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Organic bioelectrodes in clinical neurosurgery ☆

Hans von Holst *

Department of Neurosurgery, Karolinska University Hospital, 171 76 Stockholm, Sweden
Department of Neuronic Engineering, Royal Institute of Technology, 142 52 Stockholm, Sweden

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ABSTRACT

Background: Clinical neurosurgery deals with surgical procedures and intensive care of illnesses in the human central and peripheral nervous system. Neurosurgery should be looked upon as a high-tech specialty and very much dependent on new technological innovations aiming at improvements of patient's treatment and outcome. During the last decades neurosurgery has improved substantially thanks to the introduction of applied imaging technologies such as computerized tomography and magnetic resonance tomography, and new surgical modalities such as the microscope, brain navigation and neuroanesthesiology.
Neurosurgical disorders, which should have the potential to benefit from conductive organic bioelectrodes, include traumatic brain and spinal cord injury and peripheral nerve injuries due to external violence in the restoration of healthy communication. This holds true also for cerebral nerves altered in their functions due to benign and malignant brain and spinal cord tumors. Further, new innovative devices in the field of functional nervous tissue disorders make the use of organic conductive electrodes attractive by considering the electrical neurochemical properties of neural interfaces.
Conclusions: Although in its infancy, conducting organic polymers as bioelectrodes have several potential applications in clinical neurosurgery. The time it takes for new innovations and basic research to be transferred into clinical neurosurgery should not take too long. However, a prerequisite for successful implementation is the close interdisciplinary collaboration between engineers and clinicians. This article is part of a Special Issue entitled Organic Bioelectronics—Novel Applications in Biomedicine.

1. Introduction

Clinical neurosurgery has made substantial progress in the treatment of a number of different disorders. What was not possible to treat three decades ago has now become routine. The causes of this paradigm shift are the introduction of advanced technology in clinical neuroscience. The advances in technology have, for instance, introduced the stereotactic and brain navigation systems minimal invasive endoscopy and the microscope and have resulted in a remarkable improvement in neurosurgery. Due to additional new technology the introduction of neurological intensive care resulted in much better care for a number of various neurologic disorders.

The advancement of new technology, which was very well received in health care, made it natural to intensify the interdisciplinary collaboration between clinicians in the clinical neuroscience field with those who had the engineering competence (Fig. 1).

A new discipline for further improvements of the neurosurgical field is neuroengineering which is just in its infancy. Neuroengineering is a fast emerging discipline combining knowledge from mathematics, computer science and biomedical engineering aiming at the development of new innovations especially for clinical neuroscience in an effort to better understand the human nervous system. One of the most exciting neuroengineering topics for applied clinical neurosurgery is the field of conductive organic bioelectrodes focusing on electronic devices for artificial communication of neural interfaces to be used in treatment and rehabilitation.

One of the oldest therapeutic tools in the field of clinical neuroscience is the use of electricity originating several thousands of years back in history. Since then electrical stimulation has made enormous advances. Also, about a decade ago the brain computer interface made it possible to discuss artificial communication between the nervous system and neuroprostheses for different purposes and where the need for a new generation of biological electrodes became obvious. Since then the development of electroactive conjugated polymers as an integral component for the delivery but at the same time recording of neural activity has emerged [1,2].

An important aspect in the development of new interfaces is the problem with foreign body response following implantation of implants [3,4] and which may jeopardize the effectiveness of the implant. Similarities can be made with treatment of fractures which aims at inhibiting motion between the fracture ends thereby promoting healing. Implantation of conductive organic bioelectrodes faces

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* Department of Neurosurgery, Karolinska University Hospital, 171 76 Stockholm, Sweden.
E-mail address: hans.vonholst@karolinska.se.

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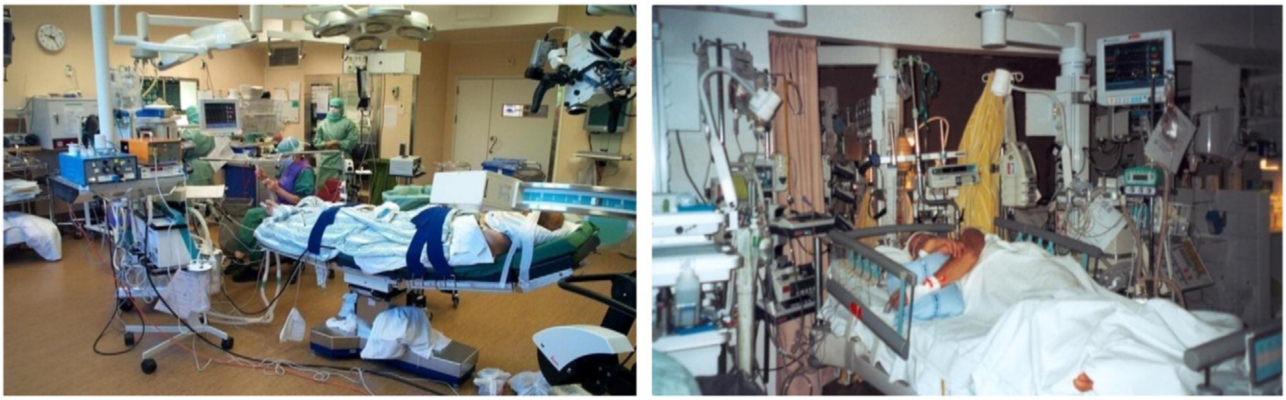

Fig. 1. New and advanced technology has improved both the neurosurgical procedure in operating theaters (left) as well as introduction of neurological intensive care units (right).

about the same situation and, hence, should be stabilized in the nervous tissue in such a way that it avoids micromotion [5].

