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Disc Herniation and Radiculopathy

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Core Messages

- ✔ Lumbar disc herniation is most frequently found in the 3rd and 4th decades of life at the level of L4/5 and L5/S1
- ✔ The cardinal symptom of lumbar disc herniation is radicular leg pain with or without a sensorimotor deficit of the affected nerve root
- ✔ The radiculopathy is not only caused by a mechanical compression of the nerve root but also by an inflammatory process caused by nucleus pulposus tissue
- ✔ MRI is the imaging modality of choice for the diagnosis of disc herniation
- ✔ In contrast to large disc extrusion and sequestrations, disc protrusions are frequently found in asymptomatic individuals
- ✔ The best discriminator of symptomatic and asymptomatic disc herniation is nerve root compromise
- ✔ The natural history of lumbar radiculopathy is benign
- ✔ Mild radiculopathy responds well to non-operative treatment, but surgical treatment results in better short-term results in selected patients
- ✔ Severe radiculopathy responds poorly to non-operative treatment and should be treated surgically
- ✔ With the exception of chemonucleolysis, none of the minimally invasive surgical techniques has been shown to provide a better outcome than conservative treatment
- ✔ The surgical treatment of choice is an open standard interlaminar discectomy or microsurgical discectomy
- ✔ Cauda equina syndromes require an emergency decompression and should be treated by complete laminectomy and wide decompression
- ✔ The surgical results are crucially dependent on patient selection
- ✔ There is increasing scientific evidence that surgically treated patients have a better short term outcome than patients treated non-operatively

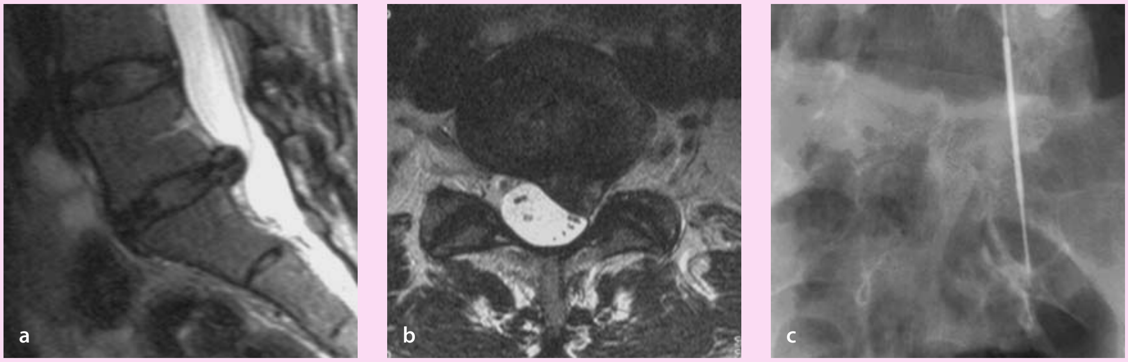
Epidemiology

Sciatica has been known since antiquity

Sciatica has been known since antiquity, but the relationship between sciatica and disc herniation was not discovered until the beginning of the 20th century. In 1934, Mixter and Barr were the first to describe this correlation in their landmark paper [95]. At that time, herniated discs were removed by a **transdural approach**. In 1939, Love [84] and Semmes [122] independently developed the classic approach, which consisted of a subtotal laminectomy and retraction of the thecal sac medially to expose and remove the disc herniation [5]. Herniated nucleus pulposus (HNP) used to be synonymous with disc herniation, but the definition of disc herniation today is wider. A disc herniation can be defined as a focal displacement of nuclear, annular, or endplate material beyond the margins of the adjacent vertebral bodies. As a result of the displacement of the disc material, there is a focal contour abnormality of the disc margin [52].

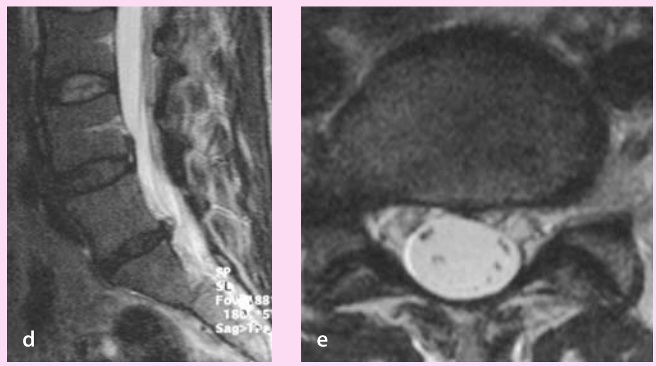
A herniation is a focal displacement of disc material beyond the vertebral body margins

Among a cohort of 2 077 employees in Finland who had no sciatic pain at baseline, 194 (9 %) experienced sciatic pain during a 1-year follow-up period. Women and men had an equal risk of suffering from sciatic pain, but the incidence increased with age. Smokers who have smoked for more than 15 years and sub-



Case Introduction

A 42-year-old mother of two young children developed severe leg pain without a previous episode of back pain. Within one week, the leg pain increased and the patient developed a mild sensorimotor deficit of S1. At the time of presentation 4 weeks later, the patient still complained of incapacitating leg pain. T2 weighted MR images (a, b) show a large disc extrusion compressing the left S1 nerve root. The patient did not want surgery because of her family situation. A nerve root block (c) was done with an injection of corticosteroids and local anesthetics which resulted in a regression of the severe pain within 3 days. The motor deficit recovered completely during a 3-month period. At one year follow-up, the patient only occasionally had back pain without sciatica. However, she desired to have a repeat MRI scan for prognosis. Follow-up MR images (d, e) demonstrate a resolution of the large herniation.



jects with mental stress are at risk from developing sciatic pain [94]. In surveys done in the 1950s, 40 % of men and 35 % of women older than 34 years experienced a history of low back and leg pain [79]. In a Swedish sample of 15- to 71-year-old females, sciatica was reported in 13.8 % [53]. In a Danish population of 4 753 men aged 40 – 59 years, 11 % experienced sciatica during 1 year of observation [49]. Bell and Rothman found prevalences of sciatic pain in a population older than 35 years of 4.8 % in men and 2.5 % in women [17]. The first episode of sciatic pain was at an average age of 37 years, with precipitating low back pain in 76 % of these patients a decade earlier [17]. In a study by Waddell on about 900 patients with low back pain, 70 % also complained of leg pain. Of these, 23 % had leg pain that was characterized as true radicular pain [141]. The epidemiology of cauda equina and conus medullaris lesions is not well known. In a study of **cauda equina/conus medullaris lesions**, an **annual incidence** rate of 3.4/1.5 per million, and period prevalence of 8.9/4.5 per 100 000 population, were calculated [110].

The annual incidence of sciatica is about 5 – 10 %

The prevalence of asymptomatic thoracic disc herniations is as high as in the lumbar spine

In contrast to lumbar disc herniation, symptomatic thoracic disc herniations are rare. An incidence of 0.25 – 0.75 % of protruded discs is found in the thoracic region. A peak incidence is noted in the 4th decade with 75 % of the protruded discs occurring below T8. However, the prevalence of **asymptomatic disc herniations** is high [150, 153].

Discectomy is the most frequently performed spinal surgery

Lumbar disc herniation is the pathologic condition for which spinal surgery is most often performed. In a computer aided analysis of 2 504 operations for disc herniation, Spangfort [128] reported that the average age was 40.8 years (range, 15 – 74 years). Males were operated on more than twice as often as female patients (sex ratio 2:1). Surgery was done most often at the level of L5/S1 (50.5 %) and L4/5 (47.5 %) [128].

The incidence of disc surgery is 160/100 000 inhabitants in the United States and 62/100 000 in Switzerland, indicating **large geographic variations** [6, 18, 144, 145]. Five- to 15-fold variations in the surgery rates have been documented in geographically adjacent small areas, between large regions of the United States, and in other Western countries [11, 34].

Discectomy rates exhibit strong geographic variations

Pathogenesis

Lumbar intervertebral disc herniation typically occurs as a result of age-related changes within the extracellular matrix of the intervertebral disc, which can lead to a weakening of the anulus fibrosus, making it susceptible to fissuring and tearing (see Chapter 4).

Risk Factors

Andersson [7] has emphasized that the identification of risk factors in low back pain and sciatica is hampered by methodological limitations. In the pre-MRI era, sciatica was used synonymously with disc herniation and radiculopathy. Image verification most often was not available. Therefore, many epidemiologic studies are confounded by the missing proof of a disc herniation in sciatica. Nevertheless, several occupational factors are believed to be associated with an **increased risk** of sciatica and disc herniation:

Occupational physical factors increase the risk of disc herniation

- frequent heavy lifting [66, 96]
- frequent twisting and bending [96]
- exposure to vibration [65, 66]
- sedentary activity [65]
- driving [67]

A more comprehensive analysis of **risk factors**, however, showed that, e.g., professional driving, was not associated with any overall tendency for greater degeneration or pathology in occupational drivers in a case control twin study [16]. Battié and Videman have demonstrated in studies of Finnish monozygotic twins that **heredity** has a dominant role in disc degeneration and would explain the variance of up to 74 % seen in adult populations [15]. The studies by Heikkilä et al. [51] and Masui et al. [91] support the strong influence of **genetic disposition** in disc herniation and sciatica. It can be deduced that the role of the aforementioned classic occupational risk factors was overestimated and they are assumed only to play a minor modulating role.

Controversy continues with regard to the occurrence of **traumatic disc herniations**. However, true traumatic disc herniation is extremely rare without additional severe injuries such as vertebral fractures or ligamentous injuries [1, 3, 44, 107]. In an in vitro biomechanical study, a disc protrusion could be produced as a result of a hyperflexion injury [2]. We recommend being very tentative using the term "traumatic disc herniation" because the injury frequently affects a motion segment which already exhibits age-related (degenerative) changes.

True traumatic disc herniations are very rare in a clinical setting

The clinical syndrome of sciatica is a direct result of the effect of the disc herniation on the adjacent nerve root. This leads to radiculopathy, which is characterized by radiating pain following a dermatomal distribution. This symptom can be accompanied by nerve root root tension signs and a sensorimotor deficit (nerve dysfunction).

Radiculopathy

Both mechanical compression and chemical irritation lead to radiculopathy

The pathophysiology of radiculopathy caused by a herniated disc is still not completely understood. In the last decade, substantial progress was gained in our understanding of disc-related radiculopathy [103]. Today, there is evidence that sciatica involves a compromise of the nerve root both in terms of mechanical deformation and chemical irritation (Fig. 1).

