



# Minimally invasive tubular laminectomies in multilevel spine surgery—an illustrative case-based review of techniques and combined approaches

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**Abstract:** Minimally invasive techniques have become part of the spine surgeons' armamentarium and are currently utilized to treat many conditions involving the cervical, thoracic, lumbar and sacral spine. Surgical treatment of severe degenerative conditions such as multilevel spinal stenosis, tandem stenosis, combination of stenosis or disk herniation and spondylolisthesis at adjacent spinal levels, as well as extensive infections or hematomas, may require a multilevel tailored approach with all the challenges that such surgical planning entails. Although the use of minimally invasive tubular decompressive procedures has gained widespread popularity in the recent years, the adoption of such techniques during multilevel spine surgery can be at times challenging. A careful tailored selection of the surgical approach that better fits needs and expectations of the patient is therefore consequential to achieve good clinical and radiological outcome without compromising efficiency and results. Many surgical techniques have been described in literature but very few reports on the use of combined tubular approaches are currently present. We therefore present an illustrative review of techniques for tubular laminectomies and combined approaches that can be utilized in the surgical treatment of multilevel spinal conditions. Illustrative cases documenting common and less common indications for the use of minimally invasive laminectomies are also presented.

**Keywords:** Minimally invasive laminectomy, minimally invasive spine surgery, combined approaches

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## Introduction

Minimally invasive procedures are nowadays commonly utilized for the treatment of many spinal pathologies. We present a review of tubular techniques, with schematic case-based illustrations, that may be utilized during the selection of tailored surgical approaches to multilevel spinal conditions.

## Surgical techniques

Patients are positioned prone on a radiolucent Jackson

table. Intraoperative lateral and antero-posterior (AP) fluoroscopy are utilized to guide the approach as needed. Neuro-navigation assisted techniques can also be utilized to minimize x-rays exposure (1).

Tubular retractors (METRx or Xtube, Medtronic) are utilized to expose the lamina and/or posterior joints, as described in previous publications (2,3). In cases of revision surgery, where the spinous process and lamina had been previously removed, antero-posterior (AP) X-rays can be particularly useful to direct the tubular approach and avoid

**Table 1** Illustrative surgical cases

Case	Pathology and approaches
Case 1	L4-L5 stenosis. L4 and L5 tubular laminectomies were performed
Case 2	L3-S1 stenosis. L3, L4, L5, partial S1 tubular laminectomies were achieved via a “double barrel” approach
Case 3	L2-S1 stenosis. Tandem unilateral laminectomies were utilized L4, partial L4, partial S1 laminectomies was achieved using caudal incision. L3, partial L4, partial L2 laminectomies was achieved using cranial incision
Case 4	L2-S1 stenosis. Tandem Alternating laminectomies were utilized in this case L3, partial L2, partial L4 laminectomies were achieved using the left cranial incision L5, partial L4, partial S1 laminectomies were achieved using the right caudal incision
Case 5	L2 to L4-L5 stenosis. Tandem Alternating laminectomies were utilized to achieve decompression L2, L3 laminectomies were achieved using one incision L4, partial L5 laminectomies were achieved using the other incision
Case 6	L2-3 to S1 stenosis. L3, L4, L5, partial S1, partial L2 tubular laminectomies were achieved via a “triple barrel” approach
Case 7	L4-5 SPL with adjacent L2-3 stenosis, treated with minimally invasive left L4-5 TLIF/laminectomy and alternating incision L2-3 tubular laminectomy (“one and a half” TLIF with UNILATERAL instrumentation)
Case 8	L5-S1 SPL with bilateral Pars defect and adjacent L3-4 disk herniation treated with minimally invasive bilateral L5 pars fractures decompression, L5-S1 TLIF and alternating incision L2-3 tubular discectomy/ laminectomy (“one and a half” TLIF with BILATERAL instrumentation)
Case 9	L4-5 SPL with adjacent L5-S1 degenerative disk disease, treated with minimally invasive right L4-5 and left L5-S1 alternating TLIF’s and bilateral instrumentation
Case 10	Rare Holocord SEA with acute tetraparesis treated with urgent minimally invasive tubular laminectomies at C6-7, T8 and L4 with catheter assisted drainage-irrigation of the epidural space

