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INDICATIONS AND ALTERNATIVES FOR FUSION IN THE LUMBOSACRAL SPINE

LUMBOSAKRAL OMURGADA FÜZYON ENDİKASYONLARI VE SEÇENEKLERİ

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SUMMARY:

Stabilization and fusion of the lumbar spine may be performed using various anterior and posterior surgical techniques. Posterolateral fusion involving segmental instrumentation is a viable procedure for the treatment of lumbar instability. In cases requiring anterior column support, supplementary lumbar interbody fusion may provide support to the anterior column and improve the fusion rate and stability of the construct. In this study, we discuss the indications and surgical techniques for lumbar spine arthrodesis.

Key Words: Lumbosacral spine, fusion, anterior fusion, posterior fusion, indication

Level of Evidence: Review article, Level V

ÖZET:

Lomber vertebraların füzyon ve stabilizasyonu anterior ve posterior pek çok cerrahi teknikle yapılabilmektedir. Segmental enstrümantasyonla birlikte posterolateral füzyon lomber instabilite tedavisinde oldukça geçerli bir yöntemdir. Anterior kolon desteğine ihtiyaç duyulan olgularda ise lomber interbody füzyonla anterior kolon desteği sağlanarak füzyon oranları ve stabilite artırılır. Bu çalışmada lomber spinal artrodezin endikasyon ve cerrahi teknikleri tartışılmıştır.

Anahtar Kelimeler: Lumbosakral omurga, füzyon, anterior füzyon, posterior füzyon, endikasyonlar

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INTRODUCTION:

The main goals of spinal surgery are neurological decompression, the provision of normal stability, reduction, the maintenance of normal sequence, and fusion. Lumbar spinal fusion has been used for nearly 70 years for degenerative spine diseases such as symptomatic spinal stability, spinal stenosis, and spondylolisthesis[35]. At present, various lumbar fusion techniques have been developed for this purpose.

INDICATIONS FOR LUMBAR FUSION:

The most important determinant of success in lumbar fusion is the choice of a suitable patient. The highest clinical and radiological success after surgical arthrodesis is obtained for patients who have an instability or deformity that can be defined radiologically.

UNSTABLE SPINAL STENOSIS:

Acquired lumbar spinal stenosis is a period of disc degeneration and collapse in addition to facet and ligamentum flavum hypertrophy. Spondylosis alone is present in the stable form, and it is possible to treat the symptoms with decompressive applications. In the unstable form, spondylosis coupled with either spondylolisthesis or scoliosis, or both, can be observed. The application of decompression alone for these patients temporarily decreases the neural symptoms, but causes extra instability[15].

DEGENERATIVE SPONDYLOLISTHESIS:

Degenerative spondylolisthesis is an acquired situation that is generally seen together with lumbar spinal stenosis. Patients are typically admitted due to lower back pain, neurological claudication and root (lateral reses) symptoms. Neurological examinations of many patients are normal. Generally, grade 1 or 2 spondylolisthesis is observed due to the translation of the upper spine forwards on the lower spine at the L4–5 level. In lumbar dynamic X-rays, an abnormal translation or angular movement can be observed. In the sagittal plane, the presence of a translation greater than 4 mm or an angulation greater than 10° are useful graduation parameters for the evaluation of the presence of instability. A lack of movement cannot eliminate segmental instability. Generally, complaints decrease with conservative methods, such as patient training, controlled physical activity, weight loss, posture control, stretching exercises for the lower back and abdominal muscles, anti-inflammatory drugs, and the use of a brace. Surgical methods such as decompression, arthrodesis, and segmental instrumentation should be applied to patients with radiological instability, excruciating pain, progressive neurological deficit, and a significant decrease in their daily activities.

DEGENERATIVE SCOLIOSIS:

Degenerative scoliosis is an acquired spinal deformity that primarily affects the lumbar vertebrae, is accompanied by neurological findings, and presents itself with lower back pain. The combination of disc collapse, facet hypertrophy, and a rotational component to the scoliosis causes a decrease in volume of the spinal canal and an increase in the spinal stenosis symptoms. Radicular symptoms, based on a collapse at the concave side and traction at the convex side, can be observed. Static and dynamic (lateral bending and flexion-extension) X-rays are helpful for the evaluation of the scoliosis levels,

the potential angulation and translation in the coronal and sagittal planes, and the instability.

