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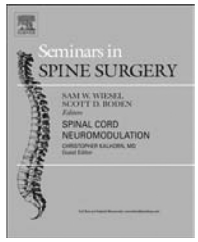

Indirect decompression of lumbar stenosis

Anuj Patel, and Thomas D. Cha*

Spine Center, Department of Orthopaedic Surgery, Massachusetts General Hospital, 55 Fruit Street, Yawkey Suite 3800, Boston, MA 02114, United States

ABSTRACT

Degenerative lumbar stenosis can lead to symptoms of neurogenic claudication and lumbar radiculopathy. Lumbar stenosis can be caused by static compression of the neural elements in the central canal, along the lateral recess, and in the neuroforamen, as well as by dynamic changes to the total area of the central canal and neuroforamen. Previously, surgical options for the treatment of degenerative lumbar stenosis were primarily based on direct posterior open decompressions and fusions. However, novel techniques of indirect decompression have now been developed that restore disc height to increase the area of the central canal and neuroforamen and address the dynamic aspect of stenosis, while avoiding the extensive soft tissue injury involved in posterior open decompressions and fusions. Interbody fusions and interspinous devices are two methods of indirect decompression that are being commonly used.

In this study, we provide a broad overview of the advantages, disadvantages, indications, evidence, and complications of ALIF, LLIF, and OLIF, as well as interspinous devices including Coflex. Though there is limited comparative evidence demonstrating that one approach is superior to another in terms of clinical and radiographic outcomes, evidence does show that interbody techniques are effective at treating lumbar stenosis by increasing the total area of the central canal and neuroforamen while having high fusion rates. Though the newer generation of interspinous devices have lower failure rates than their predecessors, they still are not comparable to the interbody devices in terms of long term outcomes. The optimal approach for the indirect treatment of lumbar stenosis therefore depends on multiple variables, including but not limited to the spinal level of disease, the anatomy of the individual patient, the pathology being treated, and the familiarity of the surgeon.

1. Introduction

Degenerative lumbar stenosis can lead to neurogenic claudication with symptoms of leg, back, and buttock pain and heaviness. Stenosis can also lead to lumbar radiculopathy with symptoms of leg pain, numbness, weakness, and paresthesias. The incidence of degenerative lumbar spinal stenosis has been shown to be between 3% and 8%[1] but continues to increase with the aging population. Anatomically, stenosis can be found centrally in the canal, along the lateral recess, and in the neuroforamen. Many etiologies have been found to contribute to stenosis by decreasing the area available to neural elements. Lumbar disc herniations, ligamentum flavum hypertrophy and buckling, facet arthropathy can all lead to symptoms.

Stenosis has also been found to have a dynamic component, with biomechanical studies showing the total area of the central canal and the neuroforamen decreases with extension of the lumbar spine.[2] Schmid et al. showed that in healthy, asymptomatic young patients, there was a significant decrease in the central spinal area in an extended position (mean of 224 mm^2) compared to in a flexed position (mean 268 mm^2) ($P < 0.0001$). The maximum thickness of the ligamentum flavum was also shown to increase with extension, contributing to the stenosis.[3] Other factors also contributing to the dynamic component stenosis including disc height loss, instability, and malalignment

*Corresponding author.
E-mail address: tcha@mgh.harvard.edu (T.D. Cha).

https://doi.org/10.1053/j.semss.2019.04.006
1040-7383/

which all decrease the total area of the central canal and neuroforamen.

Previously, surgical options for the treatment of degenerative lumbar stenosis were primarily based on direct posterior open decompressions. Options for decompressing the lateral recess and neuroforamen, including foraminotomies and facetectomies, could lead to the need for posterior fusions due to the resection of bony elements responsible for spinal stability.

Recent advances in technology have provided new techniques for treating stenosis through indirect decompression. These novel methods address the fact that stenosis is in fact a dynamic phenomenon in which disc height loss, ligamentum flavum buckling, malalignment, and instability all contribute. Indirect decompression involves the restoration of disc height to increase the accommodative volume of the epidural space while avoiding the extensive soft tissue injury involved in posterior open decompressions. Interbody fusions and interspinous devices are two commonly used techniques for indirect decompression. Both techniques have been shown to provide indirect neural decompression by expansion of the bony neuroforamen and distraction of ligamentous stenosis of the central canal. Both techniques also aim to resolve the dynamic aspect of lumbar stenosis by decreasing intervertebral motion. In addition, interbody fusions aim to maximize segmental lordosis and facilitate fusion rates. Advantages of these newer techniques include minimal soft tissue dissection, decreased blood loss, decreased operative times, shorter hospital stays, and less postoperative pain compared with open posterior surgery.[4]

The goal of this article is to present various indirect decompression techniques and to compare their benefits and effectiveness.

