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Management of symptomatic degenerative low-grade lumbar spondylolisthesis

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- Degenerative low-grade lumbar spondylolisthesis is the most common form of spondylolisthesis.
- The majority of patients are asymptomatic and do not require surgical intervention.
- Symptomatic patients present with a combination of lower back pain, radiculopathy and/or neurogenic claudication and may warrant surgery if non-operative measures fail.
- There is widespread controversy regarding the indications for surgery and appropriate treatment strategies for patients with this type of spondylolisthesis.
- This article provides a comprehensive evidence-based review of the available literature to support the management of degenerative low-grade spondylolisthesis.

Keywords: degenerative spondylolisthesis; instability; low-grade; lumbar; management; symptomatic

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Introduction

Spondylolisthesis is the anterior displacement of one vertebra relative to the subjacent vertebra. The earliest cases of spondylolisthesis were allegedly reported by the Belgian obstetrician Herbinaux,[1] in 1782. It was not until Junghanns,[2] in 1931, and Macnab,[3] in 1950, in the German and English literature respectively, that a degenerative type of lumbar spondylolisthesis was recognized, although the term ‘degenerative spondylolisthesis’ was introduced later by Newman and Stone in 1963.[4] Spondylolisthesis has since been classified by Wiltse et al,[5] according to the underlying aetiology, and the severity of the listhesis can be graded using Meyerding’s classification for isthmic spondylolisthesis.[6] This review considers the management of degenerative (Wiltse type III), low-grade (Meyerding grade 1 or 2) lumbar spondylolisthesis only.

Degenerative lumbar spondylolisthesis is an acquired condition associated with age-related degenerative changes but no defect or disruption in the vertebral ring. It classically involves the L4/5 level (Fig. 1), due to the strong iliolumbar ligaments restraining movement of the fifth lumbar vertebra, although less frequently the L5/S1 level may be affected. It is thought to be triggered by a degenerate disc that becomes incompetent. The anteroposterior translational shear forces that arise from longstanding soft-tissue instability accelerate the degenerative changes observed in the facet joints until, over time, the facet joint complex fails and the vertebrae sublux relative to each other.[1] There is limited literature on the natural history of degenerative spondylolisthesis but various local and systemic factors have been proposed as potential contributors to slip progression, including a lower intercristal line (Fig. 2),[7] tilting of the intervertebral disc,[4] tropism and sagittal orientation of the facet joints (Figs 3 and 4),[8] increased pelvic incidence,[9] increased mechanical loading across the disc space and generalized joint laxity.[10] Degenerative spondylolisthesis is an inherently stable condition, with

Fig. 1 Weight-bearing lateral radiograph demonstrating a low-grade degenerative spondylolisthesis at the L4/5 level.

Fig. 2 AP radiograph demonstrating lower intercristal line in relation to the L4/5 disc space.

Fig. 3 Axial T2-weighted magnetic resonance image demonstrating facet tropism and a left-sided facet gap sign.

slip progression occurring in only 30% of patients, and no correlation seen with the severity of the slip, patient gender or clinical symptoms.[10] Furthermore, slip progression does not tend to occur in patients with greater than 80% loss of original disc height or with radiological evidence of spur formation, subcartilaginous sclerosis or ossification of ligaments, suggesting that the degenerative process itself acts as a self-limiting inhibitory control on further slip progression by naturally restabilizing the spine.[10] Degenerative lumbar spondylolisthesis is usually detected as an incidental finding on plain radiographs and the majority of patients with the condition are asymptomatic and do not require surgery.[11] In symptomatic patients, the clinical presentation can vary and includes a combination of

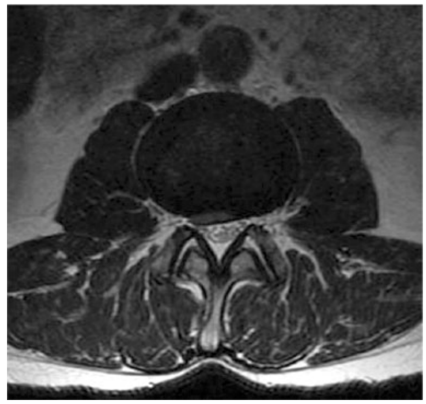

Fig. 4 Axial T2-weighted magnetic resonance image demonstrating sagittally orientated facets joints.

lower back pain, lower limb radiculopathy and neurogenic claudication. Symptoms arise through a combination of the degenerative changes themselves, segmental 'instability' and the stenotic effects and foraminal narrowing caused by facet joint hypertrophy/subluxation, thickening of the ligamentum flavum, stretching of the facet capsule and the listhesis itself. Symptoms may not be constant and can be affected by position and movement.

