Treatment Concept and Technical Considerations of Biportal Endoscopic Spine Surgery for Lumbar Spinal Stenosis

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Decompression must be a major composure of surgical procedures for degenerative lumbar spinal stenosis. In addition to sufficient decompression for guarantee of relieving neurologic pain, compensating surgical instability after wider laminectomy and foraminotomy, and instrumentation with caging and fusion with grafting are performed for securing or restoring foraminal dimension, and correcting coronal/sagittal imbalance for expecting longer survival of adjacent segment. Endoscopic spinal surgery (ESS), full-endoscopic or biportal-, has been developed under a flag of successful decompression with preserving structural integrity as much as possible in helps of magnification and illumination, and gives a technical possibility and feasibility to solve LSS by decompression-alone. There come, recently, lots of endoscopic trials for overcoming conventional surgical treatment in need of wider dissection and escaping inevitable complications from surgical damage and compensating fusion technique. However, biportal-ESS till a recent era has been showing some technical limitations including clinical difficulties in accessibility for more moderate to severe stenosis and challenges for complicated conditions with segmental ventral slip, isthmic defect, stenosis combined with foraminal stenosis or foraminal disc rupture, or degenerative segmental scoliosis with disc height collapsing and endplate fatigue fracture. Because decompression-alone, itself, is just a skill for eliminating pathologies, and no protentional function of preserving degenerative structure young forever or stopping recurrence of disc degeneration or creeping subsidence foramen. The purpose of this review on clinical reports is to suggest potential possibility of Biportal-ESS for treating degenerative lumbar disorders by sufficient decompression, adequate elimination of various pathologies, and decreasing technical complications in deep considering of skillful tricks and trades, and in hope of being a basic skill for developing better innovative spinal surgical techniques in near future.

Keywords: Biportal endoscopic; Decompression; Spinal stenosis; Lumbar spine

Introduction

1. History of decompression in technical point of view

The best surgical treatment option for lumbar spinal stenosis (LSS) must be decompression with no doubt [1]. There have been trials and developments of several techniques under the name of "sufficient decompression", showing their own benefits and limitations [2-4]. About early 1990, subtotal laminectomy with concept of wider...
decompression showed 78–88% of clinical success in early postoperative period, fell to about 70% at one-year and about 50% in 5 years [5,6]. On subtotal laminectomy, larger amount of surrounding soft and bony tissues should be eliminated to inspect pathologies locating deeper in central canal and foramen under naked-eyed identification, causing loss of laminar continuity and facet stability. That is supposed to be one of main reasons of early deterioration of clinical results and high incidence of converting to additional instrumented fusion in spite of reports that instrumentation does not affect clinical results [7]. Schaeren et al. [8] hit the point of concept of ideal decompression technique, preserving laminar continuity on laminotomy and sufficient foraminal decompression with intact isthmus. However, the ideal decompression had technical limitation in complicated cases using open dissection under naked eyes. Another trial is wider decompression with subtotal laminectomy and posterolateral fusion (PLIF) with instrumentation. Instrumentation could prevent early deterioration for surgical instability, and fusion must help preventing screw-loosening and longevity of its structural stability in mid-to-longer following up period. However, pitfalls of back muscle surgical injury by deeper and wider dissection and loss of spinal normal contouring by instrumentation have not been considered until instrumented PLF came to be spread and popular [9]. To overcome laterally wider back muscle dissection for serving bone graft bed on posterolateral side of facets and restoring lower back curvature, posterior interbody fusion (PLIF) with was tried. PLIF in open wider dissection was considered as highly invasive one with 25% of complication rate including 14% of durotomy and 3.5% of infection for several surgical factors including more bleeding and operating time for intradiscal manipulation, bone harvesting and grafting [10,11]. As instrumented fusion for degenerative lumbar diseases came to surge up dramatically in early 2000, adjacent segment disorders (ASD) as unexpected complication with incidence more than 10% in postoperative 3 years with consequently frequent need of revision extended fusion. Now a days it must be a nonnegligible issue in era of spinal fusion with popularity [12-15]. Surgical injury of back muscles with early degeneration or atrophy as an issue as one of important reasons of ASD, which justify needs of less or minimally invasive surgery [16]. Clinical trials on tubular surgery under microscopic view came out as minimally invasive surgery-transformaminal lumbar interbody fusion (MIS-TLIF) with established key-principles, minimizing soft tissue disruption & destabilization of spinal segments, unilateral laminectomy and bilateral decompression of central canal (ULBD), and indirect foraminal decompression using cage-technique [17]. Using cage-technique, several MIS trials are dramatically changing and developing for additional benefits including sagittal balance correction in longer-level instrumented fusion for minimizing physical factors on ASD. However, one-sided soft tissue release and elevation of bilateral-sided disc height using a hard cage in osteoporotic vertebrae brought about higher rate of cage-related problems including cage retropulsion, endplate breakage and foramen collapse, consequently delayed foraminal stenosis or screw loosening [18-20].

Decompression-alone is recently called back in MIS era to do sufficient decompression for pain relief and decreasing instrumented fusion for senile patients under natural spinal balance at their age. In short, previous open wider or tubular surgery, uses relatively vertical accessibility so that overlying functional bony structures should be removed widely to inspect central canal and foraminal area deeper, causing surgical instability in need of instrumented fusion. Biporta-ESS can permit accessibility into sublaminar space, ranging central canal to foraminal deeper [21-23]. Even spondylolisthesis in condition of relatively well-preserved state of disc integrity with no embrittled endplate, instrumented fusion for observational radiographic instability is no more first line of surgical treatment of option. Observational radiographic instability, i.e. more than 4 degree-ventral slip or 10-degree hyper-motion in dynamic simple radiographics, is no more absolute indication of fusion. Surgeons’ choice of instrumented fusion could mostly depend on their own decompression techniques; wider open, tubular, or endoscopic, rather than considering over patients’ anatomic specific configuration [24-26].

