

**CLAIMS**

WE CLAIM:

1. A fluid mixing device for mixing a first injection fluid and a second injection fluid, the fluid mixing device comprising:
  - a first fluid inlet configured to conduct the first injection fluid in a first direction, the first fluid inlet having a first redirecting surface;
  - a second fluid inlet configured to conduct the second injection fluid in a second direction, the second fluid inlet having a second redirecting surface;
  - a mixing chamber in fluid communication with the first fluid inlet and the second fluid inlet and having a third redirecting surface, the mixing chamber configured to mix the first injection fluid and the second injection fluid; and
  - an outlet port in fluid communication with the mixing chamber and distal to the first fluid inlet and the second fluid inlet,wherein the first redirecting surface is configured to redirect the first injection fluid in a first different direction from the first direction to enter the mixing chamber along the first different direction, and the second redirecting surface is configured to redirect the second injection fluid in a second different direction from the second direction to enter the mixing chamber along the second different direction, wherein the first different direction and the second different direction are selected so that the first injection fluid and the second injection fluid contact the third redirecting surface of the mixing chamber to turbulently mix the first injection fluid and second injection fluid in the mixing chamber, and
  - wherein a mixture of the first injection fluid and the second injection fluid exits the fluid mixing device through the outlet port.
2. The fluid mixing device of claim 1, further comprising at least one of a first check valve in the first fluid inlet; and a second check valve in the second fluid inlet.
3. The fluid mixing device of claim 2, wherein the first fluid inlet and the second fluid inlet have a non-circular cross-sectional shape, and wherein the first check valve and the second check valve have a circular cross-sectional shape.
4. The fluid mixing device of any one of claims 1 to 3, wherein the first fluid inlet and the second fluid inlet have a first inlet port and a second inlet port, respectively, wherein the first redirecting surface and second redirecting surface are positioned distally relative to the first

inlet port and second inlet port, respectively, and wherein the third redirecting surface is positioned proximally relative to the outlet port, the first redirecting surface, and the second redirecting surface.

5. The fluid mixing device of any one of claims 1 to 4, wherein the mixing chamber further comprises a first inlet, wherein the first inlet of the mixing chamber is distal to the third redirecting surface, and wherein the first redirecting surface is positioned distal to the first fluid inlet and at least partially faces the first inlet to the mixing chamber.

6. The fluid mixing device of any one of claims 1 to 5, wherein the mixing chamber further comprises a second inlet, wherein the second inlet of the mixing chamber is distant to the third redirecting surface, and wherein the second redirecting surface is positioned distal to the second fluid inlet and at least partially faces the second inlet to the mixing chamber.

7. The fluid mixing device of any one of claims 1 to 6, wherein at least one of the first redirecting surface and the second redirecting surface is substantially concave and has a radius of curvature greater than or equal to  $90^\circ$ .

8. The fluid mixing device of any one of claims 1 to 6, wherein at least one of the first redirecting surface and the second redirecting surface is substantially concave and has a radius of curvature greater than or equal to  $150^\circ$ .

9. The fluid mixing device of any of claims 1 to 8, wherein the third redirecting surface has a substantially concave-shaped surface facing the outlet port.

10. The fluid mixing device of claim 9, wherein the concave-shaped surface has a radius of curvature of greater than or equal to  $90^\circ$ .

11. The fluid mixing device of claim 9, wherein the concave-shaped surface has a radius of curvature of greater than or equal to  $150^\circ$ .

12. The fluid mixing device of any one of claims 2 to 11, wherein the first check valve has a first end in engagement with a first inlet port on the first fluid inlet and a second end in engagement with a first stop element proximal to the first redirecting surface, wherein the

second check valve has a first end in engagement with a second inlet port on the second fluid inlet and a second end in engagement with a second stop element proximal to the second redirecting surface, and wherein the first check valve and the second check valve are reversibly compressible between the first end and the second end in response to first fluid pressure of the first injection fluid flowing through the first inlet port and a second fluid pressure of the second injection fluid flowing through the second fluid port, respectively.

13. The fluid mixing device of claim 12, wherein the first stop element and the second stop element have a pointed proximal end.

