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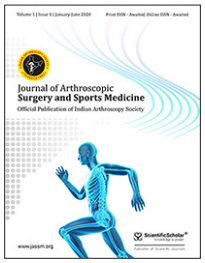

Spine *Review Article*

History of endoscopic and keyhole spinal surgery

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ABSTRACT

Development of endoscopic and keyhole surgery is often considered among the greatest scientific advancements in medicine alongside other scientific breakthroughs such as the discovery of antibiotics and the deciphering of DNA structure. The earliest concept of laparoscopy or endoscopy dates back to the use of instruments to visualize various body orifices as recorded in the notes of Hippocrates dating between 460 and 375 B.C. Adequate exposure of the surgical field which is key to safe surgical procedures required large incisions to identify the anatomical structures in the traditional open surgical approaches, and in an attempt to reduce the iatrogenic tissue trauma, smaller corridors were developed to utilize the technological advancements in magnification and illumination, and more recently navigation. As expected, perioperative morbidity is directly proportional to the extent of tissue trauma and surgical dissection, and the shift toward minimizing tissue dissection and prolonged retraction has been generally associated with earlier mobilization, reduced bleeding, and generally reduced morbidity in comparison to traditional open techniques. The advances in surgical technology, particularly in the light source and smaller cameras allowed the use of smaller incisions and adoption of minimal access surgery in the various surgical disciplines, laparoscopic cholecystectomy evolved as a cultural changing procedure and highlighted the focus on minimizing the surgical morbidity experienced by the patient. In spinal surgery, the evolution of surgical loupes, operating microscope, fiber optic light source, and minimal access surgical tools and retractors, allowed for improved surgical field visualization, resulting in smaller incisions and approaches. The initial adoption started with Lumbar discectomy and spinal stenosis decompression and evolved in other aspects of percutaneous fixation and minimal access fusion techniques applicable to trauma, degenerative disease, and tumors. This brief outline of the development of endoscopic and microscopic keyhole techniques in spinal surgery attempts to touch upon the major developments that paved the way for the large plethora of keyhole spinal surgical techniques currently available from the authors' perspective.

Keywords: Endoscopic surgery, Spine, spinal surgery, Keyhole surgery, Discectomy

INTRODUCTION

Development of endoscopic and keyhole surgery is often considered among the greatest scientific advancements in medicine alongside other scientific breakthroughs such as the discovery of antibiotics and the deciphering of DNA structure. The earliest concept of laparoscopy or endoscopy dates back to the use of instruments to visualize various body orifices as recorded in the notes of Hippocrates dating between 460 and 375 B.C.[1]

Adequate exposure of the surgical field which is key to safe surgical procedures required large incisions to identify the anatomical structures in the traditional open surgical approaches, and in an attempt to reduce the iatrogenic tissue trauma, smaller corridors were developed to utilize the technological advancements in magnification and illumination, and more recently navigation. As expected, perioperative morbidity is directly proportional to the extent of tissue trauma and surgical dissection[2,3] and the shift toward minimizing tissue dissection and prolonged retraction

has been generally associated with earlier mobilization, reduced bleeding, and generally reduced morbidity in comparison to traditional open techniques.[4,5]

The advances in surgical technology, particularly in light source and smaller cameras allowed the use of smaller incisions and adoption of minimal access surgery in the various surgical disciplines, laparoscopic cholecystectomy evolved as a cultural changing procedure and highlighted the focus on minimizing the surgical morbidity experienced by the patient.[6]

In spinal surgery, the evolution of surgical loupes, operating microscope, fiber optic light source, and minimal access surgical tools and retractors, allowed for improved surgical field visualization, resulting in smaller incisions and approaches. The initial adoption started with Lumbar discectomy and spinal stenosis decompression and evolved in other aspects of percutaneous fixation and minimal access fusion techniques applicable to trauma, degenerative disease, and tumors [Figure 1].

