1 HISTORY OF MINIMALLY INVASIVE SPINE SURGERY

Larry T Khoo MD, Ali Fahir Ozer MD,
Murat Cosar MD PhD, Farbod Asgarzadie MD

1. Introduction:

The history of spine surgery goes back at least 5000 years. The first evidence of spinal surgery was found in Egyptian mummies from 3000 BC and elucidated 15 centuries later in the Edwin Smith papyrus in 1550 BC [1, 2]. Most spine surgeons believe that Hippocrates is the father of spine surgery because of his extensive writings and treatment principles he proposed. For example the first traction procedure was proposed by Hippocrates in 390 BC [3]. In the 7th century, the first operative treatment of spinal surgery was performed by Paulus of Aegina [4]. In the 14th century, Serafettin Sabuncuoglu elucidated the treatment of spinal fracture dislocations in his surgical atlas [5].

Before the relatively recent evolution of technological advancements such as high speed drills microscopic surgical techniques and spinal instrumentation, spinal surgery consisted mainly of spinal decompressions, different fusion procedures and external corrective orthoses with staged operations. These early surgical maneuvers were often very lengthy, highly morbid and caused prolonged disability and negative psychological sequelae. The development of rigid and semi-rigid internal metallic fixation allowed the spine surgeons to rapidly stabilize the pathological spine in the early 1980s. Nowadays, it has become a worldwide standard of care. However, the placement of spinal implants often require long and extensive surgical exposures which strip away the overlying soft-tissues, thereby oftentimes denervation and regional ischemia to the adjacent soft tissues. These iatrogenic injuries can cause significant postoperative pain and disability.

With the advent of modern surgical technologies such as digital fluoroscopy, image guidance, high-resolution endoscopy, and minimally invasive surgical tools, less invasive approaches have become more popular. The majority of these minimally invasive techniques use a small corridor focusing on the area of anatomy, thereby minimizing the resultant injury to the dorsal neural, muscular and ligamentous soft tissues. Minimally invasive techniques have been successfully applied to the cervical spine, thoracic spine and the lumbar region since the 1990's [6-11].

2. Cervical Spine:

2.a. Anterior Procedures

Percutaneously establishing a safe corridor to the anterior cervical spine can be difficult and can carry the risk of potential injury to the carotid artery, jugular vein, esophagus, trachea, thyroid and laryngeal nerves. Minimally invasive tubular approaches to the anterior cervical spine are therefore less commonly reported compared to minimally invasive posterior cervical spine techniques. The first anterior cervical cord decompression was first described by Key in 1838 [12]. More than a century later in 1968, Verbeist reported the anterior cervical foraminotomy [13] and it was popularized by Cloward, Smith and Robinson for the treatment of cervical spondylotic radiculopathy and disc diseases of the cervical spine [14-16]. In 1975, Lankinson and Wilson [17] reported the use of the microscope for anterior cervical discectomy. In the early 1980s, the concept of internal fixation to aid in cervical fusion was introduced [18]. In 1989, Snyder and Berhardt [19] developed the anterior cervical foramin-

otomy in an effort to avoid adjacent segment disease after fusion procedures. Joe has popularized percutaneous anterior cervical techniques in the early 1990s [20,21].

Since then anterior cervical microforaminotomy and endoscopic-assisted anterior cervical discectomy and fusion have become popular minimally invasive anterior cervical spine procedures.

2.b. Posterior Procedures

The posterior cervical approach for cervical disc disease was first introduced by Elsberg in 1913 [22]. Over the last 4 decades the posterior cervical lamino-foraminotomy has been well documented [23-25]. Scoville and Whitcomb [26] popularized the concept of posterior cervical disc surgery in 1966. The posterior approach via a "key hole" osteotomy foraminotomy provided a better exposure to decompress the nerve roots and to remove lateral osteophytes and discs as compared to the anterior cervical approaches. Murphy *et al.* [25] reported their open lamino-foraminotomy series of 648 cases with 80 % reduction of preoperative symptoms.

