Clin Orthop Relat Res (2015) 473:1885–1895
DOI 10.1007/s11999-014-3633-7

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

SYMPOSIUM: CURRENT APPROACHES TO THE MANAGEMENT OF LUMBAR DISC HERNIATION

A History of Lumbar Disc Herniation From Hippocrates to the 1990s

Eeric Truumees MD

Published online: 22 April 2014

Abstract In ancient times, a supernatural understanding of the syndrome of lumbar radiculopathy often involved demonic forces vexing the individual with often crippling pain. The ancient Greeks and Egyptians began to take a more naturalistic view and, critically, suspected a relationship between lumbar spinal pathology and leg symptoms. Relatively little then changed for those with sciatica until the classic works by Cotugno and Kocher arrived in the late 18th century. Early lumbar canal explorations were performed in the late 1800s and early 1900s by MacEwen, Horsley, Krause, Taylor, Dandy, and Cushing, among others. In these cases, when compressive pathologies were found and removed, the lesions typically were (mis-)identified as enchondromas or osteochondritis dissecans. To better understand the history, learn more about the first treatments of lumbar disc herniation, and evaluate the impact of the early influences on modern spine practice, searches of PubMed and Embase were performed using the search terms discectomy, medical history, lumbar spine surgery, herniated disc, herniated nucleus pulposus, sciatica, and lumbar radiculopathy. Additional sources were identified from the reference lists of the reviewed papers. Many older and ancient sources including De Ischiade Nervosa are available in English translations and were used. When full texts were not available, English abstracts were used. The first true, intentional discectomy surgery was performed by Mixter and Barr in 1932. Early on, a transdural approach was favored. In 1938, Love described the intralaminar, extradural approach. His technique, although modified with improved lighting, magnification, and retractors, remains a staple approach to disc herniations today. Other modalities such as chymopapain have been investigated. Some remain a part of the therapeutic armamentarium, whereas others have disappeared. By the 1970s, CT scanning after myelography markedly improved the clinical evaluation of patients with lumbar disc herniation. In this era, use of discectomy surgery increased rapidly. Even patients with very early symptoms were offered surgery. Later work, especially by Weber and Hakelius, showed that many patients with lumbar disc herniation would improve without surgical intervention. In the ensuing decades, the debate over operative indications and timing continued, reaching another pivotal moment with the 2006 publication of the initial results of Spine Patient Outcomes Research Trial.

The author certifies that he, or a member of his immediate family, has no funding or commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research*® editors and board members are on file with the publication and can be viewed on request.

E. Truumees (✉)
Seton Spine & Scoliosis Center, A Program of the Seton Brain and Spine Institute, University Medical Center at Brackenridge, 1600 West 38th Street, Suite 200, Austin, TX 78731, USA
e-mail: etruumees@gmail.com

Introduction

The clinical syndrome of radiculopathy from lumbar disc herniation (LDH) is a major cause of morbidity and cost. Among most common diagnoses in spine practice, the incidence of symptomatic LDH in the United States has been estimated at 1% to 2% [36].

The first descriptions of sciatica go back to ancient times, but our understanding of LDH as a clinical entity arose in the mid-1700s. Although early surgeries for spinal

"enchondromas," which very likely were herniated discs, were performed in the first part of the 20th century, modern discectomy surgery is usually traced to Mixter and Barr in the 1930s. From the 1930s to the present, our understanding of the pathophysiology, natural history, and treatment of LDH has continued to grow more sophisticated. By the mid-1990s, approximately 200,000 discectomies were performed annually in the United States alone [106]. Despite its frequency, controversy remains over the best approaches to treating patients with LDH.

In an excellent historical overview, Karampelas and colleagues [55] describe a series of "slow, sequential stages" of the evolving understanding of sciatica in ancient cultures. Chedid and Chedid [24] identify three chief advances: improved understanding of LDH pathoanatomy, the introduction of surgical antisepsis (and later antibiotics), and improved means of imaging and clinical evaluation of patients with sciatica. Advances in anesthesia and spinal biomechanics also were important [24, 84, 88]. The goal of this article is to provide a history of this understanding from the earliest available sources to the mid-1990s.

The Early History of Lumbar Disc Herniation

Early societies attributed the acute lancinating pain of sciatica to evil forces such as early Germans' witch's shot (Hexenschuß) and the early British elf's arrow [99]. These ideas persisted into the mid-20th century, particularly among rural societies [111]. For the ancient Hebrews, Jacob is renamed Israel after an all-night wrestling match with God (Genesis 32:25–32). God touches Jacob's hip causing sciatica. Thereafter, animals' sciatic nerves are no longer kosher. The Talmud provides specific instructions for nerve removal from slaughtered animals. The Talmud terms sciatica "schigroma." As treatment, the painful area is to be rubbed 60 times with fresh brine [89]. Descriptions of sciatica are found only infrequently among ancient Indian medical texts [64]. They describe the concept of marmas, discrete areas in which muscles, vessels, ligaments, bones, and joints come together. When the kakundram marma, in the lumbosacral area, is injured, lower extremity numbness or paralysis could be expected [64]. When reading these ancient sources, it is not always clear that the clinical syndrome described aligns exactly with our modern notion of "sciatica." Space does not allow a close description of the primary materials, but the interested reader is referred to the fascinating sources. These cases-in-point are meant to illustrate an evolving view of disease from a supernatural to a scientific basis.

The ancient Egyptians and Greeks also suspected a relationship between spinal afflictions and lower extremity symptoms [102]. Among ancient Greek and Hellenistic physicians, a more naturalistic understanding emerged. Hippocrates observed the relationship among sciatica, an antalgic posture, and claudication [69]. Sciatica was thought more prevalent during the summer and fall because the sun could "dry up" necessary joint fluid [48]. Hippocrates prescribed rest, massage, heat, dietary changes, and music.

In the second century, Galen produced several spinal pathoanatomy treatises [70]. By the fourth century, Caelius Aurelianus offered plate depictions of the spinal column and intervertebral disc spaces. He reported that sciatica, although most common in middle age, could occur at any age [9, 22, 91] after "a sudden jerk or movement during exercise, unaccustomed digging in the ground, lifting a heavy object from a low place, lying on the ground, a sudden shock, a fall, or continuous and immoderate sexual intercourse." Initial treatment began with traditional bedrest, massage, heat, and passive ROM exercises. Aurelianus described the muscle wasting found in advanced cases and for these intractable cases leeches, hot coals, skin hooks, and blood-letting were instituted. In the seventh century, Paulus of Aegina first suggested spine surgery, although his emphasis was on spine trauma [24, 85]. His description of sciatica included pain extending from the buttock and groin to the knee and "often as far as the extremities of the foot." Like his predecessors, he recommended rest-based conservative treatments. However, for chronic cases, he advocated cauterizing the hip in three or four places to prevent dislocation.

