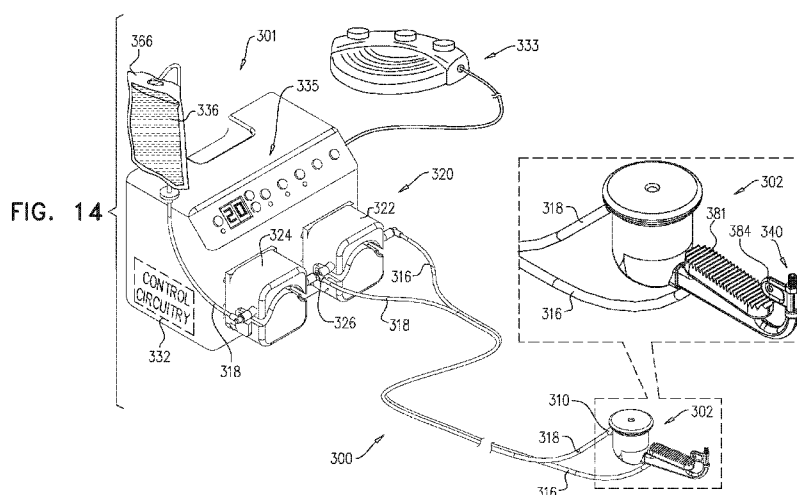




- (51) **International Patent Classification:**
A61C 8/00 (2006.01) *A61C 1/00* (2006.01)
- (21) **International Application Number:** PCT/IL2016/050423
- (22) **International Filing Date:** 20 April 2016 (20.04.2016)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
62/150,969 22 April 2015 (22.04.2015) US
14/707,688 8 May 2015 (08.05.2015) US
- (63) **Related by continuation (CON) or continuation-in-part (CIP) to earlier application:**
US 14/707,688 (CIP)
Filed on 8 May 2015 (08.05.2015)
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- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).
- Published:**
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: BONE GRAFT INJECTION OSTEOTOME



(57) **Abstract:** A composition delivery source (300) includes a chamber (302), a solid-liquid composition delivery tube (314), a mixing tube (316), and a liquid-supply tube (318). A filter (304) divides the chamber (302) into a liquid compartment (306) and a solid-liquid composition compartment (308). The solid-liquid composition delivery tube (314) is in fluid communication with the solid-liquid composition compartment (308). The mixing tube (316) is in fluid communication with the liquid compartment (306) and the solid-liquid composition compartment (308). The liquid-supply tube (318) is in fluid communication with the liquid compartment (306) and a liquid solution container (366). A pump unit (301) is provided that includes a mixing pump (322), which is arranged to cause flow in the mixing tube (316); and a liquid-supply pump (324), which is arranged to cause flow in the liquid-supply tube (318). Other embodiments are also described.

BONE GRAFT INJECTION OSTEOTOME

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application (a) claims priority from US Provisional Application 62/150,969, filed April 22, 2015, and (b) claims priority from and is a continuation-in-part
5 of US Application 14/707,688, filed May 8, 2015, both of which are assigned to the assignee of the present application and are incorporated herein by reference.

FIELD OF THE APPLICATION

The present invention relates generally to surgical tools and implantation methods, and specifically to minimally-invasive surgical tools and implantation methods.

BACKGROUND OF THE APPLICATION

Osseointegrated dental implants are typically metallic or ceramic screws that are placed in the jawbone for supporting artificial teeth after the loss of natural teeth. Replacement of the maxillary teeth is often a challenging surgical procedure when the remaining maxillary bone has insufficient height to support the implant. One surgical
15 technique for augmenting the maxillary bone includes injecting a regenerative material, such as autogenic, allogeneic, xenogeneic, or synthetic bone graft, into the vicinity of the maxillary bone. The regenerative material forms additional bone mass that integrates with the existing maxillary bone, providing the necessary alveolar height to support the implant.

20 Bone augmentation procedures are often surgically difficult to perform, and are associated with complications, including infection of the maxillary sinus. The top of the maxillary alveolar ridge forms the floor of the maxillary sinus, and is covered by a thin membrane known as the Schneiderian or subantral membrane. In one surgical procedure, known as a closed or internal sinus lift or elevation procedure, the surgeon drills a bore
25 through the maxillary alveolar ridge from the oral cavity at the desired location of the implant. The bore penetrates the ridge to below the Schneiderian membrane. The surgeon injects the regenerative material through the bore to below the membrane, forming a cavity defined by the top of the ridge and the bottom of the membrane, which cavity occupies a portion of the space initially occupied by the maxillary sinus.

To prevent potentially serious complications, the surgeon must be careful not to perforate the Schneiderian membrane. This is often difficult, because of the delicacy of the membrane, and the restricted access afforded by the closed approach.

Hydraulic sinus lifting is performed by applying hydraulic pressure between the sinus floor and the Schneiderian membrane. The hydraulic elevation can be performed via a crestal or lateral approach. Once the membrane is elevated, using a hydraulic, closed, or lateral window technique, a bone graft material is applied, typically using one of two conventional techniques. The first conventional technique is the mechanical insertion of bone graft, which is formulated in small particles. This technique is manually demanding, and it may cause application of unequal stresses to the membrane, which may result in perforation of the membrane. The second conventional technique is the injection of bone graft in a gel formulation by applying the same principles of hydraulic elevation used during raising of the membrane.

SUMMARY

Some embodiments of the present invention provide surgical tools and methods for use in conjunction with minimally-invasive sinus lift techniques for performing a bone augmentation procedure on the maxillary alveolar ridge while reducing the risk of perforating the Schneiderian membrane and of infection.

For some applications, the surgical tool is configured to inject, through a bore (osteotomy) and into a sinus cavity, a solid-liquid composition of bone graft particles and a physiological liquid solution, and to drain the physiological liquid solution through the same bore, leaving the bone graft particles in the cavity. Typically, a filter of the surgical tool is used to inhibit passage of bone graft particles from the cavity. Typically, hydraulic pressure is equally applied on the Schneiderian membrane by the solid-liquid composition throughout the injection of the solid-liquid composition. Such uniform hydraulic pressure prevents bone graft particles from applying local or uneven pressure on the Schneiderian membrane, and thus reduces the risk of perforation. The surgeon further screws an implant into the bone graft material in the cavity, either during the same procedure or after bone grows into the bone graft material. After bone grows into the bone graft material, a dental appliance, such as a crown, is coupled to the implant.

For some applications, the surgical tool comprises a composition delivery source,

which comprises a chamber, a solid-liquid composition delivery tube, a mixing tube, and a liquid-supply tube. The chamber comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment. The chamber is shaped so as to define (a) one or more liquid
5 ports in fluid communication with the liquid compartment, and (b) one or more solid-liquid composition ports in fluid communication with the solid-liquid composition compartment. The solid-liquid composition delivery tube is in fluid communication with at least one of the one or more solid-liquid composition ports. The mixing tube is in fluid communication with at least one of the one or more liquid ports and at least one of the one
10 or more solid-liquid composition ports. The liquid-supply tube is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container.

For some applications, the surgical tool further comprises a pump unit, which comprises (a) a mixing pump, which is arranged to cause flow in the mixing tube, and (b)
15 a liquid-supply pump, which is arranged to cause flow in the liquid-supply tube. Typically, the mixing pump is arranged to cause, in the mixing tube, flow that raises the solid bone graft particles in a puff into the physiological liquid solution in the chamber. For some applications, the mixing pump and the liquid-supply pump are respective peristaltic pumps.

20 For some applications, the pump unit further comprises control circuitry, which is configured to repeatedly:

- assume a mixing activation state, in which the control circuitry activates the mixing pump to mix the solid bone graft particles and the physiological liquid solution in the solid-liquid composition compartment to form a solid-liquid
25 composition, by pumping the physiological liquid solution through the mixing tube and into the solid-liquid composition compartment, and
- assume a particle-delivery activation state, wherein the control circuitry, during at least a portion of the particle-delivery activation state, activates the liquid-supply pump to apply positive pressure to pump the solid-liquid composition from the
30 solid-liquid composition compartment into the solid-liquid composition delivery tube.

For some applications, the control circuitry is configured, during each of one or

more negative-positive particle delivery cycles of the particle-delivery activation state, to assume:

- a negative particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply negative pressure to pump liquid from the solid-liquid composition delivery tube toward the liquid compartment via the solid-liquid composition compartment, and
- a positive particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply the positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube, wherein a direction of pumping of the liquid-supply pump in the positive particle-delivery activation sub-state is opposite a direction of pumping of the liquid-supply pump in the negative particle-delivery activation sub-state.

For some applications, the surgical tool comprises an automated device that both prepares (e.g., mixes) and delivers the solid-liquid composition during the procedure.

There is therefore provided, in accordance with an inventive concept 1 of the present invention, apparatus for use with solid particles and a liquid container containing a physiological liquid solution, the apparatus comprising:

- (1) a composition delivery source, which comprises:
 - (a) a chamber, which:
 - (i) comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment, and
 - (ii) is shaped so as to define (A) one or more liquid ports in fluid communication with the liquid compartment, and (B) one or more solid-liquid composition ports in fluid communication with the solid-liquid composition compartment;
 - (b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports;
 - (c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and

(d) a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container; and

(2) a pump unit, which comprises:

5 (a) a mixing pump, which is arranged to cause flow in the mixing tube; and

(b) a liquid-supply pump, which is arranged to cause flow in the liquid-supply tube.

10 Inventive concept 2. The apparatus according to inventive concept 1, wherein the solid particles are solid bone graft particles, and wherein the apparatus is for use with the solid bone graft particles.

Inventive concept 3. The apparatus according to inventive concept 1, further comprising the solid particles, wherein the filter is configured to inhibit passage of the solid particles and allow passage of the physiological liquid solution.

15 Inventive concept 4. The apparatus according to inventive concept 1, wherein the mixing pump is arranged to cause, in the mixing tube, flow that raises the solid particles in a puff into the physiological liquid solution in the solid-liquid composition compartment.

Inventive concept 5. The apparatus according to inventive concept 1, wherein a closest distance between the one or more solid-liquid composition ports and the filter equals at
20 least 5 mm.

Inventive concept 6. The apparatus according to inventive concept 5, wherein the closest distance equals at least 10 mm.

Inventive concept 7. The apparatus according to inventive concept 1, wherein a closest distance between the one or more solid-liquid composition ports and the filter equals at
25 least 75% of a distance between the filter and a point on an interior of a wall of the solid-liquid composition compartment farthest from the filter.

Inventive concept 8. The apparatus according to inventive concept 1, wherein the mixing tube (a) merges with the liquid-supply tube at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports via a portion of the
30 liquid-supply tube.

Inventive concept 9. The apparatus according to inventive concept 1, wherein the liquid-supply tube (a) merges with the mixing tube at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports via a portion of the mixing tube.

- 5 Inventive concept 10. The apparatus according to inventive concept 1, wherein the chamber is shaped so as to define exactly one liquid port in fluid communication with the liquid compartment.

- Inventive concept 11. The apparatus according to inventive concept 1, wherein the chamber is shaped so as to define exactly one solid-liquid composition port in fluid
10 communication with the solid-liquid composition compartment.

Inventive concept 12. The apparatus according to inventive concept 1,

wherein the chamber is shaped so as to define exactly one liquid port in fluid communication with the liquid compartment, and

- wherein the chamber is shaped so as to define exactly one solid-liquid composition
15 port in fluid communication with the solid-liquid composition compartment.

Inventive concept 13. The apparatus according to any one of inventive concepts 1-12, wherein the pump unit further comprises control circuitry, which is configured to repeatedly:

- (a) assume a mixing activation state, in which the control circuitry activates
20 the mixing pump to mix the solid particles and the physiological liquid solution in the solid-liquid composition compartment to form a solid-liquid composition, by pumping the physiological liquid solution through the mixing tube and into the solid-liquid composition compartment, and

- (b) assume a particle-delivery activation state, wherein the control circuitry,
25 during at least a portion of the particle-delivery activation state, activates the liquid-supply pump to apply positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube.

- Inventive concept 14. The apparatus according to inventive concept 13, wherein the control circuitry is configured to assume the mixing activation state and the particle-
30 delivery activation state at the same time.

Inventive concept 15. The apparatus according to inventive concept 13, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at partially-overlapping times.

5 Inventive concept 16. The apparatus according to inventive concept 13, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at non-overlapping times.

Inventive concept 17. The apparatus according to inventive concept 16, wherein the control circuitry is configured to assume the particle-delivery activation state within 500 ms after completing the mixing activation state.

10 Inventive concept 18. The apparatus according to inventive concept 17, wherein the control circuitry is configured to assume the particle-delivery activation state within 100 ms after completing the mixing activation state.

15 Inventive concept 19. The apparatus according to inventive concept 16, wherein the control circuitry is configured to repeatedly, in alternation, (a) assume the mixing activation state for between 100 and 1200 ms, and (b) assume the particle-delivery activation state.

20 Inventive concept 20. The apparatus according to inventive concept 19, wherein the control circuitry is configured to repeatedly, in alternation, (a) assume the mixing activation state for between 100 and 1200 ms, and (b) assume the particle-delivery activation state for between 150 and 3000 ms.

25 Inventive concept 21. The apparatus according to inventive concept 13, wherein the control circuitry is configured to, when in the particle-delivery activation state, activate the liquid-supply pump to apply the positive pressure to pump the physiological liquid solution (a) from the liquid solution container, (b) through the liquid-supply tube, (c) into the liquid compartment, (d) through the filter, (e) into the solid-liquid composition compartment, (f) from the solid-liquid composition compartment, and (g) to the solid-liquid composition delivery tube.

30 Inventive concept 22. The apparatus according to inventive concept 13, wherein the control circuitry is configured to repeatedly assume the mixing activation state and the particle-delivery activation state over a time period having a duration of between 30 and 600 seconds.

Inventive concept 23. The apparatus according to inventive concept 13, wherein the control circuitry is configured, during each of one or more negative-positive particle delivery cycles of the particle-delivery activation state, to assume:

5 a negative particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply negative pressure to pump liquid from the solid-liquid composition delivery tube toward the liquid compartment via the solid-liquid composition compartment, and

10 a positive particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply the positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube, wherein a direction of pumping of the liquid-supply pump in the positive particle-delivery activation sub-state is opposite a direction of pumping of the liquid-supply pump in the negative particle-delivery activation sub-state.

15 Inventive concept 24. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at non-overlapping times.

Inventive concept 25. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the mixing activation state and the negative particle-delivery activation sub-state at partially-overlapping times.

20 Inventive concept 26. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the particle-delivery activation state in a plurality of particle-delivery-state cycles, and to begin the particle-delivery activation state in each of the particle-delivery-state cycles with the negative particle-delivery activation sub-state.

25 Inventive concept 27. The apparatus according to inventive concept 23, wherein the control circuitry is configured to repeatedly, in alternation, (a) assume the mixing activation state for between 100 and 1200 ms, and (b) assume the particle-delivery activation state.

30 Inventive concept 28. The apparatus according to inventive concept 23, wherein the control circuitry is configured to provide a plurality of the negative-positive particle delivery cycles during the particle-delivery activation state.

Inventive concept 29. The apparatus according to inventive concept 28, wherein the control circuitry is configured to provide up to 10 of the negative-positive particle delivery cycles during the particle-delivery activation state.

5 Inventive concept 30. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles.

10 Inventive concept 31. The apparatus according to inventive concept 30, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for between 25 and 100 ms during each of the one or more negative-positive particle delivery cycles.

15 Inventive concept 32. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the positive particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles.

Inventive concept 33. The apparatus according to inventive concept 32, wherein the control circuitry is configured to assume the positive particle-delivery activation sub-state for between 25 and 100 ms during each of the one or more negative-positive particle delivery cycles.

20 Inventive concept 34. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles, and to assume the positive particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles.

25 Inventive concept 35. The apparatus according to inventive concept 23, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for a first duration during each of the one or more negative-positive particle delivery cycles, and to assume the positive particle-delivery activation sub-state for a second duration during each of the one or more negative-positive particle delivery cycles, the second duration equal to between 80% and 120% of the first duration.

Inventive concept 36. The apparatus according to inventive concept 23, wherein the control circuitry is configured to, when in the negative particle-delivery activation sub-state, activate the liquid-supply pump to pump the liquid from the solid-liquid composition delivery tube, into the solid-liquid composition compartment, and into the liquid compartment.

Inventive concept 37. The apparatus according to inventive concept 23,
wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor,
wherein the liquid-supply peristaltic pump is capable of (a) pumping fluid at an average rate throughout a full 360-degree revolution of the rotor at a certain speed, and (b) pumping fluid at a maximum rate during portions of the full 360-degree revolution at the certain speed, the maximum rate greater than the average rate, and

wherein the control circuitry is configured, when in both the positive and the negative particle-delivery activation sub-states, to activate the liquid-supply peristaltic pump to (a) rotate the rotor, at the certain speed, a partial revolution equal to a fraction of the full 360-degree revolution of the rotor, the fraction less than 1, and (b) pump, throughout the partial revolution, the fluid at the maximum rate.

Inventive concept 38. The apparatus according to inventive concept 23,
wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor, and

wherein the control circuitry is configured:
when in the positive particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to rotate the rotor, in a first rotational direction, a first partial revolution equal to a fraction of a full 360-degree revolution of the rotor, the fraction less than 1, and

when in the negative particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to rotate the rotor, in a second rotational direction opposite the first rotational direction, a second partial revolution equal to the fraction of the full 360-degree revolution of the rotor.

Inventive concept 39. The apparatus according to inventive concept 23, wherein the control circuitry is configured:

when in the positive particle-delivery activation sub-state, to activate the liquid-supply pump to pump a volume of between 0.1 and 2 cc of fluid, and

when in the negative particle-delivery activation sub-state, to activate the liquid-supply pump to pump the volume of fluid.

5 Inventive concept 40. The apparatus according to inventive concept 23,

wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor, and

wherein the control circuitry is configured, when in the positive particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to:

10 rotate the rotor a partial revolution equal to a fraction of a full 360-degree revolution of the rotor, the fraction less than 1, and

pump, throughout the partial revolution, a volume of fluid that is greater than the product of the fraction and a volume of fluid pumpable throughout the full 360-degree revolution of the rotor.

15 Inventive concept 41. The apparatus according to inventive concept 40, wherein the liquid-supply peristaltic pump further comprises a total number of rollers equal to at least two, and wherein the fraction is less than the quotient of 1 divided by the total number of rollers.

Inventive concept 42. The apparatus according to inventive concept 41, wherein the
20 fraction is less than or equal to the quotient of 0.5 divided by the total number of rollers.

Inventive concept 43. The apparatus according to inventive concept 23, wherein the control circuitry and the liquid-supply pump are configured such that during at least a portion of the positive particle-delivery activation sub-state, the liquid-supply pump pumps the physiological liquid solution at a rate of at least 3 cc/sec.

25 Inventive concept 44. The apparatus according to inventive concept 43, wherein the rate is at least 7 cc/sec.

Inventive concept 45. The apparatus according to inventive concept 23, wherein the control circuitry and the liquid-supply pump are configured such that during at least a portion of the negative particle-delivery activation sub-state, the liquid-supply pump
30 pumps the physiological liquid solution at a rate of at least 3 cc/sec.

Inventive concept 46. The apparatus according to inventive concept 45, wherein the rate is at least 7 cc/sec.

5 Inventive concept 47. The apparatus according to inventive concept 13, wherein the control circuitry and the mixing pump are configured such that during at least a portion of the mixing activation state the mixing pump pumps the physiological liquid solution at a rate of at least 3 cc/sec.

Inventive concept 48. The apparatus according to inventive concept 47, wherein the rate is at least 7 cc/sec.

10 Inventive concept 49. The apparatus according to inventive concept 13, wherein the control circuitry and the mixing pump are configured such that throughout the mixing activation state the mixing pump pumps between 0.5 and 9 cc of the physiological liquid solution.

15 Inventive concept 50. The apparatus according to inventive concept 49, wherein the control circuitry and the mixing pump are configured such that throughout the mixing activation state the mixing pump pumps between 1.8 and 3.9 cc of the physiological liquid solution.

Inventive concept 51. The apparatus according to inventive concept 13, wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor.

20 Inventive concept 52. The apparatus according to inventive concept 51, wherein the liquid-supply peristaltic pump comprises an index sensor, which identifies a rotational position of the rotor.

25 Inventive concept 53. The apparatus according to inventive concept 51, wherein the control circuitry is configured to assume the particle-delivery activation state a plurality of times in alternation with mixing activation states, and to begin each of the particle-delivery activation states with the rotor at a same rotational position.

Inventive concept 54. The apparatus according to inventive concept 13, wherein the mixing pump is a mixing peristaltic pump, which comprises a rotor.

30 Inventive concept 55. The apparatus according to inventive concept 54, wherein the mixing peristaltic pump comprises an index sensor, which identifies a rotational position of the rotor.

Inventive concept 56. The apparatus according to inventive concept 54,

wherein the mixing peristaltic pump comprises a total number of rollers equal to at least two, and

wherein the control circuitry is configured to assume the mixing activation state a plurality of times in alternation with particle-delivery activation states, and to begin the mixing activation states with the rotor at respective starting rotational positions, which are identical to one another or rotationally offset from one another by the product of (a) 360 degrees divided by the total number of rollers and (b) a positive integer.

Inventive concept 57. The apparatus according to inventive concept 54,

wherein the mixing peristaltic pump comprises (a) a pump casing that is shaped so as to define a partial-circle mixing tube channel in which the mixing tube is disposed, and (b) an odd total number of rollers, the odd total number equal to at least one, and

wherein the control circuitry is configured to assume the mixing activation state a plurality of times in alternation with particle-delivery activation states, and to begin each of the mixing activation states with an aligned total number of the rollers rotationally aligned with the mixing tube channel, the aligned total number equal to more than half of the odd total number.

Inventive concept 58. The apparatus according to inventive concept 57, wherein the odd total number equals at least three.

Inventive concept 59. The apparatus according to inventive concept 13, wherein the control circuitry is configured to, before repeatedly assuming the mixing and the particle-delivery activation states, assume a filling state, in which the control circuitry activates the liquid-supply pump to apply positive pressure to pump a volume of the physiological liquid solution from the solid-liquid composition compartment into the solid-liquid composition delivery tube, the volume equal to between 0.5 and 3 cc.

Inventive concept 60. The apparatus according to any one of inventive concepts 1-12,

wherein the chamber comprises a receptacle component and a cover component,

wherein the cover component (a) comprises the filter, and (b) is shaped so as to define (i) a cap and (ii) a bone-graft container having an opening that (x) faces away from the cap and (y) is farther from the cap than the filter is from the cap, and

wherein the receptacle component and the cover component are shaped so as to be reversibly coupleable with each another to form a watertight seal, with the bone-graft container disposed within the receptacle component.

5 Inventive concept 61. The apparatus according to inventive concept 60, wherein the bone-graft container has a volume of between 0.2 and 6 ml.

Inventive concept 62. The apparatus according to inventive concept 60, wherein the chamber has a volume of between 0.2 and 20 ml.

Inventive concept 63. The apparatus according to inventive concept 60, wherein a volume of the bone-graft container equals less than 50% of a volume of the chamber.

10 Inventive concept 64. The apparatus according to inventive concept 63, wherein the volume of the bone-graft container equals less than 33% of the volume of the chamber.

Inventive concept 65. The apparatus according to inventive concept 64, wherein the volume of the bone-graft container equals less than 20% of the volume of the chamber.

15 Inventive concept 66. The apparatus according to any one of inventive concepts 1-12, wherein the mixing pump and the liquid-supply pump are respective peristaltic pumps.

Inventive concept 67. The apparatus according to inventive concept 66, wherein the peristaltic pumps comprise respective rotors and index sensors, which identify respective rotational positions of the rotors.

20 Inventive concept 68. The apparatus according to inventive concept 66, wherein the pump unit further comprises control circuitry, which is configured to assume a mixing activation state, in which the mixing peristaltic pump rotates between 1/3 and 3 revolutions.

Inventive concept 69. The apparatus according to inventive concept 68, wherein the mixing peristaltic pump rotates one revolution throughout the mixing activation state.

25 Inventive concept 70. The apparatus according to any one of inventive concepts 1-12, wherein the mixing tube (a) merges with the solid-liquid composition delivery tube at a return junction, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition ports via a portion of the solid-liquid composition delivery tube.

30 Inventive concept 71. The apparatus according to inventive concept 70, wherein a proximal end of the solid-liquid composition delivery tube is in fluid communication with the at least one of the one or more solid-liquid composition ports, and wherein a distance

between the return junction and the proximal end of the solid-liquid composition delivery tube is less than 60 mm.

Inventive concept 72. The apparatus according to inventive concept 71, wherein the distance is less than 20 mm.

- 5 Inventive concept 73. The apparatus according to inventive concept 70, wherein an internal cross-sectional area of the solid-liquid composition delivery tube perpendicular to an axis of the solid-liquid composition delivery tube is non-decreasing from the return junction to a distal end of the solid-liquid composition delivery tube.

- 10 Inventive concept 74. The apparatus according to any one of inventive concepts 1-12, wherein the mixing tube (a) merges with the solid-liquid composition delivery tube at a return junction, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition ports via a portion of the solid-liquid composition delivery tube.

- Inventive concept 75. The apparatus according to inventive concept 74,
wherein the chamber comprises a receptacle component and a cover component,
15 which is shaped so as to define a cap,
wherein the return junction is disposed along a longitudinal portion of the solid-liquid composition delivery tube and around a circumferential portion of the solid-liquid composition delivery tube,
wherein the longitudinal portion includes a point that is closest to the cap when the
20 cap is coupled to the receptacle component, and
wherein the circumferential portion includes the point.

- Inventive concept 76. The apparatus according to any one of inventive concepts 1-12, wherein the apparatus further comprises a shaft unit, which comprises a shaft delivery tube in fluid communication with a distal end of the solid-liquid composition delivery
25 tube.

Inventive concept 77. The apparatus according to inventive concept 76, wherein the shaft delivery tube is more rigid than at least a portion of the solid-liquid composition delivery tube.

- Inventive concept 78. The apparatus according to inventive concept 76, wherein the shaft
30 unit further comprises a removable depth limiting element, which is configured to limit a

depth of insertion of the shaft delivery tube into a bore through a bone when the shaft delivery tube is inserted into the bore.

Inventive concept 79. The apparatus according to inventive concept 78,

wherein the shaft unit comprises a shaft delivery tube,

5 wherein the shaft unit further comprises a sealing element disposed around an external surface of the shaft delivery tube, and

wherein the depth limiting element is removable from the shaft unit without removal of the sealing element.

Inventive concept 80. The apparatus according to inventive concept 79, wherein a distal
10 end of the shaft delivery tube is disposed more distally than the sealing element by a distance of between 0 and 20 mm.

Inventive concept 81. The apparatus according to inventive concept 80, wherein the distance is between 3 and 15 mm.

Inventive concept 82. The apparatus according to inventive concept 76, wherein the shaft
15 delivery tube is straight.

Inventive concept 83. The apparatus according to inventive concept 82, wherein, when the chamber, the solid-liquid composition delivery tube, and the shaft unit are unconstrained, respective central longitudinal axes of the shaft delivery tube and a proximal longitudinal portion of the solid-liquid composition delivery tube form an angle of between 70 and 110
20 degrees.

Inventive concept 84. The apparatus according to inventive concept 83, wherein the angle is between 85 and 95 degrees.

Inventive concept 85. The apparatus according to inventive concept 82, wherein, when the chamber, the solid-liquid composition delivery tube, and the shaft unit are unconstrained,
25 a central longitudinal axis of the shaft delivery tube and a plane defined by the filter form an angle of between 70 and 110 degrees.

Inventive concept 86. The apparatus according to inventive concept 82, wherein, when the chamber and the solid-liquid composition delivery tube are unconstrained, (a) a central longitudinal axis of a proximal longitudinal portion of the solid-liquid composition
30 delivery tube and (b) a plane defined by the filter are parallel or form an angle of less than 20 degrees.

There is further provided, in accordance with an inventive concept 87 of the present invention, apparatus for use with solid particles and a liquid container containing a physiological liquid solution, the apparatus comprising a composition delivery source, which comprises:

- 5 (a) a chamber, which:
 - (i) comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment, and
 - (ii) is shaped so as to define (A) one or more liquid ports in fluid
10 communication with the liquid compartment, and (B) one or more solid-liquid composition ports in fluid communication with the solid-liquid composition compartment;
- (b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports;
- 15 (c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and
- (d) a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the
20 liquid solution container.

Inventive concept 88. The apparatus according to inventive concept 87, wherein the solid particles are solid bone graft particles, and wherein the apparatus is for use with the solid bone graft particles.

25 Inventive concept 89. The apparatus according to inventive concept 87, further comprising the solid particles, wherein the filter is configured to inhibit passage of the solid particles and allow passage of the physiological liquid solution.

Inventive concept 90. The apparatus according to inventive concept 87, wherein a closest distance between the one or more solid-liquid composition ports and the filter equals at least 5 mm.

30 Inventive concept 91. The apparatus according to inventive concept 90, wherein the closest distance equals at least 10 mm.

Inventive concept 92. The apparatus according to inventive concept 87, wherein a closest distance between the one or more solid-liquid composition ports and the filter equals at least 75% of a distance between the filter and a point on an interior of a wall of the solid-liquid composition compartment farthest from the filter.

- 5 Inventive concept 93. The apparatus according to inventive concept 87, wherein the mixing tube (a) merges with the liquid-supply tube at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports via a portion of the liquid-supply tube.

- 10 Inventive concept 94. The apparatus according to inventive concept 87, wherein the liquid-supply tube (a) merges with the mixing tube at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports via a portion of the mixing tube.

- 15 Inventive concept 95. The apparatus according to inventive concept 87, wherein the chamber is shaped so as to define exactly one liquid port in fluid communication with the liquid compartment.

Inventive concept 96. The apparatus according to inventive concept 87, wherein the chamber is shaped so as to define exactly one solid-liquid composition port in fluid communication with the solid-liquid composition compartment.

- 20 Inventive concept 97. The apparatus according to inventive concept 87,
wherein the chamber is shaped so as to define exactly one liquid port in fluid communication with the liquid compartment, and
wherein the chamber is shaped so as to define exactly one solid-liquid composition port in fluid communication with the solid-liquid composition compartment.

- 25 Inventive concept 98. The apparatus according to any one of inventive concepts 87-97,
wherein the chamber comprises a receptacle component and a cover component,
wherein the cover component (a) comprises the filter, and (b) is shaped so as to define (i) a cap and (ii) a bone-graft container having an opening that (x) faces away from the cap and (y) is farther from the cap than the filter is from the cap, and
wherein the receptacle component and the cover component are shaped so as to be
30 reversibly coupleable with each another to form a watertight seal, with the bone-graft container disposed within the receptacle component.

Inventive concept 99. The apparatus according to inventive concept 98, wherein the bone-graft container has a volume of between 0.2 and 6 ml.

Inventive concept 100. The apparatus according to inventive concept 98, wherein the chamber has a volume of between 0.2 and 20 ml.

- 5 Inventive concept 101. The apparatus according to inventive concept 98, wherein a volume of the bone-graft container equals less than 50% of a volume of the chamber.

Inventive concept 102. The apparatus according to inventive concept 101, wherein the volume of the bone-graft container equals less than 33% of the volume of the chamber.

- 10 Inventive concept 103. The apparatus according to inventive concept 102, wherein the volume of the bone-graft container equals less than 20% of the volume of the chamber.

Inventive concept 104. The apparatus according to any one of inventive concepts 87-97, wherein the mixing tube (a) merges with the solid-liquid composition delivery tube at a return junction, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition ports via a portion of the solid-liquid composition delivery tube.

- 15 Inventive concept 105. The apparatus according to inventive concept 104, wherein a proximal end of the solid-liquid composition delivery tube is in fluid communication with the at least one of the one or more solid-liquid composition ports, and wherein a distance between the return junction and the proximal end of the solid-liquid composition delivery tube is less than 60 mm.

- 20 Inventive concept 106. The apparatus according to inventive concept 105, wherein the distance is less than 20 mm.

- 25 Inventive concept 107. The apparatus according to inventive concept 104, wherein an internal cross-sectional area of the solid-liquid composition delivery tube perpendicular to an axis of the solid-liquid composition delivery tube is non-decreasing from the return junction to a distal end of the solid-liquid composition delivery tube.

Inventive concept 108. The apparatus according to any one of inventive concepts 87-97, wherein the mixing tube (a) merges with the solid-liquid composition delivery tube at a return junction, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition ports via a portion of the solid-liquid composition delivery tube.

- 30 Inventive concept 109. The apparatus according to inventive concept 108,

wherein the chamber comprises a receptacle component and a cover component, which is shaped so as to define a cap,

wherein the return junction is disposed along a longitudinal portion of the solid-liquid composition delivery tube and around a circumferential portion of the solid-liquid composition delivery tube,

wherein the longitudinal portion includes a point that is closest to the cap when the cap is coupled to the receptacle component, and

wherein the circumferential portion includes the point.

Inventive concept 110. The apparatus according to any one of inventive concepts 87-97, wherein the apparatus further comprises a shaft unit, which comprises a shaft delivery tube in fluid communication with a distal end of the solid-liquid composition delivery tube.

Inventive concept 111. The apparatus according to inventive concept 110, wherein the shaft delivery tube is more rigid than at least a portion of the solid-liquid composition delivery tube.

Inventive concept 112. The apparatus according to inventive concept 110, wherein the shaft unit further comprises a removable depth limiting element, which is configured to limit a depth of insertion of the shaft delivery tube into a bore through a bone when the shaft delivery tube is inserted into the bore.

Inventive concept 113. The apparatus according to inventive concept 112,

wherein the shaft unit comprises a shaft delivery tube,

wherein the shaft unit further comprises a sealing element disposed around an external surface of the shaft delivery tube, and

wherein the depth limiting element is removable from the shaft unit without removal of the sealing element.

Inventive concept 114. The apparatus according to inventive concept 113, wherein a distal end of the shaft delivery tube is disposed more distally than the sealing element by a distance of between 0 and 20 mm.

Inventive concept 115. The apparatus according to inventive concept 114, wherein the distance is between 3 and 15 mm.

Inventive concept 116. The apparatus according to inventive concept 110, wherein the shaft delivery tube is straight.

Inventive concept 117. The apparatus according to inventive concept 116, wherein, when the chamber, the solid-liquid composition delivery tube, and the shaft unit are unconstrained, respective central longitudinal axes of the shaft delivery tube and a proximal longitudinal portion of the solid-liquid composition delivery tube form an angle of between 70 and 110 degrees.

Inventive concept 118. The apparatus according to inventive concept 117, wherein the angle is between 85 and 95 degrees.

Inventive concept 119. The apparatus according to inventive concept 116, wherein, when the chamber, the solid-liquid composition delivery tube, and the shaft unit are unconstrained, a central longitudinal axis of the shaft delivery tube and a plane defined by the filter form an angle of between 70 and 110 degrees.

Inventive concept 120. The apparatus according to inventive concept 116, wherein, when the chamber and the solid-liquid composition delivery tube are unconstrained, (a) a central longitudinal axis of a proximal longitudinal portion of the solid-liquid composition delivery tube and (b) a plane defined by the filter are parallel or form an angle of less than 20 degrees.

There is still further provided, in accordance with an inventive concept 121 of the present invention, apparatus for use with solid particles and a liquid container containing a physiological liquid solution, the apparatus comprising a pump unit, which comprises:

- (a) a mixing pump;
- (b) a liquid-supply pump; and
- (c) control circuitry, which is configured to repeatedly:
 - (i) assume a mixing activation state, in which the control circuitry activates the mixing pump, and
 - (ii) assume a particle-delivery activation state,

wherein the control circuitry is configured, during each of one or more negative-positive particle delivery cycles of the particle-delivery activation state, to assume:

a negative particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump apply negative pressure to pump in a first direction, and

thereafter, a positive particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply positive pressure to pump in a second direction opposite the first direction.

Inventive concept 122. The apparatus according to inventive concept 121, wherein the solid particles are solid bone graft particles, and wherein the apparatus is for use with the solid bone graft particles.

10 Inventive concept 123. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at the same time.

Inventive concept 124. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at partially-overlapping times.

Inventive concept 125. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at non-overlapping times.

20 Inventive concept 126. The apparatus according to inventive concept 125, wherein the control circuitry is configured to assume the particle-delivery activation state within 500 ms after completing the mixing activation state.

Inventive concept 127. The apparatus according to inventive concept 126, wherein the control circuitry is configured to assume the particle-delivery activation state within 100 ms after completing the mixing activation state.

25 Inventive concept 128. The apparatus according to inventive concept 125, wherein the control circuitry is configured to repeatedly, in alternation, (a) assume the mixing activation state for between 100 and 1200 ms, and (b) assume the particle-delivery activation state.

30 Inventive concept 129. The apparatus according to inventive concept 128, wherein the control circuitry is configured to repeatedly, in alternation, (a) assume the mixing

activation state for between 100 and 1200 ms, and (b) assume the particle-delivery activation state for between 150 and 3000 ms.

Inventive concept 130. The apparatus according to inventive concept 121, wherein the control circuitry is configured to repeatedly assume the mixing activation state and the particle-delivery activation state over a time period having a duration of between 30 and 600 seconds.

Inventive concept 131. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the particle-delivery activation state in a plurality of particle-delivery-state cycles, and to begin the particle-delivery activation state in each of the particle-delivery-state cycles with the negative particle-delivery activation sub-state.

Inventive concept 132. The apparatus according to inventive concept 121, wherein the control circuitry is configured to repeatedly, in alternation, (a) assume the mixing activation state for between 100 and 1200 ms, and (b) assume the particle-delivery activation state.

Inventive concept 133. The apparatus according to inventive concept 121, wherein the control circuitry is configured to provide a plurality of the negative-positive particle delivery cycles during the particle-delivery activation state.

Inventive concept 134. The apparatus according to inventive concept 133, wherein the control circuitry is configured to provide up to 10 of the negative-positive particle delivery cycles during the particle-delivery activation state.

Inventive concept 135. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles.

Inventive concept 136. The apparatus according to inventive concept 135, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for between 25 and 100 ms during each of the one or more negative-positive particle delivery cycles

137. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the positive particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles.

5 Inventive concept 138. The apparatus according to inventive concept 137, wherein the control circuitry is configured to assume the positive particle-delivery activation sub-state for between 25 and 100 ms during each of the one or more negative-positive particle delivery cycles.

10 Inventive concept 139. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles, and to assume the positive particle-delivery activation sub-state for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles.

15 Inventive concept 140. The apparatus according to inventive concept 121, wherein the control circuitry is configured to assume the negative particle-delivery activation sub-state for a first duration during each of the one or more negative-positive particle delivery cycles, and to assume the positive particle-delivery activation sub-state for a second duration during each of the one or more negative-positive particle delivery cycles, the second duration equal to between 80% and 120% of the first duration.

20 Inventive concept 141. The apparatus according to inventive concept 121, wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor,

25 wherein the liquid-supply peristaltic pump is capable of (a) pumping fluid at an average rate throughout a full 360-degree revolution of the rotor at a certain speed, and (b) pumping fluid at a maximum rate during portions of the full 360-degree revolution at the certain speed, the maximum rate greater than the average rate, and

30 wherein the control circuitry is configured, when in both the positive and the negative particle-delivery activation sub-states, to activate the liquid-supply peristaltic pump to (a) rotate the rotor, at the certain speed, a partial revolution equal to a fraction of the full 360-degree revolution of the rotor, the fraction less than 1, and (b) pump, throughout the partial revolution, the fluid at the maximum rate.

Inventive concept 142. The apparatus according to inventive concept 121,

wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor, and

wherein the control circuitry is configured:

5 when in the positive particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to rotate the rotor, in a first rotational direction, a first partial revolution equal to a fraction of a full 360-degree revolution of the rotor, the fraction less than 1, and

10 when in the negative particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to rotate the rotor, in a second rotational direction opposite the first rotational direction, a second partial revolution equal to the fraction of the full 360-degree revolution of the rotor.

Inventive concept 143. The apparatus according to inventive concept 121, wherein the control circuitry is configured:

15 when in the positive particle-delivery activation sub-state, to activate the liquid-supply pump to pump a volume of between 0.1 and 2 cc of fluid, and

when in the negative particle-delivery activation sub-state, to activate the liquid-supply pump to pump the volume of fluid.

20 Inventive concept 144. The apparatus according to inventive concept 121, wherein the control circuitry and the liquid-supply pump are configured such that during at least a portion of the positive particle-delivery activation sub-state, the liquid-supply pump pumps the physiological liquid solution at a rate of at least 3 cc/sec.

Inventive concept 145. The apparatus according to inventive concept 144, wherein the rate is at least 7 cc/sec.

25 Inventive concept 146. The apparatus according to inventive concept 121, wherein the control circuitry and the liquid-supply pump are configured such that during at least a portion of the negative particle-delivery activation sub-state, the liquid-supply pump pumps the physiological liquid solution at a rate of at least 3 cc/sec.

Inventive concept 147. The apparatus according to inventive concept 146, wherein the rate is at least 7 cc/sec.

30 Inventive concept 148. The apparatus according to inventive concept 121, wherein the control circuitry and the mixing pump are configured such that during at least a portion of

the mixing activation state the mixing pump pumps the physiological liquid solution at a rate of at least 3 cc/sec.

Inventive concept 149. The apparatus according to inventive concept 148, wherein the rate is at least 7 cc/sec.

- 5 Inventive concept 150. The apparatus according to inventive concept 121, wherein the control circuitry and the mixing pump are configured such that throughout the mixing activation state the mixing pump pumps between 0.5 and 9 cc of the physiological liquid solution.

- 10 Inventive concept 151. The apparatus according to inventive concept 150, wherein the control circuitry and the mixing pump are configured such that throughout the mixing activation state the mixing pump pumps between 1.8 and 3.9 cc of the physiological liquid solution.

Inventive concept 152. The apparatus according to any one of inventive concepts 121-151,

- 15 wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor, and

wherein the control circuitry is configured, when in the positive particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to:

- 20 rotate the rotor a partial revolution equal to a fraction of a full 360-degree revolution of the rotor, the fraction less than 1, and
pump, throughout the partial revolution, a volume of fluid that is greater than the product of the fraction and a volume of fluid pumpable throughout the full 360-degree revolution of the rotor.

- 25 Inventive concept 153. The apparatus according to inventive concept 152, wherein the liquid-supply peristaltic pump further comprises a total number of rollers equal to at least two, and wherein the fraction is less than the quotient of 1 divided by the total number of rollers.

Inventive concept 154. The apparatus according to inventive concept 153, wherein the fraction is less than or equal to the quotient of 0.5 divided by the total number of rollers.

Inventive concept 155. The apparatus according to any one of inventive concepts 121-151, wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor.

5 Inventive concept 156. The apparatus according to inventive concept 155, wherein the liquid-supply peristaltic pump comprises an index sensor, which identifies a rotational position of the rotor.

Inventive concept 157. The apparatus according to inventive concept 155, wherein the control circuitry is configured to assume the particle-delivery activation state a plurality of times in alternation with mixing activation states, and to begin each of the particle-
10 delivery activation states with the rotor at a same rotational position.

Inventive concept 158. The apparatus according to any one of inventive concepts 121-151, wherein the mixing pump is a mixing peristaltic pump, which comprises a rotor.

Inventive concept 159. The apparatus according to inventive concept 158, wherein the mixing peristaltic pump comprises an index sensor, which identifies a rotational position
15 of the rotor.

Inventive concept 160. The apparatus according to inventive concept 158,

wherein the mixing peristaltic pump comprises a total number of rollers equal to at least two, and

wherein the control circuitry is configured to assume the mixing activation state a
20 plurality of times in alternation with particle-delivery activation states, and to begin the mixing activation states with the rotor at respective starting rotational positions, which are identical to one another or rotationally offset from one another by the product of (a) 360 degrees divided by the total number of rollers and (b) a positive integer.

Inventive concept 161. The apparatus according to inventive concept 158,

25 wherein the mixing peristaltic pump comprises (a) a pump casing that is shaped so as to define a partial-circle mixing tube channel in which the mixing tube is disposed, and (b) an odd total number of rollers, the odd total number equal to at least one, and

wherein the control circuitry is configured to assume the mixing activation state a plurality of times in alternation with particle-delivery activation states, and to begin each
30 of the mixing activation states with an aligned total number of the rollers rotationally

aligned with the mixing tube channel, the aligned total number equal to more than half of the odd total number.

Inventive concept 162. The apparatus according to inventive concept 161, wherein the odd total number equals at least three.

- 5 Inventive concept 163. The apparatus according to any one of inventive concepts 121-151, wherein the mixing pump and the liquid-supply pump are respective peristaltic pumps.

Inventive concept 164. The apparatus according to inventive concept 163, wherein the peristaltic pumps comprise respective rotors and index sensors, which identify respective
10 rotational positions of the rotors.

Inventive concept 165. The apparatus according to inventive concept 163, wherein the control circuitry is configured to rotate the mixing peristaltic pump rotates between 1/3 and 3 revolutions in the mixing activation state.