2. Concept of decompression-alone using Biportal-ESS

Biportal-ESS uses an arthroscopic system for magnifying inspection under higher magnification and brighter illumination, different from open wider surgery under naked eyes in need of digging deeper in a dark and narrow in difficulty on clearly differentiating structural margins and securing a working space for instrument handling and careful manipulation of neural structures [4,23,27]. An 8mm-sheathed scope guarantees panoramic view
with wider range of its moving under sublaminar area and foramen, and freely moving instruments, permitting forceful manipulation of hard bone and adhesive tissue to eliminate those pathologies. Its accessibility with preserving laminar and isthmic continuity decreases needs of instrumented fusion for LSS in stage of moderate to severe. It could also be beneficial to senile patients with higher comorbidity, who must need multiple level decompression and longer level instrumented fusion or revision surgery for ASD or delayed foraminal stenosis at index levels due to cage subsidence [28,29]. Another reason for considering decompression-alone first rather than wider decompression and instrumented fusion is higher incidence of persistent spinal pain after surgery. Failed back surgery syndrome has been defined as all kinds of back pain including unknown origin. Recent new definition comes as the name of persistent spinal pain syndrome (PSPS), sustaining back and radicular pain only after surgical procedure [30,31]. And lots of reports on this issue have come to increase more and more. The incidence has been reported more than 10 percent and maximally 40 percent [32]. The surgical outcome of its revision surgery is not good, satisfied less than 50 percent [32-33]. Most common reasons of PSPS are reported as inadequate decompression of spinal canal or foramen about 25%–29%, rather than judicious decompression with iatrogenic instability about 2.1%–2.9% [35,36]. Nerve root entrapment in epidural fibrosis or battered root syndrome after careless manipulation with aggressive root traction could be another reason [31]. These must be common situation on root and dural protection-and-traction using a root retractor in bone grafting and cage insertion into interbody space. However, there must be some cases in which spinal pain are not eliminated by decompression-alone even in preserving laminar continuity and no observational radiographic instability. When disc endplate is relatively sound with no subtle or fatigue fracture, the segment must be in normal functional range in daily life. In contrary, already fractured endplate with fully degenerative disc is observed in one side or anterior side with macerated change bony edge of vertebral body, it must be called as clinical symptomatic instability (Fig. 1). It means there is still on-going endplate collapsing, which are not following Kirkalday-Willis stabilizing theory at final stage [37]. And back and referred buttock pain frequently bothers daily activity in such condition. It has clinical meaning that facet function of sustaining against axial or rotational stress is lost, and

disc is fully degenerated and collapsed state until breaking down endplate and bring about chronic back and buttock pain. In such condition, decompression-alone cannot stop axial or rotational stress on the brittle endplate, and endplate’s subtle fracture progresses. It is so-called creeping subsidence of endplates, meaning clinical symptomatic instability in need of fusion.

### 3. Sufficient decompression and four-level stenosis protocol

For successful decompression of traversing and exiting roots in a segment and choosing optimal endoscopic approach among ipsilateral posterior, contralateral, and transfominal ones, “Four-level stenosis protocol” is used to evaluate foraminal zone and lateral recess zone. Four MR axial cuts in a segment are used at the levels of four guidelines drawn at lower endplate level of upper vertebral body, mid-disc space level, upper endplate level of
lower vertebral body and 3 mm farther distal (Fig. 2). The upper two levels show foraminal and extraforaminal area where exiting root can be irritated at foraminal area (Level 1) and central to lateral recess area of Level 2, 3, and 4. So, in case of extraforaminal disc or foraminal stenosis broad endplate spur overlying foramens to extraforaminal area without lateral recess stenosis at level 3 or 4, needs transfornaminal approach. In case of dominantly foraminal or extraforaminal stenotic pathology or disc extrusion at level 1 or 2 combined with lateral recess stenosis at level 3 or 4, intentionally surgeon stands on the opposite side to dominant foraminal pathology and try to decompress central stenosis at level 3 or 4 bilaterally, sublaminar area at level 2 and foramens to extraforamen at level 1 contralaterally.

**Technical Considerations**

1. Portal position, higher vs. lower

The very best points permitting access to targets with no hazard to structural durability, are recommended as portal positions. Choosing portal position must not be fixed by our preconception on 2-dimentional sagittal or axial radiographics, but designed under 3-dimentional surgical field with considering anatomic barriers. It could be a little different dependent on target’s location, depth, surrounding anatomic structures, and mostly surgeon’s peculiar experiences and skills. Good portal positioning in Biportal-ESS means that first, normal functional integrity should be preserved as much as possible and second, smooth accessing to pathology locating in deeper inside, and the third, it helps to serve an optimal view for making surgical procedure safer and easier. A lot of papers show various portal positions in Biportal-ESS. All things happening under water on performance are mostly decided from the first step of addressing portal position, resulting in different accessing angles and views, and laminectomy size to access the targets. Various portal positions in Biportal-ESS can be simply differentiated as higher portal and lower portal positions [38,39]. Higher portal position is derived from a concept of giving a freer working space to instrument handling. It is marked on back skin in dependence on disc space level, 1cm-above from the upper margin of disc space and 1cm-below from its distal margin after making endplate margins parallel on a tilted view of C-arm (Fig. 3). Two portals are located at the mid-level of pedicles along their medial margins. On putting in a scope, a scope faces the dorsal surface of upper lamina.

