CQ HAND + UPPER LIMB
SPECIALIST ORTHOPAEDIC SURGEON

EVIDENCE SUMMARY

Lumbar spinal stenosis

Anatomy & Pathophysiology

ANATOMICAL DEFINITIONS AND BOUNDARIES

- Spinal stenosis is defined as a decrease in the space available for the neural elements, which in the lumbar spine includes the cauda equina [10].
- The central spinal canal is defined as the space posterior to the posterior longitudinal ligament, anterior to the ligamentum flavum and laminae, and bordered laterally by the medial border of the superior articular process [10].
- The lateral recess is defined by the superior articular facet posteriorly, the thecal sac medially, the pedicle laterally, and the posterolateral vertebral body anteriorly [10].
- The intervertebral foramen is bordered superiorly and inferiorly by the adjacent level pedicles, posteriorly by the facet joint and lateral extensions of the ligamentum flavum, and anteriorly by the adjacent vertebral bodies and disc [4, 5, 10].
- Normal foraminal height is 20 to 30 mm [4, 5, 10].
- Normal superior foraminal width is 8 to 10 mm [4, 5, 10].
- The lateral recess, also known as "Lee's entrance zone," begins at the medial border of the superior articular process and extends to the medial border of the pedicle [28].
- The foraminal region, described as "Lee's midzone," lies ventral to the pars and is bounded medially by the lateral recess, ventrally by the posterior vertebral body and disc, dorsally by the pars and intertransverse ligament, and laterally by the lateral border of the pedicle [28].
- The dorsal root ganglion and ventral motor root occupy 30% of the space within the foraminal region [28].
- The exit zone is identified as the area lateral to the facet joint where the nerve root can be compressed by a "far lateral" disc, spondylolisthesis, or facet arthritis [28].
- In the lumbar spine, lateral recess pathology such as stenosis or posterolateral disc herniation typically involves the next nerve root exiting caudal to that disc [29].
- An L4-5 posterolateral disc herniation is expected to cause L5 nerve root symptoms [29].
- The named nerve root exits below the named pedicle in the thoracic and lumbar spine [29].

CQ HAND + UPPER LIMB
Dr Kieran Hirpara — Specialist Orthopaedic Surgeon
Suite 2, Level 1, Mater Private Hospital Rockhampton, 31 Ward Street, The Range, QLD 4700
Phone 07 4863 6556 · office@cqupperlimb.com.au · cqupperlimb.com.au

- The conus medullaris lies around the L1-L2 level in adulthood, meaning lumbar, sacral, and coccygeal roots exit the cord at lower thoracic or upper lumbar vertebral levels before forming the cauda equina [30].

ETIOLOGY AND PATHOPHYSIOLOGY

- Lumbar spinal stenosis (LSS) can be congenital, acquired, or both [10].
- Acquired lumbar spinal stenosis can be degenerative, iatrogenic, neoplastic, or traumatic [10].
- Lumbar spinal stenosis is associated with disorders such as acromegaly, Paget disease, and ankylosing spondylitis [10].
- LSS is the final stage of a cascade of events that begins with disk degeneration [10].
- As disk height decreases, the loading characteristics of the facet joints are altered [10].
- Facet joint capsules become incompetent, leading to capsular, ligamentum flavum, and facet hypertrophy [10].
- The ligamentum flavum becomes less pliable with age [10].
- The final stage of the degenerative continuum is a decrease in the diameter of the spinal canal [10].
- Degeneration of the disc occurs with disc narrowing and subsequent ligamentous redundancy, which compromises the spinal canal area [28].
- Instability resulting from disc degeneration precipitates the formation of facet overgrowth and ligamentous hypertrophy [28].
- The ligamentum flavum may be markedly thickened into the lateral recess where it attaches to the facet capsule, causing nerve root compression [28].
- When the spine is in extension, the spinal canal diameter diminishes, resulting in buckling of the shortened, hypertrophied ligamentum flavum [10].
- In flexion, there is a relative increase in the spinal canal diameter [10].
- Most authors support a multifactorial etiology of low back pain and leg pain associated with LSS, including mechanical compression, nutritive insufficiency, heredity, structural decompression, individual pain perception, and chemical insult [10].
- Pain in foraminal stenosis may be the result of intraneural edema and demyelination [4, 5].
- Lower lumbar areas (L4–L5 and L5–S1) are usually involved in foraminal stenosis because the foramina decrease in size as the nerve root increases in size [4, 5].
- Foraminal stenosis affects the exiting (upper) root at a motion segment, such as the L4 root at L4–L5 [4, 5].
- The L4-5 level is the most commonly involved segment in spinal stenosis, followed by L5-S1 and L3-4 [28].
- Stenosis is relatively uncommon at the level of the pedicles, and when it occurs at this level, it often indicates an underlying congenital or developmental stenosis of the bony canal [52].
- Spinal stenosis is often seen in patients with a developmentally narrow spinal canal who possess little reserve capacity for the accumulation of degenerative lesions [52].
- Concomitant spinal instability (lateral listhesis or spondylolisthesis) and/or deformity (e.g., scoliosis) may accentuate spinal stenosis by narrowing the canal between translating segments [52].

