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Perspective of Lumbar Segmental Instability for Surgical Evaluation of Lumbar Disc Herniation

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Abstract

Surgery of lumbar disc herniation is most common procedure in neurosurgical practice. However poor outcomes, recurrent disc herniation and recurrence of low back and leg pain which affect quality of life, are still challenging. Lumbar spine instability develops as a result of a gradual degenerative process and lumbar segmental instability is one of main reason of failed back surgery. Presence of lumbar segmental instability or potential secondary instability after surgery should not be overlooked. Accurate preoperative evaluation of patients with lumbar disc herniation needs to understand biomechanics of spinal stability and predict possible result of postoperative instability. Thus failure of treatment modalities can be avoided.

Keywords: Lumbar disc herniation; Segmental instability; Dynamic stabilization

Intorduction

Lumbar disc herniation is one of the most common entities in neurosurgery practice. The surgical management of this disease is very well defined for either microsurgical or endoscopic lumbar discectomy. However those concrete procedures can lead some unfavourable results. The recurrence of disc herniation and/or complaints of low back and radicular leg pain are still challenging [1]. Lumbar segmental instability (LSI) is another entity that can also see concurrently in patients with lumbar disc herniation and worsens the outcome of surgery. Furthermore, lumbar discectomy may lead to LSI (secondary instability). Management of patients with lumbar disc herniation under perspective of LSI can help to improve poor results. However, basic knowledge of biomechanics and anatomic structure of both normal and instable lumbar segment must be obtained.

Healthy Motion Segment of Spine

Functional Spinal Unit (FSU) expresses integrity of two adjacent vertebra, intervertebral disc and ligaments. FSU composes the microcosmic structure for stability of whole spine. This unit allows flexion, extension, lateral bending and rotational movements while resisting physiological and excessive loads overlapping on each motion segment. This resistance, which is supplied by facets, intervertebral, disc, anterior and posterior ligament structures, limits motion of the spine in every direction and keep the stable spine under physiological limits and prevents excessive motion. For example, normal motion segment preserved by posterior ligaments (interspinous and supraspinous), facet joints and facet capsule, intervertebral disc, and para-spinal muscles during flexion; by anterior longitudinal ligament, the frontal side of the annulus fibrosis, facet joints and the abdominal muscles during extension; and by intervertebral disc and facet joints during rotational motion [2]. Panjabi described 'The system of spinal stability' in terms of three subsystems. Panjabi's subsystems are classified into three in number [3].

Passive system

Intervertebral disc, vertebral body, facet joints and ligament structures constitute the passive support of spine stability by limiting the excessive motion that can appear during overload.

Active system

Muscles, fasciae and tendon structures surrounding the vertebral colon constitute the active systems and stability can be achieved only by absolute presence healthy active support of this subsystem [2]. The active subsystem enables stabilization voluntarily or as a reflex when a load is applied on to spine [4].

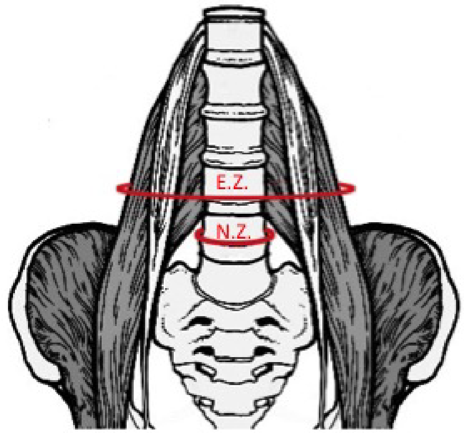

Figure 1: A schematic view of *Neutral Zone* in which the movement begins with little resistance, and *Elastic Zone* where the rest of the movement occurs against high resistance. Total movement in these 2 regions together forms total physiological Range of Motion (ROM).

Neural control

Healthy neural control receives information from muscles, fasciae and tendons, which are the active and passive subsystems, and coordinates spinal stability utilizing paravertebral and abdominal muscles (active system) [2].

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Satisfactory spinal stability can only be obtained by interrelated support of these three subsystems during posture changes and static or dynamic overloads [2]. Thus any injury related with spine can be prohibited. Hence, physicians should take care of recruiting the local stabilizers of the joint segment damaged, and improving motor control to obtain concrete neuromuscular control and endurance.

