a cartridge latch **1114**, which can be configured to secure the cartridge **2002** upon insertion into the loading aperture **1006**. Additionally, a vertical flag **1118** can be affixed to the exterior of the vertical carriage assembly **1108**, according to some configurations. As shown, the needle retract slide **1110** can further include guideposts **1124a**, **1124b**, which can be configured to guide the needle retract slide **1110** during vertical movement. In some configurations, the needle retract slide **1110** can include lockdown latches **1126**, which can be in contact with the guideposts **1124a**, **1124b**, and configured to engage and disengage the microneedles during operating of the handheld device **1000**. The needle retract slide **1110** can be a spring-loaded subassembly that serves at least two purposes. First, the slide **1110** can lock needle modules down (after being driven into the tissue). Second, the slide **1110** can retract the needles. In some configurations, the needle retract slide **1110** is only capable of retracting the needles and cannot move the needles forward. Additionally, in some configurations, the lockdown latches **1126** may be only functional after the skin grafting system **3000** has gone through initialization. Further detail regarding the operation of the skin grafting system **3000** is provided below.

(44) Referring now to FIGS. 5A-5B, the cartridge **2002** and a cartridge assembly **2000** are shown, according to some configurations. As shown, the cartridge assembly **2000** can include the cartridge **2002**, and a cartridge cover **2004** that can be removably affixed to a microneedle chamber **2018**. The microneedle chamber **2018** can enclose a plurality of microneedles **2006**. In some configurations, the microneedles **2006** can be arranged as an array within the microneedle chamber **2018**. As shown by FIG. 5A, the combination of the cartridge cover **2004** and the microneedle chamber **2018** can form an enclosure for the microneedles **2006**. The cartridge cover **2004** can include release levers **2016a**, **2016b**, which can be simultaneously depressed by a user to remove the cartridge cover **2004** from the cartridge **2002**.

(45) In some configurations, the cartridge **2002** can include a tissue stabilizer **2014**, which forms a peripheral housing and can be configured to stabilize tissue during harvesting. That is, the tissue stabilizer **2014** forms a peripheral housing that is wider than the microneedle chamber **2018**, allowing for a greater distribution of force during use of the skin grafting system **3000** on tissue. As shown, the tissue stabilizer **2014** can further include loading tabs **2012a**, **2012b** that extend outwardly. In some configurations, the loading tabs **2012a**, **2012b** can slide into contact with the engagement slot **1002** during loading of the cartridge assembly **2000** into the loading aperture **1006**.

(46) Referring now to FIGS. 6A-6C, a microneedle **2050** and a microneedle array **2006** are shown, according to configurations of the present disclosure. The microneedle **2050** can facilitate harvesting of tissue from a donor site. In some configurations, the microneedle **2050** can include a hollow tube **2054** that can include a plurality of points **2056** at the distal end thereof. In some non-limiting examples, needle systems such as described in U.S. Pat. Nos. 9,060,803; 9,827,006; 9,895,162; and U.S. Patent Application Publication Nos. 2015/0216545; 2016/0015416; 2018/0036029; 2018/0140316 and/or combinations or components thereof may be used.

(47) In some configurations of the present disclosure, the hollow tube **2054** can be provided with two points **2056**, and the points **2056** can be sufficiently angled for penetrating and cutting the biological tissue to remove small micrografts therefrom. Such a hollow tube **2054** can be provided with two points **2056**, and a “narrow heel” portion positioned between the two points **2056**. According to some embodiments, the narrow heel portion can be sharpened, such that a cutting edge corresponding to the hollow tube **2054** is created.

(48) In some configurations, the hollow tube **2054** can be slideably attached to a substrate **2058**, such that the hollow tube **2054** can pass through a hole provided in the substrate **2058**, as shown in FIG. 6A. The position of the hollow tube **2054** relative to the substrate **2058** can be controlled by

translating the hollow tube **2054** relative to the substrate **2058**, e.g., substantially along the longitudinal axis of the hollow tube **2054**. In this manner, the distance that the distal end of the hollow tube **2054** protrudes past the lower surface of the substrate **2058** can be controllably varied. (49) The microneedle **2050** can further include a pin **2052** provided in the central lumen or opening of the hollow tube **2054**. The diameter of the pin **2052** can be substantially the same as the inner diameter of the hollow tube **2054** or slightly smaller, such that the hollow tube **2054** can be translated along an axis corresponding to pin **2052** while the pin **2052** fills or occludes most or all of the inner lumen of the hollow tube **2054**. The pin **2052** can be formed of a low-friction material or coated with a low-friction material such as, e.g., Teflon® or the like, to facilitate motion of the hollow tube **2054** with respect to the pin **2052** and/or inhibit accumulation or sticking of biological material to the pin **2052**. The distal end of the pin **2052** can be substantially flat to facilitate displacement of a tissue micrograft within the hollow tube **2054**, when the hollow tube **2054** is translated relative to the pin **2052**.

(50) The hollow tube **2054** can be translated relative to the pin **2052**, e.g., substantially along the longitudinal axis of the hollow tube **2054**. In this manner, the position of the distal end of the hollow tube **2054** relative to that of the distal end of the pin **2052** can be controllably varied. For example, the location of the distal ends of both the hollow tube **2054** and the pin **2052** relative to that of the lower surface of the substrate **2058** can be controllably and independently selected and varied.