ISTHMIC SPONDYLOLISTHESIS:

Isthmic spondylolisthesis is the most common form of spondylolisthesis, and it is characterized by a pars interarticularis defect at the L5–S1 level. Patients are generally between the ages of 10–14, and lower back pain is the main complaint, sometimes accompanied by L5 root findings. Surgical treatment is recommended for symptomatic patients with a shift of Grade 3 or more, patients with a progressive shift or symptoms, and patients with severe pain or neurological signs who do not respond to conservative methods. It is possible to obtain satisfactory results with posterolateral *in situ* arthrodesis, combined with decompression when necessary.

TRAUMA:

On the basis of Denis' three column theory, traumas that concern two or more columns or include the posterior ligamentous complex are accepted as unstable and require reduction, fusion, and internal fixation[13]. Other indications for surgical treatment are wedge fractures resulting in compression of the anterior column by more than 50% with significant kyphosis and pain, spinal stenosis of more than 50% despite a normal neurological condition, burst fractures causing an angular deformity of more than 20%, and seatbelt-type injuries including the ligamentous complex and discs.

TUMOR AND INFECTIONS:

Surgical treatment of tumoral and infective diseases are performed to remove the instability and cord pressure caused by tumor infiltration to the anterior and middle columns, and destruction due to a period of inflammation. Metastatic tumors of the spine are generally related to the middle and anterior columns. The life expectancy and general health condition influence the decision regarding surgery for these patients. Intolerable pain, new or progressive neurological deficits, vertebral collapse due to middle and anterior column destruction, posterior decompression, or iatrogenic instability due to anterior vertebrectomy are indications for surgical treatment. The aims of surgical treatment are to reduce pain, to decompress the neural elements, and to provide mechanical stability. The types of fusion and instrumentation used are decided according to the localization of the tumor. For spinal infections, aggressive antibiotic therapy is essential. However, fusion and instrumentation is indicated in the presence of vertebral destruction of more than 50% due to osteomyelitis, antibiotic-resistant infections, progressive angulation, or new or progressive neurological deficits.

IATROGENIC (SECONDARY):

For a small number of patients who previously received operative treatment for any reason, fusion and stabilization are required due to a secondary instability. Biomechanical studies have shown that an unstable mobile segment can form when an entire facet or more than 50% of both facets is removed in posterior decompressive procedures, such as bilateral disc excision with decompression and removal of the pars interarticularis, especially at more than one level. In these cases, prophylactic fusion should be performed during surgery. Recurrent disc hernias are also indications for fusion

and stabilization. Patients with three or more recurrences and whose radicular symptoms and lower back pain continue should be evaluated in this group. Decompressive laminectomies, new deformities accompanied by pain and/or neurological signs after disc excision, or progression in the current deformity also require arthrodesis and instrumentation. For patients who previously received arthrodesis, indications for reoperation and fusion are progressive deformity or spondylolisthesis, symptomatic adjacent segment disease, and pseudoarthrosis.

SEGMENTAL INSTABILITY:

The indications for spinal fusion are controversial in the treatment of degenerative disc disease. The separation of discogenic pain and mechanical lower back pain with disc degeneration has been not clearly revealed. For patients with segmental instability, neurological signs and radicular pain cannot accompany the disease. Many techniques such as discography and MRI are used for diagnosis. For degenerative disc disease, arthrodesis is performed to prevent the physiological movements that cause pain by immobilization of the disc space. The success rates vary from 30–90%. Posterolateral, anterior and posterior interbody, and circumferential fusion techniques can be used in the surgical treatment of segmental instability.

SPINAL FUSION ALTERNATIVES:

Fusion, a gold-standard treatment method for many spinal diseases, including degenerative spine diseases, is the most important method used to remove pain caused by non-functional intervertebral discs. The main aim of fusion surgery in many situations is to immobilize vertebral segments whose movements are thought to be the cause of pain.

Posterolateral fusion is a technique with good clinical results that has application areas in common with fusion rates[5,17].

Many fusion techniques have been developed to remove movement and to balance distribution with or without instrumentation, and the clinical efficacies of each technique have been shown by various clinical studies.

POSTEROLATERAL FUSION:

Posterior inter-transverse and trans-facet arthrodesis of the lumbar vertebrae is the most common method of spinal fusion. This is generally applied with a posterior midline approach. After revealing the spinous projections and lamina, dissection is extended to the transverse projections and the lateral facet joints. The transverse projections, pars interarticularis and facet joints are the primary fusion regions. This procedure is generally applied alongside decompressive lumbar laminectomy and foraminotomy. Rigid internal fixation is recommended in many patients.

