Historical Vignette

History of spinal cord stereotaxy

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The development of stereotactic and functional neurosurgery is highlighted by the many innovative contributions made by neuroscientists in an attempt to reference intracranial points to a specific coordinate system using precise measurements. The originators of animal stereotactic surgery, Sir Victor Horsley and Robert H. Clarke, provided the foundation on which Ernest Spiegel and colleagues could apply this technique to humans in 1947. This was soon followed by the exponential growth and technological development of stereotactic systems designed for intracranial neurosurgical procedures.

Spinal Cord Stereotaxy

Stereotaxis has not been limited in its use to intracranial operations. Interestingly, long before Horsley and Clarke’s landmark paper appeared in Brain in 1908, the first attempts at localization of specific points in the central nervous system began with experimental studies of the spinal cord. The earliest documented use of the principle of guiding devices for directing probes to their targets appeared in the work of Dittmar in 1873. While working at The Physiological Institute of Professor Ludwig in Leipzig, Dittmar investigated the vasoconstrictor pathways of the spinal cord by directing a small knife attached to a guiding apparatus into the cord. Although his system was not based on a true coordinate system, the probes he used did have three orthogonal degrees of precision.

In the following year, Woroschiloff, from the same institution, developed his own apparatus called the “myelotome,” which was capable of guiding a scalpel into the spinal cord of rabbits to study the effects of certain lesions. Woroschiloff’s special fixation device (Fig. 1) required exposure of the spinal cord and was attached by screws to the spinous processes on both ends of the laminectomy. Attachment of a locating device to the clamps in a longitudinal axis permitted precise movements of two fine knives in the vertical and horizontal planes. These knives were later replaced by electrodes to perform electrostimulation experiments.

The devices of Dittmar and Woroschiloff should be considered precursors to true stereotaxis, a concept brought to fruition by Horsley and Clarke many years later, because they did not rely on a Cartesian or polar coordinate system. These fundamental principles form the basis for stereotaxis, which allows any point in space to be referenced to a specific coordinate system using precise measurements.

The first true stereotactic instrument designed for use on the spinal cord was reported by Clarke in 1920. The apparatus (Fig. 2) was constructed in an attempt to apply the same principles to the spinal cord as his instrument used for the brain. The device consisted of a cradle with four pivotable legs that could be firmly secured to surgically exposed vertebrae. Attached to the cradle, parallel to the cord surface, was a traveling stage that supported a needle holder capable of graduated movements in three planes. The accuracy of the lesions was confirmed by histological sections. There are no data confirming Clarke’s use of the instrument, but because it was later possessed by Barrington, it may have been used to investigate the micturition pathways via discrete spinal cord lesions.

As with cranial procedures, stereotaxis was initially

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limited to neurophysiological experiments. When Spiegel, et al., introduced their stereoecephalotome in 1947, stereotaxis began to display its usefulness in the clinical setting. However, the development of spinal cord stereotaxis lagged behind. One major impediment to the use of stereotaxis in the human spinal cord was the lack of a stereotactic atlas. Although Taren, et al., provided gross measurements for target physiological corroborations, Nádvorník and colleagues presented cat models for experimental stereotaxy, and later Zlatesco, et al., published their contributions to the topometry of the spinal cord, the location of the bulk of fiber tracts was often disputed and considerable individual variations existed. Another difficulty with spinal cord stereotaxy was the mobility of the spinal cord within the confines of the subarachnoid space and its bony coverings in contrast to the brain, which is relatively immobile.

It was not until 1963, when Mullan, et al., described their procedure for percutaneous cordotomy, that the use of closed procedures on the spinal cord became a human clinical reality. Although earlier techniques and, later, the anterior approach of Lin, et al., did not constitute true stereotaxis because they did not rely on a guiding apparatus, they were based on radiographic and anatomical landmarks to facilitate passage of a needle in a predetermined fashion.

Soon after the introduction of percutaneous cordotomy, came the first report of a true stereotactic procedure performed on the human spinal cord. In 1965, Rand and coworkers at the University of California at Los Angeles reported two cases in which they detailed the use of the Rand–Wells Mark II stereotactic guide system for cryogenic lesioning of the cervical spinal cord. The stereotactic apparatus was fixed to the skull at three points and the C1–2 intralaminar space was placed at the center of the lateral circles of the arc system (Fig. 3). Using air myelograms and telerointgenograms, a cryoprobe was inserted percutaneously so that it could lie against the anterior quadrant of the cervical spinal cord. Although the stereotactic technique worked well in their two patients, cryocordotomy did not achieve the same long-lasting pain relief as that achieved using strontium-90 or radiofrequency lesions.

The success of percutaneous cordotomy and the advances of stereotactic surgery led Crue and associates to perform a posterior percutaneous trigeminal tractotomy in 1967. Using the Todd–Wells stereotactic frame, these surgeons were able to angle a needle upward above the arch of C-1 and below the posterior rim of the foramen magnum into the brainstem successfully to lesion the descending trigeminal nucleus and tract in a patient with trigeminal neuralgia.