14. The fluid mixing device of claim any one of claims 1 to 13, wherein the first inlet port and the second inlet port have a tapered end surface.

15. The fluid mixing device of any one of claims 1 to 14, wherein the outlet port has an axis parallel to an axis of the first fluid inlet and an axis of the second fluid inlet.

16. The fluid mixing device of claim 15, wherein the axis of the outlet port extends between the axis of the first fluid inlet and the axis of the second fluid inlet.

17. The fluid mixing device of any one of claims 1 to 14, wherein an axis of the first fluid inlet is parallel to and offset from an axis of the second fluid inlet, and wherein the outlet port has an axis generally perpendicular to the axis of the first fluid inlet and the axis of the second fluid inlet.

18. The fluid mixing device of any one of claims 1 to 14, wherein an axis of the first fluid inlet is generally perpendicular to an axis of the second fluid inlet, and wherein the outlet port has an axis generally parallel and coincidental to one of the axis of the first fluid inlet and the axis of the second fluid inlet.

19. The fluid mixing device of any one of claims 1 to 14, wherein an axis of the first fluid inlet is at an angle of between  $130^{\circ}$  and  $165^{\circ}$  with respect to an axis of the second fluid inlet, and wherein the outlet port has an axis at an angle less than  $70^{\circ}$  with respect to one of the axis of the first fluid inlet and the axis of the second fluid inlet.

20. The fluid mixing device of any one of claims 1 to 19, wherein each of the first redirecting surface and the second redirecting surface are concave-shaped and face a direction of fluid flow of the first injection fluid in the first fluid inlet and the second injection fluid in the second fluid inlet, respectively.
21. The fluid mixing device of any one of claims 1 to 20, wherein at least one of the first fluid inlet, the second fluid inlet, and the outlet port has an at least partially helical-shaped rifling on at least a portion of an inner surface of the at least one of the first fluid inlet, the second fluid inlet, and the outlet port for creating a corresponding fluid vortex for at least one of the first injection fluid, the second injection fluid, and the mixture of the first injection fluid and the second injection fluid.
22. The fluid mixing device of any one of claims 1 to 21, wherein the outlet port has at least one baffle member or mixing member disposed in an inner surface thereof.
23. The fluid mixing device of any one of claims 1 to 22, wherein the outlet port further comprises a pressure isolation valve integrated therewith.
24. The fluid mixing device of claim 23, wherein the pressure isolation valve comprises a housing having a first lumen in fluid communication with the outlet port, a second lumen configured for connecting to a pressure transducer, and a valve member between the first lumen and the second lumen, wherein the valve member is configured for isolating the second lumen from the outlet port during a fluid injection procedure.
25. The fluid mixing device of any of claims 1 to 24, further comprising a connector element on an exterior or an interior of at least one of the first fluid inlet, the second fluid inlet, and the outlet port.
26. A fluid delivery tube set for delivering fluid from a fluid injector to a patient, the fluid delivery tube set comprising:
- a first inlet tube configured to deliver a first injection fluid;
  - a second inlet tube configured to deliver a second injection fluid;
  - an outlet tube configured to deliver a mixture of the first injection fluid and the second injection fluid to a patient; and

a fluid mixing device comprising:

a first fluid inlet coupled to the first inlet tube and configured to conduct the first injection fluid in a first direction, the first fluid inlet having a first redirecting surface;

a second fluid inlet coupled to the second inlet tube and configured to conduct the second injection fluid in second direction, the second fluid inlet having a second redirecting surface;

a mixing chamber in fluid communication with the first fluid inlet and the second fluid inlet and having a third redirecting surface, the mixing chamber configured to mix the first injection fluid and the second fluid; and

an outlet port coupled to the outlet tube and in fluid communication with the mixing chamber,

wherein the first redirecting surface is configured to redirect the first injection fluid in a first different direction from the first direction to enter the mixing chamber along the first different direction, and the second redirecting surface is configured to redirect the second injection fluid in a second different direction from the second direction to enter the mixing chamber along the second different direction, wherein the first different direction and the second different direction are selected so that the first injection fluid and the second injection fluid contact the third redirecting surface of the mixing chamber to turbulently mix the first injection fluid and second injection fluid together in the mixing chamber, and

wherein a mixture of the first injection fluid and the second injection fluid exits the fluid mixing device via the outlet port.