The challenge for surgeons managing patients with degenerative spondylolisthesis is firstly in deciding which patients would benefit from surgical intervention and secondly in deciding which surgical technique is likely to give the optimum clinical outcome. Currently, there is widespread variation in the treatment strategies used to manage this heterogeneous condition, with factors such as patient age, clinical symptoms, 'dynamic instability' and surgeon/institutional preference all influencing the management strategy.[12] This review considers the evidence to support the management of symptomatic degenerative low-grade lumbar spondylolisthesis and discusses a treatment algorithm used by the authors in their institution.

Assessment of stability

In the broadest terms, we define 'instability' as radiologically demonstrated motion of the spondylolisthesis beyond expected normal values in the normal spine. White and Panjabi considered sagittal plane displacement > 4.5 mm (or 15% of the anteroposterior diameter of the vertebral body) or sagittal plane angulation > 22°, to be potentially unstable (although this related to the acute traumatic setting),[13] while Nachemson considered instability to be > 3 mm translational motion and > 10° angular motion (between L1 and L5) and > 4 mm translational motion and > 20° angular motion (at L5/S1).[14] Degenerative spondylolisthesis is not always 'unstable' (i.e. it is static), as evidenced by intraoperative biomechanical

Fig. 5 Comparison of a load-bearing lateral radiograph with a supine sagittal magnetic resonance image demonstrating a dynamic spondylolisthesis at L4/5.

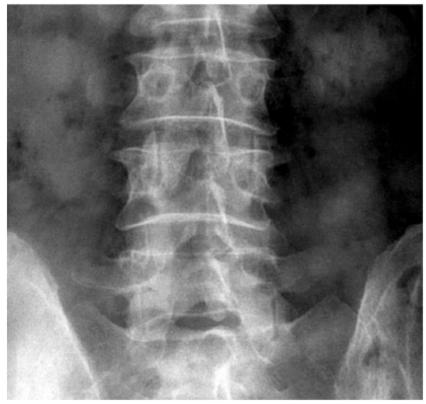

Fig. 6 AP radiograph demonstrating N-type lamina at the L3/4 level.

findings, but identifying those patients with 'dynamic instability' may help in the management of this condition.[15] Currently, however, there is no clear definition of 'motion segment instability' in relation to degenerative spondylolisthesis, and there is poor correlation between radiological findings and clinical presentation. Furthermore, the term 'instability' has negative connotations and is misleading, and so this article will use the term 'mobility/movement' to describe a dynamic spondylolisthesis where possible.

Patient factors

Factors such as patient age, sex, occupation, body mass index and clinical symptoms have been found to correlate poorly with mobility of the listhesis,[7,10,16] although Jacobsen et al found that an increase in body mass index in females was an independent risk factor for the development of degenerative spondylolisthesis,[17] supporting the evidence that increased spinal loading predisposes to the condition.[10]

Dynamic imaging

The comparison of flexion/extension films with direct standing lateral films has traditionally proved a useful means of identifying segmental mobility.[18] Parameters such as vertebral translation, disc angle, range of angular motion, disc height and the loss of lumbar lordosis on flexion have all been used to assess mobility, but there is currently no consensus on what the agreed values should be to define abnormal movement,[18–22] and the value of these radiological parameters in dictating the surgical strategy has been questioned.[23] Furthermore, Hammouri et al concluded that flexion/extension views rarely altered clinical management in the degenerative lumbar spine, compared to a standing lateral radiograph alone, and cautioned against their routine clinical use.[21] Magnetic resonance imaging (MRI), or computed tomography (CT) when MRI is contraindicated, has become a routine method of investigation for assessing the degree of stenosis in spondylolisthesis but it may also prove useful in the assessment of mobility. The supine positioning of patients during MRI can be utilized when considering the above parameters. Comparison with a standing lateral radiograph is often sufficient to identify mobility at the listhetic level, thereby negating the need for flexion/extension radiographs and the consequential additional radiation exposure (Fig. 5).[24] Studies have also shown that MRI scans performed with axial loading can identify lumbar spinal pathology not seen on recumbent scans,[25–29] although a study by McGregor et al disputes this.[30] In the future, there may be a role for dynamic MRI in the assessment of mobility in degenerative spondylolisthesis, but currently the cost and limited availability, in conjunction with the insufficient evidence,[31] prohibit its wider use.