Inventive concept 166. The apparatus according to inventive concept 165, wherein the
15 mixing peristaltic pump rotates one revolution throughout the mixing activation state.

There is additionally provided, in accordance with an inventive concept 167 of the present invention, apparatus for use with solid particles and a physiological liquid solution, the apparatus comprising:

a composition delivery source, which comprises:

- 20 (a) a chamber, which is shaped so as to define one or more liquid ports and one or more solid-liquid composition ports;

(b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports; and

- 25 (c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and

a pump unit, which comprises a mixing pump, which is arranged to cause, in the mixing tube, flow that raises the solid particles in a puff into the physiological liquid
30 solution in the chamber.

Inventive concept 168. The apparatus according to inventive concept 167, wherein the solid particles are solid bone graft particles, and wherein the apparatus is for use with the solid bone graft particles.

Inventive concept 169. The apparatus according to inventive concept 167,

5 wherein the chamber comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment,

 wherein the one or more liquid ports are in fluid communication with the liquid compartment, and

10 wherein the one or more solid-liquid composition ports are in fluid communication with the solid-liquid composition compartment.

Inventive concept 170. The apparatus according to inventive concept 169, further comprising the solid particles, wherein the filter is configured to inhibit passage of the solid particles and allow passage of the physiological liquid solution.

15 Inventive concept 171. The apparatus according to inventive concept 169, for use with a liquid container,

 wherein the composition delivery source further comprises a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container, and

20 wherein the pump unit further comprises a liquid-supply pump, which is arranged to cause flow in the liquid-supply tube.

 There is yet additionally provided, in accordance with an inventive concept 172 of the present invention, a method for use with solid particles and a liquid container containing a physiological liquid solution, the method comprising:

25 providing a composition delivery source, which comprises (a) a chamber, which (i) comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment, and (ii) is shaped so as to define (A) one or more liquid ports in fluid communication with the liquid compartment, and (B) one or more solid-liquid composition ports in fluid communication
30 with the solid-liquid composition compartment; (b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports; (c) a mixing tube, which is in fluid communication with at least one of

the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and (d) a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container;

- 5 providing a pump unit, which comprises (a) a mixing pump, which is arranged to cause flow in the mixing tube; and (b) a liquid-supply pump, which is arranged to cause flow in the liquid-supply tube;

- inserting, from a first side of a maxillary bone of a jaw, a shaft delivery tube of a shaft unit into a bore that passes through the maxillary bone from the first side to a second
10 side of the maxillary bone, such that a distal opening of the shaft delivery tube is disposed in the bore or in a cavity that is (a) adjacent to the second side of the maxillary bone and (b) between the second side of the maxillary bone and a Schneiderian membrane, wherein the distal opening is in fluid communication with the delivery tube, and the shaft delivery tube is in fluid communication with a distal end of the solid-liquid composition delivery
15 tube; and

 activating the pump unit to:

 provide a solid-liquid composition of (a) the solid particles and (b) the physiological liquid solution, and

- injecting the solid-liquid composition through the distal opening via the
20 shaft delivery tube and the solid-liquid composition delivery tube.

- Inventive concept 173. The method according to inventive concept 172, wherein the solid particles are solid bone graft particles, and wherein activating the pump unit to provide the solid-liquid composition comprises activating the pump unit to provide the solid-liquid composition of (a) the solid bone graft particles and (b) the physiological liquid
25 solution.

Inventive concept 174. The method according to inventive concept 172, further comprising raising the Schneiderian membrane to form the cavity.

Inventive concept 175. The method according to inventive concept 174,

- wherein inserting the shaft delivery tube comprises positioning the distal opening
30 at a solid-liquid-composition-delivery location,
 wherein raising the Schneiderian membrane comprises:

positioning the distal opening at a liquid-delivery location that is within the bore or within 1 mm above the bore; and

while the distal opening is positioned at the liquid-delivery location, injecting the physiological liquid solution to raise the Schneiderian membrane, and

5 wherein positioning the distal opening at the solid-liquid-composition-delivery location comprises positioning the distal opening at the solid-liquid-composition-delivery location after finishing injecting the physiological liquid solution to raise the Schneiderian membrane.

Inventive concept 176. The method according to inventive concept 175,

10 wherein positioning the distal opening at the liquid-delivery location comprises positioning the distal opening at the liquid-delivery location while a removable depth limiting element is attached to the shaft delivery tube, wherein the removable depth limiting element limits advancement of the shaft delivery tube through the bore, and

15 wherein positioning the distal opening at the solid-liquid-composition-delivery location comprises removing the depth limiting element from the shaft delivery tube, and subsequently advancing the shaft delivery tube through the bore until the distal opening reaches the solid-liquid-composition-delivery location.

Inventive concept 177. The method according to inventive concept 172, wherein activating the pump unit comprises activating control circuitry of the pump unit to
20 repeatedly:

(a) assume a mixing activation state, in which the control circuitry activates the mixing pump to mix the solid particles and the physiological liquid solution in the solid-liquid composition compartment to form a solid-liquid composition, by pumping the physiological liquid solution through the mixing tube and into the solid-liquid
25 composition compartment, and

(b) assume a particle-delivery activation state, wherein the control circuitry, during at least a portion of the particle-delivery activation state, activates the liquid-supply pump to apply positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube.

30 Inventive concept 178. The method according to inventive concept 177, wherein activating the control circuitry comprises activating the control circuitry, during each of

one or more negative-positive particle delivery cycles of the particle-delivery activation state, to assume:

5 a negative particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply negative pressure to pump liquid from the solid-liquid composition delivery tube toward the liquid compartment via the solid-liquid composition compartment, and

10 a positive particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply the positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube, wherein a direction of pumping of the liquid-supply pump in the positive particle-delivery activation sub-state is opposite a direction of pumping of the liquid-supply pump in the negative particle-delivery activation sub-state.

Inventive concept 179. The method according to inventive concept 172,

15 wherein the chamber comprises a receptacle component and a cover component, wherein the cover component (a) comprises the filter, and (b) is shaped so as to define (i) a cap and (ii) a bone-graft container having an opening that (x) faces away from the cap and (y) is farther from the cap than the filter is from the cap, and

20 wherein providing the composition delivery source comprises, while the bone-graft container contains the solid particles, reversibly coupling the receptacle component and the cover component with each another to form a watertight seal, with the bone-graft container disposed within the receptacle component.

Inventive concept 180. The method according to inventive concept 172, wherein the mixing pump and the liquid-supply pump are respective peristaltic pumps.

25 There is also provided, in accordance with an inventive concept 181 of the present invention, a method for use with solid particles and a liquid container containing a physiological liquid solution, the method comprising:

30 providing a composition delivery source, which comprises (a) a chamber, which (i) comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment, and (ii) is shaped so as to define (A) one or more liquid ports in fluid communication with the liquid compartment, and (B) one or more solid-liquid composition ports in fluid communication with the solid-liquid composition compartment; (b) a solid-liquid composition delivery

tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports; (c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and (d) a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container;

inserting, from a first side of a maxillary bone of a jaw, a shaft delivery tube of a shaft unit into a bore that passes through the maxillary bone from the first side to a second side of the maxillary bone, such that a distal opening of the shaft delivery tube is disposed in the bore or in a cavity that is (a) adjacent to the second side of the maxillary bone and (b) between the second side of the maxillary bone and a Schneiderian membrane, wherein the distal opening is in fluid communication with the delivery tube, and the shaft delivery tube is in fluid communication with a distal end of the solid-liquid composition delivery tube;

providing a solid-liquid composition of (a) the solid particles and (b) the physiological liquid solution from composition delivery source; and

injecting the solid-liquid composition through the distal opening via the shaft delivery tube and the solid-liquid composition delivery tube.

Inventive concept 182. The method according to inventive concept 181, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of (a) the solid bone graft particles and (b) the physiological liquid solution.

Inventive concept 183. The method according to inventive concept 181, wherein providing the composition delivery source comprises orienting the chamber such that the liquid compartment is above the solid-liquid composition compartment.

Inventive concept 184. The method according to inventive concept 183, wherein when the chamber is oriented such that the liquid compartment is above the solid-liquid composition compartment, the one or more solid-liquid composition ports are disposed no more than a distance from a bottom of the solid-liquid composition compartment, the distance equal to 25% of a vertical height of the solid-liquid composition compartment.

Inventive concept 185. The method according to inventive concept 183, wherein when the chamber is oriented such that the liquid compartment is above the solid-liquid

composition compartment, the one or more solid-liquid composition ports are located through a side wall of the solid-liquid composition compartment.

Inventive concept 186. The method according to inventive concept 181, wherein injecting the solid-liquid composition comprises orienting the solid-liquid composition delivery
5 tube within 45 degrees of horizontal.

Inventive concept 187. The method according to inventive concept 186, wherein orienting comprises orienting the solid-liquid composition delivery tube within 15 degrees of horizontal.

Inventive concept 188. The method according to inventive concept 181,
10 wherein the chamber comprises a receptacle component and a cover component,
wherein the cover component (a) comprises the filter, and (b) is shaped so as to define (i) a cap and (ii) a bone-graft container having an opening that (x) faces away from the cap and (y) is farther from the cap than the filter is from the cap, and
wherein providing the composition delivery source comprises, while the bone-
15 graft container contains the solid particles, reversibly coupling the receptacle component and the cover component with each another to form a watertight seal, with the bone-graft container disposed within the receptacle component.

Inventive concept 189. The method according to inventive concept 181, wherein the shaft unit further comprises a removable depth limiting element, which is configured to limit a
20 depth of insertion of the shaft delivery tube into the bore when the shaft delivery tube is inserted into the bore.

Inventive concept 190. The method according to inventive concept 189,
wherein the shaft unit comprises a shaft delivery tube,
wherein the shaft unit further comprises a sealing element disposed around an
25 external surface of the shaft delivery tube, and
wherein the depth limiting element is removable from the shaft unit without removal of the sealing element.

There is further provided, in accordance with an inventive concept 191 of the present invention, a method for use with solid particles and a physiological liquid
30 solution, the method comprising:
providing a composition delivery source, which comprises:

(a) a chamber, which is shaped so as to define one or more liquid ports and one or more solid-liquid composition ports;

(b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports; and

(c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and

activating a pump unit, which comprises a mixing pump, to cause, in the mixing tube, flow that raises the solid particles in a puff into the physiological liquid solution in the chamber, thereby forming a solid-liquid composition.

Inventive concept 192. The method according to inventive concept 191, wherein the solid particles are solid bone graft particles, and wherein activating the pump unit comprises activating the pump unit to cause, in the mixing tube, the flow that raises the solid bone graft particles in the puff.

Inventive concept 193. The method according to inventive concept 191,

wherein the chamber comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment,

wherein the one or more liquid ports are in fluid communication with the liquid compartment, and

wherein the one or more solid-liquid composition ports are in fluid communication with the solid-liquid composition compartment.

Inventive concept 194. The method according to inventive concept 193, wherein the filter is configured to inhibit passage of the solid particles and allow passage of the physiological liquid solution.

Inventive concept 195. The method according to inventive concept 193, for use with a liquid container,

wherein the composition delivery source further comprises a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container, and

wherein the pump unit further comprises a liquid-supply pump, which is arranged to cause flow in the liquid-supply tube.

Inventive concept 196. The method according to inventive concept 193, wherein providing the composition delivery source comprises orienting the chamber such that the liquid compartment is above the solid-liquid composition compartment.

Inventive concept 197. The method according to inventive concept 196, wherein when the chamber is oriented such that the liquid compartment is above the solid-liquid composition compartment, the one or more solid-liquid composition ports are disposed no more than a distance from a bottom of the solid-liquid composition compartment, the distance equal to 25% of a vertical height of the solid-liquid composition compartment.

Inventive concept 198. The method according to inventive concept 196, wherein when the chamber is oriented such that the liquid compartment is above the solid-liquid composition compartment, the one or more solid-liquid composition ports are located through a side wall of the solid-liquid composition compartment.

Inventive concept 199. The method according to inventive concept 191, further comprising activating the pump unit to pump the solid-liquid composition through the solid-liquid composition delivery tube.

Inventive concept 200. The method according to inventive concept 199, wherein activating the pump unit to pump the solid-liquid composition through the solid-liquid composition delivery tube comprises orienting the solid-liquid composition delivery tube within 45 degrees of horizontal.

Inventive concept 201. The method according to inventive concept 200, wherein orienting comprises orienting the solid-liquid composition delivery tube within 15 degrees of horizontal.

There is still further provided, in accordance with an inventive concept 202 of the present invention, a method comprising:

inserting, from a first side of a maxillary bone of a jaw, a shaft delivery tube of a shaft unit of a injection system into a bore that passes through the maxillary bone from the first side to a second side of the maxillary bone, such that a distal opening of the shaft delivery tube is disposed in a cavity that is (a) adjacent to the second side of the maxillary bone and (b) between the second side of the maxillary bone and a Schneiderian

membrane, wherein the distal opening is in fluid communication with the shaft delivery tube;

positioning the distal opening at a location at a distance from the second side of the maxillary bone, the distance equal to at least 50% of a height of the cavity directly
5 above the bore;

providing a solid-liquid composition of (a) solid particles and (b) a physiological liquid solution from a solid-liquid composition source that is coupled in fluid communication with the shaft delivery tube; and

while the distal opening is positioned at the location, injecting the solid-liquid
10 composition through the distal opening via the shaft delivery tube.

Inventive concept 203. The method according to inventive concept 202, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of (a) the solid bone graft particles and (b) the physiological liquid solution.

15 Inventive concept 204. The method according to inventive concept 202, wherein the distance is equal to at least 75% of the height of the cavity directly above the bore.

Inventive concept 205. The method according to inventive concept 202, wherein the distal opening of the shaft delivery tube is disposed within 10 mm of a distal end of the shaft delivery tube.

20 Inventive concept 206. The method according to inventive concept 202, further comprising raising the Schneiderian membrane to form the cavity.

Inventive concept 207. The method according to inventive concept 206,

wherein positioning the distal opening at the location comprises positioning the distal opening at a solid-liquid-composition-delivery location,

25 wherein raising the Schneiderian membrane comprises:

positioning the distal opening at a liquid-delivery location that is within the bore or within 1 mm above the bore; and

while the distal opening is positioned at the liquid-delivery location, injecting the physiological liquid solution to raise the Schneiderian membrane, and

30 wherein positioning the distal opening at the solid-liquid-composition-delivery location comprises positioning the distal opening at the solid-liquid-composition-delivery

location after finishing injecting the physiological liquid solution to raise the Schneiderian membrane.

Inventive concept 208. The method according to inventive concept 207,

5 wherein positioning the distal opening at the liquid-delivery location comprises positioning the distal opening at the liquid-delivery location while a removable depth limiting element is attached to the shaft delivery tube, wherein the removable depth limiting element limits advancement of the shaft delivery tube through the bore, and

10 wherein positioning the distal opening at the solid-liquid-composition-delivery location comprises removing the depth limiting element from the shaft delivery tube, and subsequently advancing the shaft delivery tube through the bore until the distal opening reaches the solid-liquid-composition-delivery location.

Inventive concept 209. The method according to inventive concept 208,

wherein the shaft unit further comprises a sealing element disposed around an external surface of the shaft delivery tube, and

15 wherein removing the depth limiting element from the shaft delivery tube comprises removing the depth limiting element from the shaft delivery tube without removing the sealing element.

Inventive concept 210. The method according to inventive concept 202, wherein positioning the distal opening comprises positioning the distal opening at between 2 and 20 12 mm from the Schneiderian membrane at a roof of the cavity directly above the bore.

Inventive concept 211. The method according to inventive concept 210, wherein positioning the distal opening comprises positioning the distal opening at between 4 and 6 mm from the Schneiderian membrane at the roof of the cavity directly above the bore.

25 Inventive concept 212. The method according to inventive concept 202, wherein the distal opening is disposed at the distal end of the shaft delivery tube, and wherein positioning the distal opening comprises positioning the distal end of the shaft delivery tube at the location.

30 Inventive concept 213. The method according to inventive concept 202, wherein raising the Schneiderian membrane comprises injecting physiological solution through the shaft delivery tube after inserting the shaft delivery tube into the bore.

Inventive concept 214. The method according to inventive concept 202, wherein injecting the solid-liquid composition comprises pumping the solid-liquid composition through the distal opening via the shaft delivery tube at a pulsating hydraulic pressure that periodically varies between positive and negative.

5 There is additionally provided, in accordance with an inventive concept 215 of the present invention, a surgical tool for use with solid particles and a physiological liquid solution, the surgical tool comprising:

 a shaft unit, which is shaped so as to define a delivery lumen, and a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication
10 with the delivery lumen;

 a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

 a pump, which is configured to pump the solid-liquid composition through the
15 distal opening via the delivery lumen.

Inventive concept 216. The apparatus according to inventive concept 215, wherein the surgical tool is configured as an oral surgical tool.

Inventive concept 217. The apparatus according to inventive concept 215, further comprising the physiological liquid solution.

20 Inventive concept 218. The apparatus according to inventive concept 215, wherein the pump is configured to pump the solid-liquid composition at a pulsating hydraulic pressure that periodically varies between positive and negative.

 Inventive concept 219. The apparatus according to inventive concept 218, wherein the pump is configured to pump the solid-liquid composition through the distal opening via
25 the delivery lumen during a plurality of positive-pressure periods that alternate with a plurality of negative-pressure periods, and to set an average duration of the positive-pressure periods to be less than or equal to an average duration of the negative-pressure periods.

 Inventive concept 220. The apparatus according to inventive concept 219, wherein the
30 pump is configured to set the average duration of the positive-pressure periods to be equal to the average duration of the negative-pressure periods.

Inventive concept 221. The apparatus according to inventive concept 215, wherein the pump is configured to pump the solid-liquid composition at a pulsating positive hydraulic pressure.

5 Inventive concept 222. The apparatus according to inventive concept 215, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

Inventive concept 223. The apparatus according to inventive concept 222, wherein the distal opening is disposed at the distal end of the shaft unit.

Inventive concept 224. The apparatus according to inventive concept 215, wherein the shaft unit comprises a nozzle disposed at the distal opening.

10 Inventive concept 225. The apparatus according to inventive concept 215, wherein the surgical tool further comprises a sealing element disposed around an external surface of the shaft unit, and configured to form a liquid-tight seal with tissue around and outside a bore through a bone when the shaft unit is inserted into the bore.

15 Inventive concept 226. The apparatus according to inventive concept 225, wherein the distal end of the shaft unit is disposed no more distal than a distal-most surface of the sealing element.

Inventive concept 227. The apparatus according to inventive concept 215, wherein the surgical tool further comprises a depth limiting element, which is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is
20 inserted into the bore.

Inventive concept 228. The apparatus according to any one of inventive concepts 215-227, wherein the composition source comprises a combining unit, which is configured to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

25 Inventive concept 229. The apparatus according to inventive concept 228, wherein the combining unit comprises a mixing unit, which is configured to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

Inventive concept 230. The apparatus according to any one of inventive concepts 215-227, wherein the surgical tool further comprises a solid-particle container, which contains
30 the solid particles for combining with the physiological liquid solution.

Inventive concept 231. The apparatus according to inventive concept 230, wherein the solid-particle container has a volume of between 0.2 and 20 ml.

Inventive concept 232. The apparatus according to inventive concept 230, wherein the surgical tool further comprises the physiological liquid solution.

- 5 Inventive concept 233. The apparatus according to any one of inventive concepts 215-227, wherein the solid particles are solid bone graft particles, and wherein the surgical tool is for use with the solid bone graft particles.

There is yet additionally provided, in accordance with an inventive concept 234 of the present invention, a method comprising:

- 10 inserting, from a first side of a bone, a shaft unit of a surgical tool into a bore that passes through the bone from the first side to a second side of the bone, such that a distal opening disposed within 10 mm of a distal end of the shaft unit is disposed in the bore or in a cavity adjacent to the second side of the bone, wherein the distal opening is in fluid communication with a delivery lumen defined by the shaft unit;

- 15 providing a solid-liquid composition of (a) solid particles and (b) a physiological liquid solution from a solid-liquid composition source that is coupled in fluid communication with the delivery lumen; and

pumping the solid-liquid composition through the distal opening via the delivery lumen.

- 20 Inventive concept 235. The method according to inventive concept 234, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of (a) the solid bone graft particles and (b) the physiological liquid solution.

- 25 Inventive concept 236. The method according to inventive concept 234, wherein pumping comprises pumping at a pulsating hydraulic pressure that periodically varies between positive and negative.

- Inventive concept 237. The method according to inventive concept 236, wherein pumping comprises pumping the solid-liquid composition through the distal opening via the delivery lumen during a plurality of positive-pressure periods that alternate with a plurality of negative-pressure periods, and setting an average duration of the positive-pressure periods to be less than an average duration of the negative-pressure periods.
- 30

Inventive concept 238. The method according to inventive concept 236, wherein pumping comprises pumping the solid-liquid composition at a pulsating positive hydraulic pressure.

5 Inventive concept 239. The method according to inventive concept 234, wherein the surgical tool is configured as an oral surgical tool, wherein the bone is a bone of a jaw, and wherein inserting comprises inserting the shaft unit of the oral surgical tool into the bore that passes through the bone of the jaw.

Inventive concept 240. The method according to inventive concept 234, wherein the cavity is between the second side of the bone and a membrane.

10 Inventive concept 241. The method according to inventive concept 240, further comprising, before pumping the solid-liquid composition, raising the membrane to form the cavity between the second side of the bone and the membrane.

Inventive concept 242. The method according to inventive concept 241,
wherein the membrane is a Schneiderian membrane, and the bone is a maxillary
15 bone,
wherein inserting the shaft unit comprises positioning the distal opening at a location at a distance from the second side of the maxillary bone, the distance equal to at least 50% of a height of the cavity directly above the bore, and
wherein pumping comprises pumping while the distal opening is positioned at the
20 location.

Inventive concept 243. The method according to inventive concept 242, wherein the distance is equal to at least 75% of the height of the cavity directly above the bore.

Inventive concept 244. The method according to inventive concept 242, wherein positioning the distal opening comprises positioning the distal opening at between 2 and
25 12 mm from the Schneiderian membrane at a roof of the cavity directly above the bore.

Inventive concept 245. The method according to inventive concept 244, wherein positioning the distal opening comprises positioning the distal opening at between 4 and 6 mm from the Schneiderian membrane at the roof of the cavity directly above the bore.

Inventive concept 246. The method according to inventive concept 242, wherein the distal
30 opening is disposed at the distal end of the shaft unit, and wherein positioning the distal opening comprises positioning the distal end of the shaft unit at the location.

Inventive concept 247. The method according to inventive concept 242, wherein raising the Schneiderian membrane comprises injecting physiological solution through the delivery lumen after inserting the shaft unit into the bore.

Inventive concept 248. The method according to inventive concept 241,

5 wherein the membrane is a Schneiderian membrane, and the bone is a maxillary bone, and

 wherein inserting the shaft unit comprises positioning the distal opening at a location at a distance of between 2 and 12 mm from the Schneiderian membrane at a roof of the cavity directly above the bore.

10 Inventive concept 249. The method according to inventive concept 248, wherein positioning the distal opening comprises positioning the distal opening at between 4 and 6 mm from the Schneiderian membrane at the roof of the cavity directly above the bore.

Inventive concept 250. The method according to inventive concept 248, wherein the distal opening is disposed at the distal end of the shaft unit, and wherein positioning the distal
15 opening comprises positioning the distal end of the shaft unit at the location.

Inventive concept 251. The method according to inventive concept 248, wherein raising the Schneiderian membrane comprises injecting physiological solution through the delivery lumen after inserting the shaft unit into the bore.

Inventive concept 252. The method according to inventive concept 240, wherein the
20 membrane is a Schneiderian membrane.

Inventive concept 253. The method according to inventive concept 234, wherein the bore is exactly one bore through the bone.

Inventive concept 254. The method according to inventive concept 234, further comprising, after pumping the solid-liquid composition, implanting an implant at least
25 partially within the cavity.

Inventive concept 255. The method according to inventive concept 234, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

Inventive concept 256. The method according to inventive concept 255, wherein the distal opening is disposed at the distal end of the shaft unit.

Inventive concept 257. The method according to inventive concept 234, wherein providing the solid-liquid composition and pumping the solid-liquid composition comprises providing the solid-liquid composition and injecting the solid-liquid composition such that between 0.2 and 20 ml of solid particles accumulate in the cavity.

- 5 Inventive concept 258. The method according to inventive concept 234, wherein the solid-liquid composition source comprises a combining unit, and wherein providing the solid-liquid composition comprises activating the combining unit to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

- 10 Inventive concept 259. The method according to inventive concept 258, wherein the combining unit comprises a mixing unit, and wherein providing the solid-liquid composition comprises activating the mixing unit to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

- There is also provided, in accordance with an inventive concept 260 of the present invention, apparatus comprising a surgical tool for use with solid particles and a
15 physiological liquid solution, the surgical tool comprising:

exactly one shaft unit, which is shaped so as to define a delivery lumen and a drainage lumen;

a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the delivery lumen;

- 20 a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

- a filter, which is disposed in fluid communication with the drainage lumen, and which is configured to inhibit passage of the solid particles of the solid-liquid composition
25 and allow passage of the physiological liquid solution of the solid-liquid composition.

Inventive concept 261. The apparatus according to inventive concept 260, wherein the filter is disposed within 10 mm of the distal end of the shaft unit.

Inventive concept 262. The apparatus according to inventive concept 260, wherein the filter is disposed around an axis of the distal opening.

- 30 Inventive concept 263. The apparatus according to inventive concept 260, wherein the drainage lumen is disposed alongside the delivery lumen in the shaft unit.

Inventive concept 264. The apparatus according to inventive concept 260, wherein the filter is disposed around the delivery lumen in the shaft unit.

Inventive concept 265. The apparatus according to inventive concept 260, further comprising a pump, which is configured to clear the solid particles that accumulate on the filter during drainage of the physiological liquid solution through the filter, by
5 periodically applying a positive pressure to the drainage lumen.

Inventive concept 266. The apparatus according to inventive concept 260, wherein the filter comprises a mesh having openings smaller than the solid particles.

Inventive concept 267. The apparatus according to inventive concept 260, wherein the filter is shaped so as to define a plurality of slits having a width narrower than the solid
10 particles.

Inventive concept 268. The apparatus according to inventive concept 260, wherein the surgical tool is configured to move the distal opening and the shaft unit with respect to each other.

15 Inventive concept 269. The apparatus according to inventive concept 268, wherein the distal opening comprises a nozzle.

Inventive concept 270. The apparatus according to inventive concept 268, wherein the surgical tool further comprises a filter clearing element, which is fixed to the distal opening, and is configured to clear the solid particles that accumulate on the filter during
20 drainage of the physiological liquid solution through the filter.

Inventive concept 271. The apparatus according to inventive concept 270, wherein the distal opening comprises a nozzle, and wherein the filter clearing element is fixed to the nozzle.

Inventive concept 272. The apparatus according to inventive concept 268, wherein the surgical tool is configured to rotate the distal opening and the shaft unit with respect to
25 each other.

Inventive concept 273. The apparatus according to inventive concept 272, wherein the surgical tool is configured to rotate the distal opening while holding the shaft unit rotationally immobile.

Inventive concept 274. The apparatus according to inventive concept 272, wherein the surgical tool is configured to rotate the shaft unit while holding the distal opening rotationally immobile.

5 Inventive concept 275. The apparatus according to inventive concept 272, wherein the surgical tool further comprises a filter clearing element, which is fixed to the distal opening, and is configured to clear the solid particles that accumulate on the filter during drainage of the physiological liquid solution through the filter.

10 Inventive concept 276. The apparatus according to inventive concept 268, wherein the surgical tool is configured to move the distal opening and the shaft unit side-to-side with respect to each other.

Inventive concept 277. The apparatus according to inventive concept 268, wherein the surgical tool is configured to move the distal opening and the shaft unit axially back-and-forth with respect to each other.

15 Inventive concept 278. The apparatus according to inventive concept 268, wherein the surgical tool is configured to vibrate the distal opening and the shaft unit side-to-side with respect to each other.

Inventive concept 279. The apparatus according to inventive concept 268, wherein the surgical tool is configured such that flow of the solid-liquid composition causes the distal opening and the shaft unit to move with respect to each other.

20 Inventive concept 280. The apparatus according to inventive concept 268, wherein the surgical tool is configured such that flow of the filtered physiological liquid solution causes the distal opening and the shaft unit to move with respect to each other.

25 Inventive concept 281. The apparatus according to inventive concept 260, wherein the surgical tool further comprises a filter clearing element, which is configured to clear the solid particles that accumulate on the filter during drainage of the physiological liquid solution through the filter.

Inventive concept 282. The apparatus according to inventive concept 281, wherein the surgical tool is configured to move the filter clearing element with respect to the filter.

30 Inventive concept 283. The apparatus according to inventive concept 282, wherein the surgical tool is configured to rotate the filter clearing element.

Inventive concept 284. The apparatus according to inventive concept 282, wherein the surgical tool is configured to axially move the filter clearing element.

Inventive concept 285. The apparatus according to inventive concept 281, wherein the filter clearing element is fixed to the distal opening.

- 5 Inventive concept 286. The apparatus according to inventive concept 285, wherein the distal opening comprises a nozzle, and wherein the filter clearing element is fixed to the nozzle.

There is further provided, in accordance with an inventive concept 287 of the present invention, apparatus comprising a surgical tool for use with solid particles and a
10 physiological liquid solution, the surgical tool comprising:

exactly one shaft unit, which is shaped so as to define a delivery lumen and a drainage lumen;

a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the delivery lumen;

- 15 a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

a plurality of elements disposed around and outside the delivery lumen for facilitating (a) inhibiting passage of the solid particles of the solid-liquid composition to
20 the drainage lumen, and (b) allowing passage of the physiological liquid solution of the solid-liquid composition to the drainage lumen.

There is still further provided, in accordance with an inventive concept 288 of the present invention, apparatus comprising a surgical tool for use with solid particles and a physiological liquid solution, the surgical tool comprising:

- 25 exactly one shaft unit, which (a) is shaped so as to define a drainage lumen, and (b) comprises a delivery shaft, which is shaped so as to define (i) a delivery lumen, and (ii) a plurality of rib elements that extend radially outward from an external surface of the delivery shaft;

a distal opening, which is disposed within 10 mm of a distal end of the shaft unit,
30 in fluid communication with the delivery lumen; and

a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution.

5 Inventive concept 289. The apparatus according to inventive concept 288, wherein the rib elements extend an average distance of between 0.1 and 2 mm radially outward from the external surface of the delivery shaft.

Inventive concept 290. The apparatus according to inventive concept 288, wherein the rib elements extend longitudinally along the external surface of the delivery shaft for an average distance of at least 1 mm.

10 Inventive concept 291. The apparatus according to inventive concept 288, wherein the surgical tool further comprises a depth limiting element, which is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is inserted into the bore.

15 Inventive concept 292. The apparatus according to inventive concept 291, wherein the depth limiting element is removably attached to the shaft unit.

Inventive concept 293. The apparatus according to inventive concept 291, wherein the depth limiting element is shaped so as to define a portion of the drainage lumen between at least a portion of an internal surface of the depth limiting element and a portion of the external surface of the delivery shaft.

20 Inventive concept 294. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool is configured as an oral surgical tool.

Inventive concept 295. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the solid particles are solid bone graft particles, and wherein the surgical tool is for use with the solid bone graft particles.

25 Inventive concept 296. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

Inventive concept 297. The apparatus according to inventive concept 296, wherein the distal opening is disposed at the distal end of the shaft unit.

Inventive concept 298. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the distal opening comprises a nozzle.

Inventive concept 299. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool is configured to vibrate the solid-liquid
5 composition in the delivery lumen.

Inventive concept 300. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the drainage lumen is disposed around the delivery lumen in the shaft unit.

Inventive concept 301. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool further comprises a suction source, which is
10 coupled in fluid communication with the drainage lumen.

Inventive concept 302. The apparatus according to any one of inventive concepts 260, 287, and 288, for use with a suction source, wherein the drainage lumen is coupleable in fluid communication with the suction source.

15 Inventive concept 303. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool further comprises a sealing element disposed around an external surface of the shaft unit, and configured to form a liquid-tight seal with tissue around and outside a bore through a bone when the shaft unit is inserted into the bore.

20 Inventive concept 304. The apparatus according to inventive concept 303, wherein the distal end of the shaft unit is disposed no more distal than a distal-most surface of the sealing element.

Inventive concept 305. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool further comprises a depth limiting element, which
25 is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is inserted into the bore.

Inventive concept 306. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the composition source comprises a combining feeder unit, which is configured to provide the solid-liquid composition by combining the solid particles with
30 the physiological liquid solution.

Inventive concept 307. The apparatus according to inventive concept 306, wherein the combining feeder unit comprises a mixing feeder unit, which is configured to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

- 5 Inventive concept 308. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool is configured to automatically apply motion to the shaft unit selected from the group consisting of: vibrational motion, rotational motion, oscillatory motion, axial back-and-forth motion, and lateral side-to-side motion.

- 10 Inventive concept 309. The apparatus according to any one of inventive concepts 260, 287, and 288, further comprising a pump, which is configured to pump the solid-liquid composition through the distal opening via the delivery lumen.

Inventive concept 310. The apparatus according to inventive concept 309, wherein the pump is configured to pump the solid-liquid composition at a pulsating positive hydraulic pressure.

- 15 Inventive concept 311. The apparatus according to inventive concept 309, wherein the pump is configured to pump the solid-liquid composition at a pulsating hydraulic pressure that periodically varies between positive and negative.

- 20 Inventive concept 312. The apparatus according to any one of inventive concepts 260, 287, and 288, wherein the surgical tool further comprises a solid-particle container, which contains the solid particles for combining with the physiological liquid solution.

Inventive concept 313. The apparatus according to inventive concept 312, wherein the solid-particle container has a volume of between 0.2 and 20 ml.

Inventive concept 314. The apparatus according to inventive concept 312, wherein the surgical tool further comprises the physiological liquid solution.

- 25 There is additionally provided, in accordance with an inventive concept 315 of the present invention, apparatus comprising a surgical tool for use with solid particles and a physiological liquid solution, the surgical tool comprising:

exactly one shaft unit, which is shaped so as to define a lumen;

- 30 a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the lumen;

a composition source, which is coupled in selective fluid communication with the lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

5 a one-way filter, which is disposed in fluid communication with the lumen, and which is configured to:

allow passage, in a proximal-to-distal direction, of the solid particles and the physiological liquid solution of the solid-liquid composition,

inhibit passage, in a distal-to-proximal direction, of the solid particles of the solid-liquid composition, and

10 allow passage, in the distal-to-proximal direction, of the physiological liquid solution of the solid-liquid composition.

Inventive concept 316. The apparatus according to inventive concept 315, wherein the surgical tool is configured as an oral surgical tool.

15 Inventive concept 317. The apparatus according to inventive concept 315, wherein the solid particles are solid bone graft particles, and wherein the surgical tool is for use with the solid bone graft particles.

Inventive concept 318. The apparatus according to inventive concept 315, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

20 Inventive concept 319. The apparatus according to inventive concept 318, wherein the distal opening is disposed at the distal end of the shaft unit.

Inventive concept 320. The apparatus according to inventive concept 315, wherein the shaft unit is shaped so as to define exactly one lumen.

Inventive concept 321. The apparatus according to inventive concept 315, wherein the one-way filter is disposed within 10 mm of the distal end of the shaft unit.

25 Inventive concept 322. The apparatus according to inventive concept 315, wherein the composition source comprises a combining feeder unit, which is configured to produce the solid-liquid composition by combining the solid particles with the physiological liquid solution.

30 Inventive concept 323. The apparatus according to inventive concept 315, wherein the distal opening comprises a nozzle.

Inventive concept 324. The apparatus according to inventive concept 315, wherein the surgical tool is configured to automatically apply motion to the shaft unit selected from the group consisting of: vibrational motion, rotational motion, oscillatory motion, axial back-and-forth motion, and lateral side-to-side motion.

- 5 Inventive concept 325. The apparatus according to inventive concept 315, wherein the surgical tool is configured to vibrate the solid-liquid composition in the lumen.

Inventive concept 326. The apparatus according to inventive concept 315, wherein the surgical tool further comprises a sealing element disposed around an external surface of the shaft unit, and configured to form a liquid-tight seal with tissue around and outside a
10 bore through a bone when the shaft unit is inserted into the bore.

Inventive concept 327. The apparatus according to inventive concept 326, wherein the distal end of the shaft unit is disposed no more distal than a distal-most surface of the sealing element.

- 15 Inventive concept 328. The apparatus according to inventive concept 315, wherein the surgical tool further comprises a depth limiting element, which is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is inserted into the bore.

Inventive concept 329. The apparatus according to any one of inventive concepts 315-328, further comprising a one-way filter valve that comprises the one-way filter, the one-
20 way filter valve in fluid communication with the lumen.

Inventive concept 330. The apparatus according to inventive concept 329, wherein the one-way filter valve comprises a leaf valve, which comprises one or more leafs that comprise mesh having openings smaller than the solid particles.

- 25 Inventive concept 331. The apparatus according to inventive concept 329, wherein the one-way filter valve comprises a leaf valve, which comprises one or more leafs that are shaped so as to define a plurality of slits having a width narrower than the solid particles.

Inventive concept 332. The apparatus according to any one of inventive concepts 315-328, for use with a suction source, wherein the surgical tool is shaped so as to define a suction port, and wherein the one-way filter is in selective fluid communication with the
30 suction source via the suction port.

Inventive concept 333. The apparatus according to inventive concept 332, wherein the suction port is disposed at a site along a fluid path between the one-way filter and the composition source, and wherein the surgical tool further comprises a source one-way valve, which is disposed along the fluid path proximal to the site at which the suction port is disposed.

Inventive concept 334. The apparatus according to any one of inventive concepts 315-328, wherein the surgical tool is shaped so as to define a suction port, and wherein the apparatus further comprises a suction source, which is in selective fluid communication with the one-way filter via the suction port.

10 Inventive concept 335. The apparatus according to inventive concept 334, wherein the suction port is disposed at a site along a fluid path between the one-way filter and the composition source, and wherein the surgical tool further comprises a source one-way valve, which is disposed along the fluid path proximal to the site at which the suction port is disposed.

15 Inventive concept 336. The apparatus according to any one of inventive concepts 315-328, wherein the surgical tool further comprises a filter clearing element, which is configured to clear the solid particles that accumulate on the one-way filter during drainage of the physiological liquid solution through the one-way filter.

Inventive concept 337. The apparatus according to inventive concept 336, wherein the surgical tool is configured to move the filter clearing element with respect to the one-way filter.

Inventive concept 338. The apparatus according to any one of inventive concepts 315-328, further comprising a pump, which is configured to pump the solid-liquid composition through the distal opening via the lumen.

25 Inventive concept 339. The apparatus according to inventive concept 338, wherein the pump is configured to pump the solid-liquid composition with an on-off duty cycle.

Inventive concept 340. The apparatus according to inventive concept 339, for use with a suction source, wherein the surgical tool is shaped so as to define a suction port, wherein the one-way filter is in selective fluid communication with the suction source via the suction port, and wherein suction port is configured to assume an open state when the pump is off, and a closed state when the pump is on.

Inventive concept 341. The apparatus according to inventive concept 339, wherein the surgical tool is shaped so as to define a suction port, and wherein the apparatus further comprises a suction source, which is in selective fluid communication with the one-way filter via the suction port, and which is configured to apply suction when the pump is off,
5 and not apply the suction when the pump is on.

Inventive concept 342. The apparatus according to inventive concept 338, wherein the pump is configured to pump the solid-liquid composition at a pulsating positive hydraulic pressure.

Inventive concept 343. The apparatus according to inventive concept 338, wherein the
10 pump is configured to pump the solid-liquid composition at a pulsating hydraulic pressure that periodically varies between positive and negative.

Inventive concept 344. The apparatus according to any one of inventive concepts 315-328, wherein the surgical tool further comprises a solid-particle container, which contains the solid particles for mixing with the physiological liquid solution.

15 Inventive concept 345. The apparatus according to inventive concept 344, wherein the solid-particle container has a volume of between 0.2 and 20 ml.

Inventive concept 346. The apparatus according to inventive concept 344, wherein the surgical tool further comprises the physiological liquid solution.

20 There is yet additionally provided, in accordance with an inventive concept 347 of the present invention, apparatus comprising an osteotome, which is shaped so as to define:

a lumen through the osteotome, a distal end of the lumen opening through a distal opening disposed within 10 mm of a distal end of the osteotome, and a proximal end of the lumen opening through a proximal opening disposed at least 5 mm proximal to the distal opening,

25 a lateral external surface, at least a portion of which is shaped so as to define a screw thread that (a) has a distal thread end that is disposed within 10 mm of the distal end of the osteotome, and (b) comprises one or more raised helical ribs going around the osteotome, and

30 one or more longitudinal drainage slots, which extend along at least respective longitudinal portions of the osteotome having respective longitudinal lengths of at least 5 mm, measured parallel to a central longitudinal axis of the osteotome.

Inventive concept 348. The apparatus according to inventive concept 347, wherein the osteotome is configured as a dental osteotome.

Inventive concept 349. The apparatus according to inventive concept 347, wherein the longitudinal lengths of the respective longitudinal portions are at least 8 mm.

- 5 Inventive concept 350. The apparatus according to inventive concept 349, wherein the longitudinal lengths of the respective longitudinal portions are at least 10 mm.

Inventive concept 351. The apparatus according to inventive concept 350, wherein the longitudinal lengths of the respective longitudinal portions are at least 12 mm.

- 10 Inventive concept 352. The apparatus according to inventive concept 347, wherein the proximal opening is disposed within 10 mm of a proximal end of the osteotome.

Inventive concept 353. The apparatus according to inventive concept 347, wherein at least one of the one or more longitudinal drainage slots reaches a proximal end of the osteotome.

- 15 Inventive concept 354. The apparatus according to inventive concept 347, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least one pitch of the screw thread from the distal thread end.

Inventive concept 355. The apparatus according to inventive concept 354, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least two pitches of the screw thread from the distal thread end.

- 20 Inventive concept 356. The apparatus according to inventive concept 347, wherein the screw thread is multi-start.

- 25 Inventive concept 357. The apparatus according to inventive concept 347, wherein the osteotome further comprises a sealing element disposed around an external surface of the osteotome, and configured to form a liquid-tight seal with tissue around and outside a bore through a bone when the osteotome is inserted into the bore.

Inventive concept 358. The apparatus according to inventive concept 347, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least 1.5 mm from the distal end of the osteotome.

Inventive concept 359. The apparatus according to inventive concept 358, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least 4 mm from the distal end of the osteotome.

5 Inventive concept 360. The apparatus according to inventive concept 358, wherein the osteotome further comprises a sealing element disposed around an external surface of the osteotome, and configured to form a liquid-tight seal with tissue around and outside a bore through a bone when the osteotome is inserted into the bore.

10 Inventive concept 361. The apparatus according to inventive concept 347, wherein respective average widths of the one or more longitudinal drainage slots are no more than 2 mm.

Inventive concept 362. The apparatus according to inventive concept 347, wherein respective average depths of the one or more longitudinal drainage slots, measured with respect to an outermost portion of the screw thread, are at least 10% greater than an average depth of the screw thread.

15 Inventive concept 363. The apparatus according to any one of inventive concepts 347-362, wherein the one or more longitudinal drainage slots cross the one or more ribs respective pluralities of times.

Inventive concept 364. The apparatus according to inventive concept 363, wherein the one or more longitudinal drainage slots comprise two or more longitudinal drainage slots.

20 Inventive concept 365. The apparatus according to inventive concept 363, wherein the one or more longitudinal drainage slots are parallel to the longitudinal axis.

Inventive concept 366. The apparatus according to inventive concept 363, wherein the one or more longitudinal drainage slots helically go around the osteotome in a direction opposite to a direction of the screw thread.

25 Inventive concept 367. The apparatus according to inventive concept 363, wherein the one or more longitudinal drainage slots helically go around the osteotome with a slot pitch greater than a thread pitch of the screw thread.

Inventive concept 368. The apparatus according to inventive concept 367, wherein the slot pitch equals at least 1.5 times the thread pitch.

Inventive concept 369. The apparatus according to inventive concept 367, wherein the screw thread has one or more starts, and wherein the slot pitch equals at least the quotient of (a) 2 mm divided by (b) the number of starts of the screw thread.

5 Inventive concept 370. The apparatus according to any one of inventive concepts 347-362, wherein the screw thread has one or more starts and a corresponding number of roots, and wherein the osteotome is shaped so as to define a number of longitudinal drainage slots that corresponds to a number of the starts of the screw thread, and which are disposed within the one or more roots of the screw thread, respectively.

10 Inventive concept 371. The apparatus according to inventive concept 370, wherein a distal end of the one or more longitudinal drainage slots is disposed at least one pitch of the screw thread from the distal thread end.

Inventive concept 372. The apparatus according to inventive concept 371, wherein the distal end of the longitudinal drainage slot is disposed at least two pitches of the screw thread from the distal thread end.

15 Inventive concept 373. The apparatus according to inventive concept 371, wherein the osteotome further comprises a sealing element disposed around an external surface of the osteotome, and configured to form a liquid-tight seal with tissue around and outside a bore through a bone when the osteotome is inserted into the bore.