![Fig. 2. Four-level stenosis protocol. Serial axial MR images cut and divided as four levels, foraminal, sublaminar, lower laminar, and distal laminar areas (A) and matched endoscopic view (B). Axial MR views at a segment are evaluated at 3 mm-interval cuts from foramens to just proximal to distal pedicle. Disc space is covered by superior articular process (SAP) tip at level 2. A traversing root starts to be budded (axillar point of traversing root) from dural stalk at level 4 in higher lumbar spine (L1-2-3-4), and at level 3 in L4-5 and L5-S1 segments.](image-url)
Wider, rectangular upper laminectomy is mandatory for a scope to be put in and inspect deeper spinal canal. The concept of laminectomy comes from tubular surgery under microscope. In contrary to scoping from proximally higher, instrument handling is somewhat free for much wider space is served not to fight with a scope’s tip, very closer to a certain instrument on triangulation way in a narrow space. Ligamentum flavum is removed as En-block style after burring off its surrounding lamina, upper and lower. If central stenosis is combined with foraminal stenosis, endoscopy-assisted fusion using a cage on ULBD technique is preferred for decompressing foramen in state of using higher portal position. In some difficulty in higher portal position with that a scoping view is caudally oblique and laminar border line comes to change even in a little rotation of scoping, surgeons in learning curve lost orientation and proceeded laminectomy not into laminar medial surface but into its distal surface with

![Figure 3](image3.png)

**Fig. 3.** Portal position and assembly angle of a scope and an instrument. Higher portal position with 4~5 cm wide apart (red circles) needs triangulation of a scope and an instrument to focus a target locating deeper after wider laminectomy. Lower portal position with 1 cm narrow apart (blue circles) uses parallel sliding to access sublaminar approach.

![Figure 4](image4.png)

**Fig. 4.** Different amounts of laminectomy dependent on portal positions. Lower portal position with facet preservation. Postoperative MR axial view showed larger amount preservation of facet contact surface (#) due to about 3 mm-laminectomy (A). Higher portal position with “vacant facet” for judicious subtotal laminectomy (B). Disorientation during laminectomy resulted in subtotal laminectomy with total loss of facet contact surface (*).
facet destruction. Then, majority of upper lamina would be resected until exposing SAP tip and consequently unilateral subtotal laminectomy, so-called “vacant facet” on postoperative MR axial view, meaning iatrogenic instability, consequently in need of instrumented fusion (Fig. 4).

In lower portal position, a proximal portal is located at lower border of upper lamina, very closed to lateral margin of proximal SP base, under a vertical C-arm view. A scope is willing to land onto distal edge of upper lamina, ready to slide down sublaminar space in cranially oblique direction with less laminar resection, which is similar concept of handling of a scope in full-endoscopic spine surgery. Posing a proximal viewing portal at the best point for sublaminar accessing is more important than making a distal working portal. A working portal is simple decided as two-finger breath apart distally from the proximal one. The distance of centers of portals should be two-finger breath, about 2cm. So, there is only less than 1cm free space between portal skin incision end margins. A scope and a certain instrument should be posed closer and a little parallel to be put inside under the interlaminar space together, deeper to closer to contralateral foramen crossing midline. Using a lower portal position, sublaminar access is permitted with minimal resection of laminar edges, about 3 mm, permitting parallel sliding access under sublaminar area. Lower portal position shows benefits for exposing bilateral exiting roots proximally and traversing roots distally, so-called unilateral laminectomy and bilateral foraminotomy (ULBF) from level 1 to 4 (Fig. 5). This portal position is very useful in decompression-alone for central and foraminal stenosis simultaneously with preservation of laminar continuity and facet integrity. This decompression-alone is one of recommendable alternative surgical strategy for multi-level LSS in elderly and senile patients with medial comorbidity.

2. Fluent water-output

Biportal-ESS is performed under water-based surgical environment. Continuous water input washes away surgical debridement matters and potential contaminated debris clearly. It must decrease surgical infection rate, very super-benefit to senile patients with medical comorbidity with lower immune response or higher susceptible condition to infection. In open wounded fractures with highly contamination, more than 10L of saline irrigation is mandatorily recommended. More than 10L of saline (3,000 ml of saline × 4 packs) is generally used for 1 or 2 hours of procedures of Biportal-ESS, which seems to be enough amount of irrigation to thoroughly wash away possible surgical debris. Preoperatively only one-shot of antibiotics injection is recommended in Biportal-ESS routine procedures. Nevertheless on its benefit, making a water output fluent is not always easy and in need of some tricks. In full-endoscopic spine surgery, a scope is docked into Kambin’s triangle, “Docking technique”, pushing into
water forcefully to wash bleeds away, and keeping surgical field clear. Used water is coming back through a tunnel in an endoscope. In Biportal-ESS, however, a scope is located at a certain distance far from target structures, so-called “Floating technique”. We can move a scope freely in any direction with panoramic views around posterior lamina or foraminal area. Various instruments such as Kerrison or Pituitary punch, generally used in open spine surgery, can be inserted through the gap between a scope and a structural surface. However, small bleeds come into a scoping view and surgical field becomes turbid. So, keeping water’s continuous flow well is a key trick to serve clear surgical field, which permits to differentiate structural margins and decreasing neural structural injury by mishandling of instruments under disorientation and mis-measuring depth in turbid water. Increasing input water pressure for trying to water output better is not a good trick. If there were not good water output already, just putting water input in higher pressure will cause cervical epidural pressure increasing with clinical meaning of potential rising of intracranial pressure [40-42]. Clinical sufficient water pressure can be made in a setting that two saline bags are posed 60 to 70 cm higher under natural gravity from the patients back level in prone position on the surgical table. That height shows the similar pressure of 30 to 50 mmHg of water pump. It is not good to try too much water infusing in higher pressure, causing fully dural compression longer time during surgery in potential ischemic state [43,44]. Don’t try to solve output problem by increasing input pressure. Water is generally trapped by subcutaneous fascia or fat. On skin incision for making portals, basic preparation steps should be kept, including subcutaneous fascia cross-cut, subcutaneous fat-block removal, and controlling of main bleeding foci on vascular geometry. Water output is mostly entrapped by subcutaneous fascia rather than deep muscles. Subcutaneous fascia cross-cut incision in transverse direction to skin incision, and deeply scratching-off lateral margin of spinous process bony surface, is very important trick for opening subcutaneous fascia always wider open to prevent water entrapment. Even in this trial, water does not come out fluently, subcutaneous fat-blocks should be removed by using a pituitary punch (Fig. 6). Another physics we should consider is that water is not running forward in one way direction as described on schematic drawings on papers on scoping surgery. In simple thinking, input water from a scope in a viewing portal will run forward and out through a working portal. It could be if you used a skin retractor for opening a working portal much wider than a scoping portal. Actually, instrument manipulation on various angle can frequently squeeze and push down a working portal flat and closed. So, input water is mostly escaping back through a viewing portal on instrument handling in a working portal. Therefore, a size of skin incision for a viewing portal should be a little larger than that of a working portal. It is a simple change, but it always helpful in heavily obese and thicker muscular cases.