(51) FIG. **6B** shows one configuration of the present disclosure, in which the pin **2052** can be positioned relative to the hollow tube **2054** such that their distal ends are substantially aligned. In another configuration, the pin **2052** can extend slightly beyond the distal end of the hollow tube **2054**, such that sharpened portions of the hollow tube **2054** can be shielded from undesired contact with objects and/or users. Portions of the pin **2052** and/or hollow tube **2054** can optionally be provided with a coating or surface treatment to reduce friction between them and/or between either component or biological tissue.

(52) As described herein, a plurality of microneedles (e.g., microneedle **2050**) can form a microneedle array **2006**. FIG. **6C** shows a top view of an exemplary microneedle array **2006**, according to configurations of the present disclosure. In some configurations, the microneedle array **2006** can be substantially circular. The microneedle array **2006** can be formed by assembling a plurality of rows of needles, either horizontal or vertical rows. This design can be modular, and the configuration can take on any shape or size using various size rows as modules. In some configurations, all of the microneedles can be actuated, e.g., inserted into the tissue, simultaneously. In other configurations, groups or sections can be actuated sequentially. For example, the microneedle array **2006** can be divided into quadrants and each quadrant can be sequentially actuated. Sequentially can refer to actuating each row in a linear order, (e.g., row1, row2, row3), or non-linear (e.g., row1, row10, row3). Or each row of microneedles can be separately and sequentially actuated. Additionally, each single microneedle can be separately and sequentially actuated. In some configurations, one row can be actuated at a time, e.g., **20** rows can be individually actuated in sequence, while in other configurations, two, three, four or more rows can be actuated at a time. An advantage to sequentially actuating segments of the microneedle array **2006** is that insertion of a segment can require less force on the donor site than insertion of the entire microneedle array **2006**. In some configurations, the microneedle array **2006** can be driven using a solenoid (e.g., solenoid **1052**). Multiple actuations using the solenoid can sequence the insertion row by row.

(53) Referring now to FIG. **7**, some non-limiting examples of steps of a process **4000** for harvesting and scattering tissue is shown, according to configurations of the present disclosure. In some configurations, the process **4000** can be implemented using the skin grafting system **3000**, as described above. As shown, the process **4000** includes providing power to the handheld device (process block **4002**). In some configurations, the handheld device can be the same or similar to

handheld device **1000**. The process **4000** is shown to further include loading a cartridge into the handheld device (process block **4004**). In some configurations, the cartridge can be the same or similar to cartridge **2002**, or cartridge assembly **2000**. Further, the process **4000** is shown to include activating a harvest mode (process block **4006**). This activation can be initiated via user interface **1008**, according to some configurations, such as will be described. Alternatively, the activation can be initiated via contact with a donor site. The process **4000** is shown to include applying a skin grafting system (e.g., skin grafting system **3000**) to a donor site (process block **4008**). The donor site can correspond to a healthy area of tissue on a patient. Next, the process **4000** is shown to include initiating a harvesting process (process block **4010**). In some configurations, this initiation can occur via the above-described trigger **1014**. The process **4000** is shown to further include removing the skin grafting system from the donor site (process block **4012**). Next, the process **4000** is shown to include activating a scatter mode (process block **4014**). In some configurations, this activation can occur via user interface **1008**, such as will be described. The process **4000** is shown to further include positioning the skin grafting system above a recipient site (process block **4016**). In some configurations, the recipient site can correspond to a damaged area of tissue on the patient. Next, the process **4000** is shown to include initiating a scatter process (process block **4018**). In some configurations, this initiation can occur via actuation of the above-described trigger **1014**. As shown, the process **4000** can end after the scatter process (process block **4018**) or can return to process block **4006** to reactivate the harvest mode. In some configurations, a single cartridge (e.g., cartridge **2002**) can be used multiple times on the same patient. Advantageously, if the recipient site is relatively large, multiple harvests and scatters can occur using a single cartridge. Accordingly, the process **4000** can continue with process blocks **4006** through **4018** until a user is ready to dispose of the cartridge.

(54) According to configurations of the present disclosure, the harvest process and scatter process can be performed using skin grafting system **3000**. A non-limiting description of the internal functions of the handheld device **1000** and cartridge **2002** are accordingly disclosed herein.

(55) User Interface

(56) Referring to FIG. 2B, as one non-limiting example, an example of using the user interface **1008** to control the above-described process is provided. Upon providing power to the handheld device, the stand-by input **1018** can flash green when the handheld device **1000** first powers on (e.g., for ~8 seconds at initial start-up). This can inform the user that the handheld device **1000** is performing a start-up self-test or other operation. As another non-limiting example, the stand-by input **1018** can produce steady green illumination when the handheld device **1000** is on and ready for subsequent use. In some configurations, pressing the stand-by input **1018** for a pre-determined amount of time (e.g., 3 seconds, 5 seconds, or the like) can cause the handheld device **1000** to enter a stand-by mode. Continuing with the non-limiting example, the stand-by input **1018** can stop producing light when the handheld device **1000** is in stand-by mode. Other light colors, patterns, and timing can be implemented, according to various configurations and preferences.

(57) As another non-limiting example, the indicator light **1020** can produce steady white light when the handheld device **1000** is in harvest mode but sufficient pressure against a donor site has not been achieved, such as will be described during a skin grafting process. Further, the indicator light **1020** can produce steady green light when the handheld device **1000** is in harvest mode and sufficient pressure against the donor site has been achieved (and the trigger **1014** is disengaged). The indicator light **1020** can produce flashing green light when the handheld device **1000** is in the process of harvesting. If pressure drops below a threshold value during the harvesting process, the indicator light **1020** can produce flashing white light. Further, the indicator light **1020** can produce flashing white light when the handheld device **1000** is experiencing a fault condition.