HISTORY OF KEYHOLE MICROSCOPIC AND ENDOSCOPIC SPINAL SURGICAL TECHNIQUES

Writing in the Journal of the American Medical Association in 1948, Valls *et al*. describe in great detail the technique for aspiration biopsy of the lesions of the spine.[7] It is interesting to read their indication for the requirement of such a technique being quite simply that the vertebral bodies cannot be surgically approached to diagnose. Only does this belie the nascent state of development of spinal surgery at the time, but it also beautifully demonstrates the practical application of the age-old adage, that necessity is the mother of invention.

Continuing to expand the indications for intervention around the spinal column, in 1964, Smith published the results of their clinical trial started the previous year using Chymopapain to treat herniations of the intervertebral discs.[8] Using a radiological guided percutaneous posterolateral approach, they injected the Chymopapain dissolved in normal saline following a discogram to confirm needle position.

The paraspinal sacrospinalis-splitting approach[9] was described by Wiltse *et al*. in 1968 to ameliorate against the disruptions of the supraspinous and interspinous ligaments. In his view, with this approach, patients were less likely to be at risk of spondylolisthesis in comparison to midline approaches (which required the removal of the posterior midline ligaments). He also advocated the approach as it resulted in less post-operative pain in patients and they had better outcomes from this procedure compared to midline approaches undertaken at the time. He professed the advantage of this muscle-splitting approach, particularly since his modifications did not require significant retraction as was necessary in other surgical approaches that attempted to access the spine lateral to the sacrospinalis. In addition, this laterally placed approach allows easier decompression of the nerves than midline approaches. While Wiltse *et al*. utilized this as an open approach and did not specifically advocate minimally invasive surgery, this open approach can be considered as another step in the ultimate development of future paramedian tubular and endoscopic approaches.

Building on the posterior-lateral radiological guided approaches to the lumbar intervertebral discs, Hijikata honed the technique in 1975 and used the term percutaneous nucleotomy to treat sciatic pathology from lumbar disk herniation by debulking the nucleus pulposus after percutaneously windowing into the annulus.[10] The technique was performed under local anesthetic and advocated to be suitable for the radiology suite. The extruded hernia fragment could not be accessed directly with this technique as there was no direct visualization at the location of the disk protrusion.

Iteratively improving their previous work, in 1986, Kambin and Sampson published their technique and results on 50 consecutive patients treated with percutaneous lateral discectomy.[11] This evolution of the c-arm fluoroscopic guided, local anesthetic percutaneous technique, described a k-wire Seldinger type technique of positioning a 4.9 mm sheath onto to the annulus fibrosis of the lumbar intervertebral disc. Through this operative port, the herniated disk material was removed using instruments and suction. However, the technique was still effectively blind, with only radiology guiding the accurate positioning of the surgical instruments and suction equipment [Figure 2].[12]

Obenchain in 1991 described the use of abdominal laparoscopy with abdominal insufflation and bowel retraction for L5/S1 discectomy[13] and followed with the evolution to the retroperitoneal approach by describing in 1997 the technique and initial results with transperitoneal and retroperitoneal laparoscopic lumbar discectomy,[14] but the anterior approaches did not gain widespread acceptance due to the significant morbidities associated with injury to the adjacent retroperitoneal structures.[14,15]

Not satisfied with the results of endoscopic approaches, Foley *et al*. pioneered the development of tubular retractors in a muscle-splitting approach to address lumbar disk herniation and its fragments as well as lumbar spinal stenosis. In 1997, he published this seminal paper on the subject of endoscopic spinal tubular access surgery, paving the way in many ways for the genesis of minimally invasive surgery of the spine as we know it today. Initial results on 15 patients operated during 1996 were presented and Foley *et al*. described hemi-laminotomy, medial facetectomy, and resection of ligamentum flavum to achieve the surgical intentions with medial

