Title: DEEP BRAIN NEURAL PROSTHETIC SYSTEM

Abstract: Devices and systems for providing electrical and chemical treatments to the brain are disclosed. The deep brain stimulation devices and methods include implantable devices having various microelectrode configurations and drug delivery mechanisms. The devices can be used to treat a variety of neurological conditions.
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
DEEP BRAIN NEURAL PROSTHETIC SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

[0001] This Application is related to and claims the benefit of the filing date of U.S. Provisional Patent Application Serial No. 60/698,314, filed July 12, 2005, entitled "Deep Brain Neural Prosthetic System," attorney docket no. 64693-137, the contents of which are incorporated herein by reference. This Application is also related to co-pending U.S. Patent Application Serial No. 11/XXX,XXX, which is being filed contemporaneously on July 12, 2006, entitled "Probe for Identifying Injection Site for Deep Brain Neural Prostheses," inventor Gerald E. Loeb, attorney docket no. 64693-167, the contents of which are also incorporated herein by reference.

BACKGROUND

[0002] 1. Field: This application relates generally to devices and systems for providing electrical and chemical treatments to the brain.

[0003] 2. Description of Related Art: Deep brain stimulation has become well-accepted clinically and successful commercially for the treatment of various symptoms of Parkinson’s disease. It is usually prescribed after systemic pharmacological treatment to restore dopamine levels becomes ineffective or unacceptable because of side effects. Its use is expanding into related motor disorders arising from dysfunction of the basal ganglia. Potential applications include a wide range of clinical neuroses such as depression, obsessive-compulsive disorder, obesity, and other addictive disorders.

[0004] One limitation of deep brain stimulation has been the complexity of chemical and electrical circuitry in the basal ganglia (BG), a small structure (~2-3 cm egg) located deep in the midbrain. Both stereotaxic and neurophysiological recording techniques are currently used to insert a four contact electrode into the BG on one or both brain hemispheres. Stimulation of the wrong site can produce poor results, including severe side effects. Penetration required to identify the correct target can produce neural damage along the track and risks extensive damage from bleeding. Continuous stimulation appears to disrupt rather than to repair pathological activity, which is likely to cause its own functional deficits, perhaps related to learning new skills. Local administration of dopamine within the BG could avoid many of the side effects.
effects of systemic administration and could potentiate the therapeutic effects of electrical stimulation, perhaps improving outcomes and prolonging the period of time for which progressively degenerative BG diseases can be successfully treated.

SUMMARY

[0005] This application presents neural prosthetic systems for deep brain stimulation that can be directed more specifically, programmed more flexibly, used for a longer period of time and integrated with various chemical therapies.

[0006] It is understood that other embodiments of the devices and methods will become readily apparent to those skilled in the art from the following detailed description, wherein it is shown and described only exemplary embodiments of the devices, methods and systems by way of illustration. As will be realized, the devices, systems and systems are capable of other and different embodiments and its several details are capable of modification in various other respects, all without departing from the spirit and scope of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Aspects of the neural prosthetic devices and systems are illustrated by way of example, and not by way of limitation, in the accompanying drawings, wherein:

[0008] FIG. 1 is a side cross-sectional illustration of an exemplary deep brain neural prosthetic system; and

[0009] FIG. 2 is a schematic illustration an exemplary deep brain neural prosthetic system.

DETAILED DESCRIPTION

[0010] The detailed description set forth below in connection with the appended drawings is intended as a description of exemplary embodiments and is not intended to represent the only embodiments in which the deep brain stimulation devices, methods and systems can be practiced. The term "exemplary" used throughout this description means "serving as an example, instance, or illustration," and should not necessarily be construed as preferred or advantageous over other embodiments. The detailed description includes specific details for the purpose of providing a
thorough understanding of the deep brain stimulation devices, methods and systems. However, it will be apparent to those skilled in the art that the deep brain stimulation devices, methods and systems may be practiced without these specific details.


[0012] The device includes a thin electrode array (about 1-2 mm diameter) with 4-8 contacts on 1-2 mm centers plus a central lumen for drug infusion from a fully implanted pump with refillable reservoir. A single electronics and pump module with connections to two electrode arrays could be small enough to locate under the scalp. Figure 1 provides a mechanical cross-section showing all major components. Figure 2 provides a functional block diagram of the chronically implanted system.