- Foraminal stenosis is usually due to the hypertrophy and/or proximal migration of the superior articular facet from the level below, along with associated encroachment of the ligamentum flavum into the foramen [52].
- A decrease in disk height or disk herniation or bulging into the foramen can lead to foraminal stenosis [52].
- Thickening of the ligamentum flavum can extend into the foramen and be associated with a spur from the undersurface of the pars, especially if foraminal height is less than 15 mm and posterior intervertebral disc height is less than 4 mm [28].
- Causes of stenosis in the foraminal region include pars fracture with proliferative fibrocartilage or a lateral disc herniation [28].
- The most common type of spinal stenosis is caused by degenerative arthritis of the spine, including Forestier disease, characterized by hyperostosis and spinal rigidity in elderly patients [28].
- Hypertrophy and ossification of the posterior longitudinal ligament, usually confined to the cervical spine, and diffuse idiopathic skeletal hyperostosis (DISH) syndrome may result in an acquired form of spinal stenosis [28].
- Congenital spinal stenosis is usually central and evident on imaging studies [28].
- Idiopathic congenital narrowing usually involves the anteroposterior dimension of the canal due to short pedicles, with the posterior elements otherwise normal [28].
- In achondroplasia, the canal is narrowed in the anteroposterior plane owing to shortened pedicles and in lateral diameter because of diminished interpedicular distance [28].
- Acquired forms of spinal stenosis are usually degenerative and most commonly localized to the facet joints and ligamentum flavum [28].
- Abnormalities in degenerative spinal stenosis are frequently symmetric bilaterally [28].
- Disc herniation and spondylolisthesis may exacerbate the narrowing of the spinal canal further [28].
- Spondylolisthesis and spondylosis rarely cause spinal stenosis in young patients [28].
- In rare instances, accumulation of epidural fat can lead to spinal stenosis [52].
- Lumbar spondylosis is due to a degenerative cascade associated with intervertebral disk degeneration (IDD) [34].
- Mechanical progression and associated disk space narrowing lead to adjacent level pedicle approximation with narrowing of the superior-inferior dimensions of the intervertebral foraminal canal [34].
- Laxity of associated ligaments and vertebral column translates into altered loading mechanics and an altered pressure relationship on vertebral bone and joint surfaces, influencing osteophyte formation and facet joint hypertrophy [34].
- IDD is a multifactorial process characterized by altered biomechanics of loading, an imbalance of extracellular matrix synthesis and degradation, increased secretion of proinflammatory cytokines, and increased apoptosis and senescence in nucleus pulposus cells [34].
- Altered biomechanics from IDD lead to further degenerative changes and osteophyte formation, potentially causing lumbar central and foraminal stenosis [34].

- The etiology of lumbar spondylosis is characterized as osteoarthritis of the spine resulting from increased stresses and repetitive microtrauma leading to an imbalance in cartilage synthesis and degradation [55].
- Increased stress on bones and ligaments leads to osteophyte formation in lumbar spondylosis [55].
- The process of lumbar spondylosis is partly due to a proinflammatory degenerative cascade initiated by intervertebral disk and facet degeneration [55].
- TNF-α is one of the main catalyzers of the proinflammatory cytokine response to lumbar spondylosis [55].
- The most important physiological change in lumbar degenerative disk disease starts with the extracellular matrix within the nucleus pulposus (NP) [55].
- Early changes in the NP include increased proteolytic degradation of aggrecan and accumulation of degraded proteoglycans [55].
- Degradation of aggrecan impairs the diffusion of nutrients and oxygen throughout the disk [55].
- Intervertebral disk degeneration results in disorganization and destruction of the collagen network [55].
- Increased levels of proinflammatory cytokines lead to increased production of proteinases such as MMPs and ADAMTS families, causing breakdown of intervertebral disk collagens [55].
- As disk hydration decreases, disk height decreases with solidification of the NP [55].
- Aging, unfavorable genetics, altered nutrition and metabolite transport, and excessive or repetitive loading contribute to intervertebral disk degeneration [55].
- Mechanical compression on nerve roots and dorsal root ganglions can reduce blood flow and cause ischemic change [55].
- Ischemia triggers increased nerve damage, which induces the release of chemical factors and accentuates the inflammatory cascade [55].
- Chemical insults to the nerve are predominantly induced by an inflammatory response surrounding the spinal nerve roots and dorsal root ganglion [55].
- Cytokines such as TNF-α and MMPs play a role in neural inflammation and radicular pain [55].
- Spinal nerve roots sensitized to inflammatory mediators, when subjected to mechanical compression, exacerbate the neural immune insult, causing macrophage-mediated degeneration with a further increase in TNF concentrations [55].
- Degenerative spondylolisthesis is differentiated from isthmic spondylolisthesis by the presence of an intact pars [46].
- In degenerative spondylolisthesis, the intact arch moves forward with the L4 vertebral body, causing progressive spinal stenosis in addition to facet degenerative changes [46].
- The true deformity of degenerative spondylolisthesis is a rotary deformity rather than pure translation, which may distort the dura and its contents and exaggerate the appearance of spinal stenosis [46].
- The sagittal facet theory suggests a predilection for slippage because of facet orientation that does not resist anterior translocation forces [46].
- The disc degenerative theory proposes that the disc narrows first, and subsequent overloading of the facets results in accelerated arthritic changes, secondary remodeling, and anterolisthesis [46].

- Facet arthritic changes seem to be more severe than disc space narrowing, with the most advanced anterolisthesis present when disc narrowing is more pronounced [46].
- Facets aligned in a more sagittal orientation provide less stability at the involved level [46].
- Boden et al. showed that sagittal facet angles of more than 45 degrees at L4-L5 predicted a 25 times greater likelihood of degenerative spondylolisthesis [46].
- Despite the increased frequency of degenerative spondylolisthesis in women, there is no sex-specific difference in facet orientation [46].
- Sagittal facet orientation has been correlated with disc space narrowing, suggesting that disc narrowing increases loading of the facet, resulting in secondary facet changes [46].
- Instability from degenerative spondylolisthesis causes facet arthritis, disc degeneration, and ligamentous hypertrophy, which all contribute to produce symptoms [46].
- The biomechanical force causing spondylolisthesis is the anteriorly directed vector created by the contraction of the posteriorly located erector spinae muscles, coupled with the force of gravity acting on the upper body mass through the lordotic lumbar spine and lumbosacral junction [61].
- For spondylolisthesis to occur, there must be a failure of anatomic structures that normally resist anteriorly directed force, including the facets, annulus fibrosus, posterior bony arch, and pedicles [61].

