

Surgical Management of Secondary Lumbar Canal Stenosis: Fenestration or Laminectomy, and the Impact of Transpedicular Fixation

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ABSTRACT

Background: Abstract: Secondary lumbar canal stenosis is a prevalent degenerative condition that significantly impacts quality of life due to chronic pain and functional limitations. Surgical intervention remains a cornerstone in its management, with fenestration and conventional laminectomy emerging as prominent approaches. This review aims to compare the efficacy and safety of fenestration and conventional laminectomy, with and without transpedicular fixation, in the treatment of secondary lumbar canal stenosis. A comprehensive analysis of the current literature was conducted to evaluate clinical outcomes, including pain relief, functional recovery, and complications. Studies incorporating fenestration, laminectomy, and their adjunctive use with transpedicular fixation were critically appraised. Fenestration offers a minimally invasive alternative with reduced soft tissue disruption, shorter recovery times, and preserved spinal stability, though its indications may be limited to less extensive stenosis. Conventional laminectomy, while effective in decompressing the spinal canal, carries a higher risk of postoperative instability, often necessitating transpedicular fixation to achieve biomechanical stability. The addition of fixation in both approaches showed improved outcomes in select cases, particularly in those with preoperative instability or significant deformity. The choice between fenestration and conventional laminectomy, with or without transpedicular fixation, should be individualized based on patient-specific factors, including the severity of stenosis, presence of instability, and overall health status. Further high-quality, randomized controlled trials are needed to establish standardized guidelines and optimize surgical decision-making for secondary lumbar canal stenosis.

Keywords: Secondary Lumbar Canal Stenosis, Fenestration or Laminectomy

1. INTRODUCTION

Degenerative lumbar canal stenosis (DLCS) is a progressive narrowing of the spinal canal that results in compression of neural elements and vascular structures. This condition is a leading cause of lower back and leg pain, particularly among older adults. The pathophysiology involves a combination of degenerative changes in intervertebral discs, facet joints, and ligamentum flavum, which collectively reduce the space available for the spinal cord and nerve roots. This multifactorial process is influenced

by age-related wear and tear, biomechanical stress, and genetic predisposition, contributing to the clinical manifestations of neurogenic claudication and chronic back pain [1].

One of the key contributors to DLCS is intervertebral disc degeneration. With aging, discs lose water content and elasticity, leading to reduced disc height and subsequent bulging into the spinal canal. This bulging compresses neural structures and exacerbates symptoms of stenosis. Additionally, disc degeneration alters the mechanical stability of the lumbar spine, promoting abnormal loading patterns on the surrounding anatomical structures, including the facet joints and ligaments [2].

Facet joint arthropathy is another hallmark feature of DLCS. Degenerative changes in these synovial joints result in hypertrophy, osteophyte formation, and subchondral bone sclerosis, all of which contribute to narrowing of the spinal canal. Hypertrophic changes in the facet joints not only encroach on the central canal but also on the neural foramina, potentially leading to radiculopathy. The biomechanical interplay between degenerating discs and facet joints creates a vicious cycle, perpetuating the progression of stenosis [3].

Ligamentum flavum hypertrophy and buckling further aggravate the narrowing of the spinal canal. This ligament, located posteriorly within the spinal canal, thickens and loses its elasticity as part of the degenerative process. The hypertrophic ligamentum flavum can encroach on the spinal canal, significantly reducing its cross-sectional area. Histological studies reveal that chronic inflammation and fibrosis are pivotal in the pathological thickening of this structure [4].

The role of spondylolisthesis in DLCS cannot be overlooked. Degenerative spondylolisthesis, characterized by the anterior slippage of one vertebra over another, often occurs at the L4-L5 level. This condition exacerbates spinal stenosis by further decreasing the space available for neural elements. The interplay of disc degeneration, facet joint instability, and ligamentum flavum buckling underpins the development of spondylolisthesis in the context of DLCS [5].

Biomechanical stress and chronic inflammation significantly contribute to the pathological remodeling of lumbar spinal structures in DLCS. Repetitive microtrauma and prolonged mechanical loading accelerate tissue damage and inflammatory responses, resulting in the proliferation of fibrocartilaginous tissue, osteophyte formation, and angiogenesis. These processes collectively worsen the narrowing of the spinal canal and amplify the symptoms of lumbar stenosis [6].