Mechanical Deformation

The extent of the nerve root compromise by mechanical deformation is a result of several effects:

- impaired blood supply
- edema
- onset of compression (rapid or slow progression)
- compromised CSF-related nutritional fluid flow
- level of compression (one or multiple)

Nerve root compression leads to intraneural edema

Olmarker et al. demonstrated in an experimental model of the pig cauda equina that there was a significant correlation between the **systemic blood pressure** and the pressure required to stop the flow in the nerve root arterioles [105]. In nerve roots exposed to significant compression, an **intraneural edema** developed. Olmarker et al. [104] further demonstrated that a rapid onset of compression induced more pronounced effects than a slow onset at corresponding pressure levels. The authors assumed that this observed difference may be related to the magnitude of intraneural edema formed outside the compression zone. The results also indicate that the **nutritional transport** might be impaired at very low pressure levels and that diffusion from adjacent tissues with a better nutritional supply, including the cerebrospinal fluid, may not fully compensate for any compression-induced impair-

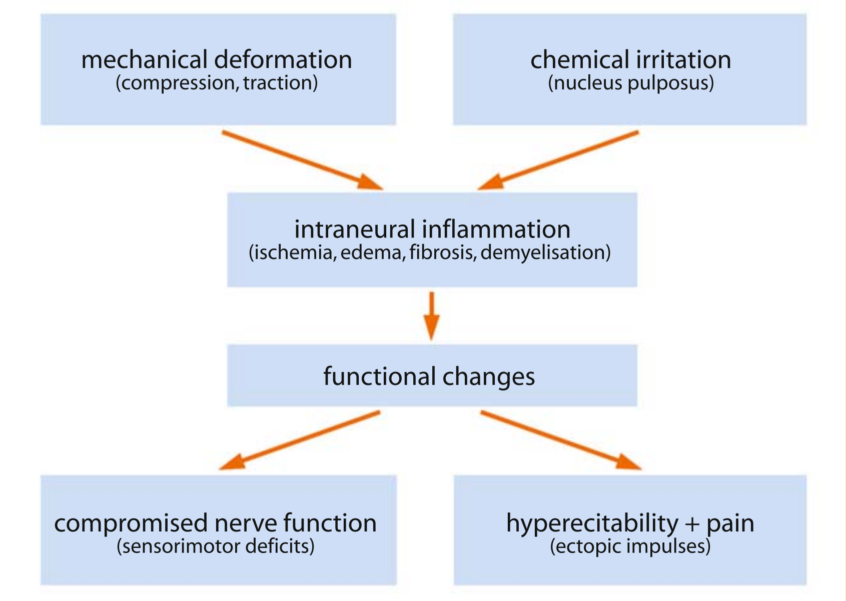


Figure 1. Pathophysiology of radiculopathy

Modified from Rydevik and Garfin [118].

ment of the **intraneural blood flow** [104]. In a subsequent study, Takahashi et al. [133] showed that double-level compression of the cauda equina induces impairment of blood flow, not only at the compression sites, but also in the intermediate nerve segments located between two compression sites, even at very low pressures.

Nerve root compression is not necessarily painful

In 1947, Inman and Saunders [57] realized that the concept that sciatica is caused solely by compression of the nerve root is not based on experimental evidence. In a clinical study on patients with disc herniation, Smyth and Wright [127] passed a nylon strip around the involved nerve root and brought its two ends to the surface. With this setup, the authors were able to show that the affected nerve root remains hypersensitive and causes pain when gently pulling at the ends of the nylon strips. Later, Kuslich et al. [75] demonstrated in a less traumatic approach that only the compressed nerve root consistently produces sciatica, while the normal, uncompressed, or unstretched nerve root was completely insensitive without causing pain. These clinical observations [75] were corroborated by an in vivo model which showed that ligation of the nerve root per se does not cause pain. Only the use of irritant gut suture material made the mechanical injury painful [63, 64]. It was hypothesized that **chemical factors** from the chromic gut play a role in the pathophysiology and development of lumbar radiculopathy [63].

Chemical Irritation

Chemical irritation plays a decisive role in sciatica

The involvement of a chemical irritation in the pathophysiology of sciatica has been suspected for many years [37, 88, 89]. First evidence of the **inflammatory properties of nucleus pulposus** was presented by McCarron et al. [92]. In a study on dogs, nucleus pulposus material was applied in the epidural space and resulted in inflammatory alterations. Olmarker et al. [106] demonstrated in a pig model that epidural application of autologous nucleus pulposus without mechanical compression induces nerve tissue injury by mechanisms other than mechanical compression. Such mechanisms are based on the **direct biochemical effects** of nucleus pulposus components on nerve fiber structure and function and microvascular changes including inflammatory reactions in the nerve [106]. In subsequent studies, the same researcher showed that the epidural application of nucleus pulposus causes proinflammatory reactions as indicated by leukotaxis and an increase in vascular permeability [100], results in an increased endoneurial fluid pressure and decreased blood flow in the dorsal root ganglia [154], and leads to morphologic changes in terms of minor axonal and Schwann cell damage [28]. Membrane-bound structures and substances of nucleus pulposus cells are responsible for axonal changes, a characteristic **myelin injury**, increased vascular permeability, and intravascular coagulation. These effects have been found to be efficiently blocked by methylprednisolone [101].

Proinflammatory Cytokines

TNFα plays a dominant role in the generation of sciatica

In searching for the pathophysiologic mechanisms of chemical irritation, the role of several substances and **proinflammatory cytokines** was explored [103], i.e.:

- hydrogen [37]
- nitric oxide (NO) [62]
- phospholipase (PL) A_2 and E_2 [62, 119]
- tumor necrosis factor (TNF) α [102]
- interleukin (IL)-1β and IL-6 [10, 62]

Of these mediators of inflammation, **TNFα** plays a dominant role in the cascade leading to the clinical symptom of sciatica [102]. Olmarker et al. [102] first showed that TNFα has been linked to the nucleus-pulposus-induced effects of nerve roots after local application. Exogenous TNFα also produced neuropathologic changes and behavior deficits that mimicked experimental studies with herniated nucleus pulposus applied to nerve roots [55]. Olmarker et al. [102] also showed that a **selective antibody to TNFα** limited the deleterious effect of nucleus pulposus on the nerve root. Furthermore, it was shown that a selective inhibition of TNFα prevents nucleus-pulposus-induced histologic changes in the dorsal root ganglion [99]. The same researchers demonstrated in a subsequent study that an increase in the concentration of TNFα applied to the nerve root induced **allodynia and hyperalgesia** responses [98]. These experimental findings justified the application of TNFα inhibitors in a clinical setting to treat sciatica [103]. Although preliminary studies were intriguing [70, 72], a randomized trial did not demonstrate results in favor of this treatment [71].

Anti-TNF treatment is an intriguing approach to treating radiculopathy

Clinical Presentation

History

Most lumbar disc herniations occur between 30 and 50 years of age. Low back pain may or may not be present in the medical history of the patient. Frequently, the patients report an acute episode with back pain which radiates increasingly into one leg within hours or a few days. With further persistence of the symptoms, patients exclusively or predominantly complain of leg pain.

The **cardinal symptoms** of a symptomatic disc herniation are:

The cardinal symptoms of disc herniation are radicular leg pain with or without a sensorimotor deficit

- radicular leg pain
- sensory loss
- motor weakness

These symptoms must correspond to the respective dermatome and myotome of the compromised nerve root to allow for a conclusive diagnosis.

Additional but **less frequent findings** may be:

- paresthesia in the affected dermatome
- radicular pain provoked by pressing, sneezing or pressing
- pain relief in supine position with hips and knees flexed
- previous episodes of acute back pain

In contrast to adults, back pain can be the prevailing symptom in children

Symptoms **in children and adolescents** can differ significantly from those of adults [135, 157]. In this young age group, patients often present with:

- predominant back pain
- radicular or pseudoradicular leg pain
- hamstring tightness
- difficulties stooping and picking up things
- restriction in running and jumping
- diminished stride

Patients infrequently present with a massive disc herniation (Case Study 1) which compresses the cauda equina, causing a **cauda equina syndrome** which is characterized by:

- incapacitating back and leg pain
- numbness and weakness of the lower extremities
- inability to urinate (early)
- paradoxic incontinence (later)
- bowel incontinence (late)

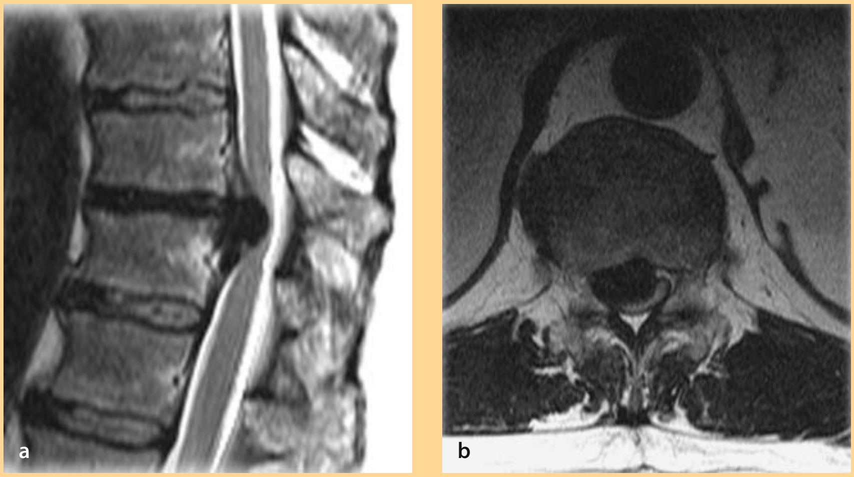


Figure 2. Thoracic disc herniation

a T2 weighted sagittal MR image showing a large disc extrusion at the level of T10/11 with significant compression of the spinal cord. **b** T2 weighted axial MR image demonstrating the severe spinal canal obliteration with compression and deformation of the spinal cord.

It is astonishing that patients often do not spontaneously report a bladder dysfunction as they do not see the correlation to their back problems. Therefore, it is crucial to inquire about bowel and/or bladder dysfunction. In the acute onset, patients present with an inability to urinate. With increasing bladder distension, the patients develop a paradoxic incontinence caused by urinary retention.

Always inquire about bladder and bowel dysfunction

The history of patients with a **thoracic disc herniation** depends on the extent of the herniation and the time course of the compression (Fig. 2). Large disc herniations which are rapidly compromising the spinal cord result in a progressive paraparesis. A slowly progressive compression causes symptoms comparable to a cervical myelopathy with the difference that the upper extremities are spared (see Chapter 17). In patients in whom the compromise of the spinal cord is less severe, diagnosis is often delayed. Frequent symptoms indicating thoracic symptoms are:

- localized dorsal pain
- belt-like pain radiation
- increased pain with coughing and sneezing
- gait disturbance
- non-dermatomal sensory deficits
- motor weakness in the lower extremities

Physical Findings

The clinical examination of patients with radicular leg pain is predominantly focused around a neurologic examination (see Chapter 11). A precise testing of dermatomal sensation and the muscle force of the lower extremities is mandatory. The neurologic assessment should include testing for sensation in the perianal region (search for saddle anesthesia) and sphincter tonus.