(58) In another non-limiting example, the scatter input **1022** can produce steady white light when the harvest process is complete. In some configurations, a subsequent press of the scatter input **1022** can cause the handheld device **1000** to enter a scatter mode. The scatter input **1022** can

produce steady green light when the handheld device **1000** is in scatter mode. Similar to the indicator light **1020**, the scatter input **1022** can produce flashing white light when the handheld device **1000** is experiencing a fault condition. In some configurations, the scatter input **1022** can produce flashing white light during the harvesting process, which can indicate that extraction recovery is needed. A subsequent press of the scatter input **1022** can activate an extraction recovery process. Once the extraction recovery process is complete, the scatter input **1022** can produce a steady white light. A detailed description of the extraction recovery process is provided below.

(59) In some configurations, similar to the indicator light **1020**, the indicator light **1016** can produce a solid green light when the handheld device **1000** is in the harvest mode and sufficient pressure against the donor site has been achieved (and the trigger **1014** is disengaged). Additionally, the indicator light **1020** can produce flashing green light during the harvesting process, according to some configurations.

(60) Skin Grafting System Operating Positions

(61) In some configurations, a plurality of operating positions corresponding to the skin grafting system **3000** can be defined. Notably, the skin grafting system **3000** can operate using additional operating positions not explicitly defined.

(62) Some configurations of the present disclosure include a horizontal carriage home position, where the horizontal carriage assembly **1082** can be in a position that occludes the horizontal flag sensor **1064**. This position can be a “safe” position that keeps the carriage away from other moving parts.

(63) Some configurations of the present disclosure include a vertical carriage home position, corresponding to a calibrated position where the vertical carriage assembly **1108** can be aligned with the corresponding components for loading or for harvesting. This position can be below the vertical flag sensor occlusion point. From a user's perspective, it can appear that the vertical carriage assembly **1108** is closest to the engagement slot **1002** of the handheld device **1000**.

(64) Some configurations of the present disclosure include a vertical carriage unlock/scatter position corresponding to a calibrated position where the vertical carriage assembly **1108** has unlocked the needle retract slide **1110** by pushing the needle retract slide latches **1116a**, **1116b** over their respective unlock cams **1102a**, **1102b**. This can be the highest position the vertical carriage assembly **1108** will travel to. From a user's perspective, it can appear that the vertical carriage assembly **1108** is up inside the handheld device **1000**.

(65) Some configurations of the present disclosure include a “flipper in” position and a “flipper out” position. Each flipper **1074** can have two defined positions that the handheld device **1000** detects via flag sensors that can provide positive feedback that each position has been reached. The “flipper in,” or retracted, position can correspond to when the flipper **1074** is safely away from moving parts. The “flipper out,” or extended, position can correspond to when the flipper **1074** is blocking the top plate **1112**. The “flipper out” position can be used for initialization when the needle retract slide **1110** (and therefore the cartridge **2002**) is locked.

(66) Some configurations of the present disclosure include a vertical carriage lock position, corresponding to a calibrated position where the vertical carriage assembly **1108** can move to (with the flippers **1074** extended out) to compress the needle retract springs **1120** and to lock the needle retract slide latches **1116**. This “locking” is what can allow the needles to later be retracted, while also locking the cartridge **2002** inside the handheld device **1000**.

(67) Some configurations of the present disclosure include a vertical carriage lock relax position, which can be a position that is offset from a calibrated lock position, where a properly locked needle retract slide top plate **1112** will no longer be putting pressure on the flippers **1074**, and therefore the flippers **1074** can be safe to retract in. Conversely, if the needle retract slide top plate **1112** is not properly locked, this position can be designed to maintain enough pressure on the flippers **1074** so that they will not retract in. This position can enable the handheld device **1000** to positively sense a proper locking of the needle retract slide **1110**.

(68) Some configurations of the present disclosure include a vertical carriage extract position, which can be a position that is offset from a calibrated unlock position, where the needle retract slide **1110** will not be unlocked and the extended needles can be behind the tissue stabilizer **2014**. After harvest, this position is where the vertical carriage assembly **1108** can go to extract the needles (containing the tissue grafts) from the tissue prior to scattering. Advantageously, tissue grafts may not be exposed in this position, as the needles remain extended.

(69) Some configurations of the present disclosure include a harvest recovery mode, which can occur during the harvest process. The harvest recovery mode can include attempting to continue deploying the needle modules into the tissue. Additionally, the harvest recovery mode can be automatic and fully controlled by on-board software (i.e., no user interaction required). In some embodiments, the harvest recovery mode can include reversing the motion of the horizontal carriage assembly **1082** by a predetermined distance or time interval. Subsequently, the horizontal carriage assembly **1082** can advance and again attempt to deploy the needle modules into the tissue.

(70) Some configurations of the present disclosure include an extraction recovery mode, which can occur after the needles have been deployed (and the handheld device **1000** is attempting to return the horizontal carriage to its home position). In some configurations, it may be possible for the horizontal carriage assembly **1082** to get stuck due to increased friction from the needle modules. If this occurs, the handheld device **1000** can blink the scatter light (on the scatter input **1022**) white, indicating that an extraction recovery is needed. The user may then relieve the downward force on the tissue, and press the scatter input **1022**, which will allow the handheld device **1000** to continue with extracting the needles from the tissue.

(71) Skin Grafting Assembly Vertical Operation

(72) Various components corresponding to the handheld device **1000** and cartridge **2002** can have a predefined operation based on the current mode of the handheld device **1000** (e.g., initialization, harvest mode, scatter mode, etc.), according to some configurations.