27. The fluid delivery tube set of claim 26, further comprising at least one of a first check valve in the first fluid inlet; and a second check valve in the second fluid inlet.

28. The fluid delivery tube set of claim 27, wherein the first fluid inlet and the second fluid inlet have a non-circular cross-sectional shape, and wherein the first check valve and the second check valve have a circular cross-sectional shape.

29. The fluid delivery tube set of any one of claims 26 to 28, wherein the first fluid inlet and the second fluid inlet have a first inlet port and a second inlet port, respectively, wherein the first redirecting surface and second redirecting surface are positioned distally relative to the first inlet port and second inlet port, respectively, and wherein the third redirecting surface is

positioned proximally relative to the outlet port, the first redirecting surface, and the second redirecting surface.

30. The fluid delivery tube set of any one of claims 26 to 29, wherein the mixing chamber further comprises a first inlet, wherein the first inlet of the mixing chamber is distal to the third redirecting surface, and wherein the first redirecting surface is positioned distal to the first fluid inlet and at least partially faces the first inlet to the mixing chamber.

31. The fluid delivery tube set of any one of claims 26 to 30, wherein the mixing chamber further comprises a second inlet, wherein the second inlet of the mixing chamber is distal to the third redirecting surface, and wherein the second redirecting surface is positioned distal to the second fluid inlet and at least partially faces the second inlet to the mixing chamber.

32. The fluid delivery tube set of any one of claims 26 to 31, wherein at least one of the first redirecting surface and the second redirecting surface is substantially concave and has a radius of curvature greater than or equal to  $90^\circ$ .

33. The fluid delivery tube set of any one of claims 26 to 31, wherein at least one of the first redirecting surface and the second redirecting surface is substantially concave and has a radius of curvature greater than or equal to  $150^\circ$ .

34. The fluid delivery tube set of any of claims 26 to 33, wherein the third redirecting surface has a substantially concave-shaped surface facing the outlet port.

35. The fluid delivery tube set of claim 34, wherein the concave-shaped surface has a radius of curvature of greater than or equal to  $90^\circ$ .

36. The fluid delivery tube set of claim 34, wherein the concave-shaped surface has a radius of curvature of greater than or equal to  $150^\circ$ .

37. The fluid delivery tube set of any of claims 26-36, wherein the first check valve has a first end in engagement with a first inlet port on the first fluid inlet and a second end in engagement with a first stop element proximal to the first redirecting surface, wherein the second check valve has a first end in engagement with a second inlet port on the second fluid

inlet and a second end in engagement with a second stop element proximal to the second redirecting surface, and wherein the first check valve and the second check valve are reversibly compressible between the first end and the second end in response to a first fluid pressure of the first injection fluid flowing through the first inlet port and a second fluid pressure of the second injection fluid flowing through the second fluid port, respectively.

38. The fluid delivery tube set of claim 37, wherein the first stop element and the second stop element have a pointed proximal end.

39. The fluid delivery tube set of any of claims 26 to 38, wherein the first inlet port and the second inlet port have a tapered end surface.

40. The fluid delivery tube set of any one of claims 26 to 39, wherein the outlet port has an axis parallel to an axis of the first fluid inlet and an axis of the second fluid inlet.

41. The fluid delivery tube set of claim 40, wherein the axis of the outlet port extends between the axis of the first fluid inlet and the axis of the second fluid inlet.

42. The fluid delivery tube set of any one of claims 26 to 39, wherein an axis of the first fluid inlet is parallel to and offset from an axis of the second fluid inlet, and wherein the outlet port has an axis generally perpendicular to the axis of the first fluid inlet and the axis of the second fluid inlet.

43. The fluid delivery tube set of any one of claims 26 to 39, wherein an axis of the first fluid inlet is generally perpendicular to an axis of the second fluid inlet, and wherein the outlet port has an axis generally parallel and coincidental to one of the axis of the first fluid inlet and the axis of the second fluid inlet.