Rigid internal fixation of the lumbar vertebrae increases the arthrodesis rate, helps deformity correction and provides stabilization in the early period. When internal fixation is added, the pseudoarthrosis rate considerably decreases. In many patients who receive posterior lumbar fusion, pedicular screw instrumentation is performed. Bone grafts obtained from decompensation are combined with a graft taken from the posterior iliac wing, if necessary, and this is filled into decorticated facets and between the transverse projections along the

lateral edge of the pars interarticularis. The most suitable method is to place corticospongious strips on spongious bone grafts after gentle squeezing, and then gently compressing (Fig-1). Placing grafts longitudinally between transverse projections by surgical wrapping is a useful method to prevent the grafts from disintegrating and providing integrity to the bone grafts (Fig-2)[19].

However, the posterolateral fusion technique and fusion rates have been improved by the development of other techniques, in particular internal fixation techniques and transpedicular screw application[31].

In a recent study that examined spinal fusion techniques in lumbar spondylosis by meta-analysis of randomized clinical studies[37], it was shown that the operation time was significantly shorter and there were less perioperative complications in posterolateral fusion cases. For patients who received interbody fusion, there was significantly more blood loss and the fusion rate was higher. There were no significant differences in terms of pain, functional improvement, and time of returning to work.

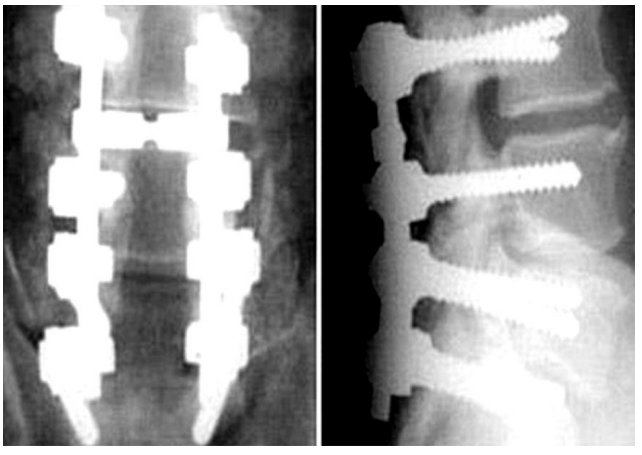

Figure-1. Instrumented laminectomy and posterolateral fusion.

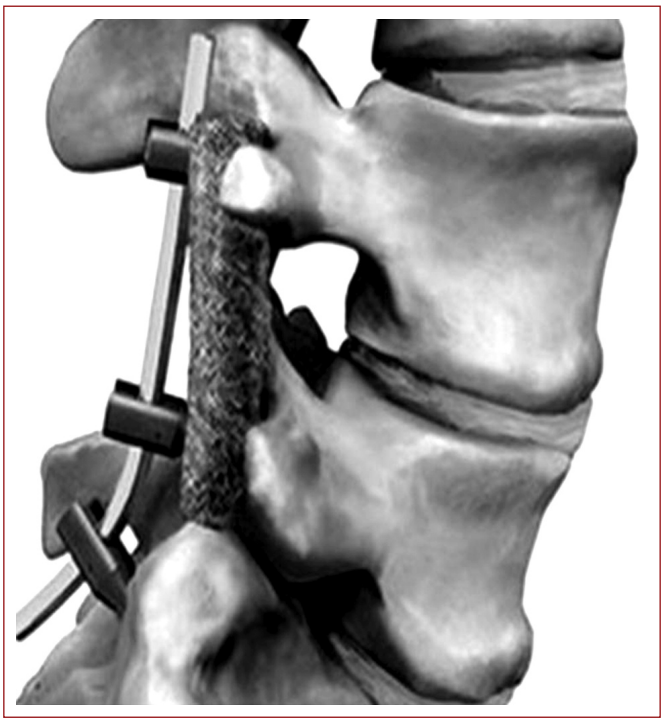

Figure-2. Schematic illustration of placement of graft by surgical wrapping during posterolateral fusion.

