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American National Standard

ANSI/AAMI NS14:1995/(R)2002

Implantable spinal cord stimulators

AAMI Association for the Advancement of Medical Instrumentation

List of Titles

Association for the Advancement of Medical Instrumentation
1110 N. Glebe Rd., Suite 220
Arlington, VA 22201-4795

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NS14 Implantable Spinal Cord Stimulators

American National Standard

ANSI/AAMI NS14:1995/(R)2002
(Revision of ANSI/AAMI NS14:1984)

Implantable spinal cord stimulators

Developed by
Association for the Advancement of Medical Instrumentation

Approved 2 February 1995 and reaffirmed 17 December 2002 by
American National Standards Institute, Inc.

Abstract:

This standard establishes minimum labeling, safety, and performance requirements for implantable spinal cord stimulators. Also covered are referee test methods and the rationale for the provisions of the standard.

Foreword

This standard was developed by the AAMI Implantable Neurostimulator Subcommittee of the Neurosurgery Committee.

The scope of this revision has been clarified. The standard establishes minimum safety and performance requirements for internally and/or externally powered implantable neurostimulators. It covers all elements of the spinal cord stimulator system, which consists of an implanted pulse generator, connecting electrodes, and an external transmitter or programmer for transmitting energy and/or information across the patient's skin to the implanted pulse generator.

Labeling requirements have been revised and stimulation parameters have been updated in this latest edition. A standard means of testing and reporting the performance of the stimulus generator is important so that physicians are able to make informed comparisons of and selections from commercially available equipment.

The concepts incorporated in this standard should be considered flexible and dynamic. To remain relevant, this standard, like any other, must be reviewed and updated periodically to assimilate new data and to reflect advances in the technology.

This standard reflects the conscientious efforts of concerned physicians, engineers, and other health care professionals, in cooperation with manufacturers, to develop a standard for those characteristics of vascular prostheses that could be addressed at this time, in view of new technology and information.

As used within the context of this document, "shall" indicates requirements strictly to be followed in order to conform to the standard; "should" indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action should be avoided but is not prohibited; "may" is used to indicate a course of action is permissible within the limits of the standard; and "can" is used as a statement of possibility and capability. "Must" is used only to describe "unavoidable" situations, including those mandated by government regulation.

Suggestions for improving this standard are invited. These should be sent to AAMI, 3330 Washington Boulevard, Suite 400, Arlington, VA 22201-4598.

NOTE—This foreword is not a part of the American National Standard, *Implantable spinal cord stimulators* (ANSI/AAMI NS14—1995).

Implantable spinal cord stimulators

1 Scope

1.1 General

This standard establishes safety and performance requirements for internally and/or externally powered implantable spinal cord stimulators.

1.2 Inclusions

This standard covers all electrode configurations and all elements of the spinal cord stimulation system. The system consists of an implanted pulse generator, connected electrodes placed over the spinal cord, and an external transmitter or programmer for transmitting energy and/or information across the patient's skin to the implanted pulse generator.

This standard covers electrodes implanted by a surgical procedure (a laminectomy) or introduced percutaneously. The devices (electrodes, pulse generator, and transmitter) used in the trial period of spinal cord stimulation are also included within the scope of this standard. Also covered by this standard are spinal cord stimulators that produce current affecting other areas of the spinal cord, including those stimulators that pass current through the spinal cord in an anterior-posterior direction.

1.3 Exclusions

Excluded from the scope of this standard are transcutaneous electrical nerve stimulators, implantable peripheral and cranial nerve stimulators, deep brain stimulators, and external stimulating electronics directly (percutaneously) attached to electrodes placed over the spinal cord.

2 Normative reference

The following standard contains provisions, which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standard listed below.

2.1 ASSOCIATION FOR THE ADVANCEMENT OF MEDICAL INSTRUMENTATION. *Safe current limits for electromedical apparatus.* ANSI/AAMI ES1. Arlington (Va.): AAMI, 1993. American National Standard.

3 Requirements

3.1 Labeling requirements

In addition to the requirements of applicable federal regulations, labeling on or accompanying spinal cord stimulators shall include the following.

3.1.1 Device markings

The device shall be labeled as an implantable spinal cord stimulator. The transmitter and pulse generator shall display:

— the manufacturer's name;

— the model number;

— the serial number and/or manufacturing lot number.