3. Making a basecamp and a working space

As we start to do upper laminectomy as first step of decompression, a basecamp should be made to inspect bony

![Skin incision](image1)
![Fascia cross-cut](image2)
![Removing fat-blocks](image3)

**Fig. 6.** Control methods of water-output fluent. After skin incision for portal, subcutaneous fascia should be cross-cut till scratching spinous process (SP) bony surface to be open wider. Subcutaneous fat-blocks could also interfere water-output flow so that removing fat-blocks beneath portals is mandatory.
margins to get an orientation, and enough working space for accessing deeper inside of spinal canal ipsilaterally or contralaterally. On putting a scope inside, we cannot get a right orientation immediately because a scope view is surrounded by just deep back muscles. To get an orientation in a dark room, we should first expand our hands to touch and lean a wall. To get an orientation on scoping, first thing we should do is to expose bony surface of interlaminar space from deep muscles. It is in real practice not easy. A common reason is that proximal portions of deep musculotendinous (MT) fibers is still attaching to basal area of proximal spinous process (SP), covering a scoping view at 10 to 1 O’ clock area. These MT fibers should be clearly detached to expose laminar margins before putting a scope. To do that, we should scratch bony surface of base area of proximal SP using a muscle-detacher (sharp-bladed Cobb’s elevator) and detach the MT fibers attaching proximal SP base about 1 cm dorsal area of SP base from the dorsal lamina (= about 1 cm area of spinolaminar junction between SP base and upper laminar distal border) (Fig. 7). This MT fiber detaching procedure before scoping can help to decrease operating time to make a basecamp, clearly exposing bony margin of proximal SP base with easily getting an orientation just on putting in a scope. Heavy bleeding on scoping should be controlled at three specific spots, 9 O’clock-left, 7 O’clock under muscle, and 5 O’ clock at facet corner. These bleeds come from main branches from segmental artery with high pressure, so that these must be complete coagulated with a radiofrequency wand. The corner bleeding at distal area of facet at 5 O’clock has a division of three-branches. Its three heads should be coagulated thoroughly one by one (Fig. 8). If not, even small missing bleed from one branch could make surgical field turbid thoroughly during whole surgical procedures.

Enough working space means that there should be about 13–15 mm midline space at interlaminar space. Through the middle of interlaminar space, an 8 mm-diameter sheathed scope and a 5m-width instrument could be inserted together for accessing contralateral side (Fig. 9). If not, an instrument is frequently jammed and trapped between a scope and bony structure with limiting its accessibility. In insufficient working space, an instrument could not reach targeted pathology around foramen and contralateral distal area, causing incomplete decompression. Inappropriately forceful or wrongly directional handling in a narrow space could also bring about dural or root injury. To make sufficient working space, proximal SP base should be resected first before starting laminectomy or flavectomy. Proximal SP base resection gives a view to contralateral side. Distal SP base should be resected before accessing contralateral side. If instrument handling is not
comfortable to touch and resect contralateral disc, SAP tip, or distal lamina, it mostly come from an instrument is pushed away proximally by distal SP base. To overcome this, a little bit more resection of distal SP base is mandatory, rather than wider laminectomy laterally.

4. Upper laminectomy

Upper lamina is not mostly compressing pathology irritating nerve roots at the level 3 and 4. Only in spondylolisthesis, sublaminar thickened spur or ventral slip itself narrow the spinal canal at the level 2. So, the purpose of upper laminectomy is mostly just to make a little more space for a scope to be put inside for inspecting lower laminar at the level 3 and 4 and superior articular process (SAP) tip at the level 2 in sublaminar space. About 3mm amount of resection of medial surface of the upper lamina using a straight chisel or burr is enough to make a space for putting a scope inside of interlaminar space. Sublaminar bony protrusion of upper lamina at the level 2 is also resected about 3mm until exposing SAP tip using a pedicle chisel with anteriorly 45-degree bent blade, preserving most of upper lamina and facet surface (Endpoint of upper laminectomy: distally 3 mm-width of lower lamina should be exposed at level 3 and 4, proximally exposing SAP tip at level 2) (Fig. 10). Resecting sublaminar protruded portion should be done about 3mm-thickness for securing spinal canal dimension at level 2 in spondylolisthesis. Ventral prolapsing in spondylolisthesis loses
canal dimension at sublaminar space and sublaminar decompression is mandatory to compensate and restore canal dimension in decompression-alone. So, if ventral prolapse is more than 1cm, decompression-alone could not compensate and restore canal dimension enough to dural expansion with release of rootlets, lying at lateral portion of dura which are ready to bud out from dura. Decompression wider with reduction using a cage and instrumentation is supposed to be more reasonable trial in high graded spondylolisthesis.

Contralateral upper laminectomy is addressed in oblique direction. It needs a different measurement concept from vertical approach on the ipsilateral side due to its different accessing angle. Resection line for exposing lower laminar distal area and SAP tip is calculated from the base line of contralateral upper lamina, rather than a high ridge on the dorsal surface of ipsilateral upper lamina. Be careful not to start resection of contralateral upper laminectomy at a high ridge. If not, nearly half of upper lamina could be resected with loss of laminar and facet integrity on exposing too much amount of laminar resection. Keep it mind that the purpose of upper laminectomy is only to expose SAP tip covering disc space at proximal portion and 3mm area of lower lamina at distal portion beneath which traversing root runs around the medial surface of pedicle (Fig. 11).