20 Inventive concept 374. The apparatus according to any one of inventive concepts 347-362, for use with solid particles and a physiological liquid solution, the apparatus further comprising a composition source, which is coupled in fluid communication with the lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution.

25 Inventive concept 375. The apparatus according to inventive concept 374, wherein the solid particles are solid bone graft particles, and wherein the osteotome is for use with the solid bone graft particles.

30 Inventive concept 376. The apparatus according to inventive concept 374, wherein the composition source comprises a combining feeder unit, which is configured to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

Inventive concept 377. The apparatus according to inventive concept 376, wherein the

combining feeder unit comprises a mixing feeder unit, which is configured to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

There is also provided, in accordance with an inventive concept 378 of the present invention, a method comprising:

inserting, from a first side of a bone, exactly one shaft unit of a surgical tool into a bore that passes through the bone from the first side to a second side of the bone, such that a distal opening disposed within 10 mm of a distal end of the shaft unit is disposed in the bore or in a cavity adjacent to the second side of the bone, wherein the distal opening is in fluid communication with a delivery lumen defined by the shaft unit;

providing a solid-liquid composition of solid particles and a physiological liquid solution from a composition source that is coupled in fluid communication with the delivery lumen; and

injecting the solid-liquid composition through the delivery lumen and the distal opening into the cavity, such that (a) a portion of the physiological liquid solution drains into a drainage lumen defined by the shaft unit, and (b) passage of solid particles of the solid-liquid composition into the drainage lumen is inhibited, such that the solid particles accumulate in the cavity.

Inventive concept 379. The method according to inventive concept 378, wherein injecting comprises injecting the solid-liquid composition through the delivery lumen and the distal opening into the cavity, such that (a) the portion of the physiological liquid solution drains through a filter of the surgical tool and into the drainage lumen, and (b) the filter inhibits the passage of the solid particles into the drainage lumen.

Inventive concept 380. The method according to inventive concept 379, wherein injecting the solid-liquid composition comprises injecting the solid-liquid composition such that at least 50% of the physiological liquid solution drains through the filter in a distal-to-proximal direction.

Inventive concept 381. The method according to inventive concept 379, wherein injecting comprises injecting the solid-liquid composition through the delivery lumen and the distal opening into the cavity, such that at least 50% of the physiological liquid solution drains through the filter while the solid-liquid composition is being injected.

Inventive concept 382. The method according to inventive concept 379, wherein the filter is disposed within 10 mm of the distal end of the shaft unit.

Inventive concept 383. The method according to inventive concept 378,

wherein the exactly one shaft unit includes a delivery shaft, which is shaped so as to define (i) the delivery lumen, and (ii) a plurality of rib elements that extend radially outward from an external surface of the delivery shaft,

wherein inserting the exactly one shaft unit into the bore comprises inserting the exactly one shaft unit into the bore such that the rib elements space the external surface of the delivery shaft away from an inner wall of the bore, thereby defining a fluid flow path between the external surface of the delivery shaft and the inner wall of the bore, and

wherein injecting comprises injecting the solid-liquid composition through the delivery lumen and the distal opening into the cavity, such that (a) the portion of the physiological liquid solution drains through the fluid flow path and into the drainage lumen, and (b) passage of solid particles of the solid-liquid composition into the fluid flow path is inhibited, such that the solid particles accumulate in the cavity.

Inventive concept 384. The method according to inventive concept 383, wherein the rib elements extend an average distance of between 0.1 and 2 mm radially outward from the external surface of the delivery shaft.

Inventive concept 385. The method according to inventive concept 383, wherein the rib elements extend longitudinally along the external surface of the delivery shaft for an average distance of at least 1 mm.

Inventive concept 386. The method according to inventive concept 383, wherein the surgical tool further includes a depth limiting element, which is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is inserted into the bore.

Inventive concept 387. The method according to inventive concept 386, wherein the depth limiting element is removably attached to the shaft unit.

Inventive concept 388. The method according to inventive concept 386, wherein the depth limiting element is shaped so as to define a portion of the drainage lumen between at least a portion of an internal surface of the depth limiting element and a portion of the external surface of the delivery shaft.

Inventive concept 389. The method according to inventive concept 378, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of the solid bone graft particles and the physiological liquid solution.

- 5 Inventive concept 390. The method according to inventive concept 378, wherein the surgical tool is configured as an oral surgical tool, wherein the bone is a bone of a jaw, and wherein inserting comprises inserting the exactly one shaft unit of the oral surgical tool into the bore that passes through the bone of the jaw.

- 10 Inventive concept 391. The method according to inventive concept 378, wherein the cavity is between the second side of the bone and a membrane.

Inventive concept 392. The method according to inventive concept 391, further comprising, before injecting the solid-liquid composition, raising the membrane to form the cavity between the second side of the bone and the membrane.

- 15 Inventive concept 393. The method according to inventive concept 391, wherein the membrane is a Schneiderian membrane.

Inventive concept 394. The method according to inventive concept 378, wherein the bore is exactly one bore through the bone.

- 20 Inventive concept 395. The method according to inventive concept 378, further comprising, after injecting the solid-liquid composition, implanting an implant at least partially within the cavity.

Inventive concept 396. The method according to inventive concept 378, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

Inventive concept 397. The method according to inventive concept 396, wherein the distal opening is disposed at the distal end of the shaft unit.

- 25 Inventive concept 398. The method according to inventive concept 378, wherein injecting the solid-liquid composition comprises injecting 2-300 ml of the solid-liquid composition.

- Inventive concept 399. The method according to inventive concept 378, wherein providing the solid-liquid composition and injecting the solid-liquid composition comprises providing the solid-liquid composition and injecting the solid-liquid composition such that between 0.2 and 20 ml of solid particles accumulate in the cavity.
- 30

Inventive concept 400. The method according to inventive concept 378, wherein the composition source comprises a combining feeder unit, and wherein providing the solid-liquid composition comprises activating the combining feeder unit to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

- 5 Inventive concept 401. The method according to inventive concept 400, wherein the combining feeder unit comprises a mixing feeder unit, and wherein providing the solid-liquid composition comprises activating the mixing feeder unit to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

10 There is further provided, in accordance with an inventive concept 402 of the present invention, a method comprising:

placing a sealing element of a surgical tool against tissue around and outside a bore that passes through a bone from a first side to a second side of the bone, such that:

the sealing element forms a liquid-tight seal with the tissue on the first side of the bone, and

- 15 a distal opening of the surgical tool is disposed in fluid communication with the bore, wherein the distal opening is in fluid communication with a delivery lumen defined by the surgical tool;

20 providing a solid-liquid composition of solid particles and a physiological liquid solution from a composition source that is coupled in fluid communication with the delivery lumen; and

injecting the solid-liquid composition through the delivery lumen, the distal opening, and the bore, into a cavity adjacent to the second side of the bone, such that (a) a portion of the physiological liquid solution drains through a filter of the surgical tool, and (b) the filter inhibits passage of solid particles of the solid-liquid composition such that
25 the solid particles accumulate in the cavity, wherein the filter is disposed in fluid communication with a drainage lumen defined by the surgical tool.

Inventive concept 403. The method according to inventive concept 402, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of the solid bone graft particles and the
30 physiological liquid solution.

Inventive concept 404. The method according to inventive concept 402,

wherein the sealing element disposed around an external surface of exactly one

shaft unit of the surgical tool,

wherein the distal opening disposed within 10 mm of a distal end of the shaft unit,

wherein the delivery lumen is defined at least in part by the shaft unit, and

wherein the drainage lumen is defined at least in part by the shaft unit.

- 5 Inventive concept 405. The method according to inventive concept 404, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

Inventive concept 406. The method according to inventive concept 405, wherein the distal opening is disposed at the distal end of the shaft unit.

- 10 Inventive concept 407. The method according to inventive concept 404, wherein the filter is disposed within 10 mm of the distal end of the shaft unit.

Inventive concept 408. The method according to inventive concept 402, wherein the surgical tool is configured as an oral surgical tool, wherein the bone is a bone of a jaw, and wherein placing comprises placing the sealing element against the tissue around and outside the bore the passes through the bone of the jaw.

- 15 Inventive concept 409. The method according to inventive concept 402, wherein the cavity is between the second side of the bone and a membrane.

Inventive concept 410. The method according to inventive concept 409, further comprising, before injecting the solid-liquid composition, raising the membrane to form the cavity between the second side of the bone and the membrane.

- 20 Inventive concept 411. The method according to inventive concept 409, wherein the membrane is a Schneiderian membrane.

Inventive concept 412. The method according to inventive concept 402, wherein the bore is exactly one bore through the bone.

- 25 Inventive concept 413. The method according to inventive concept 402, further comprising, after injecting the solid-liquid composition, implanting an implant at least partially within the cavity.

- 30 Inventive concept 414. The method according to inventive concept 402, wherein injecting the solid-liquid composition comprises injecting the solid-liquid composition such that at least 50% of the physiological liquid solution drains through the filter in a distal-to-proximal direction.

Inventive concept 415. The method according to inventive concept 402, wherein injecting the solid-liquid composition comprises injecting 2-300 ml of the solid-liquid composition.

Inventive concept 416. The method according to inventive concept 402, wherein providing the solid-liquid composition and injecting the solid-liquid composition
5 comprises providing the solid-liquid composition and injecting the solid-liquid composition such that between 0.2 and 20 ml of solid particles accumulate in the cavity.

Inventive concept 417. The method according to inventive concept 402, wherein injecting comprises injecting the solid-liquid composition through the delivery lumen and the distal opening into the cavity, such that at least 50% of the physiological liquid solution drains
10 through the filter while the solid-liquid composition is being injected.

Inventive concept 418. The method according to inventive concept 402, wherein the composition source comprises a combining feeder unit, and wherein providing the solid-liquid composition comprises activating the combining feeder unit to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

15 Inventive concept 419. The method according to inventive concept 418, wherein the combining feeder unit comprises a mixing feeder unit, and wherein providing the solid-liquid composition comprises activating the mixing feeder unit to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

20 There is still further provided, in accordance with an inventive concept 420 of the present invention, a method comprising:

inserting, from a first side of a bone, exactly one shaft unit of a surgical tool into a bore that passes through the bone from the first side to a second side of the bone, such that a distal opening disposed within 10 mm of a distal end of the shaft unit is disposed in the bore or in a cavity adjacent to the second side of the bone, wherein the distal opening is in
25 fluid communication with a lumen defined by the shaft unit;

providing a solid-liquid composition of solid particles and a physiological liquid solution from a composition source that is coupled in fluid communication with the lumen; and

30 injecting the solid-liquid composition through the lumen, a one-way filter of the surgical tool, and the distal opening into the cavity, the one-way filter disposed in fluid communication with the lumen, and configured to:

allow passage, in a proximal-to-distal direction, of the solid particles and the physiological liquid solution of the solid-liquid composition,

inhibit passage, in a distal-to-proximal direction, of the solid particles of the solid-liquid composition, such that the solid particles accumulate in the cavity,

5 and

allow passage, in the distal-to-proximal direction, of the physiological liquid solution of the solid-liquid composition.

Inventive concept 421. The method according to inventive concept 420, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of the solid bone graft particles and the physiological liquid solution.

Inventive concept 422. The method according to inventive concept 420, wherein the surgical tool is configured as an oral surgical tool, wherein the bone is a bone of a jaw, and wherein inserting comprises inserting the exactly one shaft unit of the oral surgical tool into the bore that passes through the bone of the jaw.

Inventive concept 423. The method according to inventive concept 420, wherein the cavity is between the second side of the bone and a membrane.

Inventive concept 424. The method according to inventive concept 423, further comprising, before injecting the solid-liquid composition, raising the membrane to form the cavity between the second side of the bone and the membrane.

Inventive concept 425. The method according to inventive concept 423, wherein the membrane is a Schneiderian membrane.

Inventive concept 426. The method according to inventive concept 420, wherein the bore is exactly one bore through the bone.

25 Inventive concept 427. The method according to inventive concept 420, further comprising, after injecting the solid-liquid composition, implanting an implant at least partially within the cavity.

Inventive concept 428. The method according to inventive concept 420, wherein the distal opening is disposed within 5 mm of the distal end of the shaft unit.

30 Inventive concept 429. The method according to inventive concept 428, wherein the distal opening is disposed at the distal end of the shaft unit.

Inventive concept 430. The method according to inventive concept 420, further comprising draining the physiological liquid solution of the solid-liquid composition through the one-way filter.

5 Inventive concept 431. The method according to inventive concept 430, wherein injecting and draining comprise alternatingly injecting and draining.

Inventive concept 432. The method according to inventive concept 430,
wherein injecting the solid-liquid composition comprises pumping the solid-liquid composition at a positive hydraulic pressure, and
wherein draining the physiological liquid solution comprises suctioning the
10 physiological liquid solution at a negative hydraulic pressure.

Inventive concept 433. The method according to inventive concept 432, wherein pumping and suctioning comprise alternatingly pumping and suctioning.

Inventive concept 434. The method according to inventive concept 420, wherein injecting the solid-liquid composition comprises injecting the solid-liquid composition such that at
15 least 50% of the physiological liquid solution drains through the one-way filter in the distal-to-proximal direction.

Inventive concept 435. The method according to inventive concept 420, wherein injecting the solid-liquid composition comprises injecting 2-300 ml of the solid-liquid composition.

Inventive concept 436. The method according to inventive concept 420, wherein
20 providing the solid-liquid composition and injecting the solid-liquid composition comprises providing the solid-liquid composition and injecting the solid-liquid composition such that between 0.2 and 20 ml of solid particles accumulate in the cavity.

Inventive concept 437. The method according to inventive concept 420, wherein the composition source comprises a combining feeder unit, and wherein providing the solid-
25 liquid composition comprises activating the combining feeder unit to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

Inventive concept 438. The method according to inventive concept 437, wherein the combining feeder unit comprises a mixing feeder unit, and wherein providing the solid-
liquid composition comprises activating the mixing feeder unit to provide the solid-liquid
30 composition by mixing the solid particles with the physiological liquid solution.

Inventive concept 439. The method according to inventive concept 420, wherein the one-way filter is disposed within 10 mm of the distal end of the shaft unit.

There is additionally provided, in accordance with an inventive concept 440 of the present invention, a method comprising:

5 placing a sealing element of a surgical tool against tissue around and outside a bore that passes through a bone from a first side to a second side of the bone, such that:

 the sealing element forms a liquid-tight seal with the tissue on the first side of the bone, and

 a distal opening of the surgical tool is disposed in fluid communication
10 with the bore, wherein the distal opening is in fluid communication with a lumen defined by the surgical tool;

 providing a solid-liquid composition of solid particles and a physiological liquid solution from a composition source that is coupled in fluid communication with the lumen; and

15 injecting the solid-liquid composition through the lumen, a one-way filter of the surgical tool, the distal opening, and the bore, into a cavity adjacent to the second side of the bone, wherein the one-way filter is disposed in fluid communication with the lumen, and configured to:

 allow passage, in a proximal-to-distal direction, of the solid particles and
20 the physiological liquid solution of the solid-liquid composition,

 inhibit passage, in a distal-to-proximal direction, of the solid particles of the solid-liquid composition, such that the solid particles accumulate in the cavity, and

 allow passage, in the distal-to-proximal direction, of the physiological
25 liquid solution of the solid-liquid composition.

Inventive concept 441. The method according to inventive concept 440, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition comprises providing the solid-liquid composition of the solid bone graft particles and the physiological liquid solution.

30 Inventive concept 442. The method according to inventive concept 440,

 wherein the sealing element disposed around an external surface of exactly one shaft unit of the surgical tool,

wherein the distal opening disposed within 10 mm of a distal end of the shaft unit,
and

wherein the lumen is defined at least in part by the shaft unit.

Inventive concept 443. The method according to inventive concept 442, wherein the distal
5 opening is disposed within 5 mm of the distal end of the shaft unit.

Inventive concept 444. The method according to inventive concept 443, wherein the distal
opening is disposed at the distal end of the shaft unit.

Inventive concept 445. The method according to inventive concept 442, wherein the one-
way filter is disposed within 10 mm of the distal end of the shaft unit.

10 Inventive concept 446. The method according to inventive concept 440, wherein the
surgical tool is configured as an oral surgical tool, wherein the bone is a bone of a jaw,
and wherein placing comprises placing the sealing element against the tissue around and
outside the bore that passes through the bone of the jaw.

Inventive concept 447. The method according to inventive concept 440, wherein the
15 cavity is between the second side of the bone and a membrane.

Inventive concept 448. The method according to inventive concept 447, further
comprising, before injecting the solid-liquid composition, raising the membrane to form
the cavity between the second side of the bone and the membrane.

Inventive concept 449. The method according to inventive concept 447, wherein the
20 membrane is a Schneiderian membrane.

Inventive concept 450. The method according to inventive concept 440, wherein the bore
is exactly one bore through the bone.

Inventive concept 451. The method according to inventive concept 440, further
comprising, after injecting the solid-liquid composition, implanting an implant at least
25 partially within the cavity.

Inventive concept 452. The method according to inventive concept 440, further
comprising draining the physiological liquid solution of the solid-liquid composition
through the one-way filter.

Inventive concept 453. The method according to inventive concept 452, wherein injecting
30 and draining comprise alternately injecting and draining.

Inventive concept 454. The method according to inventive concept 452,

wherein injecting the solid-liquid composition comprises pumping the solid-liquid composition at a positive hydraulic pressure, and

5 wherein draining the physiological liquid solution comprises suctioning the physiological liquid solution at a negative hydraulic pressure.

Inventive concept 455. The method according to inventive concept 454, wherein pumping and suctioning comprise alternatingly pumping and suctioning.

10 Inventive concept 456. The method according to inventive concept 440, wherein injecting the solid-liquid composition comprises injecting the solid-liquid composition such that at least 50% of the physiological liquid solution drains through the one-way filter in the distal-to-proximal direction.

Inventive concept 457. The method according to inventive concept 440, wherein injecting the solid-liquid composition comprises injecting 2-300 ml of the solid-liquid composition.

15 Inventive concept 458. The method according to inventive concept 440, wherein providing the solid-liquid composition and injecting the solid-liquid composition comprises providing the solid-liquid composition and injecting the solid-liquid composition such that between 0.2 and 20 ml of solid particles accumulate in the cavity.

20 Inventive concept 459. The method according to inventive concept 440, wherein the composition source comprises a combining feeder unit, and wherein providing the solid-liquid composition comprises activating the combining feeder unit to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

25 Inventive concept 460. The method according to inventive concept 459, wherein the combining feeder unit comprises a mixing feeder unit, and wherein providing the solid-liquid composition comprises activating the mixing feeder unit to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

There is yet additionally provided, in accordance with an inventive concept 461 of the present invention, a method comprising:

30 injecting, from a first side of a bone, through (a) a bore that passes through the bone from the first side to a second side of the bone, and (b) into a cavity adjacent to the second side of the bone, a solid-liquid composition of solid particles and a physiological liquid solution; and

draining, from the cavity and through the bore, the physiological liquid solution of the solid-liquid composition, while inhibiting passage of the solid particles of the solid-liquid composition, such that the solid particles accumulate in the cavity.

5 Inventive concept 462. The method according to inventive concept 461, wherein inhibiting the passage of the solid particles comprises using a filter to inhibit the passage of the solid particles.

10 Inventive concept 463. The method according to inventive concept 462, wherein injecting the solid-liquid composition comprises injecting the solid-liquid composition such that at least 50% of the physiological liquid solution drains through the filter in a distal-to-proximal direction.

Inventive concept 464. The method according to inventive concept 461, wherein injecting the solid-liquid composition comprises injecting 2-300 ml of the solid-liquid composition.

Inventive concept 465. The method according to inventive concept 461, wherein the cavity is between the second side of the bone and a membrane.

15 Inventive concept 466. The method according to inventive concept 465, further comprising, before injecting the solid-liquid composition, raising the membrane to form the cavity between the second side of the bone and the membrane.

Inventive concept 467. The method according to inventive concept 465, wherein the membrane is a Schneiderian membrane.

20 Inventive concept 468. The method according to inventive concept 461, wherein the bore is exactly one bore through the bone.

Inventive concept 469. The method according to inventive concept 461, further comprising, after injecting the solid-liquid composition, implanting an implant at least partially within the cavity.

25 There is also provided, in accordance with an inventive concept 470 of the present invention, a method comprising:

providing an osteotome, which is shaped so as to define (i) a lumen through the osteotome, a distal end of the lumen opening through a distal opening disposed within 10 mm of a distal end of the osteotome, and a proximal end of the lumen opening through a proximal opening disposed at least 5 mm proximal to the distal opening, (ii) a lateral

30

external surface, at least a portion of which is shaped so as to define a screw thread that (a) has a distal thread end that is disposed within 10 mm of the distal end of the osteotome, and (b) comprises one or more raised helical ribs going around the osteotome, and (iii) one or more longitudinal drainage slots, which extend along at least respective
5 longitudinal portions of the osteotome having respective longitudinal lengths of at least 5 mm, measured parallel to a central longitudinal axis of the osteotome;

inserting, from a first side of a bone, the osteotome into a bore that passes through the bone from the first side to a second side of the bone, such that the distal opening is disposed in the bore or in a cavity adjacent to the second side of the bone;

10 providing a solid-liquid composition of solid particles and a physiological liquid solution from a composition source that is coupled in fluid communication with the lumen; and

injecting the solid-liquid composition through the lumen and the distal opening into the cavity, such that (a) a portion of the physiological liquid solution drains through
15 the one or more longitudinal drainage slots, and (b) the one or more longitudinal drainage slots inhibit passage of solid particles of the solid-liquid composition such that the solid particles accumulate in the cavity.

Inventive concept 471. The method according to inventive concept 470, wherein the solid particles are solid bone graft particles, and wherein providing the solid-liquid composition
20 comprises providing the solid-liquid composition of the solid bone graft particles and the physiological liquid solution.

Inventive concept 472. The method according to inventive concept 470, wherein the osteotome is configured as a dental osteotome, wherein the bone is a bone of a jaw, and wherein inserting comprises inserting the dental osteotome into the bore that passes
25 through the bone of the jaw.

Inventive concept 473. The method according to inventive concept 470, wherein the cavity is between the second side of the bone and a membrane.

Inventive concept 474. The method according to inventive concept 473, further comprising, before injecting the solid-liquid composition, raising the membrane to form
30 the cavity between the second side of the bone and the membrane.

Inventive concept 475. The method according to inventive concept 474,

wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least one pitch of the screw thread from the distal thread end,

wherein raising the membrane comprises:

5 advancing the osteotome into the bore such that a portion of the screw thread distal to the respective distal ends of the one or more longitudinal drainage slots sealingly engages a wall of the bore; and

thereafter, injecting a fluid through the bore under sufficient pressure to raise the membrane, and

10 wherein the method further comprises, before injecting the solid-liquid composition, further advancing the osteotome into the bore until the one or more drainage slots come into fluid communication with the cavity.

Inventive concept 476. The method according to inventive concept 473, wherein the membrane is a Schneiderian membrane.

15 Inventive concept 477. The method according to inventive concept 470, wherein the bore is exactly one bore through the bone.

Inventive concept 478. The method according to inventive concept 470, further comprising, after injecting the solid-liquid composition, implanting an implant at least partially within the cavity.

20 Inventive concept 479. The method according to inventive concept 470, wherein the longitudinal lengths of the respective longitudinal portions are at least 8 mm.

Inventive concept 480. The method according to inventive concept 479, wherein the longitudinal lengths of the respective longitudinal portions are at least 10 mm.

Inventive concept 481. The method according to inventive concept 480, wherein the longitudinal lengths of the respective longitudinal portions are at least 12 mm.

25 Inventive concept 482. The method according to inventive concept 470, wherein the longitudinal lengths of the respective longitudinal portions are at least 2 mm greater than a thickness of the bone adjacently surrounding the bore.

Inventive concept 483. The method according to inventive concept 470, wherein the proximal opening is disposed within 10 mm of a proximal end of the osteotome.

Inventive concept 484. The method according to inventive concept 470, wherein at least one of the one or more longitudinal drainage slots reaches a proximal end of the osteotome.

5 Inventive concept 485. The method according to inventive concept 470, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least one pitch of the screw thread from the distal thread end.

Inventive concept 486. The method according to inventive concept 485, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least two pitches of the screw thread from the distal thread end.

10 Inventive concept 487. The method according to inventive concept 470, wherein the screw thread is multi-start.

Inventive concept 488. The method according to inventive concept 470, wherein the osteotome further comprises a sealing element disposed around an external surface of the osteotome, and wherein inserting comprises inserting the osteotome into the bore such
15 that the sealing element forms a liquid-tight seal with tissue around and outside the bore.

Inventive concept 489. The method according to inventive concept 470, wherein respective distal ends of the one or more longitudinal drainage slots are disposed at least 1.5 mm from the distal end of the osteotome.

Inventive concept 490. The method according to inventive concept 489, wherein
20 respective distal ends of the one or more longitudinal drainage slots are disposed at least 4 mm from the distal end of the osteotome.

Inventive concept 491. The method according to inventive concept 489, wherein the osteotome further comprises a sealing element disposed around an external surface of the osteotome, and wherein inserting comprises inserting the osteotome into the bore such
25 that the sealing element forms a liquid-tight seal with tissue around and outside the bore.

Inventive concept 492. The method according to inventive concept 470, wherein respective average widths of the one or more longitudinal drainage slots are no more than 2 mm.

Inventive concept 493. The method according to inventive concept 470, wherein
30 respective average depths of the one or more longitudinal drainage slots, measured with

respect to an outermost portion of the screw thread, are at least 10% greater than an average depth of the screw thread.

Inventive concept 494. The method according to inventive concept 470, wherein the one or more longitudinal drainage slots cross the one or more ribs respective pluralities of
5 times.

Inventive concept 495. The method according to inventive concept 494, wherein the one or more longitudinal drainage slots comprise two or more longitudinal drainage slots.

Inventive concept 496. The method according to inventive concept 494, wherein the one or more longitudinal drainage slots are parallel to the longitudinal axis.

10 Inventive concept 497. The method according to inventive concept 494, wherein the one or more longitudinal drainage slots helically go around the osteotome in a direction opposite to a direction of the screw thread.

Inventive concept 498. The method according to inventive concept 494, wherein the one or more longitudinal drainage slots helically go around the osteotome with a slot pitch
15 greater than a thread pitch of the screw thread.

Inventive concept 499. The method according to inventive concept 498, wherein the slot pitch equals at least 1.5 times the thread pitch.

Inventive concept 500. The method according to inventive concept 498, wherein the screw thread has one or more starts, and wherein the slot pitch equals at least the quotient
20 of (a) 2 mm divided by (b) the number of starts of the screw thread.

Inventive concept 501. The method according to inventive concept 470, wherein the screw thread has one or more starts and a corresponding number of roots, and wherein the osteotome is shaped so as to define a number of longitudinal drainage slots that corresponds to a number of the starts of the screw thread, and which are disposed within
25 the one or more roots of the screw thread, respectively.

Inventive concept 502. The method according to inventive concept 501, wherein a distal end of the one or more longitudinal drainage slots is disposed at least one pitch of the screw thread from the distal thread end.

Inventive concept 503. The method according to inventive concept 502, wherein the distal end of the longitudinal drainage slot is disposed at least two pitches of the screw thread from the distal thread end.

5 Inventive concept 504. The method according to inventive concept 502, wherein the osteotome further comprises a sealing element disposed around an external surface of the osteotome, and wherein inserting comprises inserting the osteotome into the bore such that the sealing element forms a liquid-tight seal with tissue around and outside the bore.

10 Inventive concept 505. The method according to inventive concept 470, for use with solid particles and a physiological liquid solution, the method further comprising providing a solid-liquid composition of the solid particles and the physiological liquid solution.

Inventive concept 506. The method according to inventive concept 470, wherein the composition source comprises a combining feeder unit, and wherein providing the solid-liquid composition comprises activating the combining feeder unit to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

15 Inventive concept 507. The method according to inventive concept 506, wherein the combining feeder unit comprises a mixing feeder unit, and wherein providing the solid-liquid composition comprises activating the mixing feeder unit to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

20 The present invention will be more fully understood from the following detailed description of embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of a surgical tool for the insertion of bone graft particles into a cavity, in accordance with an application of the present invention;

25 Figs. 2A-C are schematic illustrations of respective configurations of an injector unit of the surgical tool of Fig. 1, in accordance with respective applications of the present invention;

Figs. 3A-B are schematic illustrations of respective configurations of the injector unit of Fig. 1, in accordance with respective applications of the present invention;

30 Figs. 4A-B and 5A are schematic illustrations of uses of the surgical tool of Figs. 1, 2A-B, and 3A-B, in accordance with respective applications of the present invention;

Fig. 5B a schematic illustration of an alternative configuration of a shaft unit of the surgical tool of Figs. 1, 2A-B, and 3A-B and one use thereof, in accordance with an application of the present invention;

5 Figs. 6A-B and 7 are schematic illustrations of another surgical tool comprising an injector unit, in accordance with an application of the present invention;

Figs. 8A-K are highly schematic illustrations of several configurations of a mixing feeder unit, in accordance with respective applications of the present invention;

Figs. 9A-D are schematic illustrations of several configurations of an osteotome, in accordance with respective applications of the present invention;

10 Figs. 10A-D are schematic illustrations of a portion of a sinus lift and bone graft injection procedure performed using the configuration of the osteotome of Fig. 9B, in accordance with an application of the present invention;

Fig. 11 is a schematic illustration of one use of the surgical tool of Figs. 1-5B for ridge augmentation, in accordance with an application of the present invention;

15 Figs. 12A-B are schematic illustrations of one use of the surgical tool of Figs. 1-5B for performing a minimally-invasive spinal interbody fusion, in accordance with an application of the present invention;

Fig. 13 is a schematic illustration of one use of the surgical tool of Figs. 1-5B for filling a bone defect, in accordance with an application of the present invention;

20 Fig. 14 is a schematic illustration of a bone graft injection system for the insertion of solid bone graft particles into a cavity, in accordance with an application of the present invention;

Fig. 15 is a diagram illustrating the schematic arrangement of certain elements of the bone graft injection system of Fig. 14, in accordance with an application of the present
25 invention;

Fig. 16A is a schematic illustration of a portion of a composition delivery source of the bone graft injection system of Fig. 14, in accordance with an application of the present invention;

Fig. 16B is a schematic illustration of another configuration of a portion of a
30 composition delivery source of the bone graft injection system of Fig. 14, in accordance

with an application of the present invention;

Fig. 17 is a timeline schematically showing activation states of control circuitry of the bone graft injection system of Fig. 14, in accordance with an application of the present invention;

5 Figs. 18A-D are schematic illustrations of the activation states of control circuitry of Fig. 17, in accordance with an application of the present invention;

Fig. 19 is a schematic illustration of configurations of a mixing pump and a liquid-supply pump of the bone graft injection system of Fig. 14, in accordance with an application of the present invention;

10 Figs. 20A-B are schematic illustrations of a chamber of a composition delivery source of the bone graft injection system of Fig. 14, in accordance with an application of the present invention; and

Fig. 21 is a schematic illustration of a portion of a method of using the bone graft injection system of Fig. 14, in accordance with an application of the present invention.

15 DETAILED DESCRIPTION OF APPLICATIONS

Fig. 1 is a schematic illustration of a surgical tool 20 for the insertion of bone graft particles into a cavity, in accordance with an application of the present invention. For some applications, surgical tool 20 is configured as an oral surgical tool. Surgical tool 20 may comprise one or more of the following components:

- 20 • a handheld motor 24, as is known in the art, which is typically connected to external control unit 22 by a cord 26;
- an external control unit 22, which optionally comprises a conventional surgical implant external control unit; typically, external control unit 22 comprises a power supply, electronics, and a user interface for controlling handheld motor 24, as is
- 25 known in the art; for some application, external control unit 22 comprises a pump 27, such as a peristaltic pump, as is known in the art;
- one or more conventional drilling handpieces 28; and/or
- a foot control 30 for controlling external control unit 22, as is known in the art.

Surgical tool 20 further comprises a handheld bone graft injector unit 32. For

some applications, injector unit 32 is implemented as an attachment to a separate handheld motor 24, such as shown in Figs. 1, 2A, and 2C. Handheld motor 24 may be a surgeon's conventional motor, which may allow a surgeon to leverage conventional equipment already available. Alternatively, handheld motor 24 may be another external
5 motor. For other applications, injector unit 32 is implemented as a standalone unit comprising its own motor, such as described hereinbelow with reference to Fig. 2B.

Surgical tool 20 is configured to be used with bone graft particles 34 and a physiological liquid solution 36, such as saline solution or blood. For some applications, the bone graft particles comprise natural bone mineral particles (either xenograft or
10 allograft), synthetic particles, demineralized bone matrix, an autograft, or bioactive composites. To this end, surgical tool 20 comprises a composition source 38, which is configured to provide a solid-liquid composition 39 (labeled in Figs. 2A-C) of bone graft particles 34 and physiological liquid solution 36. For some applications, physiological liquid solution 36 is substantially non-viscous, e.g., has a viscosity of water.
15 Alternatively, physiological liquid solution 36 is somewhat viscous, e.g., may comprise glycerol or hyaluronic acid, which is sufficiently non-viscous to be injected and to drain under clinically-safe pressures. For some applications, solid-liquid composition 39 further comprises a radiopaque agent, to enable X-ray visualization of the procedure. For some applications, bone graft particles 34 have an average particle size (measured as the
20 greatest dimension of each particle) of at least 0.01 mm, no more than 3 mm, and/or between 0.01 mm and 3 mm. For some applications, bone graft particles 34 comprise bone graft blocks, in which case the greatest dimension is selected for ready passage through delivery lumen 42, described hereinbelow. For some applications, composition source 38 comprises a combining feeder unit 60, such as described hereinbelow with
25 reference to Figs. 2A-C. For other applications, composition source 38 comprises a container of pre-combined bone graft particles 34 and physiological liquid solution 36; for example, the container may comprise a syringe. For some applications, injector unit 32 comprises composition source 38, while for other applications, composition source 38 is provided as a separate unit, e.g., a tabletop unit, or as a component of external control unit
30 22.

For some applications, surgical tool 20 (e.g., injector unit 32 thereof) further comprises a solid-particle container 37, which contains bone graft particles 34 for combining with physiological liquid solution 36. For example, solid-particle container 37

may have a volume of at least 0.2 ml, no more than 20 ml, and/or between 0.2 and 20 ml. Optionally, solid-particle container 37, in addition to bone graft particles 34, contains some physiological liquid solution 36, which may enable combining of bone graft particles 34 and physiological liquid solution 36 in solid-particle container 37, such as
5 described hereinbelow with reference to Figs. 8A-K.

For some applications, external control unit 22 is configured to display one or more of the following: (a) bone graft volume injected, (b) bone graft volume remaining, (c) pressure of solid-liquid composition 39, and/or (d) total volume injected (bone graft plus physiological liquid solution).

10 Reference is now made to Figs. 2A-C, which are schematic illustrations of respective configurations of injector unit 32, in accordance with respective applications of the present invention.

In the configurations shown in Figs. 2A and 2C, injector unit 32 is implemented as an attachment to separate handheld motor 24.

15 In the configuration shown in Fig. 2B, injector unit 32 is implemented as a standalone unit, which typically comprises one or more of the following elements: (a) its own motor 41, (b) a pump 43, such as described hereinbelow, (c) a rechargeable or disposable battery 45, (d) liquid solution container 66, and/or (e) a drainage container 47. For some applications, injector unit 32 comprises a combined liquid-solution-drainage
20 container instead of a separate liquid solution container 66 and a separate drainage container 47. This configuration provides close loop circulation of physiological liquid solution 36, and thus may, for example, allow the use of less physiological liquid solution 36 because the solution is reused during operation.

Injector unit 32 comprises a shaft unit 40, such as exactly one shaft unit 40, which
25 is shaped so as to define a delivery lumen 42 and a drainage lumen 44. Shaft unit 40 comprises one or more shafts (including, for example, a delivery shaft 56, which defines delivery lumen 42), which may be arranged concentrically and/or alongside one another. Composition source 38 is coupled in fluid communication with delivery lumen 42, such as via a feeder tube 35, which optionally is flexible and/or transmits torque. Delivery lumen
30 42 and drainage lumen 44 are typically not in fluid communication with each other within shaft unit 40. Typically, a largest circle circumscribed by a cross-section of delivery lumen 42 has a diameter of at least 1 mm, such as at least 1.5 mm, and/or no more than 7

mm, such as no more than 4 mm (the cross-section is perpendicular to a longitudinal axis of the delivery lumen).

Injector unit 32 further comprises a distal opening 46, which is typically disposed within 10 mm of a distal end 48 of shaft unit 40 (e.g., within 5 mm of the distal end, such as at the distal end), in fluid communication with delivery lumen 42. For some applications, distal opening 46 comprises a nozzle, for controlling the direction and/or flow rate of the distribution of solid-liquid composition 39. The nozzle may be shaped so as to define one or more lateral or distal openings. As used in the present application, including in the claims, distal end 48 of shaft unit 40 means the distal-most point(s) of the shaft unit.

For some applications, such as shown in Figs. 2A-C, surgical tool 20 comprises a plurality of elements disposed around and outside delivery lumen 42 for facilitating (a) inhibiting passage of bone graft particles 34 of solid-liquid composition 39 to drainage lumen 44, and (b) allowing passage of physiological liquid solution 36 of solid-liquid composition 39 to drainage lumen 44.

To this end, for some applications, such as shown in Figs. 2A-B, injector unit 32 further comprises a filter 50 (which may comprise the plurality of elements mentioned immediately above), which is disposed in fluid communication with drainage lumen 44, and which is configured to (a) inhibit passage of bone graft particles 34 of solid-liquid composition 39 and (b) allow passage of physiological liquid solution 36 of solid-liquid composition 39. For some applications, filter 50 is disposed within 10 mm of distal end 48 of shaft unit 40, e.g., at distal end 48. For other applications filter 50 is disposed elsewhere along shaft unit 40, or outside of shaft unit 40 in fluid communication with drainage lumen 44. For some applications, such as shown in Figs. 2A, 3A, and 3B, filter 50 is shaped so as to define a plurality of slits 52 having a width narrower than bone graft particles 34. Alternatively or additionally, for some applications, filter 50 comprises a mesh having openings smaller than bone graft particles 34.

For some applications, filter 50, distal opening 46, and/or solid-particle container 37 are detachable from surgical tool 20 and/or disposable.

For other applications, such as shown in Fig. 2C, delivery shaft 56 of exactly one shaft unit 40 is shaped so as to define a plurality of rib elements 76 that extend radially outward from an external surface 78 of delivery shaft 56 (the rib elements may be the

plurality of elements mentioned above). For some applications, rib elements 76 extend an average distance of at least 0.1 mm, no more than 2 mm, and/or between 0.1 and 2 mm radially outward from external surface 78 of delivery shaft 56. Alternatively or additionally, for some applications, rib elements 76 extend longitudinally along external surface 78 of delivery shaft 56 for an average distance of at least 1 mm, such as at least 1 cm.

As mentioned above, for some applications, composition source 38 comprises combining feeder unit 60, which is configured to provide solid-liquid composition 39 by combining bone graft particles 34 with physiological liquid solution 36. For some applications, combining feeder unit 60 comprises a mixing feeder unit 62, which is configured to provide solid-liquid composition 39 by mixing bone graft particles 34 with physiological liquid solution 36. Several possible configurations of mixing feeder unit 62 are described hereinbelow with reference to Figs. 8A-K. For some applications, such as shown in Figs. 2A-B, mixing feeder unit 62 comprises an Archimedes screw 180. For other applications, such as shown in Fig. 2C, mixing feeder unit 62 comprises a shaft 72 and a plurality of mixing blades 74 attached to shaft 72, optionally extending radially outward from shaft 72.

As described hereinbelow with reference to Figs. 4A-B and 5A-B, injector unit 32 is configured to inject solid-liquid composition 39 through delivery lumen 42 and distal opening 46 into a cavity, such that (a) a portion of physiological liquid solution 36 drains through filter 50, and (b) filter 50 inhibits passage of bone graft particles 34 of solid-liquid composition 39, such that bone graft particles 34 accumulate in the cavity.

To enable such injection, for some applications surgical tool 20 further comprises a pump, which is configured to pump solid-liquid composition 39 through distal opening 46 via delivery lumen 42. For some applications, such as those in which injector unit 32 is implemented as an attachment to separate handheld motor 24 (such as shown in Figs. 2A and 2C), the pump comprises pump 27 of external control unit 22. In these applications, a supply tube 64 typically is coupled in fluid communication with (a) a liquid solution container 66 (such as a bag) that contains physiological liquid solution 36, and (b) combining feeder unit 60; supply tube 64 passes through pump 27. For other applications, such as those in which injector unit 32 is implemented as a standalone unit (such as shown in Fig. 2B), the pump comprises pump 43 of injector unit 32.

For some applications, the pump is configured to pump solid-liquid composition 39 at a pulsating positive hydraulic pressure. Such pulsation may help distribute solid-liquid composition 39 in the cavity, and/or inhibit clogging of filter 50, such as described hereinbelow. For some applications, the pump is configured to pump solid-liquid composition 39 at a pulsating hydraulic pressure that periodically varies between positive and negative (optionally, the negative pressure is applied a smaller portion of the time than is the positive pressure). Such pulsation may help inhibit clogging of filter 50, such as described hereinbelow. For some applications, the pump is configured to pump solid-liquid composition 39 through distal opening 46 via delivery lumen 42 during a plurality of positive-pressure periods that alternate with a plurality of negative-pressure periods, and to set an average duration of the positive-pressure periods to be less than or equal to an average duration of the negative-pressure periods. For some applications, the pump is configured to set the average duration of the positive-pressure periods to be equal to the average duration of the negative-pressure periods. This technique typically allows time for at least a portion (e.g., most or nearly all) of bone graft particles 34 to settle in cavity 90 before liquid of solid-liquid composition 39 is withdrawn, thereby allowing for accumulation of bone graft particles 34 in cavity 90.

For some applications, surgical tool 20 further comprises a suction source 49 (labeled in Fig. 1), which is coupled in fluid communication with drainage lumen 44, such as by a suction tube 51. The suction provided by suction source 49 facilitates drainage of the filtered physiological liquid solution 36. Alternatively, suction is not used, and passive drainage is sufficient, such as because of pressure build-up in the cavity generated by the injection of solid-liquid composition 39. For some applications, the pump is configured to clear bone graft particles 34 that accumulate on filter 50 during drainage of physiological liquid solution 36 through filter 50, by periodically applying a positive pressure to drainage lumen 44.

For some applications, surgical tool 20 (e.g., injector unit 32 thereof, such as shaft unit 40) is configured to inhibit clogging of filter 50 by bone graft particles 34 as physiological liquid solution 36 drains through filter 50. For some applications, surgical tool 20 (e.g., injector unit 32 thereof, such as shaft unit 40) is configured to move distal opening 46 and shaft unit 40 with respect to each other (for applications in which distal opening 46 comprises the nozzle, the nozzle and shaft unit 40 with respect to each other), for example during delivery of solid-liquid composition 39. For example, surgical tool 20

(e.g., injector unit 32 thereof, such as shaft unit 40) may be configured to:

- rotate distal opening 46 and shaft unit 40 with respect to each other; the rotation may be either full or partial, and/or unidirectional and/or bidirectional; for some applications, surgical tool 20 (e.g., injector unit 32 thereof) is configured to rotate distal opening 46 while holding shaft unit 40 rotationally immobile, while for other applications, surgical tool 20 (e.g., injector unit 32 thereof) is configured to rotate shaft unit 40 while holding distal opening 46 rotationally immobile;
- move distal opening 46 and shaft unit 40 side-to-side with respect to each other;
- move distal opening 46 and shaft unit 40 axially back-and-forth with respect to each other; and/or
- vibrate distal opening 46 and shaft unit 40 side-to-side with respect to each other; and/or

Alternatively or additionally, for some applications, surgical tool 20 (e.g., injector unit 32 thereof) is configured to automatically apply motion to shaft unit 40 selected from the group consisting of: vibrational motion, rotational motion, oscillatory motion, axial back-and-forth motion, and lateral side-to-side motion. Further alternatively or additionally, for some applications, surgical tool 20 (e.g., injector unit 32 thereof) is configured to vibrate solid-liquid composition 39 in delivery lumen 42.

For some applications, in order to provide any of the above-mentioned motions, surgical tool 20 uses electromagnetic power or pneumatic power.

For some applications, surgical tool 20 (e.g., injector unit 32 thereof, such as shaft unit 40) is configured such that flow of solid-liquid composition 39 causes distal opening 46 and shaft unit 40 to move with respect to each other. Alternatively or additionally, for some applications, surgical tool 20 (e.g., injector unit 32 thereof, such as shaft unit 40) is configured such that flow of filtered physiological liquid solution 36 causes distal opening 46 and shaft unit 40 to move with respect to each other.

