INTRODUCTION

Advances in spinal cord stimulation (SCS) have resulted in new stimulation platforms. Historically, creation of electrical fields resulting in paresthesia was fundamental to SCS analgesia. However, paresthesia-free therapy is now available, as are other platforms. This article will provide a brief overview of neuromodulation platforms.

CURRENT VERSUS VOLTAGE

The internal pulse generator (IPG) uses either a constant current (CC) or a constant voltage (CV) power source. A CC source supplies current to tissue by adjusting voltage in response to impedance, resulting from lead positioning, fibrous encapsulation, and scar tissue. A CV source adjusts current in response to impedance, maintaining constant voltage. Changes in impedance affect strength of stimulation during a stimulus pulse and efficacy of stimulation over time.

Although both systems produce paresthesia and effectively treat chronic pain, limited studies reveal that some patients prefer CC stimulation, describing more comfortable and better pain relief. Why patients prefer CC over CV stimulation is unknown but may reflect differences in pulse shape. CV generates spike-shaped pulses, which steepen with rise of impedance at the beginning of each pulse. CC generates rectangular-shaped smooth pulses, created in response to increased impedance, which may be perceived as more comfortable.

TONIC STIMULATION

Paresthesia is created by manipulating three basic elements of SCS: frequency, amplitude, and pulse width. Frequency is how often the device delivers charge and depolarization. Amplitude is the relative strength of charge delivered. Pulse width is the duration of charge delivery. Traditionally, tonic stimulation involves low frequencies, typically in the 20–120 Hz range. Amplitude is adjusted until the patient feels stimulation. Perception threshold is the amplitude first detected by the patient. Discomfort threshold is the amplitude when the patient feels paresthesia transitioning from pleasant to noxious. The difference between perception and discomfort threshold comprises the therapeutic window of stimulation amplitude for an individual patient.

Because pulse width is adjustable to widen or narrow the electrical field, amplitude and pulse width have been the primary parameters adjusted during trialing and maintenance of SCS. Frequency is adjusted to alter the “smoothness” of perceived stimulation.

HIGH-FREQUENCY STIMULATION

Low frequencies (20–120 Hz) result in patients feeling individual pulses. At higher frequencies, pulses start to blend, resulting in a tingling sensation without detection of individual pulses. Recently, investigators examined the effect of altering the frequency rate. In preliminary work, application of higher frequency rates in SCS has shown promise for low back pain, while maintaining efficacy for neuropathic pain syndromes. Two-year data shows maintenance of such effect.

Because of these advances, neuromodulation nomenclature has changed. Traditional methods of tonic SCS programming are called “conventional” stimulation, whereas platforms between 500 to 10,000 Hz—platforms with higher frequency bursts of stimulation—are now called “high-frequency” (HF) stimulation.

The 10 kHz setting is an energy-demanding form of stimulation, requiring frequent charging of the device.

BURST STIMULATION

Pulse shape is one factor determining nerve fiber response to SCS. Another factor is the frequency of pulses used to activate large fibers in dorsal column. Frequencies of SCS impulses vary between 30 and 120 Hz but are usually in the range of 50 Hz. Burst stimulation is an alternative paradigm created to combine elements of high-frequency stimulation with less energy-demanding requirements of tonic stimulation. As such, it offers concise signal transmission, allowing for passive discharge during the recovery phase between each pulse within the burst pulse train and between each group of burst pulse trains. This differs from cycling, as cycling requires an active discharge in the recovery phase. The de Ridder burst waveform uses pulse trains of five high-frequency spike pulses at 500 Hz, occurring 40 times per second.

Burst stimulation mirrors neuronal firing patterns in the spinal cord. These neurons fire in groups of action potentials, followed by periods of quiescence, akin to the burst program generated by the IPG. Other neurons, at the same stage of sensory processing, fire in

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a tonic or continuous manner. Neuronal languages are transmitted as firing patterns and allow communication from spinal cord to brain. To intervene effectively, a SCS device should speak the same language.

Experimental data extracted from laboratory and clinical studies suggest both bursting and tonically firing neurons efficiently transmit information to thalamus. Laboratory animal studies suggest that burst firing is more powerful than tonic firing in activating the cerebral cortex. Results have been interpreted as showing that burst activation requires less temporal integration and may activate dormant neurons not otherwise activated by tonic stimulation.

**HIGH-DENSITY STIMULATION**

As HF platforms were being trialed abroad and reported in the United States, American investigators began researching additional capabilities of existing stimulation technology to assess if frequencies in the upper ranges would benefit patients. Although most programming in the United States falls in the 20–120 Hz range, existing technology can increase the frequency of then-available systems to >1000 Hz. This option enhanced opportunities to deliver more charge per second to the spinal cord, often in a superperception threshold amplitude, resulting in a greater charge delivered per second than with conventional stimulation. This is without the higher frequencies of 10K stimulation or burst patterns described by DeRidder. Thus, SCS pulses are the equivalent of a charge dose delivered to the spinal cord, consistent with medication daily dose in intrathecal drug delivery. Specifically, the dose would be consistent with charge (dose) per second. As such, delivery of maximum frequency achievable by a conventional SCS, with manipulation of amplitude and pulse width as needed, would increase time within any given second that charge (dose) is delivered. Compared to conventional SCS, a higher density of charge delivered would be created. This concept became known as “high-density SCS [or] HD” stimulation.

**CONCLUSION**

Evolution of waveform technologies has been impressive. Pain specialists should stay informed of advances in neuromodulation to help more patients and to enhance generalizability of therapy. The ASRA Neuromodulation Special Interest Group (SIG) (link to www.asra.com/neurosig) was founded in 2014 and is an important resource for members interested in learning more about this therapy. The goals of the ASRA Neuromodulation SIG are to promote the advancement of neuromodulation in the treatment of chronic pain, provide leadership in the responsible and safe use of neuromodulation therapies, and encourage scholarship and research to support neuromodulation strategies in a patient-centric fashion.

**REFERENCES**