Stimulation of the Peripheral Nervous System
The Neuromodulation Frontier
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Stimulation of the Peripheral Nervous System

The Neuromodulation Frontier

Volume Editor

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Series Editor’s Note

As a series editor of Progress in Neurological Surgery, I would like to congratulate Dr. Slavin and the coauthors of this new update on the role of advanced stimulation technology in the management of patients with epilepsy, chronic pain, depression, treatment-resistant hypertension, obstructive sleep apnea, and other innovative indications.

The increasing adoption of peripheral nerve stimulation for a wide variety of patient conditions is a testament to the remarkable ingenuity and perseverance of this group of clinicians and investigators. Peripheral nerve stimulation techniques have continued to expand and have proven to be safe and effective for diverse conditions, often in clinical situations where virtually no other therapeutic option exists. The authors, who come from multidisciplinary backgrounds, work at centers with special expertise in the analysis and development of these technologies. The authors provide a striking example of how persistence and innovation pays off in terms of improving patient outcomes. This update on the current status of peripheral nerve stimulation should be a valuable resource to the field of neurosurgery and pain management specialists. I am sure it will become an important reference for specialists who care for these diverse patient problems that also include respiratory, gastrointestinal, genitourinary, and cardiac indications. The possibilities for neuromodulation have greatly expanded beyond its earlier role in the treatment of chronic pain and medically refractory epilepsy.

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Preface

In the most common impression, the term ‘peripheral nerve’ refers to the large nerves that travel through the trunk and extremities carrying motor, sensory, and autonomic information. These ‘peripheral nerves’ are then differentiated from ‘cranial nerves’ and used synonymously to the actual alternative of the cranial nerves, the spinal nerves. Even the most commonly used list of medical procedures, the Current Procedural Terminology (CPT) [1], differentiates interventions performed on ‘peripheral’ and ‘cranial’ nerves – thereby adding to the confusion in terminology.

Anatomy, however, is a precise science and anatomical terminology is very well defined. Even the most accepted compendium of anatomical terminology, the medical dictionary, provides clear division of the nervous system into central and peripheral parts, defining the peripheral nervous system as everything outside of the brain and spinal cord [2]. In vertebrates, mammals, primates, and humans, the central nervous system includes the brain and the spinal cord. According to the authoritative book The Peripheral Nervous System [3], the subject of the book’s title is defined as the cranial nerves, spinal nerves, and peripheral ganglia which lie outside the brain and spinal cord. With this scheme, all nerves that originate from the cranial part of the central nervous system – the cranial nerves (with the exception of the olfactory and optic nerves which are considered parts of the central nervous system) – and all those that originate from the spinal cord – the spinal nerves – fall under the same category of the peripheral nerves, and this categorization is supported by their anatomy, histology, and physiology.

This discrepancy between a common misconception (i.e. peripheral nerves differ from cranial nerves) and the actual anatomophysiologica similarity became obvious after the first volume of Peripheral Nerve Stimulation was published in 2011 [4]. Multiple clinical applications of cranial nerve stimulation remained omitted as most chapters concentrated on those nerves that travel through the trunk and extremities. Not surprisingly, those applications that dealt with indications other than pain (epilepsy, depression, sleep apnea, etc.) were not included in the book, as most of them specifically involve stimulation of the cranial nerves (vagus, hypoglossal). Along with these, the stimulation of the phrenic nerves used for respiratory insufficiency was left uncovered even though there is no controversy about phrenic nerve stimulation being
a ‘true’ example of peripheral nerve stimulation (PNS). Moreover, several applications of neuromodulation that would not fall under strict definition of PNS, but instead represent so-called ‘peripheral neurostimulation’ – i.e. stimulation of the trigeminal ganglion, dorsal root ganglion, sacral nerves, and nerve roots – are covered in this second part of *Peripheral Nerve Stimulation* from the popular and well-established series *Progress in Neurological Surgery*.

In addition to all of these new topics, this volume includes other important chapters. One of them deals with theoretical and technical aspects of peripheral nerve interface with neurostimulation devices. Others describe principles of wireless energy transmission that are used in modern miniaturized neuromodulation devices and characteristics of high-frequency PNS that results in a block of nerve conduction. Several chapters are dedicated to in-depth updates on the most common PNS indications, such as migraines, low back pain, and pain in extremities. Not surprisingly, the field of PNS is rapidly progressing, and as our experience grows, so does our understanding of surgical indications, proper patient selection, technical nuances of operative procedures, and complication-avoidance techniques. Instead of case reports and small retrospective single-surgeon or single-institution studies, we now have multi-center prospective studies that may be used in critical analysis of clinical evidence that could justify our interventions.

The growing clinical experience is paralleled by industrial developments. Instead of routinely using devices designed for spinal cord stimulation in PNS applications, there are now more than a dozen device-manufacturing companies that dedicate themselves to the creation of a new generation of electrodes and generators specifically designed for PNS use. Miniaturization, rechargeability, wireless interfaces, and customized designs – terms that only recently were considered futuristic and not applicable to PNS – are becoming reality at a very rapid pace.

The final chapter of this volume deals with regulatory aspects of PNS and related applications since over the last few years the field of peripheral neuromodulation has enjoyed several important approvals, mainly in Europe, Canada, and Australia, making PNS, once again, a legitimate intervention in the spectrum of available interventions, alongside spinal cord stimulation and deep brain stimulation approaches.

Even though this is yet another volume in *Progress in Neurological Surgery*, not all interventions covered here are performed by the neurosurgeons. The uniqueness of the neuromodulation field is that it blossomed at the intersection of multiple medical specialties, including neurosurgery, neurology, anesthesiology, psychiatry, orthopedics, cardiology, urology, gastroenterology, otolaryngology, pulmonology, psychiatry, oral surgery, colorectal surgery, and others – the field of PNS undoubtedly brings together physicians from different backgrounds. One has to keep in mind, however, that the implantable nature of neuromodulation still requires surgery, and the substrate of our interventions is still the nervous system. And who would be better qualified for surgery on the nervous system than neurosurgeons? Being a neurosurgeon myself, I can already hear the criticism from my nonneurosurgical colleagues who perform the
overwhelming majority of neuromodulation procedures, including PNS and spinal cord stimulation, and who over the years have become much more comfortable with reaching the nerves all over the human body. And since I have taught hundreds of them how to make neuromodulation procedures safer, I feel confident that this volume will be of interest to the entire neuromodulation community, reflecting the interdisciplinary nature of our field and, among other things, reminding myself and other neurosurgeon readers what we may be missing!

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References