For some applications, such as shown in Figs. 2A-C, surgical tool 20 (e.g., injector unit 32 thereof) further comprises an element 54 disposed around an external surface of shaft unit 40. For some applications, element 54 comprises a sealing element, which is configured to form a liquid-tight seal with tissue (gingiva or bone) around and outside a bore through the bone when shaft unit 40 is inserted into the bore. Sealing element 54

may inhibit flow of the filtered physiological liquid solution 36 into the patient's mouth.

For some applications, such as shown in Fig. 2A-C, element 54 comprises a depth limiting element, which is configured to limit a depth of insertion of shaft unit 40 into a bore through a bone when shaft unit 40 is inserted into the bore; optionally, the depth limiting element is removably attached to shaft unit 40. For some applications, element 54 alternatively or additionally serves as the depth limiting element; optionally, element 54 is removably attached to shaft unit 40. For some applications, a plurality of depth limiting elements are provided having different respective lengths. For some applications, such as shown in Fig. 2C, depth limiting element 54 is shaped so as to define a portion of drainage lumen 44 between at least a portion of an internal surface of depth limiting element 54 and a portion of external surface 78 of delivery shaft 56.

Reference is now made to Figs. 3A-B, which are schematic illustrations of respective configurations of injector unit 32, in accordance with respective applications of the present invention. In these configurations, surgical tool 20 (e.g., injector unit 32 thereof, such as shaft unit 40) further comprises a filter clearing element 70, which is configured to clear bone graft particles 34 that accumulate on filter 50 during drainage of physiological liquid solution 36 through filter 50. Filter clearing element 70 may also serve to distribute solid-liquid composition, in order to provide better distribution of bone graft particles 34 in cavity 90 and to prevent the bone graft particles from clogging distal opening 46.

For some applications, surgical tool 20 (e.g., injector unit 32 thereof) is configured to move filter clearing element 70 with respect to filter 50. For example, surgical tool 20 (e.g., injector unit 32 thereof) may be configured to (a) rotate filter clearing element 70 (the rotation may be either full or partial, and/or unidirectional and/or bidirectional); and/or (b) axially move filter clearing element 70.

For some applications, such as shown in Figs. 3A-B, filter clearing element 70 is fixed to distal opening 46 (i.e., to the structure that defines distal opening 46). For some applications in which distal opening 46 comprises the nozzle, filter clearing element 70 is fixed to the nozzle. In some of these applications, the various motions of distal opening 46 and shaft unit 40 with respect to each other, described hereinabove with reference to Figs. 2A-B, facilitate the movement of filter clearing element 70 with respect to filter 50.

For some applications, such as shown in Figs. 2A-C and 3A, filter 50 is disposed

around an axis 80 of distal opening 46. For some applications, such as shown in Figs. 2A-C and 3A, filter 50 is disposed around delivery lumen 42 in shaft unit 40.

For some applications, such as shown in Figs. 2A-C and 3A, drainage lumen 44 is disposed around delivery lumen 42 in shaft unit 40. For other applications, such as shown
5 in Fig. 3B, drainage lumen 44 is disposed alongside delivery lumen 42 in shaft unit 40.

Reference is now made to Figs. 4A-B and 5A, which are schematic illustrations of uses of surgical tool 20, in accordance with respective applications of the present invention. The illustrated use is typically performed in conjunction with a minimally-invasive closed sinus lift surgical procedure for implanting a dental implant. The
10 procedure is typically employed when a patient's alveolar maxillary bone 82 lacks sufficient bone mass to support a conventional dental implant. The procedure may be performed using any of the techniques described in the patents and patent application publications incorporated hereinbelow by reference, or using other sinus lift techniques known in the art. For some applications, the surgeon reflects gingiva 84, exposing an
15 occlusal surface of maxillary alveolar bone 82 as shown in Figs. 4A-B and 5A. Alternatively, a flapless procedure is performed, in which the gingiva is not reflected (approach not shown). Although a crestal approach is shown, a lateral approach may alternatively be used.

A bore 86 (e.g., exactly one bore) is formed through bone 82 from a first side of
20 the bone to a second side of the bone. A Schneiderian membrane 88 is raised to form a cavity 90 between the second side of the bone and Schneiderian membrane 88, such as using hydraulic pressure or mechanical elevation.

Reference is still made to Figs. 4A-B. Exactly one shaft unit 40 is inserted, from the first side of a bone, into bore 86, such that distal opening 46 is disposed in bore 86 or
25 in cavity 90 (in other words, distal opening 46 may or may not penetrate the sinus floor). Solid-liquid composition 39 is injected through delivery lumen 42 and distal opening 46 into cavity 90, such that (a) a portion of physiological liquid solution 36 drains into drainage lumen 44, and (b) passage of bone graft particles 34 of solid-liquid composition 39 into drainage lumen 44 is inhibited, such that bone graft particles 34 accumulate in
30 cavity 90, and function as regenerative material. Typically, at least 50% of physiological liquid solution 36 drains through filter 50 in a distal-to-proximal direction, optionally while solid-liquid composition 39 is being injected. Typically, 2-300 ml of solid-liquid

composition 39 is injected. Typically, between 0.2 and 20 ml of bone graft particles accumulate in the cavity. Typically, but not necessarily, physiological liquid solution 36 drains into drainage lumen 44 (e.g., through filter 50) at the same time that solid-liquid composition 39 is injected.

5 For some applications, such as shown in Fig. 4A, in which shaft unit 40 has the configuration described hereinabove with reference to Figs. 2A-B, (a) the portion of physiological liquid solution 36 drains through filter 50 and into drainage lumen 44, and (b) filter 50 inhibits passage of bone graft particles 34 of solid-liquid composition 39, such that bone graft particles 34 accumulate in cavity 90, and function as regenerative
10 material.

 For other applications, such as shown in Fig. 4B, in which shaft unit 40 has the configuration described hereinabove with reference to Fig. 2C, exactly one shaft unit 40 is inserted into bore 86 such that rib elements 76 space external surface 78 of delivery shaft 56 away from an inner wall of bore 86, thereby defining a fluid flow path 79 between
15 external surface 78 of delivery shaft 56 and the inner wall of bore 86. As a result, (a) the portion of physiological liquid solution 36 drains through fluid flow path 79 and into drainage lumen 44, and (b) passage of bone graft particles 34 of solid-liquid composition 39 into fluid flow path 79 is inhibited, such that the solid particles accumulate in the cavity.

20 For some applications, inserting shaft unit 40 comprises positioning distal opening 46 at a location at a distance from the second side of the bone, the distance equal to at least 50% (e.g., at least 75%) of a height of cavity 90 directly above bore 86, and solid-liquid composition is injected (e.g., pumped) while distal opening 46 is positioned at the location. For some applications, distal opening 46 is positioned at between 2 and 12 mm
25 (e.g., 4 and 6 mm) from Schneiderian membrane 88 at a roof of cavity 90 directly above bore 86. For some applications, distal opening 46 is disposed at distal end 48 of shaft unit 40, and positioning distal opening 46 comprises positioning distal end 48 of shaft unit 40 at the location. For some applications, raising Schneiderian membrane 88 comprises injecting physiological solution through delivery lumen 42 after inserting shaft unit 40
30 into bore 86.

 Alternatively, the surgeon injects solid-liquid composition 39 to lift membrane 88, thereby combining the lift and bone graft injection steps into a single step. Further

alternatively, the surgeon uses surgical tool 20 to inject physiological solution, e.g., saline solution, to raise the membrane.

After solid-liquid composition 39 is injected, an implant is implanted at least partially within cavity 90, either during the same procedure or after bone grows into bone graft particles 34 in cavity 90. After bone grows into bone graft particles 34, a dental
5 appliance, such as a crown, is coupled to the implant.

Reference is now made to Fig. 5B, which is a schematic illustration of an alternative configuration of shaft unit 40 and one use thereof, in accordance with an application of the present invention. In this configuration, distal end 48 of shaft unit 40 is disposed no
10 more distal than a distal-most surface of sealing element 54. Distal end 48 of shaft unit 40 may be either flush with the distal-most surface of sealing element 54, or recessed within sealing element 54 (i.e., proximal to the distal-most surface of sealing element 54). Because sealing element 54 forms a fluid-tight seal with the tissue (gingiva or bone) surrounding bore 86, distal opening 46 is disposed in fluid communication with bore 86
15 (and cavity 90), and solid-liquid composition 39, when injected through distal opening 46, flows into bore 86 and then into cavity 90. Similarly, filtered physiological liquid solution 36 passes from cavity 90, through bore 86, and into drainage lumen 44. For some applications, shaft unit 40 is not provided. Distal opening 46 may instead be provided by another portion of injector unit 32 (such as an external surface thereof), and
20 configured to provide fluid communication with an opening through sealing element 54.

Reference is now made to Figs. 6A-B and 7, which are schematic illustrations of a surgical tool 120 comprising an injector unit 132, in accordance with an application of the present invention. Except as described hereinbelow, surgical tool 120 and injector unit 132 are generally similar to surgical tool 20 and injector unit 32, described hereinabove
25 with reference to Figs. 1-3B, and may implement any of the features thereof. Surgical tool 120 (e.g., injector unit 132 thereof) comprises exactly one shaft unit 140, which is shaped so as to define a lumen 142, and a distal opening 146, which is typically disposed within 10 mm of a distal end 148 of shaft unit 140 (e.g., within 5 mm of the distal end, such as at the distal end), in fluid communication with lumen 142. Composition source
30 38, described hereinbelow with reference to Figs. 2A-C, is coupled in selective fluid communication with lumen 142. As used in the present application, including in the claims, distal end 148 of shaft unit 140 means the distal-most point(s) of the shaft unit.

For some applications, shaft unit 140 is shaped so as to define exactly one lumen 142. For other applications, shaft unit 140 is shaped so as to define a plurality of lumens that are in fluid communication with one another in shaft unit 140. Typically, a largest circle circumscribed by a cross-section of lumen 142 has a diameter of at least 1 mm, such as at least 1.5 mm, and/or no more than 7 mm, such as no more than 4 mm (the cross-section is perpendicular to a longitudinal axis of the lumen).

Injector unit 132 further comprises a one-way filter 150, which is disposed in fluid communication with lumen 142, and which is configured to:

- allow passage, in a proximal-to-distal direction (schematically indicated by an arrow 151 in Fig. 6A), of bone graft particles 34 and physiological liquid solution 36 of solid-liquid composition 39,
- inhibit passage, in a distal-to-proximal direction (schematically indicated by an arrow 153 in Fig. 6B), of bone graft particles 34 of solid-liquid composition 39, and
- allow passage, in the distal-to-proximal direction, of physiological liquid solution 36 of solid-liquid composition 39.

For some applications, surgical tool 120 (e.g., injector unit 132 thereof) comprises a one-way filter valve 152 that comprises one-way filter 150. One-way filter valve 152 is in fluid communication with lumen 142. For example, one-way filter valve 152 may comprise a leaf valve 154, which comprises one or more leafs 156. For example, leafs 156 may comprise mesh 158 having openings smaller than bone graft particles 34, or may be shaped so as to define a plurality of slits having a width narrower than bone graft particles 34. For some applications, one-way filter 150 is disposed within 10 mm of distal end 148 of shaft unit 140.

Composition source 38 is coupled in fluid communication with lumen 142, such as via a feeder tube 135. For some applications, surgical tool 20 is shaped so as to define a suction port 160, and one-way filter 150 is in selective fluid communication with suction source 49 via suction port 160. For some applications, suction port 160 is disposed at a site 162 along a fluid path between one-way filter 150 and composition source 38, and surgical tool 20 (e.g., injector unit 32 thereof) further comprises a source one-way valve 166, which is disposed along the fluid path proximal to site 162 at which suction port 160

is disposed.

For some applications, the pump (e.g., pump 27 of external control unit 22, or pump 43 of injector unit 132) is configured to pump solid-liquid composition 39 through distal opening 146 via lumen 142. For some applications, the pump is configured to pump solid-liquid composition 39 with an on-off duty cycle. For some applications, suction port 160 is configured to assume an open state when the pump is off, and a closed state when the pump is on. For some applications, suction source 49 is configured to apply suction when the pump is off, and not apply the suction when the pump is on.

To inhibit suctioning of bone graft particles 34 through suction port 160, for some applications, source one-way valve 166 is configured to open at a higher pressure gradient than the pressure gradient at which one-way filter valve 152 opens (the injection pressure is typically substantially higher than the suction vacuum). Alternatively or additionally, application of the suction is synchronized with application of the pressure, so that the suction is off when the solid-liquid composition 39 is injected and *vice versa*.

For some applications, surgical tool 120 is used in conjunction with a minimally-invasive sinus lift surgical procedure for implanting a dental implant. Other than as described below, the procedure is similar to the procedure described hereinabove with reference to Figs. 4A-B and 5A. After the bore has been formed and Schneiderian membrane 88 has been raised to form cavity 90, the exactly one shaft unit 140 is inserted, from a first side of bone 82, such that distal opening 146 is disposed in the bore or in cavity 90. Solid-liquid composition 39 is injected through lumen 142, one-way filter 150, and distal opening 146 into cavity 90, as shown in Figs. 6A and 7. Physiological liquid solution 36 of solid-liquid composition 39 drains through one-way filter 150, as shown in Fig. 6B. Typically, at least 50% of physiological liquid solution 36 drains through filter 50 in the distal-to-proximal direction.

For some applications, injecting and draining comprise alternately injecting (as shown in Figs. 6A and 7) and draining (as shown in Fig. 6B). For some applications, injecting solid-liquid composition 39 comprises pumping solid-liquid composition 39 at a positive hydraulic pressure, and draining physiological liquid solution 36 comprises suctioning physiological liquid solution 36 at a negative hydraulic pressure. For some applications, pumping and suctioning comprise alternately pumping and suctioning.

An implant is implanted, as described hereinabove with reference to Figs. 4A-B

and 5A.

For some applications, distal end 148 of shaft unit 140 is disposed no more distal than a distal-most surface of sealing element 54, such as described hereinabove with reference to Fig. 5B, *mutatis mutandis*. Distal end 148 of shaft unit 140 may be either
5 flush with the distal-most surface of sealing element 54, or recessed within sealing element 54 (i.e., proximal to the distal-most surface of sealing element 54). Because sealing element 54 forms a fluid-tight seal with the tissue (gingiva or bone) surrounding bore 86, distal opening 146 is disposed in fluid communication with bore 86 (and cavity 90), and solid-liquid composition 39, when injected through distal opening 146, flows into
10 bore 86 and then into cavity 90. Similarly, physiological liquid solution 36 passes from cavity 90, through bore 86 and one-way filter 150, and into lumen 142. For some applications, shaft unit 140 is not provided. Distal opening 146 may instead be provided by another portion of injector unit 132 (such as an external surface thereof), and configured to provide fluid communication with an opening through sealing element 54.

Reference is again made to Figs. 2A-C, and is additionally made to Figs. 8A-K, which are highly schematic illustrations of several configurations of mixing feeder unit 62, in accordance with respective applications of the present invention. Mixing feeder unit 62 may retrieve bone graft particles 34 from solid-particle container 37 passively (such as by gravity and/or flow of physiological liquid solution 36 through solid-particle
20 container 37). Alternatively or additionally, mixing feeder unit 62 may retrieve bone graft particles 34 from solid-particle container 37 actively, such as using one or more of the following: vibration (in order to overcome the pressure filtration effect), ultrasonic energy, positive pressure (automatic or manual) in the container applied by physiological liquid solution 36, suction, and/or dosage-controlled portioning of bone graft particles 34
25 using Archimedes screw 180 (shown in Figs. 2A-B), shaft 72 with mixing blades 74 (shown in Fig. 2C), or by periodically opening an exit orifice, which releases bone graft particles into the flow of physiological liquid solution 36.

Figs. 8A-K schematically illustrate several configurations for mixing bone graft particles 34 with physiological liquid solution 36 to generate solid-liquid composition 39.
30 By way of example and not limitation, in these figures physiological liquid solution 36 is referred to as "saline," and solid-liquid composition 39 is referred to as "mixed solution."

Fig. 8A illustrates passive mixing without application of pressure to physiological

liquid solution 36.

Fig. 8B illustrates active mixing (using a mixing unit 182) without application of pressure to physiological liquid solution 36.

Fig. 8C illustrates active mixing (using mixing unit 182) without application of
5 pressure to physiological liquid solution 36, with the addition of active retrieval of bone graft particles 34 from solid-particle container 37.

Fig. 8D illustrates passive mixing with the application of pressure to physiological liquid solution 36, and the flow of physiological liquid solution 36 through solid-particle container 37.

10 Fig. 8E illustrates active mixing (using mixing unit 182) with the application of pressure to physiological liquid solution 36, and the flow of physiological liquid solution 36 through solid-particle container 37.

Fig. 8F illustrates active mixing (using mixing unit 182) with the application of pressure to physiological liquid solution 36, with the addition of active retrieval of bone
15 graft particles 34 from solid-particle container 37, and the flow of physiological liquid solution 36 through solid-particle container 37.

Fig. 8G illustrates passive mixing with or without application of pressure to physiological liquid solution 36, and the flow of all of physiological liquid solution 36 through solid-particle container 37.

20 Fig. 8H illustrates active mixing (using mixing unit 182) with or without application of pressure to physiological liquid solution 36, and the flow of all of physiological liquid solution 36 through solid-particle container 37.

Fig. 8I illustrates active mixing (using mixing unit 182) without the application of pressure to physiological liquid solution 36, with the addition of active retrieval of bone
25 graft particles 34 from solid-particle container 37, and the flow of all of physiological liquid solution 36 through solid-particle container 37.

Fig. 8J illustrates the reverse flow of all of physiological liquid solution 36 through solid-particle container 37; the flow against gravity minimizes the pressure filtration effect.

30 Fig. 8K illustrates the reverse flow of physiological liquid solution 36 through

solid-particle container 37, with the addition of application of suction for active retrieval of bone graft particles 34 and physiological liquid solution 36 from solid-particle container 37, and active mixing (using mixing unit 182).

Reference is now made to Figs. 9A-D, which are schematic illustrations of several configurations of an osteotome 200, in accordance with respective applications of the present invention. Osteotome 200 is configured to be used with bone graft particles 34 and a physiological liquid solution 36, such as saline solution or blood, in a manner similar to surgical tool 20, described hereinabove with reference to Figs. 1-5B and 8A-K. For some applications, osteotome 200 is configured as a dental osteotome.

Osteotome 200 is shaped so as to define:

- a lumen 210 through osteotome 200. A distal end 212 of lumen 210 opens through a distal opening 214 disposed within 10 mm of a distal end 216 of osteotome 200, such as within 5 mm of distal end 216, e.g., at distal end 216. A proximal end 218 of lumen 210 opens through a proximal opening 220 disposed at least 5 mm proximal to distal opening 214. For some applications, proximal opening 220 is disposed within 10 mm of a proximal end 222 of osteotome 200, such as within 5 mm of proximal end 222, e.g., at proximal end 222,
- a lateral external surface 230, at least a portion of which is shaped so as to define a screw thread 232 that (a) has a distal thread end 234 that is disposed within 10 mm of distal end 216 of osteotome 200, such as within 5 mm of distal end 216, e.g., within 1 mm of distal end 216, and (b) comprises one or more raised helical ribs 236 going around osteotome 200, and
- one or more longitudinal drainage slots 250, which extend along at least respective longitudinal portions 252 of osteotome 200 having respective longitudinal lengths L of at least 5 mm, such as at least 8 mm, e.g., at least 10 mm, such as at least 12 mm, measured parallel to a central longitudinal axis 253 of osteotome 200 (typically, the longitudinal lengths L are no more than 20 mm).

As used in the present application, including in the claims, distal end 216 of osteotome 200 means the distal-most point(s) of the osteotome. Similarly, proximal end 222 of osteotome 200 means the proximal-most point(s) of the osteotome.

Typically, a largest circle circumscribed by a cross-section of lumen 210 has a

diameter of at least 1 mm, such as at least 1.5 mm, and/or no more than 7 mm, such as no more than 4 mm (the cross-section is perpendicular to central longitudinal axis 253).

For some applications, the longitudinal lengths L of the respective longitudinal portions 252 are at least 2 mm greater than a thickness of bone 82 adjacently surrounding bore 86. This provides for 1 mm of longitudinal draining slots on the top and the bottom of the bone.

Figs. 9A-D show four different configurations 200A, 200B, 200C, and 200D of osteotome 200. For some applications, such as in all of the configurations shown, at least one of the one or more longitudinal drainage slots 250 reaches proximal end 222 of osteotome 200. Alternatively, at least one of the one or more longitudinal drainage slots 250 does not reach proximal end 222 of osteotome 200 (configuration not shown).

For some applications, such as in configurations 200B and 200D shown in Figs. 9B and 9D, respectively, respective distal ends 260 of the one or more longitudinal drainage slots 250 are disposed at least one pitch P of the screw thread from distal thread end 234, such as at least two pitches P of the screw thread from distal thread end 234, or at least three pitches P of the screw thread from distal thread end 234. For some applications, such as in configurations 200B and 200D shown in Figs. 9B and 9D, respectively, respective distal ends 260 of the one or more longitudinal drainage slots 250 are disposed at least 1.5 mm from distal end 216 of osteotome 200, such as at least 4 mm from distal end 216 of osteotome 200. For some applications, osteotome 200 further comprises a sealing element 254 disposed around an external surface of osteotome 200, and configured to form a liquid-tight seal with tissue (gingiva 84 or bone 82) around and outside bore 86 when osteotome 200 is inserted into bore 86. Sealing element 254 may be particularly useful in configurations 200A and 200C, but may also be provided in the other configurations.

For some applications, screw thread 232 is multi-start, i.e., is shaped to define more than one start, as is known in the screw art. For example, screw thread 232 may be double-start (as shown in Figs. 9A-D), triple-start, or quadruple-start. It is noted that the pitch P of a multi-start screw is measured between axially-adjacent rib portions, even though the rib portions are from different ribs, as is known in the screw art.

For some applications, respective average widths of the one or more longitudinal drainage slots 250 are no more than 3 mm, such as no more than 2 mm, e.g., no more than

1.5 mm or 1 mm. Typically, the widths of the one or more longitudinal drainage slots 250 are selected to be smaller than the bone graft particles 34, in order to filter the bone graft particles 34 (i.e., inhibit their passage through the drainage slots).

For some applications, respective average depths of the one or more longitudinal drainage slots 250, measured with respect to an outermost portion of screw thread 232 (i.e., locally with respect to the outermost portion of the screw thread; the width of the screw thread may vary therealong), are at least 10% greater than an average depth of screw thread 232, and/or at least 0.1 mm (such as at least 0.3 mm, e.g., at least 0.5 mm) greater than the average depth of screw thread 232, and/or at least 0.4 mm from the outermost portion of screw thread 232. (Typically, the average thread depth of screw thread 232 is at least 0.1 mm, such as at least 0.3 mm.)

For some applications, such as in configurations 200A and 200B shown in Figs. 9A and 9B, respectively, the one or more longitudinal drainage slots 250 cross the one or more ribs 236 respective pluralities of times. For some of these applications, the one or more longitudinal drainage slots 250 comprise two or more longitudinal drainage slots 250, such as two, three, four, five, six, or more than six slots 250. For some of these applications, the one or more longitudinal drainage slots 250 are parallel to central longitudinal axis 253. For some of these applications, the one or more longitudinal drainage slots 250 helically go around the dental osteotome (a) either in the same or opposite direction as screw thread 232, with a slot pitch greater than a thread pitch of screw thread 232, such as at least 1.5 times the thread pitch, or (b) in the opposite direction as screw thread 232 (in which case the slot pitch is not necessarily greater than the thread pitch of screw thread 232). For some applications, the slot pitch equals at least the quotient of (a) 2 mm divided by (b) the number of starts of screw thread 232. (Typically, the thread pitch is at least the quotient of (a) 1 mm (e.g., 1.2 mm, such as 2 mm) divided by (b) the number of starts of screw thread 232.)

For other applications, such as in configurations 200C and 200D shown in Figs. 9C and 9D, respectively, screw thread 232 has one or more starts and a corresponding number of roots, and osteotome 200 is shaped so as to define a number of longitudinal drainage slots 250 that corresponds to a number of the starts of screw thread 232, and which are disposed within the one or more roots of screw thread 232, respectively, typically at the deepest part of the roots (and thus follow the helical path of screw thread

232 around the osteotome). For some of these applications, as in configuration 200D shown in Fig. 9D, distal end 260 of longitudinal drainage slot 250 is disposed at least one pitch P of screw thread 232 from distal thread end 234, such as at least two pitches P of screw thread 232 from distal thread end 234, e.g., at least three pitches P of screw thread
5 232 from distal thread end 234.

Typically, osteotome 200 is configured to be used with bone graft particles 34 and physiological liquid solution 36, as described hereinabove. During use, osteotome 200 is inserted, from a first side of bone 82, into bore 86, such that distal opening 214 is disposed in the bore or in a cavity adjacent to the second side of the bone. A solid-liquid
10 composition 39 of bone graft particles 34 and physiological liquid solution 36 is provided from composition source 38 that is coupled in fluid communication with lumen 210. Solid-liquid composition 39 is injected through lumen 210 and distal opening 214 into cavity 90, such that (a) a portion of physiological liquid solution 36 drains through the one or more longitudinal drainage slots 250, and (b) the one or more longitudinal drainage
15 slots 250 inhibit passage of bone graft particles 34 of solid-liquid composition 39 such that the bone graft particles 34 accumulate in cavity 90.

For some applications, osteotome 200 is configured as a dental osteotome, and bone 82 is a bone of a jaw. For some applications, cavity 90 is between the second side of bone 82 and a membrane, such as Schneiderian membrane 88. Typically, before inserting
20 osteotome 200, the membrane is raised to form cavity 90 between the second side of bone 82 and membrane 88.

Typically, proximal end 222 of osteotome 200 is shaped so as to define a coupling interface, such as a male or female coupling interface, which, for example, may be shaped so as to define a male or female polygon having four or more sides, such as five or more
25 sides, or six or more sides, e.g., exactly four, five, or six sides. The surgeon may use a conventional dental wrench or dental drill to engage the coupling interface and rotate the osteotome.

Reference is now made to Figs. 10A-D, which are schematic illustrations of a portion of a sinus lift and bone graft injection procedure performed using configuration
30 200B of osteotome 200, in accordance with an application of the present invention. The same method may be used with configuration 200D, *mutatis mutandis*. As mentioned above, in configurations 200B and 200D, shown in Figs. 9B and 9D, respectively,

respective distal ends 260 of the one or more longitudinal drainage slots 250 are disposed at least one pitch P of screw thread 232 from distal thread end 234.

The procedure begins as described hereinabove with reference to Figs. 4A-B and 5A, including forming bore 86 (e.g., exactly one bore) through bone 82 from a first side of bone 82 to a second side of bone 82 (steps not shown). Thereafter, membrane 88 is raised by (a) advancing osteotome 200 into bore 86 such that a portion of screw thread 232 distal to respective distal ends 260 of the one or more longitudinal drainage slots 250 sealingly engages a wall of bore 86, such as shown in Fig. 10A, and (b) thereafter, injecting a physiological fluid (e.g., saline solution) through the bore under sufficient pressure to raise membrane 88, such as shown in Fig. 10B. Such raising may be performed using any of the techniques described in the patents and patent application publications incorporated hereinbelow by reference, or using other hydraulic pressure sinus lift techniques known in the art.

As shown in Fig. 10C, osteotome 200 is further advanced into bore 86 until the one or more drainage slots 250 come into fluid communication with cavity 90. As shown in Fig. 10D, solid-liquid composition 39 is injected into cavity 90, such as described above. For some applications, the drained physiological liquid solution may be suctioned using a conventional dental suction tool, or sealing element 254 may be provided with a collecting chamber that is coupled to suction. Typically, after injecting the solid-liquid composition, an implant is implanted at least partially within cavity (step not shown).

Although the surgical tools and methods described herein have been generally described for sinus lift dental applications, these tools and methods may additionally be used for other dental applications, such as ridge augmentation (in both the maxilla and mandible) (such as by injecting the solid-liquid composition between the gingiva and the bone crest), or sinus floor elevation. In addition, these tools and methods may additionally be used for non-dental applications, such as orthopedic applications. For orthopedic applications, bone graft particles 34 may have a larger average particle size, e.g., up to 7 mm.

Reference is now made to Fig. 11, which is a schematic illustration of one use of surgical tool 20 for ridge augmentation, in accordance with an application of the present invention. In this application, surgical tool 20, described hereinabove with reference to Figs. 1-5B and 8A-K, is used to perform ridge augmentation of a jaw bone 290 (either a

mandible or a maxilla). For some applications, gingiva 292 is dissected from jaw bone 290, such as by tunneling, as is known in the art. Optionally, a structural support 294 is placed under gingiva 292; for example, structural support 294 may comprise a mesh, reinforced membrane, and/or stent. Bone graft injector unit 32 of surgical tool 20 is used
5 to inject solid-liquid composition 39 between jaw bone 290 and gingiva 292, or between jaw bone 290 and structural support 294. Alternatively, surgical tool 120, described hereinabove with reference to Figs. 6A-B, 7, and 8A-K, is used to perform this procedure.

Reference is now made to Figs. 12A-B, which are schematic illustrations of one use of surgical tool 20 for performing a minimally-invasive spinal interbody fusion, in
10 accordance with an application of the present invention. The approach to the spine (anterior, posterior, or lateral) depends on the site (e.g., lumbar, cervical, or thoracic spine). Typically, an inner vertebral disc is removed or partially removed and replaced with a structural support 296, such as a rigid cage. Bone graft injector unit 32 of surgical tool 20, described hereinabove with reference to Figs. 1-5B and 8A-K, is used to inject
15 solid-liquid composition 39 into structural support 296. Optionally, external fixation is also performed to fixate the adjacent vertebrae, as is known in the art, such as shown in Fig. 12B. For this application, shaft unit 40 is generally coaxial with the body of bone graft injector unit 32, i.e., faces forward rather than sideways; shaft unit 40 may also be somewhat longer than in the configurations shown in Figs. 1-5B. Alternatively, surgical
20 tool 120, described hereinabove with reference to Figs. 6A-B, 7, and 8A-K, is used to perform this procedure, *mutatis mutandis*.

Reference is now made to Fig. 13, which is a schematic illustration of one use of surgical tool 20 for filling a bone defect, in accordance with an application of the present invention. In this application, surgical tool 20, described hereinabove with reference to
25 Figs. 1-5B and 8A-K, is used to fill a defect 500 in a bone 510. This technique may be used for orthopedic procedures, as well as for dental procedures. For some applications, a structural element 520, such as a crib, is placed over defect 500 in order to define a volume to be filled. Bone graft injector unit 32 of surgical tool 20 is used to inject solid-liquid composition 39 into the volume defined by structural element 520. As described
30 hereinabove with reference to Figs. 12A-B, for this application, shaft unit 40 is generally coaxially with the body of bone graft injector unit 32, and be longer than in the configurations shown in Figs. 1-5B. Alternatively, surgical tool 120, described hereinabove with reference to Figs. 6A-B, 7, and 8A-K, is used to perform this procedure,

mutatis mutandis.

Reference is made to Fig. 14, which is a schematic illustration of a bone graft injection system 320 for the insertion of solid particles, typically solid bone graft particles 334, into a cavity, in accordance with an application of the present invention. For example, the cavity may be cavity 90, shown in Figs. 18A-D and 21. Reference is also made to Fig. 15, which is a diagram illustrating the schematic arrangement of certain elements of bone graft injection system 320, in accordance with an application of the present invention. Bone graft injection system 320 is for use with a liquid solution container 366 containing a physiological liquid solution 336, such as saline solution.

10 Bone graft injection system 320 comprises a composition delivery source 300 and a pump unit 301. Typically, composition delivery source 300 is single-use and disposable, while pump unit 301 is reused many times. For some applications, the components of composition delivery source 300 are provided as a preassembled unit, while for other applications, one or more of the components are provided disconnected from one another

15 and are assembled by a healthcare worker, for example, based on shape- or color-coding of the components.

Reference is still made to Figs. 14 and 15, and is additionally made to Fig. 16A, which is a schematic illustration of a portion of composition delivery source 300, in accordance with an application of the present invention. Composition delivery source 300

20 comprises a chamber 302, which comprises a filter 304. Filter 304 is disposed within chamber 302 so as to divide chamber 302 into a liquid compartment 306 and a solid-liquid composition compartment 308. Chamber 302 is shaped so as to define (a) one or more (e.g., exactly one) liquid ports 310 in fluid communication with liquid compartment 306, and (B) one or more (e.g., exactly one) solid-liquid composition ports 312 in fluid

25 communication with solid-liquid composition compartment 308.

Composition delivery source 300 further comprises:

- a solid-liquid composition delivery tube 314, which is in fluid communication with at least one of the one or more solid-liquid composition ports 312;
 - a mixing tube 316, which is in fluid communication with at least one of the one or more liquid ports 310 and at least one of the one or more solid-liquid composition ports 312; and
- 30

- a liquid-supply tube 318, which is in fluid communication with at least one of the one or more liquid ports 310, and is coupled in fluid communication with an interior of liquid solution container 366.

Pump unit 301 comprises:

- a mixing pump 322, which is arranged to cause flow in mixing tube 316, typically unidirectionally; and
- a liquid-supply pump 324, which is arranged to cause flow in liquid-supply tube 318, typically oscillating (bidirectional) flow.

It is noted that mixing tube 316 is considered to be in fluid communication with the at least one of the one or more liquid ports 310 and the at least one of the one or more solid-liquid composition ports 312 even though mixing tube 316 is intermittently not in such fluid communication because of the operation of liquid-supply pump 324, as described hereinbelow. Similarly, it is noted that liquid-supply tube 318 is considered to be in fluid communication with the at least one of the one or more liquid ports 310 and to be coupled in fluid communication with the interior of liquid solution container 366 even though liquid-supply tube 318 is intermittently not in such fluid communication because of the operation of mixing pump 322, as described hereinbelow.

For some applications, each of the tubes comprises one or more tube segments that are coupled together to form the complete tube, such as for applications in which the pumps do not comprise peristaltic pumps and respective tube segments are coupled to an inlet and an outlet of a pump.

For some applications, as shown in Figs. 14 and 15, mixing tube 316 (a) merges with liquid-supply tube 318 at an exit junction 326, and (b) is in fluid communication with the at least one of the one or more liquid ports 310 via a portion of liquid-supply tube 318. For other applications, liquid-supply tube 318 (a) merges with mixing tube 316 at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports 310 via a portion of mixing tube 316 (not shown, but functionally equivalent to the above-mentioned shown configuration).

For some applications, as shown in Figs. 15 and 16A, mixing tube 316 (a) merges with solid-liquid composition delivery tube 314 at a return junction 328, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition ports 312

via a portion of solid-liquid composition delivery tube 314. This merging may help free any solid bone graft particles 334 that may become lodged in the one or more solid-liquid composition ports 312, because the flow into the one or more solid-liquid composition ports 312 is via the portion of solid-liquid composition delivery tube 314 in the opposite
5 direction of flow during delivery of solid-liquid composition 339 in particle-delivery activation state 344, as described hereinbelow with reference to Figs. 17 and 18A-D.

For some applications, a proximal end 330 of solid-liquid composition delivery tube 314 is in fluid communication with the at least one of the one or more solid-liquid composition ports 312, and a distance D1 (labeled in Fig. 16A) between return junction
10 328 and proximal end 330 of solid-liquid composition delivery tube 314 is less than 60 mm, such as less than 20 mm. Disposing return junction 328 so close to proximal end 330 of solid-liquid composition delivery tube 314 reduces the amount of solid bone graft particles 334 pumped back from solid-liquid composition delivery tube 314 to solid-liquid composition compartment 308. For other applications, mixing tube 316 is in fluid
15 communication with the at least one of the one or more solid-liquid composition ports 312 not via a portion of solid-liquid composition delivery tube 314. For some applications, an inner diameter of solid-liquid composition delivery tube 314 is at least 1.4 mm, no more than 1.8 mm, and/or between 1.4 and 1.8 mm. For some applications, solid-liquid composition delivery tube 314 is in fluid communication with exactly one of the one or
20 more solid-liquid composition ports 312, and the exactly one port has a diameter of between 0.1 and 0.3 mm less than the inner diameter of solid-liquid composition delivery tube 314.

For some applications, an internal cross-sectional area of solid-liquid composition delivery tube 314 perpendicular to an axis of solid-liquid composition delivery tube 314 is
25 non-decreasing from return junction 328 to a distal end of solid-liquid composition delivery tube 314. Typically, solid-liquid composition 339 (described hereinbelow with reference to Fig. 17) does not flow along a converging flow path as it approaches the one or more solid-liquid composition ports 312 from solid-liquid composition compartment 308.

30 Reference is still made to Fig. 16A. For some applications, when chamber 302 is oriented upright in the operational position shown in Fig. 16A, return junction 328 is disposed on an upper side of the solid-liquid composition delivery tube 314. In other

words, for some applications, return junction 328 is disposed along a longitudinal portion 327 of solid-liquid composition delivery tube 314 and around a circumferential portion 329 of solid-liquid composition delivery tube 314, and longitudinal portion 327 includes a point 331 that is closest to cap 374 when cap 374 is coupled to receptacle component 370 (as described hereinbelow with reference to Figs. 20A-B). Circumferential portion 329 includes point 331. This arrangement may reduce bone graft clogging, because solid bone graft particles 334, because of gravity, are less likely to flow upward back into mixing tube 316 toward mixing pump 322.

Reference is still made to Fig. 16A, and is additionally made to Fig. 16B, which is a schematic illustration of another configuration of a portion of composition delivery source 300, in accordance with an application of the present invention. For some applications, bone graft injection system 320 further comprises a shaft unit 340, which comprises a shaft delivery tube 380 in fluid communication with a distal end 382 of solid-liquid composition delivery tube 314. For some applications, shaft unit 340 is more rigid than at least a portion of solid-liquid composition delivery tube 314 (all or a portion of solid-liquid composition delivery tube 314 may be flexible). Shaft delivery tube 380 is further shaped so as to define a distal opening 383, which is typically disposed within 10 mm of a distal end 388 of shaft delivery tube 380, such as within 5 mm of distal end 388, in fluid communication with shaft delivery tube 380. For example, distal opening 383 may be disposed at distal end 388, as shown in Fig. 16A. Alternatively, for some applications, such as shown in Fig. 16B, shaft delivery tube 380 further comprises a cap 389 disposed distal to distal opening 383; for these applications, distal opening 383 is typically disposed within 10 mm, e.g., within 5 mm, of distal end 388 of shaft delivery tube 380 (distal end 388 of shaft delivery tube 380 is defined by a distal-most point of cap 389).

For some applications, shaft unit 340 further comprises a removable depth limiting element 384, which is configured to limit a depth of insertion of shaft delivery tube 380 into a bore through a bone when shaft delivery tube 380 is inserted into the bore, such as described hereinbelow with reference to Fig. 21. For some applications, depth limiting element 384 has a length, measured alongside shaft delivery tube 380, of at least 6 mm, no more than 16 mm, and/or between 6 and 16 mm, such as at least 8 mm, no more than 12 mm, and/or between 8 and 12 mm. For some applications, bone graft injection system 320 further comprises a soft bite surface 381, which is configured to provide a soft surface

for the teeth to bite onto during a bone graft injection procedure. Typically, soft bite surface 381 faces in generally the same direction that shaft delivery tube 380 points.

For some applications, shaft delivery tube 380 further comprises a sealing element 386 disposed around an external surface of shaft delivery tube 380, and configured to
5 form a liquid-tight seal with (a) a channel of a screw, such as such as described hereinbelow with reference to Fig. 21, or (b) tissue around and outside the bore through the bone when shaft delivery tube 380 is inserted into the bore. Typically, depth limiting element 384 is removable from shaft unit 340 without removal of shaft unit 340 from sealing element 386. For some applications, distal end 388 of shaft delivery tube 380 is
10 disposed more distally than sealing element 386 by a distance D2 of between 0 and 20 mm, e.g., between 3 and 15 mm.

Reference is still made to Fig. 16A. For some applications, shaft delivery tube 380 is straight (as shown in the figures). For some applications, when chamber 302, solid-liquid composition delivery tube 314, and shaft unit 340 are unconstrained, (a) a
15 central longitudinal axis 390 of shaft delivery tube 380 and (b) a central longitudinal axis 392 of a proximal longitudinal portion 394 of solid-liquid composition delivery tube 314 form an angle α (alpha) of between 70 and 110 degrees, such as between 85 and 95 degrees, e.g., 90 degrees. Typically, proximal longitudinal portion 394 of solid-liquid composition delivery tube 314 includes proximal end 330 of solid-liquid composition
20 delivery tube 314. Alternatively or additionally, for some applications, when chamber 302, solid-liquid composition delivery tube 314, and shaft unit 340 are unconstrained, central longitudinal axis 390 of shaft delivery tube 380 and a plane 396 defined by filter 304 form an angle β (beta) of between 70 and 110 degrees, such as between 85 and 95 degrees, e.g., 90 degrees. Further alternatively or additionally, for some applications,
25 when chamber 302 and solid-liquid composition delivery tube 314 are unconstrained, (a) central longitudinal axes 392 of proximal longitudinal portion 394 of solid-liquid composition delivery tube 314 and (b) plane 396 defined by filter 304 are parallel or form an angle of less than 20 degrees, e.g., less than 5 degrees. Typically, proximal longitudinal portion 394 of solid-liquid composition delivery tube 314 includes proximal
30 end 330 of solid-liquid composition delivery tube 314.

Reference is still made to Fig. 16A. For some applications, a closest distance D3 between the one or more solid-liquid composition ports 312 and filter 304 equals at least 5

mm, such as at least 10 mm, and/or is less than 50 mm. Alternatively or additionally, for some applications, the closest distance D3 between the one or more solid-liquid composition ports 312 and filter 304 equals at least 75% of a distance D4 between filter 304 and a point 398 on an interior of a wall of solid-liquid composition compartment 308 farthest from filter 304. These closest distances provide space for raising solid bone graft particles 334 in a puff 399 into physiological liquid solution 336, as described hereinbelow with reference to Figs. 17 and 18B. Typically, the one or more solid-liquid composition ports 312 are located through a side wall of solid-liquid composition compartment 308 (rather than a bottom wall of the solid-liquid composition compartment), to prevent clogging of the one or more solid-liquid composition ports 312 as the solid bone graft particles 334 settle after being raised.

For some applications, pump unit 301 further comprises control circuitry 332. Typically, pump unit 301 further comprises a power supply, electronics, a user interface 335 for controlling bone graft injection system 320, and/or a foot control 333 for controlling pump unit 301. For other applications, pump unit 301 does not necessarily comprise any circuitry, and the rotation and relative timing of rotation of the pumps are achieved mechanically (i.e., non-electronically), e.g., by connecting both pumps to a common axle.

Reference is now made to Fig. 17, which is a timeline schematically showing activation states of control circuitry 332, in accordance with an application of the present invention. Reference is also made to Figs. 18A-D, which are schematic illustrations of the activation states of control circuitry 332, in accordance with an application of the present invention.

In some applications of the present application, bone graft injection system 320 is configured to repeatedly (a) mix solid bone graft particles 334 and physiological liquid solution 336 in solid-liquid composition compartment 308 to form a solid-liquid composition 339 and (b) pump solid-liquid composition 339 into cavity 90 under a membrane, such as a Schneiderian membrane 88. For some applications, in order to perform the mixing, bone graft injection system 320 pumps filtered liquid from liquid compartment 306 into the bottom of solid-liquid composition compartment 308, which raises solid bone graft particles 334 in a puff 399 into physiological liquid solution 336 higher in solid-liquid composition compartment 308. Because volume in chamber 302 is

conserved as fluid is pumped out of liquid compartment 306, the pumped fluid reenters chamber 302 (rather than entering the portion of solid-liquid composition delivery tube 314 beyond return junction 328 in the opposite direction of chamber 302 (to the right in Figs. 15 and 16A)).

5 Typically, this mixing is repeated periodically, because solid bone graft particles 334 very quickly settle and separate from physiological liquid solution 336 (generally nearly all of the particles settle within 500 ms). Typically, the immediately following particle-delivery activation state 344 occurs (a) before most of solid bone graft particles 334 settle and separate from physiological liquid solution 336 and/or (b) even after solid
10 bone graft particles 334 have settled (in which case typically the solid bone graft particles 334 that settled near the one or more solid-liquid composition ports 312, and/or bone graft particles puffed by the pulsating transfer itself).

Fig. 18A shows solid bone graft particles 334 settled at the bottom of solid-liquid composition compartment 308 before being mixed. This state occurs at the beginning of a
15 bone graft injection performed with bone graft injection system 320, and occurs, at least approximately, near (e.g., slightly before, at, or slightly after) the end of each particle-delivery activation state 344, which is described below.

For some applications, in order to perform the mixing and pumping described immediately above, control circuitry 332 is configured to repeatedly (typically, in a
20 plurality of cycles):

- assume a mixing activation state 342, as shown in Fig. 18B, in which control circuitry 332 activates mixing pump 322 to mix solid bone graft particles 334 and physiological liquid solution 336 in solid-liquid composition compartment 308 to form solid-liquid composition 339, by pumping physiological liquid solution 336
25 through mixing tube 316 and into solid-liquid composition compartment 308 (typically, the pumped physiological liquid solution was already disposed in mixing tube 316, and originated from liquid compartment 306 via the one or more liquid ports 310), and
- assume a particle-delivery activation state 344, as shown in Fig. 18C and 18D; control circuitry 332, during at least a portion of particle-delivery activation state 344 (e.g., during positive particle-delivery activation sub-state 350, shown in Fig. 18D, and described hereinbelow), activates liquid-supply pump 324 to apply
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positive pressure to pump solid-liquid composition 339 from solid-liquid composition compartment 308 into solid-liquid composition delivery tube 314.