The present chapter includes some of the disorders in clinical neuroscience and which could have the potential to benefit from the development of new conductive organic bioelectrodes.

2. From stimulus to the nerve impulse

The human body consists of several different sensory cells which convert different incoming external stimulus to electrical signals before the nervous tissue processes the signals in their respective areas of the brain. Further, an electrical signal in the nervous tissue is dependent on the permeability of cell membranes as well as selective ion concentrations between the inner and outer part of the membrane. The different stimuli originate from light, chemical, temperature, pain and mechanical sources and which influence their respective receptors located in various anatomical regions. For instance, chemical receptors are located in the nose, mouth and brain while temperature receptors are to be found in the brain and on skin. The light stimulus influences photo receptors in the eyes while pain receptors are diffusely located in the body.

In common for all the different incoming stimuli are their conversion into electrical impulses which the nervous tissue recognizes and is further processed before the response is activated (Fig. 2). The schematic presentation from stimulus into the nerve impulse shows that a conductive organic bioelectrode may have the capacity to interact with the nerve impulse directly from its own electrical activity instead of passing through a number of different thresholds.

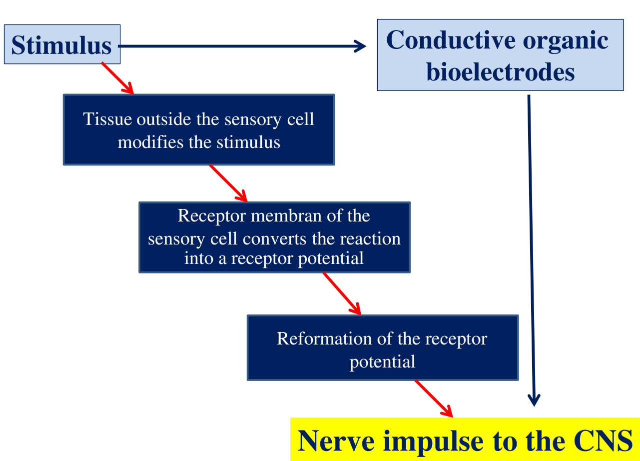

Fig. 2. The way from various stimuli and their ways in the body before transferring into a nerve impulse and the potential direct pathway of conductive organic bioelectrodes into a nerve impulse.

A prerequisite is that the conductive organic bioelectrode is constructed in such a way that it mimics the normal state of the various receptors outside the nervous tissue which has to recognize the artificial communication as the usual stimulus. This includes a number of inclusion and exclusion criteria such as the fabrication of electrodes considering stability and surface design, minimizing the foreign body encapsulation and a minimal mechanical distraction at the conductive organic bioelectrode interface to the tissue where it is to be implanted. Also, the fabrication demands that the electrical stimulation allowing the response does not become fatigued during long term repetition.

3. Traumatic brain injury

Traumatic brain injury is one of the most frequently and severely occurring disease worldwide [6]. The causes are to be found mainly in accidents due to traffic, fall, and at leisure. In general, traumatic brain injury is categorized as mild, moderate and severe although there is a considerable overlap in the use of such terminology. About 80% of the injuries are defined as mild, 10% as moderate and the other 10% as severe injuries. In contrast to most other diseases, it has a sudden onset with a substantial impact also on the patient's close relatives. Except for the medical consequences, it should also be looked upon as complicated from a psychological perspective since in many cases a personality change is shown and therefore difficult to handle for the relatives in its onset.

Imaging techniques are the modality of choice in the evaluation of acute traumatic brain injuries admitted to the hospital after a mechanical impact but also for the subsequent follow up of treatment and outcome especially for moderate and severe traumatic brain injuries. Computed tomography (CT) is the technique of choice since it is rapidly performed at low cost giving the clinician the initial information of the neuropathology pattern of both the skull bone and significant lesions in the cerebral tissue on admission to the hospital. Although magnetic resonance (MR) is more sensitive than CT, it is not used in the acute stage since it takes longer to perform, is usually placed at some distance from the emergency room and is more expensive. Instead, MR is used more for the evaluation of non-hemorrhagic diffuse axonal injuries and hemorrhagic and non-hemorrhagic cortical contusions and should be used as a complementary technique to CT. MR is of special support for the clinician in the assessment of rehabilitation and prognosis after moderate to severe traumatic brain injury. Hence, both CT and MR are of great value in analyzing primary and secondary head injuries.

Although improvements in outcome have been presented during the last decades, there are still severe secondary complications without any distinct and successful treatment such as cerebral swelling and raised intracranial pressure. Cerebral swelling is defined as an increased amount of water content in the nervous tissue and associated with