3.1.2 Information manual/package insert

A physician information manual or package insert and a patient information manual (which may be combined with the physician manual) shall be supplied with each device and shall contain at least the following:

a) prescription legend as required by federal regulations;

b) instructions for properly unpacking the unit so as to prevent physical damage and to retain the integrity of the sterile packaging (if applicable);

c) instructions for using the implantable spinal cord stimulator so that physicians are able to implant, test, and demonstrate the use of the device correctly;

d) instructions for proper sterilization (or resterilization) of the implantable components. If the device is supplied sterile by the manufacturer, the method of sterilization, date of sterilization, lot number, date by which the device must be used, and proper steps to ensure that sterility is not compromised should be specified;

e) labeling that shall include warnings, cautions, and precautions related to the use of the device, including possible interactions with other devices;

f) a table of stimulation parameter ranges that includes at least amplitude, frequency, pulse width, and a representation of the stimulation waveform;

g) instructions for the disposal of the transmitter and implantable pulse generator;

h) for a device with implanted life-limiting components, a statement as to shelf life and the projected useful life of the system over a typical range of load and stimulation parameters;

i) instructions on pre-implant testing for proper functioning.

3.1.3 Registration

The manufacturer shall provide means by which each implanted device can be registered with the manufacturer. A card to be returned to the manufacturer shall be provided with each device. This card shall provide space for:

— name;

— model number;

— serial number and/or manufacturing lot number of the device;

— patient, hospital, and physician names and addresses;

— date of implantation.

3.2 Performance requirements

3.2.1 Electrical safety

In accordance with 2.1, the risk current from the insulated wires shall not exceed 10 microamperes (μA) (source risk current limit, dc to 1 kiloHertz [kHz]). However, leakage currents above 100 nanoamperes (nA) may cause electrode corrosion and should be evaluated.

3.2.2 Stimulation parameters

A safe and effective current to stimulate the spinal cord depends on a number of factors, including frequency of stimulation, duty cycle of stimulation, length of time of continuous stimulation, current density in the nerve, and charge per stimulation phase. The output of the device shall operate within the following parameter ranges:

a) *Pulse frequency* — 1 to 1,500 pulses per second (pps);

b) *Pulse width* — 1 to 1,000 microseconds (μsec);

c) *Amplitude voltage (Current)* — 0 to 15 volts (V) or 0 to 30 mA through a 500-ohm load.

3.2.3 Waveform

The waveform shall consist of balanced positive and negative phases, so that the net dc current through the electrodes does not exceed 10 μA. (See 4.2.3.)

3.2.4 Controls

Each device shall have an output-limiting control that can be set by the physician as clinical findings indicate to limit the output of the device.

3.2.5 Test stimulation

If a trial period of epidural stimulation is conducted, the stimulating equipment provided for the test and the implanted device shall be capable of producing the same parameters.

3.2.6 Materials

The encapsulant and/or coating of the implanted pulse generator, the electrical insulation of the lead wires, the electrode pad, and the electrode shall be composed of materials shown to be biocompatible. (See A.3.2.6)

4 Tests

This section provides referee test methods that can be used to verify compliance of the device with the labeling and performance requirements of section 3. The paragraph numbers correspond, with the exception of the first digit, to those of section 3.

4.1 Compliance with the labeling requirements

4.1.1 Device markings

Compliance with the requirements of 3.1.1 can be determined by visual inspection.

4.1.2 Information manual/package insert

Compliance with the requirements of 3.1.2 can be established by visual inspection, except for the electrical performance specifications required in 3.1.2(f). The test circuit of figure 1(a) or 1(b) (see next page) shall be used to measure the output characteristics.

4.1.3 Registration

Compliance with the requirements of 3.1.3 can be determined by visual inspection.

4.2 Compliance with the performance requirements

4.2.1 Electrical safety

Test methods for establishing compliance with 2.1 are provided in that standard.

4.2.2 Stimulation parameters

The test circuit for all parameter measurements shall consist of a simple 500-ohm resistive load, as shown in figures 1(a) and 1(b). For radiofrequency coupled systems, the pulse generator output shall be tested at half-centimeter spacing between the transmitter antenna and pulse generator.

a) *Pulse frequency* or *Pulse repetition rate* (PRR) is measured as the reciprocal of the interval between two consecutive pulse onsets (PI), regardless of polarity. See figure 2(a) (page 4).

b) *Pulse width* (PW) is measured at the midpoint of the pulse at the maximum pulse amplitude. See figure 2(b) (page 4).

c) *Pulse amplitude* (PA) is measured, at a pulse width of 200 microseconds (μsec) or the nearest setting, as the linear estimate of the average value of the pulse height from the start of the pulse onset. See figure 2(c).