2. Interbody techniques

2.1. ALIF

2.1.1. History

Interbody fusion was first described by Capener in the 1930's to treat spondylolistheses using an anterior based approach to the lumbar spine.[5] He performed a complete anterior discectomy and placed a structural implant in the disc space in hopes of facilitating fusion and restoring alignment. Since that time however, the majority of interbody fusions were performed through a posterior based-approach. Significant bony resection, including the facet joints, is needed to safely access the disc space from a posterior approach, increasing soft tissue dissection and iatrogenic instability. Within the past 15 years, attention has turned back to anterolateral approaches in order to eliminate the need for large soft tissue disruption, injury of the posterior column, while also allowing wide exposure of the disc space.

3. Anatomy

The anterior approach accesses the lumbar spine through a transperitoneal or retroperitoneal approach. It is made using a transverse Pfannenstiel or vertical periumbilical incision with the patient supine on a radiolucent operating table. It allows direct midline exposure of the lumbar disc through the ALL, as well as direct visualization of the great vascular structures to minimize risk of vascular injury. A direct midline exposure allows for a wide discectomy with placement of a large interbody graft that maximizes endplate coverage and fusion rate, while minimizing risk of graft subsidence.

The direct anterior approach also requires complete release of the anterior longitudinal ligament. ALL resection permits placement of hyper-lordotic implants. In cases of sagittal imbalance, theses cages can help restore segmental and overall lumbar lordosis.

Typically, the direct anterior approach is performed most safely at the L5-S1 level in the large working corridor below the bifurcation between the iliac vessels. Higher lumbar vertebra up to L2–L3 can be exposed, but oftentimes their exposure is limited because of the need for mobilization of the aorta and iliac vessels that lie directly anterior to the vertebral body. The difficulty in cephalad exposure through the anterior approach has led to additional exposures gaining support.

4. Results

The effectiveness in decompression of the central canal and neuroforamen of anterior interbody fusions has been reported. Multiple radiographic studies have shown a clinically significant 67% increase in the foraminal cross-section area after indirect decompression through anterior lumbar interbody fusions.[6,7]

The ability to implant a larger graft with increased surface area contact with vertebral endplate has also been shown to significantly increase fusion rates. Rao et al. reported a 94.4% radiographic fusion rate for stand-alone implants in a prospective cohort of 125 consecutive ALIF patients with a mean follow-up of 20 months.[8] Lee et al. reported a fusion rate of 97.3% at a mean follow up of 16 months in patients who underwent ALIF with the addition of posterior fixation with percutaneous pedicle screws for treatment of isthmic spondylolisthesis.[9] In the same cohort, long term data with a mean follow up of 72 months showed that 88.9% had an excellent or good clinical result with 100% having solid fusion.[10] Larger grafts also have led to decreased incidence of subsidence after ALIF. In a study of 147 patients who underwent stand-alone placement of an ALIF interbody, Rao et al.[6] found only a 10.2% incidence of subsidence at an 18-month follow-up, which is significantly less than rates of subsidence in lateral interbody fusions.[7]

The clinical effectiveness of ALIF in improving symptoms from lumbar stenosis has also been shown. Rao et al showed a statistically significant improvement in patient reported pain outcomes for multiple indications that include spondylosis, spondylolisthesis, and adjacent segment disease.[8]

5. Complications

To obtain a direct midline exposure of a lumbar disc, a transperitoneal or retroperitoneal approach is needed with

inherent risks. The majority of complications from ALIF occur during this intra-abdominal access. Serious complications related to injury of the large bowel, pancreas, and other viscera have previously been reported but are becoming increasing rare with the use of a standardized retroperitoneal approach and newer retractor systems.[11] More frequent complications of ALIF now include vascular injuries and retrograde ejaculation. Vascular injury is a major concern during the surgical approach, particularly to the iliac veins. Incidence of vascular injury during ALIF have been reported from 1.9% to 4.6%[12–14] with up to 76% of vascular injuries being venous in nature.[12] In general, tears less than 5 mm long can be treated with pressure and hemostatic agents whereas larger tears and arterial injuries require repair using sutures and may require a vascular surgeon to assist with repair.