INTERBODY FUSION:

The method of fusion that is applied to the intervertebral disc space between two vertebral corpuses is called interbody fusion. The aim of interbody fusion is to provide the widest fusion area in agreement with load handling principles in the anterior column where the greatest load is, and to restore disc height, foramen height, spinal axis sequence and lumbar lordosis. Various interbody fusion techniques have been defined regarding the placement and type of graft, cage usage and type, diversity of allografts and autografts, and their uses. Almost all of the indications for interbody fusion are similar to the indications for lumbar instrumented laminectomy and posterolateral fusion. The most controversial indication for interbody fusion is discogenic lower back pain without radicular symptoms due to disc degeneration.

Although there are many advantages, there are also contraindications to this application of the surgical interbody fusion technique, which will be discussed in the relevant sections[14].

The methods for interbody fusion that are used in surgical practice are anterior lumbar interbody fusion (ALIF), axial lumbar interbody fusion (AxiaLIF), posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), and extreme lateral interbody fusion (XLIF).

ANTERIOR INTERBODY FUSION (ALIF):

The ALIF technique was first used in cases of lumbar spondylolisthesis by Capaner in 1932[4]. The ALIF method was suggested in order to totally remove the disc thought to be the source of pain, to restore the heights of the disc and foramen, and to remove abnormal segmental movement due to disc degeneration. The first lumbar ALIF approach was defined retroperitoneally[1]. Over time, a transperitoneal way was defined and is now commonly used. The L2–5 segments can be approached in a lateral retroperitoneal way, and the L4–S1 segments can be approached in a retroperitoneal or transperitoneal way from the midline. If the approach is performed at the L5–S1 level, the aorta and vena cava bifurcation should be evaluated preoperatively. The advantages, indications and contraindications of the ALIF method are given in Tables 1, 2 and 3[11].

When the application of ALIF alone is compared to ALIF in combination with posterior instrumentation, fusion rates as high as 100% are seen[18,36]. By fusion screening using a thin-section CT, the fusion rate was detected as 51% for cases using ALIF alone, 58% for cases using a translaminar screw with ALIF, and 88% for cases using a transpedicular screw with ALIF[1].

Table-1. Advantages of ALIF method

• Provides full entrance to disc tissue from anterior
• Provides wide fusion area
• Increases the load carrying capacity
• Restores disc height and therefore foramen height
• Immobilizes painful spinal segment
• Restores spinal balance
• Allows short segment fusion

Table-2. Indications for ALIF method

• Degenerative disc disease
• Degenerative spondylolisthesis
• Isthmic spondylolisthesis
• Spinal stenosis (in the presence of instability)
• After failed back surgery
• Pseudoarthrosis after other fusion approaches
• Spondylodiscitis

Table-3. Contraindications for ALIF method

• Previous abdominal operations
• Vascular abnormalities (different vessel bifurcation at L5-S1 level, etc.)
• Intra-abdominal diseases (Crohn's disease, etc.)

Therefore, the fusion rate in cases using ALIF alone is lower than in cases that also used an extra stabilization technique. In studies that measured the long-term clinical improvement, clinical improvement rates that reach 80% have been reported after a ten-year follow-up[34]. Despite the many benefits of this technique, it has been suggested that ALIF is only applied by experienced surgeons and in centers with access to general surgery and vascular surgery, because of severe complications such as peritoneal rupture, ureter and major vessel

injuries, abdominal wall hernias, and retrograde ejaculation in male patients.

Retroperitoneal approach (L2–5):

Under general anesthesia, the patient is laid down in the right lateral decubitus position, so that the left side remains up. Under fluoroscopy, the incision site is determined. The ideal skin incision is an oblique incision performed in parallel to the external oblique muscle. The peritoneum is encountered after the superficial muscles. After reaching the retroperitoneal area with blunt dissection with no damage to the peritoneum, the genitofemoral nerve is seen on the psoas muscle and is preserved. The psoas muscle is bluntly skimmed towards the posterior over the desired disc, and the disc is reached. The accuracy of the disc space is confirmed at this point by fluoroscopy, then the annulus fibrosis is opened and the discectomy is performed with direct vision. It is important in terms of fusion to perform a full discectomy with protection of the bone endplates by scraping the cartilage of the endplates. The cartilage parts of the endplates should be fully curetted, but the bone endplate and the subchondrial bone should be preserved. While removal of the cartilage endplate increases the fusion rate, protecting the bone structure decreases the risk of the graft collapsing into the corpus. Distracting the disc space before placing the graft material provides the placement of the graft under compression forces and helps restore lumbar lordosis.