(73) In some configurations, the vertical component assembly **1046** can have a predefined “loading” configuration that corresponds to loading of the cartridge **2002** into the handheld device **1000**. During loading, for example, the solenoid plunger bar **1106**, each flipper **1074**, and the needle retract slide **1110** can be retracted (the needles retracted). The vertical carriage assembly **1108** can be set to the home position (as described above).

(74) In some configurations, the vertical component assembly **1046** can have a predefined “initialization” configuration. During initialization, for example, each flipper **1074** can be extended (flipper out), and the needle retract slide **1110** can be locked with the needle retract springs **1120** loaded (the needles remain retracted). The vertical carriage assembly **1108** can be set to the lock position (see above). With each flipper **1074** extended, the vertical carriage assembly **1108** can move up to the lock position. The extended flippers **1074** can hold the needle retract slide **1110** in place. When the vertical carriage assembly **1108** reaches the lock position, the needle retract slide latches **1116** can lock the top plate **1112** in place with the needle retract springs **1120** loaded. In some configurations, this does not move the needles from their retracted state.

(75) In some configurations, the vertical component assembly **1046** can have a predefined “initialized” configuration, which can correspond to the skin grafting system **3000** being ready to harvest. During the initialized configuration, for example, each flipper **1074** can be retracted (flipper in), and the needle retract slide **1110** can be locked with the needle retract springs **1120** loaded. In some configurations, this does not move the needles from their retracted state. The vertical carriage assembly **1108** can move back down to the home position, according to some configurations.

(76) In some configurations, the vertical component assembly **1046** can have a predefined “harvest” configuration corresponding to an applied user force. During the harvest configuration, for example, the needle retract slide **1110** can remain locked with the needle retract springs **1120**

loaded and the needles retracted. The vertical carriage assembly **1108** can remain in the harvest position, according to some configurations. When the user positions the skin grafting system **3000** at the donor site and applies downward force, the user will detect the tissue stabilizer **2014** moving a small amount in the direction opposite to the applied force, causing the indicator lights **1016** and **1020** to light up, indicating to the user that there exists proper alignment for harvest. In some configurations, the indicator light **1016** can illuminate green, to provide a visual confirmation of force to the user.

(77) In some configurations, the vertical component assembly **1046** can have a predefined “harvest” configuration corresponding to needle deployment. During this harvest configuration, for example, the solenoid plunger bar **1106** can advance, and the needle retract slide **1110** can remain locked with the needle retract springs **1120** loaded. Notably, the needles (e.g., from microneedle array **2006**) can be deployed into the tissue. The vertical carriage assembly **1108** can remain at the home position, and a user force can still be applied via the handheld device **1000**, according to some configurations. When the user pulls the trigger **1014**, the skin grafting assembly **3000** can begin the harvest sequence. Accordingly, the skin graft assembly **3000** can advance each microneedle array row of needles into the tissue by hitting the hammers **1098a**, **1098b** with the solenoid plunger bar **1106**.

(78) In some configurations, the vertical component assembly **1046** can have a predefined “extraction” configuration. During the extraction configuration, for example, the solenoid plunger bar **1106** can be retracted, the needle retract slide **1110** can remain locked with the needle retract springs **1120** loaded. The needles (e.g., from microneedle array **2006**) can remain deployed into the tissue at the start of extraction. The vertical carriage assembly **1108** can move to the extraction position (described above). In some configurations, after the harvest is complete, the skin grafting system **3000** can extract the needles by lifting all of needles within the microneedle array **2006** at once. The needles can be lifted up to the extraction position, and the user force can be removed. In some configurations, the needles can remain advanced relative to the pins (e.g., pin **2052**) and the tissue stabilizer **2014** can remain stationary when the needles are retracted.

(79) In some configurations, the vertical component assembly **1046** can have a predefined “scatter” configuration. During the scatter configuration, for example, the needle retract slide **1110** can be in a retracted position, with the needles similarly retracted. In some configurations, the vertical carriage assembly **1108** can move from the extracted position. When the user activates the scatter sequence, the skin grafting system **3000** can move the vertical carriage assembly **1108** from the extracted position, which can release the loaded needle retract springs **1120**, and the needle retract slide **1110**. Accordingly, this movement can retract the needles relative to the pins (e.g., pin **2052**), thus exposing the grafts and positioning the components for a scatter sequence.

(80) In some configurations, the vertical component assembly **1046** can have a “scatter” configuration corresponding to an advanced needle position. During this scatter configuration, for example, the solenoid plunger bar **1106** can advance, and the needle retract slide **1110** can advance (similarly, the needles can advance). According to some configurations, the solenoid plunger bar **1106** can advance, first hitting the top plate **1112**, and then hitting the needle modules (e.g., within microneedle array **2006**). This can push the top plate **1112** ahead of needle carriers, thus preventing damage to the carriers. The advancing of the needles, followed by the rapid retraction of those needles (by the unlocked top plate **1112**) can disperse the grafts into the recipient site.

(81) Power On Self-Test

(82) In some configurations, the handheld device **1000** can perform a self-test upon start-up (e.g., when the handheld device **1000** is first powered on). In some configurations, the self-test can occur when the handheld device **100** is plugged in to receive power, and the stand-by input **1018** is pressed and released. The stand-by input **1018** can flash green throughout the duration of the self-test, according to some configurations. Next, the horizontal carriage assembly **1082** can move a very small amount forward, such that the horizontal flag sensor **1064** is cleared. Subsequently, the

horizontal carriage assembly **1082** can return to the home position.

