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Treatment of Lumbar Spinal Stenosis with Neurogenic Claudication: An Algorithmic Approach for the Pain Physician

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Abstract

Lumbar spinal stenosis is a common degenerative condition of the spine with high prevalence in the aging population. It is considered a clinical syndrome of buttock or lower extremity pain, with or without back pain, caused by a reduction of the space available for the neurovascular components. Classic features of lumbar spinal stenosis on physical exam include forward flexion of the spine on ambulation with limited range of motion. It requires diagnostic imaging for further pathology characterization. Traditionally, the treatment for lumbar spinal stenosis-related pain had been limited to open lumbar decompression after failure of conservative management. For the past decade, there has been a preference for minimally invasive techniques to treat patients that are not surgical candidates and to avoid possible complications from open lumbar decompression. Several minimally invasive options have become available for patients with mild to moderate lumbar spinal stenosis including: percutaneous image guided lumbar decompression, interspinous spacers, interspinous fixation devices and neuromodulation. The severity of the stenosis, the presence of multilevel disease, instability and/or neurologic symptoms as well as and selecting the correct index level, are some of the factors to be considered when choosing a technique. A literature search was performed through September 2023, reporting on effectiveness of nonsurgical and surgical treatments of lumbar spinal stenosis, using PubMed and EMBASE. The purpose of this article is to review the available treatment options for this patient population, and to create a treatment algorithm including indications and specific patient selection criteria for each technique.

Keywords: Lumbar Spinal Stenosis, Neurogenic Claudication, Physical Therapy, Lumbar Epidural Steroid Injection, Indirect Lumbar Decompression, Interspinous Process Devices, Interspinous Spacers, Interspinous Fixation Devices, Neuromodulation, Spinal Cord Stimulator, Lumbar Decompression.

1. Introduction

Lumbar spinal stenosis [LSS] is a common degenerative condition of the spine associated with significant functional limitations. Its prevalence is approximately 11% of the general population and close to 50% in those over the age of 60, although not all cases are symptomatic [1-4]. LSS can be classified as congenital or acquired due to degenerative changes or surgery. Common causes of acquired LSS include disc herniation, degenerative disc disease [DDD], hypertrophic facet changes, osteophytes and ligamentum flavum hypertrophy [LFH]. With progression of the disease, the patient could develop bladder/bowel incontinence, numbness and weakness in the lower extremities as well as gait instability. LSS is considered a clinical syndrome of buttock or lower extremity pain, which may occur with or without back pain. It is typically caused by a reduction of the space available for the neurovascular components centrally, at the lateral recess, and/or at the intervertebral foramina leading to the symptoms associated with the condition [5]. The intermittent compression of neurovascular structures leads to symptoms associated with neurogenic claudication [NC]. Classic features of LSS on physical exam include forward flexion of the spine on standing and ambulation, limited range of motion, bilateral lower extremity weakness, decreased deep tendon reflexes and positive straight leg raise test. LSS is diagnosed by CT scan or MRI, with the latter being the gold standard.

Diagnostic technology and aging of the population have led to an increase in the diagnosis of LSS. LSS also accounts for the fastest growth of lumbar surgery above 65 years of age in the United States. These surgical procedures have risks and lead to significant costs, complications, re-hospitalizations and, often times, poor outcomes [6]. In 2022, a group of experts from the American Society of Pain and Neuroscience [ASPN] published best practices for minimally invasive lumbar spinal stenosis treatment [MIST 2.0] in order to provide guidance in the use of new emerging techniques

[2]. Nonetheless, there is still a surprising lack of clarity and consensus regarding the most effective management strategies due to the constant evolution of the techniques.

Several conservative treatment options are currently available for the treatment of LSS with NC including pharmacologic treatment with nonsteroidal anti-inflammatory drugs [NSAIDs], opioid analgesics, and neuropathic agents, as well as physical therapy [PT], exercise, spinal manipulation, and lumbar epidural steroid injections [LESI]. These treatment options have limited efficacy due to the mechanical and compressive nature of LSS. Traditional direct open lumbar decompression [DOLD] has been the standard of care for patients with refractory pain secondary to LSS after failed conservative treatment or severe symptoms. Direct open surgery is defined as a procedure requiring the surgeon to create a larger incision and operate utilizing traditional instrumentation as compared to a percutaneous or minimally invasive approach.

In an attempt to fill the treatment gap in this patient population, several minimally invasive options have become available in the past decade. Procedures such as percutaneous image guided lumbar decompression [PILD], interspinous spacers [ISS] and interspinous fixation devices [ISFD] have become more popular as treatment options for patients with moderate LSS and no spinal instability. In addition, neuromodulation has been utilized as a possible treatment option; however, scientific data is somewhat limited for this specific condition. The purpose of this article is to review available treatment options for patients with LSS with NC, and to create a treatment algorithm including indications and specific patient selection criteria for each procedure [7].

2. Methods

A literature search was performed through September 2023, reporting on effectiveness of nonsurgical and surgical treatment of LSS with NC, using PubMed and EMBASE. These include pharmacologic treatment, PT, LESI, direct and indirect lumbar decompression techniques. The search was restricted to articles published in English language. For the search strategy, titled, key words and abstract were searched for the following words: “lumbar spinal stenosis”, “neurogenic claudication”, “physical therapy”, “lumbar epidural steroid injection”, “indirect lumbar decompression”, “percutaneous lumbar decompression”, “neuromodulation”, “spinal cord stimulator”, “lumbar decompression”. Manual searches were also performed to include studies reporting the use of interspinous process devices. The following terms were searched for: “interspinous spacer”, “interspinous device”, “interspinous fixation device” and specific device trademark names such as MILD®, Superion®, X-STOP, Coflex®, and Minuteman®.

3. Discussion

3.1. Non-Surgical Treatment Options

Patients with symptoms related to mild to moderate LSS are treated initially with conservative treatment options. These include observation, lifestyle modification, pharmacologic management including analgesics, NSAIDs and neuropathic agents; PT and LESIs [8-10]. However, there is very limited evidence to guide the choice of conservative options.

Physical therapy: There is insufficient evidence to make a recommendation for or against the use of PT as a single therapeutic option for LSS. Furthermore, there is no consensus regarding what type of PT will be more beneficial for this patient population. Existing scientific literature comparing PT with DOLD seems contradictory. Nonetheless, there is a consensus on the use of a limited period of PT as an appropriate initial step [11, 12].