Approach to the L4–S1 interval (Transperitoneal or retroperitoneal):

The patient is placed in a supine position on the operating table under general anesthesia. Standing between the patient's legs provides the surgeon with the ideal control of the surgical field. In weak patients, the L5–S1 interval is reached by blunt dissection from the right side of the abdominal wall, omitting the common iliac artery, vein and right ureter. In overweight patients, the transperitoneal way should be preferred. The parietal peritoneum is opened with a vertical incision, from approximately 5 mm medial to the common iliac artery in the craniocaudal direction. The intra-abdominal organs are pushed towards the upper abdomen by the abdominal pad. After opening the peritoneum, the retroperitoneal region is entered. After revealing the L5–S1 disc, the discectomy and fusion processes are completed in a similar way as described in the retroperitoneal approach (Figure-3).

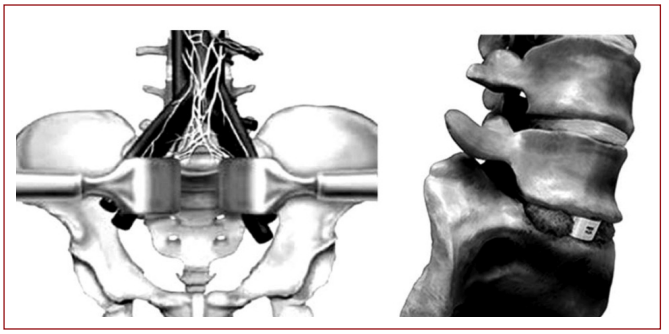

Figure-3. Schematic illustration of anterior lumbar interbody fusion.

Table-4. Indications for AxiaLIF method

• Fusion need in L4/L5-S1 segment
• Symptomatic degenerative disc disease
• Instability
• Pseudoarthrosis
• Spondylolisthesis (Grade 1 or 2)
• Failed fusion approach

Table-5. Contraindications for AxiaLIF method

• Coagulopathy
• Bowel Disease (Crohn's disease, ulcerative colitis)
• Previous bowel surgery, pelvic disease, perirectal abscess
• Previous anterior pelvic surgery (tumor, trauma)
• Sacral agenesis
• Advanced spondylolisthesis (>Grade 2)
• Osteoporosis
• Pregnancy
• Severe scoliosis

PERCUTANEOUS AXIAL LUMBAR INTERBODY FUSION (AxiaLIF):

This method aims to protect the annulus and other supportive structures and to provide interbody fusion without major surgery With minimal invasiveness at the presacral axial entrance, fusion is achieved by placing instrumentation and a graft in the L5–S1 or L5– S1 and L4–5 space.

AxiaLIF (TranS1, ININc., Wilmington. NC) combines the advantages of minimally invasive spinal surgery methods in a new approach. With a small paracoccygeal incision and a percutaneous presacral approach facing the S1 vertebra, the L5–S1 disc space and the L5 vertebra can be reached, while protecting the integrity of muscles, ligaments and the disc annulus[10,16,32]. The indications and contraindications of the AxiaLIF method are given in Tables 4 and 5[27].

The patient is placed in a prone position on a table suitable for fluoroscopy. A skin and subcutaneous incision is performed at the midline or 15 mm lateral to the midline at 20 mm caudal to the right or left side of the paracoccygeal projection.

A guide pin introducer and stylus are placed into the incision and moved gently and slowly through the sacrum anterior midline. The introducer is placed at about the S1–2 space at the presacral region with fluoroscopy. A sacral working cannula is placed and the disc space is reached by drilling the sacrum. Discectomy is performed with special instruments in the set and the endplate is cleaned. After filling the disc space with the bone graft, a rod is placed with an axial rod driver and intervertebral stabilization is performed (Figure-4).

The application of a transsacral rod was biomechanically tested on 24 mobile spine segments obtained from freshly frozen calf spines[24]. A 143.8% increase in axial compression rigidity was shown. This increase was statistically significant ($p<0.05$). Statistically significant decreases in flexion, extension and rotation movements were obtained. The average stiffness and range of motion for the transsacral rod were compared to the previously reported BAK, Harms and Brantigan cages, fixed devices, femoral ring allografts, and bone blocks[29].

The sagittal and lateral bending rigidity of the transsacral rod were greater than those of all other interbody devices.