Typically, in order to perform the mixing during mixing activation state 342, the physiological liquid solution pumped into solid-liquid composition compartment 308 raises solid bone graft particles 334 in a puff 399 into physiological liquid solution 336 in the compartment.

As mentioned above, control circuitry 332 is typically configured to repeatedly, in a plurality of cycles, assume mixing activation state 342 and particle-delivery activation state 344. For some applications, control circuitry 332 is configured to repeatedly assume mixing activation state 342 and particle-delivery activation state 344 over a period time period having a duration of at least 30 second, no more than 600 seconds, and/or between 30 and 600 seconds.

For some applications, control circuitry 332 is configured to assume mixing activation state 342 and particle-delivery activation state 344 at non-overlapping times, such as illustrated in Fig. 17. For some applications, control circuitry 332 is configured to assume particle-delivery activation state 344 within 500 ms after completing mixing activation state 342, such as within 100 ms after completing mixing activation state 342, e.g., immediately after completing mixing activation state 342, as shown in Fig. 17.

For some applications, control circuitry 332 is configured to repeatedly, in alternation, (a) assume mixing activation state 342 for between 100 and 1200 ms, such as between 200 and 800 ms, e.g., 400 ms, and (b) assume particle-delivery activation state 344. For some applications, control circuitry 332 is configured to repeatedly, in alternation, (a) assume mixing activation state 342 for between 100 and 1200 ms, and (b) assume particle-delivery activation state 344 for between 150 and 3000 ms, such as between 1000 and 2000 ms, e.g., 1400 ms.

Typically, control circuitry 332 is configured to, when in particle-delivery activation state 344, activate liquid-supply pump 324 to apply the positive pressure to pump physiological liquid solution 336 (a) from liquid solution container 366, (b) through liquid-supply tube 318, (c) into liquid compartment 306, (d) through filter 304, (e) into solid-liquid composition compartment 308, (f) from solid-liquid composition compartment 308, and (g) to solid-liquid composition delivery tube 314.

In some applications of the present invention, control circuitry 332 is configured, during each of one or more negative-positive particle delivery cycles 346 of particle-delivery activation state 344, to assume:

- a negative particle-delivery activation sub-state 348, as shown in Fig. 18C, in which control circuitry 332 activates liquid-supply pump 324 to apply negative pressure to pump liquid from solid-liquid composition delivery tube 314 toward liquid compartment 306 via solid-liquid composition compartment 308, and
- a positive particle-delivery activation sub-state 350, as shown in Fig. 18D, in which control circuitry 332 activates liquid-supply pump 324 to apply the positive pressure to pump solid-liquid composition 339 from solid-liquid composition compartment 308 into solid-liquid composition delivery tube 314; a direction of pumping of liquid-supply pump 324 in positive particle-delivery activation sub-state 350 is opposite a direction of pumping of liquid-supply pump 324 in negative particle-delivery activation sub-state 348.

In other words, control circuitry 332 is configured to cause liquid-supply pump 324 to oscillate during each of one or more negative-positive particle delivery cycles 346.

During positive particle-delivery activation sub-state 350, solid-liquid composition 339 is injected into cavity 90. Solid bone graft particles 334 of solid-liquid composition 339 typically quickly settle toward the bottom of cavity 90 (generally within 100 ms). As a result, physiological liquid solution 336, substantially without solid bone graft particles 334, remains near distal opening 383 of shaft delivery tube 380. During the immediately following negative particle-delivery activation sub-state 348, mostly this physiological liquid solution 336 remaining near distal opening 383, rather than the settled solid bone graft particles 334, is pumped back into solid-liquid composition delivery tube 314. This non-return of solid bone graft particles 334 may be aided by positioning distal opening 383 near the roof of cavity 90, as described hereinbelow with reference to blow-up C of Fig. 21. Thus each positive-negative cycle results in a net delivery of solid bone graft particles 334 to cavity 90.

For some applications, at least a portion of solid-liquid composition 339 that is pumped out of chamber 302 in a given positive particle-delivery activation sub-state 350 exits distal opening 383 into cavity 90 before the completion of the given positive particle-delivery activation sub-state 350, such as at least 50%, e.g., at least 80%, such as

100%. For some applications, control circuitry 332 is configured to pump, throughout positive particle-delivery activation sub-state 350, a volume of solid-liquid composition 339 that is greater than a combined volume of solid-liquid composition delivery tube 314 and shaft delivery tube 380, such as equal to at least 100% of the combined volume,
5 and/or less than 700% of the combined volume.

For some applications, control circuitry 332 is configured to assume particle-delivery activation state 344 in a plurality of particle-delivery-state cycles, and to begin particle-delivery activation state 344 in each of the particle-delivery-state cycles with negative particle-delivery activation sub-state 348. Beginning with the negative particle-delivery activation sub-state 348 reduces the risk of accidentally overfilling cavity 90 with solid-liquid composition 339, which might burst Schneiderian membrane 88.
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For some applications, as mentioned above, control circuitry 332 is configured to assume mixing activation state 342 and particle-delivery activation state 344 at non-overlapping times.

15 For some applications, control circuitry 332 is configured to provide a plurality of the negative-positive particle delivery cycles 346 during particle-delivery activation state 344. For some applications, control circuitry 332 is configured to provide up to 10 of the negative-positive particle delivery cycles 346 during particle-delivery activation state 344, such as between 3 and 6 cycles 346, e.g., 4 cycles 346.

20 For some applications, control circuitry 332 is configured to assume negative particle-delivery activation sub-state 348 for between 25 and 300 ms, such as between 100 and 200 ms, e.g., 175 ms, during each of the one or more negative-positive particle delivery cycles 346. For some applications, control circuitry 332 is configured to assume negative particle-delivery activation sub-state 348 for between 25 and 100 ms during each
25 of the one or more negative-positive particle delivery cycles 346

For some applications, control circuitry 332 is configured to assume positive particle-delivery activation sub-state 350 for between 25 and 300 ms, such as between 100 and 200 ms, e.g., 175 ms, during each of the one or more negative-positive particle delivery cycles 346. For some applications, control circuitry 332 is configured to assume
30 positive particle-delivery activation sub-state 350 for between 25 and 100 ms during each of the one or more negative-positive particle delivery cycles 346.

For some applications, control circuitry 332 is configured to assume negative particle-delivery activation sub-state 348 for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles 346, and to assume positive particle-delivery activation sub-state 350 for between 25 and 300 ms during each of the one or more negative-positive particle delivery cycles 346.

For some applications, control circuitry 332 is configured to assume negative particle-delivery activation sub-state 348 for a first duration during each of the one or more negative-positive particle delivery cycles 346, and to assume positive particle-delivery activation sub-state 350 for a second duration during each of the one or more negative-positive particle delivery cycles 346, the second duration equal to between 80% and 120% of the first duration, such as between 90% and 110% of the first duration.

For some applications, control circuitry 332 is configured to, when in negative particle-delivery activation sub-state 348, activate liquid-supply pump 324 to pump the liquid from solid-liquid composition delivery tube 314, into solid-liquid composition compartment 308, and into liquid compartment 306.

Reference is made to Fig. 19, which is a schematic illustration of configurations of mixing pump 322 and liquid-supply pump 324, in accordance with an application of the present invention. In these configurations, mixing pump 322 is a mixing peristaltic pump 352A, and liquid-supply pump 324 is a liquid-supply peristaltic pump 352B. Peristaltic pumps 352A and 352B comprise (a) respective rotors 354A and 354B, (b) respective motors, and, for some applications, (c) respective index sensors 356A and 356B, which identify respective rotational positions of rotors 354A and 354B. Mixing peristaltic pump 352A comprises one or more rollers 358A (typically, three or more rollers 358A, such as exactly three rollers 358A), and liquid-supply peristaltic pump 352B comprises one or more rollers 358B (typically, two or more rollers 358, such as three or more rollers 358B, such as exactly three rollers 358B). For some applications, the index sensors comprise optical sensors; for example, the rollers may comprise visible flags that serve as indices, and the optical sensors may image the flags to ascertain the rotational positions of the rollers and thus the rotors. Alternatively, for some applications, the index sensors comprise position (rotation) sensors. Fig. 19 shows mixing and liquid-supply peristaltic pumps 352A and 352B in exemplary respective starting rotational positions within respective rotational cycles.

Mixing peristaltic pump 352A comprises a pump casing 360A that is shaped so as to define a partial-circle mixing tube channel 362A in which a portion of mixing tube 316 is disposed. Similarly, liquid-supply peristaltic pump 352B comprises a pump casing 360B that is shaped so as to define a partial-circle liquid-supply tube channel 362B in which a portion of liquid-supply tube 318 is disposed. For some applications, the portions of the tubes disposed in the partial-circle liquid-supply tube channels comprise silicone, which may be more flexible than the material that other portions of the tubes comprise. Alternatively or additionally, for some applications, the portions of the tubes disposed in the partial-circle liquid-supply tube channels may have larger diameters than the diameters of the other portions of the tubes. These larger diameters may increase the pumping rate. The smaller diameters of the other portions of the tubes may reduce the total volume of fluid in the system, which may reduce the volume of fluid needed to operate the system. Typically, mixing peristaltic pump 352A rotates unidirectionally, e.g., clockwise in Fig. 19.

For some applications, mixing peristaltic pump 352A and the portion of mixing tube 316 disposed within mixing tube channel 362A are configured such that mixing peristaltic pump 352A pumps at least 2 cc, no more than 4 cc, and/or between 2 and 4 cc of fluid per full revolution, such as 2.7 cc. For some of these applications, the portion of mixing tube 316 disposed within mixing tube channel 362A has an inner diameter of at least 3.2 mm, no more than 9.6 mm, and/or between 3.2 and 9.6 mm, e.g., 6.4 mm.

For some applications, liquid-supply peristaltic pump 352B and the portion of liquid-supply tube 318 disposed within liquid-supply tube channel 362B are configured such that liquid-supply peristaltic pump 352B pumps at least 2 cc, no more than 4 cc, and/or between 2 and 4 cc of fluid per full revolution, such as 2.7 cc. For some of these applications, the portion of liquid-supply tube 318 disposed within liquid-supply tube channel 362B has an inner diameter of at least 3.2 mm, no more than 9.6 mm, and/or between 3.2 and 9.6 mm, e.g., 6.4 mm.

When a roller 358 is fully engaged and closes off a tube, the roller pushes a certain amount of liquid as it rotates. As the leading roller begins to disengage from the tube, the next roller behind the leading roller continues the pushing. However, since the leading roller is disengaging from the tube, the leading roller allows the tube to open up and hold a larger volume of liquid. This absorption of liquid not pushed out of the pump reduces

flow. There are no voids anywhere in the tube. A reverse effect occurs as the next roller begins engaging the tube. Maximum flow is achieved during the period in which the leading roller is fully engaged with tube. This is the range in which the oscillating liquid-supply peristaltic pump 352B works. In a closed system, such as described herein, the amount of liquid in the pillows in liquid-supply peristaltic pump 352B is minimal when the most rollers are engaged with the tube. If exactly three rollers are provided, this minimum occurs, for example, when two of the rollers are symmetrically located at 10 o'clock and 2 o'clock. For some applications, this is the starting rotational position of mixing pump peristaltic pump 352A, since maximum liquid is in cavity 90 under Schneiderian membrane 88.

Liquid-supply peristaltic pump 352B is capable of (a) pumping fluid at an average rate throughout a full 360-degree revolution of rotor 354B at a certain speed, and (b) pumping fluid at a maximum rate during portions of the full 360-degree revolution at the certain speed. The maximum rate is greater than the average rate. For some applications, control circuitry 332 is configured, when in both positive and negative particle-delivery activation sub-states 350 and 348, to activate liquid-supply peristaltic pump 352B to (a) rotate rotor 354B, at the certain speed, a partial revolution equal to a fraction of the full 360-degree revolution of rotor 354B, the fraction less than 1, and (b) pump, throughout the partial revolution, the fluid at the maximum rate.

For some applications, control circuitry 332 is configured:

- when in positive particle-delivery activation sub-state 350, to activate liquid-supply peristaltic pump 352B to rotate the rotor 354B, in a first rotational direction RD₁ (e.g., clockwise in Fig. 19), a first partial revolution equal to a fraction of a full 360-degree revolution of the rotor 354B, the fraction less than 1, and
- when in negative particle-delivery activation sub-state 348, to activate liquid-supply peristaltic pump 352B to rotate rotor 354B, in a second rotational direction RD₂ (e.g., counterclockwise in Fig. 19) opposite the first rotational direction RD₁, a second partial revolution equal to the fraction of the full 360-degree revolution of the rotor.

This technique for rotating rotor 354B results in liquid-supply peristaltic pump 352B producing a net output of zero, while maximizing both the positive and negative

flow, because one of rollers 358B is always squeezing, and thus occluding, liquid-supply tube 318 (and thus pumping).

For some applications, control circuitry 332 is configured, throughout positive particle-delivery activation sub-state 350, to activate liquid-supply peristaltic pump 352B

5 to:

- rotate rotor 354B a partial revolution equal to a fraction of a full 360-degree revolution of rotor 354B, the fraction less than the quotient of 1 divided by the total number of rollers 358B, or, for example, less than or equal to the quotient of 0.5 divided by the total number of rollers 358B (for example, in Fig. 19, the fraction is indicated by arrow RD₁ and equals 1/6, which is the quotient of 0.5 divided by 3), and
- pump, throughout the partial revolution, a volume of fluid that is greater than the product of the fraction and a volume of fluid pumpable throughout the full 360-degree revolution of the rotor.

15 For some applications, in order to achieve this volume of fluid pumping, control circuitry 332 is configured to rotationally position rotor 354B such that a lead one of rollers 358B is rotationally aligned with (fully squeezing) mixing tube channel 362A (and is thus operative) throughout positive particle-delivery activation sub-state 350 (the lead roller is the forward-most roller rotationally aligned with partial-circle mixing tube channel 362A; one or more additional rollers may also be rotationally aligned with the tube channel, trailing the lead roller). For example, if the upstream entrance to mixing tube channel 362A is disposed at 9 o'clock and the downstream exit of mixing tube channel 362A is disposed at 3 o'clock (as shown in Fig. 19), the exactly one of rollers 358B may operate between 11 o'clock and 1 o'clock throughout positive particle-delivery activation sub-state 350.

As used in the present application, including in the claims, "throughout" a time period (e.g., a particular state or sub-state) means from the beginning to the end of the time period (e.g., an occurrence of the state or sub-state). As mentioned above, each of the states and sub-states typically occur a plurality of non-contiguous times during operation of bone graft injection system 320.

For some applications, mixing peristaltic pump 352A comprises a total number of rollers 358A equal to at least two, and control circuitry 332 is configured to assume mixing activation state 342 a plurality of times in alternation with particle-delivery activation states 344, and to begin mixing activation states 342 with rotor 354A at
5 respective starting rotational positions, which are identical to one another or rotationally offset from one another by the product of (a) 360 degrees divided by the total number of rollers 358A and (b) a positive integer (i.e., 1 or greater). For example, for configurations in which mixing peristaltic pump 352A comprises exactly three rollers 358A, such as shown in Fig. 19, there are three starting rotational positions which result in the same flow
10 rate over the same partial rotational cycle.

For some applications, mixing peristaltic pump 352A comprises an odd total number of rollers 358A, the odd total number equal to at least one (e.g., at least three), and control circuitry 332 is configured to assume mixing activation state 342 a plurality of times in alternation with particle-delivery activation states 344, and to begin each of
15 mixing activation states 342 with an aligned total number of rollers 358A rotationally aligned with mixing tube channel 362A, the aligned total number equal to more than half of the odd total number. (Thus, in the case in which mixing peristaltic pump 352A comprises exactly three rollers 358A, as shown in Fig. 19, control circuitry 332 is configured to begin each of mixing activation states 342 with two of rollers 358A
20 rotationally aligned with mixing tube channel 362A, i.e., the aligned total number equals 2, which is more than half of the odd total number (1.5).) As a result of this configuration, each of mixing activation states 342 begins with a minimum volume of liquid held within the portion of mixing tube 316 in mixing tube channel 362A. As a result, any rotation of rotor 354A will draw liquid from the system and therefore will, if
25 anything, reduce the volume of liquid in cavity 90 under Schneiderian membrane 88, thereby avoiding accidental overfilling of cavity 90 and bursting of Schneiderian membrane 88. In addition, cavity 90 returns to its full and maximum-filled state at end of each of the mixing activation states 342. As a result, mixing peristaltic pump 352A has full control of the maximum volume and variation in volume in cavity 90. Typically, the
30 mixing activation state always begins when the volume cavity 90 is at a maximum, in order to avoid overfilling the cavity and bursting Schneiderian membrane 88.

For some applications, control circuitry 332 is configured, when in mixing activation state 342, to rotate mixing peristaltic pump 352A between $1/3$ and 3

revolutions, such as one revolution, such as for applications in which mixing peristaltic pump 352A comprises exactly three rollers 358A. More generally, for some applications, control circuitry 332 is configured, when in mixing activation state 342, to rotate mixing peristaltic pump 352A between (a) a number of revolutions and (b) 3 revolutions, the
5 number of revolutions equal to the quotient of 1 divided by the number of rollers 358A. For some applications, control circuitry 332 is configured, when in mixing activation state 342, to rotate mixing peristaltic pump 352A at a rate of at least 50 rpm (revolutions per minute), no more than 600 rpm, and/or between 50 and 600 rpm, e.g., 150 rpm. This rapid rotation helps generate the puff 399 described hereinabove with reference to Fig. 17.

10 For some applications, control circuitry 332 is configured:

- when in positive particle-delivery activation sub-state 350, to activate liquid-supply pump 324 to pump a volume of between 0.1 and 2 cc of fluid (e.g., between 0.2 and 0.9 cc, such as between 0.3 and 0.6 cc), and
- when in negative particle-delivery activation sub-state 348, to activate liquid-
15 supply pump 324 to pump the volume of fluid.

Alternatively or additionally, for some applications, control circuitry 332 and mixing pump 322 are configured such that throughout mixing activation state 342 (i.e., during each occurrence of mixing activation state 342 in configurations in which mixing activation state 342 occurs more than once in alternation with particle-delivery activation
20 state 344), pump 322 pumps between 0.5 and 9 cc of physiological liquid solution 336, such as between 1.8 and 3.9 cc of physiological liquid solution 336.

For some applications, control circuitry 332 is configured to assume particle-delivery activation state 344 a plurality of times in alternation with mixing activation states 342, and to begin each of particle-delivery activation states 344 with rotor 354B at a
25 same rotational position.

For some applications, control circuitry 332 and liquid-supply pump 324 are configured such that during at least a portion of positive particle-delivery activation sub-state 350, liquid-supply pump 324 pumps physiological liquid solution 336 at a rate of at least 3 cc/sec, such as at least 7 cc/sec. Alternatively or additionally, for some
30 applications, control circuitry 332 and liquid-supply pump 324 are configured such that during at least a portion of the negative particle-delivery activation sub-state 348, liquid-

supply pump 324 pumps physiological liquid solution 336 at a rate of at least 3 cc/sec, such as at least 7 cc/sec. Further alternatively or additionally, for some applications, control circuitry 332 and mixing pump 322 are configured such that during at least a portion of mixing activation state 342 mixing pump 322 pumps physiological liquid solution 336 at a rate of at least 3 cc/sec, such as at least 7 cc/sec.

For some applications, control circuitry 332 is configured to, before repeatedly assuming mixing and particle-delivery activation states 342 and 344, assume a filling state, in which control circuitry 332 activates liquid-supply pump 324 to apply positive pressure to pump a volume of physiological liquid solution 336 from solid-liquid composition compartment 308 into solid-liquid composition delivery tube 314, the volume equal to between 0.5 and 3 cc.

For some applications, control circuitry 332 is configured to assume mixing activation state 342 and particle-delivery activation state 344 at partially-overlapping times. For some of these applications, control circuitry 332 is configured to assume negative particle-delivery activation sub-state 348 and particle-delivery activation state 344 at partially-overlapping times. For example, control circuitry 332 may be configured to:

- begin negative particle-delivery activation sub-state 348 toward the end of mixing activation state 342 (e.g., within the last 30% of mixing activation state 342),
- complete negative particle-delivery activation sub-state 348 either simultaneously with the completion of mixing activation state 342, or after the completion of mixing activation state 342, and
- begin positive particle-delivery activation sub-state 350 upon the completion of negative particle-delivery activation sub-state 348, typically immediately upon the completion of negative particle-delivery activation sub-state 348.

For some applications, control circuitry 332 is configured to assume mixing activation state 342 and particle-delivery activation state 344 at the same time.

Reference is now made to Figs. 20A-B, which are schematic illustrations of chamber 302, in accordance with an application of the present invention. In this configuration, chamber 302 comprises a receptacle component 370 and a cover component 372. Cover component 372 (a) comprises filter 304, and (b) is shaped so as to

define (i) a cap 374 and (ii) a bone-graft container 376 having an opening 378 that (x) faces away from cap 374 and (y) is farther from cap 374 than filter 304 is from cap 374. Receptacle component 370 and cover component 372 are shaped so as to be reversibly coupleable with each another to form a watertight seal, with bone-graft container 376
5 disposed within receptacle component 370.

Before receptacle component 370 and cover component 372 are coupled to each another, bone-graft container 376 contains solid bone graft particles 334. For some applications, such as when bone-graft container 376 is provided pre-loaded with solid bone graft particles 334, bone-graft container 376 further comprises a temporary cap (not
10 shown). For some applications, bone-graft container 376 is placed upside-down on a surface, such that opening 378 is facing up. The temporary cap, if provided, is removed. Receptacle component 370 of chamber 302 is coupled to bone-graft container 376 while bone-graft container 376 remains upside-down. Typically, chamber 302 is turned over to its upright operational position only after bone graft injection system 320 has filled the
15 chamber with physiological liquid solution 336 in the filling state described above.

For some applications, bone-graft container 376 has a volume of between 0.2 and 6 ml. Alternatively or additionally, for some applications, chamber 302 has a volume of between 0.2 and 20 ml. Further alternatively or additionally, for some applications, a volume of bone-graft container 376 equals at least 10% of and/or less than 50% of a
20 volume of chamber 302, such as less than 33%, e.g., less than 20% of the volume of chamber 302.

Reference is now made to Fig. 21, which is a schematic illustration of a portion of a method of using bone graft injection system 320, in accordance with an application of the present invention. This portion of the method is typically performed after
25 Schneiderian membrane 88 has been raised to form cavity 90 between the second (upper) side of maxillary bone 82 and Schneiderian membrane 88, such as using hydraulic pressure or mechanical elevation, either using shaft unit 340 of bone graft injection system 320 (typically by injecting physiological solution through shaft delivery tube 380 after inserting shaft delivery tube 380 into bore 86), or using another dental tool or a
30 dental implant. In blow-up A of Fig. 21, Schneiderian membrane 88 has settled toward the bottom of cavity 90, such as after injected saline solution has been allowed to drain from cavity 90 through the tool and/or the bore through the bone.

For some applications, user interface 335 of bone graft injection system 320 includes one or more of the following user controls (which may comprise, for example, buttons), for performing the following functions during use of bone graft injection system 320 in a bone augmentation procedure:

- 5 • a "load" user control, which instructs control circuitry 332 to fill all of the tubes of bone graft injection system 320 with physiological liquid solution 336, during the filling state described above with reference to Fig. 19;
- a "volume" user control, which specifies the maximum volume of physiological liquid solution 336 to be injected into cavity 90 by control circuitry 332;
- 10 • a "raise" user control, which instructs control circuitry 332 to raise Schneiderian membrane 88 by injecting the volume of physiological liquid solution 336 specified by the "volume" user control (the user activates the "raise" user control when removable depth limiting element 384 is attached to shaft delivery tube 380 and shaft delivery tube 380 is disposed as described hereinbelow with reference to
- 15 blow-up B of Fig. 21);
- a "start" user control, which instructs control circuitry 332 to deliver solid bone graft particles 334 into cavity 90, as described herein (the user activates the "start" user control after removing removable depth limiting element 384 from shaft delivery tube 380 and advancing shaft delivery tube 380 into cavity 90, as
- 20 described hereinbelow with reference to blow-up C of Fig. 21);
- a "stop" user control, which instructs control circuitry 332 to cease delivering solid bone graft particles 334; and
- an "empty" user control, which instructs control circuitry 332 to pump all of physiological liquid solution 336 from the system.

25 For some applications, a method of using bone graft injection system 320 comprises inserting, from a first (lower) side of maxillary bone 82 of a jaw, shaft delivery tube 380 of shaft unit 340 of bone graft injection system 320 into bore 86 that passes through maxillary bone 82 from the first (lower) side to the second (upper) side of maxillary bone 82, such that distal opening 383 of shaft delivery tube 380 is disposed in

30 bore 86 or in cavity 90 that is (a) adjacent to the second side of maxillary bone 82 and (b) between the second side of maxillary bone 82 and Schneiderian membrane 88. (As

mentioned hereinbelow, distal opening 383 is in fluid communication with shaft delivery tube 380.) For some applications, distal opening 383 is disposed at the distal end of shaft delivery tube 380, and positioning distal opening 383 comprises positioning the distal end of shaft delivery tube 380 at the location.

5 For some applications, a screw 400 that defines a channel is screwed into bore 86 before insertion of shaft delivery tube 380, and shaft delivery tube 380 is inserted into bore 86 by being inserted into the channel of screw 400. Optionally, saline solution was previously injected through the channel of the screw in order to raise Schneiderian membrane 88. For some applications, a seal (e.g., comprising an o-ring) is provided
10 between the wall of the channel and an external surface of shaft delivery tube 380. Alternatively or additionally, a seal is provided against the first (lower) side of first maxillary bone 82.

The method typically further comprises positioning distal opening 383 near a roof 406 of cavity 90. For example, distal opening 383 may be positioned at a solid-liquid-
15 composition-delivery location 402 at a distance D5 from the second side of maxillary bone 82, the distance D5 equal to at least 50% (e.g., at least 75%) of a height H of cavity 90 directly above bore 86. Alternatively or additionally, for some applications, distal opening 383 is positioned at a distance D6 between 2 and 12 mm, such as between 4 and 6 mm from Schneiderian membrane 88 at roof 406 of cavity 90 directly above bore 86.
20 Providing such spacing between distal opening 383 and Schneiderian membrane 88 may prevent solid-liquid composition 339 from rebounding off the membrane directly back into distal opening 383 before solid bone graft particles 334 can settle in the cavity.

The method further comprises providing solid-liquid composition 339 from a solid-liquid composition source, such as chamber 302 and other elements of bone graft
25 injection system 320 that are coupled in fluid communication with shaft delivery tube 380, typically by activating pump unit 301, such as by activating control circuitry 332. While distal opening 383 is positioned at solid-liquid-composition-delivery location 402, solid-liquid composition 339 is injected through distal opening 383 via shaft delivery tube 380. Typically, while solid-liquid composition 339 is injected, chamber 302 is oriented
30 such that liquid compartment 306 is above solid-liquid composition compartment 308. Typically, when chamber 302 is oriented such that liquid compartment 306 is above solid-liquid composition compartment 308: (a) the one or more solid-liquid composition ports

312 are disposed no more than a distance from a bottom of solid-liquid composition compartment 308, the distance equal to 25% of a vertical height of solid-liquid composition compartment 308, and/or (b) the one or more solid-liquid composition ports 312 are located through a side wall of solid-liquid composition compartment 308.

5 Typically, while solid-liquid composition 339 is injected, solid-liquid composition delivery tube 314 is oriented within 45 degrees of horizontal, such as within 15 degrees of horizontal, e.g., horizontally. (As used in the present application, including in the claims, "horizontal" means horizontal with respect to the Earth, i.e., perpendicular to a vertical line directed to the center of gravity of the Earth, e.g., as ascertained using a plumb-line.)

10 For some applications, the method further comprises raising Schneiderian membrane 88 by injecting physiological liquid solution 336 through shaft delivery tube 380, such as shown in blow-up B of Fig. 21. For some applications, raising Schneiderian membrane 88 comprises positioning distal opening 383 at a liquid-delivery location 404 that is within bore 86 or within 1 mm above bore 86; and, while distal opening 383 is
15 positioned at liquid-delivery location 404, injecting physiological liquid solution 336 to raise Schneiderian membrane 88. Distal opening 383 is positioned at solid-liquid-composition-delivery location 402 after finishing injecting physiological liquid solution 336 to raise Schneiderian membrane 88.

For some applications, distal opening 383 is positioned at liquid-delivery location
20 404 while removable depth limiting element 384 is attached to shaft delivery tube 380. Removable depth limiting element 384 limits advancement of shaft delivery tube 380 through bore 86. Positioning distal opening 383 at solid-liquid-composition-delivery location 402 comprises removing depth limiting element 384 from shaft delivery tube 380, and subsequently advancing shaft delivery tube 380 through bore 86 until distal
25 opening 383 reaches solid-liquid-composition-delivery location 402, such as shown in blow-up C of Fig. 21.

For some applications, injecting solid-liquid composition 339 comprises pumping solid-liquid composition 339 through distal opening 383 via shaft delivery tube 380 at a pulsating hydraulic pressure that periodically varies between positive and negative.

30 For some applications, bone graft injection system 320 is used to perform the techniques described hereinabove with reference to Figs. 12A-B or Fig. 13, *mutatis mutandis*.

Although the techniques described herein have been generally described for use with bone graft particles, these techniques may also be used with other solid particles, such as, as for example, drug-releasing solid particles or solid drug particles.

5 The scope of the present invention includes embodiments described in the following patents and patent application publications, which are assigned to the assignee of the present application and are incorporated herein by reference. In an embodiment, techniques and apparatus described in one or more of the following patents or patent application publications are combined with techniques and apparatus described herein:

- US Patent 7,934,929 to Better et al.
- 10 • US Patent 8,029,284 to Better et al.
- US Patent 8,662,891 to Uchitel et al.
- US Patent 8,388,343 to Better et al.
- US Patent 8,702,423 to Better et al.
- PCT Publication WO 2010/035270 to Better et al.
- 15 • PCT Publication WO 2010/146573 to Better et al.
- PCT Publication WO 2014/199332 to Fostick et al.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various
20 features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

CLAIMS

1. Apparatus for use with solid particles and a liquid container containing a physiological liquid solution, the apparatus comprising:
 - (1) a composition delivery source, which comprises:
 - 5 (a) a chamber, which:
 - (i) comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment, and
 - (ii) is shaped so as to define (A) one or more liquid ports in fluid
10 communication with the liquid compartment, and (B) one or more solid-liquid composition ports in fluid communication with the solid-liquid composition compartment;
 - (b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports;
 - 15 (c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and
 - (d) a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an
20 interior of the liquid solution container; and
 - (2) a pump unit, which comprises:
 - (a) a mixing pump, which is arranged to cause flow in the mixing tube; and
 - (b) a liquid-supply pump, which is arranged to cause flow in the liquid-
25 supply tube.
2. The apparatus according to claim 1, wherein the solid particles are solid bone graft particles, and wherein the apparatus is for use with the solid bone graft particles.
3. The apparatus according to claim 1, further comprising the solid particles, wherein the filter is configured to inhibit passage of the solid particles and allow passage of the
30 physiological liquid solution.

4. The apparatus according to claim 1, wherein the mixing pump is arranged to cause, in the mixing tube, flow that raises the solid particles in a puff into the physiological liquid solution in the solid-liquid composition compartment.
5. The apparatus according to claim 1, wherein a closest distance between the one or more solid-liquid composition ports and the filter equals at least 75% of a distance between the filter and a point on an interior of a wall of the solid-liquid composition compartment farthest from the filter.
6. The apparatus according to claim 1, wherein the mixing tube (a) merges with the liquid-supply tube at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports via a portion of the liquid-supply tube.
7. The apparatus according to claim 1, wherein the liquid-supply tube (a) merges with the mixing tube at an exit junction, and (b) is in fluid communication with the at least one of the one or more liquid ports via a portion of the mixing tube.
8. The apparatus according to claim 1,
wherein the chamber is shaped so as to define exactly one liquid port in fluid communication with the liquid compartment, and
wherein the chamber is shaped so as to define exactly one solid-liquid composition port in fluid communication with the solid-liquid composition compartment.
9. The apparatus according to any one of claims 1-8, wherein the pump unit further comprises control circuitry, which is configured to repeatedly:
- (a) assume a mixing activation state, in which the control circuitry activates the mixing pump to mix the solid particles and the physiological liquid solution in the solid-liquid composition compartment to form a solid-liquid composition, by pumping the physiological liquid solution through the mixing tube and into the solid-liquid composition compartment, and
- (b) assume a particle-delivery activation state, wherein the control circuitry, during at least a portion of the particle-delivery activation state, activates the liquid-supply pump to apply positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube.

10. The apparatus according to claim 9, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at the same time.
11. The apparatus according to claim 9, wherein the control circuitry is configured to
5 assume the mixing activation state and the particle-delivery activation state at partially-overlapping times.
12. The apparatus according to claim 9, wherein the control circuitry is configured to assume the mixing activation state and the particle-delivery activation state at non-overlapping times.
- 10 13. The apparatus according to claim 9, wherein the control circuitry is configured to, when in the particle-delivery activation state, activate the liquid-supply pump to apply the positive pressure to pump the physiological liquid solution (a) from the liquid solution container, (b) through the liquid-supply tube, (c) into the liquid compartment, (d) through the filter, (e) into the solid-liquid composition compartment, (f) from the solid-liquid
15 composition compartment, and (g) to the solid-liquid composition delivery tube.
14. The apparatus according to claim 9, wherein the control circuitry is configured, during each of one or more negative-positive particle delivery cycles of the particle-delivery activation state, to assume:
- a negative particle-delivery activation sub-state, in which the control circuitry
20 activates the liquid-supply pump to apply negative pressure to pump liquid from the solid-liquid composition delivery tube toward the liquid compartment via the solid-liquid composition compartment, and
- a positive particle-delivery activation sub-state, in which the control circuitry
25 activates the liquid-supply pump to apply the positive pressure to pump the solid-liquid composition from the solid-liquid composition compartment into the solid-liquid composition delivery tube, wherein a direction of pumping of the liquid-supply pump in the positive particle-delivery activation sub-state is opposite a direction of pumping of the liquid-supply pump in the negative particle-delivery activation sub-state.
15. The apparatus according to claim 14, wherein the control circuitry is configured to
30 assume the mixing activation state and the particle-delivery activation state at non-overlapping times.

16. The apparatus according to claim 14, wherein the control circuitry is configured to assume the mixing activation state and the negative particle-delivery activation sub-state at partially-overlapping times.
17. The apparatus according to claim 14, wherein the control circuitry is configured to
5 assume the particle-delivery activation state in a plurality of particle-delivery-state cycles, and to begin the particle-delivery activation state in each of the particle-delivery-state cycles with the negative particle-delivery activation sub-state.
18. The apparatus according to claim 14, wherein the control circuitry is configured to
10 provide a plurality of the negative-positive particle delivery cycles during the particle-delivery activation state.
19. The apparatus according to claim 14, wherein the control circuitry is configured to, when in the negative particle-delivery activation sub-state, activate the liquid-supply pump to pump the liquid from the solid-liquid composition delivery tube, into the solid-liquid composition compartment, and into the liquid compartment.
20. The apparatus according to claim 14,
15 wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor,
wherein the liquid-supply peristaltic pump is capable of (a) pumping fluid at an average rate throughout a full 360-degree revolution of the rotor at a certain speed, and (b)
20 pumping fluid at a maximum rate during portions of the full 360-degree revolution at the certain speed, the maximum rate greater than the average rate, and
wherein the control circuitry is configured, when in both the positive and the negative particle-delivery activation sub-states, to activate the liquid-supply peristaltic pump to (a) rotate the rotor, at the certain speed, a partial revolution equal to a fraction of
25 the full 360-degree revolution of the rotor, the fraction less than 1, and (b) pump, throughout the partial revolution, the fluid at the maximum rate.
21. The apparatus according to claim 14,
wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor, and
30 wherein the control circuitry is configured:
when in the positive particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to rotate the rotor, in a first rotational direction, a

first partial revolution equal to a fraction of a full 360-degree revolution of the rotor, the fraction less than 1, and

when in the negative particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to rotate the rotor, in a second rotational direction opposite the first rotational direction, a second partial revolution equal to the fraction of the full 360-degree revolution of the rotor.

22. The apparatus according to claim 14,

wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor, and

wherein the control circuitry is configured, when in the positive particle-delivery activation sub-state, to activate the liquid-supply peristaltic pump to:

rotate the rotor a partial revolution equal to a fraction of a full 360-degree revolution of the rotor, the fraction less than 1, and

pump, throughout the partial revolution, a volume of fluid that is greater than the product of the fraction and a volume of fluid pumpable throughout the full 360-degree revolution of the rotor.

23. The apparatus according to claim 9, wherein the liquid-supply pump is a liquid-supply peristaltic pump, which comprises a rotor.

24. The apparatus according to claim 23, wherein the control circuitry is configured to assume the particle-delivery activation state a plurality of times in alternation with mixing activation states, and to begin each of the particle-delivery activation states with the rotor at a same rotational position.

25. The apparatus according to claim 9, wherein the mixing pump is a mixing peristaltic pump, which comprises a rotor.

26. The apparatus according to claim 25,

wherein the mixing peristaltic pump comprises a total number of rollers equal to at least two, and

wherein the control circuitry is configured to assume the mixing activation state a plurality of times in alternation with particle-delivery activation states, and to begin the mixing activation states with the rotor at respective starting rotational positions, which are identical to one another or rotationally offset from one another by the product of (a) 360 degrees divided by the total number of rollers and (b) a positive integer.

27. The apparatus according to claim 25,
wherein the mixing peristaltic pump comprises (a) a pump casing that is shaped so as to define a partial-circle mixing tube channel in which the mixing tube is disposed, and (b) an odd total number of rollers, the odd total number equal to at least one, and
- 5 wherein the control circuitry is configured to assume the mixing activation state a plurality of times in alternation with particle-delivery activation states, and to begin each of the mixing activation states with an aligned total number of the rollers rotationally aligned with the mixing tube channel, the aligned total number equal to more than half of the odd total number.
- 10 28. The apparatus according to claim 27, wherein the odd total number equals at least three.
29. The apparatus according to any one of claims 1-8,
wherein the chamber comprises a receptacle component and a cover component,
wherein the cover component (a) comprises the filter, and (b) is shaped so as to
- 15 define (i) a cap and (ii) a bone-graft container having an opening that (x) faces away from the cap and (y) is farther from the cap than the filter is from the cap, and
wherein the receptacle component and the cover component are shaped so as to be reversibly coupleable with each another to form a watertight seal, with the bone-graft container disposed within the receptacle component.
- 20 30. The apparatus according to any one of claims 1-8, wherein the mixing pump and the liquid-supply pump are respective peristaltic pumps.
31. The apparatus according to any one of claims 1-8, wherein the mixing tube (a) merges with the solid-liquid composition delivery tube at a return junction, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition
- 25 ports via a portion of the solid-liquid composition delivery tube.
32. The apparatus according to any one of claims 1-8, wherein the mixing tube (a) merges with the solid-liquid composition delivery tube at a return junction, and (b) is in fluid communication with the at least one of the one or more solid-liquid composition ports via a portion of the solid-liquid composition delivery tube.
- 30 33. The apparatus according to claim 32,

wherein the chamber comprises a receptacle component and a cover component, which is shaped so as to define a cap,

wherein the return junction is disposed along a longitudinal portion of the solid-liquid composition delivery tube and around a circumferential portion of the solid-liquid composition delivery tube,

wherein the longitudinal portion includes a point that is closest to the cap when the cap is coupled to the receptacle component, and

wherein the circumferential portion includes the point.

34. The apparatus according to any one of claims 1-8, wherein the apparatus further comprises a shaft unit, which comprises a shaft delivery tube in fluid communication with a distal end of the solid-liquid composition delivery tube.

35. The apparatus according to claim 34, wherein the shaft unit further comprises a removable depth limiting element, which is configured to limit a depth of insertion of the shaft delivery tube into a bore through a bone when the shaft delivery tube is inserted into the bore.

36. The apparatus according to claim 35, wherein the shaft unit comprises a shaft delivery tube, wherein the shaft unit further comprises a sealing element disposed around an external surface of the shaft delivery tube, and wherein the depth limiting element is removable from the shaft unit without removal of the sealing element.

37. Apparatus for use with solid particles and a liquid container containing a physiological liquid solution, the apparatus comprising a composition delivery source, which comprises:

(a) a chamber, which:

(i) comprises a filter, which is disposed within the chamber so as to divide the chamber into a liquid compartment and a solid-liquid composition compartment, and

(ii) is shaped so as to define (A) one or more liquid ports in fluid communication with the liquid compartment, and (B) one or more solid-liquid composition ports in fluid communication with the solid-liquid composition compartment;

(b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports;

(c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports;

5 and

(d) a liquid-supply tube, which is in fluid communication with at least one of the one or more liquid ports, and is coupled in fluid communication with an interior of the liquid solution container.

38. Apparatus for use with solid particles and a liquid container containing a physiological liquid solution, the apparatus comprising a pump unit, which comprises:

10

(a) a mixing pump;

(b) a liquid-supply pump; and

(c) control circuitry, which is configured to repeatedly:

15

(i) assume a mixing activation state, in which the control circuitry activates the mixing pump, and

(ii) assume a particle-delivery activation state,

wherein the control circuitry is configured, during each of one or more negative-positive particle delivery cycles of the particle-delivery activation state, to assume:

20

a negative particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump apply negative pressure to pump in a first direction, and

thereafter, a positive particle-delivery activation sub-state, in which the control circuitry activates the liquid-supply pump to apply positive pressure to pump in a second direction opposite the first direction.

39. Apparatus for use with solid particles and a physiological liquid solution, the apparatus comprising:

25

a composition delivery source, which comprises:

(a) a chamber, which is shaped so as to define one or more liquid ports and one or more solid-liquid composition ports;

30

(b) a solid-liquid composition delivery tube, which is in fluid communication with at least one of the one or more solid-liquid composition ports; and

(c) a mixing tube, which is in fluid communication with at least one of the one or more liquid ports and at least one of the one or more solid-liquid composition ports; and

a pump unit, which comprises a mixing pump, which is arranged to cause, in the mixing tube, flow that raises the solid particles in a puff into the physiological liquid solution in the chamber.

40. Apparatus comprising a surgical tool for use with solid particles and a physiological liquid solution, the surgical tool comprising:

a shaft unit, which is shaped so as to define a delivery lumen, and a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the delivery lumen;

a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

a pump, which is configured to pump the solid-liquid composition through the distal opening via the delivery lumen.

41. The apparatus according to claim 40, wherein the surgical tool is configured as an oral surgical tool.

42. The apparatus according to claim 40, wherein the pump is configured to pump the solid-liquid composition at a pulsating hydraulic pressure that periodically varies between positive and negative.

43. The apparatus according to claim 42, wherein the pump is configured to pump the solid-liquid composition through the distal opening via the delivery lumen during a plurality of positive-pressure periods that alternate with a plurality of negative-pressure periods, and to set an average duration of the positive-pressure periods to be less than or equal to an average duration of the negative-pressure periods.

44. The apparatus according to claim 43, wherein the pump is configured to set the average duration of the positive-pressure periods to be equal to the average duration of the negative-pressure periods.

45. The apparatus according to claim 40, wherein the pump is configured to pump the solid-liquid composition at a pulsating positive hydraulic pressure.

46. The apparatus according to any one of claims 40-45, wherein the composition source comprises a combining unit, which is configured to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.

47. The apparatus according to claim 46, wherein the combining unit comprises a mixing unit, which is configured to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.

48. The apparatus according to any one of claims 40-45, wherein the solid particles are solid bone graft particles, and wherein the surgical tool is for use with the solid bone graft particles.

49. Apparatus comprising a surgical tool for use with solid particles and a physiological liquid solution, the surgical tool comprising:

exactly one shaft unit, which is shaped so as to define a delivery lumen and a drainage lumen;

a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the delivery lumen;

a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

a filter, which is disposed in fluid communication with the drainage lumen, and which is configured to inhibit passage of the solid particles of the solid-liquid composition and allow passage of the physiological liquid solution of the solid-liquid composition.

50. The apparatus according to claim 49, wherein the filter is disposed within 10 mm of the distal end of the shaft unit.

51. The apparatus according to claim 49, wherein the filter is disposed around an axis of the distal opening.

52. The apparatus according to claim 49, wherein the drainage lumen is disposed alongside the delivery lumen in the shaft unit.

53. The apparatus according to claim 49, wherein the filter is disposed around the delivery lumen in the shaft unit.

54. The apparatus according to claim 49, further comprising a pump, which is configured to clear the solid particles that accumulate on the filter during drainage of the

physiological liquid solution through the filter, by periodically applying a positive pressure to the drainage lumen.

