HISTORICAL ASPECTS OF VIDEO ENDOSCOPIC SURGERY OF THE LUMBAR SPINE

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The literature review is devoted to the history of the development of endoscopic surgery of the lumbar spine: from open surgical interventions and puncture procedures — to percutaneous intracanal endoscopic operations, combining interventional and video endoscopic technologies and referred to in the English literature as "full-endoscopy". The article also touches upon the historical aspects of fibroendoscopic and laparoscopic interventions on the lumbar spine. In conclusion, the principle of classification of endoscopic techniques is proposed.
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The evolution of endoscopic techniques in medicine involves several stages, with each of them being characterized by the improvement of equipment and the emergence of new diagnostic and treatment techniques: rigid (1795–1932), semi-flexible (1932–1958), fiberoptic (1958–1981), digital (1981–2003), and modern stage of endoscopic techniques [1].

If exclude the first attempts of in vivo endoscopy of the epidural and subarachnoid spaces of the human spinal cord, undertaken by Pool in 1937 [2], the introduction of endoscopic techniques into clinical practice for treating spine diseases started in the 1980s, which was associated with the digital period of endoscopy. By that time, modern models of rigid and flexible endoscopes had already been designed and tested in various fields of surgery. For this reason, the efforts of neurosurgeons and orthopedists have promptly led to a high level of diagnostic and therapeutic endoscopic interventions on the spine.

Development and Improvement of Percutaneous Full-Endoscopic Lumbar Surgery

At present, percutaneous full-endoscopic spine surgery includes interventions performed through a percutaneous approach under control of radiologic and video endoscopic imaging techniques using rigid multichannel endoscopes and special instruments. This combination of interventional and video-assisted endoscopic techniques in spinal surgery is referred to in the English-language literature as the full-endoscopic method [3]. The state-of-the-art of percutaneous full endoscopic lumbar surgery has resulted from two parallel methods of surgical treatment of discogenic sciatica:

1) reduction in invasiveness of open discectomy through a posterior approach;

2) expansion of the possibilities of a posterolateral puncture approach for intradiscal therapeutic and diagnostic interventions.

Telfeian et al. [3] defined these evolutionary directions as follows: "big-to-small" and "small-to-big".

The evolution of posterior surgical approaches: from open surgery to percutaneous endoscopy. The history of surgery for herniated intervertebral discs through posterior approaches dates back more than 100 years. Removal of herniated lumbar intervertebral discs was first reported by Oppenheim and Krause (1909), Steinke (1918), Adson (1922), and Dandy (1929). However, herniations were misdiagnosed as spinal tumors by all authors, without exception [4]. In 1934, a neurosurgeon Mixter and an orthopedist Barr [5] reported 19 cases of surgical treatment of lumbar, thoracic, and cervical disc herniations. Mixter and Barr were the first to identify the intervertebral disc tissue as a morphological cause of pain. A technique of lumbar spine surgery described by Mixter and Barr was highly invasive and included laminectomy and transdural discectomy [4]. In 1939, Love [6] described an extradural interlaminar approach to intervertebral discs. Until the early 1970s, open hemilaminectomy was a standard surgical approach for most lumbar disc herniations [7]. In 1977, neurosurgeons Caspar [8] and Yasargil [9] independently reported on the experience of using an operating microscope to remove lumbar disc herniations. Subsequently, Ebeling, Goald, Williams, and Wilson [10–13] improved and popularized a lumbar microdiscectomy technique. The new surgical technique provided excellent illumination and an enlarged surgical field and reduced the invasiveness of surgery, which was reflected in the treatment outcomes [14]. Later, special retractors and surgical instruments were developed for surgical access and manipulations in the epidural space. Lumbar microdiscectomy is still the standard in surgical treatment of discogenic radiculopathy [7, 15].