Aryan et al.[2] applied AxiaLIF to 35 cases. Percutaneous L5–S1 screw-rod stabilization was used for 21 of them, and it was observed that the L5–S1 interbody rod was stable, and fusion occurred in 91% of the cases.

TRANSFORAMINAL LUMBAR INTERBODY FUSION (TLIF):

Transforaminal lumbar interbody fusion (TLIF) is a modified version of posterior

lumbar interbody fusion (PLIF) that was applied for the first time in 1982 by Harms and Rolinger[9].

The main aim of TLIF is to provide 360° of arthrodesis. It is commonly used by spinal surgeons, due to the fact it provides more lateral entrance, requires less dura retraction and allows better cleaning of the disc and endplates than PLIF, and therefore provides high fusion rates and low complication rates. The indications, contraindications, advantages and complications of the TLIF method are given in Tables-6,7,8,9[33].

After a posterior midline skin incision in a prone position, the skin, muscle and soft tissues are excluded to the lateral by subperiosteal dissection, so that the spinous process, lamina, and facet joints become visible. Under fluoroscopic control, pedicular screws are delivered to the relevant segment by a transpedicular way.

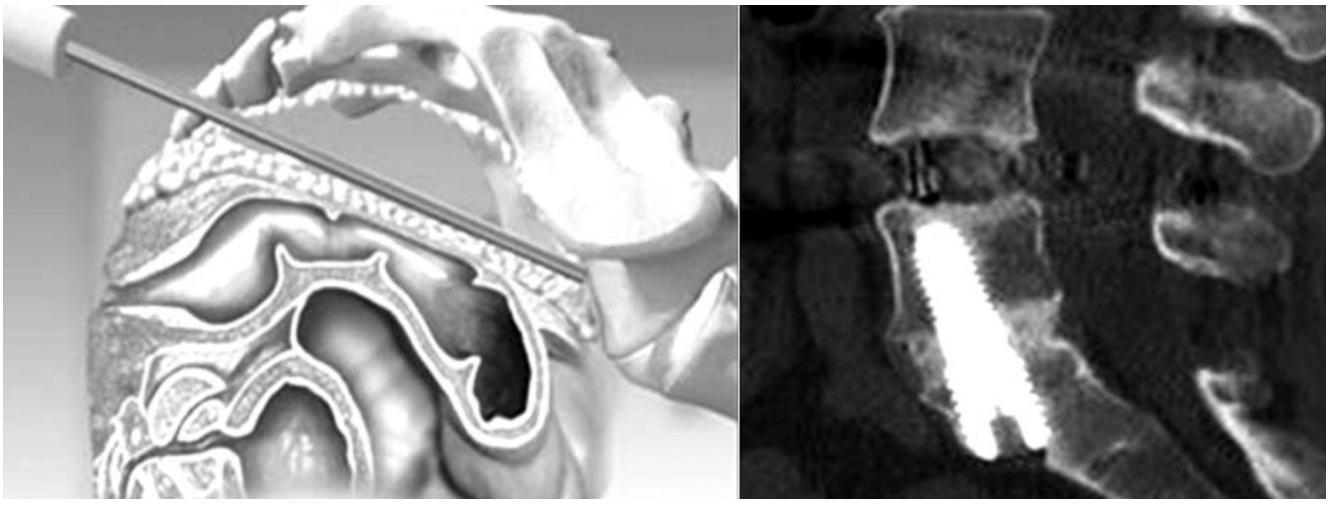

Figure-4. Trans-axial lumbar interbody fusion.