Facet joint morphology and effusion

The importance of facet joint morphology in degenerative spondylolisthesis remains widely debated. Sato et al found an association with 'N-type' laminae (where the interarticular distance is narrower than the lamina waist) and degenerative spondylolisthesis (Fig. 6).[32] While other studies have also shown a similar association with sagittally orientated facet joints and degenerative spondylolisthesis,[33–38] this has not always been borne out in the literature.[18] The importance of facet joint morphology as a direct cause of mobility is less clear, although a study by Blumenthal et al found that patients with a facet angle > 50° in the axial plane were more likely to demonstrate movement following decompression surgery for degenerative grade 1 lumbar spondylolisthesis.[20] A fluid signal in the facet joints on T2-weighted axial images has also been shown to correlate with mobility (Fig. 3).[39] Chaput et al demonstrated that a facet joint effusion > 1.5 mm is predictive of degenerative spondylolisthesis, with the size of the effusion directly correlating with the probability of having the condition.[40] This is further supported by studies by Lattig et al and Oishi et al who found that facet joint effusions of 1.77 mm and 1.3 mm respectively were associated with mobility.[41,42] Furthermore, a difference in the size of the effusion between left and right facet joints has been shown to correspond to rotational translation of the spondylolisthesis,[41] while a reduction in the size of the effusion was strongly suggestive of motion segment restabilization.[42]

Degenerative changes

It has been proposed that the spinal motion segment at the level of the listhesis stabilizes with advancing degenerative changes: a process termed restabilization.[43] Matsunaga et al found that patients with evidence of osteophytic spur formation, subcartilaginous sclerosis and ossification of the spinal ligaments had no slip progression, supporting this theory.[10] Lattig et al also highlighted the importance of hook-shaped osteophytes in providing stability,[41] although research by Anderson et al suggested that osteophytes conferred no additional stability.[19] Loss of disc height has also been implicated in the restabilization process, with 80% loss of original disc height correlating to a reduction in slip progression.[10] Sengupta and Herkowitz recommended an instrumented fusion if the disc height was > 2 mm to prevent slip progression.[44] Conversely, a number of studies have found no association with loss of disc height and stability.[18,37,41] While the objective evidence is divided into the importance of degenerative changes in preventing slip progression, it would seem logical that the presence of advanced degenerative changes would confer some degree of stability to the motion segment and should be considered in the decision-making process regarding management of the spondylolisthesis and the stenotic and/or back pain symptoms.

Classification systems

Although the Wiltse and Myerding classifications are probably the most recognized in relation to spondylolisthesis, they offer little in the way of guidance on how to manage the condition. Kepler et al have developed the clinical and radiographic degenerative spondylolisthesis (CARDS) classification to help subdivide this heterogeneous cohort of patients.[45] This classification system considers disc height, degree of translation, kyphotic alignment and the presence of leg symptoms, and has been validated for its reliability and clinical utility.[46] Although no attempt is made to guide management with this classification, it may prove a useful tool and could facilitate the decision-making process. The French Society of Spine Surgery (SFCR) have developed a classification that specifically considers the parameters that affect spino-pelvic sagittal balance in degenerative spondylolisthesis, and are the first to consider the therapeutic implications this may have.[47] Meanwhile, Simmonds et al have developed the degenerative spondylolisthesis instability classification (DSIC) which considers lower back pain, restabilization signs, disc angle/height and joint effusion on MRI as parameters of 'instability', and propose a treatment strategy stratified according to the grade of stability.[16]

Non-operative management

For the majority of patients with low-grade degenerative spondylolisthesis who present with lower back pain without stenotic symptoms, the spondylolisthesis is static and symptoms do not deteriorate.[10] This group of patients may benefit from a combination of non-operative therapeutic measures. Vibert et al and Kalichman and Hunter reviewed the evidence for therapeutic modalities including physiotherapy, analgesia, ultrasound, electrical stimulation, bracing, flexion/extension strengthening exercises, core stability exercises and spinal manipulation.[48,49] While some patients undoubtedly derive benefit from these treatments, the evidence supporting these studies is often not specific to degenerative spondylolisthesis, is of low quality and is insufficient to develop a non-operative treatment protocol. For patients presenting with features of stenosis or radiculopathy in the presence of degenerative spondylolisthesis, the natural history of the condition is less clear. In a study by Matsunaga et al, 83% of patients were found to clinically deteriorate over 10 years and to have a poor outcome without treatment.[10] Conversely, in a recent study by Wessberg and Frennered, patients rarely showed symptomatic deterioration and those that were able to manage their symptoms continued to do so at a median of 3.3 years.[50] The non-operative arm of the randomized controlled Spine Patient Outcomes Research Trial (SPORT) found that epidural steroid injections, when used in conjunction with other non-operative modalities, gave demonstrable improvement in both lower back and leg pain for two years on patient-reported outcome measures.[51] The role of facet denervation for the management of lower back pain in patients with degenerative spondylolisthesis is less clear. Klessinger et al found that 65% of patients had symptomatic improvement of at least 50% for a minimum of three months, but the quality of the evidence is poor.[52] In their systematic review, Schulte et al found clinical outcomes were inferior with conservative management compared to surgical management, but highlighted the fact that this was based on only three studies.[53] For patients with dynamic spondylolisthesis, identifying the source of pain generation can be challenging. In conjunction with the clinical history and examination, single-photon emission computerized tomography (SPECT) scanning and diagnostic injection therapy may assist in ascertaining this.