drifting toward the contralateral side while exposing the superficial tissues (as the natural barrier provided by the spinous process may not be present anymore). Correct interpretation of intraoperative AP X-rays can help adjusting the angle of the tubular dissection before the neural structures are visualized. Radiation exposure for the patient and team can be minimized by stepping away from the surgical field while implementing pulse radiation, by using protective gears and by constantly apply the ALARA concepts. For a tubular laminectomy the incision is usually made 1 fingerbreadth lateral to the midline/spinous process. For a transforaminal lumbar interbody fusion (TLIF) the placement of the skin incision is guided by the AP x-rays during K-wires pedicle placement (usually 4–5 cm lateral to the midline).

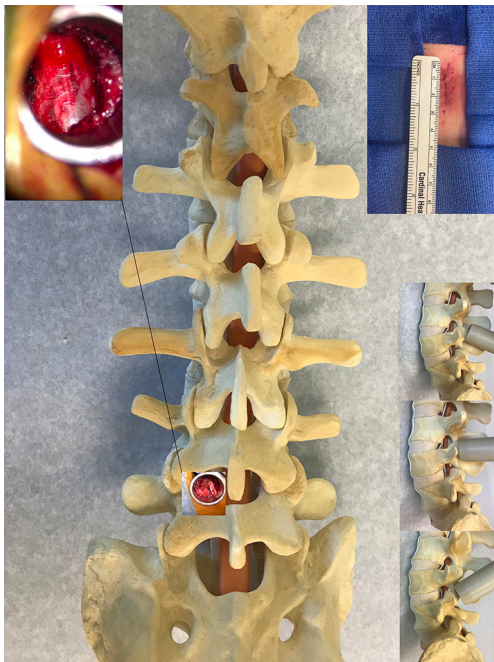
To perform the tubular laminectomies the Authors prefer to utilize a Midax-rex drill with a matchstick burr and a curved long attachment that does not impede distal

visualization at the tip. Loupe magnification is usually sufficient in these cases.

Most of the tubular laminectomies are performed using 22 mm diameter METRx tubes. In case previously placed instrumentations that does not require surgical revision is present at the operative level (Pedicles screws/ rods, Interspinous process device) an 18 mm tube can be utilized to clear the instrumentation avoiding the need for a minimally invasive removal and replacement of the hardware.

Following is an illustrative review of the tubular techniques that can be selected and combined for the treatment of multilevel spinal stenosis, tandem stenosis, spondylolisthesis with and without bilateral pars fracture associated with stenosis or disk herniation at adjacent levels and multilevel (or holocord) spinal epidural abscess.

Information related to the illustrative cases presented in the article are summarized in *Table 1*.



**Figure 1** Tubular laminectomy for stenosis. Model for 1 and a half to 2 level laminectomy. Cranial and caudal orientations of the tubular retractor and incision size are also illustrated.

## Multilevel spinal stenosis

### *1 and a half to 2 level tubular laminectomy*

In the thoraco-lumbar spine, using a single 2.5 cm incision and a 22 mm tubular retractor, a tubular laminectomy involving up to 2 adjacent levels can be performed by tilting the tube cranially and caudally as needed. For a 2-level laminectomy involving 2 vertebral levels (e.g., L4 and L5) the tube is usually docked at the level of the intervertebral space just over the yellow ligament. Tilting the tube cranially and caudally, the laminectomies are then completed following the known surgical technique. If 3 vertebrae are involved by the stenosis (e.g., L3-4, L4-5 stenosis in need of a L4 laminectomy, partial L3, partial L5 laminectomy), the tube is docked on the central vertebral and the inferior half of the superior lamina and the superior half of the inferior lamina can be exposed by tilting the tube cranially and caudally as needed (*Figure 1*). Contralateral foraminotomies can be achieved by orienting the tube towards the contralateral side, while tilting the bed slightly away from the surgeon. Case 1 illustrate this technique in a L4-5 laminectomy (*Figure 2*).