The landmark multicenter, randomized controlled study named Spine Patient Outcomes Research Trial (SPORT), which included 2,500 patients from 13 sites across the United States, examined the utilization of PT by patients with LSS, and the relationship to long-term prognosis. A study conducted by Weinstein et al. using SPORT data, compared the 4-year outcomes of surgery to nonsurgical care for LSS. A total of 289 and 365 patients from 13 centers in the United States enrolled in a randomized and observational cohorts, respectively. Patients received standard DOLD versus non-operative care. The conservative treatment arm provided recommendations for active PT, education or counseling with home exercise instruction, and/or NSAIDs. At 4-years, the previously reported clinically significant improvement in pain and functional outcomes were maintained in the surgical decompression cohort. Mean changes between groups were 12.6 for bodily pain (95% confidence interval [CI], [8.5-16.7]; physical function 8.6 [95% CI, 4.6-12.6]; and Oswestry Disability Index [ODI] -9.4 [95% CI, -12.6 to -6.2] [13, 14]. In the same cohort, 37% (90/244) of patients completed PT in the first 6 weeks. The use of PT was associated with a reduced likelihood of patients crossing over to surgery after 1 year [21% vs. 33%, P = 0.045]. There were also greater reductions on the Short Form-36 [SF-36] physical functioning scale after 6 months [mean difference = 6.0, 95% CI: 0.2-11.7] and 1 year [mean difference = 6.5, 95% CI: 0.6-12.4]. There were no differences in bodily pain or ODI across time [15].

In a more recent publication, Oster et al. summarized the 10-year clinical outcomes of SPORT study and its follow-up studies for LSS. There was significantly greater improvement in pain and physical function for patients who underwent surgical intervention from 6 weeks through 4 years. However, the difference within the surgical and nonsurgical groups diminished between 4- and 8-year follow-up. Obese patients were found to have higher rates of infection and reoperation; and less improvement from baseline function. Important risk factors for reoperation included: pretreatment symptoms for longer than 12 months, advanced age, antidepressant use, multilevel stenosis, back pain predominant without NC, leg pain predominance, and no PT prior to enrollment [16].

A multicenter, randomized, control trial conducted by Delitto et al., compared DOLD versus PT in patients with LSS. The primary outcome of the study was physical function score on SF-36 health survey at 2 years. A total of 169 patients were randomly assigned to DOLD (n = 87) and PT (n = 82). Eighty-

five [74/87] and 89% [73/82] of patients in the DOLD and PT cohorts, completed the 24-month follow-up, respectively. There was no difference between DOLD and PT groups with a mean improvement in physical function of 22.4 [95% CI, 16.9-27.9] and 19.2, [CI, 13.6-24.8], respectively [17].

A three-arm randomized trial conducted by Schneider et al., explored the clinical effectiveness of 3 nonsurgical interventions for patients with LSS and NC. A total of 259 patients were randomly assigned to medical care (34%, medication management/LESIs), group exercise [32.4%] and manual therapy/individualized exercise [33.6%, spinal mobilization/straining training] and followed-up at 6 weeks, 2 and 6 months post-treatment. At 2 months, manual therapy/individualized exercise showed greater improvement of symptoms and physical function when compared to medical care [-2.0; 95% CI, -3.6 to -0.4] or group exercise [-2.4; 95% CI, -4.1 to -0.8]. In addition, it had a greater proportion of responders in symptoms and physical function [20%] and walking capacity [65.3%] compared to medical care [7.6% and 48.7%, respectively] or group exercise [3.0% and 46.2%, respectively]. There were no group differences in 6 months [18].

Further research is needed to examine the effectiveness of PT relative to other nonsurgical management strategies for patients with LSS.

Lumbar Epidural Steroid Injections (LESIs): Epidural injections are commonly performed nonsurgical interventions in managing symptoms related to LSS; however, there has been paucity of literature in reference to efficacy of LESIs in this patient population.

A prospective study conducted by Do et al., evaluated the outcome of LESI in patients with chronic pain secondary to moderate or severe LSS and compared the effects of LESI according to the severity of LSS. A total of 60 patients with LSS and lower extremity involvement were included and received LESI. Thirty and 28 patients had moderate [group A] and severe LSS [group B], respectively. The patients were followed up at 1, 2 and 3 months after treatment. The intragroup analysis showed a significant decrease in pain intensity at 1-, 2-, and 3-month post-treatment follow-up. At 3 months, only 30% and 17.9% of patients reported more that 50% pain relief, in groups A and B, respectively. Pain intensity was significantly lower in patients with moderate LSS when compared to patients with severe LSS at each follow-up visit [19].

The effectiveness of LESI and back education with or without PT in patients with LSS was examined in a randomized clinical trial conducted by Hammerich et al. Outcome measures including disability, pain, quality of life and global rating of change were collected at 10 weeks, 6 months and 1 year. Thirty-one of 54 patient received LESIs and back education only and 23 received additional 8-10 sessions of multimodal PT. There was no significant difference between groups in the ODI at any point. All subjects had significant improvement at 10 weeks, [P < 0.001; 95% CI, -18.01 to -5.51]; and significant differences in the RAND 36-SF Health Survey 1.0 were found for the group receiving LESIs and PT in higher emotional role function [P = 0.03; 95% CI, -49.05 to -8.01], emotional well-being [P = 0.02; 95% CI, -19.52 to -2.99]; and general health perception (P = 0.05; 95% CI, -17.20 to -.78). At 1 year, the subjects had a difference above minimal clinical importance [P = 0.01; 95% CI, -14.57 to -2.03]. The study concluded that the addition of PT to LESIs was not superior to LESIs alone, in terms of functional improvement in individuals with LSS. However, there was a significant benefit related to quality-of-life factors of emotional function, emotional well-being, and perception of general health [20].

Manchikanti et al. conducted a randomized, double-blind, active control trial to determine if low back and lower extremity pain secondary to LSS could be managed with epidural injections with local anesthetic with and without steroids. A total of 120 patients were randomized to a group receiving local anesthetic [Group 1] and a second one receiving local anesthetic with betamethasone [Group 2]. Sixty patients were assessed and included in the analysis. Significant pain relief [≥ 50%] was seen in both groups at 12 months, 70% and 63% for Group 1 and Group 2, respectively. The ODI improvement [≥ 50%] in Group 1 was 70% and 60% for Group 2. Among patient with significant pain relief, the duration was 40.8 ± 11.7 weeks for Group 1 and 37.1 ± 12.6 weeks for Group 2; combined pain relief and functional status improvement were seen in 80% and 72% of patients in Group 1 and Group 2, respectively [21].

At the 2-year follow up, Manchikanti et al. reported significant relief and functional status improvement in 72% and 73% of patients in Groups 1 and 2 when considering all participants; and 84% and 85% in the successful group. Overall significant improvement was achieved for 65.7 ± 37.3 weeks in Group 1 and 68.9 ± 37.7 weeks in Group 2, in all participants; and 77 ± 27.8 weeks and 77.9 ± 30.2 weeks when separated into successful categories. This study did have some limitations which included the lack of a placebo control group and performance of multiple procedures per patient [22].