However, this open procedure can cause significant muscular injury, atrophy, pain and spasm during the recovery period. After the advent of micro endoscopic foraminotomy (MEF) for posterior cervical foraminotomy by Roh *et al.* [27] in cadavers, the wide incision and paraspinous muscular dissection for the approach was. Adamson [6] and Khoo [28] described their experience with MEF in over 125 patients demonstrating less overall postoperative narcotic use, less postoperative pain as compared to open posterior cervical spine procedures without compromising extent of nerve root decompression. Additionally, percutaneous posterior cervical instrumentation, laminectomy and laminoplasty have also been performed using minimally invasive techniques. Although these experiences are preliminary, the presented reports and technical notes are without any significant complications [29-33].

3. Thoracic Spine:

In 1779, Pott [34] performed the first thoracic spine approach to drain a tuberculosis abscess. Additionally, Key [12] reported the first case of thoracic disc disease in 1838. The lateral extracavitary approach was described by Menard in 1894 [35]. Additionally, the first known thoracic laminectomy and discectomy was performed by Adsen in 1922 [36,37]. Transsternal, transthoracic and transpedicular approaches were described in the last four decades [18].

The first thoracoscopic procedure was performed by Jacobaeus, an internal medicine professor, in 1990 [38]. After the introduction of video imaging to standard endoscopy, Mack *et al* [39] in the United States and Rosenthal *et al* [40] in Europe first reported the technique of video assisted thorascopic surgery (VATS) in 1993. Initially, thoracoscopic procedures were performed for disc herniations, pathologies of vertebral body, tumor biopsies and drainage of abscesses. As the learning curve developed, it was performed for scoliosis, tumors, fractures, fusions and instrumentations, symphatectomy, osteotomies, corpectomies, and bone grafting [1]. VATS allows visualization of the operation by the operating team with small incisions and minimum amount of rib resection.

In 1997, Joe [37] reported the first endoscopic transpedicular thoracic discectomy for disc herniations. A 0- and 70 degree 4 mm endoscope was used with a small incision and minimal tissue dissection for this technique. Additionally, the first laser thermodiskoplasty was performed with a 4 mm 0- degree endoscope by Chiu and Clifford [41].

4. Lumbar Spine:

Traumatic lumbar disc rupture was first described by Virchow in 1857 [42], It wasn't until 50 years later that the first lumbar laminectomy and discectomy was performed by Oppenheim and Krause [43]. In 1938, Love [44] reported the first minimal invasive interlaminar technique for lumbar disc surgery. Yasargil [45] and Caspar [46] were the first to popularize the use of the operating microscope for the treatment of lumbar disc disease.

4.a. Percutaneous Procedures

The first injection of chymopapain was performed by Smith *et al.* [47] into a herniated nucleus pulposus for the treatment of sciatica. Injection of chymopapain causes chemonucleolysis and polymerization of the nucleus pulposus [1]. Today, there is no consensus in the spine surgery community regarding the use of chymopapain.

Hijikata *et al.* [48] in 1975 reported the first percutaneous nucleotomy for posterolateral lumbar disc herniations using arthroscopic techniques. In 1985, Onik *et al.* [49] described the automated percutaneous lumbar discectomy using a 2 mm blunt-tipped suction cutting probe. Additionally, percutaneous laser discectomy was introduced by Choy *et al.* [50] in the late 1980s.

The first percutaneous vertebroplasty procedure was developed in 1984 by Galibert and Deramond with polymethylmethacrylate (PMMA) injection to the vertebral body through the pedicles [51]. In 2001, kyphoplasty was developed to restore the height of the vertebrae via using an inflatable bone tamp before injecting PMMA [52].

In late 1990s, Saal and Saal [53] reported intradiscal electrothermal therapy to treat discogenic back pain. Nowadays, stereotactic and magnetic resonance guided microdiscectomies are also reported [18].