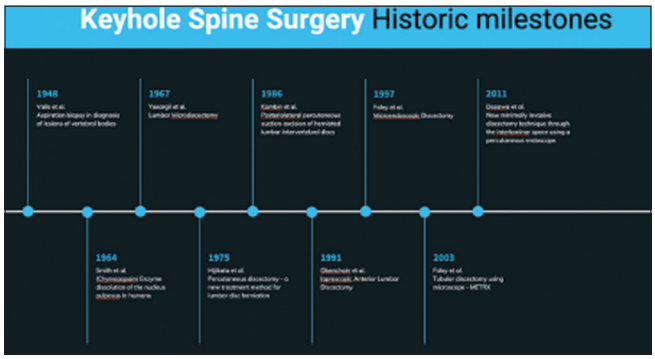

Figure 1: Milestones in keyhole spine surgery development.

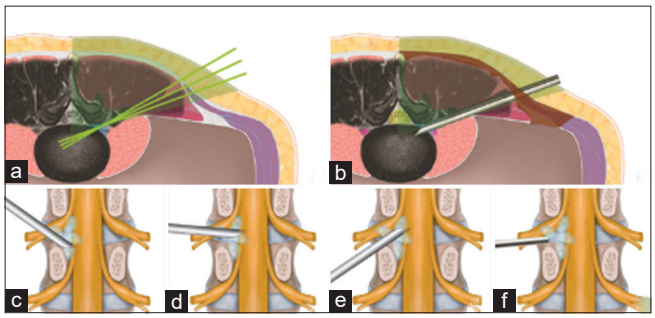

Figure 2: Illustrations of mobile outside-in technique of percutaneous endoscopic transforaminal discectomy. (a) Initial placement of the cannula in the transforaminal approach. (b) The levering of the working cannula. (c) The supra pedicular route. (d) The intervertebral route. (e) The foraminal route. (f) The round cannula placement for the far lateral disc.[12] Published under creative commons CC BY NC4.0 licence. https://creativecommons.org/licenses/by-nc/4.0/

retraction of dura and nerve root. This allowed for removal of the prolapsed lumbar disk through a small paramedian incision using tubular retractors under endoscopic views done under epidural anesthesia as day case procedure.[16]

2003 was perhaps another pivotal year in the rapid progress and refinements that minimal access spine surgery was undergoing. Foley *et al.* went on to describe lumbar, minimally invasive fusion techniques.[17] There was also the development of the METRx tubular retractor system (Medronic, Inc.) for keyhole surgery under microscopic view in 2003 which paved the way for greater adoption of these techniques among neurosurgeons who were often experienced with the skill sets required to work in confined surgical corridors created with these small tubular retractor systems under the microscopic. The higher durotomy rates and the steep learning curve noted with some of the earlier techniques could now begin to be diminished.[18]

With the body of knowledge and experience of lumbar endoscopic and microscopic keyhole surgery rapidly expanding, it was inevitable that (once the initial learning curve was mastered) application of these principles and techniques would make it way to the less forgiving cervical spine with limitations imposed by the absence of opportunity to significantly retract the theca in lieu of the intradural presence of the cervical spinal cord. Modifications of such keyhole surgery allowed for the development of techniques, including cervical spine foraminotomy.[19,20] Experienced surgeons went on to publish notes on technical refinements such as the small incision MED technique described in 2011 by Dezawa and Sairyo who advocated its use to avoid S1 root injury in herniated disk located in the axillary portion of S1 root and reported the results in 15 patients.[21]

The development of thoracoscopy and video-assisted thoracoscopic surgery[22,23] did not add significant advantages to thoracotomy due to the morbidity caused by opening the thoracic cavity[15] the transpedicular[24,25] and thoracic extracavitary approaches[26] were developed to address this aspect of procedure-related morbidity.