Different approaches for LESIs are commonly utilized in the treatment algorithm for LSS with NC and have been addressed in the literature. A randomized, double-blind, active-controlled trial conducted by Manchikanti et al., assessed the effectiveness of caudal epidural steroid injections with or without steroids in providing long-lasting pain relief for the management of chronic low back pain secondary to LSS. A total of 100 patients were randomly assigned to receiving caudal epidural injections of local anesthetic [Group 1] versus receiving caudal epidural steroid injections with 0.5% lidocaine mixed with betamethasone [Group 2]. Multiple outcome measures were assessed at 3, 6, 12, 18 and 24 months follow-up visits. At 2-years, significant pain relief and functional status improvement were seen in 51% and 57% in Group 1 and Group 2, in the successful group, respectively. However, overall, significant pain relief and functional status improvement [≥ 50%] was demonstrated in 38% in Group 1 and 44% in Group 2. In the successful group, the duration of relief was approximately 60 and 54 weeks in

Group 1 and Group 2, respectively. The authors concluded that caudal epidural injections of local anesthetic with or without steroids provide relief in a modest proportion of patients and may be considered as an effective treatment for a select group of patients with low back and lower extremity pain secondary to LSS [23].

A subgroup analysis of the SPORT trial studied the association between treatment with LESIs within 3 months of enrollment with improvement in clinical outcomes and lower rate of crossover to surgery. Sixty-nine patients received LESIs and 207 did not receive them. At approximately 4 years, there was significantly less improvement in SF-36 Health Survey Physical Function among surgically treated LESI patients [LESI 14.8 vs. no-ESI 22.5, P = 0.025]. Among nonsurgical patients, there was significantly less improvement in SF-36 bodily pain [LESI 7.3 vs. no-ESI 16.7, P = 0.007] and SF-36 physical function [LESI 5.5 vs. no-LESI 15.2, P = 0.009]. In the surgical treatment group, there was a significant increase in crossover to nonsurgical treatment among patients who received an LESI [LESI 33% vs. no-LESI 11%, P = 0.012]. There was also a significant increase in crossover to surgical treatment in LESI patients [LESI 58% vs. no-LESI 32%, P = 0.003]; in the non-operative treatment group. Overall, there was no improvement in outcomes with LESI whether patients were treated surgically or non-surgically [24].

3.2. Interventional Treatment Options

Percutaneous Image-Guided Lumbar Decompression: LSS is a common degenerative spine condition with significant prevalence over the age of 60. A classic anatomic finding is hypertrophy of the ligamentum flavum causing reduction within the spinal canal compressing neurovascular structures. PILD is a minimally invasive percutaneous procedure that addresses LFH and does not involve implants. PILD has been proven to be safe and effective for the treatment of LSS-related pain. With its efficacy being superior to LESIs, PILD can be recommended as the first intervention after failure of conservative measures for LSS patients with NC due to LFH [25].

In 2012, a study conducted by Mekhail et al., studied the long-term result of PILD for LSS. A 1-year follow-up study was conducted at 11 sites in United States. The cohort included 58 patients who underwent 170 procedures, with the majority treated bilaterally at 1 or 2 lumbar levels. There were no major procedure-related complications reported. At 1 year, there was significant reduction of pain as measured by Visual Analog Scale [VAS]. The baseline mean VAS score of 7.4 [95% CI ± 0.5] improved to an average of 4.5 [95% CI ± 0.5], an improvement of 2.9 points [95% CI ± 0.5]. A decrease in disability was demonstrated by statistically significant mobility improvement when comparing mean baseline ODI to mean ODI at 1 year [P < 0.0001]. The baseline average ODI score of 48.6 [95% CI ± 0.5], decreased to a mean of 36.7 [95% CI ± 0.5] at the 1-year follow-up, an improvement of 11.9 points [95% CI ± 0.5]. The patients also reported statistically significant improvements in all Zurich Claudication Questionnaire [*ZCQ*] domains, symptom severity [*ss*] [P < 0.0001], physical function [*pf*] [P < 0.0002] and patient satisfaction [*ps*] scale score of 2.20 with 74% of the patient reporting their satisfaction with the procedure outcome. In addition, improvement in health status was observed in all eight scales evaluated by SF-12v2 summary surveys when compared to baseline [26].

Mekhail et al. also examined the long-term durability of PILD procedures through 5-year follow-up. This retrospectively longitudinal observational cohort study included patient diagnosed with LSS secondary to LFH who underwent PILD from 2010 through 2015 at the Cleveland Clinic Department of Pain Management. Nineteen patients underwent PILD procedure at two levels and the rest were treated at one level only. The most frequently treated level was L4-L5. A total of 75 patient received treatment during this period of time. Only 9 out of 75 [12%] patients required DOLD within the 5-year follow-up period. There was a significant difference in reported numeric rating scale [NRS] pain scores at 3-, 6- and 12-month follow-up when compared to baseline [P < 0.0001]. There was also a statistically significant change in opioid medication utilization at 3-, 6-, and 12-month follow-up when compared to baseline [P = 0.0048, P = 0.0015, P = 0.0067, respectively]. Only 3 of 9 patients had DOLD at the same level where the PILD procedure was performed. Three patients [33%] reported no improvement after surgery and one (11%) experienced worsening pain [27].

In 2010, a multicenter, non-blinded, prospective clinical study named MIDAS I [mild Decompression Alternative to Open Surgery] assessed the clinical application, patient safety and functional outcomes of PILD procedure in the treatment of symptomatic LSS. Seventy-eight patients were enrolled between July 2008 and January 2010. Six-week follow-up data was only available for 75 patients. The average baseline VAS and at follow-up were 7.3 and 3.7, respectively, an improvement of 3.6 point from baseline to 6-week follow-up [P < 0.0001]. ODI at baseline and at 6 weeks were 47.4 and 29.5, respectively, an improvement of 17.9 points from baseline [P < 0.0001]. In addition, patient *pf* [17.5% improvement] and overall *ss* [26.8% improvement] were statistically significantly improved [P < 0.001] from baseline and patients were satisfied with their overall outcomes. The health of the patient's 6-weeks after PILD treatment as measured by SF-12v2 was significantly improved at 95% CI [28].