Injury to the superior hypogastric plexus is also a serious complication of any intra-abdominal surgery that can have significant long-term consequences in men. The superior hypogastric plexus lies beneath the peritoneum, ventral to the aorta and left common iliac vein and injury to the plexus may result in retrograde ejaculation. Recent reports have found an incidence of retrograde ejaculation of 2% with a retroperitoneal exposure and up to 25% with a laparoscopic transperitoneal approach.[15] Similarly, Sasso et al. found a 1.7% incidence of retrograde ejaculation in 116 patients undergoing an ALIF through a retroperitoneal exposure compared to a 13.3% incidence in 30 patients undergoing a laparoscopic approach.[16] Gentle dissection of the plexus during exposure of the ventral spine may reduce the risk of injury to the plexus, but injury to the plexus is often unavoidable and no technique has been shown to be able to clinically decrease the incidence of retrograde ejaculation. This risk should be thoroughly discussed with all male patients. If male patients are interested in procreating after an ALIF procedure, the option of banking sperm should be discussed during the informed consent process prior to surgery.

Overall, Zdeblick et al. found a significantly higher rate of complications using the laparoscopic transperitoneal approach (20%) compared to the open retroperitoneal ALIF approach (4%). This has led to the increasing popularity for retroperitoneal approaches for ALIFs.[17]

6. Lateral lumbar interbody fusion

6.1. *History*

Ozgur et al first described a lateral interbody fusion in 2006[4] as a modification on Pimenta's retroperitoneal approach to the lumbar spine presented in 2001 at the Brazilian Spine Society Meeting . They described a technique using blunt dissection through the retroperitoneal fat and psoas muscle using sequential dilators to obtain lateral access to the intervertebral disc spaces. This novel approach offered several advantages over the established anterior approach. A lateral approach eliminates the need to mobilize and retract the great vessels, decreasing the risk of vascular injury. It also avoids the need to violate or retract the peritoneum, avoiding stretch of the superior hypogastric nerve plexus and eliminating the risk of retrograde ejaculation. In turn, it eliminates the need for an access surgeon as the approach is performed solely by the operating spine surgeon. Termed extreme, direct or lateral lumbar interbody fusion (XLIF, DLIF, LLIF), the lateral trans-psoas approach has recently gained popularity for interbody fusion and indirect decompression.

7. Anatomy

The lateral approach to the intervertebral disc is performed with the patient in a lateral decubitus position on a radiolucent operating table with the approach side facing up. The decision as to which side to approach should be made based on the laterality of the patient's symptoms, foraminal stenosis, or concaving of curve. The incision is centered on the posterior one-third of the disc space except at L4–5, where it is centered on the middle of the disc space using fluoroscopy. After dividing the transversalis fascia, blunt finger dissection is used to advanced down through the retroperitoneal fat to the psoas muscle, which can be palpated deep. The psoas muscle is then bluntly dissected using dilators and fluoroscopy is used to confirm the dilator position over the intended disc space. This technique can be performed through incisions as small as 3–4-cm.

Spine levels from T12–L5 can be accessed comfortably through a lateral approach. The L5–S1 interspace is generally inaccessible laterally. The anterior course of the lumbar plexus through the psoas muscle leads to an increased risk of traction injury with a lateral approach at more caudal levels. Iliac crests and the ventrolateral course of the iliac vasculature also prevent a lateral approach to the L5-S1 level.

Ozgur et al[4] reported decreased approach related complications with this lateral transpsoas approach compared to anterior approaches. By avoiding the need to retract the major vessels, the lateral approach inherently decreases the risk of major vascular injury. Furthermore, the recent addition of real-time directional triggered electromyographic monitoring with the XLIF (NuVasive, Inc.) platform has decreased the risk of injury to the lumbosacral plexus and genitofemoral nerves. Using their Neuro- Vision JJB electromyographic (EMG) monitoring system (NuVasive, Inc.), the proximity and direction of the nerves to the stimulus can be determined by stimulus intensity; the closer the nerves are, the less stimulus intensity required to elicit a response, resulting in a lower threshold.[18] The lumbosacral plexus and genitofemoral nerves are ensured to be posterior to the dilators and retractor if the lower threshold responses are directed posterior to the dilator. The nerves are therefore able to be retracted safely posteriorly when at risk as they course through the psoas muscle.