### *2 to 3 and a half level tubular laminectomy*

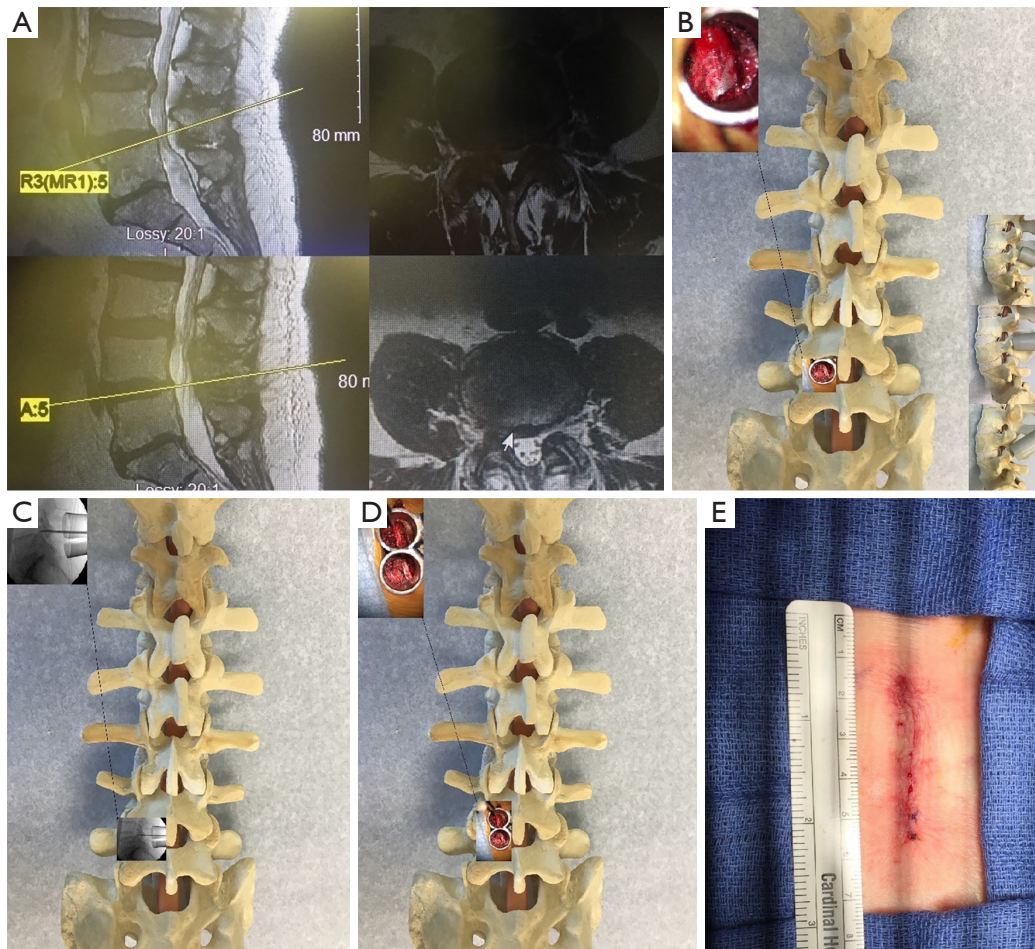
In the thoraco-lumbar spine, using a single 4 cm incision and 22 mm fixed or 24 mm expandable tubular retractors, a laminectomy involving up to 3 and a half adjacent levels can be achieved (*Figure 3*).

For a 2-level laminectomy a single fixed tubular retractor is utilized. When very bulky paraspinal muscles are encountered, or to achieve a 2 and a half level laminectomy, an expandable retractor (Xtube, Medtronic) is utilized. A “Double barrel” technique can be utilized to expose up to 3 and a half adjacent levels, as previously described by the Authors (4). The tubes are sequentially placed at the spinal levels of interest before starting the laminectomies so, when needed, the construct can be pivoted cranially and caudally to achieve exposure up to 3 and a half spinal levels as illustrated by the intraoperative X-rays in Case 2 (*Figure 4*). Placing the tubes before the starting the laminectomies also avoids the issues associated with having to re-dock the tubular system once the dura is exposed (or in case a durotomy is accidentally created before the end of the procedure).