(83) During the self-test, the vertical carriage assembly **1108** can move a very small amount upwards, such that the vertical flag **1118** clears the sensor. Subsequently, the vertical carriage assembly **1108** can return to the home position. In some configurations, the vertical carriage assembly **1108** can move up to the unlock position, where it can move the needle retract slide latches **1116**, before returning to the home position. This can, for example, release the needle retract slide **1110**, in the event that it is locked (e.g., cartridge **2002** is locked in).

(84) In some configurations, the horizontal carriage assembly **1082** can move to a predetermined position (e.g., approximately two-thirds of the way through its full range), which can verify that a cartridge (e.g., cartridge **2002**) is not present. Subsequently, the horizontal carriage assembly **1082** can return to the home position.

(85) During the self-test, the flippers **1074** can extend out and then retract back in. Further, in some configurations, some or all lights on handheld device **1000** can flash (e.g., indicator light **1016**, **1020**, scatter input **1022**, etc.). Upon completion of the self-test, the stand-by input **1018** can light up solid green, for example, which can indicate that the self-test was successful.

(86) Cartridge Loading and Initialization

(87) In some configurations, the skin grafting system **3000** can have a predefined cartridge loading and initialization process. The user can open the loading door **1004**, then slide the cartridge assembly **2000** (i.e., including the cartridge cover **2004**) into the engagement slot **1002**. The cartridge latch **1114** can lock onto the cartridge **2002**. The user can then remove the cartridge cover **2004** and close the loading door **1004**, which can activate the internal loading door switch.

(88) The initialization process can further include moving the horizontal carriage assembly **1082** from the home position, such that it can detect the cartridge presence by stalling on the first cartridge segment. Subsequently, the horizontal carriage assembly **1082** can return to the home position. Additionally, the vertical carriage assembly **1108** can move a small amount, such that the vertical flag **1118** clears the sensor, and then the vertical carriage assembly **1108** can return to the home position.

(89) In some configurations, the flippers **1074** can extend out above the top plate **1112**. The vertical carriage assembly **1108** can move to the lock position. While moving to the lock position, the flippers **1074** can hold the top plate **1112** in place while the needle retract slide latches **1116** move out, and eventually lock over the top plate **1112**. Accordingly, the needle retract springs **1120** can be held in a compressed state. While this is happening, for example, the lockdown latches **1126** can spring out under the needle segments (e.g., within the microneedle array **2006**), in preparation for locking the needle segments down during the harvest sequence. In some configurations, the vertical carriage assembly can then move a small amount down, thus moving into the lock relax position (described above). Additionally, the flippers **1074** can retract back in.

(90) The initialization process can further include returning the vertical carriage assembly **1108** to the harvest position. The horizontal carriage assembly **1082** can engage with the first needle segment (within microneedle array **2006**) by stalling against the segment and subsequently backing off by a small, predetermined distance. The handheld device **1000** can then calculate the position of each needle segment. Upon completion of the initialization process, the indicator light **1020** can illuminate white to indicate that the handheld device **1000** is ready for the harvest sequence.

(91) Methods of Harvest and Extraction

(92) In some configurations, a user can harvest and extract tissue columns using a harvesting process. The user can position the handheld device **1000** at the donor site, with the tissue stabilizer **2014** pressed against the skin. The user can use one or two hands to apply force against the skin via the handheld device **1000**. The tissue stabilizer interface components can move upward, compressing the position sensing springs **1056** until the position sensing flag **1062** occludes the flag sensor. In some configurations, the indicator lights **1016**, **1020** can illuminate green, thus indicating that the trigger **1014** is active.

(93) Once the trigger **1014** is active, the user can pull the trigger **1014** (while maintaining the force on the skin) and the handheld device **1000** can begin the harvest sequence. In some configurations, the indicator lights **1016**, **1020** can blink green throughout the duration of the harvest and the extraction. The position sensing flag **1062** can be monitored throughout the harvest (between solenoid activations) to ensure that sufficient force is maintained. The solenoid **1052** can rapidly advance the solenoid plunger bar **1106**, which can advance the two hammers **1098a**, **1098b**, and insert the first needle module into the tissue. The needle module travels past the needle module lockdown latches as it is inserted. Subsequently, the solenoid **1052** and hammers **1098a**, **1098b** can retract, and the needle segment can remain locked down in the tissue.

(94) In some configurations, the horizontal carriage assembly **1082** can advance to the calculated position of the next needle segment. Alternatively, the position of the next needle segment can be recalculated or otherwise re-verified throughout the harvest process. The solenoid **1052** can rapidly advance the solenoid plunger bar **1106**, which can advance the two hammers **1098a**, **1098b**, and insert the next needle module into the tissue. The needle module can travel past the lockdown latches **1126** as it is inserted. The lockdown latches **1126** can spring back out, and the solenoid **1052** and hammers **1098a**, **1098b** can retract. This insertion process can repeat until all needle segments have been inserted into the tissue.

(95) After completing the insertion of all segments, the horizontal carriage assembly **1082** can return to the home position, according to some configurations. The vertical carriage assembly **1108** can move up to the extraction position, extracting the needles from the tissue, and positioning the needles safely up inside the tissue stabilizer **2014**. The indicator lights **1016**, **1020** can stop blinking green and turn off. Additionally, the scatter input **1022** can be illuminated white, indicating that the handheld device **1000** is ready to proceed with the scattering process. Upon completion of the harvesting process, the user can remove the force on the tissue, and lift the handheld device **1000** away.

(96) Methods of Scatter

(97) In some configurations, a user can scatter the tissue columns after the harvesting process. Once the user has removed the handheld device **1000** from the donor site (with the tissue columns harvested), the needles can be safely up inside of the cartridge **2002** (e.g., within the tissue stabilizer **2014**). With the recipient site ready for the tissue columns, the user can activate the scatter mode by pressing the scatter input **1022**. In some configurations, the scatter input **1022** can change from being illuminated white to green.

