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Recent advances in epiduroscopy

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Introduction

Epiduroscopy is a relatively new technology that was developed toward the end of the twentieth century. Epiduroscopy is the direct viewing of the epidural space that is inside the spinal canal. The epidural space is a potential space surrounding the spinal cord between the dura that covers the spinal cord and the periosteum that covers the inside of the bony structure of the spinal canal.

How did it begin?

Direct visualization of the spinal canal was first reported in the 1930s [1,2]. It was performed with a rigid scope. Burman [1] examined the spines that were removed intact from human cavaders and named the procedure "myeloscopy." This author felt that it was of theoretical interest only. Pool [2] performed myeloscopy on a living subject. He improved the design of the myeloscope and described the structures he observed in the epidural and subarachnoidal spaces in detail. In 1986, Blomberg [3] visualized the dorsomedian connective tissue band in a human cadaver, and in 1991, Shimoji et al. [4] visualized the spinal canal and cisterna in humans. These procedures were performed by the traditional posterior spinal approach, either midline or paramedian. Because of the uniqueness of the anatomical structure of the posterior spinal column, the traditional posterior spinal approach needed the epiduroscope to be angled in its insertion toward the epidural space. In 1995, Saberski and Kitahata [5] succeeded in visualizing the human lumbosacral epidural space via the sacral approach, an entirely new procedure. These authors used the sacral route to insert the epiduroscope through the sacral hiatus straight into the lumbar epidural space without an angle. In the following year, they reported the first successful application of epiduroscopy in clinical practice [6]. Using the straight-line sacral approach, the epiduroscope could be steered and maneuvered. With the aid of fluoroscopic monitoring, the method described by Saberski and Kitahata proved to be more successful in lysing the dense connective tissue adhesions than previous methods. Thus, epiduroscopy has become a new and effective therapeutic modality for persistent lumbar radiculopathies.

Epiduroscopy in the long history of endoscopy

Epiduroscopy is the latest development in the long history of the entire field of endoscopy. Endoscopy, i.e., visualization of the inside of a body cavity, is an old concept. In 1795, Bozzini visualized the inside of the uterus and rectum with a candle [7], and thus the early stages of endosopy began. Historically, this early stage includes the late eighteenth century and the entire nienteenth century, and was characterized by the use of a rigid scope. There were very few developments in endoscopy during this early stage. In 1877, Max Nitze designed a cystoscope [8], and in 1895, the direct-vision laryngoscope was invented by Alfred Kirstein, a laryngologist [9].

The second stage of the development of endoscopy was during the first half of the twentieth century. There were many inventions during this second stage. In 1905, Jackson [10] reported the successful removal of bronchial foreign bodies using his esophagoscope. In 1907, Jackson introduced the separable laryngoscope with a "U-shaped" handle [11]. The laryngoscope soon came to

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be used by anesthesiologists, and many subsequent modifications of the instrument have been made. Professor Kenji Takagi of Tokyo University is given credit for being the first to successfully apply the principles of endoscopy to a knee joint. In 1918, Takagi succeeded in viewing the inside of a knee in a human cadaver using a cytoscope [12]. The stimulus for his work was the disastrous end result of tuberculosis of the knee, which was rampant at that time in Japan and usually resulted in an ankylosed knee. The stiff knees represented a serious social as well as physical disability, as sufferers were unable to kneel or squat. In 1931, McCarthy developed a resectoscope for transuretheral resection of the prostate [13] and in 1932, Schindler developed a gastroscope utilizing a semiflexible lens scope [7]. With the realization that it was possible to see through a curved tube with a series of short-focal-distance lenses, the semiflexible lens scope was introduced. Thus, the second stage in the development of endoscopy was very active, and was characterized by the use of the semiflexible lens scope.

