SURGICAL METHODS FOR THE TREATMENT OF INTERVERTEBRAL DISC HERNIATION: CURRENT STATE AND FUTURE PERSPECTIVES

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Abstract: This article provides a comprehensive overview of contemporary surgical methods for the treatment of intervertebral disc herniation, tracing the transition from traditional open procedures to modern minimally invasive, endoscopic, and percutaneous techniques. Evidence on clinical effectiveness, complication and recurrence rates, invasiveness, patient selection criteria, and economic considerations is summarized based on domestic and international studies from the past two decades. Special emphasis is placed on emerging technologies, including robotic-assisted navigation systems, artificial intelligence–based planning tools, intervertebral disc arthroplasty, and regenerative approaches such as cell-based therapies and biopolymer scaffolds. Key development trends are identified, highlighting the shift toward function-preserving interventions and biologically oriented restoration of disc structure. The article concludes that future progress in disc surgery will be driven by personalized treatment strategies and integration of bioengineering innovations aimed at structural recovery rather than solely symptomatic relief.

Keywords: intervertebral disc herniation; spinal surgery; microdiscectomy; endoscopic discectomy; laminectomy; percutaneous decompression; nucleoplasty; laser disc decompression; disc arthroplasty; robotic-assisted surgery; navigation systems; regenerative medicine; stem cell therapy; biopolymer scaffolds; degenerative spinal disorders.

Introduction

Intervertebral disc herniation (IDH) is one of the most common manifestations of degenerative–dystrophic diseases of the spine. According to global epidemiological data, more than 70% of adults experience at least one episode of severe low back pain during their lifetime, and up to 20% of patients with chronic pain have MRI-confirmed IDH (Balagué et al., 2012). Given its high prevalence, healthcare expenditures related to IDH represent a substantial burden, particularly in European and North American healthcare systems (Dagenais et al., 2008).

While more than 80% of patients demonstrate spontaneous improvement with conservative therapy, a considerable subgroup develops neurological deficits or prolonged, treatment-resistant pain (Peul et al., 2007). In such cases, surgery remains the primary means of improving quality of life.

Modern spinal surgery is undergoing a technological revolution, shifting from extensive open procedures to minimally invasive techniques, computer navigation, robotics, bioengineering innovations, and personalized approaches.

Classical Open Surgical Techniques

Laminectomy

Laminectomy, introduced in the early 20th century, remained the main operation for many decades. The procedure involves widening the spinal canal by removing part of the vertebral arch, thus decompressing neural structures. Although historically important, the method is now used only in select cases.

Limitations of laminectomy:

1. High surgical trauma.
2. Increased risk of postoperative spinal instability (Hart et al., 2013).
3. Significant blood loss.
4. Prolonged rehabilitation.
5. Higher rates of chronic pain compared with minimally invasive techniques.

According to Weinstein et al. (2010), more than 20% of patients require additional stabilization procedures after laminectomy.

Open Discectomy

Unlike laminectomy, open discectomy focuses on removing the extruded disc fragment. Although more effective for relieving pain and neurological symptoms, it involves injury to paraspinal muscles, facet joints, and ligaments.

A meta-analysis by Pinto et al. (2018) reported:

• Clinical improvement in up to 85% of patients;
• Complication rates of 8–12%;
• Reoperation rates of about 10%.

Due to the evolution of microscopic and endoscopic techniques, open discectomy is now used less frequently.

Microdiscectomy

Microdiscectomy is one of the best-studied and most evidence-based treatments. First introduced by Caspar (1977), it minimizes tissue trauma through the use of an operating microscope.

Technical Aspects:

• Incision 2–3 cm;
• Minimal retraction of paravertebral muscles;
• Microscopic visualization ensures precise handling of the nerve root.

Clinical Outcomes

A 10-year follow-up study by Atlas et al. (2011) demonstrated:

• Sustained improvement in 89% of patients;

• Low complication rates (~5%);
• Reoperation rates of 7–10%.