Neurovascular compromise is a critical aspect of DLCS pathophysiology. The compression of neural elements within the stenotic canal disrupts axonal transport and blood flow, leading to ischemia and nerve dysfunction. This mechanism explains the hallmark symptom of neurogenic claudication, characterized by pain, numbness, and weakness in the lower extremities exacerbated by walking and relieved by forward flexion [7].

Imaging studies play a pivotal role in diagnosing and assessing the severity of DLCS. Magnetic resonance imaging (MRI) is the gold standard for visualizing degenerative changes and neural

compression. Key findings include reduced spinal canal dimensions, ligamentum flavum hypertrophy, disc bulging, and facet joint hypertrophy. Computed tomography (CT) can complement MRI by providing detailed bony anatomy, aiding in surgical planning when necessary [8].

Magnetic resonance imaging (MRI) and computed tomography (CT) myelography are pivotal diagnostic modalities for evaluating lumbar spine stenosis, a condition that leads to narrowing of the spinal canal, nerve root canals, or intervertebral foramina. The grading of lumbar spine stenosis into mild, moderate, and severe categories is critical for determining appropriate management strategies. This grading is typically based on the degree of compromise to the spinal canal and the impact on neural structures [1].

MRI is the preferred imaging modality for lumbar spine stenosis due to its superior soft tissue contrast and ability to visualize the neural elements without ionizing radiation. It provides detailed images of the spinal cord, nerve roots, and intervertebral discs, allowing accurate assessment of the degree of stenosis. Grading stenosis with MRI generally involves measuring the anteroposterior diameter of the spinal canal and evaluating the cerebrospinal fluid (CSF) space and nerve root compression [2].

Mild stenosis on MRI is characterized by minimal narrowing of the spinal canal with preserved CSF signal around the nerve roots. There is no evidence of compression or deformation of the neural elements. In this grade, patients may exhibit minimal or no symptoms, and conservative treatment is often sufficient. Radiologically, the spinal canal diameter usually measures above 10 mm, with a normal CSF signal surrounding the nerve roots [3].

Moderate stenosis on MRI shows further narrowing of the spinal canal with partial obliteration of the CSF space. There may be mild to moderate compression of the nerve roots without significant deformation. This grade often correlates with intermittent neurogenic claudication or radicular pain. The canal diameter typically measures between 8-10 mm. MRI findings guide clinicians toward non-surgical interventions, though surgical considerations may arise if symptoms persist or worsen [4].

Severe stenosis on MRI is defined by significant spinal canal narrowing with complete obliteration of the CSF space and evident compression or deformation of the neural elements. The canal diameter is generally less than 8 mm. This grade is associated with severe clinical manifestations, including persistent or progressive neurogenic claudication, radiculopathy, or neurological deficits. Surgical intervention is frequently recommended for severe stenosis to relieve neural compression and restore function [5].

CT myelography, an invasive imaging technique, involves injecting a contrast agent into the subarachnoid space to visualize the spinal cord and nerve roots. While CT myelography is less commonly used than MRI, it remains valuable in specific cases, such as patients with contraindications to MRI or when MRI findings are inconclusive. CT myelography provides high-resolution images, especially of bony structures, aiding in the assessment of lumbar spine stenosis [6].

Mild stenosis on CT myelography demonstrates partial narrowing of the spinal canal with intact and clearly outlined nerve roots surrounded by contrast. There is no compression or distortion of the neural elements. This grade typically corresponds to minimal clinical symptoms and can often be managed conservatively. The findings complement MRI in confirming the diagnosis [7].

Moderate stenosis on CT myelography reveals further narrowing of the canal with some effacement of the nerve root sleeves and possible compression of neural elements. This is often associated with symptoms of moderate severity, including intermittent pain or functional limitations. CT myelography findings may assist in surgical planning if required, particularly in complex cases [8].

Severe stenosis on CT myelography is marked by significant canal narrowing with complete effacement of the contrast around the nerve roots and visible compression or deformation of the neural elements. This grade indicates advanced disease, correlating with severe clinical symptoms and often necessitating surgical decompression. CT myelography remains a complementary tool to MRI in these cases, providing detailed anatomical insights for preoperative planning [9].