Check for perianal sensitivity

Patients with a **herniated disc** often present with:

- positive Lasègue (straight leg raising) sign (L4–S1)
- positive reversed Lasègue sign (L2–4)
- crossed Lasègue test
- vertebral shift (Case Study 2)
- restricted spinal movements (non-specific)
- trigger points along the ischiadic nerve (non-specific)

A positive Lasègue sign with radicular pain is indicative of a radiculopathy

Testing of the **Lasègue sign** (straight leg raising) is crucial for the diagnosis of a radiculopathy (see Chapter 8). The definition of a Lasègue test is largely variable in the literature [120, 128]. Most articles do not determine radicular pain as a criterion for a positive Lasègue test. We define the Lasègue sign based on the original publication as positive if the patient reports radicular leg pain while raising the ipsilateral straight leg. Radicular pain must be differentiated from non-radicular leg pain, which is frequent and often related to **tight hamstrings.** The **key feature** is the occurrence of radicular leg pain which is pathologic regardless of whether it occurs at 10 or 70 degrees of hip flexion. The positive contralateral straight-leg raising test is most specific for disc herniation indicating a large herniation ranging to the contralateral side. The reverse straight leg raising test or femoral stretch test causes root tension at L2, L3 and L4 (see Chapter 8). A positive ipsilateral straight leg raising test is a sensitive (72–97%) but less specific finding (11–66%). However, the results are critically dependent on the definition of the test. The criterion of radicular leg pain substantially increases the diagnostic accuracy. In contrast, a positive crossed straight leg raising test is less sensitive (23–42%), but much more specific (85–100%) [6].

In **children and adolescents** key findings are [135, 157]:

- tight hamstrings
- and severely restricted spinal motion

The neurologic examination is often diagnostic

Beside the neurologic findings, the physical assessment (see Chapter 8) in patients with disc herniation is less diagnostic.

In patients with **thoracic disc herniations**, the physical findings are subtle unless the patients present with an obvious paraparesis or paraplegia. However, a careful examination may reveal [137]:

Symptomatic thoracic disc herniation presents with signs of a myelopathy

- disturbed gait
- sensory deficits (non-dermatomal)
- decreased motor weakness of the lower extremities (uni- or bilateral)
- increased muscle reflexes
- clonus
- decreased abdominal reflexes
- positive Babinski reflex
- bowel and bladder dysfunction

Diagnostic Work-up

Imaging Studies

Standard Radiographs

Standard radiographs are not helpful for the diagnosis of disc herniation and radiculopathy. Disc height decrease is not a reliable indicator of the correct level. However, the images are useful in eliminating confusion with regard to lumbosacral transitional anomalies.

Magnetic Resonance Imaging

MRI is the imaging modality of choice

Magnetic resonance imaging (MRI) has become the imaging modality of choice for the assessment of degenerative disc disorders. Compared to computed tomography (CT), the advantages of MRI are:

- absence of radiation
- better visualization of conus/cauda

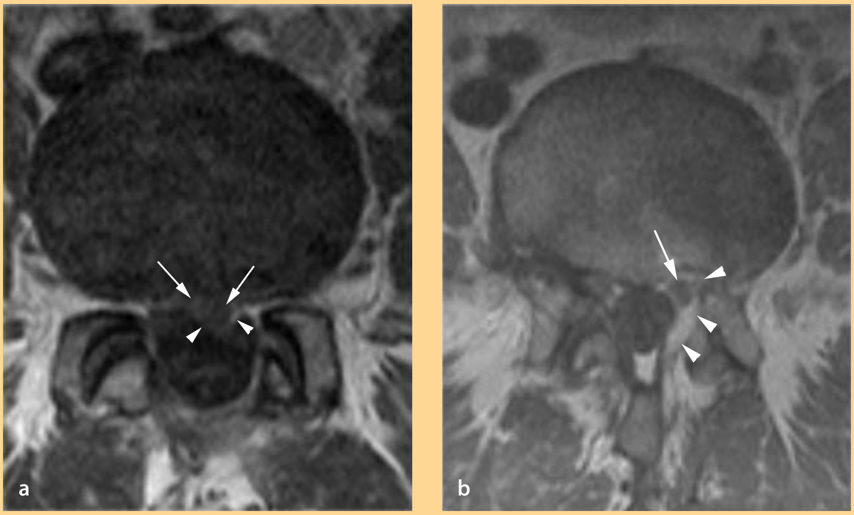


Figure 3. Postoperative MRI

MRI is helpful in differentiating recurrent herniation and scar formation. **a** T1 weighted contrast-enhanced MR image showing a small recurrent disc protrusion (*arrows*). Note the slight contrast enhancement around the disc herniation (*arrowheads*). **b** T1 weighted contrast-enhanced MR image demonstrating intense contrast medium uptake (*arrowheads*) around the nerve root (*arrow*) indicating scar formation.

- assessment of the grade of disc degeneration
- better assessment of the neural compromise

MRI is also better than CT in the postoperative period in differentiating scar from recurrent herniations. In this context, debate continues on the value of contrast enhancement to improve diagnostic accuracy. Contrast medium (gadolinium-DTPA) administered intravenously helps to differentiate between epidural fibrosis and recurrent herniations only in the late postoperative period [45] (Fig. 3a, b). However, MRI may be less sensitive in the diagnosis of a bony nerve root entrapment.

Large disc extrusions and sequestrations are rare in asymptomatic individuals

The diagnostic accuracy of MRI (and any other imaging modality) is hampered by the frequent occurrence of asymptomatic disc herniations [23]. The prevalence of asymptomatic disc herniations ranges from 0 % (sequestration) to 67 % (protrusions) depending on the asymptomatic population studied and the classification/definition of disc herniation [22, 23, 58, 148].

In children, simple disc protrusion must be differentiated from a slipped vertebral apophysis, which most frequently occurs at the inferior rim of the L4 vertebral body and at the superior rim of the sacrum. Often T1-weighted images demonstrate interposed tissue connected with the intervertebral disc. Adjacent vertebral discs may demonstrate a decrease in signal intensity [56].

Thoracic disc abnormalities are frequent

Similar to the lumbar spine, disc alterations are frequently found in the thoracic spine of asymptomatic individuals. In an MRI study, 73 % of the 90 asymptomatic individuals had positive anatomical findings at one level or more. These findings included disc herniation (37 %), disc bulging (53 %), annular tears (58 %) and deformations of the spinal cord (29 %). This study documented the high prevalence of anatomical irregularities, including herniation of a disc and deformation of the spinal cord, on the magnetic resonance images of the thoracic spine in asymptomatic individuals. The authors emphasized that these findings represent MRI abnormalities without clinical significance [153].

Computed Tomography

In patients with contraindications for MRI, CT suffices to diagnose disc herniation

Although CT has made substantial advances such as multiplanar reformations due to multislice acquisitions, and the diagnostic accuracy has substantially improved to the level of MRI, the vast majority of surgeons today prefer MRI. The application is therefore mostly limited to patients with contraindications for MRI such as pacemakers and metal implants. However, in these cases CT is often combined with myelography for better depiction of the nerve roots. Forristall et al. studied MRI and **CT myelography** in the examination of 25 patients with a suspected disc herniation who underwent surgery [46]. Compared with the surgical findings, the accuracy of MRI was 90.3 % and of CT myelography 77.4 % [52]. In another controlled comparison of myelography, CT, and MRI in 80 patients with monoradicular sciatica, the largest amount of diagnostic information was gained from CT, followed by MRI and myelography. It was concluded that both CT and MRI were significantly informative and should be the first choice for imaging in patients with suspected lumbar disc herniation [52].

Injection Studies

Nerve root blocks are applied for diagnostic and therapeutic objectives

Selective nerve root blocks (SNRBs) were first described by Macnab [86] in 1971 as a diagnostic test for the evaluation of patients with negative imaging studies and clinical findings of nerve root irritation. Indications for selective nerve root block are applied for a diagnostic as well as a therapeutic purpose. **Diagnostic selective nerve** root blocks are indicated in cases with:

- equivocal radicular leg or atypical arm pain
- discrepancy between the morphologic alterations and the patient's symptoms
- multiple nerve root involvement
- abnormalities related to a failed back surgery syndrome

Numerous studies [33, 38, 130, 139, 143] have shown that nerve root blocks are helpful in cases where this close correlation is lacking. In the case of a positive response (i.e., resolution of leg pain), the nerve root block allows the affected nerve root to be diagnosed with a sensitivity of 100 % in cases with disc protrusions and with a positive predictive value of 75–95 % in cases of foraminal stenosis [33, 139] (see Chapter 10).

Neurophysiologic Assessment

Neurophysiologic studies can differentiate peripheral and radicular neural compromise

Neurophysiologic studies do not offer any added diagnostic value in patients presenting with the typical radicular symptoms and concordant imaging findings. Furthermore, the neurophysiology has the disadvantage of exhibiting a latency in the detection of neural compromise. Neurophysiologic studies are helpful in equivocal cases and allow the differentiation of (see Chapter 12):

- radicular versus peripheral nerve entrapment
- additional neuropathic disease
- symptomatic level in multilevel nerve encroachment

Urologic Assessment

Patients with severe back pain and sciatica frequently present with subjective difficulties in emptying their bladder, prompting the suspicion of a cauda equina lesion. In this context, an ultrasonographic assessment of a putative **urinary retention** is indicated. In the case of a normal neurologic assessment (i.e., normal perianal sensitivity and normal sphincter tonus), a urinary retention of **less than 50 ml** rules out a cauda lesion with a very high probability. If the neurologic assessment is somewhat questionable, uroflowmetry is the next diagnostic step. The absence of urinary retention together with a normal uroflow profile rules out an acute cauda equina lesion.

Ultrasonic assessment of urinary retention is helpful in diagnosing cauda equina syndrome

Differential Diagnosis

A related entity in children is the so-called **slipped vertebral apophysis**, which can be confused with a common disc herniation [29]. The ring apophysis is a weak point during growth which can dislocate and migrate [19, 20]. It is believed that disc material displaces the posterior ring apophysis from the vertebra and produces symptoms. Takata et al. [134] suggested a classification into three types:

A slipped vertebral apophysis should not be confused with a simple disc herniation in children

- simple separation of the entire margin
- vertebral body avulsion fracture including the margin
- localized fracture

In patients presenting with a typical radicular syndrome, an extraspinal etiology is very rare [68] (see Chapter 11). Kleiner et al., in a study of 12 125 patients who had been referred during a 7-year period to a spine specialist, reported on 12 in whom an extraspinal cause of radiculopathy or neuropathy of the lower extremity was discovered. The cause of the symptoms was an occult malignant tumor in nine patients, a hematoma, an aneurysm of the obturator artery and a neurilemoma of the sciatic nerve. The clinical course was characterized by a delayed diagnosis (range 1 month to 2 years). In one-third of these patients, an operation was performed on the basis of an incorrect diagnosis [68]. The most important aspect is to search for rare differential diagnosis in cases with minor disc herniation and non-concordant symptoms.

Classification

Disc herniations can be classified according to their **localization** as:

- median
- posterolateral
- lateral (intra-/extraforaminal)

Most disc herniations are located posterolaterally, i.e., where the posterior longitudinal ligament is the weakest or absent. Mediolateral herniations are the main localizations in the axial plane, whereas **lateral disc herniations** (Fig. 4) are less common (3–12%) [113].