(98) In some configurations, the user can position the cartridge **2002** directly above the recipient site. The user can then pull the trigger **1014** and the vertical carriage assembly **1108** can move out of the extract position, which can release the needle retract slide **1110** and retract the needles behind the pins (e.g., pins **2052**). The handheld device **1000** can rapidly advance the solenoid plunger bar **1106** which accordingly push both the needle retract slide **1110** and the needle modules. The needle retract slide **1110** can remain pushed ahead of the needle modules to prevent damage to the needle modules. Subsequently, the solenoid plunger bar **1106** can retract, which can cause the needle retract slide **1110** to retract (pulling the needle modules back with the needle retract slide **1110**). The process of rapidly advancing the solenoid plunger bar **1106** can be repeated several times, which can ensure that as many grafts as possible have been deposited into the recipient site. In some configurations, six activations of the solenoid **1052** can occur. After the scatter process has completed, the vertical carriage assembly **1108** can return to the home position, with the needle retract slide **1110** unlocked.

(99) Cartridge Removal

(100) In some configurations, once the user has completed the harvest and scatter processes, the user can open the loading door **1004**, depress the cartridge latch **1114**, and slide the cartridge **2002** out. In some configurations, if the user wants to complete another harvest with the same cartridge **2002**, the user can open and close the loading door **1004** (i.e., without removing the cartridge

2002). This can begin another initialization process via the handheld device **1000**. Alternatively, the user can begin another initialization process via an input (not shown) on the user interface **1008**.

(101) Fluid Ingress Protection

(102) As described above, the cartridge **2002** can be used for multiple harvest and scatter processes (on a single patient), before removal from the handheld device **1000** and subsequent disposal. In some situations, repeated tissue punctures via the microneedle array **2006** can cause localized bleeding. Further, the repeated deployment and retraction of the needle modules can result in the dispersion of blood or other fluids. Since the cartridge **2002** can be disposable, blood dispersion onto, for example, the exterior of the microneedle chamber **2018** may be inconsequential. However, the handheld device **1000** can be reusable. Accordingly, it may be advantageous to prevent blood ingress into housing **1036**. As an example, should blood penetrate the housing **1036**, an extensive cleaning and disinfecting process may be required.

(103) The present disclosure includes systems and methods for preventing blood ingress. In particular, the present disclosure provides a device shield that can protect the contact point that occurs between the engagement slot **1002** and the cartridge **2002** (see, e.g., FIG. 1). Additionally, the device shield of the present disclosure can be designed to protect the contact point that occurs between the loading door **1004** and the cartridge **2002** (see, e.g., FIG. 1).

(104) Referring now to FIGS. 8-9, a device shield **5000** is shown, according to configurations of the present disclosure. In general, the device shield **5000** can be configured to removably protect contact points between the cartridge **2002** and the handheld device **1000**. The device shield **5000** is formed of a material (or multiple materials) that is impervious to liquid extending from an interior opening **5002** to an exterior edge **5004**. At the exterior edge, corner cutouts **5006** may be included. Thus, as will be described, the device shield **5000** forms a barrier to fluids that surrounds or encircles the interior opening **5002**.

(105) The opening **5002** can engage the microneedle chamber **2018**. In this way, when the cartridge **2002** is engaged with the handheld device **100**, the device shield **5000** extends from the opening **5002** over the handheld device **1000** to the exterior edge **5004**. In some configurations, a portion of the exterior edge **5004** can contact the loading door **1004** (see, e.g., FIG. 9). The loading door **1004** can optionally include a finger engagement **1005** (shown in FIG. 9), which can contact a portion of the exterior edge **5004**. As shown, the finger engagement **1005** can extend past the device shield **5000** such that the loading door **1004** can be opened and closed even when the device shield **5000** is in place on the skin grafting assembly **3000**.

(106) In some configurations, the device shield **5000** can include corner cutouts (e.g., corner cutout **5006**). As an example, the corner cutout **5006** can be inverted and/or rounded, such that a user can easily grasp the device shield **5000** during application and removal from the skin grafting assembly **3000**.

(107) In some configurations, the device shield **5000** can extend from an outer periphery of the tissue stabilizer **2014**. The device shield **5000** inhibits blood flow onto and into the handheld device **1000**, by, for example, protecting or sealing any openings corresponding to the engagement slot **1002** contact with the cartridge **2002**, and the loading door **1004** contact with the cartridge **2002**.

(108) According to some configurations, the device shield **5000** can be formed of polymer that forms a barrier to fluids. Furthermore, the device shield **5000** may be formed of a pliable or an elastomeric material. The device shield **5000** may have a generally flat geometry. By having a generally flat geometry and being formed of a pliable or elastomeric material, the device shield opening **5002** can be dimensioned smaller than a perimeter dimension of the microneedle chamber **2018**, such that the device shield **5000** can be stretched onto the microneedle chamber **2018**. The stretching of the device shield **5000** can form a seal that is designed to be generally impenetrable to blood and other fluids impinging upon the device shield **5000**, thus preventing fluid ingress into the handheld device **1000** along the tissue stabilizer **2014**.

(109) In the non-limiting example illustrated in FIG. 9, as the opening **5002** of the device shield

5000 is pulled down the tissue stabilizer **2014**, the exterior edge **5004** can be pulled and, depending upon material selection and design, stretched away from the opening **5002**, to extend toward the handheld device **1000**. In this configuration, the device shield **5000** is no longer in the default, generally flat geometry, but presents a slope or curve **5008** that extends from the opening **5002** to the exterior edge **5004**.