Operative management

Symptomatic patients with low-grade degenerative spondylolisthesis who are refractory to non-operative management may benefit from surgical intervention, but currently there is considerable controversy regarding the appropriate surgical indications and optimum surgical technique in the management of the condition.

Direct surgical decompression

The evidence for direct surgical decompression in the management of low-grade degenerative spondylolisthesis is summarized in Table 1. There are few studies comparing direct surgical decompression with non-operative management, but in the published studies, clinical outcomes are significantly better following surgery.[54,55] However, subgroup analysis of data from the SPORT trial in those patients treated surgically has identified a reoperation rate of 22% at eight years, primarily due to slip progression and recurrence of stenosis, with predominant back pain symptoms in the absence of stenotic symptoms identified as the strongest baseline positive predictor for reoperation.[56] Several studies, comparing decompression alone with decompression and fusion (uninstrumented and instrumented), have found comparability in the patient-reported clinical outcomes, complications and reoperation rates, with no good evidence to support the routine use of instrumented fusion.[56–58]

One concern of performing decompression alone in patients with degenerative spondylolisthesis is the potential for iatrogenic postoperative segmental mobility, due to excessive resection of the facet joints.[59] By adopting techniques that preserve the stabilizing anatomical structures, studies using direct decompression alone have not only demonstrated symptomatic improvement in both back and leg pain, but have also found no significant progression of the listhesis.[23,60–62] There has also been much debate regarding the management of additional stenotic levels adjacent to a single-level spondylolisthesis. Subgroup analysis of data from the SPORT trial at four years compared multilevel decompression and single-level fusion (at the level of the spondylolisthesis) with multilevel decompression and multilevel fusion, and found no significant difference in clinical outcome between the two groups.[63] Although decompression alone appears to be effective in the management of degenerative spondylolisthesis in select patients, there is evidence to suggest that decompression in combination with a fusion procedure provides not only greater symptomatic relief, but also significantly lower reoperation rates and a reduced likelihood of slip progression.[64–68] Although patient satisfaction and leg symptoms appear to improve with the addition of a fusion procedure, the benefits of fusion in improving back symptoms are less certain.[69,70]

Interpreting this evidence is difficult due to the heterogeneity of the patient groups being compared, limited subgroup analysis and poor quality of evidence. However, it seems intuitive that those patients with stenotic symptoms who do well with decompression alone are likely to be those who have a static slip, while those with a dynamic spondylolisthesis are the most likely to benefit from an additional fusion procedure to prevent symptom recurrence from slip progression. The role of fusion for the relief of back pain in patients with significant degenerative changes is less clear.

Decompression with dynamic stabilization

Dynamic stabilization devices have been used in the management of degenerative spondylolisthesis with mixed results.[71–75] In one of the earliest prospective studies, comparing decompression alone with decompression and Graf system stabilization, Konno and Kikuchi demonstrated improvement in lower back pain at three years using the Graf system but found no difference regarding the recurrence of leg symptoms between the two groups.[73] Schaeren et al and Hoppe et al, in separate case series with four and seven-year follow-up results respectively, found decompression combined with the Dynesys stabilization device gave improvement in both back and leg pain with little progression of the listhesis.[74,75] In a multicentre randomized controlled trial (RCT), Anderson et al compared indirect decompression, using the X Stop interspinous process device, with non-operative management in patients with neurogenic claudication, and found significant clinical improvement at two-year follow-up with the X Stop device.[71] However, the X Stop device was only found to be clinically successful in 67% of the patients it was used on, with 12% of patients requiring reoperation for symptomatic recurrence.[71] Furthermore, an association between degenerative spondylolisthesis and spinous process fracture following interspinous process spacer surgery has also been reported.[72] Reoperation rates following dynamic stabilization range from 0% to 21%, with adjacent segment degeneration being the most common reason for revision surgery.[73–75] While the evidence appears to suggest that dynamic stabilization devices are effective in preventing slip progression, no subgroup analysis has been performed in these studies, and it is likely that these slips were static in the first place. As for the motion-preserving effect of dynamic stabilization, in one study 47% of patients had radiographic evidence of adjacent segment degeneration at four-year follow-up, suggesting a degree of unpredictability in the ability of these devices to preserve motion.[74]