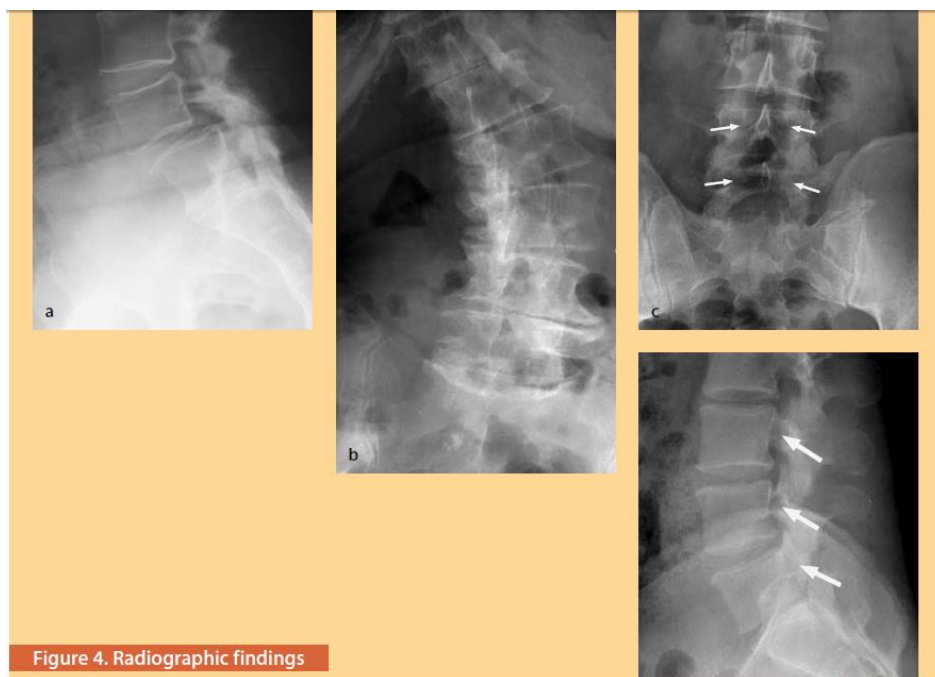


Figure 4. Radiographic findings

Figure 1: Radiographic findings; a) degenerative spondylolisthesis at the L4/5 level. b) Degenerative scoliosis with lateral shifting of the L2 and L3 vertebrae indicating central and lateral recess stenosis. c), d) Congenitally narrow spinal canal with a narrow interpedicular distance and short pedicles



Figure 2: MRI characteristics of spinal stenosis

a) Hypertrophy of the yellow ligament (arrowheads) on a T2W axial scan. b) Facet joint hypertrophy with joint effusion (arrowheads) on a T2W axial image. c) Hourglass appearance of the spinal canal (arrowheads) on a sagittal T2W image. d) Large facet joint synovial cysts on the right side (arrowheads) and a small cyst on the left side (arrow). e) A large facet joint cyst is compressing the thecal sac shown on a T2W sagittal image. f) Fat in the foramen appears with a bright signal on T1W image (arrows); Obliterated perineural fat (arrowheads) in neural foramina indicating foraminal stenosis which is aggravated by a small disc protrusion.

Management of DLCS ranges from conservative to surgical approaches, depending on the severity of symptoms and functional impairment. Conservative treatments include physical therapy, nonsteroidal anti-inflammatory drugs (NSAIDs), and epidural steroid injections, aiming to alleviate symptoms and improve quality of life. Surgical decompression, with or without spinal fusion, is reserved for patients with refractory symptoms or significant neurological deficits [9].

The prognosis of DLCS varies based on the degree of canal narrowing, patient age, and comorbidities. While conservative management provides symptomatic relief for many patients, surgical intervention has shown high success rates in improving pain and function in appropriately selected cases. Early recognition and intervention are crucial in preventing long-term complications and optimizing outcomes for individuals with DLCS [10].

Secondary lumbar canal stenosis (SLCS) can be managed through a spectrum of modalities ranging from conservative treatments to surgical interventions. Conservative approaches include physical therapy, pharmacologic management, and epidural steroid injections. These are primarily aimed at relieving symptoms and improving functionality, particularly in patients with mild or moderate stenosis who are not candidates for surgery [11].

Physical therapy focuses on strengthening the core and lumbar musculature, enhancing flexibility, and improving posture to alleviate the mechanical stress on the spine. Additionally, activity modification and the use of assistive devices, such as lumbar braces, can be helpful in reducing symptom severity. Pharmacologic therapies typically include nonsteroidal anti-inflammatory drugs (NSAIDs), muscle relaxants, and neuropathic pain agents [12].