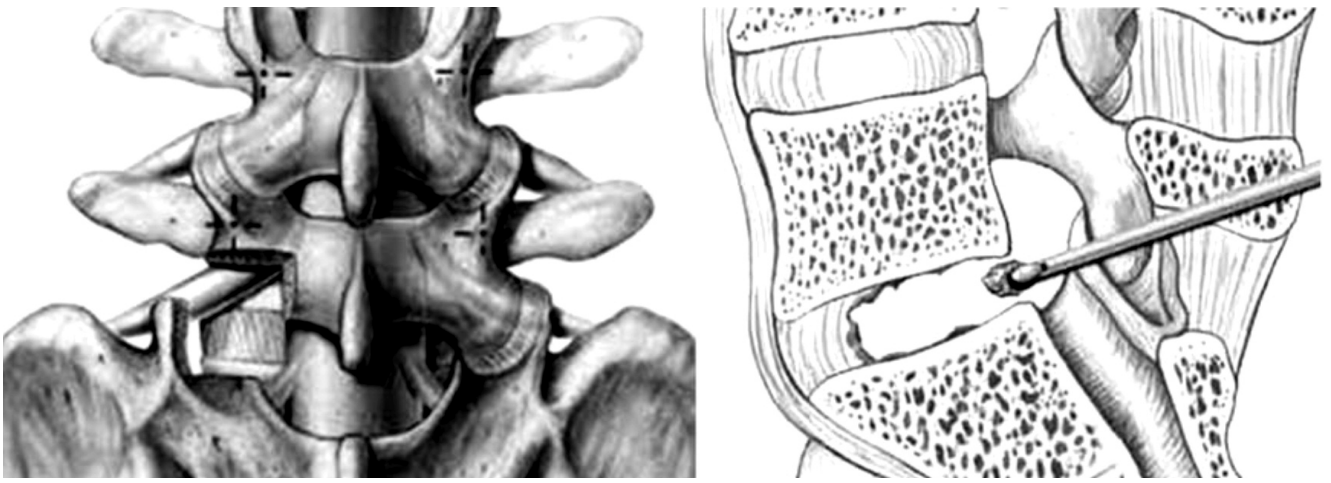

Figure-5. Transforaminal lumbar interbody fusion.

Neural decompression is provided by either hemilaminectomy, facetectomy, or both, depending on the clinical status and neurological compression. After removal of the cartilage endplates and discectomy, the intervertebral disc space is opened by pedicle screw distraction, and fusion is obtained at the anterior and medial of the disc space, generally by using cages or an autograft through the opened transforaminal way to provide lumbar lordosis. Posterolateral fusion is performed after transverse process, pars interarticularis and decortication of the contralateral lamina and facet.

TLIFis a successful posterior fusion method that provides complete decompression of the neural foramen and nerve root at the fusion level, restoration of the intervertebral disc height,and segmental lordosis, and shows a fusion rate of 74–94%, and good or better clinical results with a rate of 75– 90% (Figure-5)[3,7,8,23,28,30].

Table-6. Indications for TLIF method

• Grade 1 and 2 spondylolisthesis with mechanical lower back pain or radicular symptoms (degenerative or lytic)
• Reluctant high grade spondylolisthesis
• Central canal stenosis
• Lateral reses syndrome
• Facet joint disease
• Severe discogenic lower back pain
• Lumbar segmental instability
• Recurrent disc hernia
• Post-laminectomy instabilities
• Pseudoarthrosis treatment
• Failed lumbar fusion with other techniques

POSTERIOR LUMBAR INTERBODY FUSION (PLIF):

PLIF is a procedure that has gradually lost popularity after the development of TLIF, which provides interbody fusion by placing cages or grafts in the disc space from an annular portal opened after a classic discectomy. Partial facets and lamina/laminae at a relevant distance should be removed in order to see the annulus and nerve roots. After cauterization of the epidural veins, the dural sac should be pulled to the medial. A PLIF retractor can be used to protect the nerve roots and dura. The laminae are removed with a posterior approach, while the spinous projection can be left. Leaving the spinous projection in place can be a guide for midline orientation. After removal of the intervertebral disc, fusion is provided by placing cages that are filled with bone graft. These cages can be produced from titanium, ceramic or carbon materials. This application can be performed alone or with posterior instrumentation. Fusion rates of between 88 and 96% have been reported in different studies using PLIF (Figure-6)[38,8,26].

Table-7. Contraindications for TLİF method

• Mechanical lower back pain or radicular symptoms
• High graded spondylolisthesis
• Severe osteoporosis
• Previously performed foraminotomy

Table-8. Advantages of TLIF method

• Requires less dural sac and nerve root retraction than PLİF and reduces possible dura injury and neurological damage (6,20,21,22).
• Provides posterior fusion possibility with interbody fusion
• Complications such as retrograde ejaculation and major vessel injuries observed in anterior approaches do not occur

Table-9. Complications of TLIF method

• Nerve root edema and dura injury due to retraction
• Endoneural fibrosis
• Chronic radiculopathy
• Pseudoarthrosis

EXTREME LATERAL INTERBODY FUSION (XLIF):

XLIF is a new minimally invasive anterior spinal approach, with no need for incision of the muscles in the abdomen and lower back. In this fusion technique, the disc space is seen through two small incisions. Imaging of the spine is provided by specific retractors and C-armed fluoroscopy. In addition, protection of the adjacent neural tissues is provided by the use of neuromonitorization. After removal of the disc material, a polymer or titanium cage or a bone graft alone can be placed (Figure-7). This technique reduces the duration of hospitalization, and less pain occurs. The indications, contraindications, advantages, complications and disadvantages of the XLIF method are given in Tables-10,11,12,13 and 14[12].