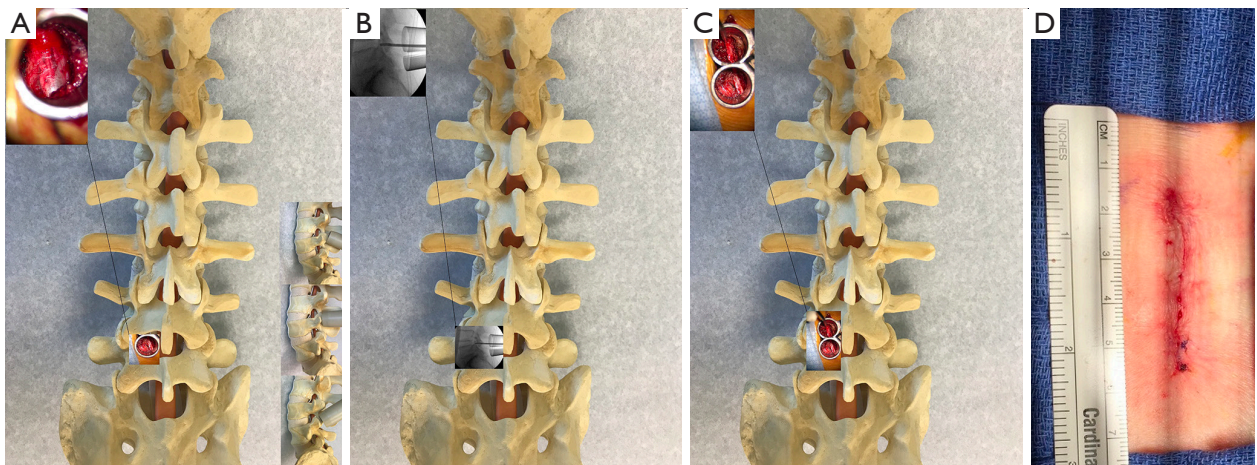
### *3 to 4 level tubular laminectomy*

In the thoraco-lumbar spine, using a single 5.5 cm incision, a laminectomy up to 4 adjacent levels can be achieved using fixed 22 mm tubular retractors, utilizing a “Triple barrel” technique as previously described (4) (*Figure 5*). The tubes are sequentially placed at the spinal levels of interest before starting the laminectomies so when needed the construct can be pivoted cranially and caudally to extend the exposure to encompassing 4 spinal levels, as illustrated by the intraoperative X-rays in Case 6 (*Figure 6*). Having all the tubes in place before the beginning of the decompression also allows the surgeon to monitor the hemostasis at the previously operated levels as the laminectomies proceed. Once the multilevel laminectomy is completed, the tubes are sequentially removed and the muscle and fascia can be closed. A surgical drain is usually not necessary but can be placed if needed. Case 6 describes a 4-level laminectomy performed utilizing the above mentioned approach (*Figure 6*).