Table 1. Summary of evidence for direct surgical decompression

Author	No. of patients	Study type	Comparison groups	Mean follow-up	Main study findings
Matsudaira et al[54]	53	Retrospective case series	• Decompression alone • Decompression + instrumented PLF • Non-operative	2 yrs	• Symptomatic improvement in operative groups only • No difference in clinical improvement between operative groups
Weinstein et al[55]	607	Multicentre prospective randomized and observational cohort study	• Decompression +/- fusion • Non-operative	4 yrs	• Clinical outcome significantly better in operative groups (ODI score, SF-36 score, leg and back pain scores)
Gerling et al[56]	406	Retrospective subgroup analysis of SPORT trial	• Decompression alone • Decompression + fusion (instrumented and uninstrumented)	8 yrs	• Overall reoperation rate of 22% in those treated surgically • No difference in reoperation rates between instrumented and uninstrumented groups
Dijkerman et al[57]	3119	Systematic review (11 studies – 2 RCTs)	• Decompression alone • Decompression + instrumented PLF	NA	• No difference in patient reported clinical outcomes (ODI score, leg and back pain scores) • No difference in complications or reoperation rates
Forsth et al[58]	247	RCT	• Decompression alone • Decompression + fusion	5 yrs and 6.5 yrs	• No difference in clinical outcomes (ODI score, EQ-5D, VAS back and leg pain scores) • No difference in reoperation rates
Lombardi et al[60]	47	Single-centre case series	• Wide posterior decompression • Facet-sparing decompression	2–7 yrs	• Patient-reported symptoms significantly improve following limited decompression (does not specify if leg and/or back symptoms)
Musluman et al[61]	84	Prospective cohort study	• Bilateral decompression via unilateral approach with preservation of midline structures (no comparison group)	2 yrs	• Significant clinical improvement following surgery (ODI score and NCOS) • Significant improvement in VAS back pain score if single-level surgery but worse if multilevel surgery
Ahmad et al[62]	83	Prospective cohort study	• Decompression using spinous process osteotomy (no comparison group)	3 yrs	• Significant clinical improvement following surgery (ODI, EQ-5D, VAS back and leg pain score) • 11% requiring conversion to fusion for slip progression
Inui et al[23]	140	Single-centre retrospective case series	• Decompression alone • Decompression and instrumented PLIF	3 yrs and 6 yrs	• Clinical improvement comparable between groups (JOA score – considers both back and leg pain) • Radiological evidence of segmental mobility pre and postoperatively did not correlate with clinical outcome
Herkowitz and Kurz[64]	50	Prospective cohort study	• Decompression alone • Decompression + uninstrumented PLF	3 yrs	• Significant improvement in back and leg pain and significant reduction in slip progression following fusion compared to decompression alone
Ghogawala et al[65]	66	RCT	• Decompression alone • Decompression + instrumented PLF	4 yrs	• For stable slips, fusion results in significantly greater clinical improvement (ODI score, SF-36) and lower reoperation rates (36% versus 14%) compared to decompression alone
Sato et al[66]	163	Retrospective case series	• Decompression alone • Decompression and fusion	6 yrs	• Fusion results in significantly lower reoperation rates
Mardjetko et al[67]	889	Meta-analysis (25 studies – 3 RCTs)	• Decompression alone • Decompression + fusion (instrumented and uninstrumented)	NA	• Fusion results in greater patient satisfaction (90% versus 69%) and reduced slip progression (17% versus 31%) compared to decompression alone
Martin et al[68]	578	Systematic review (13 studies – 4 RCTs)	• Decompression alone • Decompression + fusion (instrumented & uninstrumented)	NA	• Fusion results in improved clinical outcomes compared to decompression alone (although clinical benefit not as pronounced if patients' predominant complaint was of stenotic symptoms • Instrumented fusion confers no additional benefit to uninstrumented fusion • Non-significant trend towards lower reoperation rates with uninstrumented fusion compared to other groups
Chen et al[69]	77994	Meta-analysis (18 studies – 4 RCTs)	• Decompression alone • Decompression and fusion	NA	• Fusion results in significant improvement in VAS back and leg pain scores (although this was not deemed to be a clinically important difference) • ODI score, SF-36 score, EQ-5D, patient satisfaction, reoperation rate and complication rate are comparable between groups
Liang et al[70]	3858	Systematic review and meta-analysis (17 studies – 4 RCTs)	• Decompression alone • Decompression and fusion	NA	• Fusion results in significantly higher rates of patient satisfaction and lower leg pain scores compared to decompression alone • ODI score, back pain score, complication rate and reoperation rate are comparable between groups

Note. PLF, posterolateral fusion; PLIF, posterior lumbar interbody fusion; SPORT, Spine Patient Outcomes Research Trial; RCT, randomized controlled trial; ODI, Oswestry Disability Index; EQ-5D, EuroQol Five Dimension; VAS, Visual Analogue Scale; NCOS, Neurogenic Claudication Outcome Score; JOA, Japanese Orthopaedic Association; SF-36, Short Form 36; NA, not applicable.