55. The apparatus according to claim 49, wherein the filter is shaped so as to define a plurality of slits having a width narrower than the solid particles.

5 56. The apparatus according to claim 49, wherein the surgical tool is configured to move the distal opening and the shaft unit with respect to each other.

57. The apparatus according to claim 56, wherein the surgical tool further comprises a filter clearing element, which is fixed to the distal opening, and is configured to clear the solid particles that accumulate on the filter during drainage of the physiological liquid
10 solution through the filter.

58. The apparatus according to claim 56, wherein the surgical tool is configured to rotate the distal opening and the shaft unit with respect to each other.

59. The apparatus according to claim 49, wherein the surgical tool further comprises a filter clearing element, which is configured to clear the solid particles that accumulate on
15 the filter during drainage of the physiological liquid solution through the filter.

60. Apparatus comprising a surgical tool for use with solid particles and a physiological liquid solution, the surgical tool comprising:

exactly one shaft unit, which is shaped so as to define a delivery lumen and a drainage lumen;

20 a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the delivery lumen;

a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution; and

25 a plurality of elements disposed around and outside the delivery lumen for facilitating (a) inhibiting passage of the solid particles of the solid-liquid composition to the drainage lumen, and (b) allowing passage of the physiological liquid solution of the solid-liquid composition to the drainage lumen.

61. Apparatus comprising a surgical tool for use with solid particles and a
30 physiological liquid solution, the surgical tool comprising:

exactly one shaft unit, which (a) is shaped so as to define a drainage lumen, and (b) comprises a delivery shaft, which is shaped so as to define (i) a delivery lumen, and (ii) a plurality of rib elements that extend radially outward from an external surface of the delivery shaft;

5 a distal opening, which is disposed within 10 mm of a distal end of the shaft unit, in fluid communication with the delivery lumen; and

a composition source, which is coupled in fluid communication with the delivery lumen, and which is configured to provide a solid-liquid composition of the solid particles and the physiological liquid solution.

10 62. The apparatus according to claim 61, wherein the rib elements extend an average distance of between 0.1 and 2 mm radially outward from the external surface of the delivery shaft.

63. The apparatus according to claim 61, wherein the rib elements extend longitudinally along the external surface of the delivery shaft for an average distance of at
15 least 1 mm.

64. The apparatus according to claim 61, wherein the surgical tool further comprises a depth limiting element, which is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is inserted into the bore.

65. The apparatus according to claim 64, wherein the depth limiting element is
20 removably attached to the shaft unit.

66. The apparatus according to claim 64, wherein the depth limiting element is shaped so as to define a portion of the drainage lumen between at least a portion of an internal surface of the depth limiting element and a portion of the external surface of the delivery shaft.

25 67. The apparatus according to any one of claims 49, 60, and 61, wherein the surgical tool is configured as an oral surgical tool.

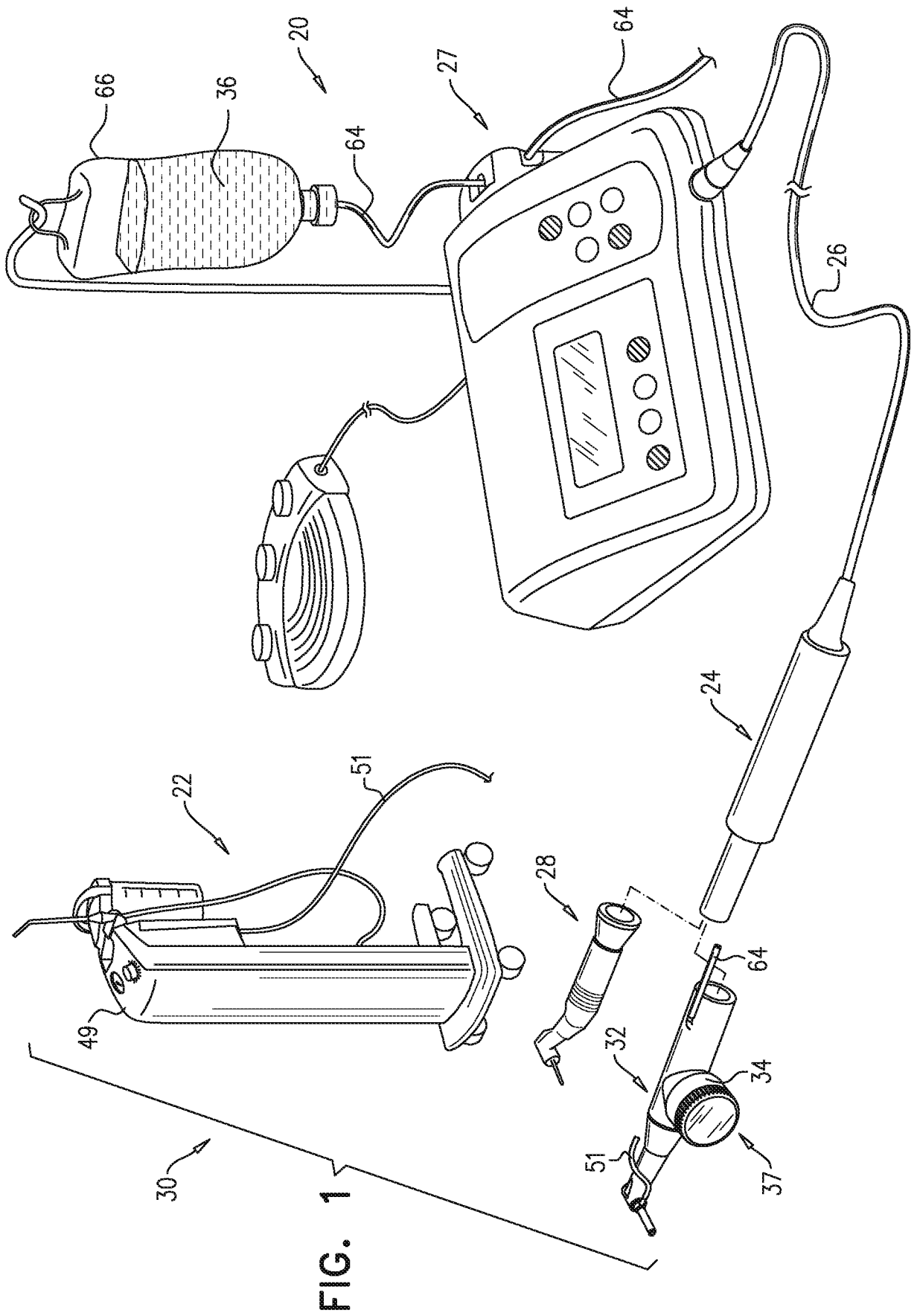
68. The apparatus according to any one of claims 49, 60, and 61, wherein the solid particles are solid bone graft particles, and wherein the surgical tool is for use with the solid bone graft particles.

30 69. The apparatus according to any one of claims 49, 60, and 61, wherein the drainage lumen is disposed around the delivery lumen in the shaft unit.

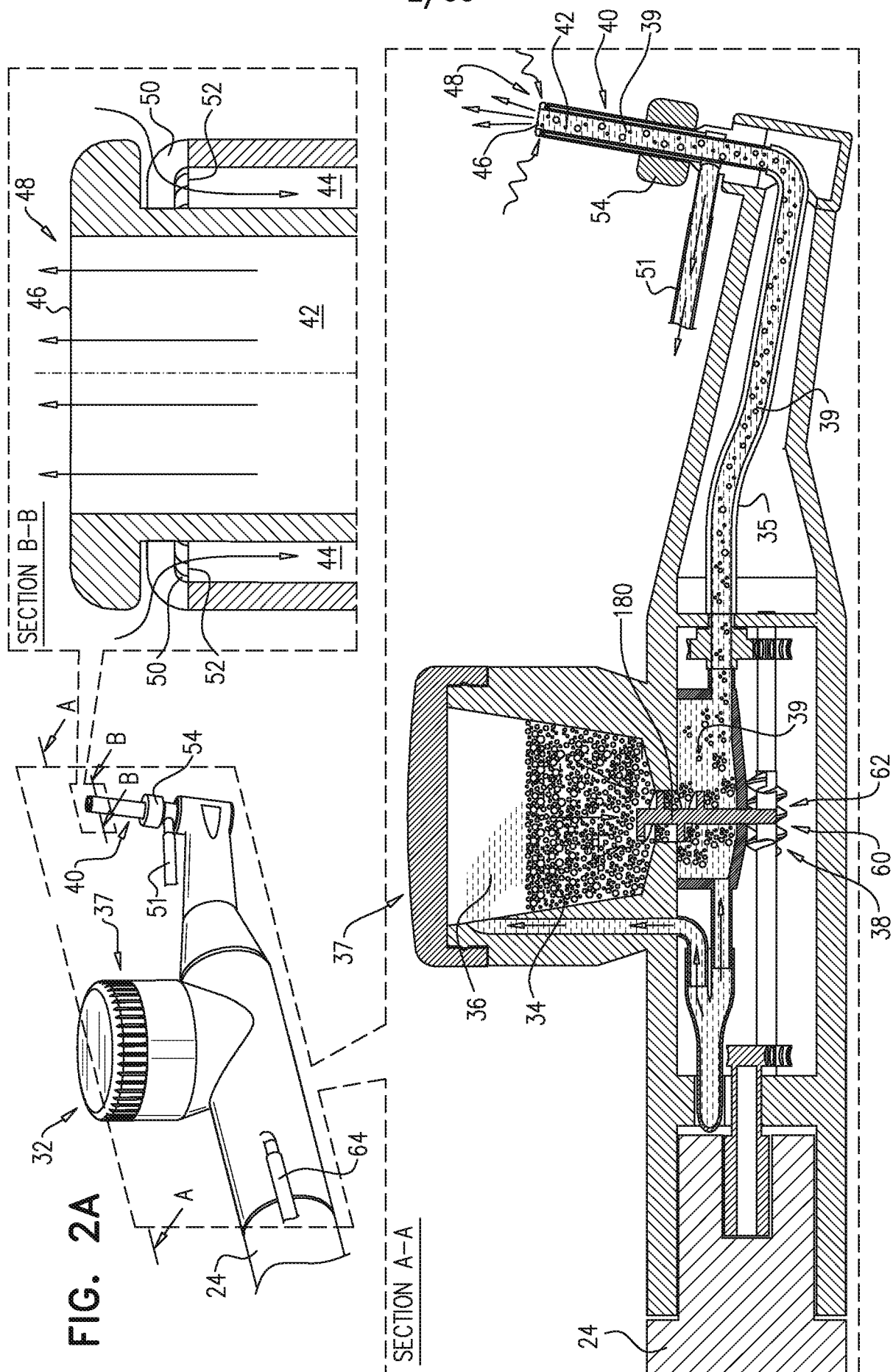
70. The apparatus according to any one of claims 49, 60, and 61, wherein the surgical tool further comprises a suction source, which is coupled in fluid communication with the drainage lumen.
71. The apparatus according to any one of claims 49, 60, and 61, for use with a suction source, wherein the drainage lumen is coupleable in fluid communication with the suction source.
72. The apparatus according to any one of claims 49, 60, and 61, wherein the surgical tool further comprises a depth limiting element, which is configured to limit a depth of insertion of the shaft unit into a bore through a bone when the shaft unit is inserted into the bore.
73. The apparatus according to any one of claims 49, 60, and 61, wherein the composition source comprises a combining feeder unit, which is configured to provide the solid-liquid composition by combining the solid particles with the physiological liquid solution.
74. The apparatus according to claim 73, wherein the combining feeder unit comprises a mixing feeder unit, which is configured to provide the solid-liquid composition by mixing the solid particles with the physiological liquid solution.
75. The apparatus according to any one of claims 49, 60, and 61, wherein the surgical tool is configured to automatically apply motion to the shaft unit selected from the group consisting of: vibrational motion, rotational motion, oscillatory motion, axial back-and-forth motion, and lateral side-to-side motion.
76. The apparatus according to any one of claims 49, 60, and 61, further comprising a pump, which is configured to pump the solid-liquid composition through the distal opening via the delivery lumen.
77. The apparatus according to claim 76, wherein the pump is configured to pump the solid-liquid composition at a pulsating positive hydraulic pressure.
78. The apparatus according to claim 76, wherein the pump is configured to pump the solid-liquid composition at a pulsating hydraulic pressure that periodically varies between positive and negative.

79. The apparatus according to any one of claims 49, 60, and 61, wherein the surgical tool further comprises a solid-particle container, which contains the solid particles for combining with the physiological liquid solution.

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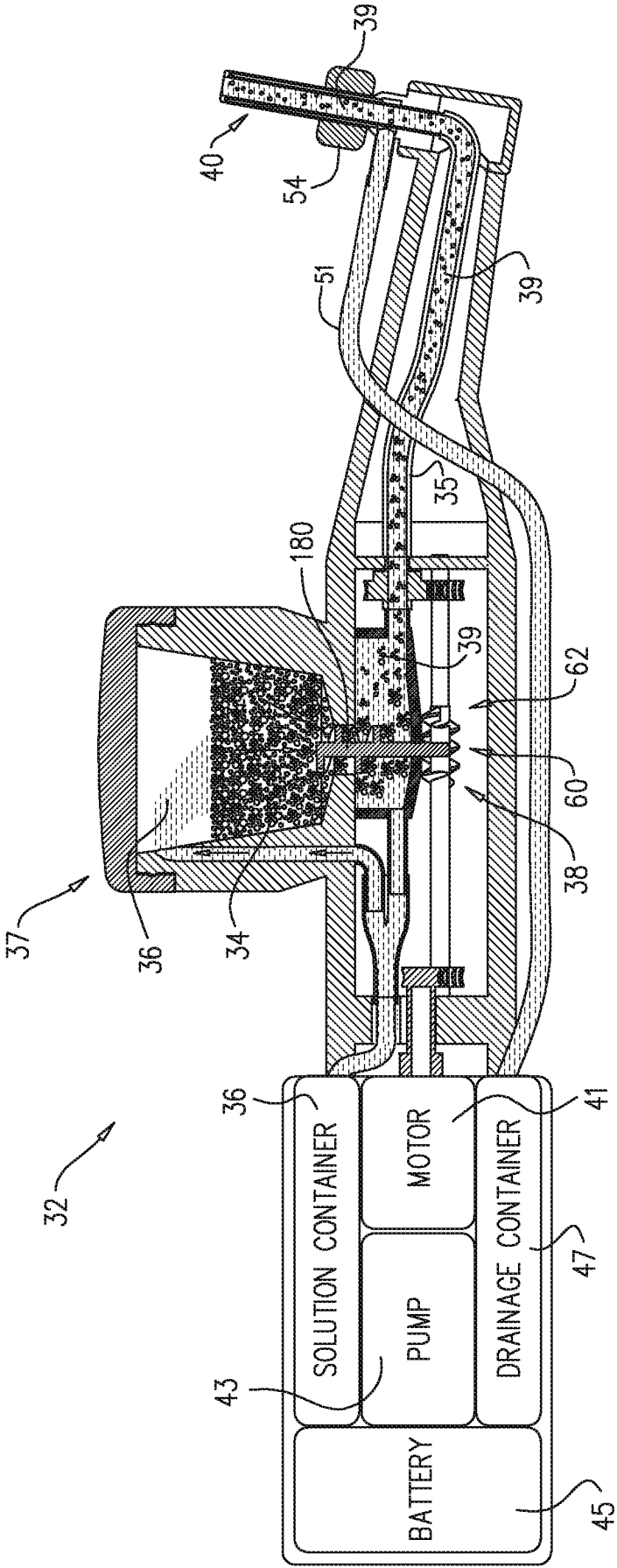
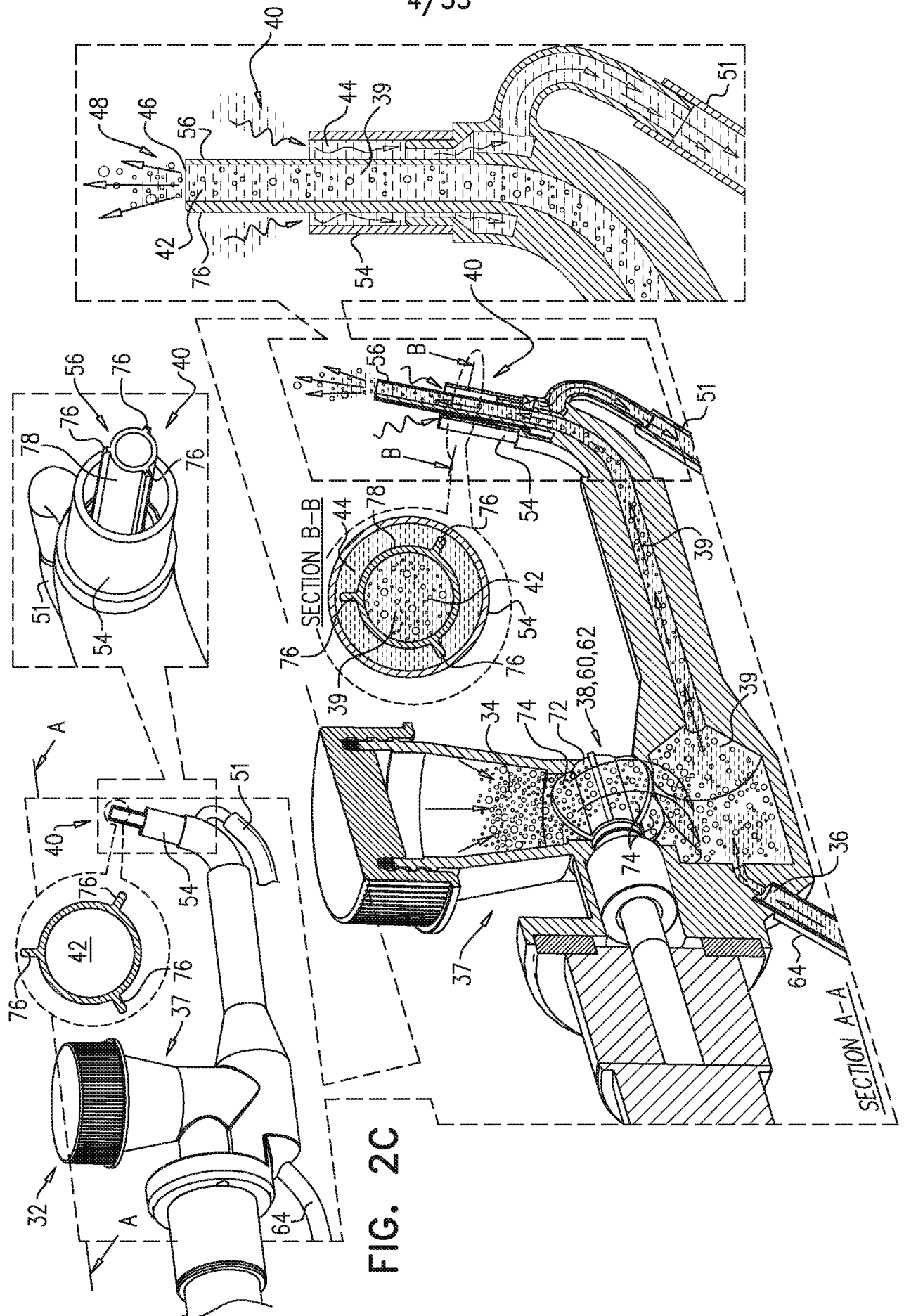
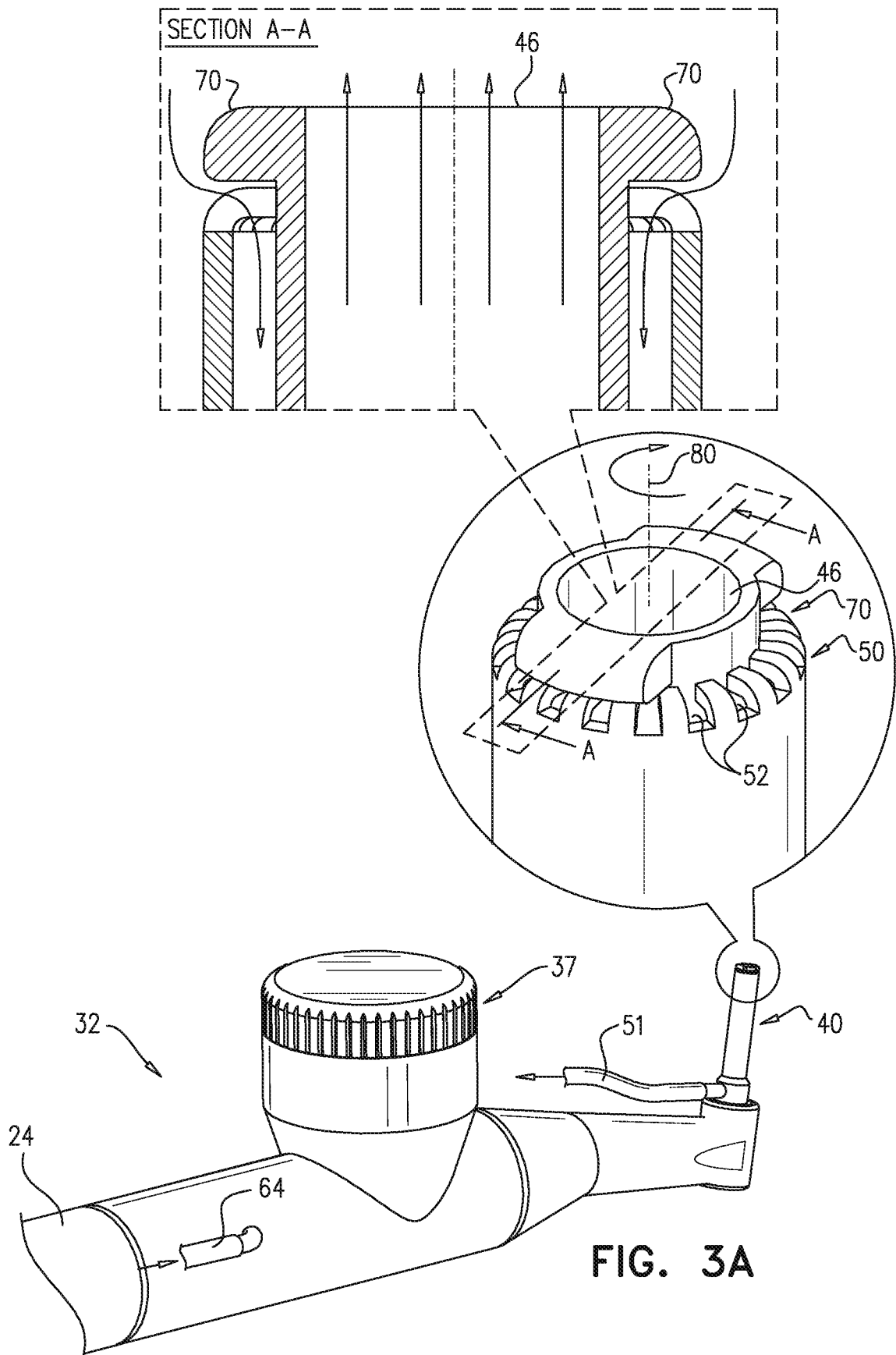


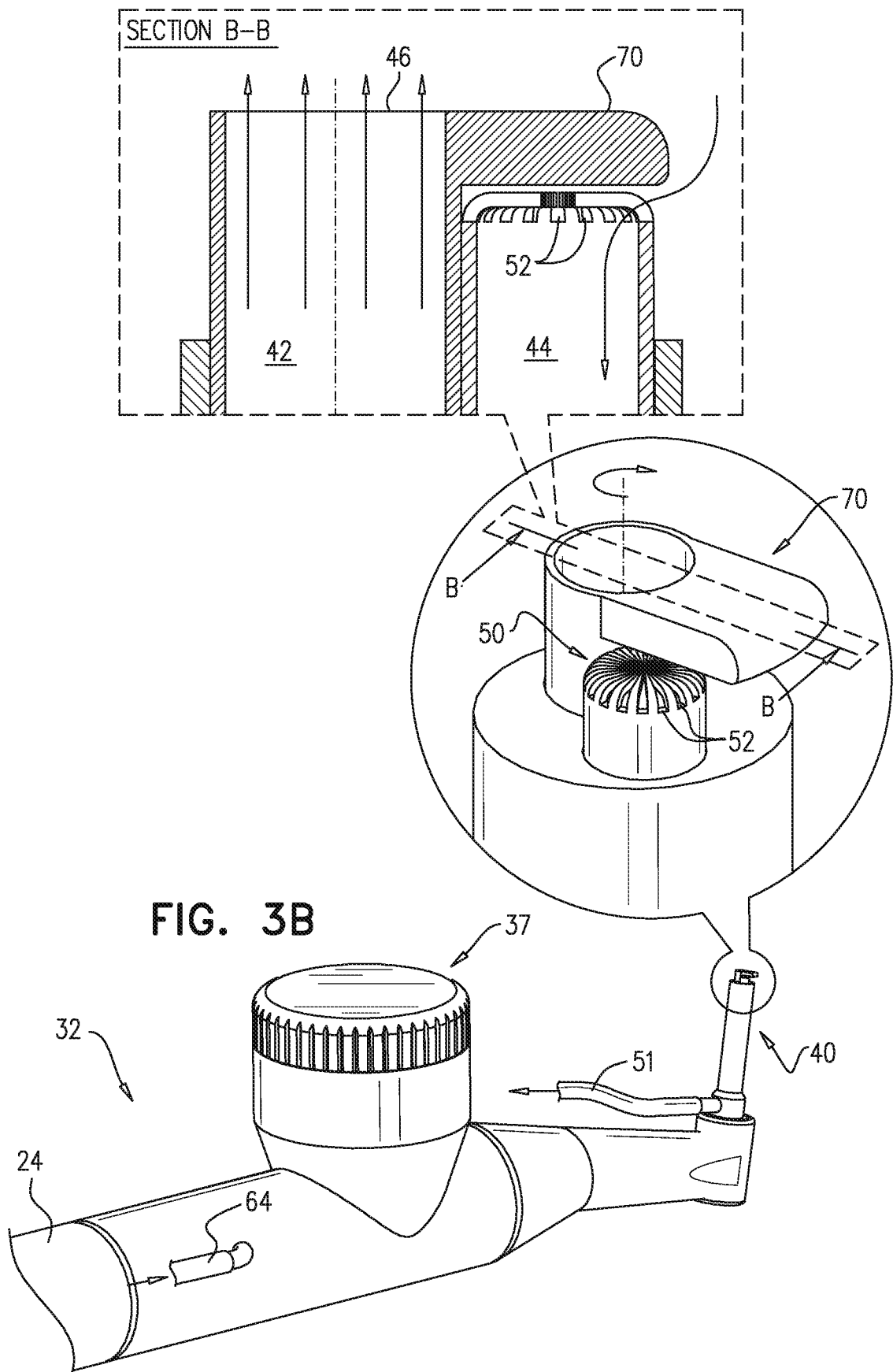
FIG. 2B



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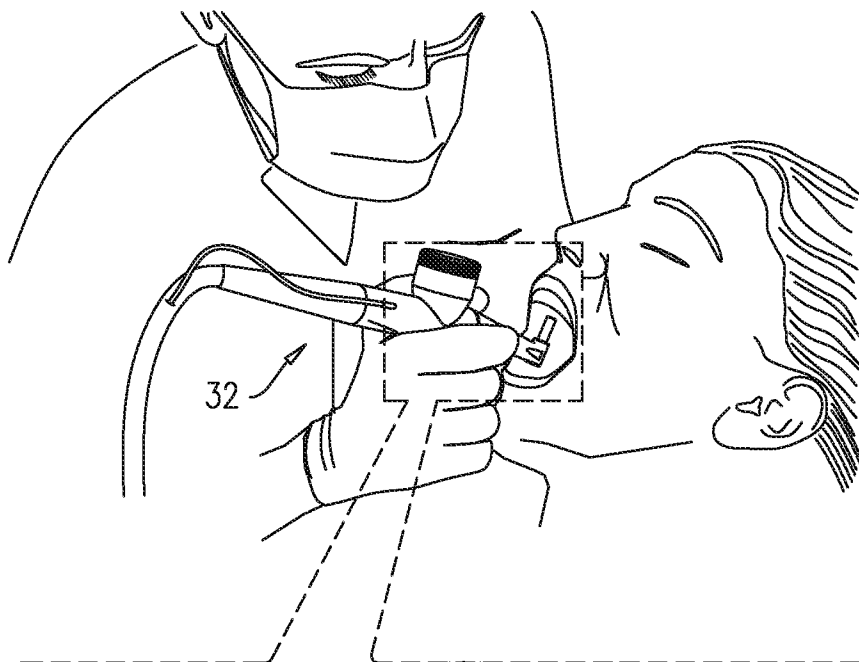
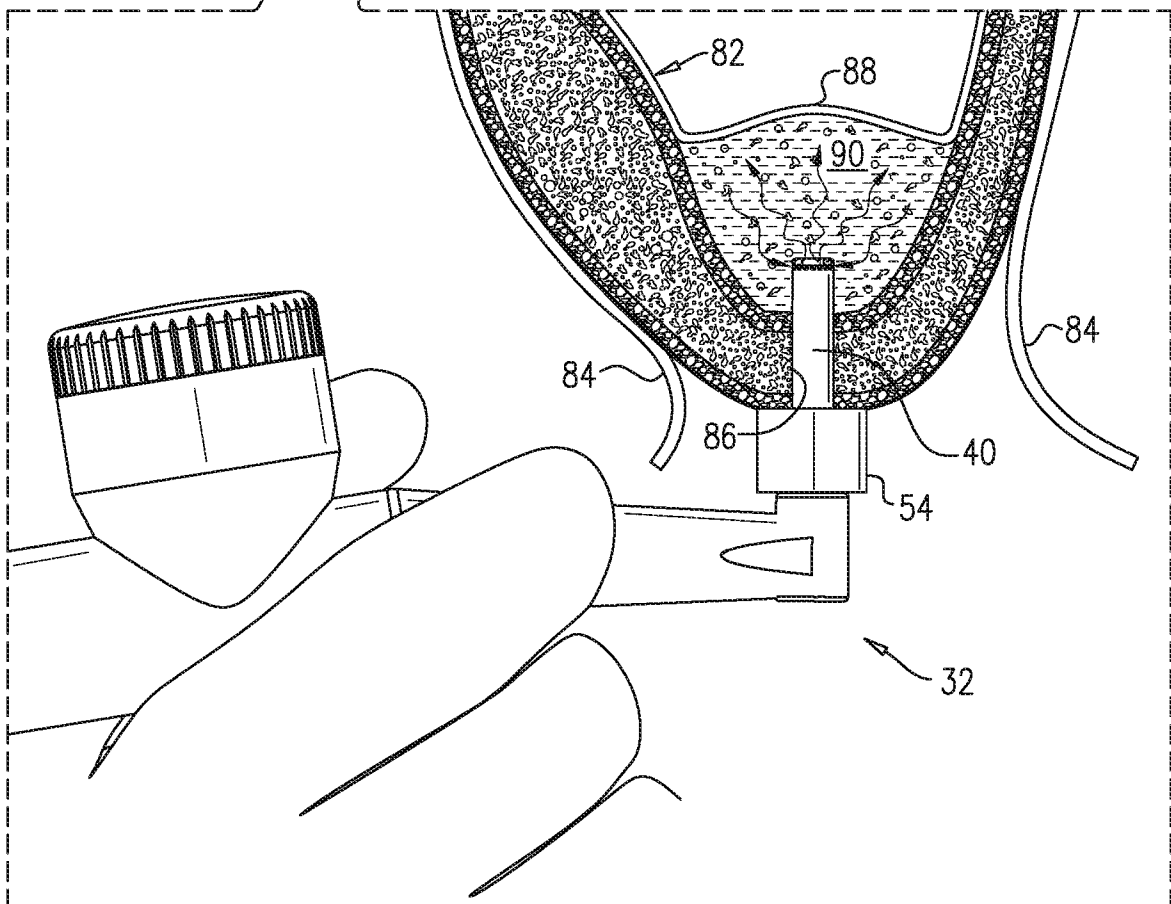


FIG. 4A



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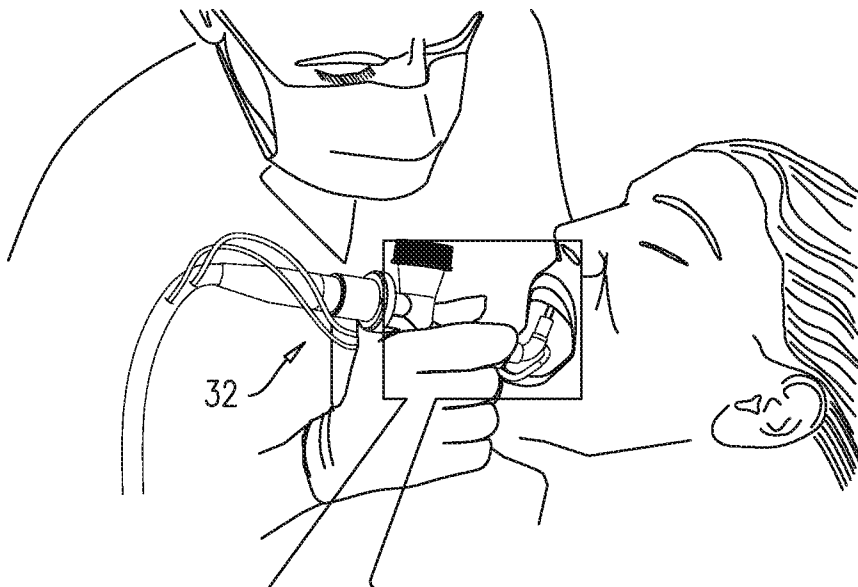
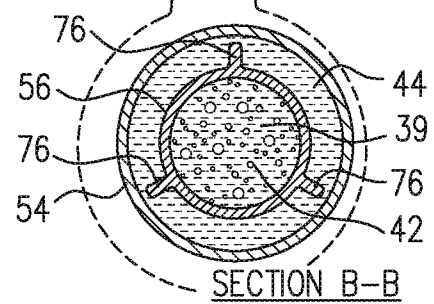
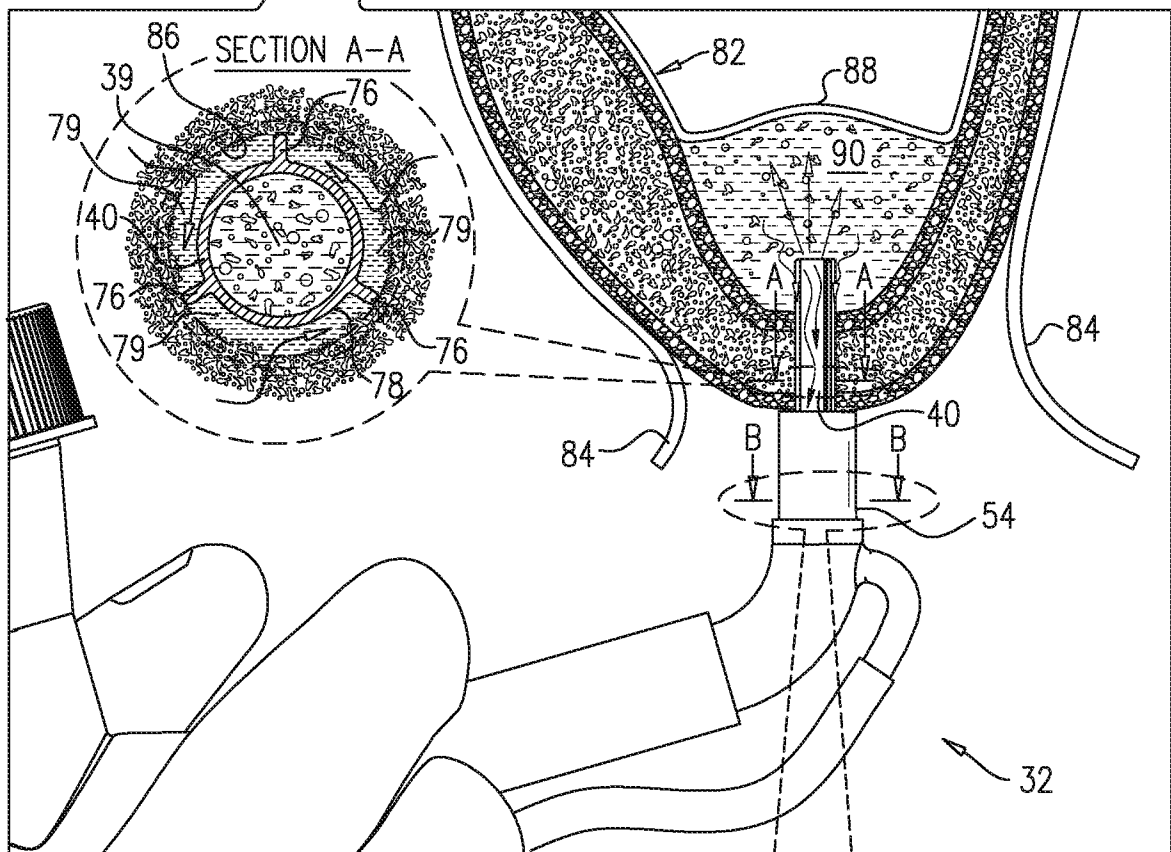
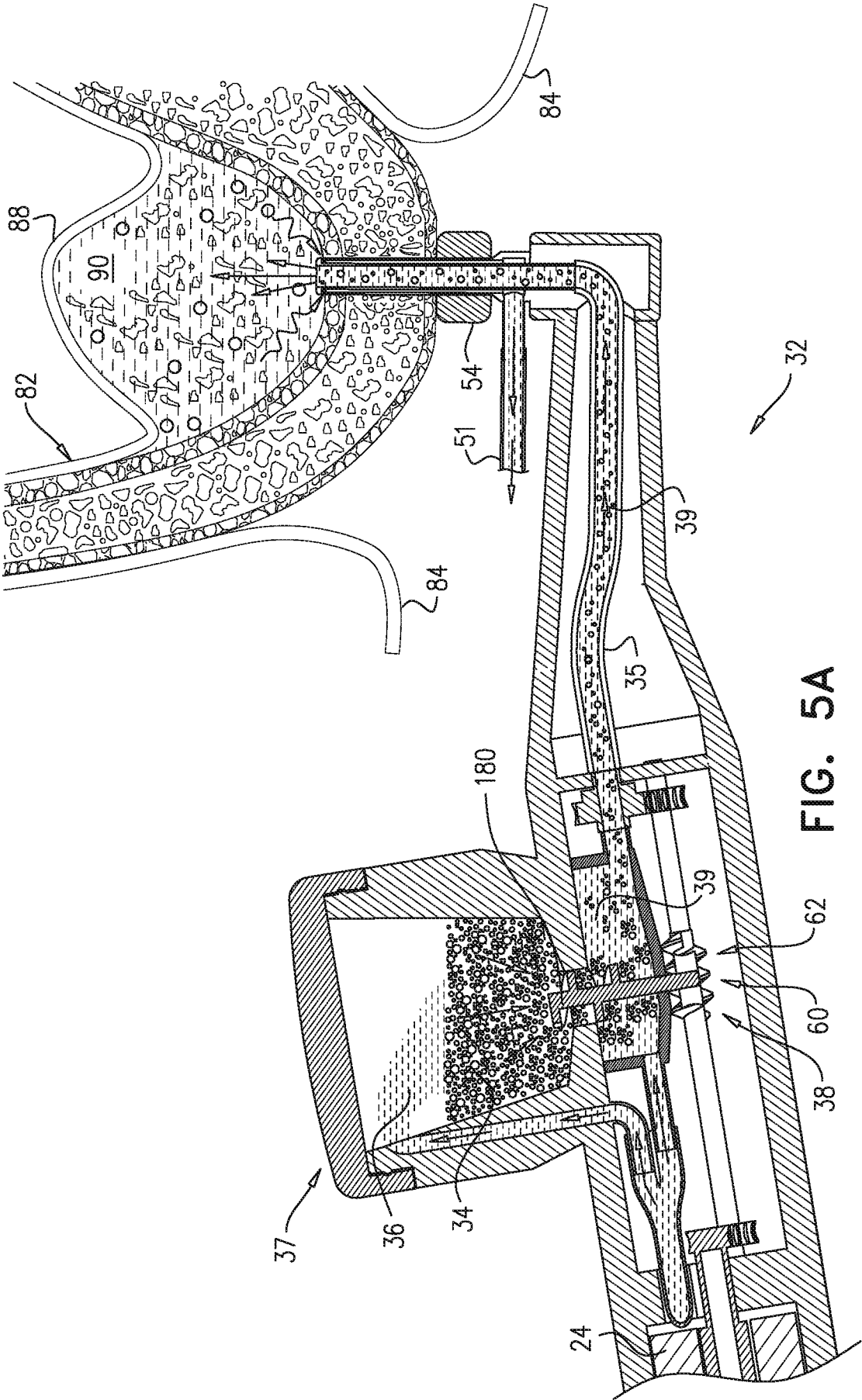
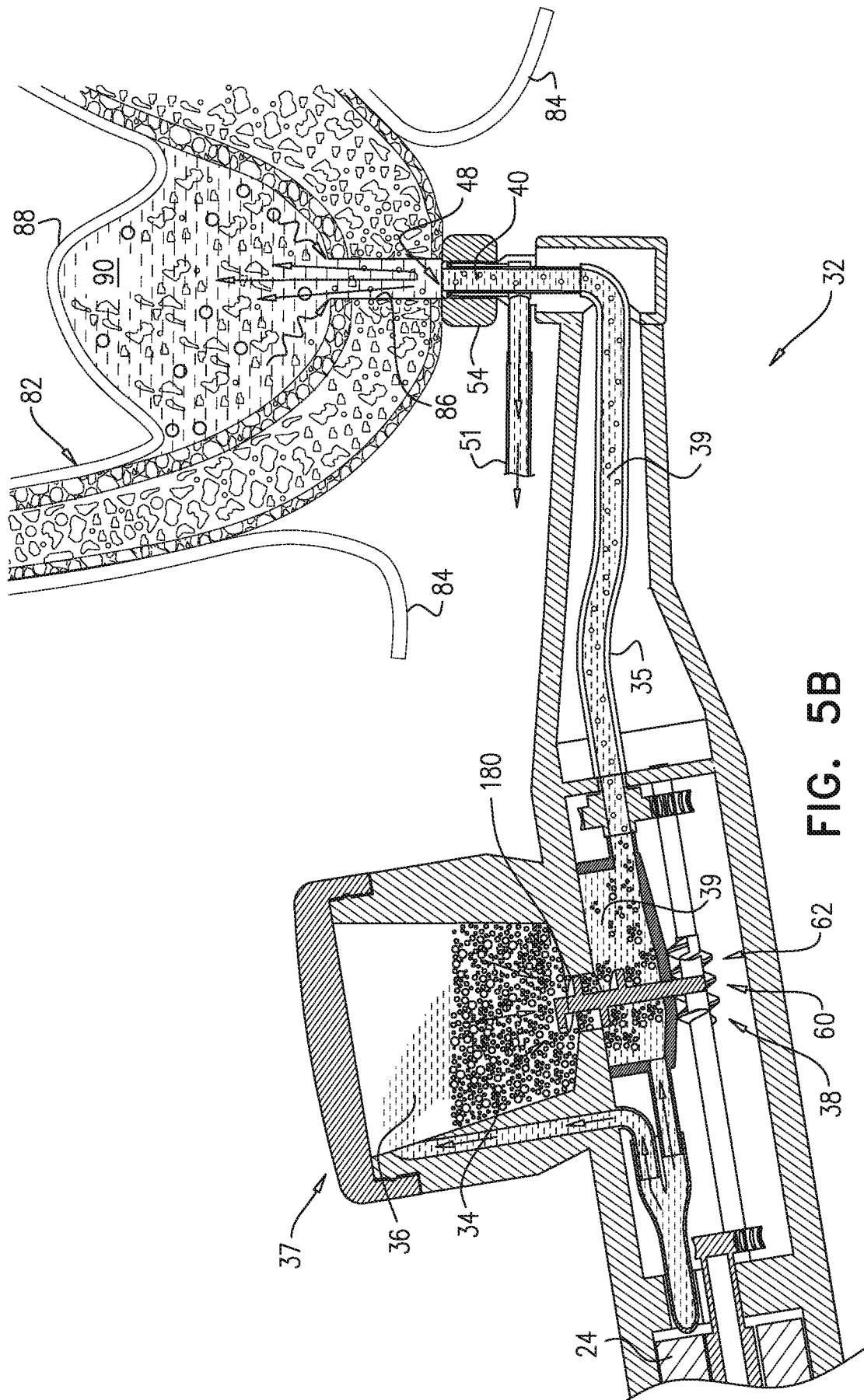