In the MiDAS ENCORE multicenter, randomized controlled study, the investigators assessed improvement of function and reduction in pain for Medicare beneficiaries following treatment with PILD in patients with LLS and NC. A total of 302 patients were enrolled, 149 randomized to PILD and 153 to an active control group receiving LESIs. At 1-year follow-up, the ODI responder rate was 58.0% in the PILD cohort versus 27.1% for the LESI group [P < 0.001]. For the NRS, and all ZCQ domains, the proportion of responders in the PILD group was statistically significantly higher than the proportion of responders in the LESI group. The ZCQ *ps* score for PILD versus LESIs was 2.4 ± 0.1 and 3.1 ± 0.1, respectively [P < 0.001], showing a higher statistical significance of patient satisfaction with PILD. A total of 54 patients, [22

PILD, 32 LESI, P = 0.16] withdrew prior to the 1-year follow-up due to poor response to the study treatment and/or their intention to receive an alternate procedure. The study did not show any difference in safety between PILD and LESIs (P = 1.00) [29].

The 2-year follow-up data of the MiDAS ENCORE study, evaluated the long-term durability of PILD procedures in terms of functional improvement and pain reduction for patients with LSS. A total of 143 patients were treated with PILD versus 131 who underwent LESIs. Ninety-nine PILD patients comprised the modified intent-to-treat population available for a 2-year follow-up. At 2 years, responder rates for ODI, NPRS, and ZCQ *ss/pf/ps* were 72.4%, 71.7%, 73.5%, 59.6% and 76.8%, respectively. The mean changes from baseline achieved statistical significance (P < 0.001) for all efficacy end-points. There was no evidence of spinal instability through the 2-year period or serious procedure-related adverse events [30].

A more recent prospective, multicenter, randomized controlled trial conducted by Deer et al., provided Level-1 objective, real-world outcome data for patients with LSS with NC secondary to LFH. A total of 155 patients with LSS were randomized in a 1:1 ratio to PILD plus conventional medical management CMM (N = 77) versus CMM alone (N = 78). Sixty-nine patients were included in the analysis for each group at 1-year follow-up. Most patient were treated at one level only (59.7%) with L4-5 level as the most commonly treated level (76.4%). Objective outcomes included improvement in walking, incidence of subsequent lumbar spine interventions, and safety. Patients in the PILD plus CMM group had a mean improvement of 258% in walking time to onset of severe symptoms, as compared to 64% in the CMM group, (P < 0.001). At 1-year follow-up, 26.1% and 5.8% of patients had undergone a subsequent lumbar spine intervention, in the CMM and PILD plus CMM group, respectively (P = 0.002). Safety was similar between the groups at 1 year. In addition, patients in PILD plus CMM group experienced a 16.1-point composite ODI mean improvement, compared with a 2.0-point mean improvement for patients in the CMM arm (P < 0.001). All secondary outcomes, including NRS for back and leg pain, as well as ZCQ pf and ss domains favored PILD plus CMM (P < 0.001). Patient were statistically significantly more satisfied in the PILD plus CMM group as shown by the ZCQ *ps* (P < 0.001). A within-group analysis demonstrated statistically significant mean improvements for all primary and secondary outcome measures for PILD plus CMM at 6-month and 1-year follow-ups [31].

Staats et al. conducted a prospective longitudinal study to compare outcomes between Medicare beneficiaries receiving PILD and a control group of patients receiving ISS for the treatment of patient with LSS with NC. A total of 5,630 were included in the study, 2229 and 3401 patients in the PILD and ISS groups, respectively. At the 2-year follow up, the rate of harms for those treated with PILD was less than 50% of patients implanted with ISS, 5.6% vs. 12.1%, respectively (P < 0.0001). However, the rate of subsequent interventions was not significantly different between the groups, 24.9% and 26.1% for PILD and ISS, respectively (P = 0.7679). This study showed non-inferiority of PILD when compared to ISS [32].

Interspinous Process Devices: Interspinous process devices are minimally invasive implants proven be safe and to provide significant pain relief in patients with LSS-related pain. These devices can be divided in two categories: indirect decompression without rigid fixation (ISS) and indirect decompression with rigid fixation (ISFD). Both devices are implanted in a similar way, with either posterior or lateral approach, to open the space between interspinous processes and indirectly decompress the spinal canal.

Interspinous Spacers: The use of ISS devices has gained significant popularity in the past decade among interventional pain physicians, in the pursuit to close the treatment gap between conservative treatment and DOLD, in patients suffering from LSS-associated NC. ISS has demonstrated long-term, durable relief of symptoms, improved quality of life, opioid medication reduction, and an association with high patient satisfaction [33].

In 2011, a pilot study conducted by Shabat et al., assessed safety and effectiveness of minimally invasive ISS in patients with moderate LSS who failed non-operative treatment and met strict anatomic criteria. A total of 53 patients with intermittent NC were treated with ISS and followed up at 6 weeks, 1 and 2 years. There was a 54% reduction in axial and extremity pain over the 2-year follow-up period. ZCQ ss and pf scores improved by 43% and 44% (P <0.001), respectively, from pre-treatment to 2 years post-treatment. A 50% improvement (P < 0.001) in low back function was also noticed. Physical Component Summary [PCS] and Mental Component Summary [MCS] scores improved by 40% from pre-treatment to 2 years. The clinical success rates at 2 years were 83-89% for ZCQ subscores, 75% for ODI, 78% for PCS and 80% for MCS. Two patients underwent explant with subsequent laminectomy, otherwise no device infection, breakage, migration or removal was observed [34].

A prospective, multicenter, randomized, controlled investigational device exemption non-inferiority trial, conducted by Patel et al. studied the 2-year outcomes in patients with intermittent NC secondary to moderate LSS who underwent indirect lumbar decompression with ISS. A total of 391 patients were randomized to implant with ISS (N = 190) versus control spacers (N = 201) at 29 sites in the United States between August 2008 and December 2011. The predominant pain complaint, leg pain, decreased by 70% in severity at 2 year follow up in both groups. Seventy-seven percent and 68% of patients achieved leg and back pain clinical success at 2 years, respectively, without differences between groups. Clinically significant ODI improvement was achieved in 65% of patients [35].

Four-year data was extracted from the above randomized, control FDA investigational device exemption trial. At 4 years, 75 of 89 patients with ISS (84.3%) demonstrated clinical success. For ZCQ *ss*, *pf* and *ps*, the responder rates were

83% (74/89), 79% (70/89), and 87% (77/89), respectively. For leg and back pain VAS; 78% (67/86) at 66% (57/86), respectively; and 62% (55/89) for ODI. For ZCQ*ss*, ZCQ*pf*, leg VAS, back pain VAS and ODI, patients demonstrated percentage improvements over baseline of 41%, 40%, 73%, 69% and 61%, respectively.[33] At 5 years, 74 of 88 of patients (84%) demonstrated clinical success on at least two of three ZCQ domains. Success rates were 75% (66/88), 81% (71/88), and 90% (79/88) for ZCQ *ss, pf,* and *ps*, respectively. For leg and back pain success rates were 80% (68/85) and 65% (55/85), respectively, and for ODI was 65% (57/88). Percentage improvements over baseline were 42%, 39%, 75%, 66%, and 58% for ZCQ*ss*, ZCQ*pf*, leg and back pain VAS, and ODI, respectively (P < 0.001). Seventy-five percent of IPD patients were free from reoperation, revision, or supplemental fixation at 5 years [36].