Decompression with posterolateral lumbar fusion (PLF)

The supplementation of decompression with a PLF can be achieved with or without instrumentation. Herkowitz and Kurz found uninstrumented PLF was superior to decompression alone with regards to clinical outcome, and although they reported a non-union rate of 36%, this did not impact on the clinical outcome.[64] Surgeons have migrated towards instrumented PLF in an attempt to improve stability and subsequent outcome. In an RCT comparing decompressive laminectomy and PLF with and without instrumentation for degenerative spondylolisthesis, Fischgrund et al also found that clinical outcomes (in relation to back and leg pain) were comparable between the two fusion groups despite a significantly higher non-union rate with uninstrumented fusion (55% versus 18%) at two-year follow-up;[76] a finding that is supported by the results of a meta-analysis by Mardjetko et al and a systematic review by Martin et al.[67,68] However, some of the reported studies have been criticized for their relatively short follow-up period of between two and three years, and there is evidence to suggest that the clinical outcome with uninstrumented fusion deteriorates over time.[77] In their prospective study of patients treated with decompression and instrumented PLF only, Booth et al found that patient satisfaction remained high at a mean follow-up of 6.5 years.[78] Conversely, in their prospective cohort study of patients treated with decompression and uninstrumented PLF, Kornblum et al found a significant deterioration in clinical outcome in patients who had developed a non-union at mean 7.5 year follow-up.[77] The evidence appears to demonstrate superiority of instrumented over uninstrumented fusion with respect to sustained long-term improvement in clinical and functional outcomes, and this needs to be balanced against the non-significant trend towards higher reoperation rates with instrumented fusion (relative risk 1.86) when deciding which technique to use.[68]

Interbody fusion

There has been much debate about the need for interbody fusion in the management of degenerative spondylolisthesis, fuelled in part by the paucity of clinical studies, but in recent years the evidence has started to mount. In a small retrospective study by Rousseau et al comparing PLF with posterolateral interbody fusion (PLIF), functional outcomes were significantly better in the PLIF group at mean two-year follow-up.[79] Ha et al also demonstrated significant clinical improvement (in Oswestry Disability Index [ODI] and Visual Analogue Scale [VAS] scores) with PLIF over PLF at a minimum two-year follow-up, but only in those patients with preoperative radiographic evidence of segmental mobility (> 4 mm translation or > 10° angulation).[80] In that study, disc height was significantly increased in both the dynamic and static groups following PLIF, suggesting that the additional stability conferred by the interbody device, and the resultant indirect decompression of the neural foramen, is not required if the spondylolisthesis is static. Although both these studies have demonstrated superiority of interbody fusion over PLF, the quality of these studies has been questioned. Liu et al conducted a systematic review and meta-analysis, identifying four RCTs and five comparative observational studies comparing PLF with PLIF, and found that PLIF resulted in better patient satisfaction and fusion rates with no increase in complication rates.[81] A systematic review and meta-analysis by Levin et al comparing PLF with transforaminal lumbar interbody fusion (TLIF) from five observational studies, also favoured TLIF for achieving improvement in ODI and back pain and better fusion rates.[82] However, these findings have been challenged by a recent RCT with two-year follow-up, which has found no additional benefit of TLIF over PLF with regard to clinical or radiographic alignment parameters despite a better fusion rate,[83] with similar findings reported in a retrospective cohort study by Fujimori et al.[84] Furthermore, a systematic review and meta-analysis by McAnany et al, comparing the effectiveness of PLF and interbody fusion from five observational studies, has found no difference in clinical outcome (ODI, Short Form-36 [SF-36], VAS score), fusion rates or complication rates.[85]

While interbody devices are not required in all cases of low-grade degenerative spondylolisthesis, Derman and Albert believe there is now enough evidence to support their use if the spondylolisthesis is dynamic.[86] The choice of interbody technique comes down to surgeon preference, but a systematic review and meta-analysis by de Kunder et al, comparing TLIF with PLIF from one RCT and eight case series, has found TLIF has significantly lower complication rates (8.7% versus 17.0%) with statistically significant (but not clinically significant) improvement in clinical outcome.[87]

