Spinal and Epidural Endoscopy: A Historical Review

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In current-day medicine, endoscopy plays an important role in the diagnosis and treatment of many different conditions. This improving technology has led to new areas of endoscopic visualization, particularly of the epidural space, spinal cord and contiguous structures. A review of the medical literature indicates that clinicians have been working with various types of endoscopes for over sixty years, with varying degrees of success. Only recently has fiberoptic technology been integrated with computer-enhanced imaging to provide a new medium for viewing the central nervous system. The initial results are promising and will likely pave the way for newer, less invasive means of diagnosis and treatment of central nervous system pathology. The direct visualization of the spinal canal and its contents was born in 1931 from the pioneering work of Michael Burman, an orthopedic surgeon from the New York Hospital for Joint Diseases [1]. With each decade since then, myeloscopists and epiduroscopists have attempted to develop a means of fiberoptic visualization that would be easy and safe to apply in medical practice. Unfortunately, until the recent advent of both flexible fiberoptic light sources and optics [2], this could not be achieved. In 1931, Burman removed eleven vertebral columns from cadavera and examined them using then-currently available arthroscope equipment with the hope of developing a minimally invasive technique for the assessment of spinal pathology. As might be expected, the diameter of the trocar in which the lamp was mounted was greater than the average width of the spinal canal itself (approximately 3/8 inch or 9.5 mm). Thus, the viewing lens often was not completely within the spinal canal. In some locations, the spinal canal was wide enough to allow insertion of the scope, permitting visualization of the spinal canal contents such as the dura mater, blood vessels and the cauda equina. However, the field of view allowed by the scope was limited to one inch (2.54 cm). Burman thus concluded that myeloscopy was limited by the available technology, but that with higher quality instrumentation, a better postmortem examination of the cauda equina could be performed in situ. He felt that the ability to visualize the contents of the spinal canal might be especially important in establishing a diagnosis of tumor or inflammation, although he did not anticipate the possibility that an improved device might also allow advances in therapy.

In 1936, Elias Stern from Columbia University’s Department of Anatomy was among the first to describe a spinascope [3]. A working model of this instrument (Figures 1 and 2) was manufactured by American Cystoscope Makers, Inc., and it was specifically designed for the in vivo examination of the spinal canal contents during spinal anesthesia. The instrument was never used clinically, but Stern did envision its use for the direct observation of the posterior roots for rhizotomies in patients with intractable pain and sectioning of these roots for treatment of spastic conditions. With technologic improvements,

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\textsuperscript{b}Abbreviations: CT, computerized tomography.
Figures 1 and 2. Elias Stern's stainless steel introducer with side flush port (Figure 1 [top]). Trocar is removed from introducer, while the rigid optical system (with light source and flush system attached) are inserted (Figure 2 [bottom]). (Reproduced with permission from Reference 3.)

he predicted that this technology could obviate the necessity for extensive exploratory laminotomies.

In March of 1937, a neurosurgeon, J. Lawrence Pool of New York, attempted to improve the preoperative diagnostic assessment of lumbar-sciatic syndrome by examining an anesthetized patient with a myeloscope designed by himself and manufactured by American Cystoscope Makers, Inc. (Figures 3, 4 and 5). Unfortunately, hemorrhage obscured the field of vision, permitting only a fleeting glimpse of the lumbosacral nerve roots [4]. Subsequently, seven volunteer patients were examined without complications, and the cauda equina and blood vessels were first visualized. In addition, flow of blood through epidural vessels was witnessed. In 1942, Pool published a summary of his experience with 400 patients in the journal Surgery [5, 6]. Even in the era before the advent of computerized tomographic (CT) imaging, he noted that by using the myeloscope, he often could establish or confirm a diagnosis, thus avoiding extensive explorations. He was able to identify neuritis, herniated nucleus pulposus, hypertrophied ligamentum flavum,
primary and metastatic neoplasms, varicose vessels, and arachnoid adhesions. Despite his successes and the relative ease of performing such examinations, no further reports of this technique are found in the literature until 1967. This is perhaps because of the widespread acceptance and ease of performance of myelography, coupled with the inability to record intra-procedural images photographically. Much of Pool’s formal documentation was done by hand-drawn sketches (Figure 6).