In terms of quality-of-life assessment, 189 patients treated with ISS were evaluated with the SF-12. For the PCS, mean scores improved from 29.4 ± 8.1 preoperatively to 41.2 ± 12.4 at 2 years (40%) and to 43.8 ± 11.6 at 5 years (49%) (P < 0.001). The mean MCS score improved from 50.0 ± 12.7 preoperatively to 54.4 ± 10.6 and 54.7 ± 8.6 at 2 and 5 years, respectively (P > 0.10) [37].

Cairns et al. reviewed data on cost-effectiveness, safety, and performance of LSS treatment modalities compared with the ISS procedure. A wide range of modalities were included in the analysis such as medicinal treatments, LESIs, PT, and alternative methods, as well as DOLD with and without fusion, and ISS. There was only minimal improvement in pain and functional status in patients with persistent conservative treatment (>12 weeks) for LSS. As expected, DOLD with fusion had greater costs than an open procedure without instrumentation due to increase in length of stay, risks of complications and implant costs. In addition, ISS is placed percutaneously which minimizes the recovery period and the need for rehabilitation [38].

A retrospective study conducted by Rosner et al. utilized the Medicare Standard Analytical Files to examine safety outcomes and the rate of subsequent spinal procedures among LSS patients receiving ISS versus PILD as their first surgical intervention. A total of 7,228 patients (3,614 in each group) who underwent ISS and PILD from 2017 to 2021 were included in the analysis after matching demographics [mean age = 74 years, mean follow-up = 20 months]. The risk of undergoing subsequent surgical interventions, LSS-related intervention, DOLD, and PILD were 21%, 28%, 21%, and 81% lower among ISS when compared with the PILD cohort. There were no significant differences between cohorts in rates of complications [4.3% vs 4.1%, P = 0.711], which occurred in less than 0.3% patients in each cohort. These results showed that ISS and PILD have an equivalent safety profile; however, ISS demonstrated lower rates of DOLD than PILD. A subsequent surgical procedure occurred in 9.8% of the ISS cohort, which is less than half of previously reported 20% in the Investigational Device Exemption (IDE) trial [39, 40].

Tekmyster et al. reported real world perioperative and clinical data from the PRESS registry for patients treated with ISS for LSS with NC. Seven hundred seventy-two patients [mean age 73 ± 9.1 years, 54% females] treated with ISS were registered, however, only 603, 521, 184 and 53 patient provided data at baseline, 3 weeks, 6 and 12 months, respectively. At 12 months, there was an overall 60% improvement in mean leg pain severity, from 76.6 ± 22.4 mm at baseline to 30.4 ± 34.6 mm and 48% improvement in back pain severity, from 76.8 ± 22.2 mm to 39.9 ± 32.3 mm. Corresponding responder rates were 64% (484/751), 72% (1,097/1,523) and 75% (317/423) at 3 weeks, 6 and 12 months, respectively. In terms of patient satisfaction, 89%, 80%, and 80% were satisfied/somewhat satisfied with their treatment at 3 weeks, 6 and 12 months, respectively; and 90%, 75%, and 75% would definitely/probably undergo the same treatment again. The rate of revision/reoperation was 3.6% (51/126) [41].

Another multicenter observational study examined real-world outcomes derived from a cohort of patients treated with ISS for LSS post 1-year implant. This report included data from 41 patients, 23 were female with a mean age of 69.7 ± 11.2. There was a 5.4-point improvement in mean NRS, from 9.4 ± 0.5 to 4.0 (P < 0.000); from baseline to last follow up [mean = 115 days], respectively [42].

The FDA has approved three types of ISS devices for the United States market. However, the first ISS approved in 2005 was taken off the marked due to its adverse if events profile [43]. Another device has been approved for moderate to severe LSS to promote stabilization after decompression but without pedicle screw fusion. Nonetheless, this procedure can only be performed in conjunction with DOLD [44, 45].

Interspinous Fixation Devices: Regardless of the paucity of existing scientific literature for ISFD, there is an increased interest in the development and utilization of this type of minimally invasive technique to avoid the need for DOLD. ISFD is a valuable tool in the treatment of moderate LSS and DDD which has decreased morbidity and significant efficacy. ISFD was developed to provide a rigid fixation between spinous processes limiting the flexion motion allowed by ISS and to avoid reoperation. Besides the indirect decompression of the spinal canal, ISFD limits posterior process movement with the use of a graft component.

Falowski et al. conducted a multicenter retrospective analysis to evaluate safety and efficacy of a novel minimally invasive lumbar ISFD. Thirty-two patients with lumbar degenerative disc disease and secondary LSS treated with ISFD were included in the review. The analysis included changes in VAS and post-procedural serious adverse effects. There was a 67% reduction in VAS, 8.1 to 2.65, from the pre-operative to the post-operative period, respectively. No adverse events, reoperation or device explants were reported within the first 90 days post-procedure. Even though this study had many limitations, it demonstrated the efficacy and safety of an ISFD performed in an outpatient setting [46].

A single-arm, multicenter, prospective, open-label clinical trial by the same group explored ISFD as a standalone posterior approach to treat lumbar degenerative disc disease in the setting of LSS with NC, determine safety and efficacy; and report adverse events. This is the 3-month interim analysis of the first 20% of enrolled patients, however they are expected to follow up at 12 months and out to 5 years. Patients were enrolled in the study, if they had at least 1-2 symptomatic lumbar degenerative disc disease at adjacent levels from T1 through S1, with or without grade 1 spondylolisthesis, MRI findings with at least mild-to-moderate spinal stenosis at the index level. At the time of this publication, there were 54 active and 32 implanted patients. At 3-months, 82% of patients reported improvement from the procedure. Sixty-five percent of patients demonstrated clinical meaningful improvement in their pain and functional status, as defined by the VAS, ODI, and ZCQ. There was a mean improvement from baseline in PROMIS 29 with statistical significance for all but anxiety and depression, and only one adverse event with no complications identified [47].