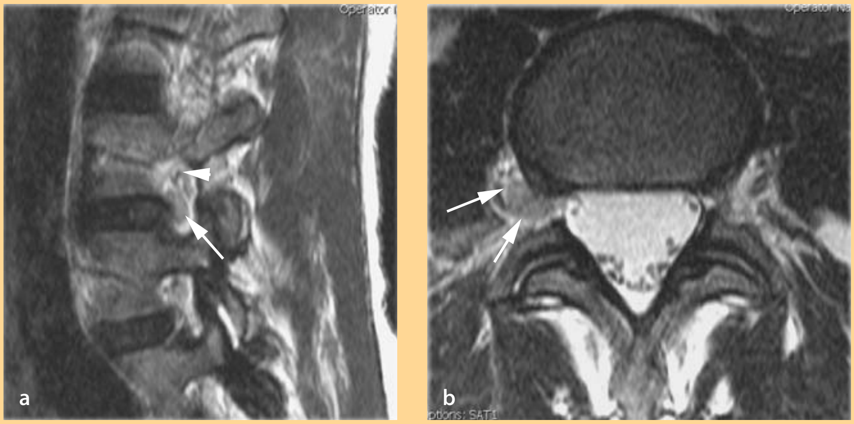
Two anatomically different types of lumbar disc herniation have been described with regard to a penetration of the posterior anulus and longitudinal ligament, respectively. Disc herniations can be classified as:

- contained
- non-contained

Contained discs, which are completely covered by outer annular fibers or posterior longitudinal ligament, are not in direct contact with epidural tissue. By contrast, **non-contained discs** are in direct contact with epidural tissue. This differentiation is of importance for minimally invasive surgical procedures such as chemonucleolysis or percutaneous disc decompression.

The most commonly used classification today is based on the MR morphology of the disc herniation [90] (Fig. 5).

Figure 4. Lateral disc herniation



a T2 weighted parasagittal MR image of the foramen clearly showing the sequestrated disc material (*arrow*) pushing the nerve root (*arrowhead*) cranially. **b** Axial T2 weighted MR image demonstrating a large extraforaminal disc extrusion (*arrows*).

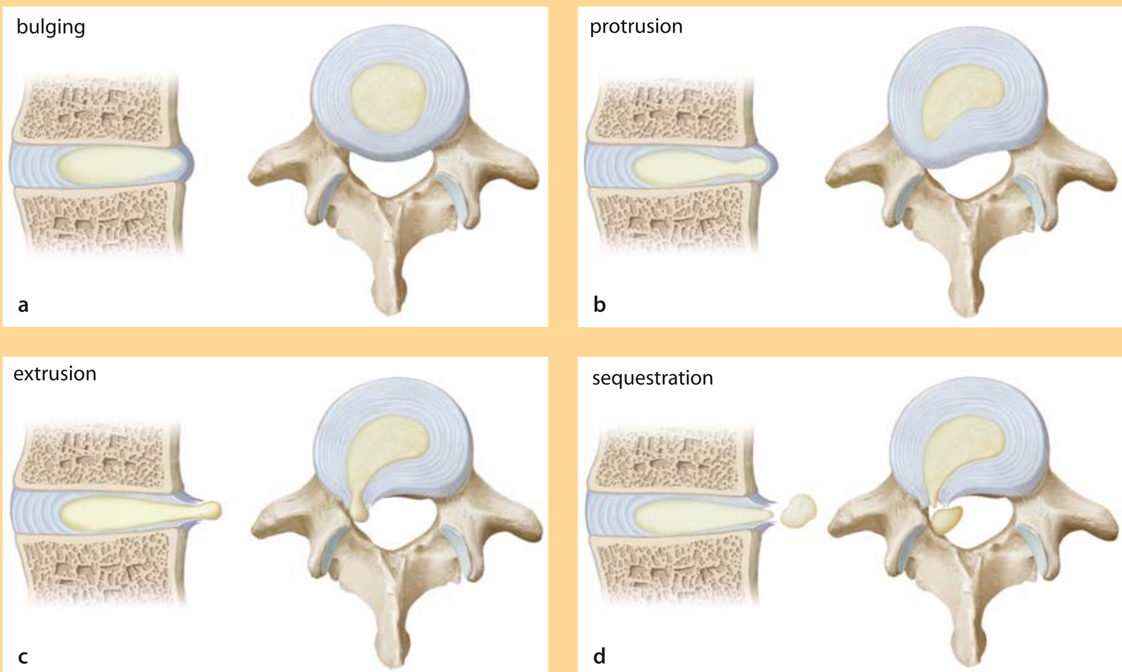


Figure 5. Classification of lumbar disc herniation

Modified from Masaryk et al. [90].

The size of the spinal canal determines whether a disc herniation becomes symptomatic

Particularly the definition of disc bulging is problematic because of the frequent finding (51 %) in discs of asymptomatic individuals [23]. Therefore, this classification is not helpful in **discriminating symptomatic and asymptomatic disc herniation**. A large disc extrusion in a wide spinal canal may not produce symptoms. On the contrary, a small disc protrusion in a congenitally narrow spinal canal may cause a significant sensorimotor deficit (Case Introduction). In a matched pair control study, Boos et al. [23] demonstrated that the **best discriminator** between symptomatic and asymptomatic disc herniation is nerve root compromise. Dora et al. [40] have shown that a symptomatic disc herniation is critically dependent on the size of the spinal canal. These findings have led to the suggestion [109] of a classification based on neural compromise (Fig. 6).

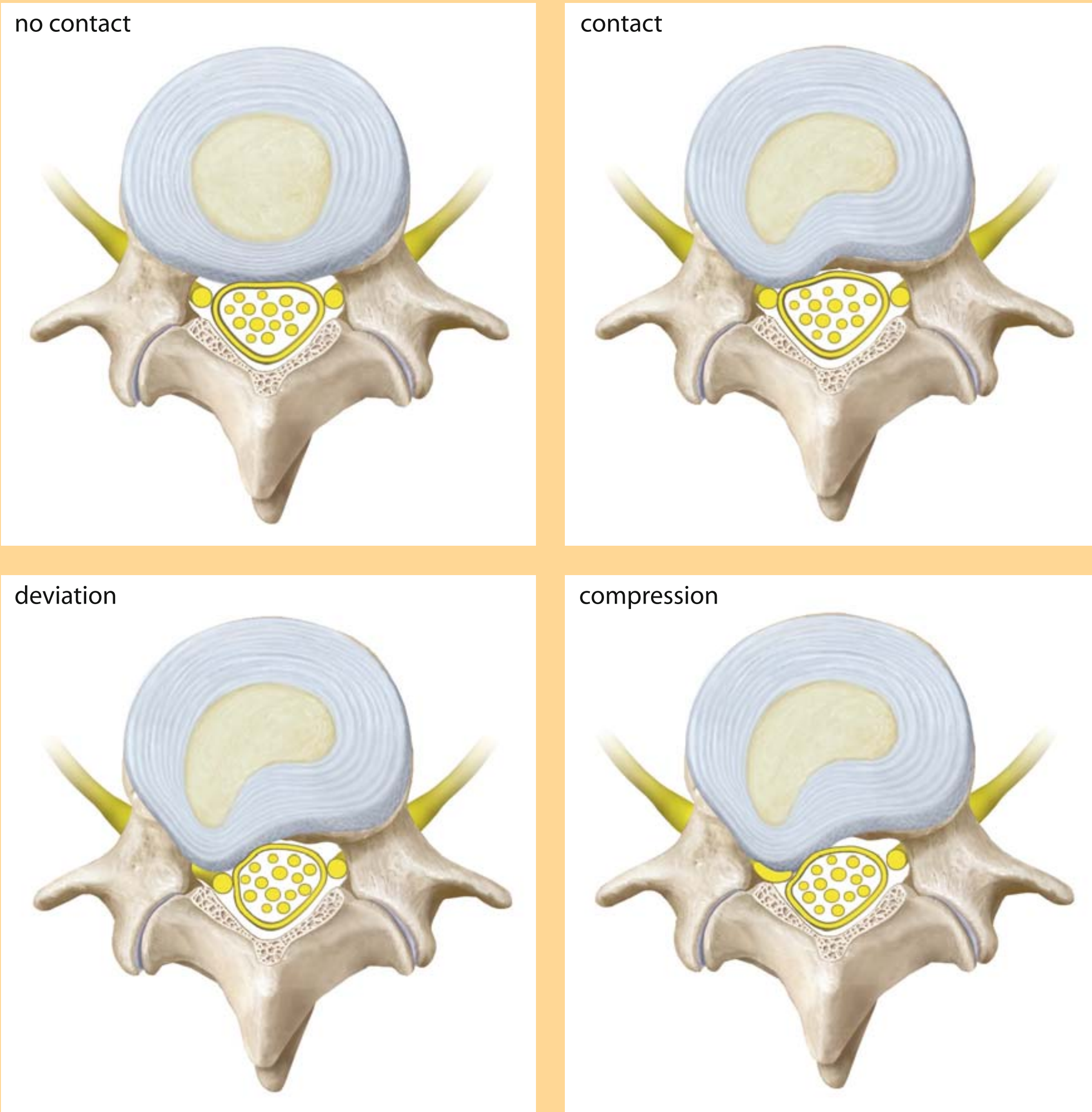


Figure 6. Classification of nerve root compromise

Modified from Pfirrmann et al. [109].

Non-operative Treatment

Symptomatic lumbar disc herniation is a condition which exhibits a benign natural history. The patients who exhibit an absolute but rare indication for surgery are those who present with a cauda equina syndrome or a severe paresis (< MRC Grade 3). The general goals of treatment are shown in **Table 1**:

The natural history of disc herniation is benign

Table 1. General objectives of treatment

• relief of pain	• regaining of activities of daily living
• reversal of neurologic function	• return to work and leisure activities

Although based more on anecdotal experience than scientific evidence, several factors have been associated with a favorable outcome of non-operative treatment (Table 2):

Table 2. Favorable indications for non-operative treatment

• sequestrated disc herniation	• small herniation
• young age	• mild disc degeneration
• minor neural compromise	• mild to moderate sciatica

A detailed knowledge of the natural history is a prerequisite for advising patients on the appropriate choice of treatment.

Natural History

Radicular symptoms have a benign course

The natural history of sciatica is generally benign. In most cases, an acute episode of sciatica takes a brief course. This phase is normally followed by a subacute or chronic period of residual symptoms. Most patients recover within 1 month, but the recurrence rate is approximately 10–15% [21]. In most patients with an extruded or sequestered herniation, the symptoms disappear with the herniation within a few weeks or months [112] (Case Introduction).