The third stage in the development of endoscopy, which started in the middle of the twentieth century and continued to the present time, has been characterized by the use of fiberoptic endoscopes. In 1951, Watanabe used fiber "cold light" for arthroscopy of a knee [14]. This paper was written in the Japanese language, and thus the credit for the development of the fiberscope is usually given to Hopkins and Kapany who, in 1954, developed an optically arranged fiber bundle, named it the fiberscope, and suggested its use as a flexible instrument for investigating the stomach [15]. In 1955, Watanabe et al. carried out the first therapeutic application of arthroscopy to remove a giant cell tumor from a knee [16]. In 1958, Hirschowitz et al. performed fiberoptic gastroscopy [17]. In 1970, the first fiberoptic bronchoscope was constructed, based on specifications and characteristics reported by Ikeda [18]. Laparoscopy was developed during the 1980s, first for gynecological procedures, then for gall bladder surgery, and later for kidney surgery.

The development of fiberoptic instruments ushered in the third stage of the development of endoscopy, and revolutionary improvements took place. These affected all known endoscopic procedures, and led to many new possibilities. Thus, the developments in endoscopy during the third stage have been epoch-making. The advances in technology during this third stage made it possible to develop endoscopy of the central nervous system, i.e., the epiduroscopy.

Difficulties in the development of epiduroscopy

Epiduroscopy means viewing the contents of an epidural space located inside the spinal canal. As compared with other endoscopic procedures, spinal endoscopy presented unique technical difficulties, e.g., (1) the size of the epidural space, (2) the content of the epidural space, (3) the limited expandability of the potential epidural space, and (4) difficulty in approaching the spinal canal. In order to reach the epidural space, a miniature scope had to be developed. Manufacturing a miniature fiberoptic scope with an extremely small diameter was necessary. The contents of the epidural space, i.e., the spinal cord and the spinal nerves, are extremely vulnerable to mechanical damage. The ability to steer and maneuver the epiduroscope precisely was a great challenge for the developer. The epidural space is a potential space, and has to be expanded by the infusion of normal saline solution under pressure to obtain the visual field. It has been shown that this elevated epidural pressure impairs the blood flow to the cauda equina. The critical pressures are over 127 mmHg for arterial blood flow, over 40 mmHg for capillary blood flow, and over 30 mmHg for venous blood flow [19]. Since the arteries to the cauda equina are end-arteries without collateral circulation, ischemia of the cauda equina occurs easily with either central or peripheral pressure elevation [20,21]. Therefore, the blood flow to the cauda equina might be compromised if the pressure exceeds 50 mmHg [22]. Thus, in order to prevent nerve damage, the infusion of normal saline solution to expand the epidural space to obtain a visual field must be limited in both volume and speed.

Approaching the spinal canal via the conventional method of a posterior spinal approach, through either a midline or a para-median approach, necessitated an angled insertion of the epiduroscope, and steering and maneuvering were very difficult. It was as late as 1986 when Blomberg visualized the spinal canal in a human cadaver by the conventional posterior spinal approach [3]. In 1991, Shimoji et al. visualized the subarachnoid space and the cisterna [4]. The conventional approach, either through the posterior-spinal, i.e., midline or the paramedian, approach made it difficult to maneuver the epiduroscope because of the angled insertion. In 1995, Saberski and Kitahata used the sacral approach for the first time to view the lumbosacral epidural space [5].

The sacral approach gave straight-line instrumentation without an angle, thus making it possible to steer and maneuver the epiduroscope to give three-dimensional color views, which are an essential requirement in the successful application of epiduroscopy in clinical practice. Saberski and Kitahata also succeeded in the first clinical application of epiduroscopy as a treatment for persistent lumbar radiculopathy [6]. They were able to lyse dense connective tissue adhesions by targeted injection of normal saline solution with the aid of fluoroscopic monitoring. It has been reported that

the blood flow in the cauda equina changes during Laseque's test [23]. Therefore, connective tissue adhesion around the nerve roots limits the free movement of the root and may interfere with the blood flow. Lysing the connective tissue adhesions and providing freer nerve root movement might prevent ischemic changes in the nerve roots involved.