Range of motion (ROM) of spine refers movements within specific limits in in the sagittal, coronal and axial planes and ROM is different for each motion segment of lumbar spine [5]. Panjabi was divided this physiological motion range into 2 parts (Figure 1) [3].

1. Neutral zone.
2. Elastic zone.

The movement of motion segment begins with minimal resistance in neutral zone. When higher loads are applied on motion segment, the movement continues into more resistant elastic zone till end of ROM. The stability of spine is provided with controlling ROM through these two zones [3]. This control is supplied under control of tendomuscular structures of active system in neutral zone and osteoligamentous structure of passive system in elastic zone [2].

Panjabi represented the stable (pain – free), unstable (painful) and re – stabilized spine (pain free) by using "a ball in a bowl" analogy and load – displacement curve. A ball can move easily in the bottom of the bowl (neutral zone) and in a deeper bowl like a wine glass, the neutral zone is decreased and this represents a stabilized pain – free spine. However, neutral zone is enlarged in a shallow bowl like a soup plate, the ball moves more and this express to unstable (painful) spine (Figure 2) [6].

Lumbar Segmental Instability (LSI)

Instability simply is a situation that stability parameters described above are absent or dysfunctional. Panjabi defined segmental instability as "*Extension of the neutral region that cannot be held at physiological limits when a problem occurs in subsystems that provide the stability in the spine*". Segmental instability is defined by AAOS (American Academy of Orthopedic Surgeons) as "*development of motion above normal when there is any load on the spine*" [2].

Because of the neutral zone is the most vulnerable region for instability in lumbar spine, in case of lack of active subsystem support and pathologic changes in passive subsystem, instability might occur even under small loadings. The loosening of resistance in motion segment due to anatomic or physiological pathologies related to the vertebral corpus, intervertebral disc, facet joints, ligaments or muscles which keep the spine stable, the lumbar segment can't stay in normal physiological limits. Therefore an enlargement in the limits of neutral zone causes to increase at total ROM. Taking all these point into the consideration, LSI is defined as "expansion of the motion in the segment that does not remain in the limits due to problems developed in the stabilizing subsystems of the spine" [2].

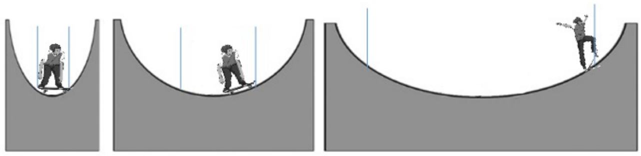

Figure 2: The skater moves easily against minimal resistance in the bottom of the skate platform (Neutral Zone), and moves against high resistance and needs more power at the lateral part of the skate platform (Elastic Zone). The movement of the skater is limited when the bottom of the skate platform is narrow which represents a small Neutral Zone (stable spine). When the base of the skate platform is splayed, skater move easily against lower resistance and needs less power at the lateral part of the skate platform (disturbed and enlarged Neutral Zone with Elastic Zone).

Evaluation of LSI in Lumbar Disc Herniation

There are some clinical tests to detect LSI evaluate while examine the patient. The patient lies prone for passive accessory intervertebral motion (PAIVM) test. The clinician presses the spinous process of the target vertebra with his hypothenar eminence, and forces gradually. The passive physiological intervertebral motion (PPIVM) test is done under flexion and extension posture. The patient is positioned side – lying and the clinician palpates the interspace between the adjacent spinous processes of the target motion segment with one finger. Then hypermobility is evaluated according to scale while moving the lumbar spine from neutral into flexion or extension via the patient's uppermost limb. High specifity of PAIVMs and PPIVMs for detection of translation LSI were reported. However sensitivity is low for those testes [7,8]. Passive lumbar extension test (PLE) is relatively new technique to evaluate LSI. The patient lies in the prone position. Lower extremities were then gently pulled and elevated together which knees are in extended position. Passive elevation is performed till approximately 30 cm above from the bed. Increase in pain during lifting and relieving while turn to neutral position indicates LSI [8].

Indirect findings with regards to instability such as narrowing in disc space, disc degeneration vertebra endplate sclerosis, osteophyte development, bone spur structures, facet joint degeneration and vacuum phenomenon can be detected in neutral radiography and computed tomography (CT). Additionally dynamic radiographs are obtained in the sagittal plane in the neutral position, flexion, and extension. Translations more than 3 mm or 10^0 of angulation in dynamic graphs are accepted as instability criteria [9,10]. Even though dynamic graphics are cheap and easy to obtain, specificity and accuracy of the findings are matter of debate. Miscalculation of translations or angulation, overlooked instability in case of muscle spasm, and being non beneficial on other planes (coronal, rotational instability) are some problems related with dynamic graphics [2].