5. Flavectomy

Ligamentum flavum (LF) could be handled superficial layer from deep layer rather than En-block. LF superficial layer is covering lower laminar joint margin and disturbing a surgical view to contralateral side. Ventral margin of upper lamina and facet joint margin between upper and lower lamina can be inspected after removing it, helping safe and accurate laminectomy. LF deep layer should be kept intact as longer as possible till nearly finishing over lower laminectomy and foraminotomy by burring (Fig. 12). When LF deep layer is resected before finishing lower laminectomy, a burr should not be used for higher risk of dural tear. In such situation, we should use a chisel and Kerrison punch for bony procedures. LF Deep layer works as dural protector from a scope and an instrument and covering epidural vessels with keeping clear surgical view (Fig. 13). Most cases of incidental dural tears are reported as midline slit tear [28,46]. It would happen for a certain instrument such as a Kerrison punch or dissector to be inserted under LF on crossing the midline under LF. Saline input pressures the lateral side of dura and its central portion elevates like a thin band or folding. Without noticing it, careless inserting an instrument beneath epidural fat under LF can make dural tear. There is a key trick to escape dural tear when crossing the midline for flavectomy of LF deep layer. Don’t insert any instrument under the epidural fat. The safe way is there between LF and epidural fat. When LF superficial layer is peeled and separated thinning enough for capillaries to come out on thin LF deep layer in central area of spinal canal over the dura, with its full layer resection at lateral recess overlying traversing roots, dura can be decompressed and expand fully, and radicular pain is also subsided. This is a LF deep layer sparing technique with intention of preventing tech-
Technical risks including dural tear, epidural haziness during surgery and postoperative epidural hematoma, preventive effect on dural adhesion which is one of potential risk factors of dural tear in revision surgery. To keep tension of LF deep layer, its distal attaching point to distal SP basal surface should be protected. Resecting proximal high and long peak of distal SP base with preserving its very basal surface can work on preserving tension of LF deep layer with keeping enough working space.

Fig. 12. Ligament flavum deep layer preservation technique. At first view, LF superficial layer covers contralateral side of upper laminar bony surface (A). Using a freer dissector, LF is divided superficial layer over the level of lower lamina and deep layer (B). Superficial layer is gotten rid of from medial surface of contralateral upper lamina by shavering (C). Contralateral side can be inspected after only removing LF superficial layer and preserved LF deep layer works as protector of dura with no bothering of upper and lower laminectomy.

Fig. 13. Surgical meaning of LF deep layer sparing. LF Superficial layer should be peeled until exposing capillaries on deep layer. It can protect dura during bony procedures under less bleeding from epidural space with lower risks of dural tear or possible epidural hematoma. It is also thin enough for dura to permit dural pulsation and expansion for restoring spinal canal dimension.
6. Lower laminectomy

Lower laminectomy is processed in separated steps, resection of distal SP base including distal lamina and SAP tip resection. When trying to insert an instrument into the contralateral side, its accessibility is limited due to blocking by higher heighted distal SP. After flattening resection of its top, ipsilateral and contralateral distal lamina can be resected much easily. There must be frequently lower laminar spur at the junction between upper and lower lamina joint surface. Proximally and ventrally grown-up spur are hidden and covered by LF deep layer, compressing and irritating traversing nerve root. Sometimes without grown-up spur, only its cortical thickening could bring about stenotic compressing of traversing root. Distal laminectomy of lower lamina should be always enough with distally at least 3 to 5 mm resection, until exposing a critical point where vessel bundles crossing traversing root are coming out, so-called “crossing vessel” overlying traversing root and touching medial surface of pedicle. Hard disc extrusion or distal laminar cortical bone thickening or collapsed disc height or dynamic aggravation of disc space narrowing in weight-bearing state, can decrease the dimension where traversing root runs under the distal lamina. So, a little insufficiency of distal laminectomy could result in root compression dynamically with patients’ symptoms that they could have no complaints on sitting or lying down on sleeping or resting state, but could not lift up their back on straight for a long time due to early back fatigue and gradual buttock pain within an hour or so, frequently coming to be in need of rest in sitting position for back stooping to increase the space of distal lamina.

SAP tip is partially resected for exposing disc space about 3 to 5 mm or foraminal decompression. In higher lumbar spine, dura can expand wider till overlying SAP margin during pulsation after flavectomy and remnant sharp-straight or medially growing SAP which is located at somewhat medial side of spinal canal, could injure dural lateral side with a risk of late onset spontaneous dural tear (Fig. 14). Even in lower lumbar with relatively wider spinal canal, trying discectomy without SAP tip resection could need additional retraction of dura or root for making a working space on disc space. In Biportal-ESS, generally a root retractor is not needed even for central broad type lumbar disc herniation. Disc space is located under the SAP tip and SAP tip resection can serve a free disc space for discectomy sufficiently.

Fig. 14. Lower laminectomy. (A) Contralateral lower laminectomy. SAP tip is resected by a hockey chisel after making a notch for safe approach on chiseling by 2 mm-Kerrison punch. (B) Ipsilateral lower laminectomy. SAP is partially covered by upper lamina. It can be resected with wider upper laminectomy using a hockey chisel. (C) Insufficient SAP tip could bring about delayed dural tear due to restoring dural pulsation with no covering of ligamentum flavum. (D) Hockey chisel, left and right bladed.
7. Foraminotomy

Foraminotomy can be ipsilaterally or contralaterally available via posterior approach in Biportal-ESS. Workflow of foraminotomy in posterior approach is included SAP tip resection, subpedicular seal resection, foraminal flavectomy, and foraminal discectomy if needed. SAP tip is contact with under-surface of upper lamina obliquely in facet joint. Long time of surface stress brings about not only SAP tip hypertrophy, but also sublaminar cortical hypertrophy just distal to the pedicle distal surface, so-called “Subpedicular seal”, named from similar looking of “window seal” (Fig. 15). An exiting root looks hidden under subpedicular seal on oblique-scoping view. Proximally wider upper laminectomy would be mandatory in vertical accessing skills in open or microscopic surgery, and even in Biportal-ESS with using higher portal position. Using lower portal position in Biportal-ESS, however, caudal to cranial directional scoping view can unveil an exiting root just after resecting subpedicular seal. SAP tip should be resected at its ventral portion, compressing an exiting root. Lateral portion of SAP tip is located far lateral side and should be preserved as a functional structure which supports against transverse process-isthmus junction not to collapse further with decreasing foraminal height as progressed disc degeneration (Fig. 16). The seal is located under the sublaminar area, and it could be resected by a pedicle chisel with anteriorly 45-degreed blade rather than a straight chisel. Additional foraminal discectomy or endplate spur resection could be needed in dependent on correlation of root mobility and restored foraminal dimension.