Ancient Arabic medicine was offered descriptions and treatments similar to those of the ancient Hebrews [74]. After the fall of the Roman Empire, and until the renaissance, many of the advances in spine care occurred in the Arabic and Turkish worlds. By the 15th century, Turkish physician Sabuncuöglu treated sciatica recalcitrant to analgesics with cauterization [24].

In his 1764 monograph, De Ischiade Nervosa Commentarius, Domenico Cotugno ascribed radicular pain to the sciatic nerve [28]. For years afterward, sciatica was called Cotugno's disease. In 1857, Virchow published a discussion of disc pathology that included a ruptured disc, which at that time was called "Virchow's Tumor" [22, 91]. The next year, Luschka further described disc ruptures but did not relate these pathologic findings to clinical symptoms [67]. In 1864, Ernest Lasègue, recognizing the close association between back pain and sciatica, described the straight leg raise, or Lasègue's maneuver [22, 91].

The safety of open surgery increased with Lister's work in antisepsis [24]. The first lumbar laminectomy is variably attributed to William MacEwen or Victor Horsley around 1887 [3]. Following the advice of neuropathologist Hermann Oppenheim, surgeon Fedor Krause performed the first discectomy in 1908 at the Berlin Augusta Hospital [8]. The

procedure began with a low midline incision and reflection of the paravertebral muscles from the laminae. The laminae were removed in one piece and the lesion was resected transdurally. Oppenheim reported that the patient had immediate, complete relief of pain. The tissue was mistaken for an enchondroma [80]. In 1896, Kocher reported post-mortem findings of L1-2 disc displacement in a man who had fallen 100 feet [60]. Kocher considered the possibility that the disc fragment may have compressed the spinal cord.

Lumbar Disc Herniation in the Early 20th Century

Alfred Taylor performed the first unilateral laminectomy on a cadaver in 1909 [84]. At least one source also credits Taylor with the first extradural discectomy at Presbyterian Hospital in New York City [83]. In 1911, Goldthwait and Osgood interpreted a disc protrusion as the cause of lower extremity paresis. Cushing operated on the patient with resolution of the patient's cauda equina syndrome [43]. Interestingly, Cushing's surgery had been a negative exploration. Goldthwait suggested that the disc had "slipped back into place." In the 1920s, German pathologist Christian Georg Schmorl studied 10,000 spines. He described protrusions of disc material, including into the vertebral body and the spinal canal, as herniations. Although no clinical significance was attributed to the findings, the term disc herniation became popular in the parts of Europe that read the German literature [95]. In English-speaking countries, other terms became popular, including disc collapse, retropulsion, and rupture [82].

In 1929, American neurosurgeon Walter Dandy reported two cases of lumbar surgery for back and leg pain [29]. Loose cartilaginous fragments were discovered in the epidural space. He ascribed the process to osteochondritis dissecans from trauma with fragments acting as a sequestrum. Other sources credit A. G. Smith with the first discectomy procedure performed in the United States [59, 84]. In 1930, at the Surgical Academy of Paris, Alajouanine and Petit-Dutaillis presented a case of sciatica associated with an intraspinal lesion at L5-S1. They suggested that the lesion, previously identified as a tumor, was actually a herniation of the nucleus pulposus [2]. By the 1940s, the term herniation of the nucleus pulposis was favored and, in fact, continues to be used today. Unfortunately, this term poorly describes the histology of the displaced elements. In particular, in older patients with degenerated discs, the displaced material often includes little nucleus and far more annulus [15]. Today, other common terms include disc prolapse and intervertebral disc herniation. The 2013 revision of the NASS Nomenclature and Classification of Disc Pathology monograph recommends LDH [40].

By 1932, the first operation carrying a preoperative diagnosis of "ruptured intervertebral disc" was carried out by Mixter, a neurosurgeon, and Barr, an orthopaedic surgeon [75]. At that time, an L2 to S1 laminectomy was performed on a 28 year old who exhibited the "classic" signs of nerve root compression: limited motion at the lumbosacral junction, positive straight leg raise on the affected side, and an absent ankle reflex [96]. A 1-cm mass was removed and the patient recovered from surgery with complete resolution of his radicular symptoms. In that the patient's symptoms began shortly after a traumatic event, Barr rejected the tumor theory of the "enchondroma's" origin. Along with pathologist Charles S. Kubik, he compared samples from this and other specimens with disc tissue harvested at autopsy. They concluded there was no difference between them [10, 96].

By 1934, Mixter and Barr presented a correlation of disc prolapse and the clinical syndromes associated with the resulting nerve and cord compression. They advocated a surgical approach. After their publication of 19 cases, the diagnosis of a "ruptured" disc gained traction in the medical community. Mixter advocated use of the pituitary rongeur to enter the disc space [4]. Later, Barr reported a larger, 35-patient series and was one of the first to identify preexisting degeneration as an etiologic factor in herniations [11]. Some controversy lingers over the relative contributions of Dandy and Mixter and Barr. Ultimately, credit for discectomy surgery is usually given to Mixter and Barr because Dandy focused solely on cauda equina syndrome and reported only two cases [30, 96]. Dandy's report garnered less attention and was less influential in subsequent research.

In 1938, Love described the intralaminar, extradural approach to discectomy. He removed the flavum but minimized bone removal. Today's standard, open technique is a modification of Love's technique [24, 65, 66]. Love and Walsh presented the results of first series of 100 patients undergoing surgical discectomy. For the first time, recurrent herniation was described. By 1940, their series included 300 patients [66]. By the 1960s, surgical removal of herniated discs rapidly became one of the most frequently performed procedures for orthopaedic and neurological surgeons. In 1977, Caspar reported good results in 102 patients undergoing discectomy through medial facetectomy and extradural dissection [20]. Specialized instruments allowed smaller incisions, typically approximately 5 cm by this time.

Lumbar Disc Herniation in the Modern Era

In the early 1970s, even patients with very early, acute symptoms were offered surgery [88]. By the 1980s, the

favorable natural history of most patients with LDH was increasingly recognized as a result of the seminal papers by Weber [112] and Hakelius [44]. Both studies compared long-term outcomes in surgically and nonsurgically managed patients. In Weber's series, at 10 years, 60% of both groups were free of pain, but earlier relief was seen in the surgical group. For Hakelius' 583 patients, there were no differences between the surgical and nonsurgical groups at 6 months. At 7 years, however, operatively treated patients did have fewer episodes of low back pain, sciatica, and missed work. By 1996, microdiscectomy pioneer John A. McCulloch wrote, "long-term results of surgery are only slightly better than conservative measures and the natural history of lumbar disc herniation" [72].