Extruded and sequestrated discs have a strong tendency to resolve

Bozzao et al. [25] evaluated prospectively the evolution of lumbar disc herniation using MRI. Follow-up MRI scan performed 6–15 months after baseline demonstrated that 48% of patients had a reduction in size of their lumbar disc herniation greater than 70%, 15% had a reduction of 30–70%, 29% had no change in size, and only 8% had an increase in size. There was a good clinical outcome in 71% of patients, and outcome correlated with the size reduction of the lumbar disc herniation. The largest disc herniations showed the greatest degree of reduction in size of lumbar disc herniation [25]. Komori et al. [69] investigated the morphologic changes in 77 patients with disc herniation and radiculopathy by sequential MRI. In 64 patients clinical improvement corresponded to a decrease of herniated disc, and in 13 patients no changes on MRI could be noticed despite symptom improvement. A decrease in size was observed in 46% of herniated discs within 3 months. Patients with marked morphologic changes showed significantly lower duration of leg pain compared to patients with slight clinical improvement. In this study morphologic changes corresponded to clinical outcome. Clinical improvement tended to be earlier than morphologic changes. Dislocated herniated discs frequently showed an obvious **decrease in size**, and in seven cases complete disappearance was observed. The further the herniated disc migrated, the more decrease in size could be observed [69]. However, disc protrusion, i.e., contained discs, did not have a tendency to resolve over a 5-year period [24]. These findings indicate that the highest chance for a **resolution** is exhibited by a sequestrated disc in a young patient. The exact mechanism of disc disappearance is not known. The contact between disc material and the vascular system may lead to an inflammatory response, invasion of macrophages and phagocytosis of the fragment.

Conservative Measures

The **key measures** of non-operative treatment include:

- Bed rest (<3 days)
- Analgesics
- Anti-inflammatory medication
- Physiotherapy

Acute sciatica may be so severe that the patient cannot be mobilized. In this first period, the most important goal is to reduce pain and gradually increase the physical activity. It is also very important to reassure the distressed patient that the course is usually benign. However, bed rest should not be prolonged for more than 3 days [50, 140]. **Anti-inflammatory drugs** aim to tackle the inflammatory component. Physiotherapy in the acute phases focuses on a pain reducing positioning. After the acute phases therapeutic exercises which strengthen the back muscles and improve health status of the patients represent a cornerstone of conservative treatment. Exercise that improves trunk strength and balance and does not exacerbate leg pain appears to be preferable.

Conservative treatment has a 70–80% success rate

Non-operative treatment consists of analgesics, NSAIDs and physiotherapy

However, the clinical course is quite different in patients with **severe sciatica** and sensorimotor deficits. In a prospective study performed by Balague et al., 82 consecutive patients with severe acute sciatica were evaluated after 3, 6 and 12 months of conservative treatment. Only a minority of the patients (29%) had fully recovered after 12 months and one-third had surgery within 1 year. The recovery of clinical symptoms and signs was observed mainly in the first 3 months [14].

The natural history of severe sciatica is not benign

Nerve Root and Epidural Blocks

Epidural corticoid therapy of patients with sciatica is done in many centers based on anecdotal experience, but the scientific evidence is still lacking for the effectiveness of this treatment [81]. We prefer the transforaminal route for the application of the steroids because the medication can be injected directly at the site of the nerve root compromise under fluoroscopic guidance. The pain resolution usually starts immediately with the main effect evident after 3 days. In patients with minor sensorimotor deficits and radiculopathy, an effective pain treatment can facilitate non-operative care and bridge the time until a potential resolution of the herniation (Case Introduction).

Nerve root blocks are a useful adjunct to non-operative care

Buttermann reported on a prospective, non-blinded study in which patients were randomly assigned to receive either epidural steroid injection or discectomy after a minimum of 6 weeks of non-invasive treatment. Patients who underwent discectomy had the most rapid decrease in symptoms, with 92–98% of patients reporting that the treatment had been successful over the various follow-up periods. Only 42–56% of the 50 patients who had undergone the epidural steroid injection reported that the treatment had been effective [27]. Carette et al. reported on a randomized, double blind trial with 158 patients who had sciatica due to herniated nucleus pulposus. Patients with epidural injections of methylprednisolone acetate had no significantly better outcome after 3 months compared to patients in the placebo group. They found no reduction of the cumulative probability of back surgery after 12 months [30]. In another prospective, randomized, double blind study, 55 patients with lumbar radicular pain and radiographic confirmation of nerve root compression underwent a selective nerve-root injection with either bupivacaine alone or bupivacaine with betamethasone. Of the 27 patients who had bupivacaine alone, nine elected not to have decompression surgery, compared to 20 of the 28 patients who had bupivacaine with betamethasone [114]. The authors concluded that selective nerve-root injections of corticosteroids are significantly more effective than those of bupivacaine alone in obviating the need for a decompression for a period of 13–28 months (see Chapter 10).

Nerve root blocks can reduce the need for surgery by an effective pain treatment

Operative Treatment

General Principles

The goal of surgery in degenerative disc herniation is decompression of neural structures. There must be a strong correlation between clinical symptoms and radiological compression of nerve root [138]. Under these conditions, the results of lumbar disc surgery are very favorable.

Absolute indications for surgery are a cauda equina syndrome or acute/subacute compression syndrome of the spinal cord. In this case, surgery must be performed early. A further indication is significant muscle paresis (MRC Grade < 3) and severe incapacitating pain that do not respond to any form of pharmacological therapy. A relative indication is a persistent radiculopathy unresponsive to an adequate trial of non-operative care for at least 4 weeks (Table 3):

Table 3. Indications for surgery

Absolute indications	Relative indications
• cauda equina syndrome • severe paresis (MRC < 3) • paraparesis/paraplegia (thoracic disc herniation)	• severe sciatica with large herniation non-responsive to analgesics and NSAIDs • persistent mild sensorimotor deficit (MRC > 3) and sciatica > 6 weeks • persistent radicular leg pain unresponsive to conservative measures for 6–12 weeks • persistent radicular leg pain in conjunction with a narrow spinal canal

The indications for surgery in **children and adolescents** with slipped apophysis are similar to those of true disc herniation and consist of removal of both the slipped apophysis and prolapsed disc material [29, 47].

Surgery is indicated for thoracic herniations with spinal cord compromise

Indications for the surgical treatment of **thoracic disc herniation** must be made very carefully because of the high rate of asymptomatic disc alterations. However, indications for surgery are progressive myelopathy, lower extremity weakness and pain refractory to conservative treatment.

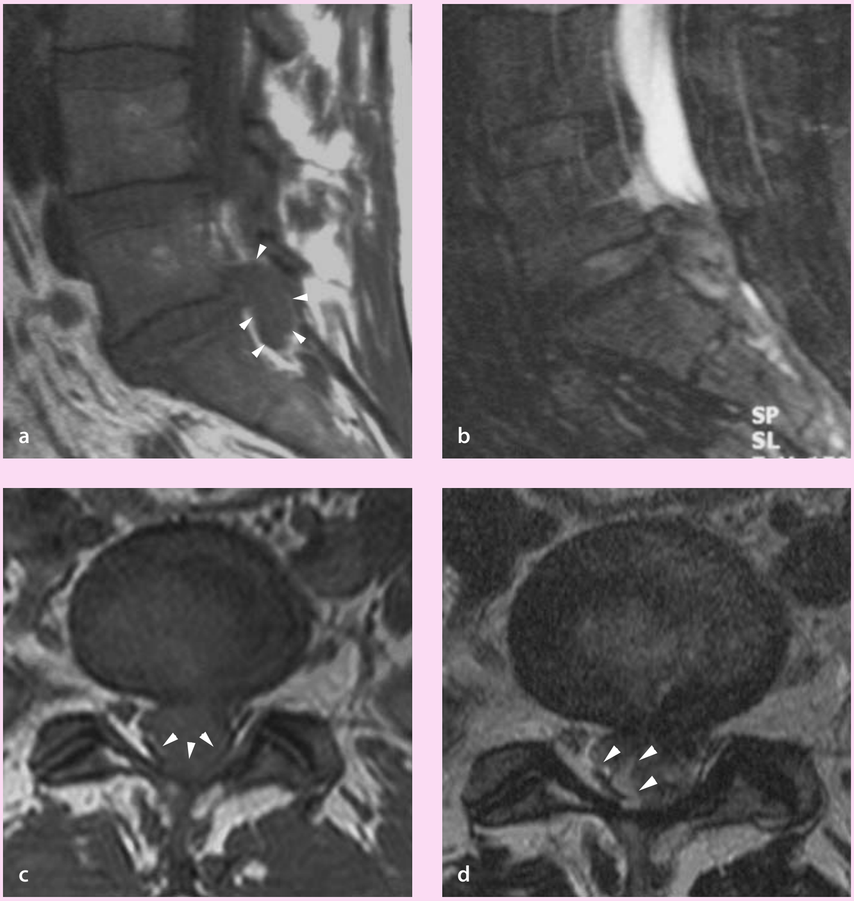
Timing of Surgery

Cauda equina syndrome or a progressive paresis should be operated on as early as possible

In the case of a cauda equina syndrome (Case Study 1), debate continues about the correct timing of surgery. Although it is recommended that surgery should be performed as early as possible, Kostuik [73] has found that decompression does not have to be performed in less than 6 h if recovery is to occur, as has been suggested in the past. A meta-analysis of surgical outcomes of 322 patients with cauda equina syndrome due to lumbar disc herniation showed no significantly better outcome if surgery was performed within 24 h from the onset of cauda equina syndrome compared to patients treated within 24–48 h. Significantly better resolutions of sensory and motor deficits as well as urinary and rectal function were found in patients treated within 48 h compared to those operated on after 48 h after onset of cauda syndrome [4]. Further, the study showed that preoperative back pain was associated with worse outcomes in urinary and rectal function, and preoperative rectal dysfunction was associated with a worsened outcome in urinary continence [4].

Prolonged conservative care may be associated with poorer outcome in patients requiring surgery

McCulloch [93] stated that surgical intervention in patients with acute radiculopathy who do not respond to conservative management should occur before 3 months of symptoms to avoid chronic pathologic changes within a nerve root. It is an anecdotal finding that patients with long-standing preoperative symptoms are less likely to obtain satisfactory results from surgery than those in whom symptoms are of short duration. In a prospective study, Rothoerl et al.



Case Study 1

A 35-year-old female felt a sharp pain in her back while bending down. Within 6 h she developed severe incapacitating back pain. She realized there was increasing numbness in her buttocks and weakness in both feet which was more pronounced on the left side. During the night, she consulted her family practitioner, who immediately referred her to our emergency department. On admission, the patient was diagnosed with a sensorimotor deficit of S1 (MRC Grade 2), flaccid sphincter tonus, and inability to urinate with a full bladder. An emergency MRI was indicated. T1 and T2 weighted images (a, b) demonstrate a massive sequestrated disc filling up the lumbosacral spinal canal. Axial T1 and T2 weighted MR images (c, d) show the severe obliteration of the thecal sac and cauda equina compression (*arrowheads*). Immediate surgery was indicated to decompress the cauda equina. Surgery consisted of a complete removal of the yellow ligament and a partial laminectomy of S1 and L5 to completely remove the massive herniation. The patient completely recovered from her pain but bladder dysfunction only resolved 6 months later.