Lumbar Magnetic Resonance Imaging (MRI) gives information about intervertebral disc, facets, endplates, bone marrow and spinal canal. Presence of large annular defect, recurrent disc herniation and/or Modic changes, which can be seen in Lumbar MRI, might be very significant indicators of LSI [11]. The Modic vertebral endplate and bone marrow changes are classified under three types according to view at Lumbar MRI [12] :

- **Type I changes:** These indicate bone marrow oedema and inflammation which appear hypo intense on T 1 – weighted imaging (T1WI) and hyper intense on T 2 – weighted imaging (T2WI).
- **Type II changes:** These indicate yellow fatty formation in bone marrow due to ischemia which appears hyper intense on T1WI and iso intense or slightly hyper intense on T2WI.
- **Type III changes:** These indicate subchondral bone sclerosis which appears hypo intense both on T1W1 and T2W1.

Although patients with Modic type I changes are more likely to have LSI, both type I and type II Modic changes are accepted as unstable lesions and type III Modic changes still remains unclear [11]. Modic changes represent degeneration on endplate and bone marrow, which lead to reduction at nutrient supply of intervertebral disc [13]. This disruption of perfusion and diffusion of intervertebral disc may

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lead to insufficient postoperative recovery of disc tissue. Therefore, recurrent disc herniation or recurrent discogenic pain might be more risky independent from whether presence of LSI (Figure 3).

Intraoperative evaluation is also essential. Even there is not clinical and radiological evidence of LSI, hypermobility at intervertebral disc or facet joint must be evaluated. Furthermore, surgical manipulations such as thinning of pars interarticularis or impairment at facet joint lead to postoperative LSI. Therefore, stabilization can be performed in that situation.

Management of Lumbar Disc Herniation with LSI

Many indications of surgery for lumbar disc herniation are still in debate except some urgent situations such as cauda equina or conus medullaris syndrome or acute motor worsening. The purpose of conservative or surgical treatment is stabilizing the instable motion segment to prevent worsening low back pain and recurrence of disc herniation. Thus, patients can perform their daily normal life activities.

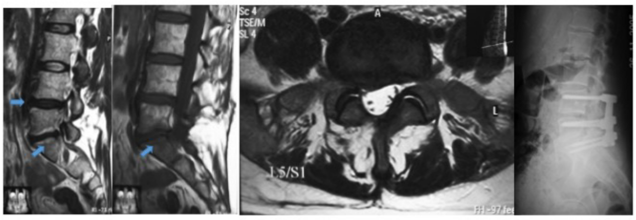

Figure 3: 43 years old female patient. Lomber MRI shows degenerative disc disease in L4–S5 segment and Modic type II degeneration in L5–S1 segment with recurrent disc herniation. Cosmic Mia® dynamic system was applied after the discectomy.

Figure 4: 38 years old male patient, muscular extensive fatty degeneration at L5– S1 level and broad based disc herniation are shown in Lumbar MRI. Cosmic Mia® dynamic system stabilization was used after the discectomy.

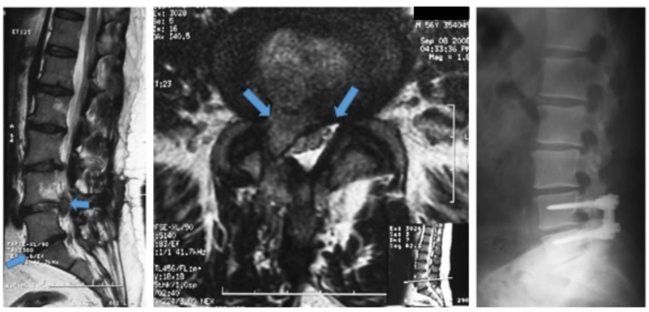

Figure 5: 56 years old male patient, there is a severe degeneration in L5–S1 level with low ROM. Recurrent huge disc herniation with large annular defect occurred in hypermobile L4–S5 level. Saphinas® dynamic screw system was used in treatment.