44. The fluid delivery tube set of any one of claims 26 to 39, wherein an axis of the first fluid inlet is at an angle of between  $130^{\circ}$  and  $165^{\circ}$  with respect to an axis of the second fluid inlet, and wherein the outlet port has an axis at an angle less than  $70^{\circ}$  with respect to one of the axis of the first fluid inlet and the axis of the second fluid inlet.

45. The fluid delivery tube set of any one of claims 26 to 44, wherein each of the first redirecting surface and the second redirecting surface are concave-shaped and face a direction of fluid flow of the first injection fluid in the first fluid inlet and the second injection fluid in the second fluid inlet, respectively.

46. The fluid delivery tube set of any one of claims 26 to 45, wherein at least one of the first fluid inlet, the second fluid inlet, and the outlet port has an at least partially helical-shaped rifling on at least a portion of an inner surface of the at least one of the first fluid inlet, the second fluid inlet, and the outlet port for creating a corresponding fluid vortex for at least one of the first injection fluid, the second injection fluid, and the mixture of the first injection fluid and the second injection fluid.

47. The fluid delivery tube set of any one of claims 26 to 46, wherein the outlet port has at least one baffle member or mixing member disposed in an inner surface thereof.

48. The fluid delivery tube set of any one of claims 26 to 47, wherein the outlet port further comprises a pressure isolation valve integrated therewith.

49. The fluid delivery tube set of claim 48, wherein the pressure isolation valve comprises a housing having a first lumen in fluid communication with the outlet port, a second lumen configured for connecting to a pressure transducer, and a valve member between the first lumen and the second lumen, wherein the valve member is configured for isolating the second lumen from the outlet port during a fluid injection procedure.

50. The fluid delivery tube set of any of claims 26 to 49, further comprising a connector element on an exterior or an interior of at least one of the first fluid inlet, the second fluid inlet, and the outlet port.

51. A method for turbulently mixing a first injection fluid and a second injection fluid to form a substantially homogeneous mixture of the first injection fluid and the second injection fluid, the method comprising:

contacting a fluid flow of the first injection fluid with a first concave redirecting surface associated with a first fluid inlet;

redirecting the fluid flow of the first injection fluid to a first different direction, wherein the first different direction flows at an angle ranging from 90-175° from a fluid flow direction of the first injection fluid and towards a third concave redirecting surface in a mixing chamber;

contacting a fluid flow of the second injection fluid with a second concave redirecting surface associated with a second fluid inlet;

redirecting the fluid flow of the second injection fluid to a second different direction, wherein the second different direction flows at an angle ranging from 90-175° from a fluid flow direction of the second injection fluid and towards the third concave redirecting surface in the mixing chamber;

turbulently mixing the first injection fluid and the second injection fluid in the mixing chamber upon contact of the first injection fluid and the second injection fluid with the third concave redirecting surface to form a mixture of the first injection fluid and the second injection fluid; and

redirecting the mixture of the first injection fluid and the second injection fluid through an outlet port of the mixing chamber.

52. The method of claim 51, further comprising at least one of a first check valve in the first fluid inlet; and a second check valve in the second fluid inlet.

53. The method of claim 52, wherein the first fluid inlet and the second fluid inlet have a non-circular cross-sectional shape, and wherein the first check valve and the second check valve have a circular cross-sectional shape.

54. The method of any one of claims 51 to 53, wherein the first fluid inlet and the second fluid inlet have a first inlet port and a second inlet port, respectively, wherein the first redirecting surface and second redirecting surface are positioned distally relative to the first inlet port and second inlet port, respectively, and wherein the third redirecting surface is positioned proximally relative to the outlet port, the first redirecting surface, and the second redirecting surface.

55. The method of any one of claims 51 to 54, wherein the mixing chamber further comprises a first inlet, wherein the first inlet of the mixing chamber is distal to the third redirecting surface, and wherein the first redirecting surface is positioned distal to the first fluid inlet and at least partially faces the first inlet to the mixing chamber.

56. The method of any one of claims 51 to 55, wherein the mixing chamber further comprises a second inlet, wherein the second inlet of the mixing chamber is distal to the third redirecting surface, and wherein the second redirecting surface is positioned distal to the second fluid inlet and at least partially faces the second inlet to the mixing chamber.