[0013] Figure 1 shows a probe 60 with two microelectrodes within a hollow guide tube 66, a fixed, straight microelectrode 70 that advances with the probe 60, and a curved, lateral microelectrode 75 that can be independently moved by advancer 64 so as to extend laterally on an arc away from the central track. The direction of the extension can depend on axial rotation of the probe 60 in the guide tube 66. Both electrodes may be made of pure iridium metal with laser-exposed insulation composed of any of the polymers of polyparaxylylene (commonly trademarked as
Parylene), as described in U.S. Patent No. 5,524,338, incorporated herein by reference. This combination of materials can be used safely to apply stimuli at therapeutic levels without degrading their single unit recording capabilities. These materials also have the requisite springiness, elasticity, and durability to survive multiple cycles of straightening when the curved lateral microelectrode 75 is pulled into the lumen of the guide tube 66, followed by reforming of curvature when extended from the guide tube 66.

[0014] Referring also to Figure 2, the electrode contacts 42 that make up the interface region 40 of the implanted array 30 can be made from thin-wall rings of sintered Ta stacked with polymeric spacing rings to form a relatively rigid distal segment with a hollow core through which the Ta leads and drug infusion can pass. The central core may be built around a thin-walled flexible tubing such as polyimide (not illustrated), with laser-drilled perforations at the levels of the electrode contacts 42 to permit egress of the drug being infused via pump 154. The proximal part of the shaft and leads functions as a cable 34, which may be made of silicone elastomer molded around a multifilar spiral for the electrode leads with a central hollow core. This core may accommodate a stiffening stylus during implantation, which can be removed to leave the lumen for drug infusion. The drug passes through and may be diffused by the sintered Ta electrode contacts 42, which can be a sponge-like structure with continuous pores that are too fine to be clogged by connective tissue, typically 5 µ or less pore size. By making both the leads 32 and electrode contacts 42 from pure tantalum metal, they may be anodized to provide an integral insulation and capacitive coupling for the stimulation. Such electrode materials also provide frequency response down to the 2Hz low-cutoff of the evoked potentials that may be detected by recording function 134 from one or more electrode contacts 42 selected by switching matrix 136. An all-tantalum electrode and lead system that can be used is described in U.S. Patent No. 5,833,714, which is incorporated herein by reference. The drug solution may have a low enough ionic content so that it does not significantly shunt the electrodes, which can be used independently to stimulate and record from selectable sites along the distal shaft.

[0015] A single titanium case may contain all electronic components of the implanted controller 100 except for the one or two implanted arrays 30 and their associated connectors 120 and an RF internal coil 112 that surrounds the hermetic
case or can be attached as a satellite in the manner of cochlear implants. The RF coil can be used for inductive coupling to an external coil 210 in order to recharge an internal, rechargeable battery 118 and for bidirectional data transmission to query and program the electronic functions. In normal operation, the system may work autonomously according to a control algorithm 130, with only simple on-off and perhaps state commands transmitted from a patient-operated remote control.

[0016] Each electrode may be switchable to record or stimulate. There may be 4-8 independently programmable sources of bipolar stimulation that could be combined to provide steerable stimulation fields. Recordings can be low frequency field potentials (2-70 Hz) from a low impedance (~1 kΩ), low amplitude (~100 µV) source, in some examples no more than one channel per array. The signal may be digitized and processed to detect energy in various frequency bands, which could trigger state changes in stimulation or drug delivery according to control algorithm 130. The stimulation may be timed to temporal details of the recorded signal. A data logging capacity may be included that could be transmitted between the internal coil 112 and the external coil 210 and hence to the clinical programmer 230 via the data encoder 122 and telemetry processor 114 when the patient is seen in the clinic. In some embodiments individual contacts in each array may be more or less permanently assigned during the postoperative fitting and programming period to record and/or stimulate.

[0017] Conventional pacemaker technology may be employed for encasing implanted controller 100. For example, a thin wall, drawn titanium case with laser or electron-beam welded feedthroughs and seals may be utilized. Given an appropriate curvature, a fairly large diameter may be used under the scalp at midline. Some portion may be recessed partially into the skull to provide adequate vertical height and anchoring.