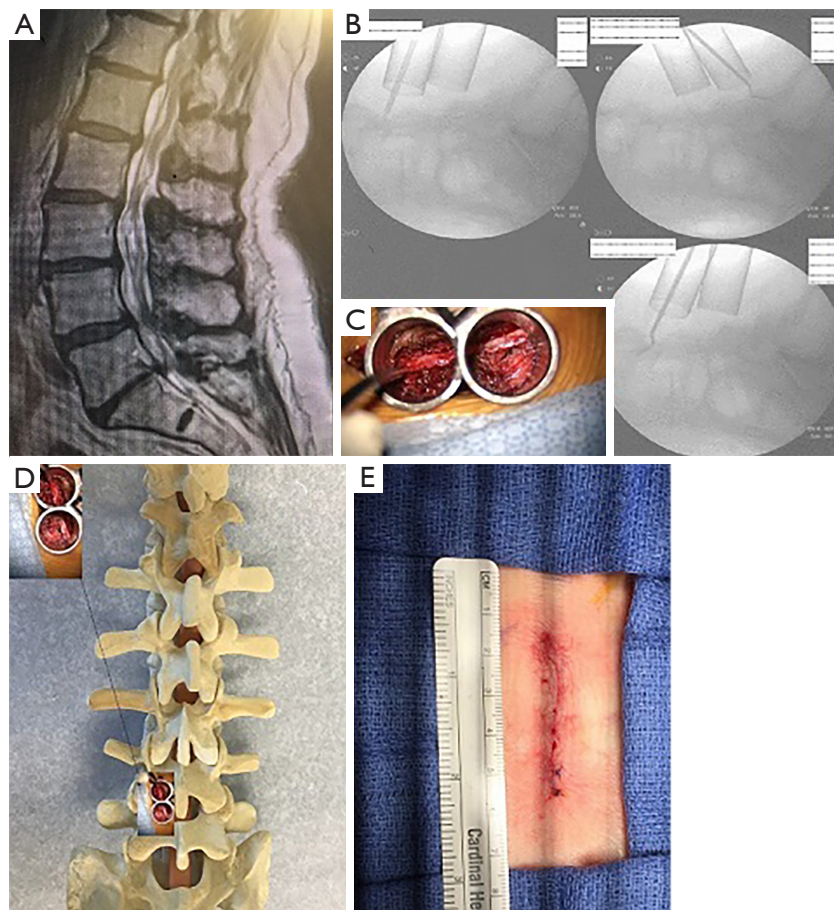
Only one set of METRx tubes can be utilized when performing a laminectomy following a “double/triple barrel” technique”, as the use of tubular dilators of slightly different length at contiguous levels does not create any problem with correct placement and visualization. We usually place an appropriate size tube at the caudal level to



**Figure 2** Case 1. L4-L5 stenosis. L4 and L5 tubular laminectomies were achieved using a single tube. (A) Superior row: Preoperative T2 weighted MRI showing the multilevel stenosis. Inferior row: Postoperative T2 weighted MRI confirming good decompression; (B) Model for 2 level laminectomy (single tube); (C) Model for 2 and a half level laminectomy (expandable tube-Xtube); (D) Model for “double barrel” laminectomy; (E) Incision after 2 level tubular laminectomy.



**Figure 3** Tubular laminectomy for stenosis. From left to right: Model for 2, 2 and a half and 3 and a half level laminectomy.



**Figure 4** Case 2. L3 to S1 stenosis. L3, L4, L5, partial S1 tubular laminectomies were achieved via a “double barrel” approach. (A) Preoperative T2 weighted sagittal MRI showing the multilevel stenosis; (B) Intraoperative X-rays showing the extent of exposure obtained tilting the tubes cranially and caudally; (C) Intraoperative visualization of the decompressed dura during a “double barrel” approach; (D) Model for the “double barrel” laminectomy; (E) Incision after 3 and a half “double barrel” laminectomy