57. The method of any one of claims 51 to 56, wherein at least one of the first redirecting surface and the second redirecting surface is substantially concave and has a radius of curvature greater than or equal to  $90^\circ$ .

58. The method of any one of claims 51 to 57, wherein at least one of the first redirecting surface and the second redirecting surface is substantially concave and has a radius of curvature greater than or equal to  $150^\circ$ .

59. The method of any of claims 51 to 58, wherein the third redirecting surface has a substantially concave-shaped surface facing the outlet port.

60. The method of claim 59, wherein the concave-shaped surface has a radius of curvature of greater than or equal to  $90^\circ$ .

61. The method of claim 59, wherein the concave-shaped surface has a radius of curvature of greater than or equal to  $150^\circ$ .

62. The method of any of claims 51 to 61, wherein the first check valve has a first end in engagement with a first inlet port on the first fluid inlet and a second end in engagement with a first stop element proximal to the first redirecting surface, wherein the second check valve has a first end in engagement with a second inlet port on the second fluid inlet and a second end in engagement with a second stop element proximal to the second redirecting surface, and wherein the first check valve and the second check valve are reversibly compressible between the first end and the second end in response to a first fluid pressure of the first injection fluid flowing through the first inlet port and a second fluid pressure of the second injection fluid flowing through the second fluid port, respectively.

63. The method of claim 62, wherein the first stop element and the second stop element have a pointed proximal end.
64. The method of any of claims 51 to 63, wherein the first inlet port and the second inlet port have a tapered end surface.
65. The method of any one of claims 51 to 64, wherein the outlet port has an axis parallel to an axis of the first fluid inlet and an axis of the second fluid inlet.
66. The method of claim 65, wherein the axis of the outlet port extends between the axis of the first fluid inlet and the axis of the second fluid inlet.
67. The method of any one of claims 51 to 64, wherein an axis of the first fluid inlet is parallel to and offset from an axis of the second fluid inlet, and wherein the outlet port has an axis generally perpendicular to the axis of the first fluid inlet and the axis of the second fluid inlet.
68. The method of any one of claims 51 to 64, wherein an axis of the first fluid inlet is generally perpendicular to an axis of the second fluid inlet, and wherein the outlet port has an axis generally parallel and coincidental to one of the axis of the first fluid inlet and the axis of the second fluid inlet.
69. The method of any one of claims 51 to 64, wherein an axis of the first fluid inlet is at an angle of between  $130^{\circ}$  and  $165^{\circ}$  with respect to an axis of the second fluid inlet, and wherein the outlet port has an axis at an angle less than  $70^{\circ}$  with respect to one of the axis of the first fluid inlet and the axis of the second fluid inlet.
70. The method of any one of claims 51 to 69, wherein each of the first redirecting surface and the second redirecting surface are concave-shaped and face a direction of fluid flow of the first injection fluid in the first fluid inlet and the second injection fluid in the second fluid inlet, respectively.
71. The method of any one of claims 51 to 70, wherein at least one of the first fluid inlet, the second fluid inlet, and the outlet port has an at least partially helical-shaped rifling on at

least a portion of an inner surface of the at least one of the first fluid inlet, the second fluid inlet, and the outlet port for creating a corresponding fluid vortex for at least one of the first injection fluid, the second injection fluid, and the mixture of the first injection fluid and the second injection fluid.

72. The method of any one of claims 51 to 71, wherein the outlet port has at least one baffle member or mixing member disposed in an inner surface thereof.

73. The method of any one of claims 51 to 72, wherein the outlet port further comprises a pressure isolation valve integrated therewith.

74. The method of claim 73, wherein the pressure isolation valve comprises a housing having a first lumen in fluid communication with the outlet port, a second lumen configured for connecting to a pressure transducer, and a valve member between the first lumen and the second lumen, wherein the valve member is configured for isolating the second lumen from the outlet port during a fluid injection procedure.

75. The method of any of claims 51 to 74, further comprising a connector element on an exterior or an interior of at least one of the first fluid inlet, the second fluid inlet, and the outlet port.