Minimally invasive surgery

Minimally invasive surgical (MIS) decompression via a unilateral laminotomy and 'over the top' approach, in patients having an isolated decompression for the management of their degenerative spondylolisthesis, is thought to be less destabilizing than a traditional decompressive laminectomy. In a systematic review and meta-analysis of the two techniques, Scholler et al found that patient satisfaction was greater following MIS decompression with a reduced likelihood of slip progression, reoperation and secondary fusion.[88] Kelleher et al also found MIS decompression to be clinically effective at improving function in their observational cohort study, but in patients with a concomitant scoliosis, the significantly higher revision rate needed to be factored into the decision-making process when deciding what surgical strategy to adopt.[89] Minimally invasive surgical techniques have also been popularized to reduce soft-tissue trauma and subsequent postoperative pain, with reduced damage to the multifidus, a muscle which crosses multiple motion segments, potentially protecting against adjacent segment degeneration. Most studies comparing open with MIS-TLIF/PLIF have demonstrated reduced length of hospital stay, improved cost effectiveness and quicker return to work with the MIS technique,[90–92] but have found no difference in clinical or radiological outcomes or complication rates at mean two-year follow-up,[93,94] although a significant increase in neurological deficit following MIS-TLIF, attributed to the steep learning curve, was found in one study[95] and short-term clinical improvement following MIS-TLIF was noted in another.[94] These findings are further supported in a systematic review by Goldstein et al, but the authors acknowledge that the quality of the evidence in the literature is too poor to draw any firm conclusions.[96] Stand-alone lateral lumbar interbody fusion (LLIF) and anterior lumbar interbody fusion (ALIF) have also been found to give good clinical outcomes while maintaining slip reduction and restoration of both disc height and segmental lordosis,[97–99] and the clinical outcomes following ALIF have been maintained at long-term follow-up.[100] Rodgers et al reported no complications or non-unions using LLIF at mean one-year follow-up,[97] as did Xu et al using LLIF and ALIF.[98] However, in their prospective observational study using LLIF, with minimum two-year follow-up, Marchi et al reported evidence of cage subsidence in 17% of patients, with 13% of patients requiring revision surgery.[99] In a prospective randomized trial comparing MIS-TLIF with LLIF, Sembrano et al demonstrated comparability between the procedures in relation to the improvement in back and leg pain at mean two-year follow-up and found both techniques to be acceptable in the management of degenerative spondylolisthesis.[101] While there appears to be some merit in adopting decompressive MIS techniques to prevent postoperative segmental mobility, due to the quality of the evidence the benefit of MIS techniques for interbody fusion is perhaps less clear. Furthermore, Satomi et al caution against the use of a stand-alone ALIF in the presence of advanced degenerative changes, advocating posterior decompressive surgery instead.[102]

Biomechanical considerations

Recently, greater consideration has been directed towards improving spinal biomechanics, in particular, reduction of the listhesis and restoration of segmental lordosis and global sagittal balance. Bai et al conducted a systematic review and meta-analysis to establish whether reduction of the listhesis in patients with low-grade degenerative spondylolisthesis conferred any benefit over fusion in situ.[103] They identified four RCTs and three cohort studies and found no significant difference in clinical outcome, fusion rate, complication rate and lumbar lordosis. In a retrospective case series of patients treated with decompression and fusion for their degenerative spondylolisthesis, Radovanovic et al found that those with a positive sagittal balance (sagittal vertical axis > 50 mm) postoperatively had worse patient reported outcomes (ODI, SF-36 and back pain score) at mean three-year follow-up.[104] Furthermore, it appears that global sagittal balance can be effectively restored with single-level L4/5 interbody fusion using either the ALIF or PLIF technique, but whether this results in improved clinical outcome has yet to be fully established.[105,106]

Summary

The management of patients with symptomatic degenerative low-grade lumbar spondylolisthesis who have failed non-operative management is controversial, not least because of the lack of robust clinical studies. The heterogeneity of the patient population, the absence of a precise definition of 'segmental mobility' and the difficulty in identifying the definitive source of pain generation are fundamental factors that contribute to the problem. Decompression to relieve stenotic symptoms has generally been considered the mainstay of surgical treatment,[44] but between 1999 and 2011, the United States witnessed a shift in surgical strategy, with a significant decrease in both stand-alone decompression and uninstrumented fusion and a corresponding increase in interbody fusion.[107] Yet the drivers for this change in national trend remain unclear. Following their systematic review, a guideline summary has been developed by the North American Spine Society in an attempt to facilitate decision-making, but this too recognizes the problem of insufficient or low-quality evidence to support a particular strategy.[31] Despite a number of review articles that consider the controversies of surgical management,[44,108–110] we are still unable to establish a definitive evidence-based answer to address the following questions:

- What parameters define abnormal mobility in patients with degenerative spondylolisthesis?
- Is an interbody device required when performing an instrumented fusion?
- Should MIS techniques be employed to improve clinical outcome?
- How important is slip reduction and restoration of sagittal balance in degenerative spondylolisthesis?