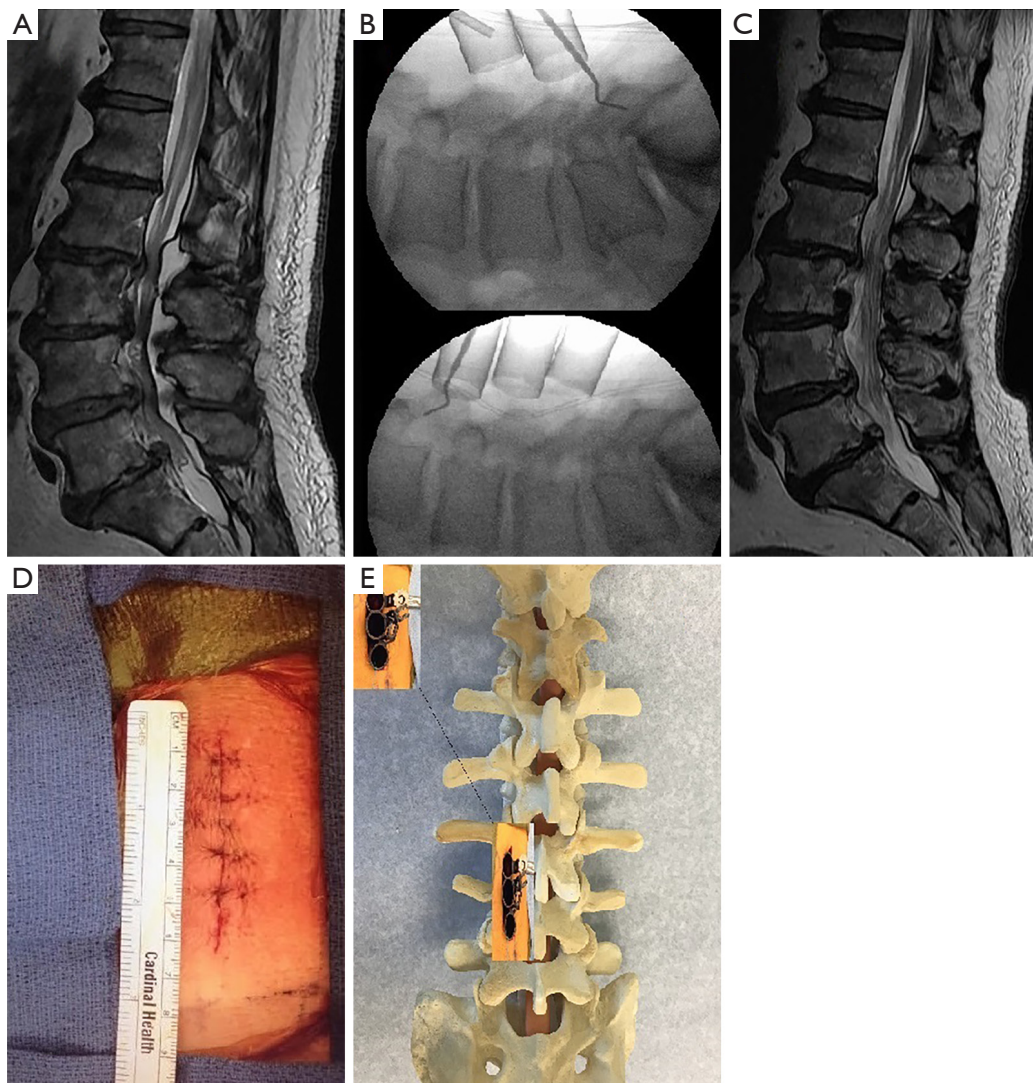
**Figure 5** Tubular laminectomy for stenosis. Model of the “triple barrel” technique for 3 to 4 level laminectomy.

be decompressed, as the “next size down” dilator usually fits properly when exposing the contiguous cranial level. If tubular retractors of similar length are to be utilized, than a second set of METRx tubes can be kept available in the Operative Room.

### **Tandem stenosis**

#### ***Tandem unilateral tubular laminectomies for multilevel tandem stenosis***

Tandem tubular laminectomies can be used in lieu of the “Triple barrel” technique to achieve multilevel posterior decompression at adjacent levels minimizing the amount of continuous muscle dissection (*Figure 7*). Two (or more) unilateral 1-inch incisions are utilized and tubular



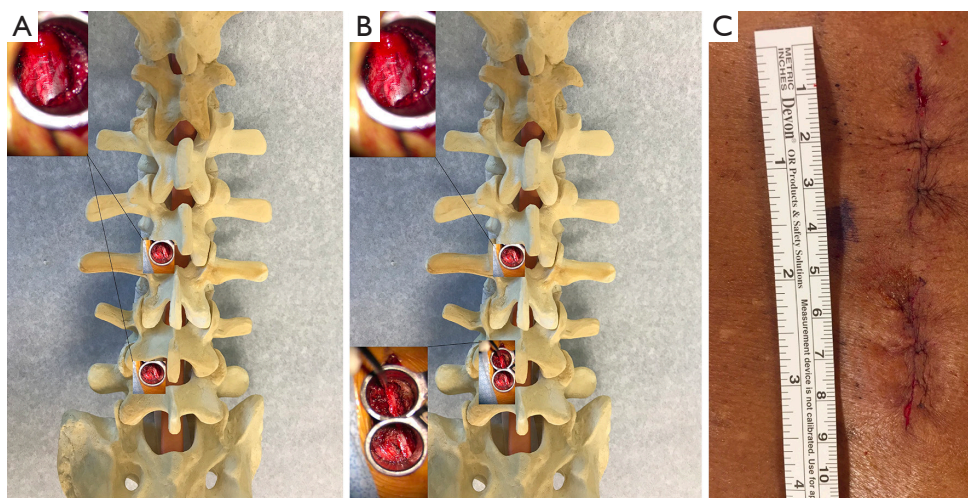
**Figure 6** Case 6. L2-3 to S1 stenosis. L3, L4, L5, partial S1, partial L2 tubular laminectomies were achieved via a “triple barrel” approach. (A) Preoperative T2 weighted sagittal MRI showing the multilevel stenosis; (B) Intraoperative X-rays showing the extent of exposure obtained tilting the tubes cranially and caudally; (C) Postoperative T2 weighted sagittal MRI confirming good decompression; (D) Incision after 4 level “triple barrel” laminectomy; (E) Model for the “triple” laminectomy.