Given the desire to further reduce surgical invasion, Foley and Smith [16] in 1996 developed an endoscopic-assisted technique for microsurgical removal of

lumbar disc herniation, the first reports of which appeared in 1997 and 1999. In the early 2000s, there appeared a detailed report on a surgical technique of microendoscopic discectomy and main characteristics of instruments, an endoscope, and a micro endoscopic tubular retractor (METRx) system (Medtronic). The advantages of microendoscopic discectomy over microdiscectomy included smaller incisions (1.5–2.0 cm), reduced intermuscular dissection during approaching the interlaminar space, and better illumination and visualization [3, 17]. This reduced the degree of tissue damage and shortened the period of patient disability [18–20]. In 2009, the Karl Storz company developed an Easy-Go endoscopy system, similar to the METRx in design, for posterior decompression procedures [21]. The technology of video-assisted tubular-based endoscopy is actively used today in lumbar surgery [22].

In the 1990s, a technique was developed for endoscopic removal of lumbar disc herniations through a posterior approach using the Destandau system [23]. In contrast to microendoscopy that used endoscopic assistance, direct visualization of the surgical field in the Destandau system was excluded before removal of the working insert. The course of surgery was controlled exclusively through a video-assisted endoscope, which brought this discectomy technique closer to full-endoscopy. Between 1999 and 2001, Destandau operated on 1,562 patients using a commercial version EndospineTM of his endoscopic system [24]. However, this technique was not so widespread compared to tubular microendoscopy.

In 1996, De Antoni et al. [25] proposed the first lumbar endoscopic discectomy through a posterior approach in a liquid physiological saline solution. The surgery was performed using endoscopic assistance through a 1.5 cm skin incision. The technique was not further developed.

By the early 2000s, new technical solutions in the production of rigid endoscopes and special instruments as well as mastering of transforaminal endoscopic spine surgery (see below) [26–28] enabled the use of a percutaneous uniportal endoscopic technique in interventions on the lumbar spine through a posterior interlaminar approach. This direction was pioneered by Ruetten [29] from Germany who substantiated the use of percutaneous interlaminar lumbar discectomy as an alternative to a transforaminal endoscopic technique. In 2001–2002, he performed 423 percutaneous full-endoscopic lumbar discectomies through the interlaminar approach and an about 1 cm skin incision. The author guided an operation sheath with 7 mm outer diameter to the ligamentum flavum under X-ray control. A 6 mm Wolf endoscope with a 2.7 mm working channel and an irrigation channel was inserted in the sheath. All manipulations were performed through the working channel under full endoscopy in a liquid physiological saline solution. The sheath was used as a second tool for displacement and retention of the nerve root during removal of a herniated disc [30]. In 2008, Ruetten et al. [31] published a first prospective randomized study evaluating the advantages of closed uniportal percutaneous endoscopic (interlaminar and transforaminal) lumbar discectomy over standard microdiscectomy. Since then, this technique has been extensively used in clinical practice [32, 33].

The evolution of surgical posterolateral approaches: from a puncture of the intervertebral disc to percutaneous transforaminal neuroendoscopy. A posterolateral approach for biopsy of the lumbar and thoracic vertebral bodies was reported in the 1940s and 1950s [34]. In 1951, Hult demonstrated the results of fenestration of the fibrous ring of the intervertebral disc through a posterolateral puncture retroperitoneal approach in sciatica. The efficacy of this procedure was related to a decrease in hydrostatic pressure in the intervertebral disc. In 1956, Feffer described a hydrocortisone injection into the intervertebral disc through a similar approach. In 1963, Smith, having studied Thomas's experiments in rabbits, proposed enzymatic dissolution of the nucleus pulposus by chymopapain. The ease of intervention and the fact that the surgical technique did not involve invasion into the spinal canal attracted attention of many orthopedists and neurosurgeons; this was the first alternative to open discectomy [35, 36]. Several years after the peak in popularity of chymopapain, there appeared reports of percutaneous mechanical discectomy (nucleotomy) through a posterolateral approach. In 1975, Hijikata [37] was the first to demonstrate the capability of nucleotomy through a posterolateral approach under radiological control. Kambin and Gellmann [35] described in more detail a similar technique in 1983. In the same year, Forst and Hausmann [38] first reported insertion of a modified rigid arthroscope into the intervertebral disc for its full endoscopic visualization during open lumbar laminectomy and discectomy. In 1986, Schreiber and Suezawa [39] described the first experience of percutaneous full-endoscopic nucleotomy through a bilateral biportal posterolateral approach. According to the authors, the surgical technique of posterolateral percutaneous discoscopy in combination with mechanical nucleotomy was safer than techniques for removal of the nucleus pulposus performed exclusively under fluoroscopic control [40]. However, the bilateral approach increased the duration of surgery and X-ray exposure and enhanced the risk of infection [39]. In the mid and late 1980s, Kambin [41] in collaboration with the Dyonies company developed rigid arthroscopes with a working channel and instruments for discectomy. Kambin made the first attempts to perform lumbar nucleotomy under irrigation with a liquid physiological saline solution through a uniportal percutaneous endoscopic intradiscal approach.