NATURAL HISTORY

- The natural history of spinal stenosis is not well understood [10].
- The natural history of spinal stenosis is typically favorable, with approximately 15% deteriorating clinically [10].
- Improvement occurs in 30% to 50% of patients with spinal stenosis [10].
- In a study of 145 patients examined annually for a minimum of 10 years, progressive spondylolisthesis occurred in 34% [46].
- Further disc space narrowing continued in patients without further slip [46].
- Patients with disc space narrowing, spur formation, and ligamentous ossification did not develop an increased amount of slip [46].
- There was no correlation between radiographic findings and a patient's clinical picture in the study of 145 patients with spondylolisthesis [46].
- Low back pain improved in patients with continued disc space narrowing, which may imply autostabilization [46].
- Of the 145 patients in the Matsunaga et al. study, 76% remained without neurologic deficits [46].
- 83% of patients with neurologic symptoms, including claudication and vesicorectal disorder, experienced a deterioration in their disorder and had a poor prognosis [46].
- Over 60 to 176 months, progressive slipping occurred in 30% of patients without significant effect on clinical outcome [46].
- In a prospective study with a cohort of 160 patients, only 32% had slip progression over 5 years [46].

- Many patients improved over a 5-year period with regard to ODI and SF-12 Physical Health Composite scores, even in those with slip progression [46].
- Back pain improved only in the group without slip progression in the Cushnie et al. study [46].
- Spinal stenosis due to bony or ligamentous hypertrophy does not spontaneously regress with either time or nonoperative treatment [52].
- Nonoperative treatment in lumbar spinal stenosis is purely symptomatic and does not modify the underlying stenosis [52].

Clinical Presentation

HISTORY AND SYMPTOMS

- The natural history of most forms of lumbar spinal stenosis is the insidious development of symptoms [64].
- Occasionally, there can be an acute onset of symptoms precipitated by trauma or heavy activity [64].
- Neurogenic claudication improves with trunk flexion, stooping, or lying [64].
- Neurogenic claudication may require 20 minutes to improve after rest [64].
- Patients with neurogenic claudication often report better endurance walking uphill or up steps [64].
- Patients with neurogenic claudication tolerate riding a bicycle better than walking on a treadmill because of the flexed posture that occurs [64].
- Pushing a grocery cart allows spinal flexion, which enhances endurance and decreases discomfort in most patients with neurogenic claudication, known as the positive “shopping cart” sign [64].
- Vascular claudication symptoms are typically felt in the upper calf [64].
- Vascular claudication symptoms are relieved after a short rest of 5 minutes while standing [64].
- Vascular claudication symptoms do not require sitting or bending for relief [64].
- Vascular claudication symptoms worsen despite walking uphill or riding a stationary bicycle [64].
- In the SPORT study, only 50% of patients with lumbar spinal stenosis had physical examination findings including depressed reflexes, sensory or motor deficits, or positive nerve tension signs [47].
- Radiographic findings of spinal stenosis increase with age, yet many patients never become symptomatic [47].
- In a study of asymptomatic individuals, over 20% of patients older than 60 years had MRI evidence of lumbar spinal stenosis [47].
- One study found no significant association between clinical symptoms and anteroposterior spinal canal diameter [64].
- Spinal stenosis from degenerative arthritis is a complication of bony overgrowth compromising neural tissue in the late instability and early stabilization stages of spinal degeneration [16].
- The primary indication for surgery in patients with spinal stenosis is increasing pain that is resistant to conservative measures [17].

- Because the primary complaint often is back pain and some leg pain, pain relief after surgery may not be complete [17].
- Most series report a 64% to 91% rate of improvement after surgery for lumbar spinal stenosis, with 42% in patients with diabetes [17].
- Most patients still have some minor complaints after surgery, usually referable to the preexisting degenerative arthritis of the spine [17].
- Neurologic findings, if present, improve inconsistently after surgery [17].
- Patients whose predominant complaint was leg pain improved significantly more with operative treatment than those whose predominant complaint was low back pain [17].
- Both patients with predominant leg pain and those with predominant low back pain improved significantly with operative treatment compared with conservative treatment [17].
- Reoperation rates for lumbar spinal stenosis vary from 6% to 23% [17].
- Prognostic factors for better results include a disc herniation, stenosis at a single level, weakness of less than 6 weeks' duration, monoradiculopathy, and age younger than 65 years [17].
- Depression, psychiatric disease, cardiovascular disease, higher body mass index, scoliosis, and disorders affecting ambulation have been associated with a poorer prognosis [17].
- Reversal of neurologic consequences of spinal stenosis seems to be a relative indication for surgery unless the symptoms are acute [17].
- Radiographic findings alone are never an indication for surgery [17].
- Correlation of imaging with symptoms seems to be the best guarantee of improvement after surgery [17].
- Localized lesions on radiograph without general involvement respond best to treatment [17].
- Ganz reported a 96% success rate in patients whose preoperative symptoms were relieved by postural change [17].
- A patient's inability to tolerate the restricted lifestyle necessitated by the disease and the failure of a good conservative treatment regimen should be the primary determining factors for surgery [17].
- Lumbar spinal stenosis does not result in paralysis, only decreased ambulatory capacity [17].
- Conservative management is warranted indefinitely in a patient with good function and manageable symptoms [17].
- Delaying surgical treatment for a trial of nonoperative treatment has not been shown to affect outcome [17].
- One study reported less favorable results in patients who had symptoms for more than 33 months [17].
- Cervical and thoracic spinal stenoses are associated with painless paralysis in the form of cervical and thoracic myelopathy and require closer attention and follow-up [17].
- Other pathologies that can mimic or overlap the signs and symptoms of degenerative spondylolisthesis and associated spinal stenosis include vascular claudication, degenerative hip arthritis, and peripheral neuropathy [53].