In the late 1960s and early 1970s, Yoshio Ooi et al., working without knowledge of the American experience, developed an endoscope for intradural and extradural examinations [7-11]. With the advent of fiberoptic light source technology in the 1970s, the device was miniaturized enough to be inserted between lumbar spinous processes in the same manner as a percutaneous lumbar puncture [12]. The fiberoptic technology also protected the tissues from heat injury, since the fibers absorb infrared rays and reflect visible rays. There were no serious complications reported from his series of 86 patients. Post-spinal cephalgia was a common, albeit temporary, feature in 70 percent of the study patients. Descriptions and blurry pictures of normal and abnormal anatomy were obtained, including ligamentum flavum, epidural adipose tissue, the surface of the dural sac and the cauda equina.
From 1967 to 1977, Yoshio Ooi and his colleagues performed 208 myeloscopies using various types of equipment. Their progress was reported in several publications [13, 14] and culminated in 1981 with publication of their technique of myeloscopy and cauda equina blood flow changes during Lasègue's test (stretching of the sciatic nerve caused by extension of the leg) [15]. During these procedures, the intrathecal space was regularly entered with a 1.8 mm rigid scope (Figure 7). The fiberoptics used with this instrument were only for the light source, as the fiberoptic technology for direct epidural space visualization was still a decade away. The authors noted a change in the blood flow of vessels accompanying the cauda equina during the straight-leg raising test. During this maneuver, there was displacement of the cauda equina caudad and anteriorly, which led to a temporary cessation of blood flow. Abdominal straining, coughing and sneezing did not alter the blood flow but did cause slight up-and-down movements of the cauda equina in the lateral position. Unfortunately, with the decrease in diameter of the scope, the amount of light available for good quality pictures was also reduced; thus, a larger myeloscope (2.5 mm) was needed for visualization of the epidural space. Myeloscopy (epiduroscopy), therefore,
Figure 6. A) Normal anatomy with dura mater open and cauda equina visualized; B) Neuritis with reddened, inflamed-looking nerve roots; C) Herniated nucleus pulposus; D) Ventral disc herniation (not seen) with dorsally displaced, broadened nerve roots; E) Hypertrophied ligamentum flavum caused compression of the nerve root near its foramen of exit. The lesion itself was not visualized, but the greatly dilated vessel indicated pressure on that nerve at a lower level; F) Tumor. (Reproduced with permission from Reference 5.)

continued to be considered of limited value in the diagnosis of spinal stenosis, while being an important aid in the diagnosis of pathology associated with development of spinal pain syndromes, such as intrathecal arachnoiditis, tumors and vascular abnormalities. Procedures such as removal of a herniated nucleus pulposus were considered, but due to limitations in the flexibility of the rigid scope, insufficient light and difficulty in distinguishing normal from abnormal tissue, the use of spinal endoscopic equipment remained limited. A flexible myeloscope was theorized to have many advantages, but another decade passed before the advent of such a micromyeloscope.

Rune Blomberg of Sweden was the next to describe a method of epiduroscopy and spinaloscopy in 1985 [16]. It was his interest to study the anatomical variations of the epidural space so that a better understanding about the delivery of epidural anesthetics could be obtained. Blomberg determined that the contents of the epidural space varied
widely, especially with regard to the amounts of fat and connective tissue present in the epidural space. In 12 of 30 postmortem cases that he examined, the epidural contents limited the visibility of the epidural space. Adhesions between the dura mater and the ligamentum flavum, which restricted the opening of the epidural space when gently flushing saline, were demonstrated. In addition, Blomberg was able to position the epiduroscope, which was still quite similar to the original myeloscopes, to visualize the entry of Tuohy needles (specially designed blunt needles used routinely by anesthesiologists to access the epidural space) through the ligamentum flavum into the epidural space. An appreciable amount of dural tenting was often seen when the catheter was introduced through the needle into the epidural space. Once in the epidural space, the orientation of the catheter upon advancement varied greatly and was ultimately determined by the local anatomy. Dr. Blomberg surmised that it was “too early to decide to what extent clinical application is possible with epiduroscopy. Under all circumstances it would be necessary to improve lighting conditions, and to shorten shutter speeds in order to make the method more easily handled.” In 1989, Blomberg and Olsson performed 10 epiduroscopies on patients scheduled for partial laminectomies for herniated lumbar discs [17]. The authors felt that the conclusions drawn from previous autopsy work were not necessarily applicable to the clinical setting. Their concerns pertained to the absence of circulation in cadavers and to
the low, or completely absent, cerebrospinal fluid pressure, possibly having impact on the appearance of the epidural space [17]. They determined that the epidural space was indeed only a potential space that remained open for brief periods of time when fluid or air were injected. Blomberg and Olsson also confirmed the presence of a dorsomedian connective tissue band that divided the epidural space into compartments. They further determined that the midline approach to the epidural space was often associated with bleeding and that a paramedian approach was less likely to cause this complication [18].