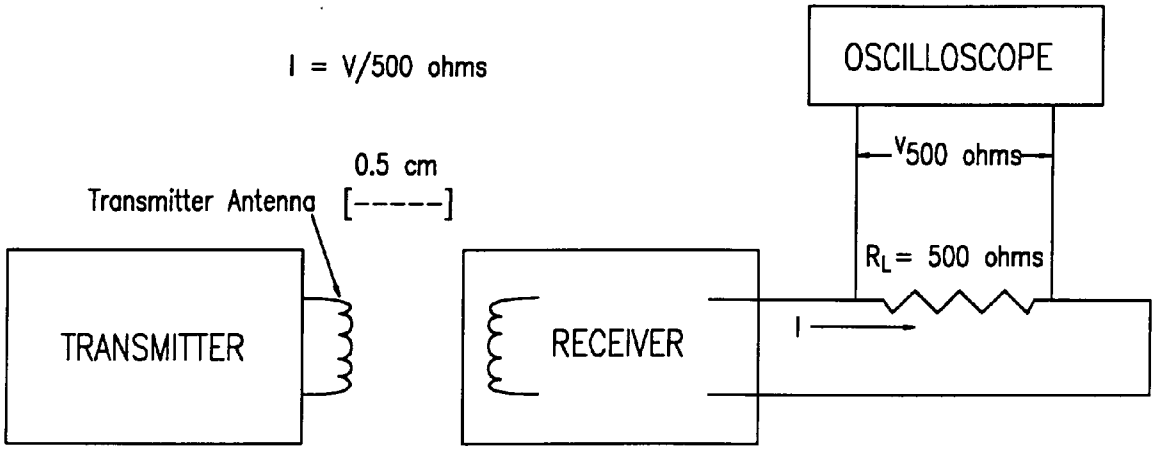

Figure 1(a)—Test circuit for verifying performance specifications of externally powered stimulator

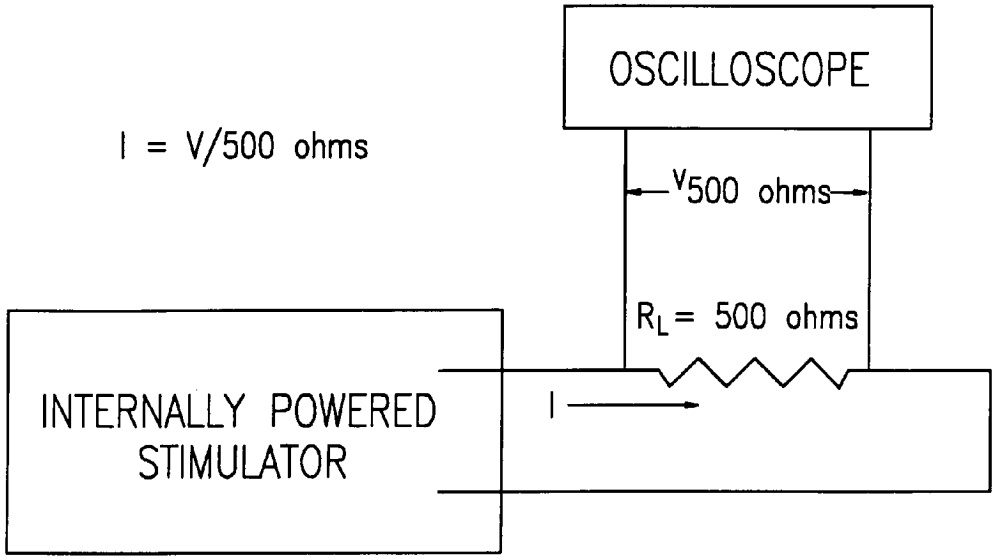

Figure 1(b)—Test circuit for verifying performance specifications of internally powered stimulator

4.2.3 Waveform

The waveform shall be observed by means of the test circuit shown in figures 1(a) and 1(b). The pulse generator output should block the dc component of current into the load. If one checks the dc = 0 volts (V) level on the oscilloscope at a high enough sensitivity, one will see the current distribution around 0 volts (see figure 3). The current averaged over the stimulation cycle shall be less than 10 microamperes (μA).

4.2.4 Controls

Compliance with the requirement of 3.2.4 can be determined by inspection.

4.2.5 Test stimulation

No test method required.

4.2.6 Materials

Test methods are under study. (See A.3.2.6.)