The Kambin's description and illustration of anatomical landmarks of a safe triangular working zone in the intervertebral foramen area in 1991 [41] enabled the widespread use of percutaneous arthroscopic (intradiscal) lumbar spine surgery. Subsequently, there were a large number of works that improved percutaneous indirect arthroscopic decompression of the neural structures in discogenic sciatica, in particular with the use of a laser, as well as studies comparing the efficacy of this

technique with standard microdiscectomy [42–44].

The development of percutaneous neuroendoscopic spine surgery began with the substantiation of a transforaminal approach to the spinal canal, the purpose of which was to reach the epidural space at the affected intervertebral disc level by insertion of a rigid endoscope through the intervertebral foramen. The first experience of intervertebral foramen endoscopy was gained by spinal surgeons during arthroscopic intradiscal decompression through the Kambin's triangular working zone during removal of instruments and an endoscope with angled optics [45]. Subsequently, the idea arose not only to perform endoscopic examination of the intervertebral foramen but also to use it for passage into the epidural space of the spinal canal, bypassing the intervertebral disc [36]. In 1996 and 1998, Ditsworth [46] and Mathews [47] first reported the use of a foraminoscopic approach in percutaneous surgery for lumbar disc herniations.

Since that time, the concept of percutaneous full-endoscopic lumbar surgery has fundamentally changed. The intradiscal arthroscopic technique with access to the intervertebral disc through the Kambin's safe triangle was replaced by the endoscopic transforaminal intracanal technique that significantly increased the capabilities of this field of spinal surgery [1].

In parallel with an increase in the options of percutaneous transforaminal lumbar surgery, improvement of endoscopes and development of special surgical instruments were undertaken. Hoogland [26] proposed the Thomas Hoogland Endoscopic Spine System (THESSYS) in 1994. In 1997, Yeung et al. [28] presented a rigid integrated multichannel surgical spinal endoscope of the Yeung Endoscopic Spine System (YESS). The development of multichannel endoscopes with enlarged working channels was contributed by Tsou et al. [27] in 1997 and Ruetten et al. [30] in 2007. Clear visualization of the spinal canal structures was achieved due to the development of foraminoplasty techniques [48–50] and achievement of reliable hemostasis by increasing irrigation pressure of a 0.9 % sodium chloride solution and using radiofrequency or bipolar coagulation [36].

Since the 2000s, there have been reports on the clinical efficacy of percutaneous uniportal endoscopic transforaminal decompression of the neural structures of the lumbar spinal canal [28, 31, 51–57].

Current state of percutaneous full-endoscopic lumbar surgery. Today, percutaneous endoscopic spine surgery is becoming increasingly widespread due to its minimal invasiveness, efficiency, economic feasibility, and aesthetics [58, 59]. While the "Standards of Percutaneous Endoscopic Spine Surgery" [60] in 2010 included only three nosologies treated with this type of surgery (herniated discs, spinal canal and intervertebral foramen stenosis, cysts of the intervertebral joints), the range of applications of percutaneous spinal endoscopy has expanded to date. The list of nosologies additionally includes recurrent herniations [61, 62], cysts [63], spondylolisthesis [64, 65], spinal deformities [66], chronic back pain [27], and radiculopathy associated with pathological fractures and complications of osteosynthesis, intervertebral disc replacement, and vertebral augmentation [67–72]. In addition, percutaneous endoscopic techniques have been tested for stabilization of the spine [73, 74], spondylodiscitis, tumors, chronic spinal epidural hematoma [75–77], and gunshot injuries [78, 79]. In 2020, there were the first reports on the use of a biportal percutaneous endoscopic decompression technique for lumbar herniation and stenosis [80, 81]. In this year, electromagnetic navigation in percutaneous endoscopic lumbar surgery was also introduced in clinical practice [82].