8. Results

The lateral transpsoas approach to the intervertebral disc allows for placement of an intervertebral cage with a large footprint that spans the width of the dense ring apophysis, the strongest bony surface in the endplate. Compared to a cage placed through a posterior approach, larger lateral implants prevent subsidence as well as create a greater surface area for fusion. Multiple studies have shown a higher

fusion rate with lateral interbody fusion compared to other fusion techniques ranging from 94.3% to 97.4% in LLIF levels assessed with CT imaging.[19–21] The decreased rate of subsidence after LLIF has also been reported in many studies, ranging from 3.4% - 17.3%.[22,23] In a meta-analysis of all studies looking at the subsidence rates, Macki et al. showed an overall subsidence rate of 10.3%, with a reoperation rate for subsidence of 2.7%.[24] Marchi et al. showed that the use of a wide (22 mm) cage that can be placed through a lateral approach has decreased rates of subsidence compared to a standard (18 mm) cage at both 3 months (3.7% vs. 8.0%, respectively) and 12 months (7.4%, vs. 12% respectively).[25]

The larger cage also leads to restoration of disc height allowing for significant indirect decompression of the neural elements through increased disc height and ligamentous distraction. Radiographic studies have shown significant increases in neuroforaminal cross-sectional area between 25 and 35%,[26,27] dural sac dimensions of 54% in the anterior-posterior plane and 48% in the medial-lateral plane with a 143% increase in the total area of the dural sac,[28] as well as a 42% increase in disc height[26] with placement of an cage through a lateral approach.

Opposed to cages placed from an anterior approach, LLIF results in preservation of the anterior longitudinal ligament, enabling correction of alignment through ligamentotaxis of the ALL and PLL with restoration of disc height. When used for spinal deformity, LLIF can provide substantial segmental coronal and sagittal Cobb angle correction.[29] For spondylolisthesis, LLIF has been demonstrated to be extremely effective in reducing the degree of slippage of both grade I and grade II lesions with clinically significant improvement in clinical pain scores.[30]

LLIF has also been shown to improve clinical outcomes in patients with lumbar stenosis. VAS scores for back pain and leg pain have been found to significantly decrease after LLIF, with up to 48.9 and 48.2 % improvements being reported, respectively.[20,28] The Oswestry disability index and treatment intensity scale have also been found to significantly improve with up to a 41.7% improvement of ODI reported.[20,28]

In a large prospective study of 122 patients treated with LLIF without direct decompression, 111 out of the 122 patients had good results with improvement or resolution of their preoperative radicular pain.[20] There was a 9% re-operation rate due to failure of treatment, with risk factors for re-operation including bony lateral recess stenosis, osteoporosis, and unstable spondylolisthesis. Osteoporosis can lead to subsidence of the interbody cage, decreasing disk height restoration.[31] Bony lateral recess stenosis was also shown to be predictive of failure of LLIF by Wang et al.[32] CT scans to assess for bony lateral recess stenosis in the setting of facet arthropathy and dynamic imaging to further investigate spondylolisthesis may therefore be prudent prior to attempting indirect decompression with lateral interbody fusion.

9. Complications

Though there are decreased reported complications of vascular injuries and retrograde ejaculation with the lateral transpsoas approach compared to anterior approaches, the lateral approach does carry its own set of significant risks. An overall complication of up to 19.4% has been reported in a large series of 2334 XLIF cases.[33] Neurological injury to the lumbosacral plexus is the most common reported risk from LLIF, though the reported rates vary widely. The incidence of thigh paresthesias and numbness has ranged from 0.7% to 30%, while the incidence of motor weakness has ranged from 1.1% to 23.7%.[19,33–35] The majority of these neurological injuries do recover, with 90% resolving spontaneously within a year after surgery.[34] Directional neuromonitoring with the XLIF (NuVasive, Inc.) platform has significantly reduced the incidence of neurologic injury, with only a 0.7% incidence of transient neurological injury reported in the largest series of 600 cases using directional real-time neuromonitoring.[36]

Peritoneal injuries are also rare but significant complications of LLIFs, with Fujibayashi reporting a rate of peritoneal lacerations of 0.05% in his series of 2334 XLIFs. However, there are multiple case reports of catastrophic bowel injuries as well, requiring further surgical procedures and even leading to death in rare occurrences.[33] Though the incidence of great vessel injury is much less than in ALIFs, they have also been reported with LLIF, with a reported incidence of vascular complications of 0.56% in a large patient series by Kueper et al.[33] Retroperitoneal hematomas have also been reported in multiple cases due to the blunt dissection through the psoas muscle.[37]