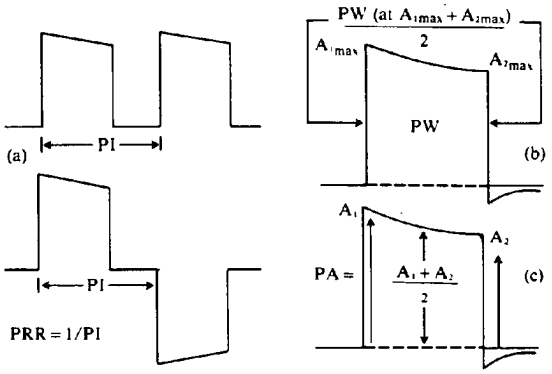

Figure 2—Measurement of pulse repetition rate (a), pulse width (b), and pulse amplitude (c)

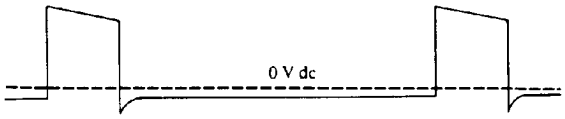

Figure 3—Current distribution around 0 volts dc

Annex A
(informative)

Rationale for the development and provisions of this standard

A.1 Introduction

This standard was developed by the Implantable Neurostimulator Subcommittee of the AAMI Neurosurgery Committee. It sets forth the labeling, reporting, and performance materials requirements that the committee considered would provide reasonable assurance of the safe and effective use of implantable spinal cord stimulators for the relief of chronic pain. Like all standards, this standard reflects current technology, and as advances in the field occur, it must be modified to accommodate new data.

A.1.1 Spinal cord stimulator systems

Implanted spinal cord stimulators for pain relief are devices that electrically stimulate the nervous system, specifically, the nerve fiber tracts and/or neurons of the spinal cord. Spinal cord stimulators are used in patients to relieve severe, intractable pain of the extremities and the trunk (FDA, 1979).

Radiofrequency coupled neural stimulators, as used for spinal cord stimulation, are partially implantable pulse generator systems consisting of an external battery-powered transmitter/antenna system and a subcutaneously implanted receiver/lead system. Pulse-modulated radiofrequency energy produced by the external transmitter is radiated by the antenna. When the antenna is affixed to the skin overlying the implanted receiver, the stimulating pulses are transmitted across the skin to the implanted receiver. The receiver detects the pulsed energy and produces electrical pulses of variable frequency (repetition rate), height (amplitude), and width (duration). These electrical pulses are transmitted—via implanted, insulated lead wires with bare electrode surfaces—to the neural tissues of the spinal cord.

The stimulation pulse repetition rate, pulse amplitude, and pulse width are adjustable by means of controls on the external transmitter. For optimal efficiency, the transmitting coil of the antenna must be placed directly over and in proximity to the implanted receiver (Kahn & Maveus, 1972; Ray and Mayer, 1975). The characteristics of the stimulus pulse (e.g., amplitude) may vary with changes in antenna/receiver coupling.

"Totally implanted" pulse generators, used for spinal cord stimulation, are powered by an implanted primary (or rechargeable) battery. These devices allow stimulation to be delivered autonomously, i.e., independently of any externally worn device. Control of the implant by the patient may be accomplished by using a magnet or by using a radiotelemetry device.

Some implanted pulse generators, of both radiofrequency-coupled and "totally implanted" design, allow noninvasive selection of anodes and cathodes from an array of electrodes, hardwired to the pulse generator. These devices may be described as multichannel in common usage; technically, contemporary new devices are single-channel generators, with programmable gates to multiple outputs (North et al., 1991).

A.1.2 History

The idea that electrical stimulation of body organs can serve as a therapeutic modality for the modification of abnormal physiology in humans has been applied in several fields, most notably cardiology. The use of electrical stimulation of spinal cord nerve fibers in the management of chronic, intractable pain began in the 1960s.

Interest in this field was sparked by the publication of the "Gate Control Theory" (Melzack and Wall, 1965). According to this theory, sensory mechanisms for the perception of pain are controlled by a negative feedback or gating mechanism located in the spinal cord. Activated by impulse activity in large-diameter, myelinated, peripheral, cutaneous nerve fibers or their collaterals in the dorsal columns of the spinal cord, this "gate" closes to inhibit the transmission of nerve impulses from the smaller fibers associated with nociception. Although such impulse activity could be achieved by mechanical stimulation of peripheral mechanoreceptors, electrical stimulation is easier to apply. The Gate Control Theory, though later questioned, has served as the rationale for the clinical use of electrical stimulation of the nervous system as a therapeutic modality in the management of pain.

The initial clinical application of current to nerves for the relief of pain involved the stimulation of myelinated afferent nerve fibers in peripheral nerve pathways. Shelden (1966) proposed that the pain relief observed upon stimulation of the trigeminal nerve was due to depolarization and the reduction of afferent impulses. Wall and Sweet (1967) reported that stimulation of peripheral nerves caused temporary pain relief that outlasted the period of application of current, occasionally by several hours. Sweet and Wepsic (1967) reported that peripheral nerve stimulation produced continued satisfactory pain relief in a small group of patients.