Indications

In 1996, Saberski and Kitahata, successfully used epiduroscopy as a treatment modality for the first time [6]. Thus, epiduroscopy has a very short history in clinical practice. Therefore, the indications described below must be probable indications only until well-designed and well-conducted outcome studies have been completed.

Failed-back syndrome

Failed-back syndrome, following either surgical procedures and/or various modes of nonsurgical conservative treatment, is considered to be an indication for epiduroscopy.

Failed-back syndromes following surgical proced ures have been attributed to post-operative fibrosis, adhesions, and inflammation [24,25]. It has been reported that repeating the surgical procedure does not always solve the problem [26]. Instead, it may produce further complications [27]. The case reported by Saberski and Kitahata [6] concerned a patient who had a history of undergoing a successful discectomy and spinal fusion for a persistent low lumbar radiculopathy, and years later suffered a recurrence of pain for which conservative therapy was not successful. Magnetic resonance imaging (MRI) of that patient prior to the epiduroscopic treatment indicated the presence of an extradural scar adjacent to the nerve root involved. This seemed to be the major cause of the patient's symptoms. Epiduroscopic treatment with the aid of fluoroscopic monitoring made it possible to give a targeted injection of saline solution to the specific nerve root with adhesion. The adhesions around the nerve root were lysed. This was followed by the irrigation of inflammatory substances, and the administration of anti-inflammatory medication directly aimed at the nerve root with pathology.

In order to lyse the connective tissue adhesions around the nerve root, the technique developed by Saberski and Kitahata [6] using epiduroscopy and fluoroscopy seemed to be more effective than the method described by Racz et al. [28], which did not have the benefit of epiduroscopy.

Lumbar intervertebral disc disease

A herniated disc and/or a degenerative disc disease are considered to be indications for epiduroscopy. The most common surgical interventions for spinal pain pertain to a herniated disc. The associated sciatica is usually self-limited, and resolves with conservative care [29–33]. Even for patients with a herniated disc with a neurological deficit such as numbness or motor weakness, there is an equal resolution with conservative treatment and with surgical treatment [30,31]. According to Weber [31,34], who compared the results of surgical and non-surgical treatments for pain syndrome associated with lumbar disc herniation, surgical treatment has no long-term advantage over nonsurgical treatment, although surgical treatment provides short-term advantages over conservative therapy. Moreover, McCarron [35] established that disc material, when placed into the spinal canal of dogs, caused an inflammatory response. This response is initiated by various inflammatory mediators such as phospholipase A.

Thus, low back pain due to disc disease qualifies as a medical disease as well as a surgical problem. Until recently, medical management for disc-related phenomena involved the use of oral medication and exercise programs. With the advent of spinal canal endoscopy, additional options are now available for the medical care of disc disease. Epiduroscopy, as currently practiced, can irrigate, dilute, and remove inflammatory mediators, and decrease the chance of reactivity to chemical and biological mediators. In addition, epiduroscopy combined with a fluoroscopic examination can provide a better method of lysing the adhesions around the nerve root, and can make it possible to administer anti-inflammatory medication directly at the site of the pathology. Such targeted injections serve to suppress the components of the inflammatory response, and become an effective drug therapy for disc-related inflammatory responses.

Other indications

Other probable indications for epiduroscopy are (a) low back pain secondary to a spinal stenosis, (b) the removal of foreign bodies, and (c) tumor removal.

Spinal stenosis

Spinal stenosis has a multifaceted pathology involving various forms of lumbosacral spinal column pathology. Not only is the type of pathology complex, but the nature of the pathophysiology causing the low back pain is also complex. The types of pathophysiology involved are the compression of the spinal nerves [27], ischemia of the spinal nerves as a result of a long-term compression [36], and inflammatory changes secondary to the

injured axons [37]. Epiduroscopy may be of benefit in those cases in which the lysis of adhesions, irrigation of the inflammatory materials, and a targeted administration of anti-inflammatory medication are feasible.

Removal of foreign bodies
The removal of foreign bodies left in the epidural space, such as severed plastic tubes or migrated indwelling catheters, is a probable indication for epiduroscopy.