10. OLIF

Oblique lateral interbody fusion utilizes a novel retroperitoneal approach to access the intervertebral disc from an antero-lateral approach. It was first described by Michael Mayer in 1977[38] in response to the LLIF as a way to perform interbody fusion while avoiding dissection through the psoas muscle to decrease the risk of neurologic injury, psoas weakness, and retroperitoneal hematomas. The goals of oblique lateral interbody fusion are the same as for lateral interbody fusion; by placing a spacer in the disc space and restoring disc height, dimensions of the central canal and neuroforamen are restored and solid fusion can be obtained. The OLIF procedure has indications similar to those of the LLIF and can be used to treat degenerative, traumatic, and scoliotic pathologies causing spinal stenosis.

11. Anatomy

The approach for OLIF travels through the retroperitoneal fat anterior to the psoas muscle, which is mobilized posteriorly, avoiding retraction on the lumbosacral plexus and genitofemoral nerves. The patient is positioned in the lateral decubitus position, and the incision is made centered on the anterior aspect of the disc space. After piercing through the transversalis fascia, blunt dissection is then carried down through the peritoneal fat, just anterior to the psoas muscle. The OLIF accesses the anterolateral surface of the disc space between the aorta and psoas. A significant benefit to this is approach is the retraction of the psoas muscle from its anterior margin keeps the entire lumbar plexus posterior to the

retractor, precluding the need for neuromonitoring. Another benefit is that the anterior oblique approach allows for access to the L5-S1 disc space as opposed to LLIF, as it is not blocked by the iliac crests.

The discectomy and cage implantation in an OLIF are performed at an oblique angle and as the direction of insertion projects the interbody initially into a contralateral posterior direction toward the neuroforamen, the length of the implant is typically shorter than that for an LLIF. The posteromedial trajectory also has a small risk of displacing additional disc or ligamentous material in the direction of the central canal or the contralateral neuroforamen, making the procedure relatively contraindicated in patients with high-grade central canal stenosis. Furthermore, patients with spondylolisthesis more severe than Meyerding grade I are unsuitable for OLIF because they do not have enough overlap of adjacent endplates to accommodate support for the interbody placed from an anterolateral position.[39]

12. Results

OLIF has also been found to provide significant amounts of indirect compression by increasing disc height. MRI studies have shown a mean disk height increase of 61%, also resulting in an 30.2% median increase in cross-sectional area of the thecal sac.[40] This increase in disc height was also shown to result in a 30.0% average increase in the neuroforamen area.[41] Clinically, OLIF has been shown to statistically reduce VAS scores of low back and leg pain, as well as decrease lower extremity numbness caused by spinal stenosis.[41–43]

Though less literature is available for fusion rates with OLIF due to its shorter history, fusion rates seem comparable to those of ALIF and LLIF. 12-month fusion rates assessed with CT have been reported at 92.9% in patients with posterior pedicle screw supplementation[10] compared to 81.9% in stand-alone OLIF constructs.[44] Similarly to lateral interbody fusion, the OLIF has also been used to treat instability and malalignment. Sato et al. also showed a reduction in slip angle of 9% in low grade spondylolisthesis treated with OLIF.

13. Complications

By avoiding blunt dissection through the psoas and decreasing retraction on the lumbosacral plexus and genitofemoral nerves, the OLIF aims to decrease the risk of neurologic complications. In a survey of 2998 lumbar interbody cases (1995 XLIF and 1003 OLIF), OLIF was found to have lower rates of sensory nerve injury and psoas weakness than XLIF.[33] The risk, however, is still not negligible. The incidence of postoperative thigh numbness ranges from 3.5% up to 21.4%.[33,45] The reported incidence of postoperative weakness of hip flexion and knee extension ranges from 1% up to 13.5%.[33,46] Both numbness and weakness have been reported to resolve in greater than 90% of patients by 3 months.[33]

Another common complication of OLIF is vascular injury, which occurs at a rate similar to that of ALIF. An incidence of segmental artery injury of approximately 2.7% has been reported in multiple studies.[43,46] Silvestre et al. reported a venous injury rate of 1.7% in 176 patients.[42] Other infrequently reported complications of OLIF include injury to the sympathetic trunk, with a reported incidence of 1.7%,[42] and peritoneal laceration and ureteral injuries.[33]