In an effort to apply stimulation to larger anatomic regions, Shealy et al. (1967) suggested that by stimulating the dorsal columns of the spinal cord, one would be able to control pain over wider areas, involving not only one extremity, but also bilateral extremities and areas of the trunk. The effect of spinal cord stimulation could be perceived over a wide area of the body in the segments below the region of the spinal cord where current was applied. The first reported use of chronic neural stimulator implants in patients took place in 1969 (Shealy et al., 1970).

Neural stimulation offers the clinician an alternative to creating destructive lesions of the nervous system, which had been the primary neurosurgical method for the management of pain.

Spinal cord stimulation may reduce the perception of pain by:

— interfering with action potential conduction, particularly at branch points of primary afferents (frequency related conduction block);

— local "gate" mechanisms in the dorsal horn, where pain signals may be blocked;

— producing effects higher in the central nervous system, possibly by the competitive "jamming" of pain signals;

— initiating an ascending-descending pain control loop that terminates in the spinal "gate";

— influencing release of endogenous factors that act on pain perception or nociception centrally or peripherally, e.g., sympathetic neurotransmitters.

A.1.3 Electrode systems

Spinal cord stimulation initially was performed by surgically implanting electrodes via laminectomy in patients under general anesthesia. To implant the lead, part of the bony structure protecting the spinal cord was removed. The electrodes consisted of a polyester pad coated with silicone elastomer in which platinum electrodes were embedded. Electrode pads were sutured onto or below the membranes (dura or meninges) that protect the spinal cord. Depending on the location of the electrodes relative to this membrane, they were described as epi- (above), endo- (within), or sub- (below) dural (Shelden et al., 1975).

The percutaneous technique of implanting electrodes through hollow needles into the epidural space was introduced several years later. Since the patient is under local anesthesia, this procedure allows the patient to direct the clinician in the placement of leads to achieve optimal electrode location (so that paresthesias cover the entire painful area). Percutaneous trial stimulation with implanted electrodes enables the patient and the clinician to evaluate, over a period of days, the effects of spinal cord stimulation, without committing the patient to the implantation of a permanent neural stimulator (Hosobuchi et al., 1972; Erickson, 1975; Urban and Nashold, 1978).

The percutaneous implantation technique avoids the need for laminectomy, which in turn may require general anesthesia, and hence reduces the risks to the patient that accompany a major surgical procedure. With this technique, the patient's response to stimulation can be checked repeatedly during surgery, and the electrodes can be manipulated until stimulation produces paresthesias in the specific anatomic area(s) of the patient's pain.

A.1.4 Clinical results of spinal cord stimulation

During the 1970s, numerous reports on the use of spinal cord stimulation for pain control appeared in the literature. The reported long-term results of the treatment of intractable pain with implanted spinal cord stimulators have varied widely, from a success rate of about 17% to over 80% (De la Porte, 1983; Kumar, 1991; Law, 1983; Long and Erickson, 1985; Neilson et al., 1975; North et al., 1977; Siegfried, 1982; Spiegelmann,1991). Disinterested, third-party follow-up of a large series of patients, up to 20 years following implantation, has shown that over 50% of patients report at least 50% continued relief of pain (North et al., 1993).

Patient selection and evaluation criteria differ, and the definition of a successful outcome with stimulation is subjective. In most reports, success is defined as a reduction of the pain experience by the patient's own evaluation (Long, 1983; Young, 1978). In others, the results were considered successful if patients were able to reduce or discontinue the use of pain medications (Krainick and Thoden, 1981; Young, 1978). Others consider work status and activities of daily living (North et al., 1993).

One pattern (common among treatments for chronic pain) appears no matter how success is defined: The effectiveness of treatment decreases with continued use (Krainick and Thoden, 1981). Virtually all authors agree that the key to successful application of implanted stimulators is the careful selection of patients. They do not all agree, however, on which criteria are significant in predicting the success of treatment to relieve a patient's pain.

When this technique is not successful, failures occur under three principal circumstances (Urban and Nashold, 1978):

— the stimulation has not been referred to the painful area of the body (i.e., failure of electrode positioning);

— pain relief has not been achieved despite acceptable stimulation;

— pain relief has not been maintained after initial, successful stimulation.

In the use of spinal cord stimulators for pain management, equipment-related problems may occur; surgical revision may be required by electrode migration or by component failures in the implanted pulse generator circuitry and leads and electrodes. In addition, complications may occur when the system is misused (e.g., accidental adjustment of the patient controls to inappropriate stimulus parameters) or as a result of the effects of extraneous radiofrequency wave transmission on the production of stimuli by the implanted receiver (Kahn and Maveus, 1972; Long and Erickson, 1985).