[0018] The electrodes may be detachable from the electronics package, due to variable skull size and approach angles to the BG. In some embodiments, the electronics may be replaced without dislodging electrodes. If the central lumen is used for a stiffening trochar during insertion, the lumen may be able to self-seal or be sealed after removal to prevent leakage of unfused drug. It is generally necessary for the entire connector 120 for the implanted array 30, including both its fluidic coupling 158 and connector contacts 122 to be designed so as to have an outside
diameter no greater than the outside diameter of cable 34 and any jacket 36 encasing it and small than the inside diameter of guide tube 66, which must be removed by passing it over the implanted array 30 after its interface 40 is correctly located in the BG. This can be achieved by circumferential band-shape for connector contacts 122 such as are commonly employed in spinal cord electrode arrays that are inserted similarly through a guide tube, and elastomeric gaskets for coupling 158 such as are commonly employed in intrathecal drug pumps whose catheters are inserted similarly through a guide tube.

[0019] The deep brain stimulation devices may control the release of neurotransmitters such as dopamine into the BG around the electrode sites. The release may be fairly diffuse to avoid toxic local doses and it may be modulated over a range of about 0.2 - 10X baseline. Baseline release tends to occur for 1-5 seconds, followed by a peak or valley lasting about 0.2-1 s. A control algorithm 130 could trigger these releases according to field potentials recorded by electrode contacts 42 in the BG (see, for example, discussion of closed-loop control below). Local injection may avoid the blood-brain barrier, high dosages and side-effects of systemically administered drugs.

[0020] The device may employ multiple, closely spaced and independently controllable electrode contacts so that stimulation can be adjusted after the electrode is fixed in place. The device may provide therapeutic stimulation parameters such as 200-500 µA x 100 µs @ 160pps. Stimulation and drug delivery may be gated and modulated according to oscillatory field potentials that could be recordable by selected contacts in the array. Single unit potentials are normally used to guide initial placement (see below), but recording them chronically would be problematic. During normal function, the BG has relatively continuous and asynchronous activity that produces little or no coherent field potentials. In a pathological state, neural activity segments into bursts and oscillations that produce field potentials in the range of 2-70 Hz. Electromechanical activity may also be recorded from the limbs that might signify different states of tremor, akinesia and rigidity requiring different treatment modes. BIONs with accelerometers and EMG recording capability in the limbs might be useful (as described by Loeb et al., 2001, Medical Engineering and Physics 23:9-18, and incorporated herein by reference), but would probably require
rechargeable battery-power and E-field data transmission to avoid encumbering the limbs.

[0021] Site searching may be conducted by various methods known to those skilled in the art. For example, electrodes may be inserted through a rigid 2 mm guide-tube that is placed initially according to stereotaxic coordinates. A straight microelectrode probe may be passed through the guide-tube to record from the various nuclei of the BG, whose characteristic patterns of single unit activity allow them to be identified individually. Glass-insulated tungsten probes, which are made from coarsely sharpened 300 µ wire with tip exposures of 10-50 µ, may be utilized. The insulation and tip materials may not support extensive trial stimulation through the tips, so a second stimulation contact may be used about 2mm proximal from the recording tip. In cases where sites can be probed only along this single depth axis, a suitable site may be found by insertion of a second guidetube and similar probing along a track ~2mm away and parallel to the original track. Such probes may be used instead of or in addition to the shaft 62 with both straight microelectrode 70 and lateral microelectrode 75 illustrated in Figure 1.

[0022] The devices can be implanted and used in various ways as known by those skilled in the art. For example, various methods and devices used for implantation and use of brain stimulators are described in the following U.S. patents, which are incorporated by reference: No. 6,324,433 to Errico; No. 6,782,292 to Whitehurst; No. 6,427,086 to Fischell et al.; No. 6,788,975 to Whitehurst et al.; No. 6,263,237 to Rise; and No. 6,795,737 to Gielen et al.

[0023] Various power systems known to those skilled in the art may be used with the deep brain stimulation devices. Currently available systems use considerable power for the continuous, high frequency stimulation, which is provided by primary batteries in a hermetic package. Leads can be tunneled under the scalp and across the neck to supraclavicular site used for pacemakers. If both sides of the brain are implanted, two such leads may be connected to the stimulator. It is feasible and often necessary to have the patient awake during the electrode implantation and testing, but the tunneling requires general anesthesia, either at the end of an already lengthy surgery or as a separate surgical procedure a week or so after electrode implantation. A rechargeable lithium ion battery with disk or half-disk shape may be used. The battery may be able to power the implant for several days and be
recharged enough times so that the electronics package does not have to be replaced for >10 yr.