VALUE OF KEYHOLE ENDOSCOPIC AND MICROSCOPIC APPROACHES

Both endoscopic and microscopic keyhole approaches allow for some significant advantages over conventional open surgery which is performed using the naked eye or is often done using operative or surgical loupes. The most significant among these is the opportunity to minimize surgical trauma that invariably ensues while attempting to gain access to the deep spinal structure (e.g., spinal laminae/facet joints/posterior aspect of the intervertebral disc/anterior longitudinal ligament) to allow the intended surgical procedure to be performed (e.g., discectomy/resection of ligamentum flavum/foraminotomy). Proponents and surgeons that advocate such approaches often summarize this intent as a philosophy rather than a particular surgical technique that is encompassed within the term MISS or minimally invasive spine surgery. José-Antonio *et al.* encapsulate this philosophy well as embodying the preservation of vertebral anatomical structures, the preservation of paravertebral anatomical structures and finally the preservation of the functionality of the motion segment as well.[27] They summarize that the attainment of these principles can be accomplished by the amalgamation of the three distinct but overarching resulting concepts of minimal surgery, minimal access surgery, and motion preservation surgery.

However, there are a number of additional advantages, beyond access and tissue damage and trauma, that both approaches afford the surgeon and thus help benefit the patient.

Advantages of keyhole surgery:[28]

- Significantly higher level of magnification
- Substantially improved illumination

- Greater teaching value for trainee (both surgeon and trainee visualize exact same focused surgical field)
- Ability to record key aspects of the surgery for training and for medicolegal purposes (if required and recording module available with endoscopic/microscopic stack).

Disadvantages of keyhole surgery:[29]

- Increased training requirement for theatre staff
- Marginal increase in operative time initially (so-called learning curve)
- Additional cost related to endoscopic or keyhole equipment
- Reduction of operative room space due to microscope or endoscopic stack.

In addition to the smaller incisions resulting in lower bleeding and faster post-operative recovery, the development of paramedian muscle splitting approaches and the use of dilators and tubular retractors reduces paraspinal muscles injury and preserved the midline structures resulting in adequate exposure of the targeted surgical field for a satisfactory outcome while minimizing the iatrogenic spinal trauma and future instability.

ENDOSCOPIC VERSUS KEYHOLE MICROSCOPIC SURGERY

However, there are some nuances to both the endoscopic and keyhole microscopic approaches that afford differential advantages and disadvantages.

Microscopic keyhole spine surgery relies on the use of a conventional operating microscope for surgical visualization. This affords the method of certain advantages compared to the endoscopic approach such as:

- Binocular vision allowing for greater depth perception
- Larger surgical corridor for instruments in comparison to uniport endoscopic approach
- Ergonomic alignment of line of vision (through eyepiece) and working direction of both hands (endoscopic work often requires the surgeon to look away toward the screen which is often not directly in line of the operative field)
- Easy translation of operative skillsets microscopic acquired in other fields (e.g., cranial neurosurgery) into the domain of spinal keyhole surgery.

However paradoxically, often the more expensive microscopic equipment, due to the optical engineering requirements of conventional microscopy and principles of rectilinear propagation, cannot change the direction of vision which must be in line with the access port/tubular retractors, i.e., microscopes cannot see "around the corner" which angled endoscopes can, thus bringing the viewpoint closer to the site of pathology.

CONCLUSION

This brief outline of the development of endoscopic and microscopic keyhole techniques in spinal surgery attempts to touch upon the major developments, from the authors' perspective, that paved the way for the large plethora of keyhole spinal surgical techniques currently available from the authors' perspective. By no means is it a definitive work of reference that catalogs the dedicated and timeless work of so many skilled surgeons, scientists, and innovators that have enabled modern surgeons to have so much technical advancement available to them. These keyhole techniques in effect provide a larger repertoire of "tools" in the armamentarium that is available to the spinal surgeon to address the patients' pathology. But as in much of life, the utility of the "tool" is highly dependent on the skills and preferences of the craftsman with respect to the use of the tool and his or her ability to deliver the intended results based on their mastery of the tools. As always, surgery will remain an art as well as a science with its greatest accomplishment, perhaps being able to know when not to operate apart from knowing how to operate and who to operate upon.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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