Several reports have summarized the incidence of equipment-related problems associated with radiofrequency-coupled neural stimulator systems used for spinal cord stimulation for intractable pain (Fox, 1977; Grillo et al., 1974; North et al., 1993; Pineda, 1975; Young, 1978). Fox (1977) lists 26 problems or comments that were reported in his survey of 10 neurosurgeons who had used these devices.

Complications have included spinal cord compression or injury by the electrode, resulting in transient paralysis (Burton, 1977; Fox, 1977; Grillo et al., 1974; Nashold and Friedman, 1972; Sweet and Wepsic, 1974); and infection (Fox, 1977). In addition, one case was reported in which the patient was temporarily paralyzed when bleeding occurred beneath an electrode 18 months after implantation (Grillo et al., 1974). Such complications have been reported primarily with laminectomy electrodes.

In 30-40% of the cases reported to the researchers, the intended result (pain relief) was not achieved (Fox, 1977; Neilson et al., 1975; Pineda, 1975). Lead migration or breakage occurred in about 30% of the cases (Fox, 1977; Young, 1978). This occurs significantly less often with contemporary "multichannel" devices (North et al., 1993). Infection or erosion has been reported in 2–15% of cases (Fox, 1977; Neilson et al., 1975; Pineda, 1975; Young, 1978).

A.2 Need for the standard

Work on the development of a standard for implantable neurostimulators began in the early 1970s, under the auspices of the AAMI Neurosurgery Committee. A proposed standard — primarily covering labeling requirements — was published in 1975. Subsequently, in 1980, an Implantable Neurostimulator Subcommittee was established to refine the labeling requirements contained in the 1975 proposal and to develop performance criteria for peripheral nerve stimulators and spinal cord stimulators. This subcommittee was reorganized and this standard revised in 1991–1993.

The goal was to establish criteria that would help provide reasonable assurance that these devices are safe and effective for the indications claimed in the labeling. In addition, a standard means of testing and reporting the performance of the stimulus generator was considered important, so that physicians would be able to make informed comparisons of and selections from commercially available equipment. The committee's conclusion that a performance standard was needed for implantable stimulators has been reinforced both by the published medical literature (see A.1.4) and by regulatory action taken on these devices under the Medical Device Amendments of 1976.

On 28 November 1978, the U.S. Food and Drug Administration (FDA) published a proposed rule to classify implantable spinal cord stimulators for pain relief into Class II. The effect of classifying a device into Class II is to provide for the future development of performance standards to assure the safety and effectiveness of that device. The FDA's advisory panel on neurological devices had recommended this classification and had further recommended that the development of a performance standard be designated a high priority by the agency.

The advisory panel decided that a performance standard was necessary in order to address the potential risks to health associated with the device: "(a) Injury to neural tissue: The patient's spinal cord may be damaged

by the presence of the electrodes or by the output current of the device. (b) Tissue toxicity: The implanted stimulator, lead wires, or electrodes may contain material that is not biocompatible. (c) Cerebrospinal fluid leakage: The fluid which surrounds the spinal cord (cerebrospinal fluid) may leak around the electrode wires." The panel did not believe that general controls (Class I) would be adequate to address these potential risks. Premarket approval (Class III), on the other hand, was not deemed necessary because the panel judged that a performance standard would be sufficient to provide reasonable assurance of safety and effectiveness, and because the panel believed there was enough information available to establish such a standard (FDA, 1978).

On 4 September 1979, the final classification rules for neurosurgical devices were published. Implantable spinal cord stimulators remained in Class II as originally proposed (FDA, 1979).

A.3 Rationale for the specific provisions of this standard

A.3.1 Labeling requirements

A.3.1.1 Device markings/A.3.1.2 information manual/package insert

The requirements of 3.1.1 and 3.1.2 are intended to ensure that sufficient product information will be available to the physician and to patients for the safe and effective use of spinal cord stimulators.

A.3.1.3 Registration

The registration of spinal cord stimulators is considered to be essential for responsible follow-up of product performance by the manufacturer. The data requested are the minimum needed by the manufacturer for proper assessment of a product's performance, and for compliance with device tracking requirements.

A.3.2 Performance requirements

A.3.2.1 Electrical safety

The rationale for the risk current limits specified in the American National Standard, *Safe current limits for electromedical apparatus*, is provided in the rationale statement for that standard.

A.3.2.2 Stimulation parameters

The appropriate limits for maximum current are not clear from the published data. In any case, these limits can vary depending upon the relationship of the electrode surface to the region of the spinal cord being stimulated. Although there have been no reports of nerve damage in patients due to excessive current, there have been fundamental studies conducted in animals that identify the stimulation parameter windows that allow safe stimulation (Agnew and McCreery, 1990). Since patient discomfort or transient interference with movement or sensation may occur as a result of excessive spinal cord stimulation, the standard requires a maximum output control that can be set by the physician.

