nerve distance and relationship respective to the layers of a specific fascicle, nerve and/or plexus. Nonetheless, an EMR at a very low current has been found to be highly specific of intra-neural location of the needle tip.

[0010] Injection pressure monitoring (IPM) is highly sensitive to detect a peak pressure as soon as the needle tip encounters a dense connective tissue. However, IPM is not specific of the nature of the dense connective tissue. A low-pressure range is specific of a low-density tissue loose connective tissue such as fat, interstitium, or muscle. A high-pressure range is specific of a dense connective tissue (fascia, tendon, nerve…) but a pressure signature is not highly specific of the tissue type. For instance, a tendon and a nerve have similar aspect on an ultrasound image. Indenting the surface layer of the tendon and the nerve may produce similar high peak pressure. Similarly, IPM cannot differentiate paraneural from extra-neural interstitium.

Tissue density	Dense	Intermediate	Loose
Evoked motor response to NS	Perineurium Outer epineurium	Inner epineurium	paraneurium
no motor response	Tendon Muscle fascia	Intermuscular fascial plane	Subcutaneous fat Intermuscular, perivascular interstitium

Summary of the Invention

[0010a] According to a first aspect of the present invention, there is provided a system for providing a peripheral nerve block to a patient, comprising:

a needle having a sharpened tip;

a fluid pump providing a flow of fluid to the needle,

a controller for controlling the fluid pump to control the flow of fluid to the needle;

a sensor for detecting the fluid pressure in the needle; and

a conductive element for providing an electric nerve stimulation at the tip of the needle;

wherein the controller is configured to provide varying electrical stimulation in response to the sensor detecting a fluid pressure above a first threshold.

[0010b] According to a second aspect of the present invention, there is provided an apparatus for injecting medicinal fluid, comprising:

an injection system for controlling a flow of fluid from a fluid reservoir to a needle, wherein the needle is configured for subcutaneous insertion into a mammalian subject;

a sensor for detecting a characteristic indicative of the fluid pressure in the needle, wherein the sensor is configured to continuously detect the characteristic as the needle is inserted into the subject; and

an electric nerve stimulation element for providing an electric nerve stimulation at or adjacent to a tip of the needle;

wherein the electric nerve stimulation element varies the intensity of the electric nerve stimulation to a patient after the sensor detects a characteristic of the fluid pressure indicative of the fluid pressure exceeding a first threshold.

[0010c] According to a third aspect of the present invention, there is a system for injection fluid into a patient, comprising:

a needle having a sharpened tip;

a fluid pump providing a flow of fluid to the needle,

a controller for controlling the fluid pump to control the flow of fluid to the needle;

a sensor for detecting the fluid pressure in the needle; and

a conductive element for providing an electric nerve stimulation at the tip of the needle;

wherein the controller is configured to control the fluid pump to provide a dose of fluid in response to a signal from the sensor indicative of a pressure exceeding a threshold and the absence of a signal indicative of an electric motor response in response to electric nerve stimulation when the electric nerve stimulation exceeds a threshold intensity.

[0011] Ultrasonography allows simultaneous visualization of the target nerve, needle, local anesthetic solution and surrounding anatomical structures. Nevertheless, ultrasonography as a sole method of monitoring may not reliably prevent neurologic injury. Nerve stimulation has low sensitivity to differentiate relative needle tip position to the nerve layers but is highly specific of neural tissue nearness. Injection pressure

monitoring is sensitive for detecting high injection pressure in dense tissues such as needle-nerve contact or intra-fascicular injection. Embodiments of the present invention provide combines these monitoring options in a multimodal approach, to decrease the risk of neurologic complications when performing PNBs.

[0012] Embodiments of the present invention combine IPM sensibility and NS specificity to differentiate different needle tip locations during peripheral nerve blockade, to detect nerve puncture and to help avoid intra-neural injection. The IP can be continuously monitored during the procedure of needle guidance to the nerve, so that when the pressure exceeds a threshold the electric stimulation is increased. The lack or occurrence of EMR indicates the absence or presence of the nerve at the needle tip, respectively. The occurrence of a pressure peak and a low intensity at EMR indicates the vicinity of the nerve. A pressure peak and very low intensity stimulation with an associated EMR indicates a nerve puncture or intra-neural needle tip location.

[0013] Embodiments of the present invention provide a mechanism to assist with nerve detection, decrease the occurrence of intra-neural injections and avoid injection in a dense connective tissue close to or particularly into the fascicles. Embodiments of the present invention enable one to use pressure sensing to differentiate between dense (low compliance) tissues such as neural (neural fascicle) versus connective tissues (muscle fascia).

[0014] There is disclosed a system in which continuous infusion of fluid medium at a fixed flow-rate is provided so that the hydraulic pressure can be precisely measured by an in-line pressure sensor. The ionic properties of fluid medium influence the transmission of an electrical current charge thru the tissues. The solution injected can be ionized (saline or local anesthetic) or non-ionized (dextrose in water). The solution may be dispensed through a disposable syringe and tubing in a uniform way to the tip of the needle for the purpose of nerve stimulation conduction. An ionic solution decreases the impedance so that electrical current charge can more effectively be dispersed through the tissues; the voltage is less for the same current intensity (Ohm’s law) so that the stimulating current is less painful and the electric field reduced.

[0015] There is disclosed a system that provides an ability to enhance ultrasound visualization at the injection site by providing an increased fluid flow rate at appropriate needle tip location. The increased fluid flow allows the tip of the needle to be more easily identified during the advancement of a needle through tissues when performing a peripheral nerve block, thus aiding in the prevention of needle tip placement, particularly into the nerve.

[0016] There is also disclosed controlling the electrical stimulation based on signals received regarding fluid pressure in the needle.

Brief Description of the Drawings

[0017] The foregoing summary and the following detailed description of the preferred embodiments of the present invention will be best understood when read in conjunction with the appended drawings, in which:

[0018] Fig. 1 is a cross-section view of a fascicle of nerve fibers;

[0019] Fig. 2 is a perspective view of a drug delivery system;

[0020] Fig. 3 is an enlarged side view of a handpiece of the drug delivery system illustrated in Fig. 2;

[0021] Fig. 4 is a diagrammatic view of an injection device of the drug delivery system illustrated in Fig. 2;

[0022] Fig. 5 is a flow chart of a method for injecting fluid;

[0023] Fig. 6 is a diagrammatic view of an alternate embodiment of a drug delivery system;

[0024] Fig. 7 is a diagrammatic view of a target nerve; and

[0025] Fig. 8 is a flow chart of an alternate method for injecting fluid.