[0024] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the deep brain stimulators, methods and systems. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the deep brain stimulators, methods and systems. Thus, the deep brain stimulators, methods and systems are not intended to be limited to the embodiments shown herein but are to be accorded the widest scope consistent with the principles and novel features disclosed herein.
CLAIMS

1. An implantable multimode deep brain stimulation array for providing therapy to a brain of a patient, comprising:
   a) an elongated shaft configured to be implanted within the brain;
   b) a plurality of sponge-like electrodes having pores, spaced apart along the shaft, and configured to deliver electrical pulses to the brain; and
   c) a lumen within the shaft configured to deliver drug solution through the pores in the electrodes.

2. The array of claim 1, wherein the electrodes comprise sintered tantalum.

3. The array of claim 1, wherein the shaft has a diameter of about 1mm.

4. The array of claim 1, wherein the shaft comprises silicone elastomer molded around a multifiler spiral electrode leads with a central hollow core.

5. The array of claim 1, wherein the electrodes are anodized.

6. The array of claim 1, wherein the array includes circuitry coupled to the electrodes configured to switch between delivering a signal to and receiving a signal from the electrodes.

7. The array of claim 1, wherein the electrodes are configured to be detachable from the elongated shaft.

8. The array of claim 1, further including a seal configured to seal the lumen.

9. The array of claim 9, wherein the seal is configured to seal the lumen to prevent leakage.

10. The array of claim 1, wherein each electrode is electrically isolated from the others.
11. An implantable deep brain stimulation system for providing therapy to brain tissue of a patient comprising:

   a) a probe configured to be moved to different locations within the brain tissue;
   
   b) an elongated array configured to be implanted within the brain, having a plurality of electrodes spaced apart along the array comprised of sponge-like material having pores, and being configured to controllably deliver to the brain tissue electrical pulse stimulation and/or drug solution; and
   
   c) a first controller configured to be implanted within the patient to control the delivery of the electrical pulse stimulation and/or drug solution through the pores of the electrodes to the brain tissue.

12. The system of claim 11, further comprising a case hermetically sealing the controller.

13. The system of claim 12, wherein the case is configured to be placed at least partially within the cranium of the patient.

14. The system of claim 11, further comprising a coil configured to be implanted in the patient.

15. The system of claim 14, wherein the coil is configured to convert electromagnetic radiation into energy sufficient to recharge a rechargeable cell or battery.

16. The system of claim 14, wherein the coil is connected to circuitry that effectuates bidirectional data transmission through the coil.

17. The system of claim 16, wherein the circuitry is configured such that the bidirectional data can query and program functions of the controller.

18. The system of claim 14, wherein the system is configured to be controlled by a wireless remote control.
19. The system of claim 11, wherein each electrode is electrically isolated from the other and is connected to programmable circuitry that provides a bipolar signal.

20. The system of claim 19, wherein the programmable circuitry is configured to steer the stimulation provided by the electrodes within the tissue.

21. The system of claim 11, wherein circuitry coupled to the electrodes is configured to be switchable between providing stimulation to the electrodes and recording a signal from the electrodes.

22. The system of claim 21, wherein the circuitry is configured to record a signal having a frequency within 2-70 hertz.

23. The system of claim 22, wherein the system is configured to provide stimulation with a timing that is based on the recorded signal.

24. The system of claim 22, further comprising a data logging sub-system that is configured to facilitate down-loading of logged data via a back telemetry link.

25. The system of claim 21, wherein each of the electrodes in the array is permanently assigned during a postoperative fitting and programmed to record signals from or stimulate the brain tissue.

26. The system of claim 11, wherein the controller is configured to control the time of the drug delivery by the array.

27. The system of claim 26, wherein the controller is configured to cause the array to deliver drug solution after detection of a peak and a valley signal from the electrodes.

28. The system of claim 11, further including a drug solution that comprises a neurotransmitter substance or analog thereof.
29. The system of claim 11, wherein the controller is configured to gate and modulate the stimulation and drug delivery according to a field potential across the electrodes.

30. The system of claim 14, further comprising a second controller and a second coil that are configured to be used external to the patient and to communicate with the first controller and coil, respectively.

31. The system of claim 30, further comprising a clinical programmable module configured to program the electrical pulse and/or drug delivery to the brain tissue by the array.