After Weber, a 4- to 8-week trial of "conservative care" before surgery was typically recommended [72]. Exceptions of course were, and are, made for patients with progressive neurological deficits or cauda equina syndrome. This nonoperative care has included bedrest, medications, physical therapy, injections, and lumbar traction. Since the Middle Ages, spinal traction has offered another therapeutic option in the treatment of lumbar radiculopathy. Earlier, this traction specifically sought to correct the "curvature" (listing) associated with radiculopathy [97]. Later, traction was theorized to promote regression of the herniated disc, enlargement of the neural foramen, or improvement of disc nutrition or radicular blood flow [90]. In the 1970s, manual traction modalities, with or without ropes and pulleys (such as the Hippocratic Board), were augmented by motorized and computer controlled systems (eg, Vax-D). In 1967, Pearce and Moll [86] concluded that "there is no real evidence that traction does any more than keep the patient still." A more recent Cochrane review [113] concluded: "For people with LBP with sciatica and acute, subacute or chronic pain, there was low- to moderate-quality evidence that traction probably has no impact on pain intensity, functional status or global improvement." Regardless, these modalities still enjoy broad use. Specifically, the more expensive computerized systems have no demonstrated benefit over more traditional approaches.

In the 1990s, newer histopathologic and immunochemical studies revealed that in migrated or extruded disc herniations, the displaced disc material may undergo phagocytosis by macrophages in the epidural tissue or arriving from epidural veins [88].

Another factor influencing treatment choices for patients with LDH was the increased risks those patients bore for recurrent or other level disc pathologies in the future. Repeat surgery has remained common [35, 49, 115]. Although early studies emphasized the role of trauma in LDH, studies in the 1980s and 1990s increasingly identified strong genetic susceptibility to both disc herniation and degeneration [24, 56, 71]. Although truly protective strategies remain elusive, our understanding of the pathophysiology and genetics of disc herniation have improved.

Studies in the 1980s and 1990s began to elucidate the mechanisms of pain generation from disc herniations. These include the variable impact of mechanical pressure on the nerve roots and dorsal root ganglia, their blood supply, and their nutritional transport systems [78]. Before 1947, the lumbar disc itself was considered a nerve-free, painless structure. In 1947, Inman and Saunders discovered pain fibers in the annulus [50]. Later, more sophisticated histological techniques confirmed these earlier findings and the presence of twigs from the sinuvertebral nerve into the outer third of the annulus and posterior longitudinal ligament [61]. The concept of mechanical low back pain arising from disc degeneration was popularized in 1968 by neurosurgeon Francis Murphey [76]. He based his theory on surgeries performed under local anesthesia and intravenous sedation. These findings led to a period in which many patients with LDH were treated by decompression and fusion.

Patient Evaluation: A Century of Changes

During the last 100 years, the evaluation of patients with radiculopathy has evolved substantially. Initially, assessment was based primarily on the clinical history and physical examination [88]. Those patients with sciatic pain reproducible with trunk flexion were often offered surgery. By the mid-1980s, many studies sought to better identify clinical signs of surgically significant radiculopathy. Although the value of the straight leg raise had previously been identified, crossed straight leg raise, muscle wasting, and diminished reflexes were identified in patients "requiring" surgery [62]. Purely sensory symptoms, ie, nonpainful numbness, tingling, poorly predicted good surgical outcomes [57, 62].

Advances in spinal imaging have markedly impacted the evolution of both our understanding of intervertebral disc herniation pathoanatomy, but also less invasive surgical management for intractable cases. Röntgen reported first medical use of radiographs in 1896 [96]. Initially, only AP views were obtained; Davis obtained the first lateral view in 1925 [24]. Plain radiographs, of course, are unable to directly identify the neurocompressive pathology in patients with LDH. In 1928, Sicard and Forestier introduced Lipidiol myelography [98]. For the next three decades, these studies, performed on inpatients by the surgeon, involved suboccipital injection of a nonhydrosoluble contrast medium. In the 1950s, because the involved level was not clearly determined, two levels were usually explored [88]. When mild protrusion or no

significant compression was found, the nerve root irritation was attributed to epidural varices.

In the 1960s, myelography improved significantly with the introduction of new, hydrosoluble contrast media, including iodomethamate, which could be injected from a lumbar approach [82]. In one study from 1977, water-soluble myelography correlated with intraoperative findings in 90.2% of 886 cases [94]. In 1984, a study of 100 patients found that of the 16 patients undergoing surgery with a negative myelogram, LDH was identified in only five at the time of surgery [39]. Still, these patients with negative imaging did not have a good result. Since that time, most experts militate against aggressive searches for obscure disc pathology because subsequent surgery typically offers poor results. Although still of dubious value in most patients with LDH, electrodiagnostics were commonly used by the 1960s as well [88].

Computerized axial tomography became available in the 1980s from work by Hounsfield and Ambrose in the early 1970s [82]. Although plain CT is found to be most accurate for LDH when sufficient epidural fat is present, myelography was soon added to CT scans to improve resolution of soft tissue neurocompressive pathologies [105]. In 1940, De Sèze reported that most disc herniations affect the nerve root in the spinal canal, before its entrance into the foramen [33]. By the 1980s, these new imaging modalities allowed LDH to be preoperatively classified by the direction (anterior, central, posterolateral, and far lateral) and degree (protrusion versus extrusion) of displacement. For example, the diagnosis of far lateral disc herniations on axial CT slices led to Wiltse's lateral approach to the disc space [31, 33, 118]. Disc bulging, on the other hand, was increasingly identified as "not pathological and should not be removed" [57, 62]. Later studies suggested that classification of LDH by fragment type and annular defect may better predict risk of recurrence [17].

First suggested by Lindblom in 1948, discography remains a controversial imaging modality [24]. Extension of contrast material into the canal gave surgeons additional evidence of LDH. In some areas, discography continues to be used to provoke a radicular pain response in patients with multiple disc herniations to better localize invasive treatment [58]. Evidence of early dye leakage, suggesting disc extrusion, remains a contraindication to several percutaneous treatment approaches, particularly chemonucleolysis [34, 58]. In the United States, discography is occasionally used to document chemical nerve irritation from "leaking discs" [7]. More typically, however, the study is used to assess mechanical back pain in patients with lumbar disc degeneration, ostensibly from annular tears or endplate microfractures [7].

Introduced clinically in the 1990s, MRI offered another major advance in the evaluation of LDH [82, 88]. As a noninvasive procedure without ionizing radiation exposure, MRI allowed serial evaluation of the same patient. Some disc herniations were demonstrated to decrease in size, which, along with other natural history data, prompted reevaluation of the timing of surgery in symptomatic patients. MRI rapidly became sensitive enough that "absence of a clear cut abnormality on an MRI is a contraindication to surgery" [72]. On the other hand, high rates of asymptomatic disc herniations were identified. Surgeons realized that "the observation of a herniation on MRI does not necessarily mean that the source of the patient's symptoms has been located" [14, 72]. Soon thereafter, intravenous contrast MR images in the postoperative setting were recommended to distinguish scar from recurrent LDH [107].

Evolving Treatment Options

Initially, LDH surgery was only available at a few centers. As a practical matter, most patients had months of symptoms before surgery was considered. By the 1970s, surgery became more widely available and gradually less invasive. As a result, rates of discectomy increased rapidly from 1979 to 1990 [32]. Aside from the question of when a symptomatic patient should be offered surgery, the indications for discectomy do not appear to have changed much over the last hundred years. Better evaluative tools have increasingly focused the requirement of "a clearly defined, unequivocal lesion on imaging that corresponds, anatomically, with the clinical root level" [39, 62, 72].