laminectomies are carried out at each level, following the known technique. If needed, and depending on the extent of the stenosis, a “double barrel” approach can also be combined.

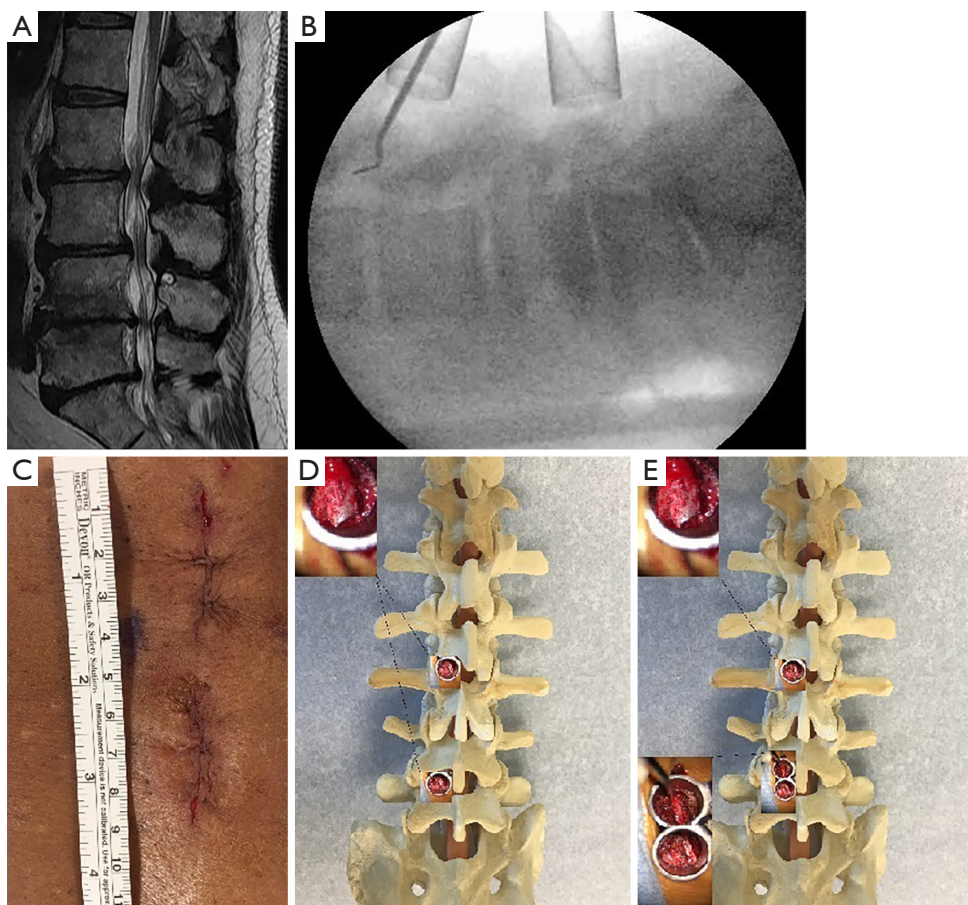
Tandem unilateral laminectomies can also be utilized to treat tandem stenosis involving non adjacent spinal levels. Case 3 is an illustrative example of the use of such approach (Figure 8).