More recently, Skoblar et al. evaluated radiographic outcomes in patients who received minimally invasive ISFD. Patients from a single United States private practice (N = 110) who received ISFD in 2020, were invited to receive a follow up CT Scan for assessment of the arthrodesis post ISFD (mean 459 days, 177-652). A total of 69 levels were assessed in 43 patients with 92.8% of the levels considered fused. A small number of spontaneously healed spinous process fractures (5.8%) were identified on imaging; however, there were no instances of ISFD mechanical failure or reoperation [48].

In a prospective, multicenter study, Pencle et al. explored the use of ISFD to increase foraminal height in patients with severe disc collapse secondary to advanced degenerative disc disease. The study included patients with more than 50% decrease in foraminal volume, treated between December 2019 and December 2020, with a follow-up visit in July 2021. All the patients had an increase in foraminal height, maintained on follow up and improvement in VAS and ODI. There was no evidence of spinous process fractures, complication, device failure, or revisions. However, the group concluded that an increase in foraminal height may not be as significant for patients with less severe disc degeneration [49].

Neuromodulation: Chronic low back and lower extremity pain on exertion is a common complaint of patients suffering LLS with NC caused by degenerative spine changes. DOLD is usually performed when conservative approaches fail, however, there is still a debate regarding the long-term outcomes of DOLD in the management of LSS. Neuromodulation therapies such as SCS have been proven to be effective for the management of chronic neuropathic pain in the limbs, pain associated with post-laminectomy syndrome, intractable low back pain, pain associated with diabetic neuropathy, and refractory back pain in non-surgical patients. However, there is no consensus on the usefulness of SCS in the management of LSS-associated NC. Nonetheless, due to the less invasive and reversible nature of the technique, SCS could be considered in our treatment algorithm before DOLD, predominantly in patients with increased surgical risk. Despite the paucity of scientific data available for the use of SCS in this patient population, it seems to be effective against LSS-associated NC.

In 2010, Constantini et al. evaluated the long-term outcomes of patients with symptomatic LSS treated with SCS in three European registries. Data was systematically recorded from a total of 69 patients with a mean follow-up of 27 months. All patients had statistically significant pain reduction as evidenced by a decrease in VAS from 7.4 ± 2.3 to 2.8 ± 2.4 ($P < 0.05$). There was also an improvement in functional status and reduction in analgesic medication usage. This study proposed SCS as an effective alternative therapy for patients suffering from LSS-related pain [50].

Another retrospective study conducted by Kamihara et al. evaluated the efficacy of SCS for LSS-associated lower extremity pain. A total of 91 patients underwent SCS trials for LSS-associated leg pain from January 2003 to December 2011. Sixty-five percent (59/91) received 50% or greater pain relief; 69.5% (41/59) underwent permanent implantation and 95% (39/41) showed continued response for 1 year or longer [51].

More recently, Awad et al. assessed the outcomes and efficacy of SCS therapy in patients with NC with or without prior DOLD. This study included patients who had undergone SCS from 2013 through 2020 in a single United States academic medical center and a follow-up for at least a year. Eighty-six percent (N = 118) of patients had successful SCS trials, 78.8 % (93/118) underwent permanent implantation and 74% (69/93) of those patients had at least one year follow-up. At 1-year follow-up, 80% (55/69) of patients had sustained relief of NC symptoms and 75% (52/69) had sustained benefit for an average of at least 27 months. Eighty-six percent of patients without prior DOLD had sustained pain relief at the latest follow-up [52].

SCS must be considered after failing conservative measures but before considering DOLD, if clinically indicated. However, more randomized controlled trials are needed in this patient population to be able to incorporate LSS as a clinical indication for SCS therapy.

Direct Open Lumbar Decompression: Traditionally, DOLD with or without instrumentation has been the standard of care for patients with LSS and NC that fail conservative treatment. This surgical option is preferred for patients with severe disease and/or spinal instability; however, like any other surgical procedure, it comes with some risks. It is well documented in the scientific literature that DOLD is not appropriate for all patients with LSS. Due to the nature of the procedure, it may increase the length of the hospital stay and the possibility of complications due to the size of the incision. In addition, recovery and healing times are generally longer in comparison to minimally invasive procedures due to extensive muscle dissection as well as an increase in post-operative return to work time. Patients

could also developed chronic low back pain associated with post-laminectomy syndrome. Recent studies of DOLD have reported complications in 7.5% – 12.15% of patients [53, 54]. In fusion surgeries, while a claims analysis reported a complication rate of 24.9% at 2 years; an RCT reported complications in 23% of patients [55, 56].

A detailed review of the different kinds of DOLD is beyond the scope of this article. Nonetheless, we would like to present scientific evidence regarding safety outcomes as well as cost-effectiveness in LSS patients undergoing DOLD.

A recent retrospective, comparative, Medicare claims analysis study conducted by Whang et al., included patients with LSS who underwent qualifying procedures between 2017 and 2021. Patient data was included from the procedure until end of data availability. The outcomes assessed included subsequent surgical interventions, long-term complications, and short-term life-treating events. A cost analysis during a 3-year follow-up was also performed. A total of 400,685 patients were identified (mean age 71.5 years). The patients receiving DOLD were more likely to have a subsequent fusion or another lumbar spine surgery, [hazard ratio (HR), 95% CI: 1.49 (1.17, 1.89) - 2.54 (2.00, 3.23)] or other lumbar spine surgery [HR 95% CI: 3.05 (2.18, 4.27) - 5.72 (4.08, 8.02)], when compared to ISS patients. Those patients who underwent DOLD had more short-term life-threatening events [odds ratio (CI): 2.42 (2.03, 2.88) - 6.36 (5.33, 7.57)] and long-term complications [HR (CI): 1:31 (1.13, 1.52)-2.38 (2.05, 2.75)] than patients receiving ISS. In the cost analysis, adjusted mean index costs were lowest for decompression and highest for fusion alone. ISS patients had significantly lower 1-year complication-related costs than all surgery cohorts and lower 3-year all-cause costs than fusion cohorts [57].

Treatment Algorithm for Patient with LSS with NC: The introduction of newer and innovative treatment options for the management of patients with LSS and NC presents some challenges. For the past decade, there has been a preference for minimally invasive techniques to treat patients that are not surgical candidates and to avoid possible complications from DOLD. This has led to a shift in the LSS treatment algorithm and has raised questions regarding the appropriateness of techniques based on severity of symptoms and lumbar spine pathology. This article has gathered scientific literature on available techniques for LSS-related leg pain in order to facilitate a treatment algorithm and reiterate in specific indications for each procedure. (Figure 1).