In the late 1980s and early 1990s, the advent of video chips made it possible to have simultaneous video images while recording all aspects of a surgical procedure. This new technology enabled Koki Shimoji and colleagues [2] to publish their experience using small (0.5 to 1.4 mm) flexible fiberoptic scopes in 1991 (Figure 8); ten patients with intractable spinal pain syndromes had flexible fiberoptic myeloscopes placed into either the subarachnoid space, epidural space or both, via a lumbar paramedian approach through a Tuohy needle. The epidural space, however, could only be visualized after withdrawal of the fiberoptic myeloscope from the subarachnoid position. The authors attributed this to the leak of cerebrospinal fluid into the potential epidural space, which decreased the adhesiveness of the tissues and allowed the lens to achieve its focal length.

The procedures were performed without sedatives or local anesthetics to allow for assessment of dysesthesia. In addition, since their patients were treated for chronic pain syndromes, the authors felt it would be important to determine whether the patients’ pain could be reproduced mechanically. Accurate identification of spinal level was facilitated by simultaneous use of x-ray, and in four of the study patients, the fiberoptic scopes could be advanced up to the cisterna magna. In patients with the diagnosis of aseptic adhesive arachnoiditis, there was no evidence of structural lesions, and the nerve roots were matted by a filamentous tissue, such that it was difficult to visualize the subarachnoid space. Three of the five patients diagnosed with adhesive arachnoiditis prior to the procedure had either a reduction or a complete remission of their pain syndrome following the procedure. Although the myeloscopic examinations did not establish the anatomical etiology for the pain, the authors felt that further studies would be fruitful in this regard. Most importantly, the complications associated with the procedures were minimal: transient post-dural puncture headaches and fever. The only few cases of dysesthesia that occurred during the procedure were alleviated by slowly withdrawing the scope from the nerve root in question.

Figure 8. Koki Shimoji's flexible fiberoptic scope and light source. A) The fiberscope with its lead to a high intensity light source; B) Tips of three types of fibrescopes with diameters of 1.4, 0.9 and 0.5 mm, shown from top to bottom, respectively. Observation of spinal canal and cisternae with the newly developed small-diameter, flexible fibrescopes. (Reproduced with permission from Reference 2.)
Figure 9. The 2-mm fiberoptic catheter is introduced through the sacral hiatus. This allows for a straight entry into the epidural space. (A straight caudal catheter is easier to steer than lumbar epidural catheters, which may bend when introduced into the epidural space.) A Touhy-Borst adapter is attached to the distal end and is flushed with normal saline.

In 1991, Saberski and Kitahata began evaluations of several fiberoptic systems for use in clinical epiduroscopy. The technology had markedly improved, but an appropriate indication for epiduroscopy was not clear. As a diagnostic tool, the uncertainty remained as to whether this technique could provide an advantage over readily available imaging procedures that were non-invasive (e.g., CT scan, magnetic resonance imaging). In addition, a number of technological shortcomings needed to be overcome before seriously considering clinical use of these devices. First, the fiberoptic catheters only allowed visualization of tissues that were immediately in front of the lens (i.e., when a 2 mm focal length was maintained). However, this focal distance was difficult to achieve in a potential space like the epidural space. Second, the placement of the device into the epidural space was difficult, even when guided by fluoroscopy. Third, the fiberoptic catheters did not incorporate separate channels that would allow tissue sampling or delivery of medication to the site being investigated. Thus, the ideal fiberoptic scope, yet to be developed, would need to be maneuverable, have a working lumen and have a lens with a short focal length or incorporate a mechanism to prevent tissues from occluding the fiberoptic lens.

The caudal approach to the epidural space seemed to offer some advantage over the paramedian lumbar approach. At the authors’ institution, it was the preferred technique for administration of epidural steroid for the treatment of radiculopathy. The direct access to the epidural space permitted by this approach contrasted sharply with the approximate 45-degree bend required to introduce a catheter into the lumbar epidural space when using the paramedian approach. The caudal approach also facilitated correct catheter positioning. Furthermore, it had become a routine part of clinical practice to administer large volumes of normal saline containing steroids into the epidural space using the caudal
approach for radiculopathy [19]. Thus, the clinical practice of distending the epidural space by injecting normal saline facilitated the fiberoptic visualization of the epidural space.

Using a series of introducers and guide wires, Saberski and Kitahata were able to access the caudal canal (Figure 9). The subsequent flushing of normal saline during passage of the epiduroscope allowed the fiberoptic lenses to achieve their needed focal length and facilitated visualization of the epidural space structures. In a series of 10 volunteer patients, epidural fat, connective tissue, duramater, nerve roots and ligamentum flavum were easily identified. In addition, fiberoptic-guided injections of depot steroid were directed towards the nerve roots suspected of pathology. The initial results indicate that such endoscopic procedures can be done safely and may prove very effective in delivering medication to specific nerve roots for the treatment of radiculopathy.

Thus, the visions of Drs. Burman, Stern and Pool of minimally invasive technology to assist in the diagnosis, and perhaps treatment, of spinal disease is one step closer to becoming reality.

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