8. Discectomy

There are distinctive anatomic specificities of bony structures in higher lumbar spine (L1–2–3–4) from lower lumbar spine (L4–5–S1). Approach decision for lumbar disc herniation (LDH) is very important for successful discectomy in this point of view. Higher lumbar spine has narrow laminar width, and dura lateral surface and axillary portion is located at very close to isthmus under-surface. To access foraminal or central broad disc rupture by oblique angled approach using Biportal-ESS, wider isthmus resection is not necessary which is common in vertical accessing tubular surgery in need of isthmus resection.
with higher potency of iatrogenic pars fracture due to over-resection of the facet especially in higher lumbar spine [46]. In addition, disc space in higher lumbar spine is apart from about 10mm proximally from the interlaminar space. If ruptured disc fragment migrated up to the pedicle (up-migration LDH), posterior approach must be in need proximally wider laminectomy and even if possible, due to dura retraction in narrow interlaminar space could cause higher risk of conus medullaris syndrome (Fig. 17). In case of huge and broad type of disc extrusion, it could be very challenging to remove it safely under direct visualization in hazy, and narrow surgical view in posterior approach. Transforaminal approach (TFA) in higher lumbar spine is the best choice for reaching up-migration, central broad, or foraminal and extraforaminal LDH with no retraction of dura and clear view on axilla area and dural lateral margin. Posterior approach for discectomy in higher lumbar spine is only useful in down-migrated LDH, which is located just in front of interlaminar space in no need of wider laminectomy and very short distance from interlaminar basecamp to a target point.

Disc is constructed with soft nucleus and hard annulus. Most symptomatic disc rupture means root is harshly compressed by hard and stiff annulus. Soft nucleus rupture with no annular fragment is generally tolerable with-in a few weeks and easily resorbable sufficiently in conservative management. Intolerable radicular pain comes from irritation by ruptured annulus fragment harder than root or root impingement between extruded annulus and bony margin of lower lamina at the lateral recess. In open surgery under natural eyed view, however, broad and radical discectomy is generally performed to removal pathologic fragment including surrounding innocent nu-

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Fig. 17. Conus medullaris in higher lumbar spine. There is anatomic variance in position of Conus medullaris from L1 to L3. Forceful and longer time of dural retraction could cause Conus medullaris syndrome.

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Fig. 18. Radical nucleotomy and selective annulectomy. (A) Technical concept of open surgery under natural eyed view is radical nucleotomy, during which larger amount of innocent soft nucleus must be eliminated and possible remnant extruded annulus. Posterior decompression could affect decreasing radicular pain, but due to dura looks compressed by still extruded hard annulus. (B) Annular layer can be inspected under magnified endoscopic view, permitting selective annulectomy, eliminating ruptured hard annular mass with preserving deep layer of annulus and nucleus.
nucleus not to miss and lose targeted fragment. Wide range of radical discectomy including innocent nucleus deeper inside could bring about early collapsing of disc space after surgery, which might be same mechanical results of razor debridement of disc space after tubular surgery for discectomy [47,48]. Revision surgery has been very harsh and a burden to spine surgeons who used open dissection for wider laminectomy, back muscle destruction, and consequent in need of fusion for recurrent LDH. Escaping early revision using a bigger surgical intervention, radical discectomy could have been supposed to be one of option. However, under magnified endoscopic view, ruptured out or extruded annular fragment can be inspected under superficial layer of annulus. After annular superficial layer incision, probing and eliminating ruptured annular fragment is much more suitable for purpose of selective annulectomy of torn portion in Biportal-ESS. Selective annulectomy in Biportal-ESS is more precise elimination of pathology to decrease early recurrence of disc rupture or deterioration of disc space with consequence of secondary foraminal height collapse in radical nucleotomy in open surgery (Fig. 18). Selective annulectomy may come to be a reasonable concept in Biportal-ESS because revision surgery using Biportal-ESS is safer and less destructive rather than previous open spine surgery in aspect of overcoming safe scar release and less laminectomy with no need of conversion to instrumented fusion [49].

9. Right-Side Posterior Approach

We could easily disorientate in right-side posterior approach because our preconception and expectation in learning curve are dominantly dependent on our anatomic experiences under vertical views. On right-side posterior approach, a scope addresses in caudal to cranial direction at the very closed to midline of interlaminar space. Simply to say, don’t expect posterior anatomic sceneries on your imagination full of vertical views by open surgery or anatomic textbooks. They are composed in real by an oblique view in proximal direction. We should accustom ourselves to them through several times of trials. The right-side posterior approach serves medial surface of the upper lamina as wide and flat one, dorsal surface as narrow and vertical one, in contrary to left-sided approach in which medial surface as narrow and vertical one, and dorsal surface as broad and flat one (Fig. 19).