In early cases, after the displaced fragment had been removed, a radical discectomy, including curettage of the remaining nucleus pulposus and cartilaginous endplates, was performed to reduce recurrence rates. In many patients, this aggressive approach required more neural tissue manipulation and resulted in postoperative destabilization, marked disc height loss, and ongoing back pain. By the 1970s, Robert Williams and others increasingly recommended removal of the displaced and any loose fragments instead of subtotal or radical discectomy [23, 90, 92, 103, 116]. Subsequent studies showed minimal impact on the recurrence rate.

Other investigators studied the role adjunctive fusion in patients with LDH. In 1947, Barr himself reported improved outcomes in patients with LDH treated with decompression and fusion over those treated with discectomy alone. In particular, he cited decreased back and leg pain and increased return to preinjury activity levels [11]. Later in his career, however, Barr retreated from this stance, writing "additional fusion of the spine does not significantly improve the results of lumbar disc surgery … and may lead to more serious postoperative complications"

[12, 96]. By 1988, concomitant fusion was termed "wholly unnecessary" [62]. Still, the routine fusion of patients with LDH remains controversial. A subset of patients with LDH at risk for "postoperative instability" (eg, spondylolisthesis) has been associated with poor outcomes from discectomy alone [42, 63, 81]. Recurrent disc herniation is a more common indication for adjunctive fusion. The risk of additional, index-level pathology is thought to increase with each recurrent LDH [42]. As a result, many authors recommend concomitant fusion after the second recurrent disc herniation. Others recommend repeat discectomy alone for focal, recurrent LDH [45, 52].

In 1988, Vaughan and coworkers compared the outcomes of discectomy alone versus discectomy and fusion in 85 patients [109]. Using the Smiley-Webster scale, at an average 7.3-years followup, the nonfusion group had a significantly higher percentage of patients with chronic back pain. The fusion group had significantly better results compared with the nonfusion group (85% satisfactory results versus 39% satisfactory results). The reoperation rate was 13.5% in the nonfusion group and 3% in the fusion group. Over time, however, spine surgeons increasingly considered the clinical entity of painful lumbar disc degeneration leading to axial rather than predominantly radicular pain. Although this clinical syndrome remains extremely controversial, it has spawned a variety of mechanical treatment approaches from threaded fusion cages to disc replacement systems [24]. It may surprise some readers to discover that the first "artificial disc" designs go back to Van Steenbrugghe and Nachemson in 1955 and 1956, respectively. Fernström's stainless steel ball was introduced in the late 1950s [24, 41].

The most important trend in discectomy surgery has been toward minimizing soft tissue dissection. Specialized retractors were developed to accommodate smaller incisions even in the deeper dissections required in larger patients. By the 1990s, table-mounted, tubular retractors were increasingly used to further decrease incision size, muscle injury, and dead space formation [87]. The first use of an operating microscope in lumbar discectomy surgery was by Yasargil in 1967 but reported as part of a series of 105 patients in 1977 [119]. Microscope use was popularized, at first mainly among neurosurgeons, in the late 1970s and 1980s by, among others, Robert Williams who published very favorable results in 534 patients in 1979 [116]. Microdiscectomy was further refined in the early 1990s by orthopaedic spine surgeon John McCulloch [72]. In the 1990s, the combination of better retractors, lighting, and magnification led to an increasingly standardized technique performed through 2.5-cm or smaller incisions. At the same time, improvements in anesthetic techniques (and the increased use of spinal and epidural anesthesia) decreased associated hospital stays [37, 51]. Increasingly, microdiscectomy procedures are offered in an outpatient setting [6, 16, 77]. Similarly, postdiscectomy activity recommendations have evolved. Initially, days or weeks of bedrest were ordered. In the 1990s, Carragee and colleagues reported postoperative restrictions do not improve outcomes or decrease recurrence rates [18, 19]. Although many surgeons continue to recommend limited bending, lifting, and twisting in their postdiscectomy patients for periods up to 6 weeks, there is little evidence that ad libitum activity is harmful.

Other adjuncts to the management of LDH have been introduced, flourished, and waned only, in some cases, to reemerge again later. For example, chemonucleolysis, the injection of the enzyme chymopapain into the disc, was introduced in the 1960s [98, 101]. Although widely used in North America in the 1970s and 1980s, reports of serious complications including anaphylactic shock and neurotoxicity diminished its popularity [58, 88]. Although chymopapain was withdrawn from the market of many Western countries in the 1990s, it continues to be used with reasonable results in Korea and elsewhere [1, 58]. Other techniques sought, like chemonucleolysis, decrease disc protrusion by destroying nuclear material in the central portion of the disc. Endoscopic disc removal through a far lateral, foraminal approach allowed disc material to be removed manually with a pituitary or radiofrequency probe [25]. This technique was first introduced in 1975 by Hijikata and Yamagishi [47]. Instrumentation for a percutaneous automated nucleotomy using a reciprocating section cutter was introduced by Onik and Helmes in 1985 [79]. Although initial outcomes were favorable, later reports demonstrated success rates less than 65%.

Although these posterolateral, "nucleoplasty" approaches were almost completely abandoned by the early 1990s, their popularity resurged more recently with newer disc ablative technologies such as laser, radiofrequency, ozone, and thermal ablation [5, 26, 73]. The most popular of these approaches allows transforaminal, endoscopic visualization of the disc followed by either pituitary or radiofrequency removal [25]. Direct visualization means this approach can remove extruded and even migrated discs while theoretically decreasing muscle injury, protecting the posterior boney elements, and preserving the integrity of the rest of the disc. One series reported a 70% success rate with "very low complications" [73]. There have been reports of serious complications when nonsurgically trained physicians perform these procedures [38].

Laser can also be used as an adjunct to more formal microdiscectomy procedures. Here, evaporating the protruded disc with a laser requires less nerve retraction than exposure for a pituitary. Aside from the prowess of lasers in marketing campaigns, the rationale lies in the decreased soft tissue trauma and, theoretically, less epidural scarring [27].

Measuring Patients' Outcomes

Even the earliest studies reported "highly satisfactory" outcomes after surgical discectomy. However, these reports are difficult to compare as far as the analytical tools and perspectives. The surgeon's assessment of an "excellent outcome" in 10 to 15 patients has evolved into in-depth analysis of patient-reported outcome measures in hundreds or thousands of patients. Although the frequency of obtaining "good to excellent outcomes" has ranged from 70% to 90% for decades now, patient selection, rather than the specifics of surgical technique, is usually identified as the key to success [53, 72]. Poorer results are typically noted in in workers compensation patients, patients in psychological distress, those on long-term opioids, and, possibly, smokers and diabetics [46, 62, 72, 104, 110]. The severity of root compression discovered at surgery has also been correlated to the degree of patient-reported relief [57]. "Negative explorations" are associated with poor surgical results [39, 110].