In Russia, microdiscectomy is widely practiced and is considered the first-line standard in major neurosurgical centers (Kiselev et al., 2018).

Advantages:

• Short hospitalization (2–3 days);
• Minimal blood loss;
• Rapid recovery;
• Excellent results for sequestered herniations.

Endoscopic Discectomy

Endoscopic spine surgery is the fastest-developing field in modern neurosurgery.

Transforaminal Approach (TESSYS)

This approach allows surgeons to bypass bone structures and avoid injury to the ligamentum flavum and paraspinal muscles.

Hoogland et al. (2008):

• 90% successful outcomes;
• Minimal blood loss;
• Ambulatory surgery.

Ideal for working-age patients requiring rapid rehabilitation.

Interlaminar Endoscopic Approach

Preferable for L5–S1 herniations due to the specific anatomy of this level.

Ruetten et al. (2009) showed:

• Efficacy comparable to microdiscectomy (up to 93%);
• Less muscle damage.

Limitations:

• Requires extensive surgeon expertise;
• Limited effectiveness for far-migrated sequestrations;
• High equipment cost.

Percutaneous Techniques

Nucleoplasty (Cold Plasma Technology)

This method removes part of the nucleus pulposus using low-temperature plasma.

Effectiveness:

• Up to 70% improvement for disc protrusions (Gerszten, 2011);
• Very low invasiveness;
• Outpatient procedure.

Ineffective for true sequestered herniations.

Laser Disc Decompression

Laser energy vaporizes part of the nucleus.

Knight & Goswami (2020) reported recurrence rates up to 30–35%, limiting widespread use.

Intervertebral Disc Arthroplasty (Disc Replacement)

The goal is to preserve segmental mobility and prevent overload of adjacent levels.

Advantages:

• Preservation of physiological biomechanics;

• Reduced risk of adjacent segment disease.

Clinical Evidence

Zigler et al. (2012):

• Better functional outcomes than fusion at 5 years;

• Lower reoperation rates.

Use is limited in many countries due to implant cost.

Robotic and Navigation-Assisted Surgery

Robotic systems such as Mazor X and ROSA Spine, along with 3D-CT navigation, greatly enhance precision during instrumentation.

Benefits:

• Screw placement accuracy up to 98% (Lonjon et al., 2017);

• Reduced operative time;

• Minimal radiation exposure.

Future Directions:

Integration of AI-based planning algorithms (Kernbach et al., 2021).

Biotechnological and Hybrid Approaches

Cell-Based Therapies

Mesenchymal stem cells (MSCs) show promise for disc regeneration (Oehme et al., 2020).

Biopolymer Scaffolds

Collagen- and hyaluronic acid–based scaffolds may restore disc volume and reduce pain (Leung et al., 2020).

Hybrid Procedures

Combining microdecompression with intradiscal biomaterial injection is an emerging strategy.

Comparative Analysis of Surgical Methods

Method	Invasiveness	Success Rate	Recurrence	Hospital Stay	Notes
Laminectomy	High	70–80%	10–15%	5–10 days	Highly traumatic
Open discectomy	Moderate	80–85%	10–12%	5–7 days	Less commonly used today
Microdiscectomy	Low	85–95%	7–10%	2–3 days	“Gold standard”

Endoscopic discectomy	Very low	85–93%	5–10%	1–2 days	Rapid return to activity
Nucleoplasty	Minimal	60–70%	up to 20%	1 day	Effective only for protrusions
Disc arthroplasty	Moderate	~90%	<5%	4–7 days	Preserves motion

Conclusion

Modern surgery for intervertebral disc herniation is becoming progressively less invasive. Microdiscectomy remains the most universal and well-validated procedure. Endoscopic approaches offer excellent outcomes with minimal tissue trauma. Disc arthroplasty and robotic technologies represent promising directions in function-preserving spinal surgery.

In the next decade, rapid advances in bioengineering are expected to shift treatment paradigms—from symptomatic relief toward restoration of disc structure and function.

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