Table-10. XLIF indications

• Lumbar degenerative scoliosis
• Lumbar degenerative disc disease (adjacent segment disease etc.)
• Grade 1–2 lumbar spondylolisthesis
• Lumbar pseudoarthrosis
• Discogenic lower back pain
• Lumbar discitis
• Lumbar disc diseases requiring anterior approach
• Total disc replacement revision

Table-11. XLIF contraindications

• Symptomatic L5–S1 disc disease
• Lumbar deformity with rotation of more than 30°
• Lumbar spondylolisthesis of more than Grade 2
• Retroperitoneal two-sided adhesion
• Approaches requiring only decompression

Table-12. XLIF advantages

• No ileus is observed
• Mobilization is possible next day
• High patient satisfaction
• Safe
• Short-term anesthesia
• Can be applied to obese patients
• Low morbidity rate

Table-13. XLIF complications

• Paresthesia in the femur: 30% (5% permanent)
• Psoas hematoma: 5%

Table-14. XLIF disadvantages

• Requires learning process
• Does not allow decompression
• Needs special instruments
• Posterior stabilization can be required
• Difficult to apply to L5–S1 level

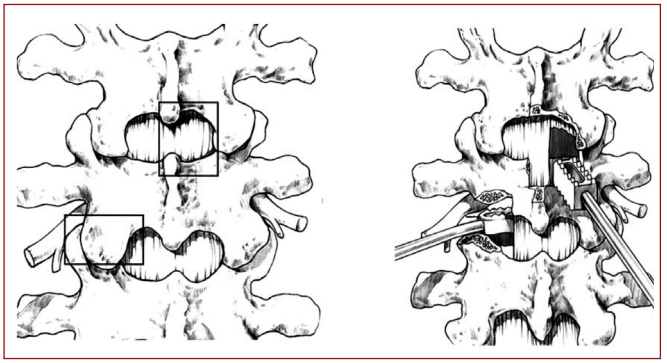

Figure-6. Schematic illustrations of sites of PLIF and TLIF entrance.

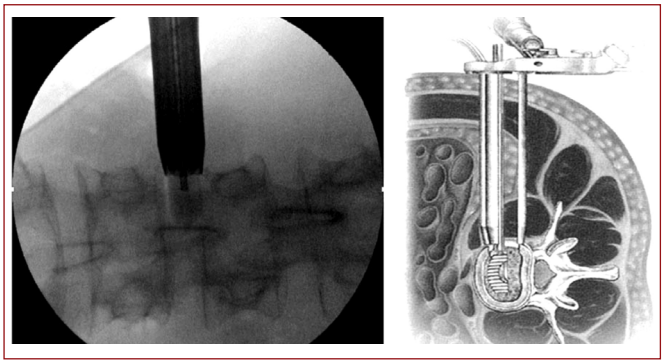

Figure-7. XLIF: Extreme lateral interbody fusion.

CONCLUSIONS:

As described above, various different fusion methods are available to re-stabilize the lumbar vertebrae after decompression. The surgeon should prefer the most suitable fusion method, taking into consideration the patient's need, the surgeon's experience, and the physical conditions of the hospital. The most important factor for the success of surgical treatment is a solid grasp of these techniques and their applications in a broad spectrum of clinical practices.

Interbody fusion is increasingly being used with a high success rate by spinal surgeons, especially for failed lower back and revision surgeries. We commonly use interbody fusion in our practice, in particular transforaminal lumbar interbody fusion, due to its advantages.

Today, although approaches to lumbar fusion with fusion rates of about 90% and improvements in graft, implant and surgical techniques are gold standards for the treatment of lumbar deformity and instability, a major disadvantage is the removal of movement and extra problems such as adjacent segment disease. We consider it likely in the near future, as the molecular basis of disc degeneration is elucidated, that systems will be developed that allow physiological movement with decompressive surgery, that are not subject to failure, and that protect the discs from degeneration.

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