(110) The size of the device shield **5000** can vary, and in some embodiments, can be customized. As one example, the device shield **5000** can be cut to different shapes and sizes to customize the inhibition of blood ingress and usability of the skin grafting assembly **3000**. According to some embodiments of the present disclosure, the device shield **5000** can be molded to a generally fixed shape and/or dimension. As one non-limiting example, the device shield **5000** can contact the exterior of the microneedle chamber **2018** (e.g., the tissue stabilizer **2014**), and can otherwise extend outward therefrom (e.g., at a 90-degree angle, 45-degree angle, etc.). Accordingly, the device shield **5000** can provide a non-contact barrier for ingress points on the housing **1036**.

(111) Referring to FIG. **10**, one non-limiting example of the device shield **5000** engaged with the tissue stabilizer **2014** and extending to loading door **1004** and housing **1036** is illustrated in vertical cross section. In this example, the device shield **5000** has an internal opening **5002** that is sized to be slightly smaller than or matched to the exterior of the tissue stabilizer. In this way, the device shield **5000** has been extended down over the tissue stabilizer **2014** by pulling on the exterior edge **5004**, which stretches the device shield **5000** and, in this illustration, caused an interior surface **5010** of the device shield **5000** forming the interior opening **5002** when in a non-mounted position to extend perpendicular to the interior normal position and the tissue stabilizer. That is, because the interior opening **5002** is sized to carefully match the size of the tissue stabilizer **2014**, the opening must stretch and deform to accommodate extension over the tissue stabilizer **2014**, which causes the interior surface **5010** to be displaced to the illustrated, transverse position.

(112) In some configurations, the device shield **5000** can be molded to provide a customized downward seal against the handheld device **1000** (and associated ingress points). As one non-limiting example, the device shield **5000** can be molded to align with a curvature of the tissue stabilizer **2014**, the microneedle chamber **2018**, and/or the loading door **1004**. In the non-limiting example illustrated in FIG. **10**, the device shield has assumed a concave orientation that forms a tight seal with the tissue stabilizer **2014** at the interior opening **5002** and the housing **1036** and loading door **1004** at the exterior edge **5004**. Additionally, the device shield **5000** can be designed to provide a pocket **5012** between the device shield **5000** and the engagement slot **1002**. The pocket **5012** can be configured to hold an absorbent material **5014** that can further inhibit blood ingress into the handheld device **1000**. As illustrated, the absorbent material **5014** may be arranged as a ring or rectangle that engages and surrounds the tissue stabilizer **2014** and resides in the pocket **5012** over the engagement slot **1002**. Alternatively, as illustrated in phantom, the absorbent material **5014a** may have any of a variety of cross-sectional geometries or thicknesses.

(113) While the present disclosure may be susceptible to various modifications and alternative forms, specific configurations have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the present disclosure is not intended to be limited to the particular forms disclosed. Rather, the present disclosure is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present disclosure as defined by the following appended claims.

(114) This written description uses examples to disclose the present disclosure, including the best mode, and also to enable any person skilled in the art to practice the present disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the present disclosure is defined by the claims and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal

languages of the claims.

(115) Finally, it is expressly contemplated that any of the processes or steps described herein may be combined, eliminated, or reordered. Accordingly, this description is meant to be taken only by way of example, and not to otherwise limit the scope of this present disclosure.

Claims

1. A skin grafting system comprising: a cartridge including: a plurality of microneedles; and a cartridge housing including a microneedle chamber, the plurality of microneedles being arranged within the microneedle chamber; a handheld device including: a device housing defining a loading aperture; and a loading door that hinges between an open position and a closed position; a cartridge latch that is configured to secure the cartridge upon insertion of the cartridge into the loading aperture of the device housing when the loading door exposes the loading aperture in the open position; and wherein the loading door is configured to close over the loading aperture of the handheld device to secure the cartridge; a shield configured to inhibit ingress of fluids into an interior of the device housing from fluid about the cartridge housing during a skin grafting process performed using the skin grafting system; and wherein the cartridge housing is configured to be inserted into the loading aperture of the device housing to secure the cartridge to the handheld device.
2. The skin grafting system of claim 1, wherein the device housing includes an engagement slot; wherein the cartridge housing is configured to slide into and out of the engagement slot of the device housing; wherein the cartridge housing includes a first loading tab that extends outwardly, and a second loading tab that extends outwardly opposite the first loading tab; and wherein the first loading tab and the second loading tab are configured to slide into contact with the engagement slot.
3. The skin grafting system of claim 1, further comprising: a cartridge cover removably coupled to the cartridge housing; and wherein the microneedle chamber and the cartridge cover form an enclosure for the plurality of microneedles.
4. The skin grafting system of claim 1, wherein the cartridge includes a plurality of pins; and wherein each pin of the plurality of pins is received in a lumen of a respective microneedle of the plurality of microneedles.
5. The skin grafting system of claim 1, wherein the handheld device includes a door sensor to determine a position of the loading door.
6. The skin grafting system of claim 1, wherein the device housing includes a hole configured to receive a hand of a user; and wherein the handheld device includes a trigger coupled to the device housing at the hole of the device housing; and wherein the trigger is configured to active at least one of a harvest process or a scattering process of the skin grafting system.
7. The skin grafting system of claim 1, wherein the plurality of microneedles includes a first group of microneedles and a second group of microneedles; wherein the handheld device is configured to sequentially actuate the first group of microneedles and the second group of microneedles; wherein when the first group of microneedles is actuated, the first group of microneedles extend past the cartridge housing to harvest tissue during the skin grafting process; and wherein when the second group of microneedles is actuated, the second group of microneedles extend past the cartridge housing to harvest tissue during the skin grafting process.
8. The skin grafting system of claim 1, wherein the shield includes a shield opening; wherein a portion of the cartridge housing is insertable through the shield opening of the shield; wherein the shield extends across an opening defined by the engagement between the cartridge housing and the handheld device; and wherein the opening is at least one of: an opening formed between the cartridge housing and the handheld device at the loading aperture of the device housing; an opening formed between the cartridge housing and the handheld device at a loading door of the handheld

device; or an opening formed between the cartridge housing and the handheld device at an engagement slot that receives the cartridge housing.

