Functional Electrical Stimulation and Spinal Cord Injury

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KEYWORDS

- Electric stimulation • Electrodes • Spinal cord injuries • Rehabilitation
- Muscle spasticity • Pressure ulcer • Neurogenic urinary bladder • Paralysis

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KEY POINTS

- Functional electrical stimulation (FES) of the peripheral and central nervous system may be used for rehabilitation and management of complications after spinal cord injury (SCI).
- FES may improve the functional status and quality of life of many persons with spinal cord injuries.
- Many of the FES strategies are already commercially available, whereas others are being tested in human and laboratory studies.
- FES should be routinely considered as part of the rehabilitation and medical management of eligible persons with spinal cord injuries.

An injury to the spinal cord can disrupt communications between the brain and body, leading to a loss of control over otherwise intact neuromuscular systems. By taking advantage of these intact neuromuscular systems, several neuroprostheses have been developed to restore functions through functional electrical stimulation (FES) of the central and peripheral nervous system. Neuroprostheses using FES to control the paralyzed muscles may prevent many secondary medical complications and improve functional independence by providing a means to exercise and negotiate physical barriers. Improvements in multiple body systems and functions have been reported through the use of FES, and they are discussed in this article. These devices range in complexity and include components such as power supplies (which may be completely external to the body or implanted and recharged with radio frequency waves), a control circuit (ie, the brains of the device), lead wires, connectors, external braces, and sensors. This article describes the basic properties of the electrodes, the current FES system being developed in research and in clinical practice, and the future of these devices.

THE BASIC PROPERTIES OF ELECTRODES FOR NERVE STIMULATION

In neuroprostheses, electrodes are the interface between the external circuitry and the tissue, delivering a charge that stimulates the nerves connected to the muscles of interest. This charge perturbs the resting potential of the neuron (typically around -65 mV); if this value is raised beyond a threshold, membrane depolarization occurs. This depolarization results in an influx of Na^+ ions, initiating an action potential that can travel spatially down the length of an axon. A coordinated group of action potentials can lead to a muscle contraction.[1] By targeting nerves rather than the muscle fibers themselves (which can also be stimulated electrically), substantially smaller charge densities may be used, consuming less power and avoiding tissue damage.[2]

Provided that the neuromuscular system is intact, stimulation may be achieved at a variety of locations (from the origin of the neuron in the spinal cord to the peripheral nerve and to the skin above the muscle) using various types of electrodes. The simplest configuration uses large (of the order of square centimeters) electrodes placed on the surface of the skin. The electrodes are easily replaced; however, achieving accurate and precise positioning is challenging, and charge is distributed over a large area. A more invasive approach is to implant needlelike electrodes percutaneously into the muscle of interest. This method is considered a precursor to fully implanted systems, although subcutaneous electrodes themselves can remain functional for years.[3] When electrodes are fully implanted in close proximity to the nerve,