Epidural steroid injections are a minimally invasive option for managing inflammation and pain caused by nerve root compression. These injections deliver corticosteroids directly to the epidural space, reducing inflammation and swelling around the compressed nerves. While effective for short-term relief, their benefits may diminish over time, and repeated injections may carry risks [13].

For patients with severe or progressive SLCS, surgical intervention is often necessary. The primary goal of surgery is to decompress the neural structures, alleviate pain, and restore function. The choice of surgical technique depends on various factors, including the extent of stenosis, anatomical considerations, and the patient's overall health and preferences [14].

Emerging modalities, such as interspinous spacers and minimally invasive surgical techniques, are gaining attention for their ability to achieve decompression with minimal tissue disruption. These options are particularly appealing for patients at higher risk of complications associated with traditional surgeries [15].

Fenestration and conventional laminectomy are two surgical techniques employed for managing secondary lumbar canal stenosis (SLCS), a condition characterized by a narrowed spinal canal leading to neural compression and subsequent symptoms. Fenestration involves a less invasive approach, focusing on limited bone removal to decompress specific nerve roots while preserving the structural integrity of the spine. In contrast, conventional laminectomy entails removing the lamina and associated ligamentum flavum, allowing a more extensive decompression of the spinal canal [16].

Secondary lumbar canal stenosis arises due to degenerative changes, trauma, or post-surgical complications. Fenestration is considered advantageous for selected cases as it minimizes disruption to stabilizing structures, potentially reducing the risk of post-operative instability and preserving normal spinal biomechanics. However, it may be less effective in cases where extensive decompression is required, as the limited exposure could restrict the surgeon's ability to address severe stenosis comprehensively [17].

Conventional laminectomy is often favored for patients with significant multilevel stenosis, as it provides broad access to the spinal canal. This technique enables the surgeon to address pathologies such as ligamentous hypertrophy, osteophytes, and facet joint overgrowth. However, the extensive bone and ligament removal associated with laminectomy can compromise spinal stability, necessitating additional interventions such as transpedicular fixation in certain cases to prevent iatrogenic instability [18].

The decision between fenestration and laminectomy depends on multiple factors, including the severity and extent of stenosis, patient's clinical presentation, and surgeon's expertise. Fenestration may be better suited for unilateral or localized stenosis, particularly in patients who prioritize minimal surgical trauma. Conversely, laminectomy is appropriate for patients requiring extensive decompression or those presenting with bilateral or multilevel pathology [19].

Transpedicular fixation is often combined with laminectomy to enhance spinal stability, especially in cases with significant instability or deformity. This technique involves the placement of screws through the pedicles into the vertebral bodies, connecting them with rods to provide rigid fixation. Transpedicular fixation can reduce the risk of post-operative complications, such as spondylolisthesis, but it may increase operative time and surgical morbidity [20].

Biomechanical studies suggest that fenestration preserves more of the spinal integrity compared to laminectomy, reducing the likelihood of adjacent segment disease. This benefit is particularly relevant in younger patients or those with limited degenerative changes. By preserving the posterior elements, fenestration helps maintain the physiological load distribution across the spine [21].

Clinical outcomes following fenestration and laminectomy vary depending on patient selection, surgical technique, and postoperative care. Fenestration is often associated with shorter recovery times and reduced perioperative pain, while laminectomy provides more reliable symptomatic relief in severe cases. Studies indicate that both techniques yield comparable outcomes in terms of pain relief and functional improvement when appropriately applied [22].

Patient-reported outcomes and quality-of-life measures are increasingly used to assess the success of surgical interventions for SLCS. Fenestration typically scores higher on patient satisfaction scales due to its less invasive nature and faster recovery. However, the long-term success of fenestration depends on careful patient selection and thorough preoperative evaluation [23].

One of the primary limitations of fenestration is the risk of incomplete decompression, particularly in cases with extensive stenosis or complex anatomy. In contrast, laminectomy offers comprehensive decompression but at the cost of increased potential for complications such as instability, epidural fibrosis, and prolonged recovery [24].

When comparing fenestration with conventional laminectomy, the trade-offs between invasiveness and effectiveness are evident. Fenestration is less invasive, causing minimal disruption to the spinal structures, while laminectomy ensures thorough decompression but may require adjunctive stabilization procedures like transpedicular fixation. The choice should be individualized based on the patient's pathology and overall health status [25].

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