In the following year, these surgeons applied their posterior stereotactic approach to the spinal cord of patients with intractable pain due to advanced neoplastic disease. The impetus for a new approach arose from their less-than-optimal experience in nine patients using the lateral approach described by Mullan, et al. Despite adequate visualization of the dentate ligament using pantopaque contrast and air mixed with cerebrospinal fluid, as suggested by Rosomoff and coworkers, Crue and associates believed that some discrepancy existed in the correct placement of the tip of the needle electrodes. They also...
noted that the spinal cord exhibited considerable movement in the anteroposterior and rotational planes, which could alter the accurate placement of target lesions.3

Crue and associates’ posterior cordotomy procedure also enlisted the use of the Todd–Wells stereotactic frame. Based on experimental work in cat and human cadavers, they used a line 3 to 4 mm lateral to the midline of the odontoid on a posteroanterior x-ray view as a landmark. They then passed an electrode at a right angle through the C1–2 interspace until it reached the anterior floor of the cervical canal and made multiple lesions as the needle was withdrawn (Fig. 4).3,31 All five of their original patients achieved initial satisfactory pain relief from the posterior stereotactic method.3

Another contribution to the development of spinal cord stereotaxis came from the work of Puletti and Blomquist26 at the University of Wisconsin. They devised a technique for recording single neuron potentials in the human spinal cord and provided two illustrative examples. A microelectrode holder capable of vertical movements was fastened to a micromanipulator, which could be moved in two translational planes. The micromanipulator was bolted to a Scoville retractor that, when placed in an open laminectomy wound, provided a constant distance between the electrode holder and the spinal cord during respiratory cycles (Fig. 5).26 Puletti and Blomquist envisioned the use of these single neuron activity recordings as an adjunct to selecting specific pathways for sectioning during surgery for intractable pain.

A major contribution to spinal stereotaxis came from the work of Edward Hitchcock8–16 at the University of Edinburgh in Scotland. Based on cadaveric and surgical observations, he noted that the upper cervical cord had the least mobility due to the lower cranial nerves and a large first dentate ligament when the neck was in the fully flexed position.10,13,16 Using these observations he began to perform stereotactic lesions on the human spinal cord in 1967. His first attempt was in a 22-year-old man with metastatic teratoma.15 Using a modified Leksell frame, Hitchcock performed a successful stereotactic spinothalamic tractotomy via the atlantooccipital membrane. Histological examination confirmed the placement of the lesion; however, he noted several problems with the Leksell frame, including difficulty with frame fixation for a posterior cervical approach. He also had doubts regarding the accuracy of the lesion because the target was at the extreme corner of the frame.16

To remedy these problems, Hitchcock developed a stereotactic frame designed specifically for use in spinal cord stereotaxis.8,13 (It was later used for intracranial stereotaxis as well.) The square frame was of constructed aluminum alloy with three-point skull fixation (Fig. 6). Using teleradiography and specifying the odontoid process as a reference point, the target site (chosen on the basis of the desired analgesic level) could be related to the stereotactic apparatus. The frame had two bars that allowed for vertical and horizontal movements to set the electrode length and laterality.14

In his initial report Hitchcock detailed two cases of successful high cervical spinothalamic tractotomies. He later expanded his technique to include stereotactic trigeminal tractotomies and myelotomies in the surgical treatment of intractable pain.15,12,15 Although more time-consuming than simple aiming techniques, he believed that his stereotactic methods offered greater accuracy and he envisioned the possible expansion of his technique to other applications, such as spinal cord biopsy, aspiration of syringomyelic cysts, and treatment of certain movement disorders.9,16 Not only did Hitchcock contribute to the field of stereotaxis by his invention of a new apparatus, but he also deserves much credit for furthering our understanding of spinal cord function through his electrophysiological studies.

Up to this point spinal cord stereotaxis was limited to the cervicomedullary region. In 1972, Nádvorník, et al.,23 expanded its clinical usefulness one step further with their development of an apparatus designed for use in the lumbar region. Their instrument resembled that of Woroschiloff and required fixation to the vertebral arch in an open laminectomy wound. Nádvorník’s device (Fig. 7) carried a uni- or bipolar electrode capable of movements in perpendicular planes. The target point was reached by referring to model maps of single segments in the lumbar enlargement, which were made in the Anatomy Institute of the Comenius University in Bratislava.23 The instrument was initially used for treating flexor spasms in a patient with spastic paraparesis by lesioning the anterior horns of L3–S1 and for treating a neurogenic bladder in another patient by surgery in the S-2 segment. Nádvorník later modified his instrument so that it could attach to a wound retractor and support a suction device, cold light, and magnifying glass. Over a 15-year period, he and his colleagues performed 88 procedures, including 66 C1–2 procedures for pain, 19 thoracolumbar procedures for spasticity, and three sacral procedures for neurogenic bladders.22

In 1981, Nashold and Cosman (unpublished data) designed and tested a human spinal cord stereotactic instrument built by the Radionics Corporation. It had a small aluminum frame and an electrode drive that could be fixed to the spinal lamina after the spinal cord was exposed (Fig. 8). The electrode holder was advanced by a vernier drive.
mechanism and the radiofrequency electrode could be manipulated in three dimensions as well as angled. The frame was tested in animals, but its use in humans was limited to producing midline myelotomies by making small radiofrequency coagulations.