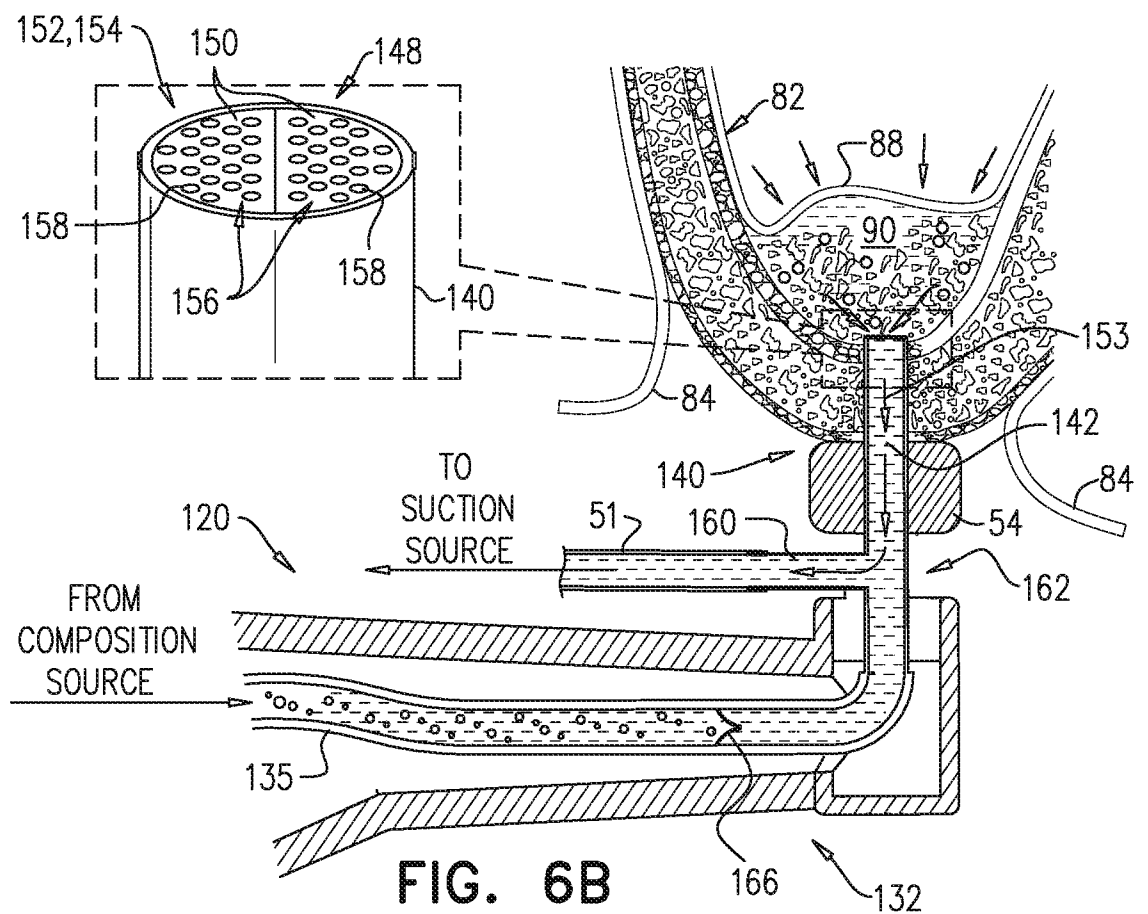
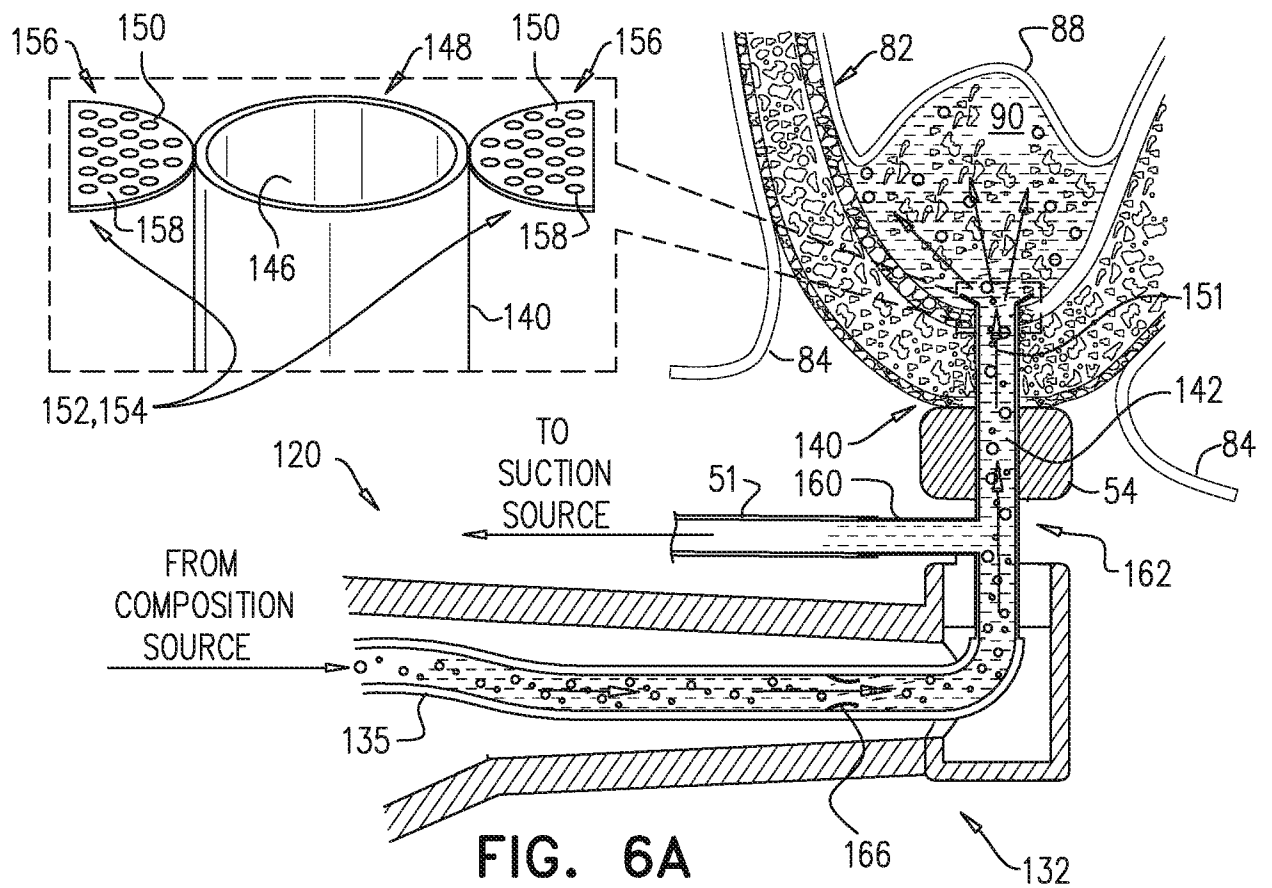
FIG. 4B



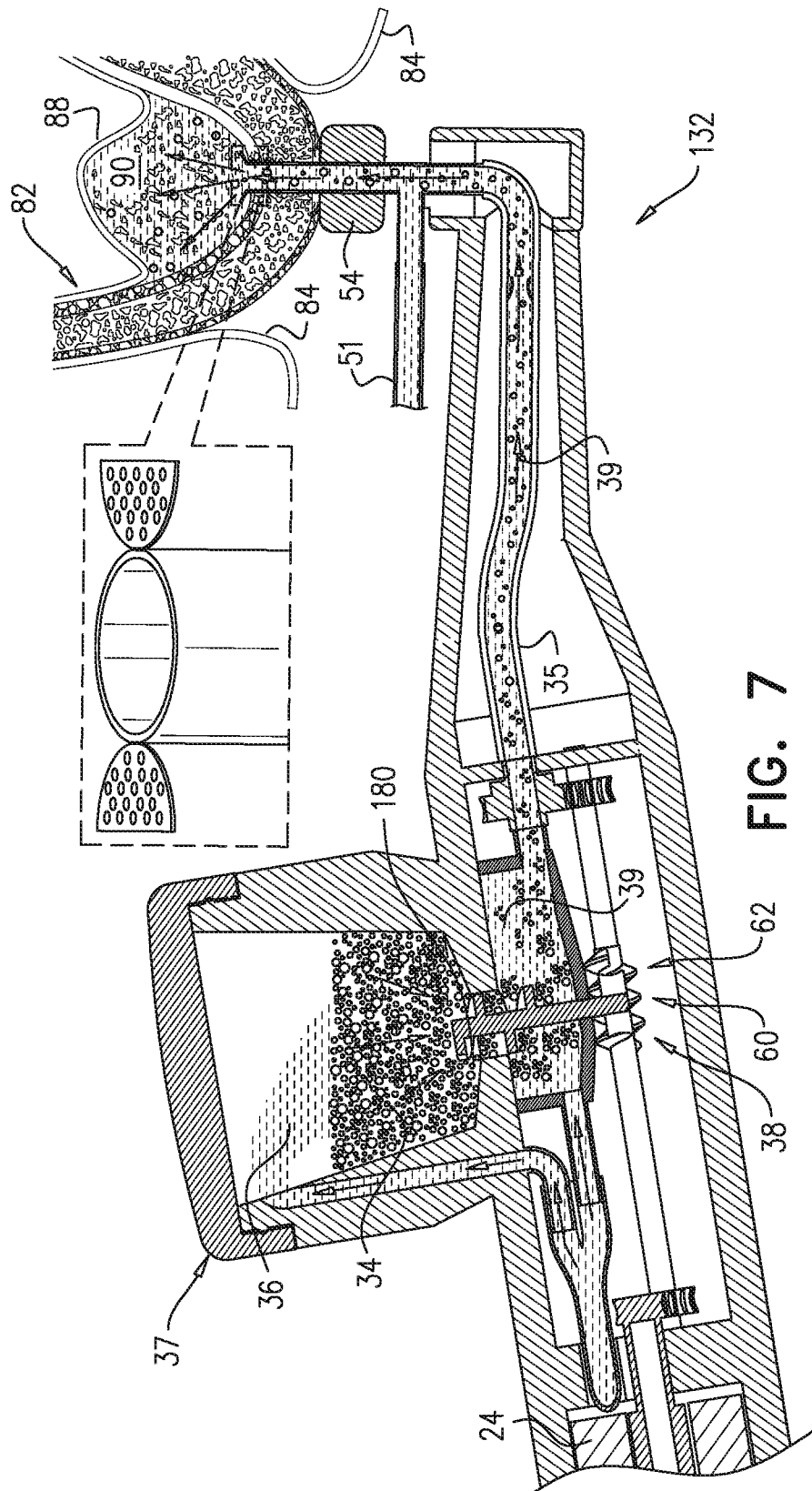




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FIG. 8A

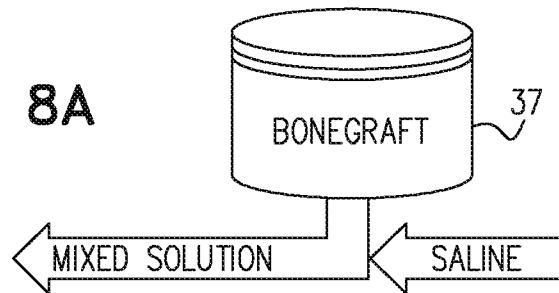


FIG. 8B

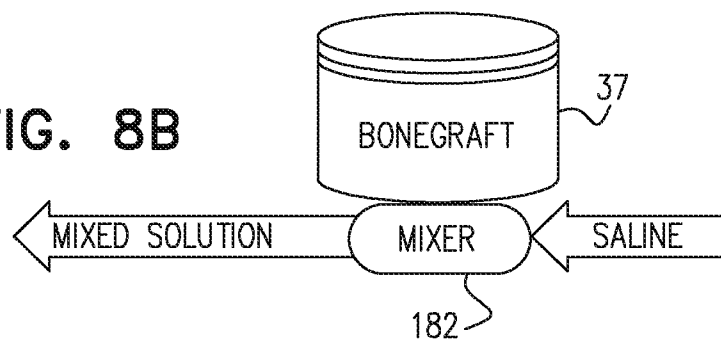


FIG. 8C

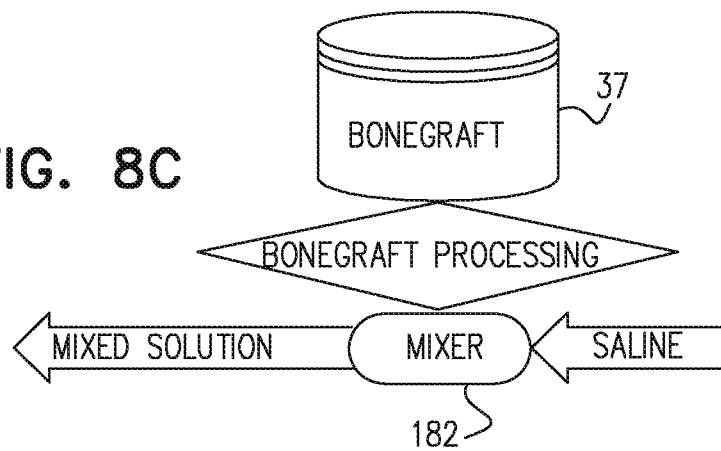
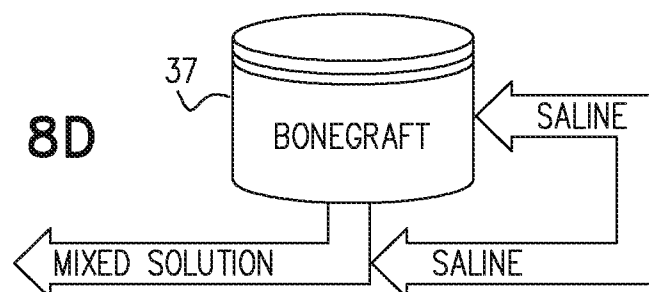
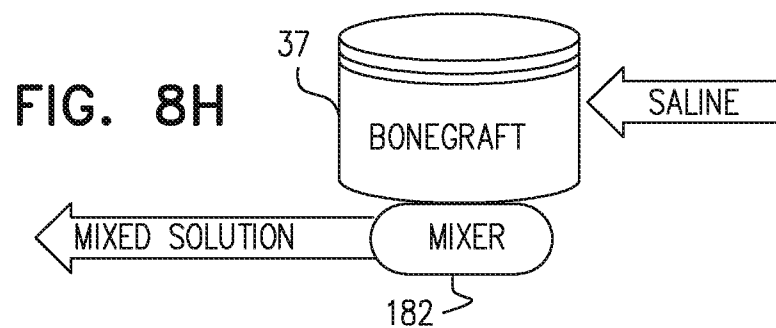
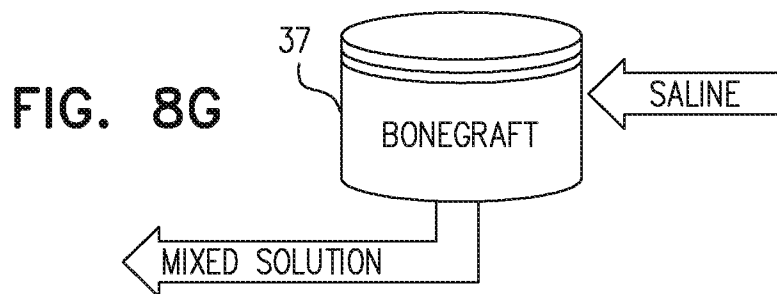
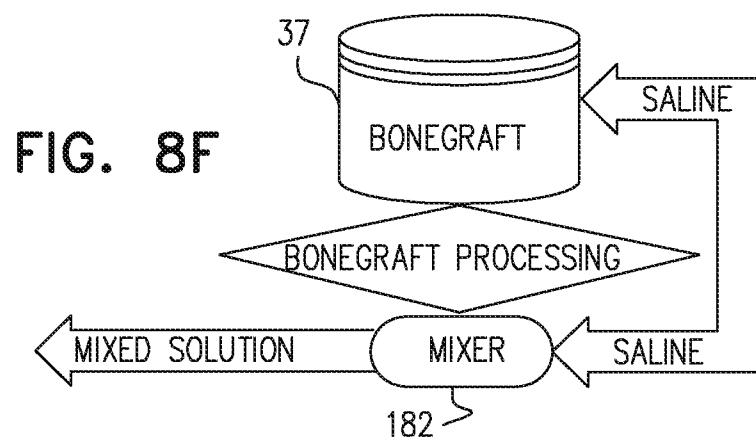
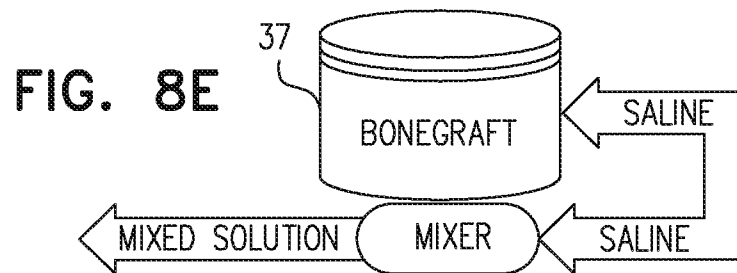


FIG. 8D



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FIG. 8I

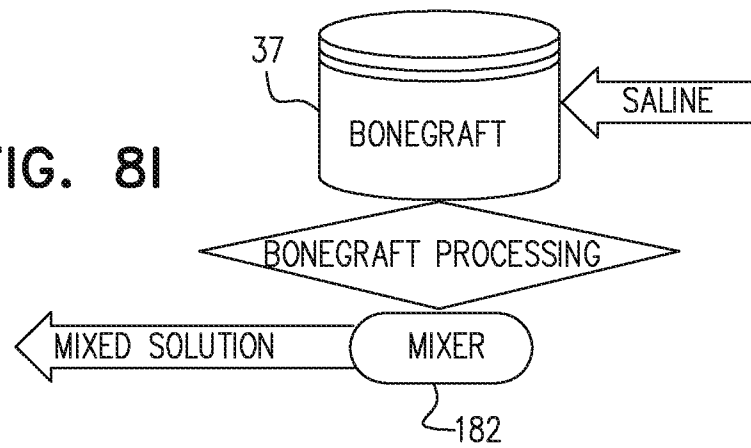


FIG. 8J

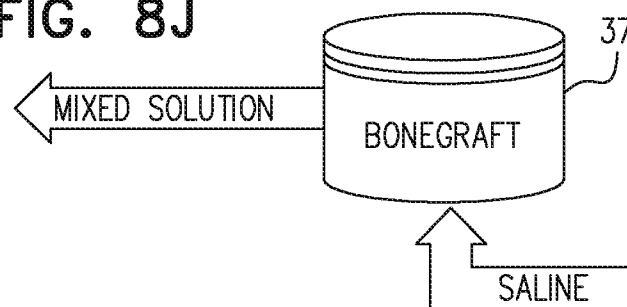
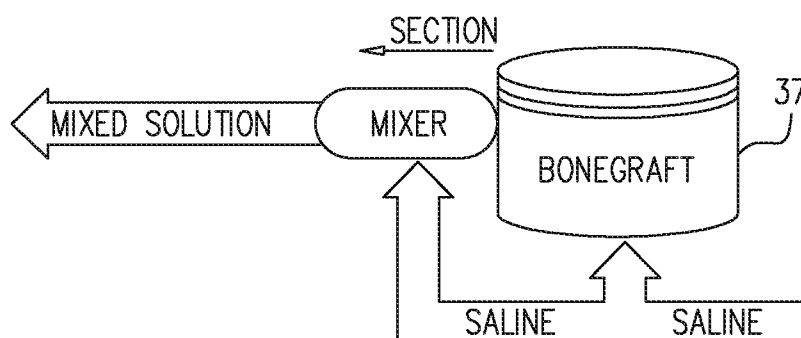


FIG. 8K



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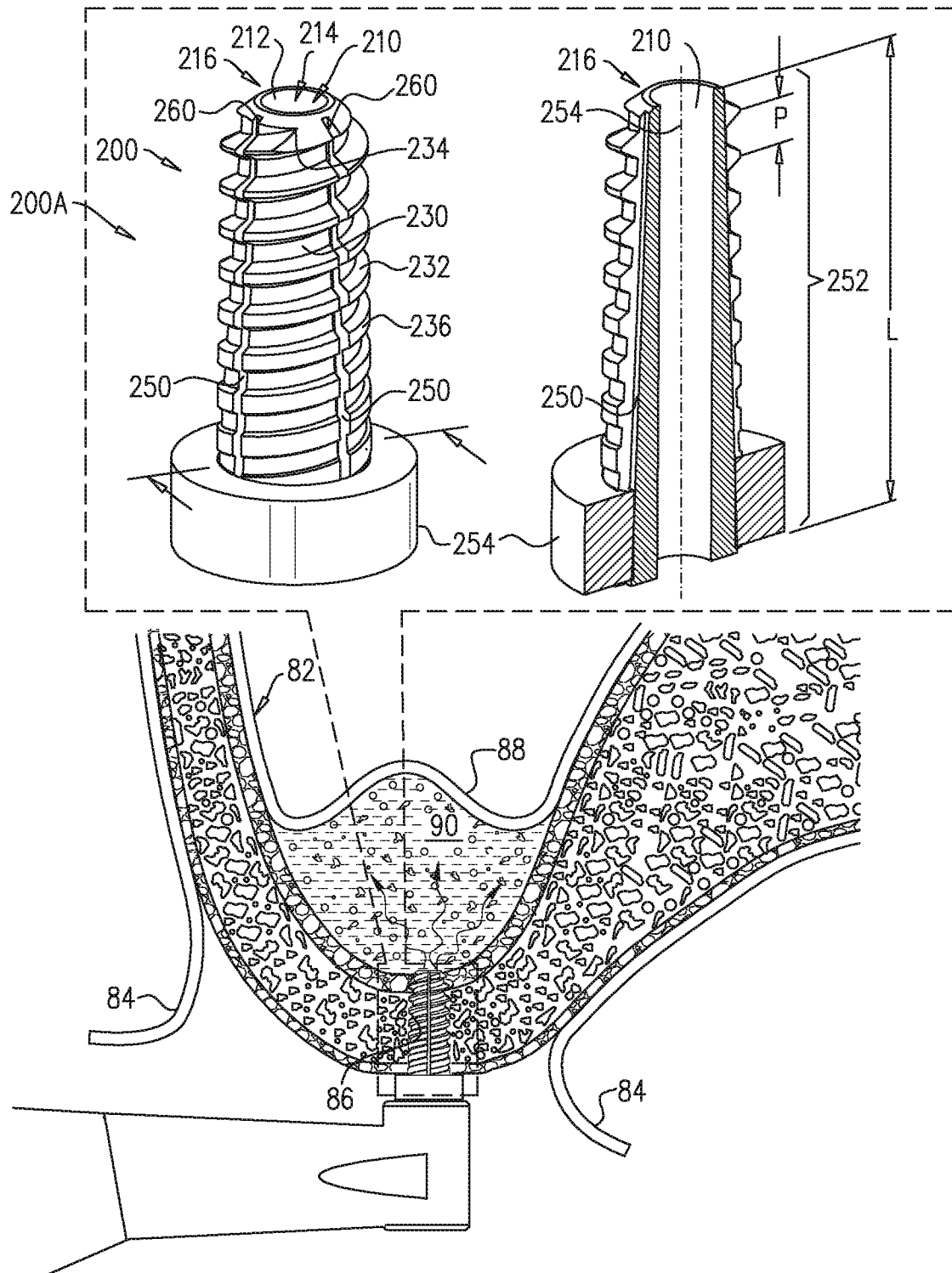


FIG. 9A

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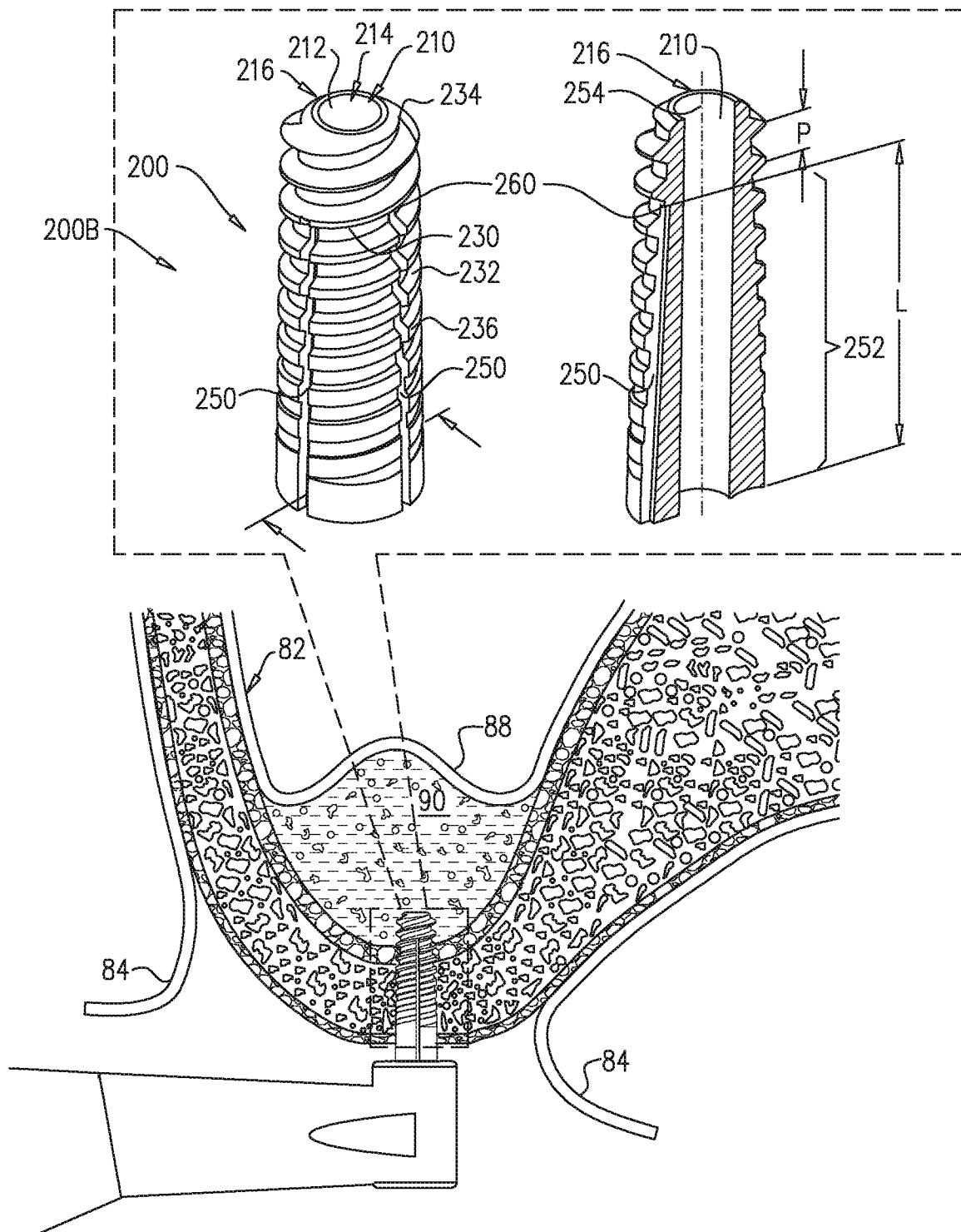
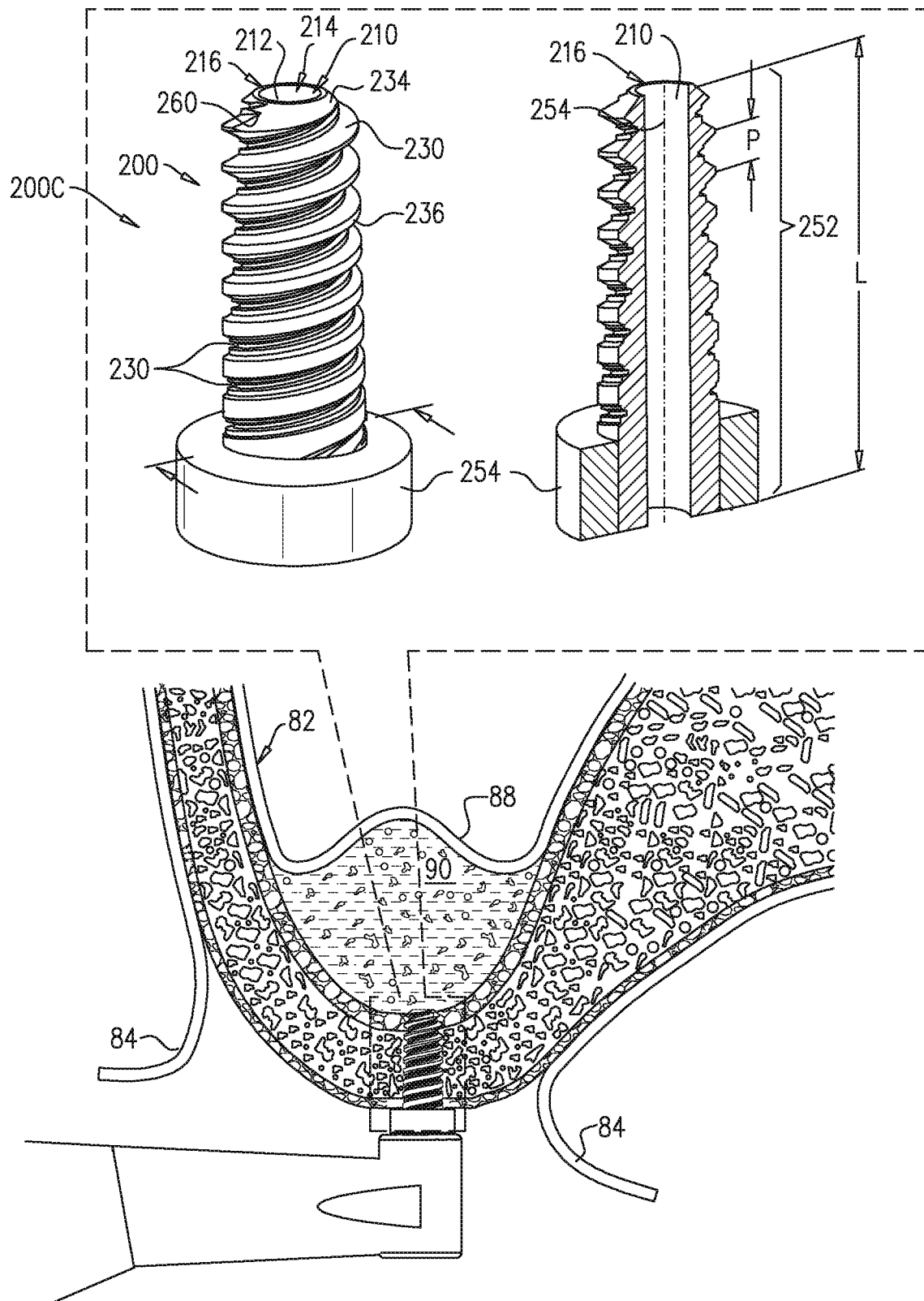


FIG. 9B

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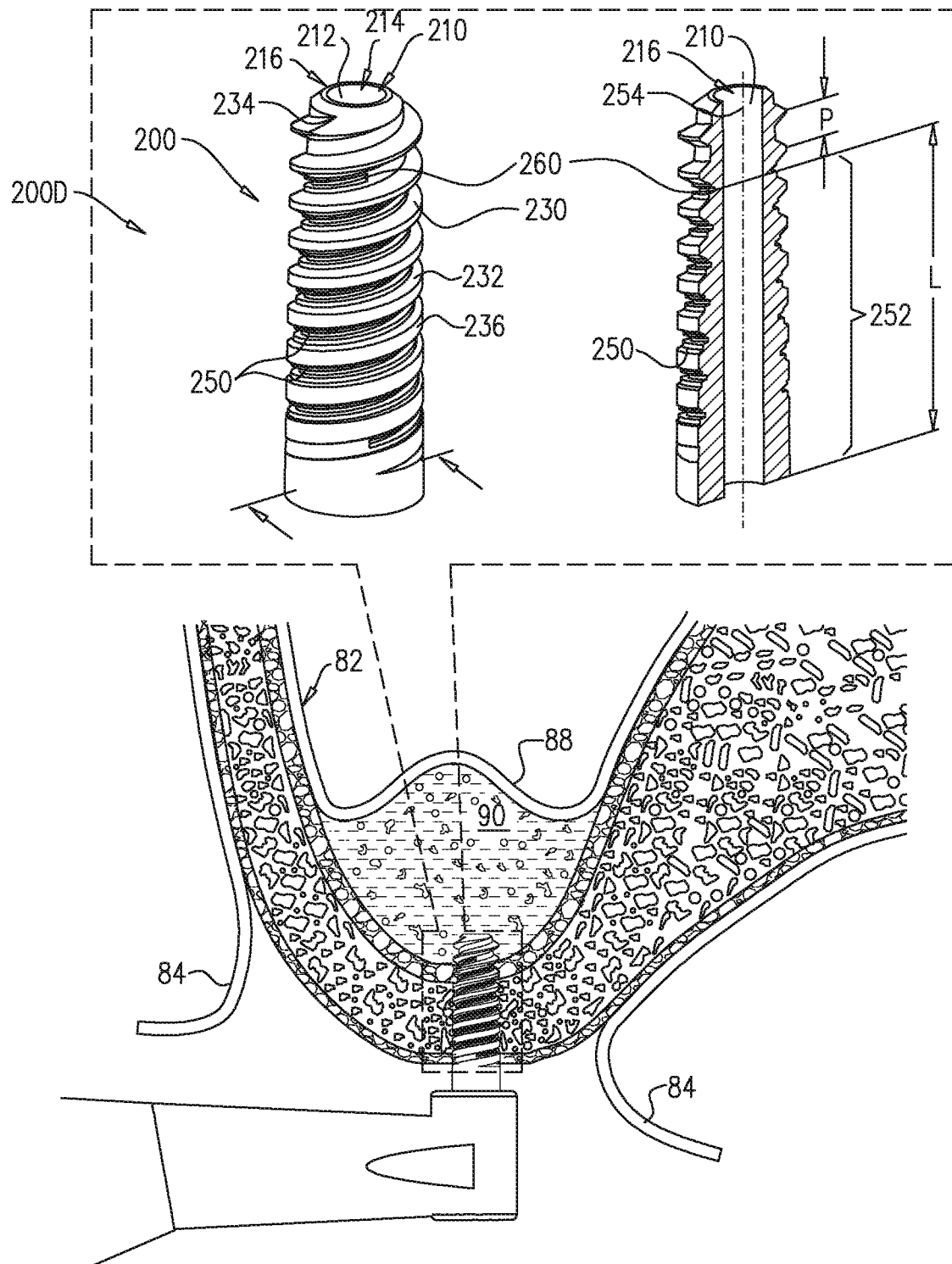
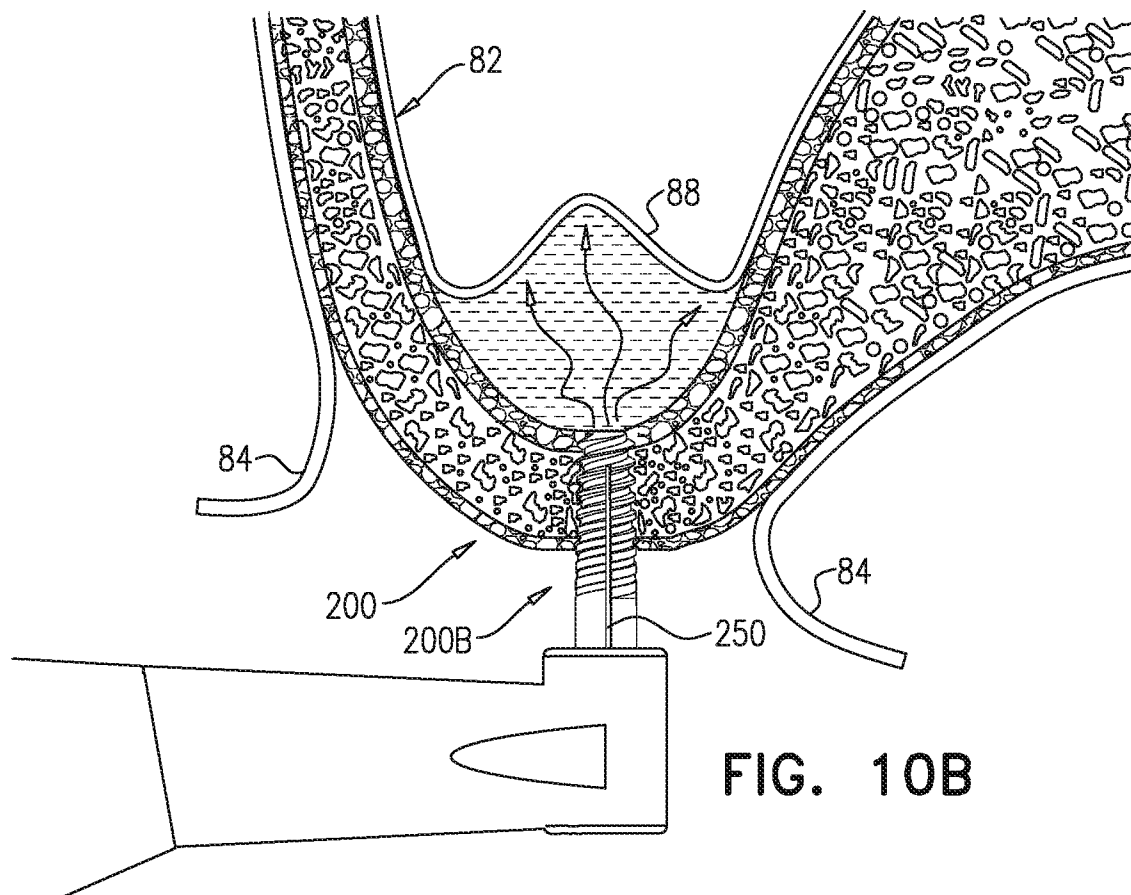
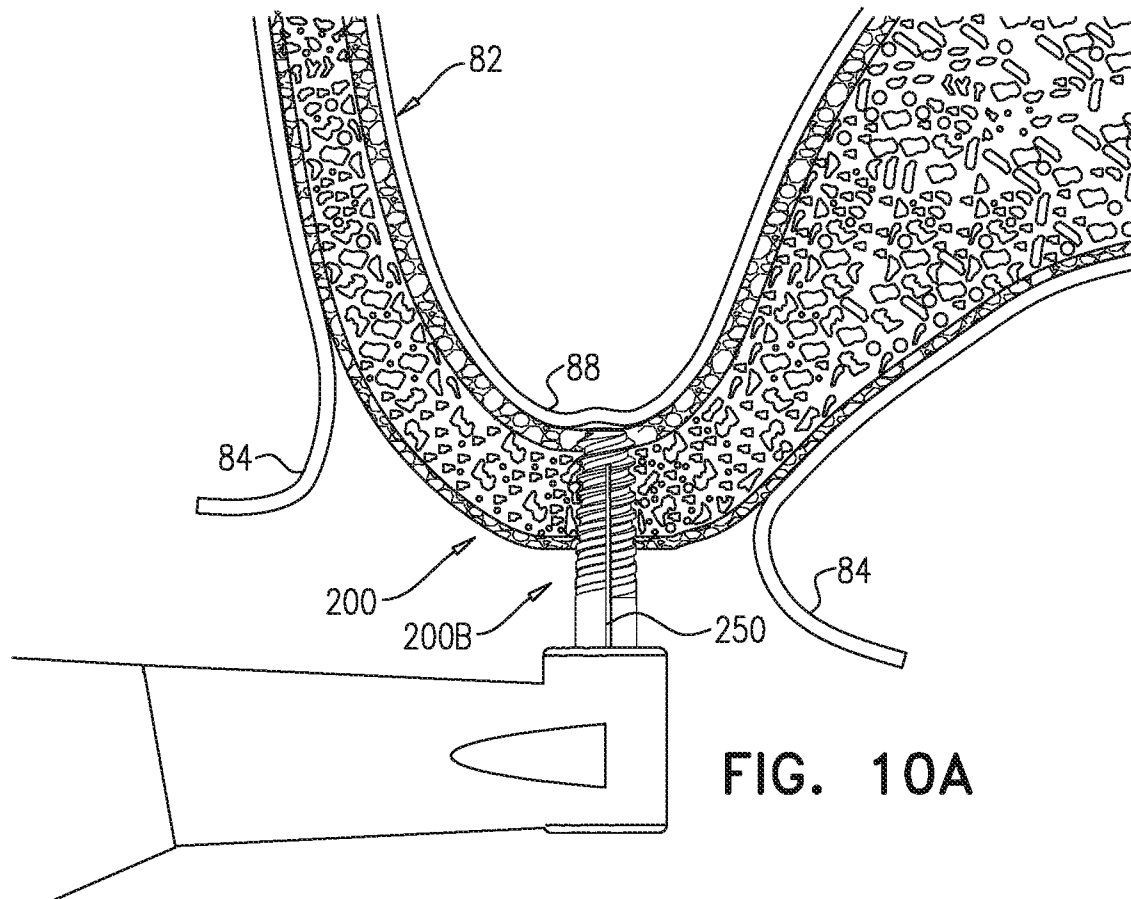
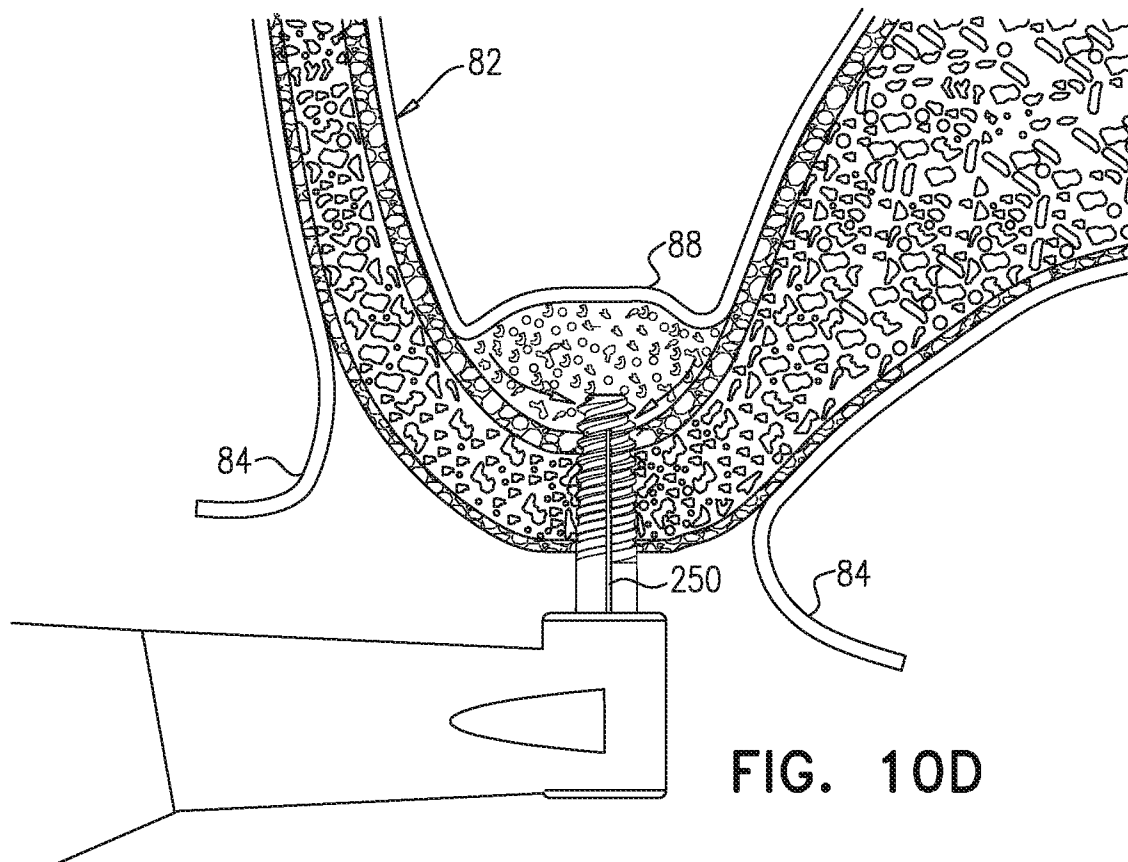
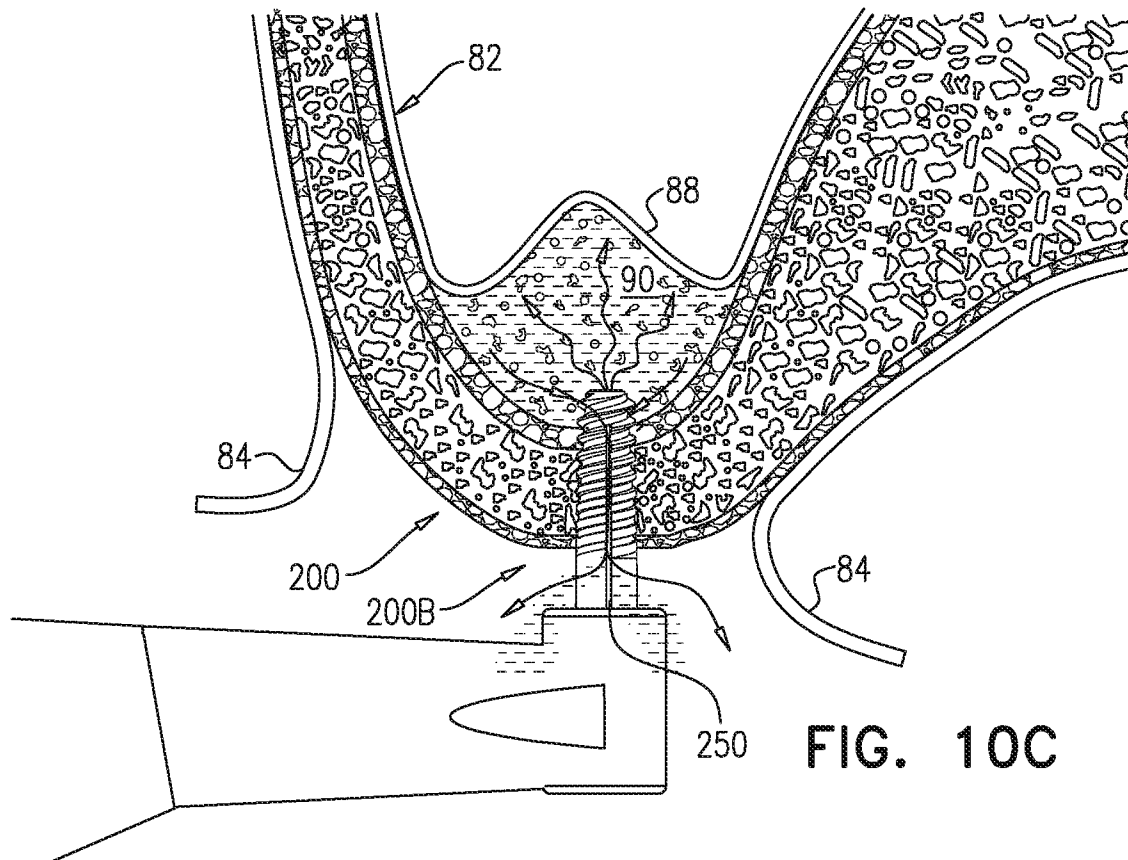