14. Interspinous devices

14.1. *History*

Interspinous devices were developed as an alternative method to fusion for indirect decompression of the lumbar spine. Interspinous devices aim to distract adjacent spinous processes, indirectly increasing the height of the central canal and neuroforamen. The devices also block extension between two adjacent vertebrae, preventing the dynamic phenomena of lumbar stenosis. Benefits to interspinous devices include decreased operative time, blood loss, and soft tissue injury compared with fusion procedures,[47] as well as the maintenance of lumbar motion and a theoretical decreased risk of adjacent segment disease. The X-STOP interspinous process distraction device (Medtronic, Memphis TN) was the first interspinous device to be FDA approved for treatment of lumbar spinal stenosis with neurogenic claudication in November 2005. Newer devices have since been introduced, including the Wallis (Abbott Spine, Austin, TX), Diam (Medtronic, Memphis, TN), and Coflex (Paradigm Spine, LLC, New York, NY), and have shown the ability to indirectly decompress the neural elements and relieve symptoms in clinical studies.

15. Indications

Interspinous devices are FDA approved for treatment of neurogenic claudication in patients with lumbar stenosis. However, due to the biomechanics of these implants, a key subset of patients with neurogenic claudication who would benefit are patients with dynamic stenosis and achieve pain relief in flexion. While clinical studies have shown clinical improvement with these devices in patients with neurogenic claudication with flexion relief, other studies have also shown recurrence in symptoms in patients treated for disc herniations, discogenic back pain, and lumbar spondylosis.[48] Specific contra-indications to interspinous devices include instability, including isthmic spondylolisthesis and degenerative spondylolistheses more severe than Meyerding grade I, ankylosis, and stenosis at L5-S1 due to the anatomy of the S1 spinous process. Conversely, as these devices do not aim to fuse levels, as opposed to interbodies, they may be more suitable for patients in need of indirect decompression of central and foraminal stenosis wanting to avoid fusion procedures.

16. Results

Interspinous devices distract the spinous processes of the adjacent levels, aiming to increase inter-laminar height and stretch the ligamentum flavum. They ultimately aim to indirectly decompress the neural elements by increasing the dimensions of the central canal and neuroforamen.

A statistically significant increase in the spinal canal area of 21–23% in single level and 15–21% in 2 level interspinous procedures has been shown in prospective studies comparing preoperative and postoperative MRIs.[49] In a cadaveric study, a 25% increase in foraminal area was also found after interspinous implantation.[50] The radiographic indirect decompression has also correlated with clinical outcomes. In an FDA–IDE trial between 2001 and 2001, there was a statistically significant improvement in all SF-36 domains in patients treated with the X-stop device compared to a non-operative group at 6 week, 6 month, and 1 year follow up.[51] In the same cohort, 2 year data showed the operative patients had improved by 45.4% over the mean baseline Symptom Severity score compared with 7.4% in the non-operative group. Overall, 73.1% of patients were satisfied with the X-stop treatment compared with 35.9% in the non-operative group at 2 year follow up.[52]

17. Complications

Throughout their history, interspinous devices have been linked to multiple methods of failure, limiting their acceptance and use since their inception. The Knowles device, the first interspinous process device, was first implemented in the 1950s. The device prevented extension at the level of disc herniation, leading to symptomatic relief. The initial design, however, was unfortunately prone to migration and failure. Newer devices have implemented a wing buttress that helps to prevent migration, however, the failure rate still remains unacceptably high. The ultimate re-operation rate has been reported as high as 85%, increasing over time.[53]

The effectiveness at relieving symptoms has also been short-lived. In long term follow up data, 80% of patients were found to have poor or average clinical results at up to a seven year follow up despite initial satisfactory outcomes.[54] This has been called the “bounce-back” effect, with radiologic changes and recurrence of symptoms often seen 2 years following implantation. Next-generation interspinous devices have aimed to fix this and do not appear to be subject to the same “bounce back” effect in recent studies. Reoperation rates in newer generation interspinous devices have been reported at 3.7% at a mean follow up of 24 months.[55]

Implantation of interspinous devices also carries the inherent risk of sagittal imbalance. By distracting between two spinous processes, the devices increase the height of the posterior column without any anterior support, leading to focal kyphosis.