Against these reports of good to excellent results, the possibility of complications and the notion that surgical results diminish over time has tamed enthusiasm for surgery. In 1977, Salenius and Laurent reported late outcomes in 886 patients undergoing discectomy surgery [94]. Results were "good" in 56% and 63% returned to their former occupation. Perineural scarring was identified as one culprit for diminishing results and less invasive surgery recommended. Caspar and coworkers reported the outcomes of 418 patients who had undergone open or microdiscectomy [21]. They concluded "results in the microsurgical group were significantly favorable: fewer levels were explored: there was less operative blood loss and a decreased incidence of deep venous thrombosis, urinary tract infections, pulmonary emboli, and bladder catheterization; the time to full ambulation, discharge, and return to work was faster: and there was a decrease in change of occupation and a greater percentage of satisfactory final outcomes, as measured both objectively and subjectively."

In 1988, Silvers reported outcomes in 540 patients [100]. Of patients undergoing microdiscectomy, 95% had an excellent result as compared with 89% of the standard laminectomy group. Also, "the time before return to work was significantly shorter in patients undergoing microdiscectomy. Microdiscectomy proved to be superior in both clinical results and cost effectiveness." In contrast, Tullberg and others performed a randomized study in which microscope use did not improve outcomes or decrease recovery times or blood loss [108]. Others have concluded that microsurgery speeds recovery but has little impact on long-term outcomes [13, 54, 117].

Until the Spine Patient Outcomes Research Trial (SPORT) studies, the most frequently quoted discectomy outcomes papers were those by Weber and the Maine Group [8, 112, 114]. In a 1983 "controlled, prospective study with 10 years of observation," Weber divided 280 patients with LDH into three groups. In one group of 87, "there was no indication for operative intervention" and nonoperative management ensued. Another group of 67 presented with "symptoms and signs that beyond doubt, required surgical therapy." Weber's report focused on the 126 patients with "uncertain indication for surgical treatment" randomized in discectomy and nonoperative groups. At 1 year, the surgically treated group "showed a statistically significant better result." By 4 and 10 years, the differences between groups were "no longer statistically significant." At the time, many readers understood these results to mean that discectomy does not offer long-term benefits. Others reanalyzed these data concluding that many patients with severe, ongoing pain crossed over into the surgery group; these critics concluded that discectomy surgery is, in fact, cost-effective [68].

The Maine Lumbar Spine Study was a unique early effort. The study group prospectively collected a cohort of patients with sciatica "recruited from the practices of orthopedic surgeons, neurosurgeons, and occupational medicine physicians throughout Maine." Five hundred seven patients with sciatica resulting from LDH were divided; of the 507 patients available for followup, 275 were treated surgically and 232 were treated "nonsurgically initially." The groups were not randomized. On average, at study entry, the surgically treated patients had more severe symptoms and had more severe physical and imaging findings than nonsurgically treated patients. Few surgically treated patients had mild symptoms. Few nonsurgically treated patients had severe symptoms. However, approximately half in each group had moderate symptoms. At the 1-year followup, both groups demonstrated improved symptoms, functional status, and disability, but the patients undergoing discectomy reported significantly greater improvement. Seventy-one percent of surgically treated and 43% of nonsurgically treated patients reported definite improvement ($p < 0.001$). For patients with mild symptoms, the benefits of surgical and nonsurgical treatment were similar. The authors concluded that patients with sciatica treated surgically reported substantially greater improvement at 1-year followup. However, employment and compensation outcomes were similar between the two treatment groups [8].

There are fewer studies examining the role of nonoperative management of LDH. The most frequently cited is the 1989 retrospective study by Saal and Saal [93]. All patients underwent "an aggressive physical rehabilitation program consisting of back school and stabilization exercise training." Of 347 consecutive patients, 64 were

followed for 31.1 months. Of these 90% reported good or excellent outcomes. The authors concluded that "these results compared favorably with previously published surgical studies." The study has been criticized, however, for its poor enrollee retention. The percentage of the 183 patients lost to followup seeking additional (and possibly surgical) care elsewhere cannot be known. Saal and Saal suggested that patients with LDH at an already stenotic level had a far greater chance of requiring surgical decompression.

Conclusions

As a clinical entity, lumbar radiculopathy was recognized in ancient times. Initially seen as a scourge of demons or witches, a more naturalistic understanding arose with Hippocrates and the Greeks. The modern conception of LDH advanced with Contugno, Schmorl, Oppenheim, Dandy, and Mixter and Barr, and others. As the conception of the causes of radiculopathy advanced, so did treatment options. Surgical management also benefitted from improvements in antiseptic technique and new imaging modalities. Although major, open, transdural resections of displaced disc material were initially performed, patients with LDH have benefitted from a long trend toward decreased dissection and dead space creation. Full laminectomies gave way to laminotomies and the transdural approach was quickly replaced with a peridural corridor. Improvements in lighting, magnification, and retractor systems have allowed discectomy surgery to be performed, in many cases, on an outpatient basis and under local or regional anesthesia.

We have also seen that the majority of patients with LDH will not require surgery. MRIs obtained on asymptomatic individuals often demonstrate disc herniations. Even symptomatic patients will often rapidly improve with expectant management. For those patients with intractable pain or weakness, however, surgery is commonly offered. For the well-selected patient with discrete, radicular pain, the results have long been reported as a "good to excellent." The quality of outcomes data has improved and newer, patient-centered outcomes measures have replaced the physician's determination of the surgical result. Potential complications remain. These include recurrent radiculopathy and herniation. Patients with large annular defects and extruded disc fragments are at higher risk as are patients carrying a strong genetic predisposition to disc degeneration. Behavioral and lifestyle factors have been identified that increase risk for both primary and recurrent disc herniation. Perhaps, in time, spine care physicians will be able to offer preventive modalities.