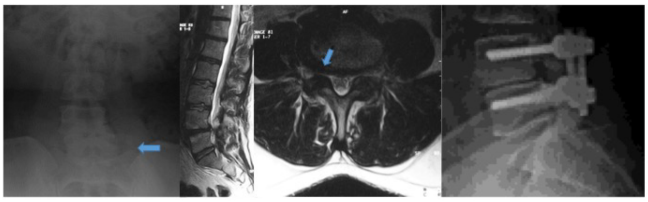

Figure 6: 36 years old, female patient, sacralization appears on AP X-ray. Sagittal T2WI MRI section showed severe degeneration with Modic changes wide based disc herniation is seen in axial T2WI MRI. Lateral X – ray (right) shows Saphinas® dynamic system that been used for the treatment after the decompression.

Preventive posture and life style with modest exercise programs are proposed at early period of disease with the purpose of avoiding excessive load on spine and conservative treatment methods such as patient training programs in order to provide the required information to protect spine health. Physical therapy is aimed to improve active system of spine stability. Even though patients do not benefit from physical therapy, strengthening of abdomen muscles, lumbar extensor muscles such as erector spinae muscles, and segmental muscles such as multifidus is essential to obtain better outcome after surgery [2,3]. Fatty degeneration and atrophy of paravertebral muscles disturb the active system of spine stability and are responsible for poor outcome of physical therapy and simple discectomy. Therefore stabilization should be considered (Figure 4).

The reported incidence of recurrent low back and leg pain within 2 years after simple discectomy is 14 %. Limited discectomy with the purpose of avoiding secondary segmental instability has 7 % recurrent disc herniation rate at more than 2 years long – term follow up. Even though aggressive discectomy has less incidence (3.5%) of recurrent disc herniation, low back and leg pain recurrence is much higher (27.8 %) after more than 2 years long – term follow – up. The main problem after aggressive discectomy is height loss at intervertebral disc space and neural foramina in almost two third of patients undergone aggressive discectomy [1]. On the other hand overlooked LSI during preoperative evaluation or secondary instability after surgery is one of the predisposing factors for recurrence. Especially patients with large annular defect are candidate for recurrence. Additionally disrupted intervertebral disc diffusion and perfusion disables recovery of disc tissue and may cause to postoperative LSI. Those patients should be proposed for stabilization in addition to discectomy (Figure 5).

Discussion

Lumbarization of S1 vertebra and sacralization of L 5 vertebra also should be taken into consideration. Either sacralization of the lowest lumbar segment or lumbarization of the most superior sacral segment of the spine is defined as 'lumbosacral transitional vertebrae (LSTV)' [14]. Even patients with S 1 lumbarization have higher lordosis values; there is no evidence that lumbarization lead to degenerative disc disease (DDD) [15]. Similarly there is not significantly difference on occurrence of degenerative spondylolisthesis or low back pain between patients with normal anatomy and patients with sacralization of L 5 vertebra [16-18]. Even though a lumbosacral transitional vertebra does not carry additional risk for DDD or low back pain, fusion between an LSTV and the sacrum may lead to hypermobility to adjacent motion segment [14,15]. Therefore potential spinal instability at adjacent level after surgery should be under consideration while planning discectomy to patient with L 5 sacralization (Figure 6).

