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Original Research Article

Anatomical Considerations for Placing Spinal Cord Stimulators in Patients with Coronary Vascular Disease and Cardiomegaly

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ABSTRACT

Background: The Spinal Column Stimulator (SCS) of the dorsal columns was first used in 1967 as a nonpharmacologic option for treating chronic intractable cancer pain. It works by blocking pain signals before they reach the brain. The device sends electrical pulses to electrodes placed over the spinal cord. These pulses modify the pain signals, which either make them imperceptible or replace them with a tingling sensation. It is important to note that spinal cord stimulation does not eliminate the source of pain, but rather changes how the brain perceives it. The placement of the electrode leads varies depending on the conditions being treated. SCS has become widely used both as an effective and practical option for the management of refractory chronic pain that is unresponsive to conventional treatments.

Results: While medical students were dissecting the body of a 91-year-old male donor who died of atherosclerotic coronary vascular disease and cardiomegaly, they encountered an implanted SCS device. Further dissection showed electrodes from the pulse generator reaching midthoracic level; the anodes and cathode leads were in the dorsal epidural space. The fact that the leads were in the midthoracic region and the donor had chronic atherosclerotic coronary vascular disease and cardiomegaly, he was probably treated for pain related to his cardiac conditions (refractory angina pectoris).

Conclusions: In the SCS procedure, numerous anatomical structures within the spinal canal, such as the fatty tissue inside the epidural space, membranes of the dural sac, cerebrospinal fluid (CSF), and spinal cord nerve roots and rootlets, could affect the outcome for the patient.

KEYWORDS: Spinal Cord Stimulators; Anatomy of the spinal canal; Treating chronic intractable pain; Neural mechanism of pain perception.

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INTRODUCTION

Shealy and colleagues first used the SCS of the dorsal columns in 1967 as a nonpharmacologic option for treating chronic intractable cancer pain [1]. The SCS has become widely used as both an effective and practical option for the management of refractory chronic pain that is unresponsive to conventional treatments [2].

Based "on Melzack and Wall's gate control theory of pain, it was initially hypothesized that electrical stimulation of Aβ fiber projections within the dorsal horn would inhibit nociceptive signals conducted by small Aδ and C fibers" [3,4]. Its simplicity has provided a valuable frame of reference to explain pain generation and control mechanisms. The pain could be controlled by selective activation of large-diameter fibers. Anatomically, this physiological stimulation of dorsal columns inhibits activity in the lateral spinothalamic tract and increases activity in descending antinociceptive pathways [5]. A spinal cord stimulator delivers electric pulses through electrodes placed over the spinal cord, masking pain signals before they reach the brain. The pain signals are either not perceived or are replaced by a tingling feeling [6].

Patients use a remote control to send electrical impulses through the implanted device when they feel pain. Both the remote control and its transmitter are outside the body.

De Andres, et al. made a detailed morphological analysis of spinal anatomical structures and their influence on neuromodulation [7].

This will be further discussed in a later section. Various metal electrodes are placed in the dorsal epidural space to achieve spinal cord stimulation. A pulse generator supplies the energy and the contacts are programmed with combinations of anodes and cathodes to generate an electric field that stimulates the axons of the dorsal root and dorsal column fibers in the spinal column. The resulting stimulation of dorsal columns is an inhibition of activity in the lateral spinothalamic tract and increased activity in descending antinociceptive pathways[5].

During dissection of the body of a 91-year-old male donor who died of atherosclerotic coronary vascular disease and had an enlarged heart (cardiomegaly), medical students encountered an implanted SCS device with electrodes reaching midthoracic level and the pulse generator embedded subcutaneously on the lower back. An extensive literature search indicated that one of the factors in the success of SCS is the anatomical structures between the electrodes and the spinal cord.

For achieving the desired result, several anatomical factors, such as size of the epidural space, amount of epidural fat, and amount of CSF where the leads will be placed, should be considered. The largest epidural space is in the lumbar region, and the smallest is in the cervical region [8].

The placement of leads varies with the goal of the implantation. Feirabend, et al. presented a case of midthoracic placement for refractory angina pectoris (severe chest pain due to coronary artery disease) [10].

METHODS

The cadaveric specimen was obtained from the willed body program intended for the purpose of medical student dissection. This case report is based on the dissection of a 91-year-old Caucasian male donor who died of atherosclerotic coronary vascular disease. As part of their learning, the students performed a major part of the dissection; hence, some normal anatomical structures were not optimally dissected and preserved. When dissecting to expose the spinal cord and its related structures at the lower end of the thoracic and lumbar regions, we encountered the implanted SCS device and the pulse generator embedded subcutaneously on the lower back with its anode and cathode leads in the dorsal epidural space (see Figures 1-4). To establish where the leads ended, we performed a laminectomy of the entire vertebral canal and noted that the leads ended at the midthoracic level (see Figures 1-4).