18. Coflex

The Coflex device is one commonly used interbody device developed in 1994 by Jacques Samani. It is a U-shaped titanium implant that is implanted between two adjacent spinous processes. It has lateral wings that are crimped to the spinous processes to improve fixation and prevent migration and failure that have plagued previous interspinous devices. The device theoretically aims to provide indirect decompression by restoring foraminal height, as well as to unload the facet joints and provide stability to decrease dynamic stenosis. Though it is not FDA approved for use for indirect decompression alone, it is frequently used in addition to a direct decompression.

19. Results

Errico et al. showed that in 127 patients with lumbar spinal stenosis, lumbar disc herniation, degenerative spondylolisthesis, or degenerative disc disease treated with Coflex, mean severity of back pain was decreased by 33% at 2 years post op, and remained lowered by 33% at 5-years. VAS scores for back and leg pain were also significantly decreased by 66% with Coflex implantation. However, Richter et al. showed that there were no significant differences in ODI, the Roland-Morris Disability Questionnaire, and VAS scores in patients with lumbar stenosis treated with a decompression alone versus decompression with the additional placement of Coflex interspinous device at 2 years follow up.[56] In terms of maintaining indirect decompression, Park et al. showed radiographically, disc height was increased at initially with Coflex. However, at a minimum of 2 year follow-up, the Coflex group had lost its disc height restoration.[47] This compared unfavorably to an interbody fusion group, which maintained its disc height at similar follow up.

20. Complications

The newer generation Coflex implants with lateral wings which crimp to adjacent spinous processes have been shown to have stronger stability in flexion and lateral bending and axial rotation than devices without crimping.[57] Errico et al. found that 98% of Coflex implants were retained at 7-year follow-up. However, Wilke et al. found that the newer generation Coflex exhibited a wide range of rotation in flexion indicating while crimping may provide good anchorage to the spinous processes, it may also loosen the implant–bony interface.[58]

21. Conclusion

Indirect decompression has been shown to be an effective technique for treating central and foraminal spinal stenosis. Though various techniques for indirect decompression have been presented and discussed, they all aim to increase the height of the disk and interlaminar space. They all effectively increase the total area of the central canal and neuroforamen while reducing the thickness and buckling of the ligamentum flavum. These techniques also aim to treat the dynamic nature of spinal stenosis by blocking end extension either through fusion or by inhibiting movement between spinous process. These devices can all be implanted through minimally invasive technique which can improve patient recovery and decrease surgical morbidity.

There is limited comparative evidence demonstrating that one approach is superior to another in terms of clinical and radiographic outcomes. The present study provides a

broad overview of the advantages, disadvantages, indications and evidence for different indirect decompression techniques. Though the newer generation of interspinous devices have lower failure rates than their predecessors, they still are not comparable to the interbody devices in terms of long term outcomes. Comparing the interbodies, the ALIF, LLIF, OLIF, and MIS-TLIF all have unique surgical applications, executions, and associated complications. All four have similarly high fusion rates. ALIF is generally limited to treating L4-5 and L5-S1 levels, confers the greatest degree of indirect decompression, and has the lowest risk of subsidence. However, the ALIF also has significant complication risks including vascular injury and retrograde ejaculation, often requiring an approach surgeon. LLIF, including XLIF, enables implantation of wide interbody grafts with a low risk of subsidence. It can be used to treat levels L1-L5 but has difficulty reaching L5-S1. The lateral approach also necessitates directional neuromonitoring to minimize neurological complications. OLIF can be used to treat all lumbar levels from L1 to S1 without the need for neuromonitoring. Though it does carry a higher risk of vascular injury than LLIF, the risks of vascular and peritoneal injury are still less than ALIF. However, the oblique postero-lateral trajectory of insertion leads to smaller interbody grafts, thus requiring concurrent posterior fixation due to a higher risk of subsidence. The minimally invasive TLIF has limited the risks that were inherent in the PLIF, but still does carry a higher risk of nerve root and dural injury than the other approaches. Limited visualization of the disc space also leads to smaller interbody grafts, limiting height restoration. However, the established posterior approach allows for concomitant direct decompression, anterior and posterior fusion through the same approach, and access to all lumbar levels. Thus, the optimal approach depends on multiple variables, including but not limited to the spinal level of disease, the anatomy of the individual patient, the pathology being treated, and the familiarity of the surgeon.

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