References

1. Abdel-Salam A, Eyres KS, Cleary J. Management of the herniated lumbar disc: the outcome after chemonucleolysis, surgical disc excision and conservative treatments. *Eur Spine J.* 1992;1:89–95.
2. Alajouanine T, Petit-Dutaillis D. Fibrocartilage nodules from the posterior aspect of the intervertebral disc. *Presse Méd.* 1930;98:1657.
3. Alemo S, Sayadipour A. Sources and patterns of pain in lumbar disc disease: revisiting Francis Murphey's theory. *Acta Neurochir (Wien).* 2010;152:1555–1558.
4. Alexander E Jr. Lumbar disk lesions in retrospect and prospect. *Surg Neurol.* 1992;38:315–317.
5. Alexandre A, Coro L, Azuelos A, Buric J, Salgado H, Murga M, Marin F, Giocoli H. Intradiscal injection of oxygen-ozone gas mixture for the treatment of cervical disc herniations. *Acta Neurochir Suppl.* 2005;92:79–82.
6. An HS, Simpson JM, Stein R. Outpatient laminotomy and discectomy. *J Spinal Disord.* 1999;12:192–196.
7. Anderson MW. Lumbar discography: an update. *Semin Roentgenol.* 2004;39:52–67.
8. Atlas SJ, Deyo RA, Keller RB, Chapin AM, Patrick DL, Long JM, Singer DE. The Maine Lumbar Spine Study, Part II. 1-year outcomes of surgical and nonsurgical management of sciatica. *Spine (Phila Pa 1976).* 1996;21:1777–1786.
9. Auralianus C. *Acute Diseases and Chronic Diseases*. Chicago, IL, USA: University of Chicago Press; 1950.
10. Ballantine HT Jr. 'Sciatica' and the neurosurgeon: historical perspectives and personal reminiscences. *Clin Neurosurg.* 1980;27:541–552.
11. Barr JS. Ruptured intervertebral disc and sciatic pain. *J Bone Joint Surg Am.* 1947;29:429–437.
12. Barr JS, Kubik CS, Molloy MK. Evaluation of end results in treatment of ruptured lumbar intervertebral disc with protrusion of nucleus pulposis. *Surg Gynecol Obstet.* 1967;125:250–256.
13. Barrios C, Ahmed M, Arrotegui J, Bjornsson A, Gillstrom P. Microsurgery versus standard removal of the herniated lumbar disc. A 3-year comparison in 150 cases. *Acta Orthop Scand.* 1990;61:399–403.
14. Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. *J Bone Joint Surg Am.* 1990;72:403–408.
15. Brock M, Patt S, Mayer HM. The form and structure of the extruded disc. *Spine (Phila Pa 1976).* 1992;17:1457–1461.
16. Cares HL, Steinberg RS, Robertson ET, Caldini P. Ambulatory microsurgery for ruptured lumbar discs: report of ten cases. *Neurosurgery.* 1988;22:523–526.
17. Carragee EJ, Han MY, Suen PW, Kim D. Clinical outcomes after lumbar discectomy for sciatica: the effects of fragment type and anular competence. *J Bone Joint Surg Am.* 2003;85:102–108.
18. Carragee EJ, Han MY, Yang B, Kim DH, Kraemer H, Billys J. Activity restrictions after posterior lumbar discectomy. A prospective study of outcomes in 152 cases with no postoperative restrictions. *Spine (Phila Pa 1976).* 1999;24:2346–2351.
19. Carragee EJ, Helms E, O'Sullivan GS. Are postoperative activity restrictions necessary after posterior lumbar discectomy? A prospective study of outcomes in 50 consecutive cases. *Spine (Phila Pa 1976).* 1996;21:1893–1897.
20. Caspar W. A new surgical procedure for lumbar disc herniation causing less tissue damage through a microsurgical approach. *Adv Neurosurg.* 1977;4:74–80.
21. Caspar W, Campbell B, Barbier DD, Kretschmmer R, Gotfried Y. The Caspar microsurgical discectomy and comparison with a