RESULTS

When dissecting to study the anatomy of the back, students performed laminectomy to expose the spinal cord and its related anatomical structures from the level of midthoracic to the lumbosacral region. In this process, the students encountered the implanted SCS device and the pulse generator (Boston Scientific, Spectra WaveWriter), embedded subcutaneously on the lower back with its anode and cathode electrode leads in the

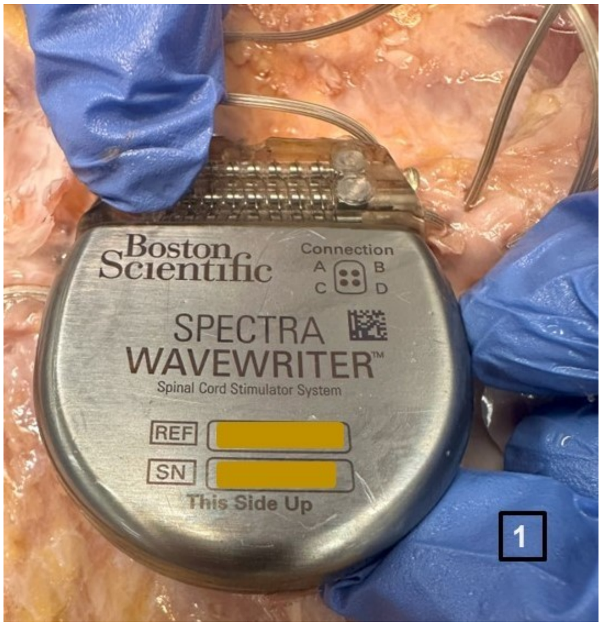

Fig. 1: SCS device (Boston Scientific)

Legend: The image shows the Boston Scientific spinal column stimulator system (Spectra Wavewriter) implanted in the donor's lumbar region. The reference number and other identifiers are blocked to make the donor unidentifiable.

Fig. 2: SCS device with leads

Legend: This image shows the implantation of the SCS system in the left lower lumbar region with the leads extending into the dorsal thoracic epidural space.

Fig. 3: Lead placement along the spinal column

Legend: A closer view of the leads placed in the epidural space through the original incision, making it possible to avoid making a second incision for "snaking" the leads. There are two leads on either side of the spinal cord since the leads sometime move.

Fig. 4: Detail of the lead placement in the dorsal epidural space

Legend: A closer view of the epidural space with the two leads and the 6 electrodes situated on either side of the spinal cord. Normally, the lead wires will have 4 to 8 electrodes, and, because of lead migration, a second lead is placed to improve more pain coverage (as seen in this case in Figure 3 and 4), where the 2 leads are placed lateral to the midline.

dorsal epidural space (see Figures 1-4) reaching up to midthoracic level. Additionally, laminectomy of the entire vertebral column ascertained that the two electrode leads with six electrodes ended at midthoracic level (see Figures 3-4). As seen in the figures, the implantation followed the 'percutaneous approach,' since there was only one incision on the left flank to place the rechargeable implantable pulse generator (IPG); the same incision was used to insert the electrode leads to the dorsal epidural space.

Further dissections of the thoracic structures also revealed cardiomegaly resulting from left ventricular hypertrophy and dilated right and left atriums. The right ventricle was nearly normal without obvious hypertrophy. There were vast coronary artery atherosclerotic lesions and moderate valvular calcifications of the tricuspid, mitral, and aortic valves. The thickness of the ventricular walls varied between 191 and 226 mm on the left (normal range: 12-18 mm) and between 61 and 69 mm on the right. Calcification and thickening of the tricuspid and mitral valves resulted in the enlarged (volume capacity) atriums observed. During the examination, we noticed some heart-related changes. These included the presence of sclerotic plaques in the aorta and coronary arteries and the calcification of the aortic valves. It is essential to note that the heart was enlarged to twice its normal size and the left ventricle wall was twice as thick as normal. Additionally, the right ventricle wall was also thickened. Although the atria were thinned and enlarged, the left atrium was more enlarged than the right.

We observed a small incisional mark on the right epigastric region during the examination. Further dissection revealed that the mark was a remnant of a previous cholecystectomy surgery. Additionally, we discovered a large mass of lipoma in the right epigastric space of the abdomen, which was contained within its own pocket.

DISCUSSION

SCS is mostly utilized after nonsurgical pain treatment choices have failed to give adequate relief [11]. SCS is often used to treat or manage several different types of chronic pain, such as failed back surgery syndrome, complex regional pain syndrome, refractory angina pectoris (severe chest pain due to coronary artery disease), pain after amputation, cancer pain, spinal cord injury, low back pain and sciatica, multiple sclerosis, neuropathic pain, etc. [3].

However, there also are contraindications to SCS placement that include bleeding disorders, sepsis, cognitive impairment, unresolved psychiatric disorders, and/or substance use disorder [3].