In addition to difference in view, proximal working space, accessed through a proximal working portal, is much narrower than that via a distal working portal in left-side posterior approach. It is somewhat hard to make a wider working space enough due to different anatomic configuration and narrow accessibility. To overcome those limitation, posterior approach on the right side needs lower portal position as standard approach, in which a proximal working portal is located on the same level of midportion of interlaminar space at the just lateral of spinous process and a viewing portal should be a part 3cm distally from the working portal. Somewhat distal moving of a working portal at the same level of middle of interlaminar space is for escaping from being blocked by proximal lamina and proximal SP base with higher height. In left-side posterior approach, an instrument is inserted
from “the lower field” around a facet. However, in right-side approach, an instrument should be inserted from “the higher mountain” of a proximal SP base and upper laminar distal border with higher profile. If using higher portal position in right-side posterior approach, instrument handling is frequently disturbed and instruments cannot reach the deeper inside in spinal canal without wider laminectomy, and especially ipsilateral SAP tip on the right side come to be inaccessible or untouchable. That is one of common reason of insufficient decompression of right posterior side and incomplete discectomy with difficulty of SAP tip resection for securing safe discectomy and enough working space, inaccessible to contralateral side with remnant stenotic pathology, and impossible ipsilateral foraminal access or foraminal decompression. On right-side approach, surgeons in learning curve could be standing in dilemma whether wider upper laminectomy for safer accessing lower laminar area with higher risk of laminar fracture or less upper laminectomy for preserving laminar continuity, but with higher risks of incomplete SAP tip resection, leaving sharp and irregular laminected ends, causing delayed dural tear by dural pulsation wider after flavectomy. To overcome this physical problem of portal position, most instruments designed as curved shapes should be used for preserving upper laminar width enough and sufficiently resecting SAP tip (Fig. 20). Recommended indication of right-side posterior approach is LDH down-migration on the right side. For decompressing bilateral sided stenosis and LDH up-migration or at foraminal area on the right, left-sided posterior approach using contralateral approach with left to right access is much more reasonable with higher success rate and lower potency of technical complication.

10. Contralateral approach

To access a case with central stenosis in both sides with foraminal stenosis or foraminal LDH on the right side, we should stand on the left side and use left-side posterior approach. Intentional choose of opposite posterior portal to access the contralateral target obliquely through sublaminar space with purpose of bilateral central decompression and combined contralateral foraminal decompression, is called contralateral approach (CLA). Left-side ipsilateral posterior approach for foraminal decompression can permit reaching only ipsilateral foraminal area, but not reaching ipsilateral extraforaminal area (mostly extraforaminal LDH). In this case, additional left-side transfemoral approach (TFA) should be needed or right-side CLA for contralateral access to left-side foramen to extraforaminal pathology.

Prevention and Management of Complications

There are some technical complications in critical point of view we should keep in mind on full knowledge before starting Biportal-ESS. It is the same situation that “a seasoned fisher can read the sky before out going fishing.” Learning curve period of ESS up to a certain level, needs longer time, rather than just decreasing operating time in a short period [50,51]. There are following issues including radiofrequency and electrical brain-zap, burring and bone dust, incidental dural tear and patch method, postoperative hematoma and vascular geometry, frequent neglected zone of decompression [27,45,52-54].

Using a radiofrequency (RF) in higher volage of ablation mode for debridement of deep muscles to expose bony surface and making a basecamp, is very critical to brain neural tissue and it can bring about postictal seizure-like condition, so-called “brain-zap” with stuporous mentality and hyperventilation, mid-sized fixed pupil for several hours. It should be used in set of lower voltage of coagulation mode for coagulation of small bleeds and shrinkage of peripheral rugged margin of soft tissue for making clear surgical view. It should be better to use a shaver for debridement of larger amount of soft tissue in
wider area and additional short time use of RF for shrink-
age and cleansing of flappy ends of soft tissue on bony margin.

A burr is one of the best effective devices for laminectomy, sharp, fast, and delicate. In Biportal-ESS, however, portal size is not wide enough for bone dust to be washed out. Bone dust is not well detected because debris are collected and gathered under deep muscles behind a scope. After finishing surgery and scope removing, inflated deep muscle comes down and covers closer to interlaminar space, where remnant bone dust would be grafted over pluripotent laminar bone bleeding. In such condition, hematoma would not be rather degraded and resolved in a few weeks but changed into hard fibrous tissue in early a few weeks with consequently restenosis compressing traversing root and dura, definitely with corresponding neurologic pain (Fig 21). To overcome this situation, soft tissue retractor or cannula can be adapted for opening wider of portals in full time of procedures in higher portal position with portals’ wide apart, or using a chisel only in lower portal position with narrow portal distance.

Incidental dural tear or root injury in endoscopic spine surgery has been reported about 3.7% [56]. Patch method for sealing tear site with expecting natural healing should be recommended rather than direct suture after converting to wider open laminectomy. It is effective in 1cm-less sized slit, longitudinal tear with lower risk of rootlet incarceration. A case with more than 1 cm or flap-like tear, should be need of suture with a vascular clip device or converting to open repair. CSF continuously leaks from surgical wound postoperatively within a week, immediate endoscopic revision for re-patch and subcutaneous tight suture is mandatory. Even in such kind of endeavor or insufficient trial, there could be palpable soft mass, pseudomeningocele, on the back in postoperative 3–5 weeks. All the better in pseudomeningocele, a drain way of CSF in muscle layers is sealed and isolated by pseudomembrane like bursa with partially healed and closing smaller of a tear site. Revision on Biportal-ESS over the cyst leads you to the tear site through pseudomembrane tunnel with no loss of your way. Repatch over there well and do debridement of cyst-like pseudomembrane in muscle layer. In any condition in dural tear, do not leave a drain. Iatrogenic muscular hematoma is necessary to compress dura to prevent dural pulsation and prohibit torn site diversion and rootlet incarceration [45,52,57].

Senile and elderly patients have relatively higher thromboembolic risk (pulmonary embolism or deep vein thrombosis) with commonly taking preventive medica-

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**Fig. 21.** Early restenosis after decompression. Radicular pain on the right side recurred after postoperative (po) 2 weeks. Immediate postoperative MR axial view (A) showed sufficient decompression. MR axial view at po 2 week (B) and 4 week (C). Early fibrosis and restenosis were progressing in inflammatory period. It could be supposed to fibrosis of hematoma due to bone graft effect of bone dust generated from burning of lamina (D) Endoscopic view, (E) Hematoma with bone dust grafted down in surgical field, which was strongly suspected by HE staining with thick fibrous change containing dead bone materials (F).
tions (anticoagulants). So, any surgical interventions have to run a higher risk of postoperative hematoma. It can always happen, and you just have your own strategy to decide the exact timing of endoscopic revision irrigation and evacuation of hematoma. To prevent it as much as possible during surgery, bone bleeding and soft tissue bleeding should be controlled well with thrombin-mixed materials or bone-waxing, and selective focal control of bleeding on muscle by RF. A drain could not prevent thoroughly from collecting of blood in interlaminar space for its canal diameter is not sufficiently wide. There should be a try to coagulate small bleeds as much as possible on closing water input at last stage of operation [58]. During waking up from anesthesia, keep not to elevate systolic blood pressure so high is a reasonable trick [59].