[116] found that patients suffering for more than 60 days from disc herniation have a statistically worse outcome than patients suffering for 60 days or less. The authors recommend not to extend conservative treatment beyond 2 months and are in favor of surgery after that time period.

Surgical Techniques

Chemonucleolysis

Chemonucleolysis is a percutaneous intradiscal injection of chymopapain into the intervertebral disc. In 1963, Smith first described the dissolution of the disc by chemopapain [126]. The role of chemonucleolysis as an alternative to disc sur-

Chemonucleolysis is effective for selected indications gery became controversial because of the occurrence of rare but significant complications such as transverse myelitis and paraplegia [26, 97]. Chemonucleolysis is the only minimally invasive technique shown to be effective in prospective randomized studies. A meta-analysis showed that chymopapain was more effective than placebo. But, surgical discectomy produces better clinical outcomes than chemonucleolysis [48]. In this analysis approximately 30 % of patients with chemonucleolysis had further disc surgery within 2 years, and a second procedure was more likely after chemonucleolysis [124, 126].

Chemonucleolysis is effective based on RCTs

Percutaneous Techniques

These techniques have several theoretical advantages over open procedures:

- less collateral damage to the back muscles
- shorter hospital stay
- less scar formation
- cosmetic result

The percutaneous posterolateral approach to a herniated disc allows evacuation of extruded disc material and decompression of nerve root without entrance into the spinal canal and without destruction of the articular processes and ligamentum flavum. These procedures are limited in the extent to which migrated or sequestrated fragments can be retrieved or ablated, and proper patient selection is critical to their success. The approach to the L5/S1 disc space is more difficult because of limitations imposed by the iliac crest.

The indications for percutaneous techniques are limited

Automated Percutaneous Lumbar Discectomy

Automated percutaneous lumbar discectomy (APLD) and laser discectomy are percutaneous techniques which indirectly decompress the neural structures [87]. Both procedures were performed in patients with contained disc herniations or protrusions. The method was applied especially in the 1990s and the success rate ranged between 55 % and 85 %. Automated percutaneous discectomy was compared to microdiscectomy in two trials. In one trial similar clinical outcomes were achieved, whereas the other showed less satisfactory outcomes in percutaneous technique compared to microdiscectomy (29 % vs. 80 %) [48].

APLD is inferior to microdiscectomy

Endoscopic Discectomy

Endoscopic discectomy is compelling but must still pass the test of time

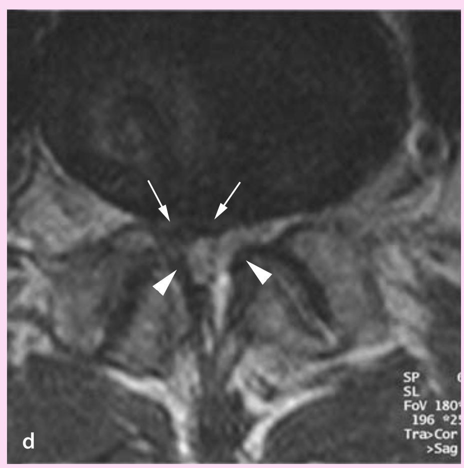
Kambin in 1988 published the first discoscopic view of a herniated disc. Percutaneous endoscopic removal of lumbar herniated disc can be performed via a midline or a posterolateral approach. Endoscopic procedures moved from indirect discectomy to direct excision of extruded fragments under vision. Further development of tools and techniques by Kambin and Yeung allowed uniportal direct decompression of the nerve root by foraminotomy, osteophytectomy and sequestrectomy [155]. Kambin et al. reported a favorable outcome in 87 % of cases similar to those of open disc surgery in selected patients [61]. Yeung reported about 307 patients who underwent percutaneous posterolateral nucleotomy for herniated discs [155]. After 1 year, 90.7 % of patients were satisfied and would undergo the same procedure again. He concluded that percutaneous endoscopic discectomy has comparable results to open microdiscectomy. The procedure offers the advantages of outpatient surgery, less surgical trauma, and early functional recovery. In a prospective study, Ruetten et al. reported about 463 patients who had removal of herniated lumbar disc via an extreme lateral access. Using an endoscopic uniportal transforaminal approach, 81 % of patients had a completely resolved leg pain [117]. With the recent improvement in endoscopic techniques, a greater acceptance rate, patient demand and dissemination can be expected in the future.

Standard Limited Laminotomy

Standard limited laminotomy is the current gold standard for discectomy

Standard discectomy today consists of a unilateral exposure of the interlaminar window and partial flavectomy to expose the dura and nerve roots as well as the intervertebral disc. An excision of a 1- to 2-cm^2 area of the superior and inferior lamina results in a better exposure which is not always needed [42, 111]. Optionally, this technique can be used with **magnification loops** and **headlights** [129] to enhance visibility.

A more extensive approach with complete bilateral removal of the yellow ligament and partial laminotomy may be indicated in cases with massive disc herniations and patients with a congenitally narrow spinal canal (Case Study 2). Extrac-



Case Study 2

A 33-year-old male reported recurrent episodes of low back pain. One morning, he woke up immobilized by back pain and could hardly move. Symptomatic treatment with analgesics, NSAIDs and physiotherapy was begun after a visit to his general practitioner. After 3–4 days the back pain slowly disappeared but the patient developed severe leg pain. During the course of one week the patient developed paresthesia and weakness of the right foot. On referral 6 weeks after symptom onset, the patient still presented with a severe spinal shift to the right (a). A standing anteroposterior radiograph confirmed this shift and ruled out scoliosis (b). On examination, the patient presented with a sensorimotor (MRC Grade 3) deficit for dorsiflexion of the greater toe (L5). Sagittal T2 weighted MR image (c) shows a small disc protrusion at the level of L4/5 on the right side. The axial T2 weighted MR image (d) demonstrates a congenitally narrow spinal canal with flavum hypertrophy (*arrowheads*) and a small disc protrusion compressing the L5 nerve root. After failure of non-operative care, surgery at L4/5 was carried out not only decompressing the nerve root L5 but also the congenitally narrow spinal canal with the beginning of stenosis.

tion of a large disc fragment through a tiny opening in the flavum may cause a rapid increase in intrathecal pressure and may lead to neurologic deterioration. In cases with cauda equina syndrome, complete flavectomy and in some cases laminectomy is therefore needed before the fragments can be extracted (Case Study 1).

Microdiscectomy

The technique of microsurgical discectomy was introduced by **Caspar** [32] and **Williams** [151] in the late 1970s [32] (Fig. 7). The use of the operating microscope to expose the compressed nerve root has several theoretical advantages. The most important reason is the maintenance of a three-dimensional view in the

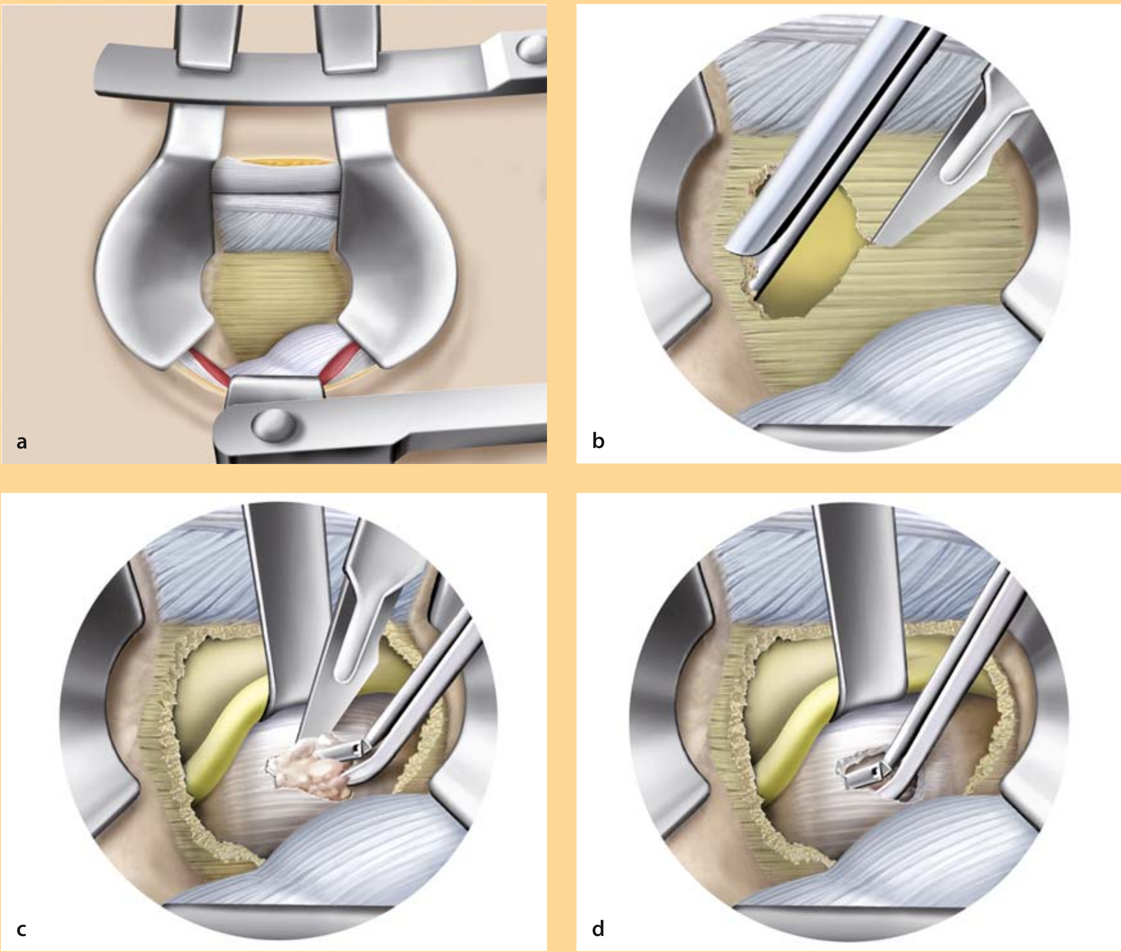


Figure 7. Interlaminar approach

The patient is positioned with the abdomen hanging freely minimizing intra-abdominal pressure and related epidural bleeding. Verification of the correct level before and after exposure of the target interlaminar window is mandatory. **a** Interlaminar approach with a tubular retractor after a 3-cm skin incision placed over the target interlaminar window. **b** Incision of the yellow ligament with a knife or a Kerrison rongeur. **c** Partial flavectomy and exposure of the nerve root and disc herniation. The lateral border of the nerve root must be identified clearly before further preparation. The nerve root should only be retracted medially to avoid nerve root and dura injuries. Sometimes the nerve root must be decompressed laterally first by undercutting the facet joint before it can be mobilized over the disc herniation. **d** The decompression of the intervertebral disc should be limited to the extraction of free intradiscal fragments. Resection of the anulus increases the risk of recurrent herniation.

depth of a spinal wound. Furthermore, microscopic discectomy exhibits the advantage of stronger illumination and magnification of the operative field and a smaller approach, which may result in a more rapid recovery [8, 60]. In an EMG study, it was shown that the use of a microscope resulted in less irritation of the nerve root [121]. Debate continues about the superiority of microdiscectomy over standard limited laminotomy [93, 123]. So far, no convincing evidence has been provided in the literature [48]. McCulloch has indicated that the outcome of lumbar discectomy does not appear to be affected by the use of a microscope and depends more on patient selection than on surgical technique [93].