Another frame was designed by Zlatoš under the influence of Nádvorník, specifically for interventions on the cadaveric spinal cord. This device consists of a “static” part, which rests on the back of the cadaver and is held in place with rubber bands, and a “measuring system,” which is capable of rotational and three-dimensional translational movements (Fig. 9). Zlatoš has compiled an impressive collection of topometric maps from cadaveric human spinal cords; an example of an atlas representation of a cervical spinal cord segment is depicted in Fig. 10. Using computerized tomography (CT) images to determine the transverse and sagittal diameters of the spinal cord at a site of intervention, Zlatoš has been able to localize a target using his stereotactic data with 90% accuracy (J Zlatoš, personal communication, 1995). Although he
concedes that spinal cord stereotaxis is accompanied by several problems intrinsic to the anatomy and individual variability of the cord itself, his atlas may play an important role in the future of stereotactic surgery.

Despite these unique contributions, the practice of spinal cord stereotaxy has not become commonplace in the neurosurgeon’s operative armamentarium. This is probably due to the logistics and time necessary to perform the procedures without any proven significant benefit. Also, the mobility of the spinal cord yields a certain degree of inaccuracy, which can be intolerable when dealing with the precise target lesion necessary for spinal cord surgery.

More recently, the pendulum has shifted toward greater use of stereotaxis for the spinal column. As percutaneous and endoscopic techniques have been developed, attempts have been made to incorporate the principles of stereotaxis to refine their accuracy. In 1990, Heikkinen, a
Finnish neurosurgeon, reported his technique, which uses a modification of the standard Laitinen frame attached to the operating table. By drawing a reference point on the patient’s back and using data from a preoperative CT scan, all three stereotactic coordinates can be measured. Heikkinen’s first experience with this device was in a 60-year-old man suffering from radicular pain caused by a prolapsed disc. With the patient anesthetized, a small trephine opening was made in the lamina and annulus fibrosus to remove the nucleus pulposus. The patient was relieved of his symptoms for 3 months before experiencing a recurrence.

Another method of percutaneous stereotactic discectomy was developed by Koutrouvelis and is named the “PGK” stereotactic device. This apparatus is mounted on the floor and extends over the gantry of a CT scanner (Fig. 11). The angles and trajectory lengths between the entry and target points are defined in relation to an external skin fiducial mark with the electronic cursor on the CT computer screen. The discectomy is then performed with the patient under local anesthesia on the gantry table. The authors’ experience with 77 patients resulted in a 73% success rate for pain-free outcome at 6 to 12 weeks postoperatively with no complications.

With the advent of frameless stereotaxis, the clinical utility of stereotactic technology for operations on the spine has expanded even further. Cadaveric and clinical data are being accumulated on the use of frameless stereotaxis in the accurate placement of pedicle screws for spinal fusions. For example, Nolte, et al, reported a method for safe and accurate placement of pedicle screw fixation in cadaveric lumbar vertebrae. Using a space pointer (Northern Digital, Waterloo, Ontario, Canada) and the Neurological Surgery Planning System, they were able to place 20 pedicle screws without perforating the pedicular walls (Fig. 12). Also, based on their analysis, they did not believe that the total time of surgical intervention using an image-guided system was affected.

However, frameless stereotaxy is still in the early stages of refinement. In the Dartmouth experience with lumbar spine operations using a frameless operating microscope, a 28.8-mm mean error in localizing disc space was reported. This inaccuracy may have been caused by deformations of paraspinal tissues and the vertebral column relative to external skin fiducial markers.

Obviously, more clinical data must be collected before the utility of frameless stereotaxis in spinal operations can be determined. However, the outlook appears promising, especially as technology advances, and greater accuracy should translate into less patient morbidity. As further refinements are achieved, frameless stereotaxy may also come to play a role in intramedullary surgery.
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Summary

In summary, spinal cord stereotaxy is not new to the field of functional and stereotactic neurosurgery. Long before the invention of Horsley and Clarke came the first instruments of Dittmar and Woroschiloff. Although spinal cord stereotaxy has not achieved the same technical advances as intracranial stereotaxis, it has increased our understanding of spinal cord anatomy and physiology. Intramedullary spinal cord frame stereotaxy may never prove to be beneficial, but as percutaneous techniques for disc disease and frameless stereotaxis continue to be refined, spinal cord stereotaxy may still have a future.

References


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