After surgery, postoperative MRI checking within 1 to 3 days must be the very exact examination to differentiate postoperative hematoma from other reasons such as remnant or incomplete decompression. Intolerable back and buttock pain even with eliminating radicular pain or cauda equina syndrome in immediate postoperative a few days, must be considered as red-flag sign in need of early revision for hematoma evacuation [53]. Remnant stenotic pathology is one of common reasons of patients’ dissatisfaction [35,60,61]. In Biportal-ESS, frequent neglected zone of decompression in learning curve period is sublaminar space in level 2 which is hidden in vertical scoping view, and foraminal area for unskillful accessibility or mismatching view on scoping to radiographic examination (Fig. 22). Central decompression alone with leaving foraminal stenosis neglected is also one of common mistakes. A patient who has central and foraminal stenosis simultaneously, are generally in stooping state for make central canal dimension wider to relieve buttock and radicular pain. So, there could be little complaint on foraminal stenosis due to dynamic foraminal widening in stooping position. If no detail medical interviewing after MR interpretation, there could be miss a need of foraminal decompression for a simple excuse, “no pain, no pathology”, even under common knowledge that foraminal stenotic symptom dynamically occurs (Fig. 23).

**Postoperative Management**

A drain is inserted through a portal and its tip should be located at the dorsal surface of lamina. Its deeper location could irritate or tear the dura when dura inflates wider on pulsation with no protection of LF. A little sticky blood clot is not sucked out through such narrow diameter. Postoperative hematoma should be prevented intraop-
eratively well or using anti-thrombin mixed materials. It might not be a reasonable choice to depend on a longer time of residence of drain in the operating site. It is mainly for draining irrigation saline left in the spinal canal upward and downward. A drain is removed at postoperative 1 or 2 days. If drain amount would abruptly increase after ambulation and drained blood-mixed saline come to be much clear, insensible dural tear should be suspected first and a drain should be removed immediately. Don’t hesitate to remove a drain for fear of potential hematoma. A drain with a narrow canal never prevents postoperative hematoma.

After full recovery postoperatively of patient’s mentality and distal lower extremities sensory and motor, patient’s free ambulation can be permitted as soon as possible. It may take 4 to 6 hours after returning to a ward and resting for a while, not dependent on methods of anesthesia. Patients could feel back heaviness or buttock pain postoperatively at the 3rd or 4th day. It might be come from back and buttock muscle strain due to longer time of surgical position in prone. Caudal block can help to solve this kind of muscle fatigue and tolerable discomfort on back and buttock.

Another reason of back and buttock pain in early a few days could come from postoperative hematoma, generating mild to severe pain, sometimes with radicular pain.Resting in supine position could aggravate the pain in the night and walking with a little stooping posture decreases the pain. So, walking well with some back heaviness and buttock pain is not in a serious complicated state. Mostly hematoma is resorbed spontaneously after postoperative 3 or 4 weeks. Ambulation and back stretching under analgesics, or two to three times of root block at every 3 or 4 days, is effective in conservative management for saline infusion into spinal canal to promote resorption and dilation for its early degradation. Postoperative hematoma with larger amount compromising spinal canal more than 50% and corresponding moderate to severe pain should be irrigated immediately and removed using Biportal-ESS. No need of conversion to open debridement. Endoscopic debridement is much effective to remove it thoroughly from distal interlaminar to proximal sublaminar area.

Driving in short distance can be no reason of prohibition. Walking as aerobic exercise in one hour should be recommended for better functional recovery. After postoperative one month later, gym exercise, swimming, climbing, and golfing could also be permitted. Longer-time sitting as office-job might cause more frequently back heaviness and pain. Back muscle exercise and stretching education should be mandatory to the patients before discharge.

Fig. 23. Neglected foraminal stenosis. (A) Preoperative MR views, central stenosis at L4-5, and foraminal stenosis on the right. (B) Postoperatively, sufficient central decompression with neglected foraminal stenosis. (C) Additional foraminal decompression was performed in 4 weeks after first central decompression.
There could be remnant neural symptoms with somewhat intolerable or early aggravated radicular pain with painful limping gait. If there were no direct neural tissue damage, remnant symptom could come from neural dysfunctional neuralgia for longer exposure to severely compressive state. Even with sufficient decompression, there could leave weakness of motor power or paresthesia in lower extremities. Longer time of moderate to severe neural compression could show thigh or calf muscle volume decrease with sensory decrease and/or coldness the foot. Such kind of discomfort prolonged mostly more than 6 months and permanently. However, more aggravated symptoms with painful limping gait could come from incomplete decompression especially remnant disc fragment under root, insufficient distal laminectomy with less free space for traversing root, or neglected foraminal stenosis. If there is painful limping gait, early revision using Biportal-ESS could solve the problem under the suspicion of incomplete decompression. There may be no need of early conversion to wider re-decompression and instrumented fusion under the name of instability. According to lots of reports on postoperative spinal pain syndrome, incomplete decompression happened much higher than postoperative surgical instability [31,34,35].

Conclusions

The purpose of decompression using open wider, microscopic, or endoscopic approach is same for surgical removal of pathologies compressing neural structures. However, accompanied surgical damage during dissection, accessibility with preserving segmental integrity, and successibility of eliminating pathologies with less damage to surrounding tissues are quietly different from each other, which is the reason why they are called as their own surgical names and generally considered as different techniques in compatibility. Decompression-alone can be performed by Biportal-ESS shows outstanding benefits in view of preserving innocent structures and accessibility to various pathology locating deeper inside of spinal canal and foramen. Remnant neurologic pain should be supposed to be incomplete decompression in need of our endeavor to overcome technical challenges rather than impetuous decision of instrumented fusion for concept of observational radiographic hyper-motion or instability in early degenerative stage.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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