- If the history and physical examination findings are inconsistent with degenerative spondylolisthesis, evaluation for vascular claudication, degenerative hip arthritis, and peripheral neuropathy should be considered [53].
- At a minimum, hip range of motion and irritability should be evaluated as well as peripheral pulses in the feet and proprioception when evaluating for mimicking pathologies [53].
- The approach to the active patient with low back pain with or without leg pain begins with a thorough history and physical examination [58].
- It is important to establish a timeline for the patient's report and to identify the nature, duration, onset, and characterization of the symptoms [58].
- When eliciting the history, the provider must focus on any inciting event and the presence or absence of certain red flags [58].
- Red flag signs indicate the potential for an underlying pathology that warrants a timely, focused workup [58].
- Evaluation of a patient presenting with low back or leg pain and a history of fevers, chills, weight loss, a history of cancer, immunosuppression, and/or intravenous drug abuse should prompt the clinician to consider infection or malignancy as a possible etiology [58].
- Evaluation of a patient presenting with back pain and reports of clumsiness, gait instability, bowel, bladder, or sexual dysfunction should prompt the clinician to carefully assess for causes of spinal cord dysfunction such as cervical or thoracic myelopathy [58].
- Asking the patient to describe the pain in relation to certain activities can point to a possible etiology [58].
- Diskogenic pain related to disk degeneration or disk herniation may be worse in flexion, while sitting, or with prolonged axial loading and is often described in a diffuse, bandlike distribution [58].
- Facet-mediated pain related to facet arthrosis or spondylolysis may be worse in extension and is often activity related and well localized [58].

PHYSICAL EXAMINATION

- Physical examination is often normal in patients with lumbar spinal stenosis, and therefore, the history is crucial to the diagnosis [47].
- It is crucial to perform an examination of the lower extremities to rule out alternative causes for pain, as lumbar spine pathology and lower extremity joint dysfunction, especially the hip, are common [47].
- Generally, physical findings with all forms of spinal stenosis are inconsistent [64].
- Distal pulses should be felt and confirmed to be strong [64].
- Internal and external rotation of the hips in extension should be full, symmetric, and painless [64].
- Straight-leg raising and sciatic tension tests usually are normal in patients with spinal stenosis [64].
- The neurologic examination usually is normal, but some abnormality may be detected if the patient is allowed to walk to the limit of pain and is then reexamined [64].
- The gait and posture after walking may reveal a positive "stoop test" [64].
- The stoop test is done by asking the patient to walk briskly [64].

- As pain intensifies during the stoop test, the patient may complain of sensory symptoms followed by motor symptoms [64].
- If the patient is asked to continue to walk, he or she may assume a stooped posture in a chair bent forward, and the same resolution of symptoms occurs [64].
- A thorough examination should begin by observing the patient walk, which allows an assessment of coordination, strength, and symmetry of motion [58].
- Palpation of the back should assess for any points of maximal tenderness such as the facets, paraspinal musculature, or sacroiliac joints [58].
- Assessing the range of motion of the hips can help to rule out referred pain due to hip arthrosis [58].
- A thorough sensorimotor examination should follow the initial observation and palpation [58].
- Provocative tests can be performed to elicit responses to corroborate physical examination or imaging findings [58].
- These tests may include nerve root tension signs such as a straight leg raise, contralateral straight leg raise, or femoral nerve stretch test [58].
- For the purpose of detecting lumbar disk herniation, the straight leg raise is more sensitive but less specific than the contralateral straight leg raise in patients with single leg radicular pain [58].
- The provider must be aware of possible indications of nonorganic or psychologic pain etiology [58].
- The five categories of signs for nonorganic pain, as described in a 1980 study, are tenderness, simulation, distraction, regional disturbances, and overreaction [58].
- Presence of three or more Waddell signs should prompt the provider to evaluate for other etiologies of the reports such as depression, hypochondriasis, or secondary gain issues [58].
- Presence of three or more Waddell signs does not discount the possibility of a spine problem [58].
- Waddell signs are associated with higher pain scores and poorer treatment outcomes overall [58].
- In foraminal stenosis, pain, numbness, and/or dysesthesia typically follow a dermatomal distribution [4].
- Motor and reflex findings in foraminal stenosis are typically normal but in the presence of weakness will follow myotome [4].
- Reflexes in foraminal stenosis are typically normal or hyporeflexic [4].
- Tension signs can be present in foraminal stenosis [4].
- Foraminal stenosis affects the exiting (upper) root at a motion segment, such as L4 at L4–L5 [4].
- Normal superior width of the intervertebral foramen is 8 to 10 mm [4].
- Intraforaminal disc protrusion is an etiology of foraminal stenosis [4].
- Impingement of the tip of the superior facet is an etiology of foraminal stenosis [4].
- The history and physical examination findings for foraminal stenosis are more consistent with nerve root compression, as with radiculopathy from herniated disc [4].
- In spondylolysis, focal tenderness to palpation is often noted adjacent to the midline and in the paraspinal musculature at the level of spondylolysis [67].

- Forward flexion will not elicit any pain in spondylolysis in contrast to extension, which may be limited and will likely be painful if forced [67].
- Other physical examination findings in spondylolysis may include hamstring tightness, antalgic gait, functional scoliosis due to muscle spasm, palpable step-off of the spinous process in cases of spondylolysis with spondylolisthesis, and increased lumbar lordosis [67].
- A single-leg lumbar hyperextension test can be used to assess for unilateral versus bilateral spondylolysis but has poor specificity for spondylolysis because it may be positive in multiple lumbar spine disorders [67].
- A thorough neurologic examination should be performed for spondylolysis but is often normal [67].
- Spondylolysis is most often asymptomatic and may be an incidental finding on radiography [67].
- Active youth with spondylolysis frequently develop back pain, which leads to a physician visit [67].
- They may recall a specific inciting event, but often symptom onset will not be readily definable [67].
- Initially they may only have back pain with activity that improves with rest, but may develop chronic low level pain at all time [67].
- The most common report is back pain that increases with high-intensity activity [67].
- Radicular pain into the buttocks or posterior thigh may rarely be present in isolated spondylolysis [67].
- In spondylolytic spondylolisthesis, foraminal stenosis may cause radicular symptoms [67].