Microdiscectomy results in less nerve root irritation than with standard techniques

Outcome of discectomy is independent of the type of open surgical technique

The microscopic approach has also been described for the treatment of **lateral (extracanicular) disc herniations** in which full visual control allows a decompression of the respective spinal nerve or ganglion and removal of the herniated disc [113]. With this approach, there is minimal resection of bone and facet joint and minimal risk of injury to neural structures (Fig. 8).

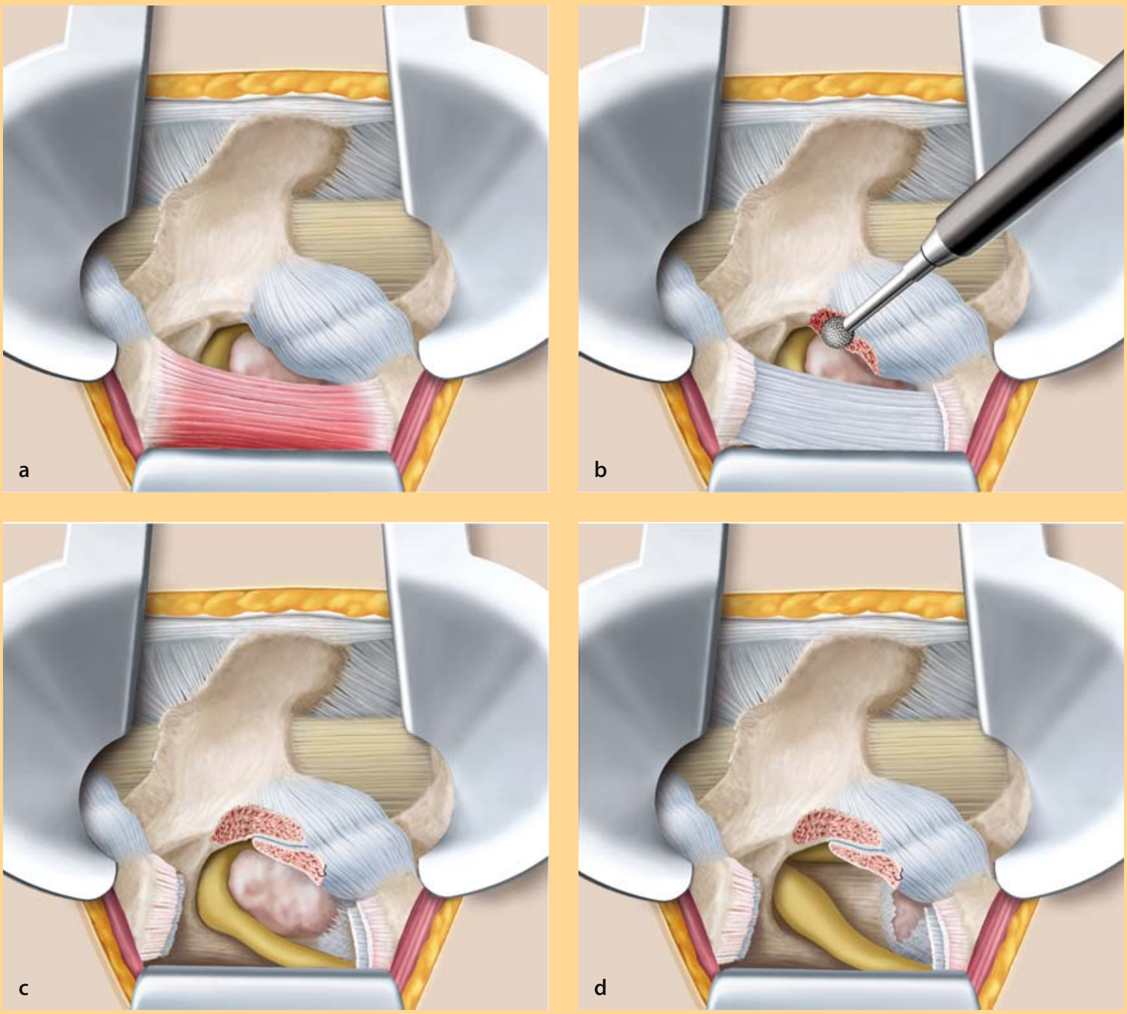


Figure 8. Extraforaminal approach

The extraforaminal approach is similar to the interlaminar approach using a tubular retractor. **a** Exposure of the facet joint, isthmus of the lamina and the superior and inferior transverse process. **b** Resection of the lateral inferior border of the isthmus with a high-speed diamond burr is sometimes necessary for a better exposure. **c** Exposure of the exiting nerve root, search and extraction of free fragments. **d** Decompression of the intervertebral disc may be necessary to completely liberate the nerve root in case of a disc protrusion deviating or compressing the nerve root.

Complete Discectomy Versus Sequestrectomy

Debate also continues about the extent of discectomy. Williams has advocated an approach without laminectomy or curettement of the disc space, preservation of extradural fat and blunt perforation of the anulus fibrosus, rather than scalpel incision with the goal of minimizing reherniations and adhesion reactions [151, 152]. In a prospective randomized study [136], 84 consecutive patients with free, subligamentary, or transannular herniated lumbar discs were randomized to sequestrectomy alone or microdiscectomy groups. At 4 and 6 months, SF-36 scales and PSI scores showed a trend in favor of sequestrectomy, leaving 3% of patients unsatisfied compared with 18% of those treated with discectomy. Reherniation occurred in four patients after discectomy (10%) and two patients after sequestrectomy (5%) within 18 months [136]. There appears to be little benefit from more radical disc excisions compared with removing only sequestered fragments in the case of adequate decompression of the nerve root.

Sequestrectomy is preferred over radical discectomy

Surgery for Thoracic Disc Herniations

The choice of surgical approach depends on the **location and extent** of the herniation but also on the general condition of the patient. Surgery for the treatment of thoracic disc herniations is demanding because:

- the spinal cord does not tolerate any retraction for exposure of the disc herniation
- correct localization of the target level is difficult
- the herniation is usually hard (calcified) and difficult to remove
- corpectomy may be required to remove dislocated fragments
- verification of a complete removal is hampered by the limited sight
- bone resection for exposure may require subsequent spinal instrumentation

Several approaches have been described (Table 4):

Table 4. Surgical approaches for thoracic disc herniations

Posterolateral approaches	Anterior transthoracic approaches
• costotransversectomy [54] • lateral extracavitary [77] • transverse arthro-pediculectomy [82] • transfacet pedicle-sparing [131]	• anterior transpleural [36] • thoracoscopic [115]

Laminectomy alone is contraindicated

Laminectomy alone is contraindicated in thoracic disc herniation (TDH) because the compression is anterior, which is not addressed by a posterior decompression. For many years, the **costotransversectomy** was the gold standard for surgery of the TDH. Nearly all types of TDH can be reached with this approach. The approach was introduced by Hulme in 1960 [54]. After a median or paramedian incision, the processus transversus must be removed followed by resection of 10–15 cm of the medial rib of the lower vertebra. After reaching the disc space, the discectomy can be performed. The parietal pleura of the lung is pushed ventrally and the disc fragment can be resected without touching the thecal sac. This approach was modified in many ways to a less invasive procedure. The transfacet pedicle-sparing approach allows for complete disc removal with limited spinal column disruption and soft-tissue dissection [131]. With additional use of the microscope good removal of lateral and centrolateral TDH is possible. Anterior approaches have been developed for direct exposure of central calcified and centrolateral herniations. In 1958, Crafoord reported on the removal of TDH by the anterior transthoracic transpleural approach [36]. In the 1990s, Rosenthal and others [80, 85] developed a thoracoscopic approach for thoracic herniations. The clinical outcome of surgery for thoracic disc herniations is satisfactory in 76–86% of cases [83, 108, 125, 131, 156]. However, the risk of postoperative paraplegia is imminent [83].

The risk of postoperative neurologic deterioration is imminent

Conservative Versus Operative Treatment

One of the first randomized controlled trials in spinal surgery was the comparison of conservative and surgical treatment for lumbar disc herniations by **Weber** [142]. Two hundred and eighty patients with herniated lumbar discs, verified by radiculography, were divided into three groups. One group consisted of 126 patients with uncertain indications for surgical treatment, who had their therapy decided by randomization, which permitted comparison between the results of surgical and conservative treatment. Another group comprising 67 patients had symptoms and signs that were beyond doubt, requiring surgical therapy. The third group of 87 patients were treated conservatively because there were no indications for operative intervention. Follow-up examinations in the first group ($n=126$) were performed after 1, 4, and 10 years. The controlled trial showed a statistically significantly better result in the surgically treated group at the 1-year follow-up examination. After 4 years, the operated on patients still showed better results, but the difference was no longer statistically significant. Only minor changes took place during the last 6 years of observation [142].

Surgery provides better short-term results than non-operative care

The **Maine Lumbar Spine Study** demonstrated that while patients with sciatica generally improve regardless of the type of treatment given, those who are surgically treated report significantly greater improvement in symptoms, health-related quality of life, and satisfaction compared with non-surgically treated patients at a 1-year follow-up. In this study 86% of surgically treated patients stated if they were to do it again they would still choose surgery [11, 12]. The **SPORT** (**Spine Patient Outcomes Research Trial**) trial consisted of 1220 prospectively followed patients with sciatica due to disc herniation who were divided into surgical and non-surgical groups [146, 147]. One part of the study included 501 patients who were randomized into two groups (surgery vs. conservative). The remaining patients ($n=719$) who chose one of the two treatment options were included in an observational arm. In the randomized group, adherence to the assigned treatment was limited: 50% of patients assigned to surgery received surgery within 3 months of enrollment, while 30% of those assigned to non-operative treatment received surgery in the same period. Intent-to-treat analyses demonstrated substantial improvements for all primary and secondary outcomes in both treatment groups. Between-group differences in improvements were consistently in favor of surgery for all periods but were small and not statistically significant for the primary outcomes. The randomized study was hampered by the large numbers of patients who crossed over in both directions. Conclusions about the superiority or equivalence of the treatments are not warranted based on an intent-to-treat analysis. Of the 743 patients enrolled in the observational cohort, 528 patients received surgery and 191 received the usual non-operative care. At 3 months, patients who chose surgery had greater improvement in the primary outcome measures of bodily pain, physical function, and Oswestry Disability Index. These differences narrowed somewhat at 2 years. The overall comparison demonstrated a significantly better outcome for surgery compared to conservative care. However, the authors stressed that non-randomized comparisons of self-reported outcomes are subject to potential confounding and must be interpreted cautiously (Table 5).