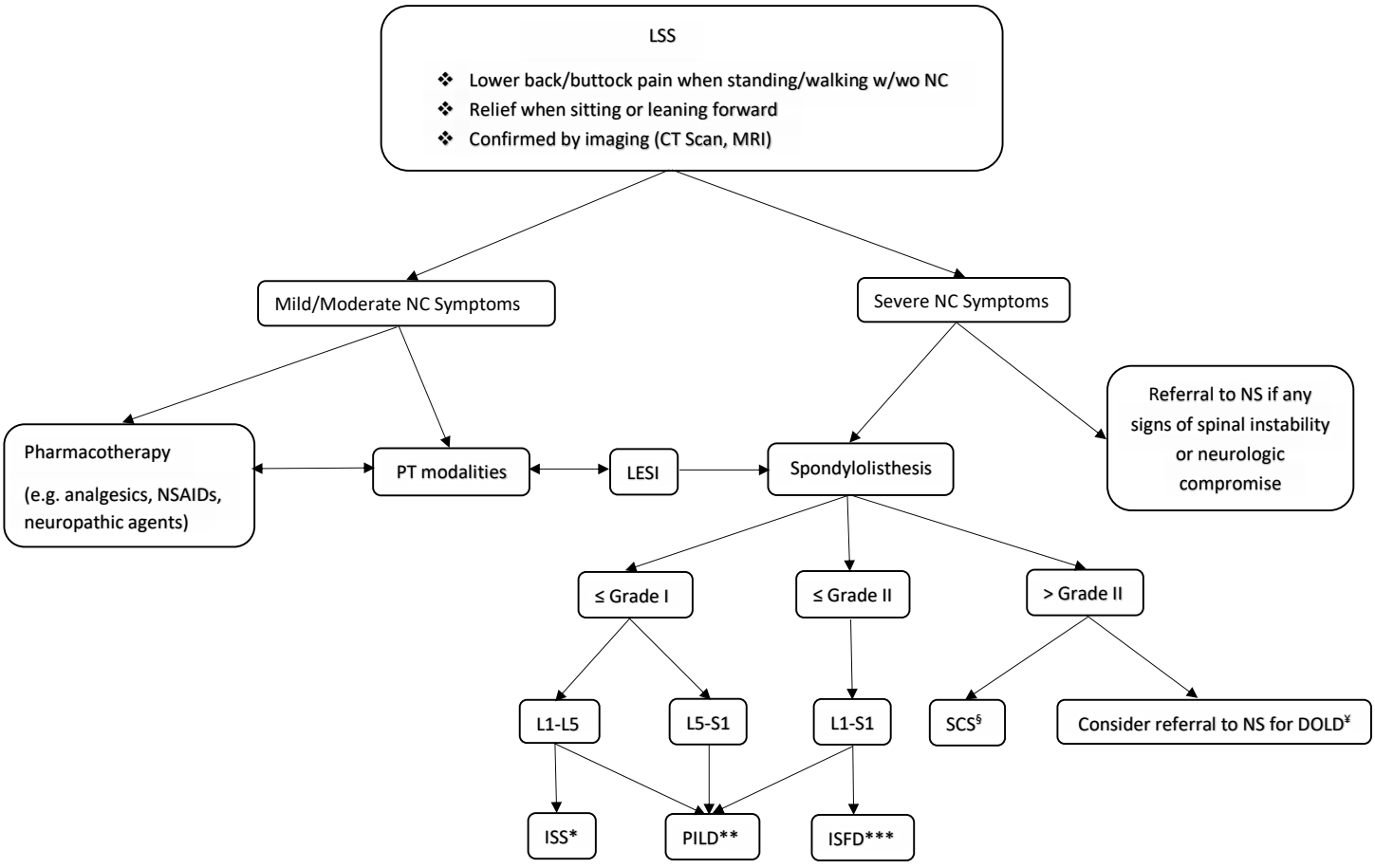

Figure 1: Treatment Algorithm for Patients with LSS/NC.

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*ISS Criteria: LSS ± Grade I Spondylolisthesis; radiologic evidence of LFH, narrowed lateral recess and/or central canal.
**PILD Criteria: ≤ 13mm lumbar canal diameter on CT Scan; visible LFH > 2.5mm, pain/numbness in low back when standing; pain/numbness in buttocks/legs when walking; relief when sitting/leaning forward.
***ISFD Criteria: ≤ Grade II spondylolisthesis, LSS, painful DDD.
¥ Contraindications: poor general health with comorbidities that may preclude general anesthesia, risk factors associated with poor outcomes (physical deconditioning, psychosocial/emotional distress, unrealistic expectations, smoking, fear avoidance behavior, litigation, and job dissatisfaction), inadequate correlation between symptoms and findings on physical examination, neurologic examination, imaging, or other diagnostic testing. Chronic low back pain alone without predominant leg symptoms is a relative contraindication for DOLD.
§ SCS: beneficial therapy at multiple steps throughout the LSS/NC algorithm. Patients who are not surgical, ISS or ISFD candidates, have > Grade II spondylolisthesis, status post DOLD with/without instrumentation will also benefit from SCS.

Abbreviations: DOLD: Direct open lumbar decompression; ISFD: Interspinous fixation device; ISS: Interspinous spacer; LESI: Lumbar epidural steroid injection; LFH: Ligamentum flavum hypertrophy; LSS: lumbar spinal stenosis; NC: Neurogenic claudication; NS: Neurosurgery; PILD: Percutaneous image-guided lumbar decompression; PT: Physical therapy

A stated above, LSS is defined as lower back and/or buttock pain when standing or walking, with or without NC. A pathognomonic sign of LSS is pain relief with lumbar forward flexion ("shopping cart sign") or sitting ("seated flexion"). Nonetheless, even with a clinical picture suggesting LSS, formal diagnostic cross sectional and dynamic standing plain film imaging must be performed to evaluate the severity of the stenosis, location (central, foraminal, lateral recess), presence of spondylolisthesis, single versus multilevel involvement, ligamentum flavum thickness, and spinal instability. Due to a poor correlation between radiographic findings and clinical symptoms, the severity of LSS symptoms must be addressed to identify the presence of neurologic compromise requiring a more aggressive neurosurgical intervention.

Several scales such as the self-paced walking test (SPWT) and Hufschmidt-grade can guide the diagnosis of LSS based on observed clinical symptoms [58-61]. The SPWT is a measure for walking capacity, and categorized as poor (< 100 m), fair (100 m - 800 m), good (800 m - 1,600 m), and very good (> 1,600 m). Hufschmidt-grade is a 4-grade scale categorized as follows: Grade 0; NC characterized by a reduced walking distance and short term intermittent sensory and/or motor deficits that at rest might be unremarkable, but might worsen while walking > 100 m and < 100 m for Grade 1. Patients with Grade 2 experience intermittent paresis, and loss of reflexes, and Grade 4; persistent, progressive paresis, accompanied by partial regression of pain.