DIAGNOSTIC WORKUP

- AP and lateral radiographs of the lumbar spine, with consideration for dynamic radiographs are important to evaluate alignment and evidence of instability [47].
- MRI has become the benchmark for identifying spinal pathology [47].
- T2-weighted sagittal and axial images can demonstrate disk bulges, facet hypertrophy, ligamentum flavum hypertrophy, cysts, and other causes of stenosis [47].
- Sagittal T1-weighted images best show foraminal stenosis [47].
- Although imaging is an important modality, it cannot replace a history and physical examination [47].
- For those patients who cannot undergo MRI, CT myelography can also demonstrate compression although with less detail than MRI [47].
- Electrodiagnostic studies can be used to help rule out a peripheral neuropathy; however, their role in diagnosis of spinal stenosis is unclear [47].
- MRI is helpful in identifying disease processes, such as tumors and infections, and is a good noninvasive study for patients with persistent lower extremity complaints after radiographic screening evaluation [8].
- MRI should be confirmatory in patients with a consistent history of neurogenic claudication or radiculopathy, but it should not be used as a screening examination because of the high rate of asymptomatic disease [8].
- Morphologic changes have been correlated with preoperative findings, such as pain and function, however, only to a limited extent [8].
- Sagittal T2-weighted MR images are a good starting point because they give a myelogram-like image [8].

- Sagittal T1-weighted images are evaluated with particular attention focused on the root indicates foraminal stenosis [8].
- Axial images provide a good view of the central spinal canal and its contents on T1- and T2-weighted images [8].
- Far lateral disc protrusions are identified on axial T1-weighted images by obliteration of the normal interval of fat between the disc and nerve root [8].
- The foraminal zone is better evaluated with sagittal T1-weighted sequences, which illustrates the presence of fat around the nerve root [8].
- Foraminal disc herniations should be confirmed on both sagittal and axial MRI images [8].
- Absolute anatomic measures also can be used for MRI evaluation [8].
- Spinal deformity, including scoliosis and significant spondylolisthesis, can result in suboptimal imaging by MRI [8].
- This is secondary to the curvature of the spine in and out of the plane of the scanner on sagittal sequences and difficulty obtaining true axial cuts [8].
- Another disadvantage of MRI is the cost [8].
- Nonetheless, MRI has become a useful, noninvasive diagnostic tool for the evaluation of patients with extremity complaints [8].
- Standing lateral, seated or standing flexion/extension laterals, and anteroposterior radiographs are imperative because 15% of deformities spontaneously reduce on supine imaging such as an MRI [53].
- Instability is considered to be present when 4 mm of translation or 10 degrees of sagittal rotation greater than the adjacent level is identified [53].
- Disc space narrowing indicates degenerative changes [53].
- Upright flexion-extension lateral views may reveal translational motion, indicating a more unstable motion segment [53].
- The Ferguson anteroposterior view shows any significant degenerative changes in the lumbosacral joint and allows a better view of the transverse processes of L5 [53].
- Hypoplastic transverse processes also should prompt consideration for interbody fusion because of the paucity of bony substrate for fusion, especially for lumbosacral fusions [53].
- Dynamically unstable spondylolisthesis also may benefit from interbody fusions that improve stability through annular tension and decrease shear stress on posterior instrumentation by sharing load through the disc space [53].
- The presence of retrolisthesis, scoliosis, or lateral listhesis also should be noted [53].
- In addition to plain radiographs, advanced neuroimaging is necessary to appropriately evaluate these patients [53].
- MRI generally is satisfactory, but a significant subset of patients cannot have an MRI because of the presence of a pacemaker or cardiac stents for example [53].

- In this case, lumbar myelography and post-myelogram high-resolution CT scans are quite satisfactory and often demonstrate the bony pathology better than MRI [53].
- Post-myelogram CT scans do not show pathology as well in the mid and lateral foramen because the subarachnoid space is not present out to the dorsal root ganglion and, thus, there is no contrast present in this area [53].
- Intraforaminal stenosis is relatively common, affecting the L4 nerve root, which is compressed against the inferior aspect of the L4 pedicle by annulus from a pseudohermiation due

Investigations

IMAGING MODALITIES

- MRI is the standard for advanced imaging of the spine and is superior to CT in most circumstances, particularly for identifying infections, tumors, and degenerative changes within discs [37].
- MRI is superior to CT for directly imaging neural structures and the intervertebral disc [37].
- MRI allows for imaging of the nerve root within the foramen, a capability that is difficult to achieve even with postmyelography CT because contrast does not fully extend through the foramen [37].
- MRI should be used as a confirmatory study in patients with a consistent history of neurogenic claudication or radiculopathy, not as a screening examination due to the high rate of asymptomatic disease [8].
- Sagittal T2-weighted MR images provide a myelogram-like image and serve as a good starting point for evaluation [8].
- Sagittal T1-weighted images are evaluated with attention to the root to identify foraminal stenosis [8].
- Axial images provide a view of the central spinal canal and its contents on T1- and T2-weighted sequences [8].
- Far lateral disc protrusions are identified on axial T1-weighted images by the obliteration of the normal interval of fat between the disc and nerve root [8].
- Spinal deformity, including scoliosis and significant spondylolisthesis, can result in suboptimal MRI imaging due to the curvature of the spine moving in and out of the scanner plane on sagittal sequences and difficulty obtaining true axial cuts [8].
- CT is the diagnostic imaging modality of choice for injuries involving the thoracic, lumbar, or sacral regions of the spine [45].
- In patients who do not respond to nonsurgical treatment or deteriorate neurologically, plain radiographs, MRI, and/or myelogram with CT are indicated to delineate the pattern and degree of stenosis [10].
- High-resolution CT scans are obtained to evaluate pedicle morphology, adequacy of the L5 transverse process, sacral morphology, facet arthritis at adjacent levels, and bony foraminal dimensions when more thorough anatomic evaluation is needed [9].
- Standing lateral and posteroanterior scoliosis radiographs are obtained to assess global balance and pelvic parameters, including the skull and proximal femoral heads to determine the hip axis [9].