9. The skin grafting system of claim 1, wherein the shield includes a shield opening; wherein a portion of the cartridge housing is insertable through the shield opening of the shield; and wherein when the portion of the cartridge is inserted through the shield opening of the shield, a seal is formed at the shield opening to block fluid from flowing through the shield opening.

10. The skin grafting system of claim 1, wherein the shield includes a polymer; and wherein the shield contacts an exterior of the cartridge housing.

11. The skin grafting system of claim 1, wherein the shield is configured to surround the cartridge when the cartridge is secured to the handheld device.

12. A skin grafting system comprising: a cartridge including: a plurality of microneedles; a plurality of pins, each pin of the plurality of pins being received within a lumen of a respective microneedle of the plurality of microneedles; a cartridge housing including a microneedle chamber, the plurality of microneedles being arranged within the microneedle chamber; a handheld device including a device housing defining an engagement slot, the cartridge housing being slidable into the engagement slot to receive the cartridge; and a shield configured to inhibit ingress of fluids into an interior of the device housing from fluid about the cartridge housing during a skin grafting process performed using the skin grafting system; and wherein the shield extends across an opening defined by the engagement between the cartridge housing and the handheld device at the engagement slot to block fluid from flowing into the opening.

13. The skin grafting system of claim 12, wherein the plurality of microneedles includes a first group of microneedles and a second group of microneedles; wherein the handheld device is configured to sequentially actuate the first group of microneedles and the second group of microneedles to harvest tissue; wherein when the first group of microneedles is actuated, the first group of microneedles extend past the cartridge housing to harvest tissue during a skin grafting process; and wherein when the second group of microneedles is actuated, the second group of microneedles extend past the cartridge housing to harvest tissue during the skin grafting process.

14. The skin grafting system of claim 13, wherein the handheld device is configured to sequentially actuate the first group of microneedles and the second group of microneedles to insert the plurality of microneedles into a recipient site; wherein the handheld device includes a vertical carriage assembly including one or more needle retract springs; and wherein the one or more needle retract springs are configured to retract the plurality of microneedles all at one.

15. The skin grafting system of claim 12, wherein the handheld device includes a cartridge latch configured to secure the cartridge upon insertion of the cartridge into a loading aperture of the device housing.

16. A skin grafting system comprising: a cartridge including: a plurality of microneedles including a first group of microneedles and a second group of microneedles; and a cartridge housing including a microneedle chamber, the plurality of microneedles being arranged within the microneedle chamber; a handheld device including: a device housing defining a loading aperture; a solenoid configured to drive the first group and the second group of microneedles into skin tissue; a horizontal carriage assembly; and a horizontal motor configured to move the horizontal carriage assembly; and a shield configured to inhibit ingress of fluids into an interior of the device housing from fluid about the cartridge housing during a skin grafting process performed using the skin grafting system; wherein the handheld device is configured to sequentially actuate the first group of microneedles and the second group of microneedles; and wherein a position of the horizontal carriage assembly selects which of the first group of microneedles or the second group of microneedles is driven into the skin tissue.

17. The skin grafting system of claim 16, wherein during a first actuation of the solenoid, the solenoid is configured to drive the first group of microneedles past the cartridge housing into the skin tissue to harvest skin tissue; wherein during a second actuation of the solenoid, the solenoid is

configured to drive the second group of microneedles past the cartridge housing into the skin tissue to harvest skin tissue; wherein the horizontal carriage assembly includes a hammer configured to drive the first group of microneedles and the second group of microneedles into skin tissue; wherein the solenoid is configured to drive the hammer thereby driving the first group of microneedles into the skin tissue; and wherein the solenoid is configured to drive the hammer thereby driving the second group of microneedles into the skin tissue.

18. The skin grafting system of claim 17, wherein the hammer is a first hammer; wherein the horizontal carriage assembly includes a second hammer, a first return spring coupled to the first hammer, and a second return spring coupled to the second hammer; and wherein during the first actuation of the solenoid, the first group of microneedles are aligned with the first hammer and the second hammer, and the solenoid forces the first hammer and the second hammer to drive the first group of microneedles into the skin tissue; and wherein during the second actuation of the solenoid, the second group of microneedles are aligned with the first hammer and the second hammer, and the solenoid forces the first hammer and the second hammer to drive the second group of microneedles into the skin tissue.

19. The skin grafting system of claim 16, wherein the handheld device includes a first lockdown latch and a second lockdown latch; wherein the first lockdown latch is configured to lock the first group of microneedles into the skin tissue; and wherein the second lockdown latch is configured to lock the second group of microneedles into the skin tissue.

20. The skin grafting system of claim 16, wherein the handheld device includes a vertical carriage assembly including one or more needle retract springs; and wherein the one or more needle retract springs are configured to retract the plurality of microneedles all at once.