Current from epidural electrodes is largely shunted through the cerebrospinal fluid; for short dipoles, these current limits may be excessively low.

The rationale for the test circuit of figure 1 is, first, simplicity. Second, the pure resistive load presents a worst-case (maximum) measurement of average pulse amplitude. The addition of a parallel resistor capacitor circuit in series with the 500-ohm resistor to simulate the electrode-tissue interface would decrease the average amplitude of each pulse by decreasing the time constant of the pulse drop.

A.3.2.3 Waveform

Because the optimum waveform is not known, only documentation of the waveform is required. Nevertheless, the negative and positive currents must be balanced over time in order to avoid electrode deterioration.

A.3.2.4 Controls

See A.3.2.2.

A.3.2.5 Test stimulation

One reason for using temporary spinal electrodes is to test the effectiveness of the system. Therefore, the parameters for the test electrodes must be the same as those for the permanent implant. Sometimes the epidural electrodes are also the permanent electrodes, in which case the problem of equivalent parameters does not arise.

A.3.2.6 Materials

Criteria for biocompatibility remain a subject of scientific research. Therefore, setting specific requirements for acceptance is not a feasible or responsible approach to this issue. There have been clinical experiences with a number of materials for the receiver encapsulant or coating, the wire insulation, and the electrode pad (e.g., silicone rubber, fluorinated polymers, epoxies, polyethylurethanes, and polyester fabrics). Platinum or platinum-iridium metals have been used as materials of composition for the electrodes. New materials that have been shown to be biocompatible for use in cardiac pacemakers and cardiac pacing leads might be appropriate for use in spinal cord stimulators and thus warrant evaluation.

The assessment of the biocompatibility of materials used in medical devices depends, to a large degree, upon the end use of the device. The committee judged that an evaluation of the biocompatibility of materials for use in implanted stimulators could best be approached by reviewing the tests described in the ASTM *Recommended practice for selecting generic biological test methods for materials and devices* (ASTM, 1982). This standard provides a guide to the selection of biocompatibility tests based upon end use, and it discusses the significance of each test. Selection and use of any or all of these tests should be determined according to the specific intended use of the material in the implanted stimulation device; this determination is best left to the discretion of the device manufacturer. It should be noted that the tests suggested in the ASTM standard address the "effect of the material on body tissue and/or fluid."

Annex B
(informative)

Bibliography

AGNEW, WF. and MCCREERY, DB. *Neural prostheses, fundamental studies.* Englewood Cliffs, NJ: Prentice Hall, 1990.

AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Recommended practice for selecting generic biological test methods for materials and devices*. F748. Philadelphia: ASTM, 1982.

BURTON, CV. Session on spinal cord stimulation: Safety and clinical efficacy. *Neurosurgery*, 1977, vol. 1, p. 164-165.

DE LA PORTE, C. and SIEGFRIED, J. Lumbosacral spinal fibrosis (spinal arachnoiditis): Its diagnosis and treatment by spinal cord stimulation. *Spine*, 1983, vol. 8, no. 6, p. 593-603.

ERICKSON, DL. Percutaneous trial of stimulation for patient selection for implantable stimulating devices. *J. Neurosurg*., 1975, vol. 43, p. 440-444.

FOX, JL. Problems encountered with implanted electrodes for dorsal column stimulation for pain. In FT Hambrecht & JR Reswick (Eds). *Functional electrical stimulation.* New York: Marcel Dekker, 1977.

GRILLO, PJ., HENRY, CY., and PATTERSON, RH. Delayed intraspinal hemorrhage after dorsal column stimulation for pain. *Arch. Neurol*., 1974, vol. 30, p. 105-106.

HOSOBUCHI, Y., ADAMS, JE., and WEINSTEIN, PR. Preliminary percutaneous dorsal column stimulation prior to permanent implantation. *J. Neurosurg.*, 1972, vol. 37, p. 242-245.

KAHN, AR. and MAVEUS, TC. Technical aspects of electrical stimulation devices. *Med. Prog. Technol.*, 1972, vol. 1, p. 58-68.

KRAINICK, JU. and THODEN, U. Experience with spinal cord stimulation for the control of postamputation pain. Paper presented at the 7th International Congress on Neurological Surgery, Munich, Germany, July 12-18, 1981.

KUMAR, K., NATH, R., and WYANT, GM. Treatment of chronic pain by epidural spinal cord stimulation: A 10-year experience. *J. Neurosurg*., 1991, vol. 75, p. 402-407.