- The sacral table angle can be used to assess the sacral buttress [9].
- MRI is helpful in identifying disease processes such as tumors and infections and is a good noninvasive study for patients with persistent lower extremity complaints after radiographic screening [8].
- Morphologic changes on MRI have been correlated with preoperative findings such as pain and function, but only to a limited extent [8].
- MRI evidence of disc degeneration has been reported in 25% of patients younger than 40 years and in 60% of patients 60 years and older in the cervical spine, necessitating careful correlation with clinical impression [37].
- The best way to obtain meaningful clinical information from MRI is to have a specific question derived from history and physical examination, posed using parameters of neural compression, instability, and deformity [37].
- Diffusion tensor imaging has been reported to demonstrate spinal cord impairment in patients with early stage cervical spondylosis before it is visible on plain MRI scans [37].

ELECTRODIAGNOSTICS AND OTHER TESTS

- Needle EMG has a lower false positive rate than MRI in asymptomatic older adults being evaluated for lumbar spinal stenosis [1].
- EMG may be helpful to distinguish peripheral neuropathy from lumbar spinal stenosis [10].
- Provocative discography has been recommended by some authors to evaluate adjacent levels, but it has not been found to be reliable [9].
- A pars injection with a small volume of long-acting local anesthetic is helpful as a diagnostic tool when evaluating patients with extensive degenerative changes at multiple levels in addition to isthmic spondylolisthesis [9].

CLINICAL EVALUATION CONTEXT

- A positive lumbar extension test is highly predictive of lumbar spinal stenosis [10].
- A vascular examination must be performed in all patients with suspected lumbar spinal stenosis [10].
- The differential diagnosis for lumbar spinal stenosis should always include peripheral vascular disease, hip arthritis, and peripheral neuropathy [10].

Treatment

NON-OPERATIVE MANAGEMENT

- Symptoms of lumbar spinal stenosis usually respond favorably to nonoperative management, with satisfactory results reported in 69% of patients at 3 years [50].
- Conservative management for lumbar spinal stenosis is successful in most patients despite symptoms of back pain, radiculopathy, or neurogenic claudication [50].

- Patients with lumbar spinal stenosis and radicular type pain respond well to nonoperative treatment [50].
- Patients with lumbar spinal stenosis and scoliosis tend to have worse results with nonoperative treatment [50].
- Conservative measures for lumbar spinal stenosis should include rest not exceeding 2 days [50].
- Conservative measures for lumbar spinal stenosis should include pain management with antiinflammatory medications or acetaminophen [50].
- Conservative measures for lumbar spinal stenosis should include participation in a trunk-stabilization exercise program and good aerobic fitness [50].
- Traction has no proven benefit in the adult lumbar spine for the treatment of lumbar spinal stenosis [50].
- Epidural steroid injections may be useful in alleviating symptoms of radiculopathy or neurogenic claudication to allow better participation in physical therapy [50].
- Epidural steroids can provide significant symptomatic relief for lumbar spinal stenosis, although no scientific study has documented long-term efficacy [50].
- Percutaneous adhesiolysis with injection of lidocaine, hypertonic sodium chloride solution, and nonparticulate betamethasone resulted in significant pain relief in 76% of 25 patients with lumbar spinal stenosis [50].
- If lumbar spinal stenosis is present with coexistent degenerative arthritis in the hips or knees, some permanent limitation in activity may be necessary regardless of treatment [50].
- Nonoperative treatment should be the mainstay of management for foraminal stenosis [4].
- Nonsurgical treatment is usually first-line for thoracolumbar spine issues unless substantial or worsening neurologic involvement, infection, or spine instability is present [3].
- The literature supports an active care approach for lumbar disc disease and stenosis, minimizing centrally acting medications [16].
- The judicious use of epidural steroids is supported for short-term relief in lumbar disc disease and stenosis but does not have an effect on long-term outcomes [16].
- Nonprogressive neurologic deficits associated with lumbar disc disease and stenosis can be treated nonoperatively with expected clinical improvement [16].
- If surgery is necessary for lumbar disc disease and stenosis, it usually can be delayed 6 to 12 weeks to allow adequate opportunity for improvement [16].
- Conservative management is warranted indefinitely in a patient with lumbar spinal stenosis who has good function and manageable symptoms [17].
- Delaying surgical treatment for a trial of nonoperative treatment has not been shown to affect outcome in lumbar spinal stenosis [17].
- One study reported less favorable results in patients with lumbar spinal stenosis who had symptoms for more than 33 months [17].