Sciatica patients improve with surgery as well as with conservative care

The outcome benefits of surgery seem to vanish over time

Table 5. Treatment outcome

Author	Study	Patients and treatment	Follow-up and outcome
Weber [142]	prospective randomized	operative ($n=66$) vs. non-operative ($n=60$) treatment	significantly better outcome of surgery at one year which is no longer significant at 4 and 10 years
Atlas et al. [11–13]	prospective cohort study	operative ($n=217$) vs. non-operative ($n=183$) treatment	surgically treated patients are more satisfied (71% vs. 56%) and have less back and leg pain (56% vs. 40%) at 10 years follow-up
Weinstein et al. [147]	prospective randomized	operative ($n=245$) vs. non-operative ($n=256$) treatment	better outcome in the surgical group which did not reach statistical significance. Methodological problems (high number of cross-overs) limit the conclusions
Weinstein et al. [146]	prospective observational	operative ($n=528$) vs. non-operative ($n=191$) treatment	significantly better outcome of the surgical group at 1 and 2 year follow-up

Complications

Complications in surgery for lumbar disc herniation are rare

For all kinds of surgery, the benefits have to be weighed against the risks. In general, the risks associated with discectomy are very low. **Early complications** of the procedure may include [76, 149]:

- nerve root injuries or increasing neurologic deficit (0.5–1%)
- cerebrospinal fluid leaks (0.8–7.3%)
- infections (0–2%)
- great vessel or intestinal injury (0–0.04%)

Late complications could be segmental instability and the so-called "failed back surgery syndrome." The overall rate of unsatisfactory results following discectomy is between 5% and 20% [78, 132].

The frequent **causes of persistent sciatica** after discectomy are [74, 132]:

- wrong level surgery
- insufficient disc removal
- recurrent herniation
- unrecognized additional nerve root compromise
- nerve root injury
- insufficient decompression of concomitant spinal stenosis
- spondylolisthesis
- extravertebral nerve compression

Recurrent Herniation

The rate of recurrent herniations ranges between 5% and 11%

Contained disc exhibits a higher recurrency rate

Minimal disc degeneration is a risk factor for recurrent herniations

The recurrence of back and/or sciatic pain can be caused by a true recurrent herniation or an incomplete removal. The reported rate of recurrent disc herniation after primary discectomy ranges between 5% and 11% [35, 43, 132]. Carragee et al. [31] presented a prospective observational study with 187 patients who underwent primary lumbar discectomy. The morphology of the disc herniations was recorded according to **annular deficiency** and **presence of fragments**. Patients with fragments and small annular defects had a recurrence rate of 1%, patients with fragments and contained disc herniation 10%, patients with fragments and massive posterior annular loss 27%. The highest recurrence rate (38%) had patients with no fragments and **contained disc herniations** [31]. In a case-control study, MR findings of patients with and without recurrent disc herniation were analyzed [39]. Advanced disc degeneration (Grades IV and V) was significantly less frequent in the study group than in the control group ($P<0.006$). The risk of recurrent disc herniation decreased by a factor of 3.4 with each grade of disc degeneration. Mean disc herniation volume as a percentage of intervertebral disc volume was equal in both groups. The authors concluded that minor disc degeneration but not herniation volume represents a risk factor for the recurrence of disk herniation after discectomy.

The **results of revision surgery** for recurrent lumbar disc herniation are as good as those of primary surgery when a true recurrent herniation is the source of sciatica [41, 59]. Controversy exists as to whether **epidural fibrosis** may be a reason for persistent back and leg pain after discectomy. In a contrast-enhanced MRI study, however, no differences regarding the presence and extent of epidural fibrosis between symptomatic and asymptomatic patients were found, questioning the role of epidural fibrosis as the causative agent in the lumbar postdiscectomy syndrome [9]. Many attempts have been made to reduce postoperative perineural fibrosis by interposition membranes but so far no convincing evidence has been provided in the literature for a superior outcome or a lower reoperation rate when applying such material [48]. We concur with Johnsson and Stromqvist [59] that sciatica due to nerve-root scarring is seldom improved by repeat operations.

The clinical significance of epidural fibrosis is unclear

Reoperation for epidural fibrosis is rarely successful

Recapitulation

Epidemiology. Lumbar disc herniation is the pathologic condition most commonly responsible for radicular pain. Episodes of back pain usually precede sciatica. Spinal surgery is most frequently carried out for disc herniation. The incidence rate of surgery for disc herniation exhibits substantial regional variations. Symptomatic thoracic disc herniations are very rare.

Pathophysiology. Disc herniation results from age-related (degenerative) alterations of the intervertebral disc leading to annular incompetence. Nuclear migration caused by annular disruption leads to the disc herniation. The major **risk factor** is genetic predisposition and classic risk factors (e.g., heavy lifting, twisting and bending, vibration) may only have a modulating effect. The pathophysiology of radiculopathy involves both **mechanical deformation** and **chemical irritation** of the nerve root. **Proinflammatory cytokines** play a major role in the development of sciatica.

Clinical presentation. The **cardinal symptom** of a disc herniation is radicular leg pain with or without a sensorimotor deficit. Neurologic examination is important to determine the involved nerve root(s) and rule out a cauda equina lesion. Children and adolescents with disc herniation may present only with back pain and hamstring tightness. **Potential bowel and bladder dysfunction** must be systematically assessed. Thoracic disc herniations can lead to progressive paraparesis but are rarely the cause of dorsal pain.

Diagnostic work-up. MRI has become the imaging modality of choice for assessing degenerative or herniated intervertebral discs. Diagnostic and prognostic implications are limited by the high prevalence of asymptomatic disc alterations. MRI and CT are equally good at diagnosing disc herniation. In equivocal cases, selective nerve root blocks can be helpful to identify the involved nerve root. Urologic assessment may be required in cases with questionable cauda equina syndrome. Nerve root compromise is the best indicator for symptomatic disc herniation.

Non-operative treatment. The **natural history** of disc herniations is favorable. Large sequestrated discs exhibit a tendency to resolve with time. Conservative care consists of analgesics, NSAIDs, physiotherapy and **epidural/nerve root blocks**. The scientific evidence for therapeutic injections is limited. Prolonged conservative treatment (>3 months) may result in an inferior outcome in the presence of a large disc herniation with concordant clinical symptoms.

Surgical treatment. Patient selection is the most important issue when considering surgical decompression. The high prevalence of asymptomatic disc herniations indicates that there must be a strong correlation between clinical-neurologic compression signs and radiological findings to justify surgery. **Absolute indications** for surgery are progressive neurologic deficit, cauda equina syndrome or paraparesis (thoracic disc herniation). Relative indications include persistent leg pain with or without mild sensorimotor deficits. **Chemonucleolysis** is the only minimally invasive technique which has been shown to be superior to non-operative treatment. Endoscopic techniques are compelling but still require the test of time. Standard interlaminar discectomy and **microdiscectomy** are the most frequently used techniques. So far, the microscopic approach has not been demonstrated to be superior to the conventional technique. Less degenerated discs exhibit a high rate of **recurrent disc herniations**. Surgical and non-surgical treatment have an equally satisfactory outcome but surgical candidates report better short-term results.

Key Articles

Mixter WJ, Barr JS (1934) Rupture of intervertebral disc with involvement of the spinal canal. N Engl J Med 211:210
Classic paper with the first description of disc herniation as the cause of sciatica.

Williams RW (1978) Microlumbar discectomy: a conservative surgical approach to the virgin herniated lumbar disc. Spine 3:175 – 82
Landmark paper introducing microdiscectomy as a surgical technique.

Atlas SJ, Keller RB, Wu YA, Deyo RA, Singer DE (2005) Long-term outcomes of surgical and non-surgical management of sciatica secondary to a lumbar disc herniation: 10 year results from the Maine Lumbar Spine Study. Spine 30:927 – 935
This paper presents the long term treatment outcomes of sciatica caused by lumbar disc herniation. Focus is on the relative benefits of surgical and conservative therapy. The 10-year outcome for 402 patients is reported. Outcomes included patient-reported symptoms of leg and back pain, functional status, satisfaction, and employment and compensation status. The Maine Lumbar Spine Study demonstrated that while patients with sciatica generally improve regardless of the type of treatment given, those who are surgically treated report significantly greater improvement in symptoms, health-related quality of life, and satisfaction compared with non-surgically treated patients at a 1-year follow-up. In this study 86 % of surgically treated patients stated if they were to do it again they would still choose surgery.

Balague F, Nordin M, Sheikhzadeh A, Echegoyen AC, Brisby H Hoogewoud HM, Fredman P (1999) Recovery of severe sciatica. Spine 24(23):2516 – 2524
In this prospective study, the recovery rates of 82 consecutive patients with severe acute sciatica were evaluated after 3, 6 and 12 months of conservative treatment. Only a minority of the patients (29 %) had fully recovered after 12 months and one-third had surgery within 1 year. The recovery of clinical symptoms and signs was observed mainly in the first 3 months. The authors concluded that the outcome of non-operative care for severe sciatica is poor.

Weber H (1983) Lumbar disc herniation. A controlled, prospective study with ten years of observation. Spine 8:131 – 140
This paper first reported in a randomized, prospective study the outcome of surgically treated patients compared to non-operatively treated patients. In 126 patients, the authors found significantly better results in the surgical group at 1 year. This significance is lost at 4 and 10 years with the surgical patients still being better.

Weinstein JN, Lurie JD, Tosteson TD, et al. (2006) Surgical vs nonoperative treatment for lumbar disk herniation. The Spine Patient Outcomes Research Trial (SPORT), a randomized trial. JAMA 296:2441 – 2450
Weinstein JN, Lurie JD, Tosteson TD, et al. (2006) Surgical vs nonoperative treatment for lumbar disk herniation. The Spine Patient Outcomes Research Trial (SPORT) observational cohort. JAMA 296:2451 – 2459
These two papers are important papers comparing the conservative treatment with discectomy in patients with sciatica due to lumbar disc herniation. The SPORT trial consists of 1 220 prospectively followed patients who were divided into surgical and non-surgical groups. One part of the study included 501 patients who were randomized to the two groups; the other part included 719 patients who chose one of the two treatment options. In the latter study part, more patients had good results and less pain after surgery compared to those who choose non-operative care. In the randomized part improvements

were also found consistently more in the surgical group, but the differences did not reach significance. Both papers showed a trend toward a better outcome for the surgically treated patients.

Gibson JN, Grant IC, Waddell G (1999) The Cochrane review of surgery for lumbar disc prolapse and degenerative lumbar spondylosis. Spine 24:1820 – 1832
Gibson JN, Waddell G (2005) Surgery for degenerative lumbar spondylosis: updated Cochrane Review. Spine 30:2312 – 20
Excellent summary of the scientific evidence for the treatment of disc herniations.

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