Patients suffering from mild to moderate NC symptoms can be managed conservatively with a combination of pharmacotherapy (e.g. analgesics, NSAIDs, neuropathic agents) and a wide spectrum of PT modalities. Although there is paucity of data supporting pharmacotherapy as effective treatment for LSS and NC, PT aims to improve stability and flexibility by using a combination of aerobic, stretching, range of motion, strengthening exercises as well as manual therapy, postural education, gait/balance training and use equipment to avoid possible injuries.

There is a role for LESI, if those conservative modalities fail. However, its benefit may vary according to the degree of lumbar stenosis. Patients with mild to moderate disease tend to have better outcomes than patients with severe LSS. Several factors may affect the delivery of the medication into the epidural space including: difficult access in the interlaminar or transforaminal approach due to central or foraminal stenosis, respectively; volume of injectate used, presence of multilevel disease and patient's tolerance to the procedure. Although, LESIs have been performed in patients with LSS with NC for decades, the technique limitations are well documented.

Patients with mild to moderate recalcitrant symptoms as well as patients with severe LSS-related leg pain or NC will benefit from an exhaustive evaluation to better comprehend the possible pain generators involved and to guide more advanced treatment options. Nonetheless, patients with signs of neurologic compromise and/or spinal instability on flexion/extension imaging, must be evaluated by Neurosurgery/Spine Surgery, for open lumbar decompression with or without stabilization.

Patients with spondylolisthesis in addition to LSS must be classified before considering direct or indirect lumbar decompression. The Meyerding classification system is a widely utilized grading system for spondylolisthesis. It is determined by measuring the degree of slippage using standing, neutral lateral radiographs of the lumbar spine as well as lateral flexion and extension views, which allows for a further assessment of mobility and slippage severity. The classification system divides slip into five grades: 0% to 25% is Grade I (0% to 25%), Grade II (25% to 50%), Grade III (50% to 75%), Grade IV (75% to 100%), and Grade V (> 100%). These grade percentages are determined by drawing a line through the posterior wall of the superior and inferior vertebral bodies and measuring the translation of the superior vertebral body as a percentage of the distance between the two lines. Grades I and II are generally considered low-grade slip, whereas Grades III, IV, and V are considered high-grade slip [62].

Patient suffering from LSS with NC with ≤ Grade 1 spondylolisthesis who fail conservative therapies may benefit from percutaneous or indirect lumbar spine decompression with or without fixation. The severity of the stenosis, the presence of multilevel disease and the lumbar level are three important factors to be considered. These

techniques are indicated for patients with mild to moderate LSS. Specific criteria for PILD includes: ≤ 13mm lumbar canal diameter on CT Scan; visible LFH > 2.5mm, pain/numbness in low back when standing; pain/numbness in buttocks/legs when walking; relief when sitting/leaning forward. It is also important that there is absence of spinal instability, > Grade 2 spondylolisthesis and severe symptomatic foraminal or lateral stenosis. In patients without prior surgical intervention, PILD could be performed from L1 to L5 levels and in the presence of multilevel disease.

Those patients with LSS-related leg pain and ≤ Grade I spondylolisthesis may also benefit from ISS for indirect lumbar decompression. ISS devices limit lumbar extension to avoid compression of neurovascular structures that cause NC symptoms. The ideal patient for ISS has radiologic evidence of narrowed central (moderate), lateral recess, and/or foraminal stenosis with or without LFH as well as impaired physical function but obtains pain relief on lumbar flexion. ISS can only be implanted from L1 to L5 due to the lack of a spinous process at the S1 level, and has been only studied being implanted at a maximum of two contiguous levels. However, it is a reversible technique (as compared to PILD), and can be removed to pursue another surgical intervention such as ISFD or DOLD. The combination of PILD and ISS is not an uncommon clinical practice for patients with multilevel disease who meet criteria. ISS is contraindicated in patients with spinal anatomy that prevents proper device implantation, cauda equine syndrome, prior decompression, or instrumentation at index level.

For patients who require additional immobilization and stabilization with bone graft material, ISFD is a potential option. This device accommodates for patients with ≤ Grade II spondylolisthesis, LSS, and painful DDD. It is intended for single level use from L1-S1. Due to its minimally invasive lateral approach, a particular ISFD allows for minimal tissue disruption including supraspinous ligament and multifidus muscle, in addition to reducing the risk of damaging neurovascular structures. ISFD could also be combined with PILD if multilevel disease is present.

The specific use of SCS in patients with LSS with NC has limited scientific data, however, its effect on low back and lower extremity neuropathic pain has been well studied and documented. The full spectrum of neuromodulation techniques, devices and waveforms will be addressed in a subsequent article. However, we would like to establish the fact that SCS may be a beneficial therapy at multiple steps throughout the LSS with NC algorithm. Patients who fail conservative treatment who are non-surgical, ISS or ISFD candidates can benefit from SCS therapy as well as patients with > Grade II spondylolisthesis, post DOLD with or without instrumentation.

Lastly, we would like to reiterate on the importance of ideal patient candidacy for any of the procedures mentioned above. These minimally invasive techniques do not substitute the need for DOLD in patients with severe LSS, spinal instability and/or neurologic symptoms. Nonetheless, it is also important to consider the contraindications to DOLD such as poor general health with comorbidities that may preclude general anesthesia, risk factors associated with poor outcomes (e.g. physical deconditioning, psychosocial/emotional distress, and unrealistic expectations), poor correlation between symptoms and physical and neurologic examination findings, imaging, or other diagnostic testing. Chronic low back pain alone without predominant leg symptoms is a relative contraindication for DOLD.

4. Conclusion

Lumbar spinal stenosis is a degenerative disorder of the spine with high prevalence among the aging population. The presence of disc herniations, DDD, hypertrophic facet changes, osteophytes and LFH may lead to intermittent compression of the spinal neurovascular structures causing NC symptoms. Historically, treatment options for patients suffering from LSS with NC have been limited to conservative treatment and open decompression with or without instrumentation. Multiple treatment modalities have been developed in the last decade to fill in the treatment gap, improve outcomes, and reduce potential complications from open surgery. Percutaneous techniques such as PILD, ISS, ISFD and SCS have specific patient criteria and indications that must be followed to increase the chances of better outcomes. This is all described in our LSS treatment algorithm. Lastly, patients with severe LSS, signs of spinal instability and/or cauda equine must be referred to Neurosurgery for DOLD with or without instrumentation. Further randomized control trials are needed in some of the above-mentioned techniques for this specific patient population with LSS with NC.

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