OPERATIVE INDICATIONS AND SELECTION

- The primary indication for surgery in patients with lumbar spinal stenosis is increasing pain that is resistant to conservative measures [17].
- A patient's inability to tolerate the restricted lifestyle necessitated by the disease and the failure of a good conservative treatment regimen should be the primary determining factors for surgery in lumbar spinal stenosis [17].
- Radiographic findings alone are never an indication for surgery in lumbar spinal stenosis [17].
- Surgical indications for foraminal stenosis include positive study results and a persistent, unacceptably impaired quality of life [4].
- Surgical indications for foraminal stenosis include progressive motor weakness and/or bowel and bladder dysfunction [4].
- The decision to consider operative treatment for degenerative spondylolisthesis is based primarily on the degree of disability and the severity of pain experienced by the patient [56].
- Only 10% to 15% of patients with degenerative spondylolisthesis require surgery [56].
- Indications for surgery in adult spinal deformity include inability to perform activities of daily living due to deformity-associated disability [15].
- Indications for surgery in adult spinal deformity include progressive deformity in the coronal or sagittal plane [15].
- Indications for surgery in adult spinal deformity include neurological compression causing claudication or radiculopathy not responsive to nonsurgical treatment [15].
- Contraindications for surgery in adult spinal deformity include cardiopulmonary conditions or associated comorbidities [15].
- Contraindications for surgery in adult spinal deformity include profound osteoporosis, which may prevent durable and effective fixation [15].
- Contraindications for surgery in adult spinal deformity include physical or mental condition that would impair surgical preparation or recovery [15].
- Indications for decompression alone in adult spinal deformity include patients presenting with radiculopathy, a stable deformity, sometimes with bridging osteophytes or ankylosis and without subluxations, with radicular symptoms from compression of nerve roots from the convexity of the curvature, and with central or lateral recess stenosis [15].
- Indications for decompression with limited fusion in adult spinal deformity include patients who cannot undergo a long fusion or when radiographs show apical progression or symptomatic lumbosacral fractional curve [15].
- Indications for decompression and long fusion with deformity correction in adult spinal deformity include lumbar degenerative scoliosis, large scoliosis curve, and severe subluxation of apical vertebra [15].

SURGICAL TECHNIQUES

- Decompression by laminectomy or a fenestration procedure is the treatment of choice for lumbar spinal stenosis [17].
- Laminectomy may be preferable in older patients with severe, multilevel lumbar spinal stenosis [17].
- Fenestration procedures, consisting of bilateral laminotomies and partial facetectomies that preserve the midline structures, are an alternative in younger patients with intact discs [17].
- Fenestration procedures for lumbar spinal stenosis are especially attractive when performed through a minimally invasive approach because injury to the dynamic spinal stabilizers is minimized [17].
- Fewer complications and less postoperative instability were reported after bilateral laminotomies than after laminectomy in one study [17].
- Central stenosis that fails nonoperative management should be treated with laminectomy and partial medial facetectomy [11].
- Lateral recess stenosis that fails nonoperative management should be treated with decompression of the hypertrophied lamina and ligamentum flavum, and partial medial facetectomy [11].
- Surgical techniques for foraminal stenosis typically involve partial medial facetectomy and resection of the medial process of the superior articular process [4].
- Care should be taken to preserve more than 50% of the facet joint and pars intraarticularis during foraminal stenosis surgery to preserve stability [4].
- Fusion and stabilization should be considered for foraminal stenosis if there is preoperative evidence of instability or iatrogenic intraoperative instability [4].
- Fusion is required for lumbar spinal stenosis if excessive bony resection compromises stability or if isthmic or degenerative spondylolisthesis, scoliosis, or kyphosis is present [17].
- Surgical instability via removal of a facet, a pars defect, spondylolisthesis, scoliosis, and radiographic instability are indications for inclusion of fusion in central stenosis [11].
- The removal of more than one complete facet joint during lumbar spinal stenosis surgery may require instrumented fusion [17].
- A transforaminal lumbar interbody fusion (TLIF) can be used when both ipsilateral lateral decompression and foraminal decompressions are necessary without risking subsequent instability at the level [17].
- Open posterior fusions can be done using a midline approach or the muscle-splitting approach described by Wiltse and Spencer [9].
- The muscle-splitting approach uses the intermuscular plane between the multifidus and longissimus muscles [9].
- The muscle-splitting approach is considered by most to have the advantage of being less traumatic to the musculature and producing less “fusion disease” attributable to muscle fibrosis postoperatively [9].
- The muscle-splitting approach is not recommended if a direct decompression is planned [9].
- Operative treatment for degenerative spondylolisthesis involves decompression of nerve roots and stabilization with posterolateral fusion [11].

- Surgical stabilization with posterolateral fusion, frequently from L4 to S1, should be considered for high-grade (>50%) pediatric isthmic spondylolisthesis slips [11].
- Operative treatment for adult isthmic spondylolisthesis frequently requires associated decompression for neurologic compression, stabilization, and posterolateral fusion [11].
- Decompression alone could result in increased postoperative deformity or iatrogenic instability in adult spinal deformity [15].
- Goals of surgery for adult spinal deformity include decompression of the involved neural elements [15].
- Goals of surgery for adult spinal deformity include reestablishment of coronal and sagittal balance, which is more important than absolute Cobb angle correction [15].
- Goals of surgery for adult spinal deformity include reestablishment of horizontal gaze without compensatory mechanisms [15].
- Correct scoliosis with posterior instrumentation, restore lumbar lordosis with anterior column release and anterior column support, and restore sagittal balance with anterior column support or vertebral osteotomy are components of decompression and long fusion with deformity correction [15].
- The apex of the deformity, severe lateral subluxation, and spondylolisthesis/retrolisthesis should be included in the fusion for adult spinal deformity [15].
- The upper instrumented vertebra (UIV) should be horizontal rather than tilted [15].
- The UIV is often chosen as having neutral rotation and being stable, bisected by the central sacral vertical line [15].
- The proximal construct should not stop within kyphotic regions [15].
- For thoracic and lumbar double-curve degenerative scoliosis, the proximal construct should include the thoracic curve and any portion of the curve [15].
- Surgical risk factors for proximal junctional kyphosis/failure include posterior soft-tissue injury, combined anterior-posterior fusion, fusion to the sacrum or ilium, and thoracoplasty [15].
- Techniques for preventing proximal junctional kyphosis/failure include choosing an appropriate UIV [15].
- Techniques for preventing proximal junctional kyphosis/failure include preserving supra-adjacent facets and facet capsules, intraspinous ligaments, and supraspinous ligaments [15].
- Techniques for preventing proximal junctional kyphosis/failure include reducing stiffness of the instrumentation by using smaller diameter rods, transitional rods, or rods of a less stiff material [15].
- Techniques for preventing proximal junctional kyphosis/failure include using hooks or sublaminar wires rather than pedicle screws in the UIV [15].
- Techniques for preventing proximal junctional kyphosis/failure include augmenting the UIV or UIV+1 with cement [15].
- Techniques for preventing proximal junctional kyphosis/failure include fixating ribs, without fusion, at UIV+1 [15].
- Techniques for preventing proximal junctional kyphosis/failure include choosing age-appropriate spinopelvic alignment goals [15].