Based on the available evidence and our own experience, it is our belief that the clinical presentation, radiographic evidence of translational and angular motion and

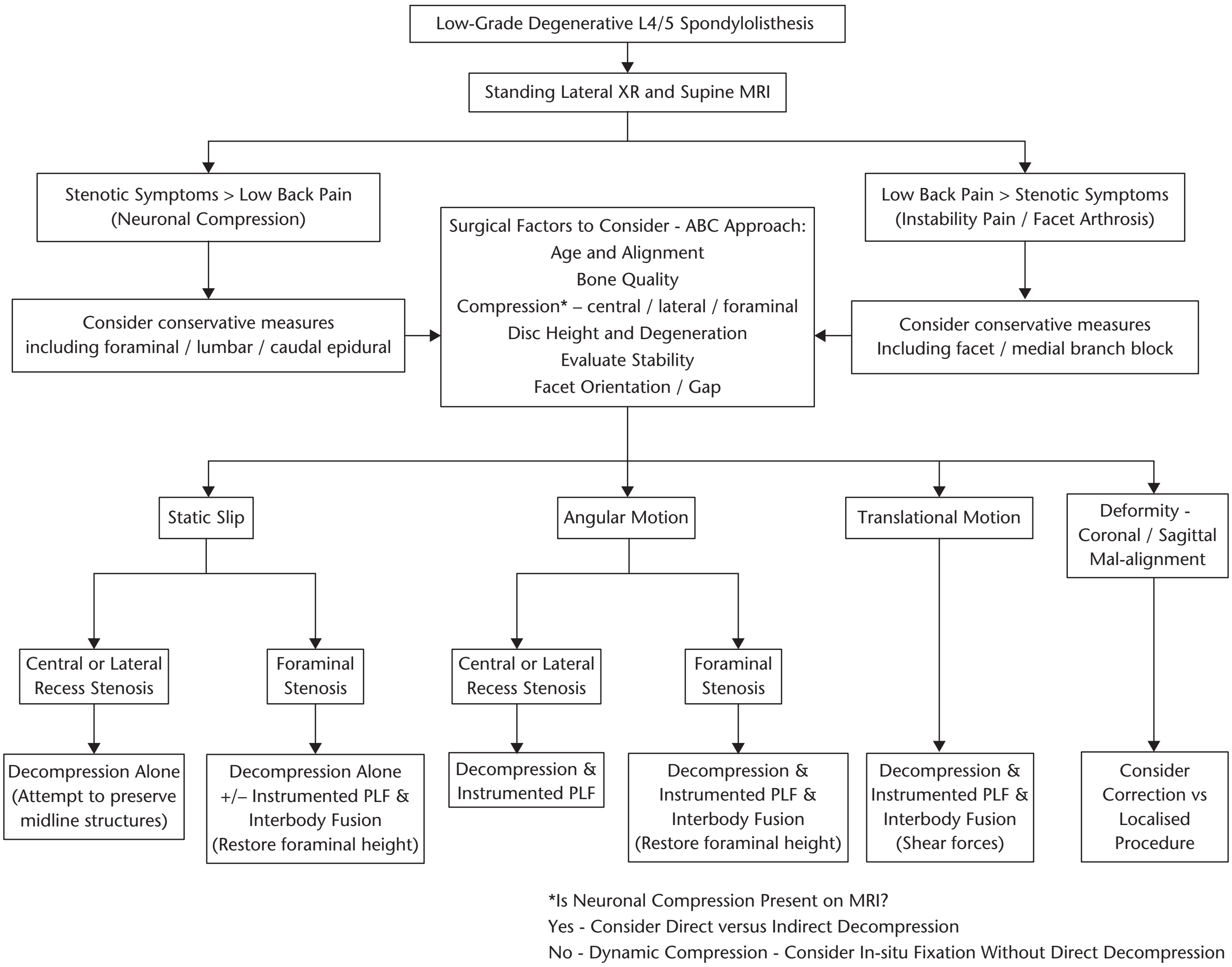

Fig. 7 Treatment algorithm for the management of symptomatic degenerative low-grade spondylolisthesis.

patient comorbidities are the key factors to consider in the decision-making process regarding surgery. Furthermore, a clear understanding of the surgical goal is required if the optimum clinical outcome is to be achieved. Here we present our treatment algorithm for symptomatic patients presenting with lower back pain and/or radicular pain and/or neurogenic claudication (Fig. 7).

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ICMJE CONFLICT OF INTEREST STATEMENT

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