The placement of the electrode leads varies depending on the condition(s) being treated. In this case, the fact that the leads were in the midthoracic region and the donor had chronic atherosclerotic coronary vascular disease and cardiomegaly, he probably was treated for pain related to his cardiac conditions (refractory angina pectoris).

Spinal cord stimulation has become a widely used and efficient alternative for the management of refractory chronic pain that is unresponsive to conservative therapies [2]. SCS is typically used with other pain management modalities, including medications, exercise, physical therapy, and relaxation.

For achieving the desired result, several anatomical factors, such as the size of the epidural space, amount of epidural fat, and amount of CSF where the leads will be placed, are to be considered. The epidural space superiorly extends from the dura of the foramen magnum to the lumbosacral space inferiorly and is the target for threading the percutaneous trial electrode. The size of epidural space, as measured by the distance between the ligamentum flavum and the dura, varies, being largest in the lumbar (5-6 mm), thoracic (3-4 mm), and smallest in the cervical region (1.5-2 mm) [8]. Normally, the lead wires will have 4 to 8 electrodes and, because of lead migration, a second lead is placed to improve more pain coverage (as seen in this case in Figure 3), where the two leads are placed lateral to the midline [9].

The placement of leads varies with the purpose: cervical for shoulder and upper limb pain; lumbar for lower limb and pelvic pain; and midthoracic, as seen here, for refractory angina pectoris [10].

It is important to consider the anatomical barriers in the placement of the SCS system in the dorsal epidural space. De Andres, et al. made a comprehensive morphological analysis of the influence of spinal anatomical structures in neuromodulation [7].

The electric field generated by the electrodes is affected by the morphology of the different structures between them, as well as the axons themselves, their thickness, and their electric conductivity [7].

In the SCS procedure, anatomic structures, such as the fatty tissue inside the epidural space, membranes of the dural sac, CSF, spinal cord, nerve roots, and rootlets, influence the intent of the procedure [7]. The amount of epidural fat and its distribution varies in any given region of the spinal column and other spinal deformities, such as scoliosis and kyphosis, contribute to the distribution of both fat [12,13] and spinal fluid [14].

The number and size of the anterior and posterior roots and rootlets vary in any given spinal cord region; this important anatomical structure influences the SCS purpose and placement [15].

In placing the leads in the epidural space, it is important to be aware of the normal cervical and lumbar enlargement that includes spinal segments C5-T1 and spinal segments L2-S3 [16].

CSF is the most conductive intraspinal element, followed by nerve fibers of white matter. Therefore, an electrical field that reaches the CSF has the greatest potential to be conducted to nearby structures within the cord; the longitudinal white matter demonstrates the greatest conductivity [17].

Leads are placed in the posterior epidural space in the midthoracic region with a large epidural space; the paresthesia is the highest. The percutaneous cylindrical and flexible lead is easy to place in the epidural space; the donor had cylindrical leads with seven 3 to 4 mm bead-like contacts (electrodes) in the epidural space (see Figure 4), which had the advantage of recapturing stimulation [18,19].

CONCLUSION

Persistent and unmanageable pain can greatly reduce one's quality of life. For those patients who have tried traditional treatments without success, spinal cord stimulators offer a non-pharmacological alternative. This study allowed us to explain to the learners how a physiological function can be interfered with by the anatomy surrounding the placement of a device that functions based on the principles of physiology. The placement of the electrode leads varies depending on the conditions being treated. The fact that the leads were in the midthoracic region and that the donor had chronic atherosclerotic coronary vascular disease and cardiomegaly indicates that he was probably treated for pain related to his cardiac conditions (refractory angina pectoris). Similarly, any chronic pelvic pain due to cancer and shoulder pain due to injury can be treated by placing electrodes in the lumbar and cervical regions.

ABBREVIATIONS

SCS- Spinal cord stimulator;
CSF- Cerebrospinal fluid;
IPG-implantable pulse generator

Author Contributions

Dr. Melovitz-Vasan participated in the initiation and design of the project, as well as conducting microdissections and taking photographs. She contributed to the analysis and interpretation of data and the preparation and editing of the manuscript. She has given final approval of the version to be published.

Ms. Huff conducted a literature search and reviewed and revised the manuscript critically for important intellectual content. She has given final approval of the version to be published.

Dr. Vasan participated in the initiation and design of the project, as well as conducting microdissections and taking photographs. He contributed to the analysis and interpretation of data and the preparation and editing of the manuscript. He has given final approval of the version to be published.

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The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human donors in anatomical research. For research using human subjects, AAA endorses the protections embodied in the Basic Principles of the Declaration of Helsinki and their expansion in the regulations governing research supported by the U.S. Government (45 CFR Part 46; 56 FR 28003).

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Conflicts of Interests: There are no competing interests to declare.

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