- The distal fusion level should stop below a symptomatic fractional curve [15].
- Extending distal fusion to S1, rather than stopping at L5, improves and better maintains correction of coronal and sagittal balance [15].
- Extending distal fusion to S1, rather than stopping at L5, avoids subsequent L5–S1 disk degeneration and fusion extension [15].
- Extending distal fusion to S1, rather than stopping at L5, increases operative time, complication rate, revision rate, and risk of pseudarthrosis [15].
- Indications for extending distal fusion to S1 include existing pathology or symptomatic degenerative changes at L5–S1 [15].
- Indications for extending distal fusion to S1 include L5 being involved in the fractional curve with lumbosacral obliquity [15].
- Indications for extending distal fusion to S1 include incomplete correction of global sagittal imbalance [15].
- L5–S1 fusion outcomes can be improved by adding interbody fusion or pelvic fixation [15].
- Indications for osteotomy in adult spinal deformity include rigid coronal, sagittal, or biplanar deformities [15].
- Cervical spine anterior osteotomy involves removing a wedge between two vertebral bodies including the intervertebral disk, distracting the osteotomy, and inserting bone graft into the distracted osteotomy site [15].
- Cervical spine anterior osteotomy is usually accompanied by posterior augmentation [15].
- Cervical spine anterior osteotomy achieves approximately 17° of correction per level [15].
- Schwab Grade 1 osteotomy involves partial facet joint resection [15].
- Schwab Grade 1 osteotomy achieves 5° to 10° of correction per level [15].
- Schwab Grade 2 osteotomy involves complete facet joint resection [15].
- Posterior column osteotomy (PCO) involves resecting facet joints, ligamentum flavum, and possibly other posterior elements [15].
- Ponte osteotomy is performed at an unfused segment [15].
- Smith-Petersen osteotomy is performed at a fused segment [15].
- Schwab Grade 2 osteotomy achieves approximately 10° of correction per level [15].
- Schwab Grades 3 + 4 osteotomy involves pedicle and partial body resection [15].
- Pedicle subtraction osteotomy (PSO) involves removing posterior elements, pedicles, and a vertebral body wedge [15].
- Grade 4 osteotomy also resects the cranial segment disk [15].
- Schwab Grades 3 + 4 osteotomy achieves 25° to 35° of correction per level [15].
- Schwab Grades 5 + 6 osteotomy involves complete vertebra and discs resection [15].
- Vertebral column resection (VCR) involves removing posterior elements, pedicles, vertebral body, and the cranial and caudal intervertebral disks [15].

- Grade 6 osteotomy involves VCR of multiple vertebral bodies [15].
- High biplanar angular correction is achievable with Schwab Grades 5 + 6 osteotomy [15].

OUTCOMES AND PROGNOSIS

- Operative intervention for lumbar spinal stenosis should be expected to give good relief of claudicatory leg pain with variable response to back pain [17].
- Most series report a 64% to 91% rate of improvement after surgery for lumbar spinal stenosis [17].
- Improvement rates after surgery for lumbar spinal stenosis are 42% in patients with diabetes [17].
- Most patients still have some minor complaints after surgery for lumbar spinal stenosis, usually referable to the preexisting degenerative arthritis of the spine [17].
- Neurologic findings, if present, improve inconsistently after surgery for lumbar spinal stenosis [17].
- Prognostic factors for better results in lumbar spinal stenosis surgery include a disc herniation, stenosis at a single level, weakness of less than 6 weeks' duration, monoradiculopathy, and age younger than 65 years [17].
- Depression, psychiatric disease, cardiovascular disease, higher body mass index, scoliosis, and disorders affecting ambulation have been associated with a poorer prognosis in lumbar spinal sten

Complications

- Decompression alone for lumbar spinal stenosis could result in increased postoperative deformity or iatrogenic instability [15].
- The complication rate for patients undergoing adult spinal deformity surgery is high [13].
- Patients undergoing adult spinal deformity surgery should be counseled on their risk for short- and long-term complications and the need for potential revision surgery [13].
- Pseudarthrosis is the most common level for fusion failure when distal fusion is extended to S1 [15].
- Surgical risk factors for proximal junctional kyphosis or failure include posterior soft-tissue injury, combined anterior-posterior fusion, fusion to the sacrum or ilium, and thoracoplasty [15].

Recovery

- A prospective and consecutive study of surgically treated lumbar spinal stenosis included a five-year follow-up by an independent observer [1].
- The effect of the duration of symptoms on standard outcome measures in the surgical treatment of spinal stenosis has been evaluated [1].
- Complications associated with minimally invasive decompression for lumbar spinal stenosis have been reported [1].

- Clinical outcome of nonoperative treatment for lumbar spinal stenosis, and predictive factors relating to prognosis, were assessed in a study with a 5-year minimum follow-up [1].
- Nonoperative treatment for lumbar spinal stenosis was analyzed for clinical and outcome results and 3-year survivorship [1].
- A 4-year follow-up study evaluated interspinous process decompression of the X-STOP device for lumbar spinal stenosis [1].
- One-year results of the X-Stop interspinous implant for the treatment of lumbar spinal stenosis were reported [1].

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CQ HAND + UPPER LIMB
Dr Kieran Hirpara — Specialist Orthopaedic Surgeon
Suite 2, Level 1, Mater Private Hospital Rockhampton, 31 Ward Street, The Range, QLD 4700
Phone 07 4863 6556 · office@cqupperlimb.com.au · cqupperlimb.com.au