FIG. 9D

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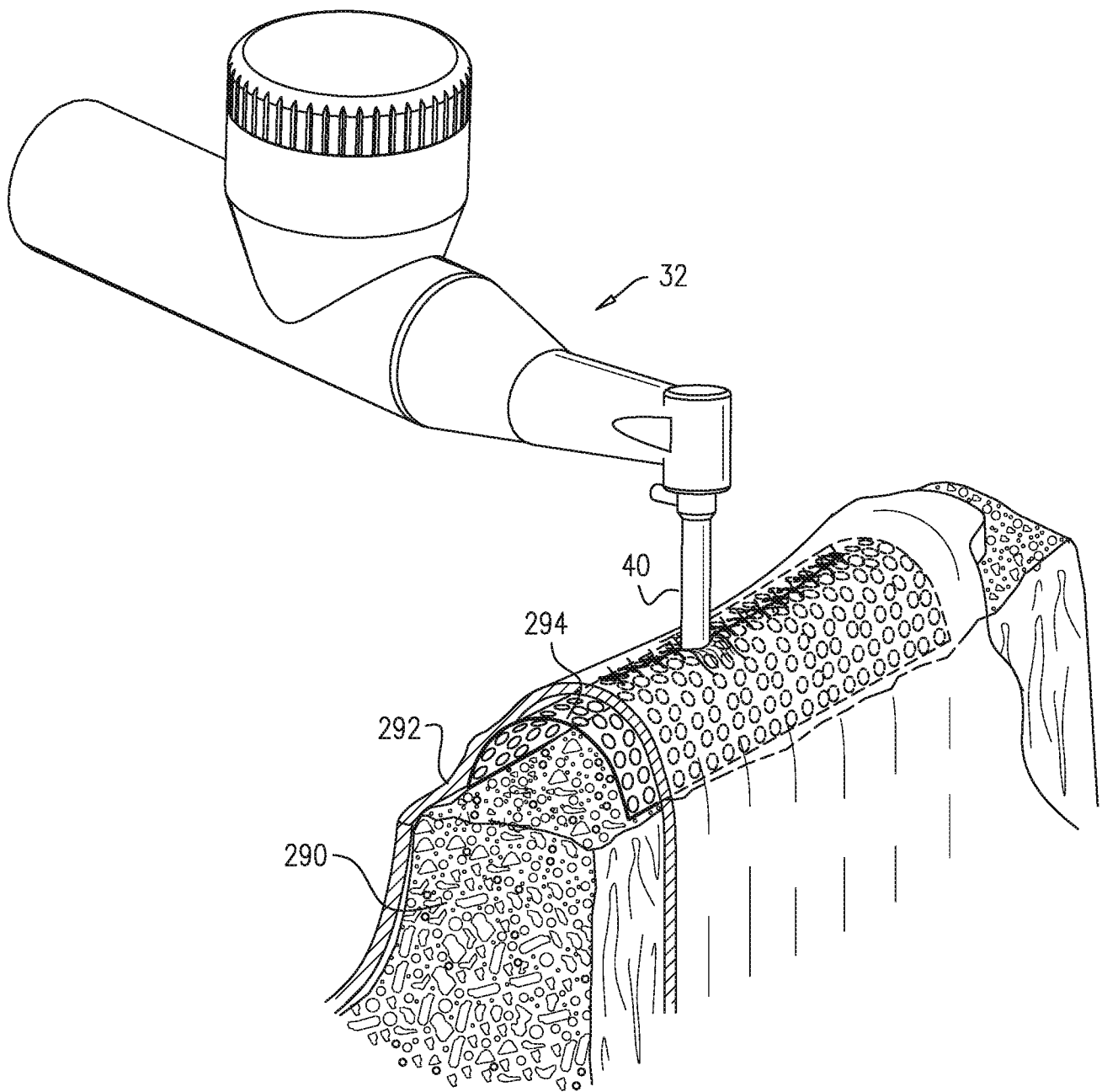


FIG. 11

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FIG. 12A

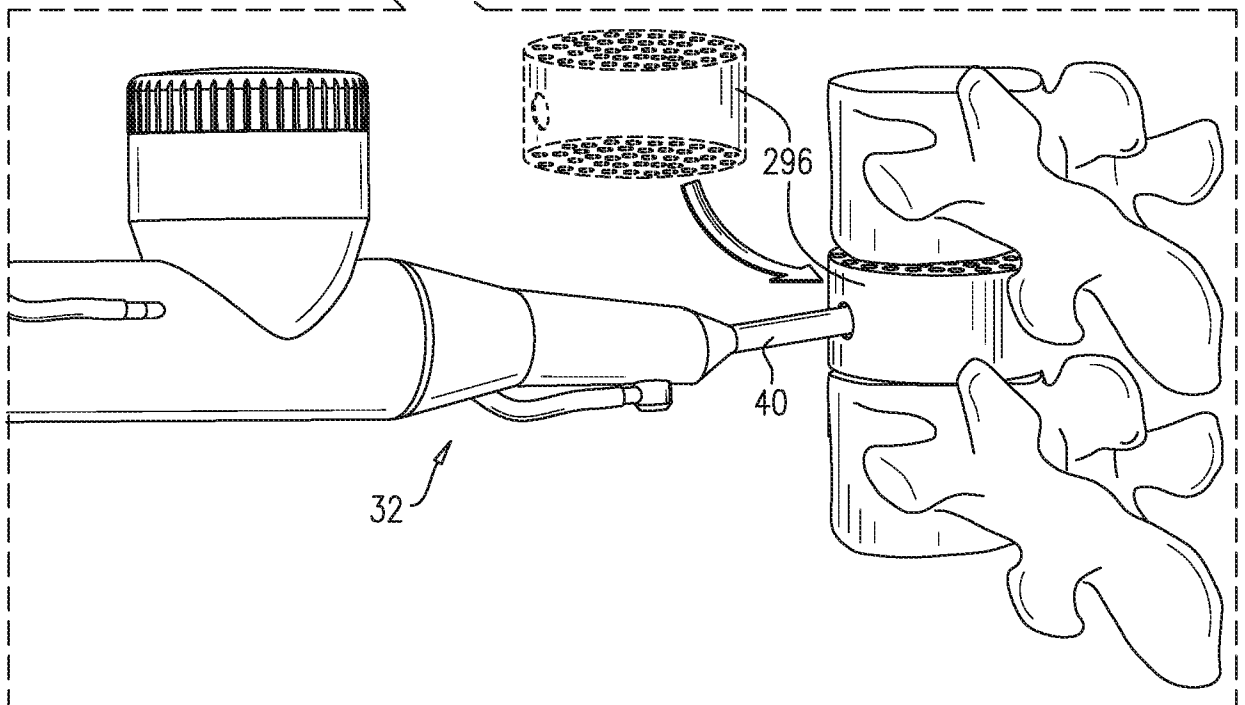
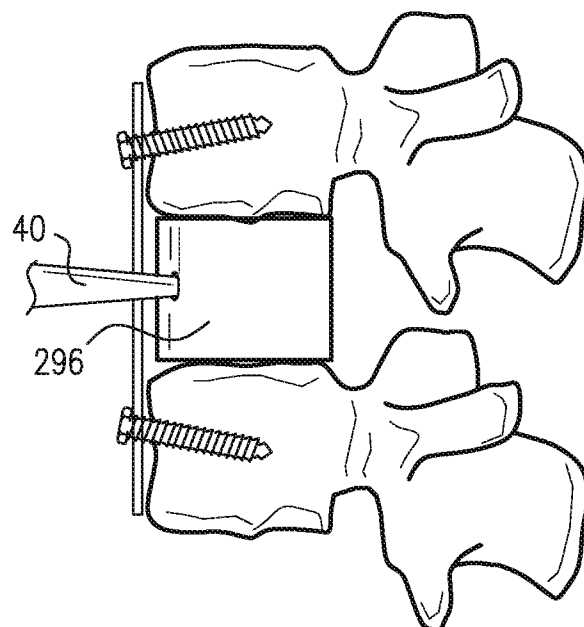
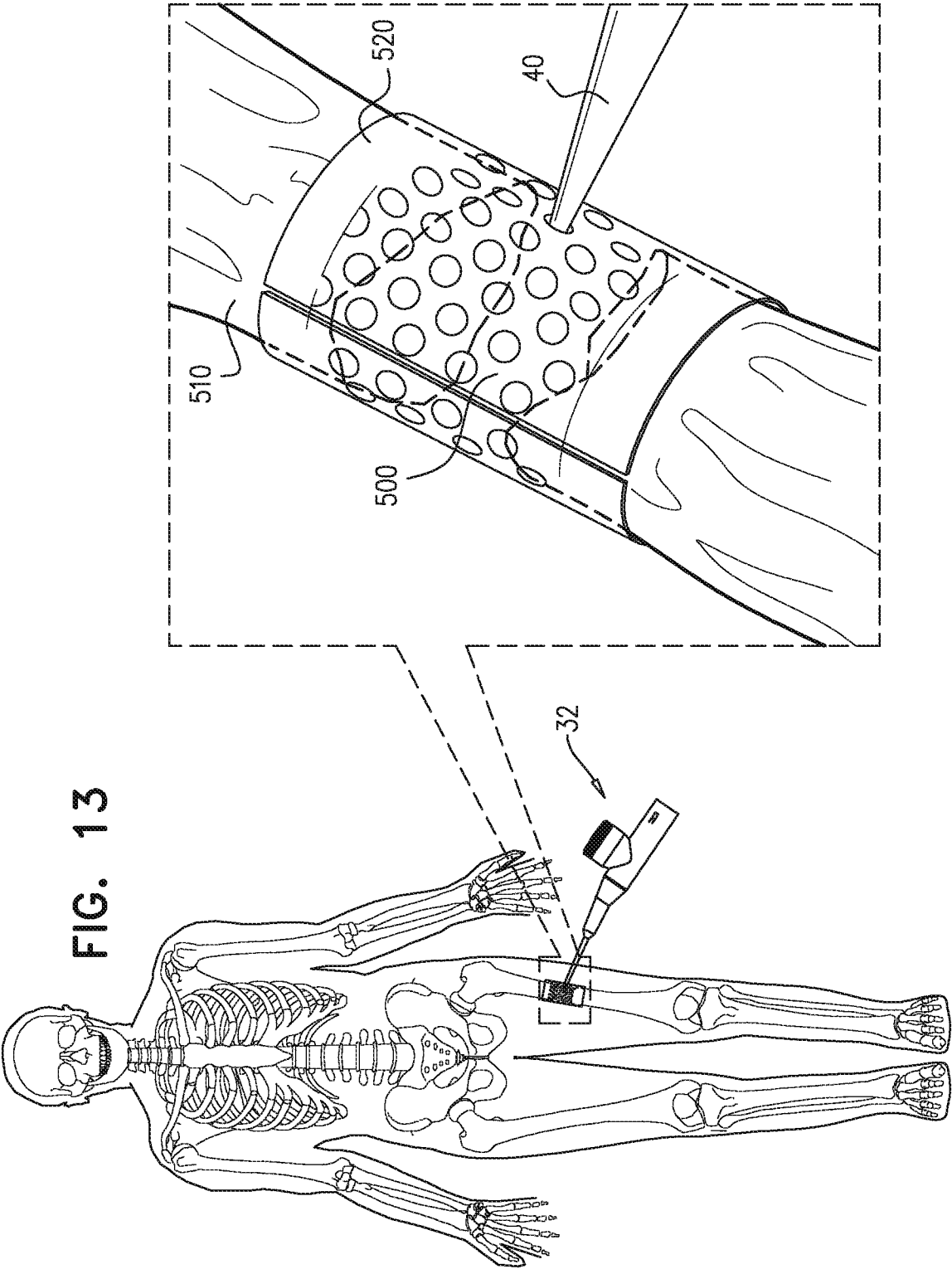
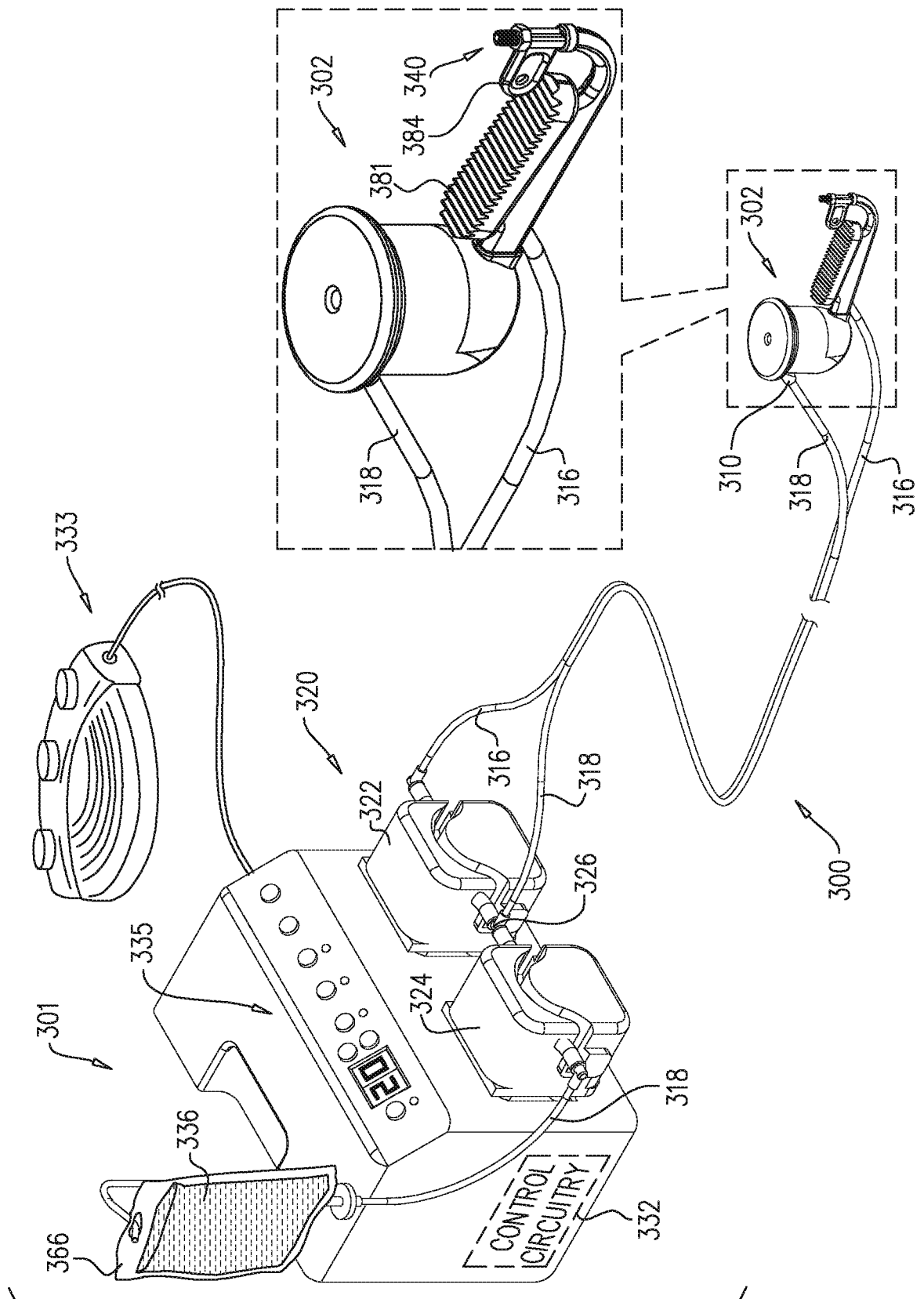
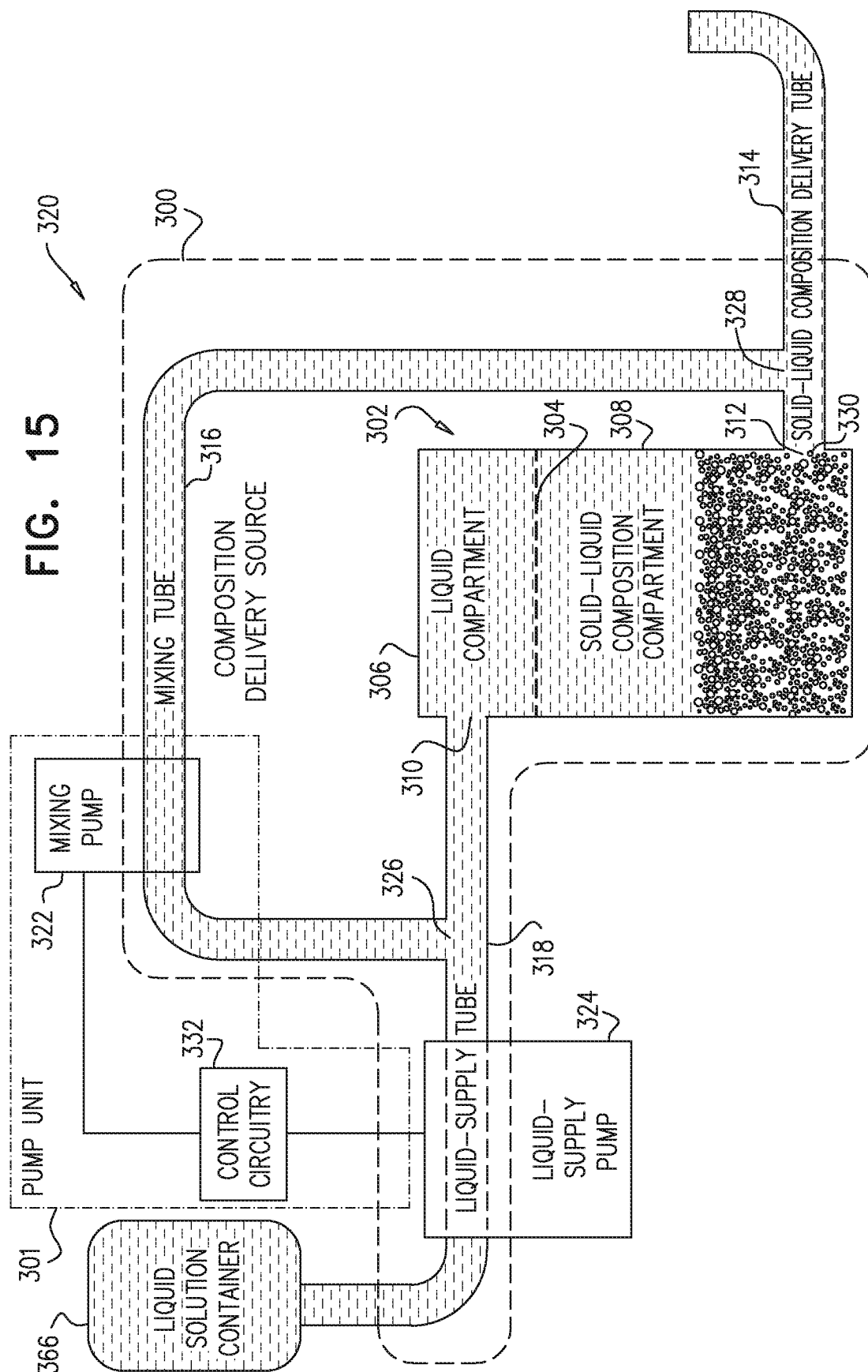


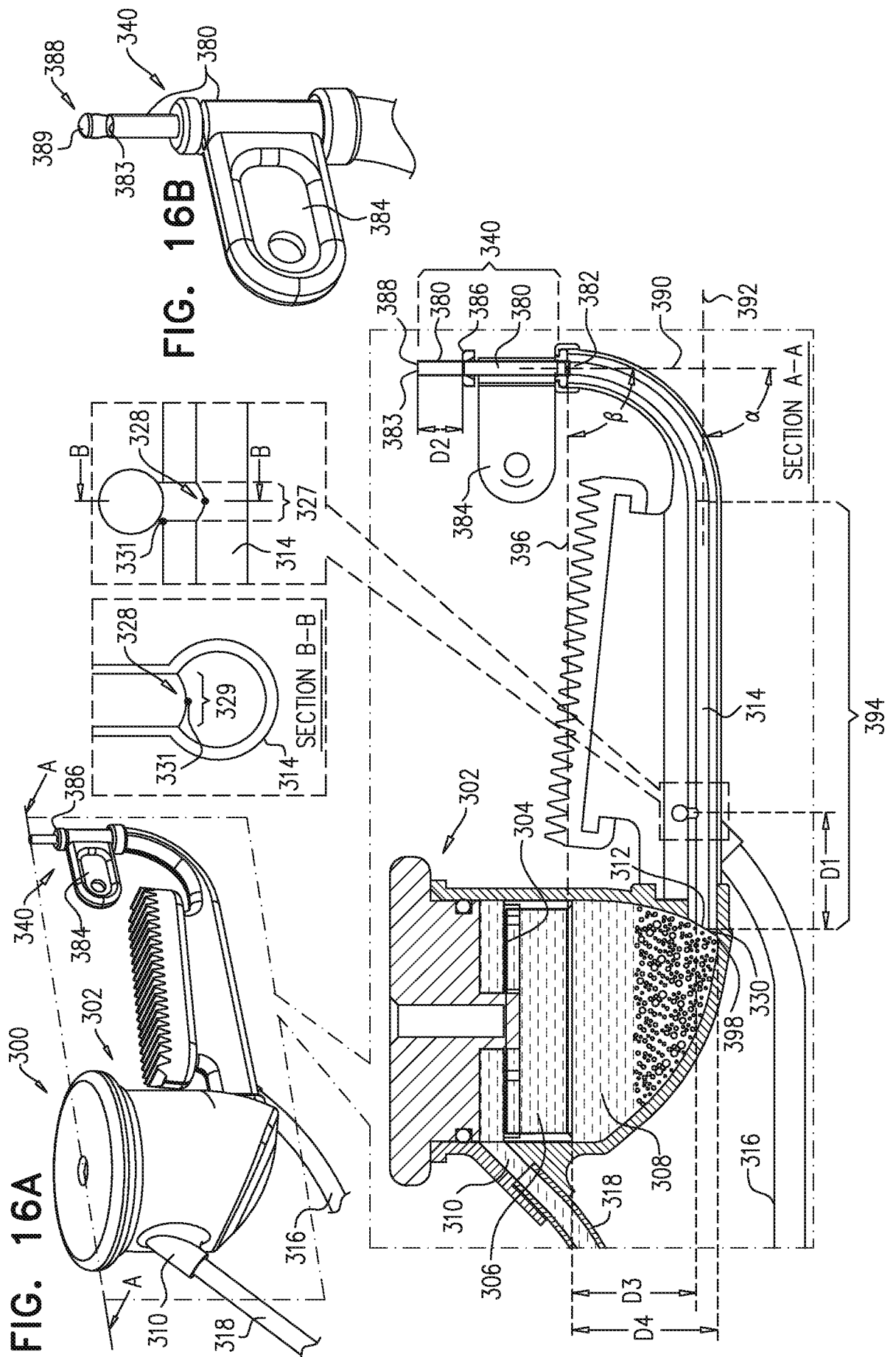
FIG. 12B





14. Gi





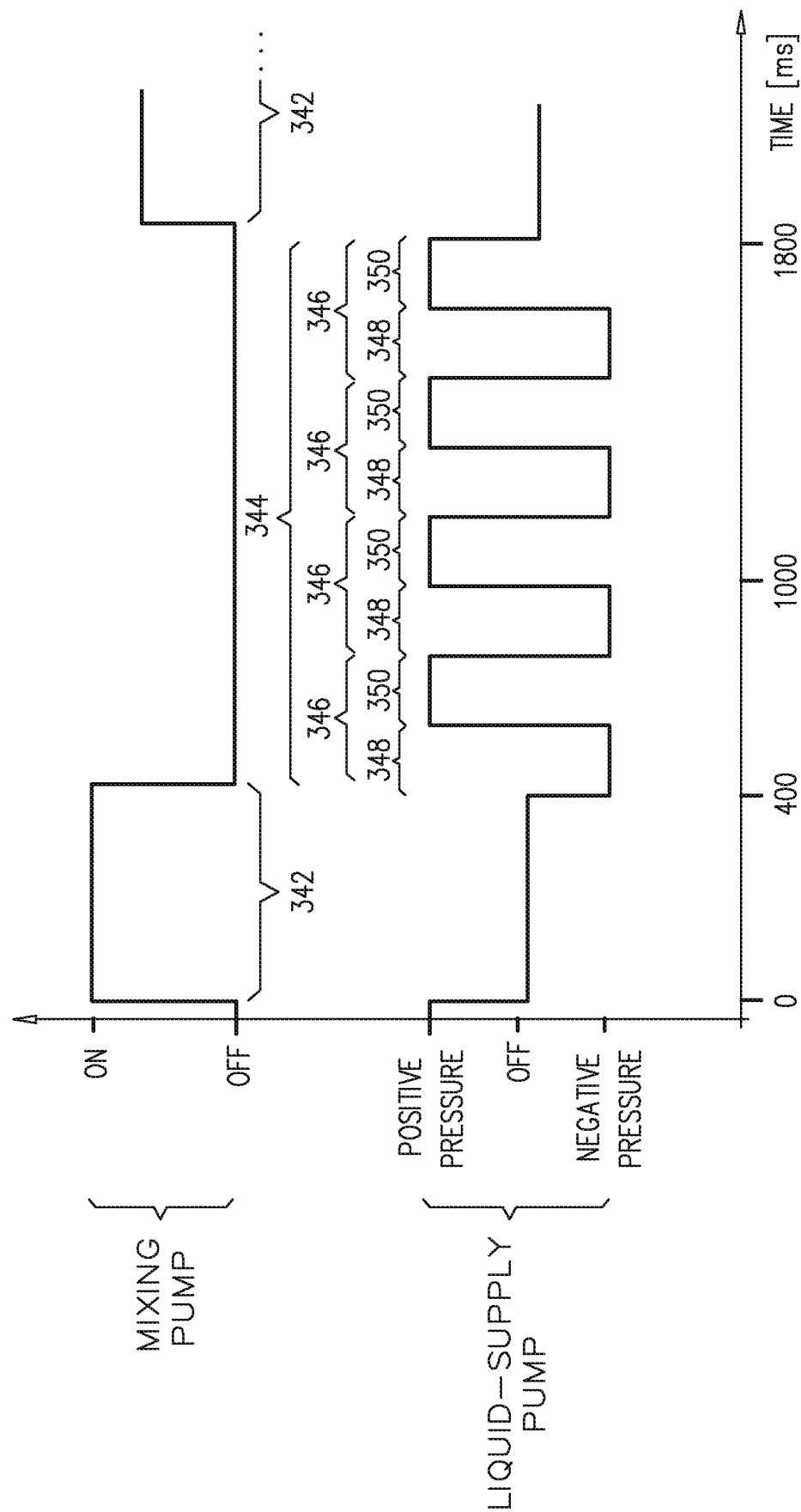
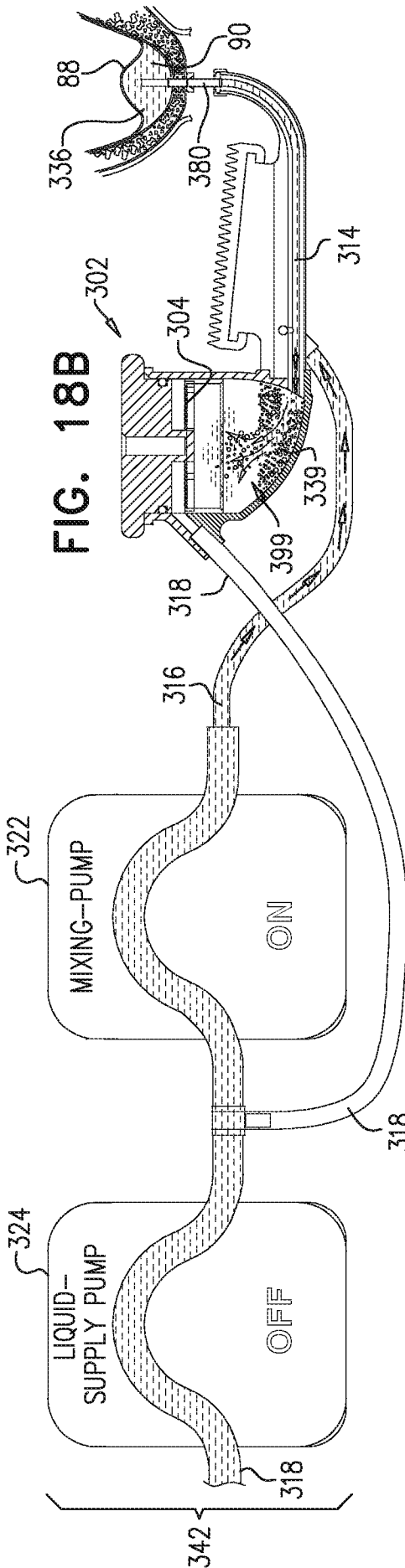
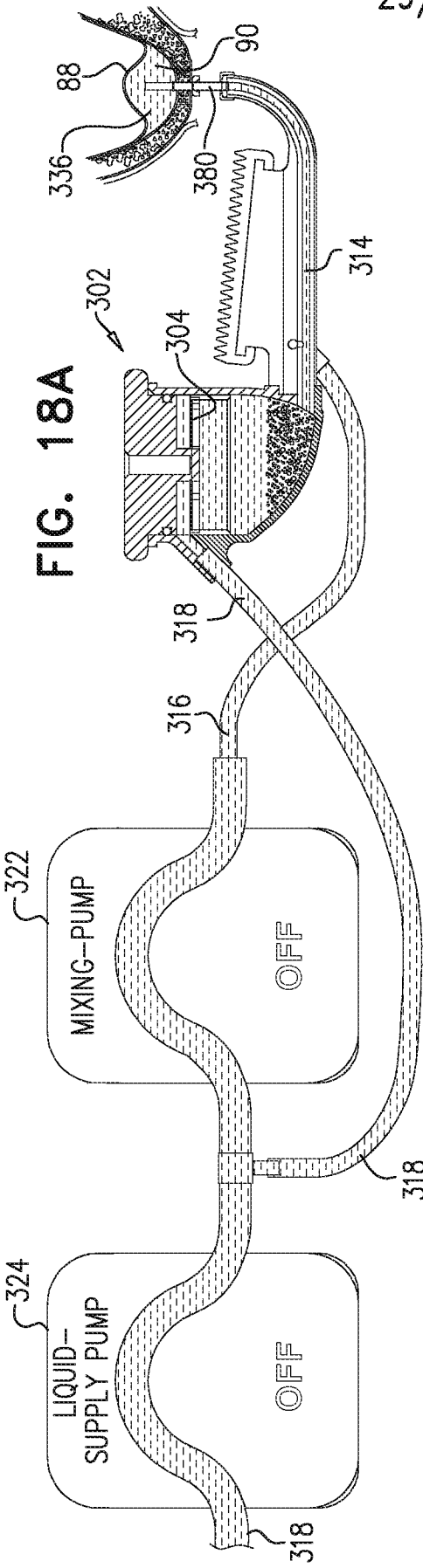
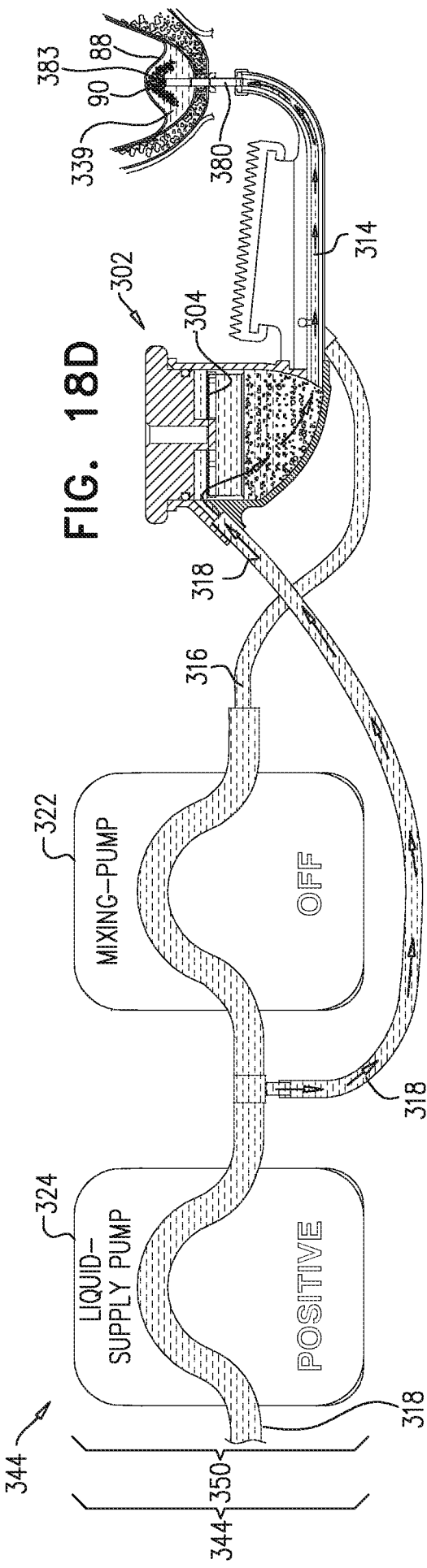
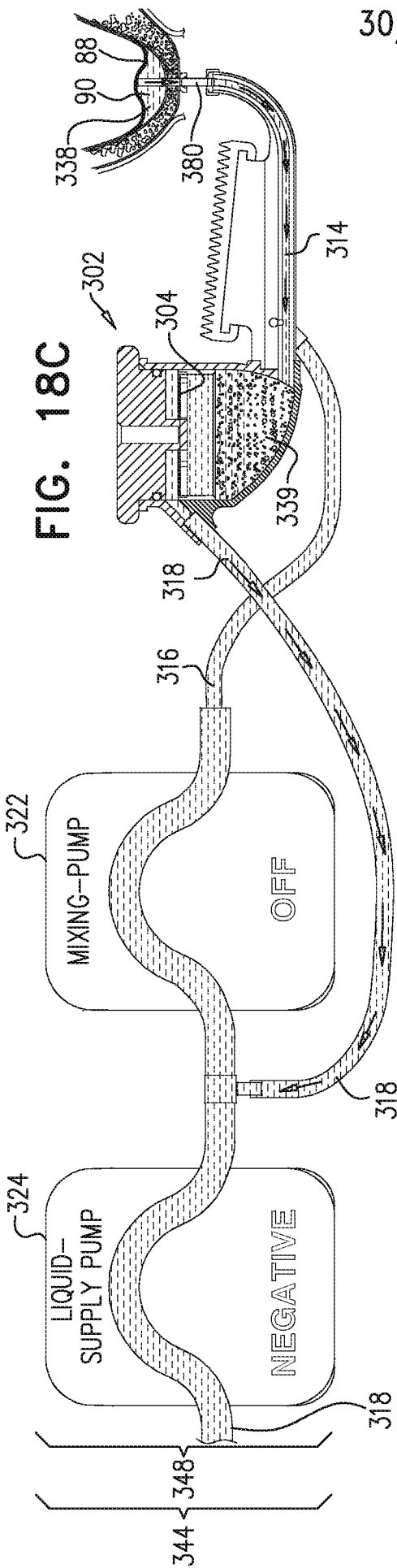
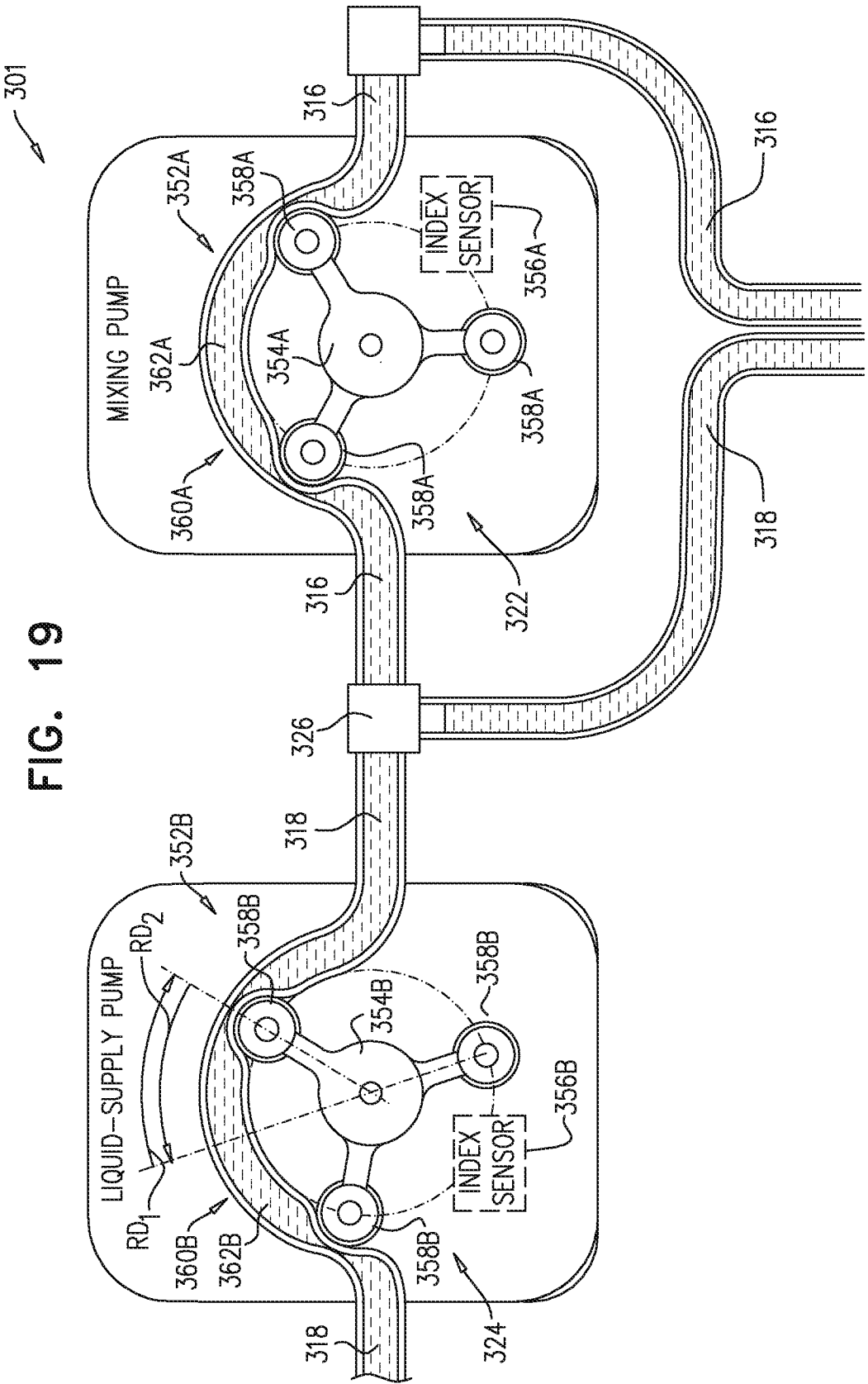


FIG. 17







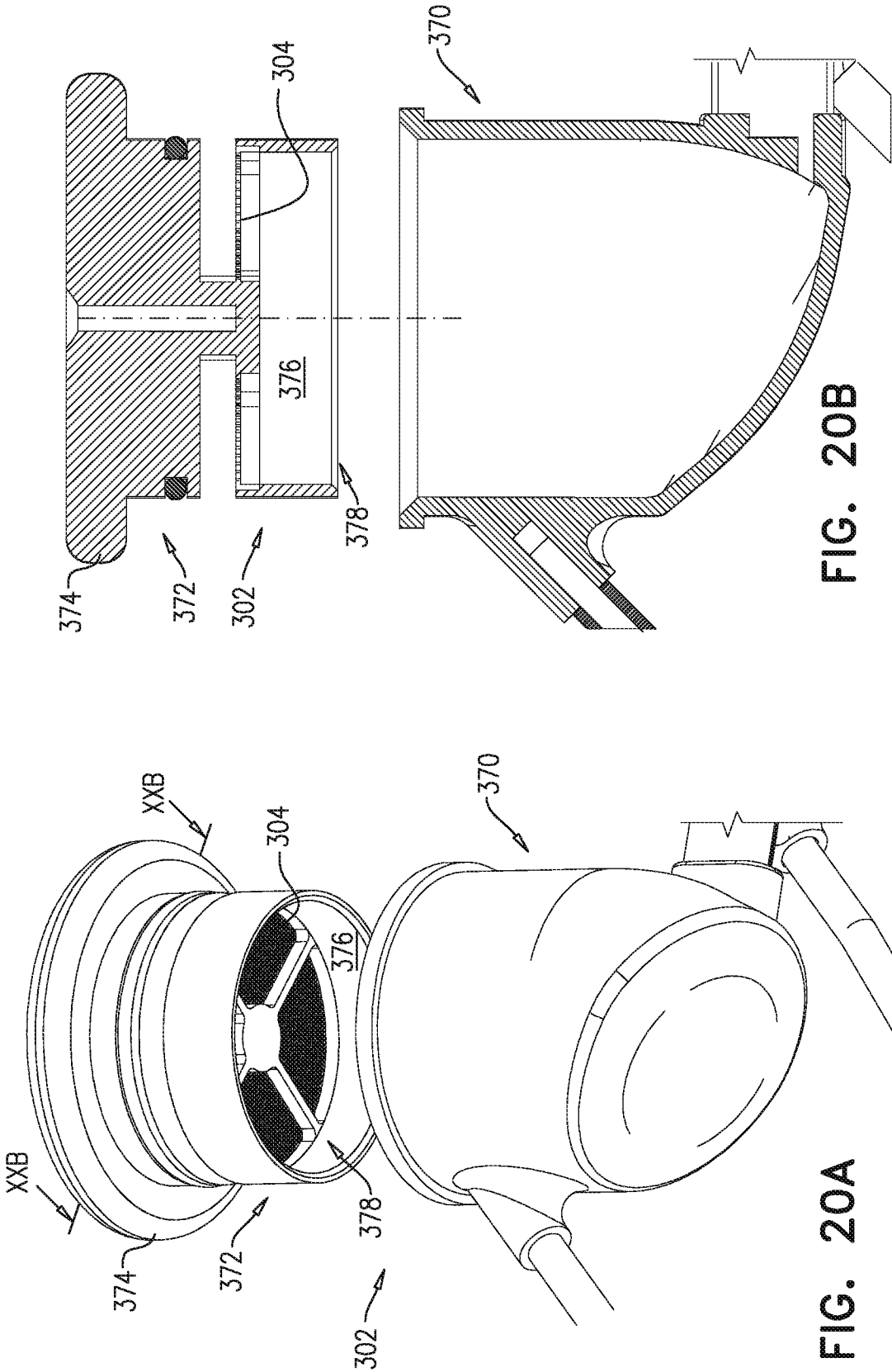


FIG. 20B

FIG. 20A

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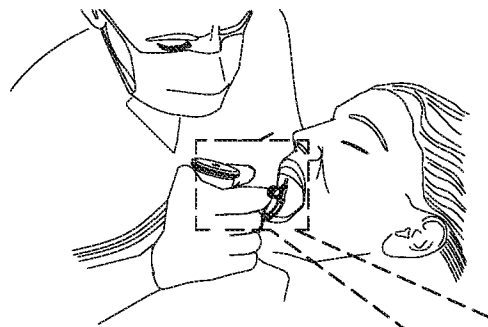


FIG. 21