Tumor removal
The author has had experience of draining a sacral cyst during an epiduroscopic examination. Drainage of a spinal cyst, cauterization of hemoangioma, and the removal of benign tumors such as neurofibroma are also probable indications for epiduroscopy. In order to accomplish these tasks, modifications and improvements to the epiduroscopic instrument, such as the addition of a laser technique [38] and an electrocautery, are necessary.

When considering the indications for epiduroscopy, one cannot overemphasize the importance of making a correct diagnosis.

Contraindications

When considering contraindications for epiduroscopy, one has to be absolutely certain about the correctness of the diagnosis, and in particular of the need to differentiate between low back pain of nonspinal origin, such as cognitive affective disorder, and low back pain of psychological origin, e.g., compensation psychosis.

An absolute contraindication for epiduroscopy is patient refusal. Several preexisting conditions increase the risk of this technique, e.g., increased intracranial pressure increase the risk of brain herniation. Coagulopathy or thrombocytopenia increase the risk of epidural hematoma. Sepsis and infection at the site of insertion of the epiduroscopic instrument increase the risk of meningitis. Pregnancy is another contraindication. Special consideration should be given to preexisting neurological conditions, although this is a legitimate concern.

Complications

Because of the short history of clinically applied epiduroscopy, some possible complications must be considered. These are hemorrhage, traumatic dural puncture, headache, cranial nerve disturbances, infections, meningismus, exacerbation of preexisting spinal cord disease, myelitis, bladder and rectal dysfunction, and peripheral neuropathies. For safe epiduroscopy, obtaining a clear visual field is essential. However, the infusion of saline solution should be done with extreme care [39], and over-distension of the epidural space should be avoided.

Japanese contributions to endoscopy

The early stage of endoscopy during the late eighteenth century and throughout the nineteenth century showed few advances. Significant developments took place during the second stage of endoscopy, i.e., the first half of the twentieth century. In 1918, Takagi, in Japan, succeeded in performing arthroscopy of a knee in a human cadaver [40].

More dramatic developments in endoscopy came about during the third stage, i.e., from the second half of the twentieth century until the present day. In 1951, Watanabe used a "cold light" fiber source for the first time to visualize inside the knee, and the modern era of endoscopy was born [14]. In 1952, Uji made a significant contribution by developing a gastrocamera [41]. In 1957, Watanabe et al. [16] applied arthroscopy as a treatment modality for the first time by removing a giant cell tumor from a knee space, and Yoshitoshi and co-workers [42] developed closed-circuit color television endoscopy, another epoch-making event. Ooi and Morisaki [43] postulated the possibility of observing the lumbar epidural space, and Shimoji et al. [4] visualized the spinal canal in humans. Saberski, with his mentor Kitahata from Japan and Yale University, used the sacral approach for the first time [5], and applied epiduroscopy as a treatment modality for persistent lumbar radiculopathy in a human [6].

In the recent past, Japanese scholars have been active in investigating the clinical applications of epiduroscopy. Igarashi et al. [44] observed that deep breathing expanded the potential cavity of the epidural space. This is technically important, because deep breathing may assist in the insertion of an epidural catheter. Igarashi et al. [45] also investigated the epidural space in pregnant women, and found that epidural blood vessels became engorged in the first trimester, and the density of the vascular networks increased in the third trimester. These changes in the epidural space during pregnancy are an important finding for anesthesiologists, as they may affect the spread of analgesic agents in pregnant women.

Thus, Japanese scholars have made significant contributions to the field of endoscopy that led to the development of epiduroscopy. As we enter the new millennium, Japanese scholars will very likely continue to make contributions to the future development of epiduroscopy, and to establishing epiduroscopy as a standard therapeutic modality for various spinal cord diseases.