4.b. Endoscopic Procedures

Forst and Hausman [54] reported the first insertion of a modified rigid arthroscope into the center of the intervertebral disc space for visualization purposes in 1983. In 1988, Kambin [55] went on to apply this "discoscopic" view of a herniated disc fragment from within the disc. Additionally, in 1996, Kambin [56] went on to describe and document a safe posterolateral triangular working zone known subsequently as "*Kambin's triangle*". In 1997, Foley and Smith introduced and illustrated the MicroEndoscopic Discectomy (MED) system to decompress a symptomatic lumbar nerve root [57]. The MED system allowed surgeons to address not only contained lumbar disc herniations, but also sequestered disc fragments and bony lateral recess stenosis.

AS experience and efficacy with tubular-type endoscopic approaches grew, these techniques were beginning to be applied to a broader range of pathologies. Khoo *et al.* [16] have previously reported a prospective, nonrandomized comparison of patients undergoing either open hemilaminotomy versus minimally-invasive microendoscopic decompressive hemilaminotomy (MEDL) for the treatment of lumbar stenosis. Since then, advancement in the wide angled endoscopes and wider working channels have allowed for multiple types of mechanical instruments, drills and lasers to be applied as well.

4.c. Lumbar Arthrodesis Procedures

The first posterior lumbar interbody fusion (PLIF) was introduced by Cloward in 1953 for degenerative disc disease and spondylolisthesis [58]. Since the advent of minimally invasive teqhniques, tubular approaches have also been applied to lumbar interbody fusions. Near total facetectomies and foraminotomies were performed to create a pedicle-to-pedicle exposure to allow for interbody fusion and grafting while ensuring the safety of the neural elements without overly aggressive retraction by extending the decompression through the access portal. After decompression, all phases of the interbody process including distraction, scraping, end plate preparation and placement of the allograft interbody spacers can be accomplished through the tubular access portal under close inspection of the neural elements [14].

In 1995, Matthews and Long [59] introduced the first percutaneous lumbar instrumentation using pedicle screws connected by subcutaneous plates placed above the dorsolumbar fascia. In 2000, Lowery *et al* [60]. subsequently described a similar procedure utilizing a rod as the joining member. However, these early attempts at spinal fixation necessitated subsequent hardware removal in some cases due to patient discomfort and nonunion [14]. In 2002, Foley [61] introduced the Sextant (Medtronic Sofamor Danek, Memphis, TN) system for the purpose of achieving a percutaneous pedicle screw rod fixation. Since the Sextant, several other minimally-invasive lumbar fixation systems have been developed including the ATAVI (Endius; Plainville, MA), Aperture (Depuy Spine; Raynham, MA), and Pathfinder (Spinal Concepts; Austin, TX) systems [14]. Multilevel instrumentation, compression, distraction and reduction of spondylolisthesis are possible with several of these newer systems thus allowing for fixation of most common lumbar pathologies via a truly percutaneous technique through only two small incisions [14].

Anterior lumbar interbody fusion (ALIF) was introduced as an alternative to PLIF in 1965 [63]. In recent years, more minimally invasive ALIF procedures were reported [62], McAfee *et al.* [64] reported the first endoscopic retroperitoneal approach to the lumbar spine in 1997. The first laparoscopic approach to the lumbar spine was introduced by Obenchain in 1991 [65]

and this paved the way for other laporoscopic lumbar spine procedures [66, 67].

5. Conclusion:

In the 5000? year-old history of spine surgery, the last 4 decades have seen a tremendous amount of development. With the advance of surgical, microspcopic and endoscopic tools, MIS surgery has made significant progress in the last ten years. We believe MIS surgery will continue to make strides in all subdisciplines of spinal surgery. Advances in MIS surgery have led to greatly improved outcomes, while reducing complication rates, shortening hospital stays, and lowering costs. Appropriate patient selection and strict adherence to indications will help to result in optimal outcomes and patient satisfaction.

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