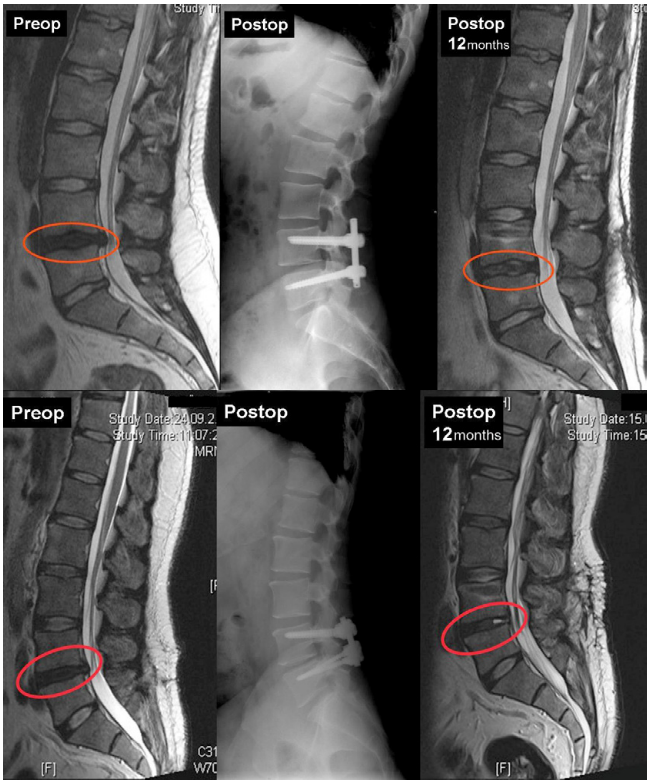

Figure 7: Two patients with L4–S5 disc herniation that underwent discectomy and transpedicular dynamic stabilization. Preoperative (left) and postoperative (right) Lomber MRI's and post-operative X–ray graphics (middle) are shown. Higher intensity in T2 weighted images (red circular line) suggests rehydration of nuclei pulposus.

Even though fusion still is the most common surgical method to stabilization of the spine, unsatisfactory long – term results such as adjacent segment disease, pseudoarthrosis, instrument failure, and complexity of revision surgery is still challenging [2,19]. After motion segment is fused, adjacent upper and lower segment become more mobile and degeneration is accelerated. Adjacent segment disease incidence among patients underwent fusion surgery is approximately 30 – 45 % within 5 years after operation. On the other hand pseudoarthrosis at fused segment lead to recurrence of low back pain and/or disc herniation, which affect life quality [2].

However interspinous device (ISD) implantation is not commonly used for lumbar disc herniation, the procedure has been performing to patients with lumbar spinal canal stenosis in terms of enlargement of diameter of spinal canal and preserve segmental stability. The meta – analyses showed no significant difference on clinical outcomes in comparison with decompressive surgery. Additionally ISD has higher incidence of long – term reoperation and might lead to burden of cost [20,21]. Furthermore biomechanical changes such as decrease in ROM, and increase of interdiscal pressure and facet load at the adjacent segment following implantation of ISD are reported in both finite element and *in vitro* biomechanical studies [22,23]. ISD implantation causes to kyphotic position, segmental tilt and changes at instantaneous axis of rotation at the level of surgery. Therefore ISD implant could cause adjacent level facet pain or accelerated facet joint degeneration [23].

Motion preservation procedures, dynamic stabilization, are popularized instead of fusion for spine in last two decades. Most common method is posterior transpedicular dynamic stabilization, which has the most successful results. Dynamic stabilization supports load distribution and avoid exaggerated painful movements of spine while enable FSU move within limits of neutral and elastic zone. Thus, adjacent segment disorder and pseudoarthrosis are no more under consideration because of fusion is not an aim anymore [2,24]. Many articles reported better outcomes at patients underwent dynamic stabilization comparison with fusion surgery [2,24–26]. Limited discectomy avoids disc height loss. Furthermore, recovery in degenerated disc tissue and annular tears, and development of rehydration in the intervertebral disc may be detected after posterior dynamic stabilization in patients with segmental instability (Figure 7). This recovery of the impaired tissue is an important evidence of posterior dynamic stabilization preserves normal physiology and biomechanics of the spine [2,27]. Thus, protection of intervertebral disc height and neural foramina and regain of normal range of motion would overcome the problem of recurrent disc herniation and recurrent back and leg pain.

Even though total disc replacement (TDR) surgery is not first choice for lumbar disc herniation and its recurrence, the procedure can be performed under specific indications for lumbar degenerative disc disease [28]. TDR is another motion preservation surgery and meta – analyses revealed beneficial outcomes at patient with degenerative disc diseases [29]. However the results are similar for TDR, posterior transpedicular dynamic stabilization, and fusion surgery, posterior stabilization has slight advantage due to easier surgical practicability and lesser complication rates [29,30].

Conclusion

Some associated pathologies are very important to evaluate in lumbar disc herniation. The question of "Why the outcomes are not always successful for lumbar disc herniation surgery?" comes forward. The satisfactory outcomes can simply be related with the presence of healthy 'System of the Spinal Stability'. However in case of overlooking preoperative presence of instability or the possibility of developing instability after surgery, the situation can be turn into a nightmare. Therefore we should notice if there some associated pathologies with disc herniation. These are Modic changes, sacralisation, muscle weakness and size of annular tear, which are discussed in this article.

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