conventional standard lumbar disc procedure. *Neurosurgery*. 1991;28:78–86; discussion 86–87.
22. Castro I, Santos DP, Christoph Dde H, Landeiro JA. The history of spinal surgery for disc disease: an illustrated timeline. *Arq Neuropsiquiatr*. 2005;63:701–706.
23. Cauchoix J, Ficat C, Girard B. Repeat surgery after disc excision. *Spine (Phila Pa 1976)*. 1978;3:256–259.
24. Chedid KJ, Chedid MK. The 'tract' of history in the treatment of lumbar degenerative disc disease. *Neurosurg Focus*. 2004;16:E7.
25. Chiu JC. Evolving transforaminal endoscopic microdecompression for herniated lumbar discs and spinal stenosis. *Surg Technol Int*. 2004;13:276–286.
26. Choy DS, Ascher PW, Ranu HS, Saddekni S, Alkaitis D, Liebler W, Hughes J, Diwan S, Altman P. Percutaneous laser disc decompression. A new therapeutic modality. *Spine (Phila Pa 1976)*. 1992;17:949–956.
27. Colak A, Bavbek M, Aydin NE, Renda N, Acikgoz B. Effect of CO2 laser on spinal epidural fibrosis. *Acta Neurochir (Wien)*. 1996;138:162–166.
28. Cotugno D. *The Ischial Nerve*. Naples, Italy: Fratres Simonios; 1764.
29. Dandy W. Loose cartilage from intervertebral disk simulating tumor of the spinal cord. *Arch Surg*. 1929;19:660–672.
30. Dandy WE. Loose cartilage from intervertebral disk simulating tumor of the spinal cord. By Walter E. Dandy, 1929. *Clin Orthop Relat Res*. 1989;238:4–8.
31. Darden BV 2nd, Wade JF, Alexander R, Wood KE, Rhyne AL 3rd, Hicks JR. Far lateral disc herniations treated by microscopic fragment excision. Techniques and results. *Spine (Phila Pa 1976)*. 1995;20:1500–1505.
32. Davis H. Increasing rates of cervical and lumbar spine surgery in the United States, 1979–1990. *Spine (Phila Pa 1976)*. 1994;19:1117–1123; discussion 1123–1124.
33. De Sèze S. 'Banal" sciatica and lumbosacral discs. *Presse Méd*. 1940;48:570–577.
34. Deburge A, Benoist M, Boyer D. The diagnosis of disc sequestration. *Spine (Phila Pa 1976)*. 1984;9:496–499.
35. Deyo RA. Results of discectomy compared with discectomy and fusion. *Acta Orthop Scand Suppl*. 1993;251:45–46.
36. Deyo RA, Tsui-Wu YJ. Descriptive epidemiology of low-back pain and its related medical care in the United States. *Spine (Phila Pa 1976)*. 1987;12:264–268.
37. Ditzler JW, Dumke PR, Harrington JJ, Fox JD. Should spinal anesthesia be used in surgery for herniated intervertebral disk. *Anesth Analg*. 1959;38:118–124.
38. Epstein NE. Laser-assisted diskectomy performed by an internist resulting in cauda equina syndrome. *J Spinal Disord*. 1999;12:77–79.
39. Espersen JO, Kosteljanetz M, Halaburt H, Miletic T. Predictive value of radiculography in patients with lumbago-sciatica. A prospective study (Part II). *Acta Neurochir (Wien)*. 1984;73:213–221.
40. Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze G. Lumbar disc nomenclature: version 2.0. *Spine (Phila Pa 1976)*. 2013 Aug 21 [Epub ahead of print].
41. Fernstrom U. Lumbar intervertebral disc degeneration with abdominal pain. *Acta Chir Scand*. 1957;113:436–437.
42. Fritsch EW, Heisel J, Rupp S. The failed back surgery syndrome: reasons, intraoperative findings, and long-term results: a report of 182 operative treatments. *Spine (Phila Pa 1976)*. 1996;21:626–633.
43. Goldthwait J, Osgood R. A consideration of the pelvic articulations from an anatomical, pathological and clinical standpoint. *Boston Med Surg J*. 1905;152:365–372.
44. Hakelius A. Prognosis in sciatica. A clinical follow-up of surgical and non-surgical treatment. *Acta Orthop Scand Suppl*. 1970;129:1–76.
45. Herron L. Recurrent lumbar disc herniation: results of repeat laminectomy and discectomy. *J Spinal Disord*. 1994;7:161–166.
46. Herron LD, Turner JA, Novell LA, Kreif SL. Patient selection for lumbar discectomy with a revised objective rating system. *Clin Orthop Relat Res*. 1996;325:148–155.
47. Hijikata S, Yamagishi M. Percutaneous discectomy. A new treatment method for lumbar disc herniation. *J Toden Hosp*. 1975;5:5–13.
48. Hippocrates. *The Genuine Works of Hippocrates* (translated by Adams F). New York, NY, USA: W. Wood; 1929.
49. Hirabayashi S, Kumano K, Ogawa Y, Aota Y, Maehiro S. Microdiscectomy and second operation for lumbar disc herniation. *Spine (Phila Pa 1976)*. 1993;18:2206–2211.
50. Inman VT, Saunders JB. Anatomicophysiological aspects of injuries to the intervertebral disc. *J Bone Joint Surg Am*. 1947;29:461–475.
51. Jellish WS, Thalji Z, Stevenson K, Shea J. A prospective randomized study comparing short- and intermediate-term perioperative outcome variables after spinal or general anesthesia for lumbar disk and laminectomy surgery. *Anesth Analg*. 1996;83:559–564.
52. Jonsson B, Stromqvist B. Repeat decompression of lumbar nerve roots. A prospective two-year evaluation. *J Bone Joint Surg Br*. 1993;75:894–897.
53. Junge A, Dvorak J, Ahrens S. Predictors of bad and good outcomes of lumbar disc surgery. A prospective clinical study with recommendations for screening to avoid bad outcomes. *Spine (Phila Pa 1976)*. 1995;20:460–468.
54. Kahanovitz N, Viola K, Muculloch J. Limited surgical discectomy and microdiscectomy. A clinical comparison. *Spine (Phila Pa 1976)*. 1989;14:79–81.
55. Karampelas I, Boev AN 3rd, Fountas KN, Robinson JS Jr. Sciatica: a historical perspective on early views of a distinct medical syndrome. *Neurosurg Focus*. 2004;16:E6.
56. Kawaguchi Y, Kanamori M, Ishihara H, Ohmori K, Matsui H, Kimura T. The association of lumbar disc disease with vitamin-D receptor gene polymorphism. *J Bone Joint Surg Am*. 2002;84:2022–2028.
57. Kerr RS, Cadoux-Hudson TA, Adams CB. The value of accurate clinical assessment in the surgical management of the lumbar disc protrusion. *J Neurol Neurosurg Psychiatry*. 1988;51:169–173.
58. Kim YS, Chin DK, Yoon DH, Jin BH, Cho YE. Predictors of successful outcome for lumbar chemonucleolysis: analysis of 3000 cases during the past 14 years. *Neurosurgery*. 2002;51(Suppl):S123–128.
59. Knoeller SM, Seifried C. Historical perspective: history of spinal surgery. *Spine (Phila Pa 1976)*. 2000;25:2838–2843.
60. Kocher T. Spinal injuries described relative to the physiology of the human spinal cord. *Mitt Grenzgeb Med Chir*. 1896:415–480.
61. Konttinen YT, Gronblad M, Antti-Poika I, Seitsalo S, Santavirta S, Hukkanen M, Polak JM.. Neuroimmunohistochemical analysis of peridiscal nociceptive neural elements. *Spine (Phila Pa 1976)*. 1990;15:383–386.
62. Kosteljanetz M, Espersen JO, Halaburt H, Miletic T. Predictive value of clinical and surgical findings in patients with lumbago-sciatica. A prospective study (Part I). *Acta Neurochir (Wien)*. 1984;73:67–76.
63. Kotilainen E, Valtonen S. Clinical instability of the lumbar spine after microdiscectomy. *Acta Neurochir (Wien)*. 1993;125:120–126.
64. Kutumbiah P. *Ancient Indian Medicine*. Calcutta: Orient Longmans; 1962.
65. Love J. Removal of protruded intervertebral disc without laminectomy. *Proc Staff Meet Mayo Clin*. 1939;14:800–805.
66. Love J, Walsh M. Protruded intervertebral disks. Report of one hundred cases in which operation was performed. *JAMA*. 1938;111:396–400.