Future roles of epiduroscopy

Medical role

During the short period since the first application of epiduroscopy in clinical practice, it has been successfully applied to treat failed-back syndrome after multiple surgical interventions [6,46], low back pain after failed conservative treatment [6], and low back pain due to spinal stenosis [47]. The indications for the low back pain of intervertebral disc disease have been discussed in the section on indications, and there has been ample evidence to support the hope that epiduroscopy will be a useful procedure for this disease.

Well-designed and well-conducted outcome studies would prove that the diseases mentioned above could become accepted as indications for epiduroscopy. With future developments in techniques and instrumentation, such as the computerization of video epiduroscopy, it is anticipated that the indications for epiduroscopy would be widened to the extent that some of the surgical treatments performed today with open-system laminectomy might be performed successfully by a closed-system epiduroscopic procedure. This will benefit patients by less discomfort and shorter recovery times.

Economic role

In the USA, about 90% of the population will suffer from low back pain syndrome at some time in their life, and 85% of them will seek medical help. Low back pain syndrome is the second leading cause of doctors' visits in the USA. Annually, about two million people seek treatment for low back pain syndrome, and half a million of these suffer from failed-back syndrome.

Failed-back syndrome following multiple surgical procedures is one of the indications for epiduroscopy. Patients with failed-back syndrome after multiple surgical procedures with laminectomy are usually disabled for a prolonged period of time. To my knowledge, disability costs the United States Government approximately $15000 per person per year. As about half a million people are diagnosed with failed-back syndrome, the annual medical and disability expenses for those patients may amount to as much as 20 billion dollars.

If epiduroscopy, as an out-patient procedure, becomes a successful alternative treatment to surgical laminectomy as an in-patient procedure, the cost savings by this advance alone will be sizable. In addition to failed-back syndrome, if epiduroscopy was indicated for other low back pain problems, the economic impact of the treatment would be enormous.

I believe that increasing numbers of techniques and procedures will be performed by an epiduroscopic procedure. I am hopeful that new instruments and techniques will be developed, such as laser equipment and electrosurgical techniques. Where the developments will end is impossible to predict. The next historian might have the same delightful challenge to outline even greater advances in the field of epiduroscopic procedures.

Summary

The early stage of endoscopy, that started in the late eighteenth century and continued throughout the entire nineteenth century, was characterized by the use of a rigid scope, and brought very little progress. The second stage, in the first half of the twentieth century, was characterized by the use of semiflexible lens scopes, and brought many advances.

The third stage of endoscopy, that started during the second half of the twentieth century and continues to the present day, is characterized by the use of flexible, fiberoptic endoscopes, and has seen many new inventions. Several surgical procedures formerly done in the hospital have been replaced by endoscopic treatment done in a 1-day surgical clinic. This has brought tremendous medical benefits and enormous economic savings.

Epiduroscopy is the latest development in the field of endoscopy. Because of the unique anatomical structure of the spinal column, it was necessary to await the advent of miniature endoscopic equipment to visualize the content of the epidural space. Inserting the epiduroscope straight into the epidural space, with no angle, was not possible by the conventional posterior spinal approach. The sacral approach solved the problems associated with the conventional posterior spinal approach. Epiduroscopy performed through the sacral hiatus allowed the straight insertion of the epiduroscope, and provided a visual field with a three-dimensional color view, and the capability to steer and maneuver the epiduroscope. Sacral epiduroscopy with the aid of a fluoroscopic monitor allowed targeted injections of normal saline solution to lyse dense connective tissue adhesions around the nerve root, irrigation of inflammatory substances, and the administration of anti-inflammatory medication directly at the site of the pathology.

These procedures are a necessary requirement for the successful treatment of persistent lumbar radiculopathy. During the short history of clinical epiduroscopy, it has been used successfully to treat low back pain syndrome of various pathologies. With well-designed and well-conducted outcome studies, the indications for epiduroscopy could be extended, and some of the open-system surgical procedures performed today by lumbar laminectomy and requiring hospitalization might be replaced with a closed-system endoscopic procedure done

in a 1-day surgery clinic. This will not only bring benefits to the patient from less discomfort and a shorter recovery period, but its economic impact on patients and on society will also be enormous.

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