The History of Fiberoptic Lumbar Endoscopy

Flexible fiberoptic spinal endoscopy resulted from the evolution of puncture therapeutic and diagnostic procedures: epidural blockade, X-ray epidurography [83], epidural anesthesia, and percutaneous adhesiolysis [84]. In the early 1970s, two groups of researchers, Ooi et al. [85] and Mohri et al. [86], developed a rigid endoscope for intradural and extradural examinations. Later, Ooi et al. published studies on the use of myeloscopy in clinical practice. Blomberg [87] was the next to describe (1985) methods of rigid epiduroscopy and spinaloscopy.

The integration of fiberoptic technology with computerized image processing enabled the development of new methods for imaging of the spinal epidural and subdural spaces [88]. Shimoji et al. [89] reported the experience of treating patients with chronic back pain using fiberoptic myeloscopy of the subarachnoid and epidural spaces through a paramedian lumbar puncture with a Tuohy needle. Saberski et al. [90] and Kitahata [91] evaluated the efficacy of fiberoptic systems in clinical epiduroscopy via puncture access through the sacral foramen. Warnke et al. [92] proposed a new term thecaloscopy for flexible endoscopy of the spinal subdural space. Since the late 1990s, various aspects of fiberoptic spinal endoscopy, including the clinical basis, safety, and cost-effectiveness, have been described [88, 90, 91, 93, 94].

Historical Data on Laparoscopic Approaches to the Lumbar Spine

Laparoscopic approaches to the lumbar spine have been used in surgical practice since the early 1990s [95]. Some researchers suggested that anterior endoscopic approaches should have certain advantages in the treatment of lumbar intervertebral disc diseases due to the lack of sequelae associated with laminectomy and facetectomy [96].

The surgical technique of anterior endoscopic lumbar discectomy was similar to the principles of laparoscopic abdominal surgery: rigid endoscopy and pneumoperitoneum were used, and the small bowel and colon were retracted to provide access to the lumbar disc [96]. A retroperitoneal laparoscopic approach to the lumbar spine has been reported [95, 97]. There have also been published studies on the use of lapa-

roscopy for anterior lumbar interbody fusion (ALIF) [98–100]. The reasonability of using endoscopic assistance with mini-open anterior approaches to the lumbar intervertebral discs was considered [101]. There were also disadvantages of laparoscopic lumbar surgery: complex surgical technique and risk of injury to the sympathetic trunk, segmental lumbar arteries and veins, ureter, and superior hypogastric plexus [98], which led to gradual limitation of this technique in clinical practice.

Conclusion

To date, there are a large number of endoscopic techniques to treat pathology of the lumbar spine. Some of them are only of historical interest. Because the capabilities and clinical and economic efficiency of the listed interventions can significantly differ, reporting the study results should clearly indicate the used video-assisted endoscopic technique to objectively assess the conclusions and correctly interpret the proposed algorithms and recommendations. In this regard, there is a need for an international classification of spinal endoscopies. In 2020, AOSpine proposed such a classification and approved the nomenclature for percutaneous full-endoscopic spinal surgery [102]. But to date, it does not include laparoscopy and thoracoscopy, percutaneous endoscopic stabilizing interventions, and therapeutic and diagnostic fiberoptic endoscopic devices. Further development of the classification will probably include criteria such as the endoscopy conditions (cavitary/extracavitary), endoscope type (rigid/flexible), surgical technique features (uniportal/biportal), and main goal of treatment (decompression/stabilization, etc.).

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