67. Luschka H, ed. *The Half Joints of the Human Body*. Berlin, Germany: Deutche Ned Wochenschrift; 1858.
68. Malter AD, Larson EB, Urban N, Deyo RA. Cost-effectiveness of lumbar discectomy for the treatment of herniated intervertebral disc. *Spine (Phila Pa 1976)*. 1996;21:1048–1054; discussion 1055.
69. Marketos SG, Skiadas P. Hippocrates. The father of spine surgery. *Spine (Phila Pa 1976)*. 1999;24:1381–1387.
70. Marketos SG, Skiadas PK. Galen: a pioneer of spine research. *Spine (Phila Pa 1976)*. 1999;24:2358–2362.
71. Matsui H, Kanamori M, Ishihara H, Yudoh K, Naruse Y, Tsuji H. Familial predisposition for lumbar degenerative disc disease. A case-control study. *Spine (Phila Pa 1976)*. 1998;23: 1029–1034.
72. McCulloch JA. Focus issue on lumbar disc herniation: macro- and microdiscectomy. *Spine (Phila Pa 1976)*. 1996;21(Suppl):45S–56S.
73. Menchetti PP, Canero G, Bini W. Percutaneous laser discectomy: experience and long term follow-up. *Acta Neurochir Suppl*. 2011;108:117–121.
74. Mettler C, Mettler F. *History of Medicine: A Correlative Text*. Philadelphia, PA, USA: Blakiston; 1947.
75. Mixter W, Barr J. Rupture of the intervertebral disc with involvement of the spinal canal. *N Engl J Med*. 1934;211: 210–215.
76. Murphey F. Sources and patterns of pain in disc disease. *Clin Neurosurg*. 1968;15:343–351.
77. Newman MH. Outpatient conventional laminotomy and disc excision. *Spine (Phila Pa 1976)*. 1995;20:353–355.
78. Olmarker K, Rydevik B. Pathophysiology of sciatica. *Orthop Clin North Am*. 1991;22:223–234.
79. Onik G, Helmes C. Percutaneous lumbar discectomy using a new aspiration probe. *AJR Am J Roentgenol*. 1985;144: 1137–1140.
80. Oppenheim H, Krause F. About the entrapment or strangulation of the cauda equina. *Dtsch Med Wochenschr*. 1909;35:697–700.
81. Ozgen S, Naderi S, Ozek MM, Pamir MN. Findings and outcome of revision lumbar disc surgery. *J Spinal Disord*. 1999;12:287–292.
82. Padua R. The history of the diagnosis and treatment of lumbar sciatic disc herniation. *Chir Organi Mov*. 1999;84:367–373.
83. Patwardhan AG, Carandang G, Ghanayem AJ, Havey RM, Cunningham B, Voronov LI, Phillips FM.. Compressive preload improves the stability of anterior lumbar interbody fusion cage constructs. *J Bone Joint Surg Am*. 2003;85:1749–1756.
84. Patwardhan RV, Hadley MN. History of surgery for ruptured disk. *Neurosurg Clin N Am*. 2001;12:173–179, x.
85. Paulus A. *The Seven Books of Paulus*. London, UK: Syndenham Society Publications; 1844.
86. Pearce J, Moll JMH. Conservative treatment and natural history of acute lumbar disc lesions. *J Neurol Neurosurg Psychiatry*. 1967;30:13–17.
87. Postacchini F, Cinotti G, Gumina S. Microsurgical excision of lateral lumbar disc herniation through an interlaminar approach. *J Bone Joint Surg Br*. 1998;80:201–207.86.
88. Postacchini F, Postacchini R. Operative management of lumbar disc herniation: the evolution of knowledge and surgical techniques in the last century. *Acta Neurochir Suppl*. 2011;108: 17–21.
89. Preuss J. *Biblical and Talmudic Medicine*. New York, NY, USA: Sanhedrin Press; 1978.
90. Ramos G, Martin W. Effects of vertebral axial decompression on intradiscal pressure. *J Neurosurg*. 1994;81:350–353.
91. Robinson JS. Sciatica and the lumbar disk syndrome: a historic perspective. *South Med J*. 1983;76:232–238.
92. Rogers LA. Experience with limited versus extensive disc removal in patients undergoing microsurgical operations for ruptured lumbar discs. *Neurosurgery*. 1988;22:82–85.
93. Saal JA, Saal JS. Nonoperative treatment of herniated lumbar intervertebral disc with radiculopathy. An outcome study. *Spine (Phila Pa 1976)*. 1989;14:431–437.
94. Salenius P, Laurent LE. Results of operative treatment of lumbar disc herniation. A survey of 886 patients. *Acta Orthop Scand*. 1977;48:630–634.
95. Schmorl G, Junghanns H. *The Human Spine in Health and Disease: Anatomicopathologic Studies*. 1st American ed. New York, NY, USA: Grune & Stratton; 1959.
96. Schoenfeld AJ. Historical contributions from the Harvard system to adult spine surgery. *Spine (Phila Pa 1976)*. 2011;36:E1477–1484.
97. Shterenshis MV. The history of modern spinal traction with particular reference to neural disorders. *Spinal Cord*. 1997;35:139.
98. Sicard J, Forestier J. *Diagnostic and Therapeutic Uses of Lipidiol*. Paris, France: Masson; 1928.
99. Sigerist H. *A History of Medicine*. London, UK: Luzac; 1934.
100. Silvers HR. Microsurgical versus standard lumbar discectomy. *Neurosurgery*. 1988;22:837–841.
101. Smith L. Enzyme dissolution of nucleus pulposus in humans. *JAMA*. 1964;187:137–140.
102. Sonntag V. History of degenerative and traumatic disease of the spine. In: Samuel H, Greenblatt T, Forcht D, Epstein M, eds. *A History of Neurosurgery: In Its Scientific and Professional Contexts*. Park Ridge, IL, USA: American Association of Neurological Surgeons; 1997.
103. Spengler DM. Lumbar discectomy. Results with limited disc excision and selective foraminotomy. *Spine (Phila Pa 1976)*. 1982;7:604–607.
104. Spengler DM, Ouellette EA, Battie M, Zeh J. Elective discectomy for herniation of a lumbar disc. Additional experience with an objective method. *J Bone Joint Surg Am*. 1990;72:230–237.
105. Tan WS, Spigos DG, Khine N, Capek V. Computed air myelography of the lumbosacral spine. *AJNR Am J Neuroradiol*. 1983;4:609–610.
106. Taylor VM, Deyo RA, Cherkin DC, Kreuter W. Low back pain hospitalization. Recent United States trends and regional variations. *Spine (Phila Pa 1976)*. 1994;19:1207–1212; discussion 1213.
107. Tullberg T, Grane P, Rydberg J, Isacson J. Comparison of contrast-enhanced computed tomography and gadolinium-enhanced magnetic resonance imaging one year after lumbar discectomy. *Spine (Phila Pa 1976)*. 1994;19:183–188.
108. Tullberg T, Isacson J, Weidenhielm L. Does microscopic removal of lumbar disc herniation lead to better results than the standard procedure? Results of a one-year randomized study. *Spine (Phila Pa 1976)*. 1993;18:24–27.
109. Vaughan PA, Malcolm BW, Maistrelli GL. Results of L4-L5 disc excision alone versus disc excision and fusion. *Spine (Phila Pa 1976)*. 1988;13:690–695.
110. Vucetic N, de Bri E, Svensson O. Clinical history in lumbar disc herniation. A prospective study in 160 patients. *Acta Orthop Scand*. 1997;68:116–120.
111. Walker J. *Folk Medicine in Modern Egypt: Being the Relevant Parts of the Tibb al-Rukka, or, Old Wives' Medicine*. London, UK: Luzac; 1934.
112. Weber H. Lumbar disc herniation. A controlled, prospective study with ten years of observation. *Spine (Phila Pa 1976)*. 1983;8:131–140.
113. Wegner I, Widyahening IS, van Tulder MW, Blomberg SEI, de Vet HCW, Brønfort G, Bouter LM, van der Heijden GJ. Traction

for low-back pain with or without sciatica. *Cochrane Database Syst Rev*. 2013;8:CD003010

114. Weinstein JN, Tosteson TD, Lurie JD, Tosteson AN, Hanscom B, Skinner JS, Abdu WA, Hilibrand AS, Boden SD, Deyo RA. Surgical vs nonoperative treatment for lumbar disk herniation: the Spine Patient Outcomes Research Trial (SPORT): a randomized trial. *JAMA*. 2006;296:2441–2450.
115. Weir BK, Jacobs GA. Reoperation rate following lumbar discectomy. An analysis of 662 lumbar discectomies. *Spine (Phila Pa 1976)*. 1980;5:366–370.
116. Williams RW. Microlumbar discectomy: a conservative surgical approach to the virgin herniated lumbar disc. *Spine (Phila Pa 1976)*. 1978;3:175–182.
117. Wilson DH, Harbaugh R. Microsurgical and standard removal of the protruded lumbar disc: a comparative study. *Neurosurgery*. 1981;8:422–427.
118. Wiltse LL. Surgery for intervertebral disk disease of the lumbar spine. *Clin Orthop Relat Res*. 1977;129:22–45.
119. Yasargil MG, Vise WM, Bader DC. Technical adjuncts in neurosurgery. *Surg Neurol*. 1977;8:331–336.