LAW, J. Spinal stimulation: Statistical superiority of monophasic stimulation of narrowly separated, longitudinal bipoles having rostral cathodes. *Appl. Neurophys.*, 1983, vol. 46, p. 129-137.

LONG, DM. and ERICKSON, DE. Stimulation of the posterior columns of the spinal cord for relief of intractable pain. *Surg. Neurol.*, 1985, vol. 4, p. 134-141.

LONG, DM. Stimulation of the peripheral nervous system for pain control. *Clin. Neurosurg*., 1983, vol. 31, p. 323-343.

MELZACK, P. and WALL, PD. Pain mechanisms: A new theory. *Science*, 1965, vol. 150, no. 3699, p. 971-978.

NASHOLD, BS. and FRIEDMAN, H. Dorsal column stimulation for control of pain: Preliminary report on 30 patients. *J. Neurosurg*., 1972, vol. 36, p. 590-597.

NEILSON, KD., ADAMS, JE., and HOSOBUCHI, Y. Experience with dorsal column stimulation for relief of chronic intractable pain. *Surg. Neurol*., 1975, vol. 4, p. 148-152.

NORTH, RB., FISCHELL, TA., and LONG, DM. Chronic stimulation via percutaneously inserted epidural electrodes. *Neurosurgery*, 1977, vol. 1, p. 215-218.

NORTH, RB., EWEND, MG., LAWTON, MT., and PIANTADOSI, S. Spinal cord stimulation for chronic, intractable pain: Superiority of "multichannel" devices. *Pain*, 1991, vol. 44, p. 119-130.

NORTH, RB., KIDD, DH., ZAHURAK, M., JAMES, CS., and LONG, DM. Spinal cord stimulation for chronic, intractable pain: Two decades' experience. *Neurosurgery*, 1993, vol. 32, p. 384-395.

PINEDA, A. Dorsal column stimulation and its prospects. *Surg. Neurol.*, 1975, vol 4, p. 157-163.

RAY, CD. and MAYER, DD. Electrical neurological stimulation systems: A review of contemporary methodology. *Surg. Neurol.*, 1975, vol. 4, p. 82-89.

SHEALY, C., MORTIMER, J., and RESWICK, J. Electrical inhibition of pain by stimulation of the dorsal columns: A preliminary report. *Anesth. Analg*., 1967, vol. 46, p. 489-491.

SHEALY, CM., MORTIMER, JT., and HAGFORS, NR. Dorsal column electroanalgesia. *J. Neurosurg*., 1970, vol. 32, p. 560-564.

SHELDEN, CH. Depolarization in the treatment of trigeminal neuralgia: Evaluation of compression and electrical methods, clinical concept of neurophysiological mechanism. In *Pain* (Henry Ford Hospital Symposium). Boston: Little, Brown & Co., 1966.

SHELDEN, CH., PAUL, F., JACQUES, DB., and PUDENZ, RH. Electrical stimulation of the nervous system. *Surg. Neurol*., 1975, vol. 4, p. 127-132.

SIEGFRIED, J. and LAYORTHES, Y. Long-term follow-up of dorsal column stimulation for chronic pain

syndrome after multiple lumbar operations. *Appl. Neurophysiol.*, 1982, vol. 45, p. 201-204.

SPIEGELMANN, R. and FRIEDMAN, WA. Spinal cord stimulation: A contemporary series. *Neurosurgery*, 1991, vol. 28, p. 65-71.

SWEET, W. and WEPSIC, J. Treatment of chronic pain by stimulation of primary afferent neuron. *Trans. Amer. Neurol. Assn*., 1967, vol. 93, p. 103.

SWEET, W. and WEPSIC, J. Stimulation of the posterior columns of the spinal cord for pain control. *Clin. Neurosurg.*, 1974, vol. 21, p. 278-310.

URBAN, BJ. and NASHOLD, B. Percutaneous epidural stimulation of the spinal cord for relief of pain: Long term results. *J. Neurosurg.*, 1978, vol. 48, p. 323-328.

U.S. FOOD AND DRUG ADMINISTRATION. Medical devices: Classification of implanted spinal cord stimulators for pain relief (Proposed Rule; 21 CFR Part 882). *Federal Register*, vol. 43 p. 229.

U.S. FOOD AND DRUG ADMINISTRATION. Neurological devices: Classification of implanted spinal cord stimulators for pain relief (Final Rule; 21 CFR Part 882). *Federal Register*, vol. 44, p. 172.

WALL, PD. and SWEET, WH. Temporary abolition of pain in man. *Science*, 1967, vol. 155, p. 108-109.

YOUNG, RF. Evaluation of dorsal column stimulation in the treatment of chronic pain. *Neurosurgery*, 1978, vol. 3, p. 373-379.