#### ***Tandem alternating tubular laminectomies for multilevel stenosis***

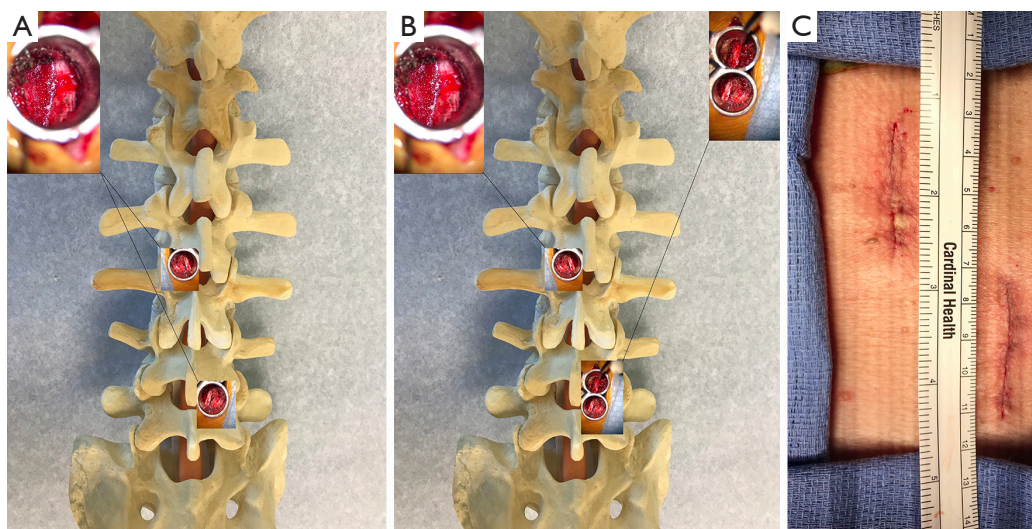
Tandem tubular alternating laminectomies can be utilized to treat multilevel lumbar stenosis at adjacent levels or tandem stenosis at non adjacent levels (Figure 9). Bilateral 1-inch tandem incisions are placed at the levels of interest and tubular dissection and laminectomies are carried out sequentially. Although we prefer to close the fascia



**Figure 7** Tandem Unilateral laminectomies for multilevel adjacent or tandem stenosis. From left to right: Model for tandem stenosis and combined “single-double barrel” approach.



**Figure 8** Case 3. L2 to S1 stenosis. Tandem unilateral laminectomies were utilized. L4, partial L4, partial S1 laminectomies was achieved using caudal incision. L3, partial L4, partial L2 laminectomies was achieved using cranial incision. (A) Preoperative T2 weighted sagittal MRI showing the multilevel stenosis; (B) Intraoperative X-rays showing the tubular retractors at L4-5 and L3; (C) Incisions after unilateral tandem laminectomies; (D) Model for unilateral tandem laminectomies; (E) Model for combined “single-double barrel” unilateral approach.



**Figure 9** Tandem Alternating laminectomies for multilevel adjacent or tandem stenosis. From left to right: Model for tandem stenosis and combined “single-double barrel” approach.

right after a laminectomy is completed at one level, the alternating tubes can also be left in place while treating the other levels, so that hemostasis can be monitored throughout the procedure. If needed, and depending on the extent of the stenosis, a “double barrel” approach can also be combined. Alternating tandem laminectomies were used in Case 4 (*Figure 10*) and Case 5 (*Figure 11*). To minimize the degree of unilateral postoperative muscle spasms, we prefer to utilize alternating over unilateral incisions when treating multilevel stenosis.

### Lumbar spondylolisthesis

#### *Lumbar spondylolisthesis with stenosis or disk herniation at the adjacent level (with unilateral instrumentation)*

The use of minimally invasive transforaminal lumbar interbody fusion (TLIF) with adjacent segment unilateral laminectomy and decompression has been already described by Hartl and colleagues in the so called “One and a half” approach to lumbar spondylolisthesis and adjacent level stenosis (5). In low grade (grade 1-2) spondylolisthesis (SPL), the minimally invasive instrumented fusion is performed with a unilateral exposure and bilateral decompression, by tilting the tubular retractor contralaterally to achieve “over the top” and foraminal decompression as previously described (6).

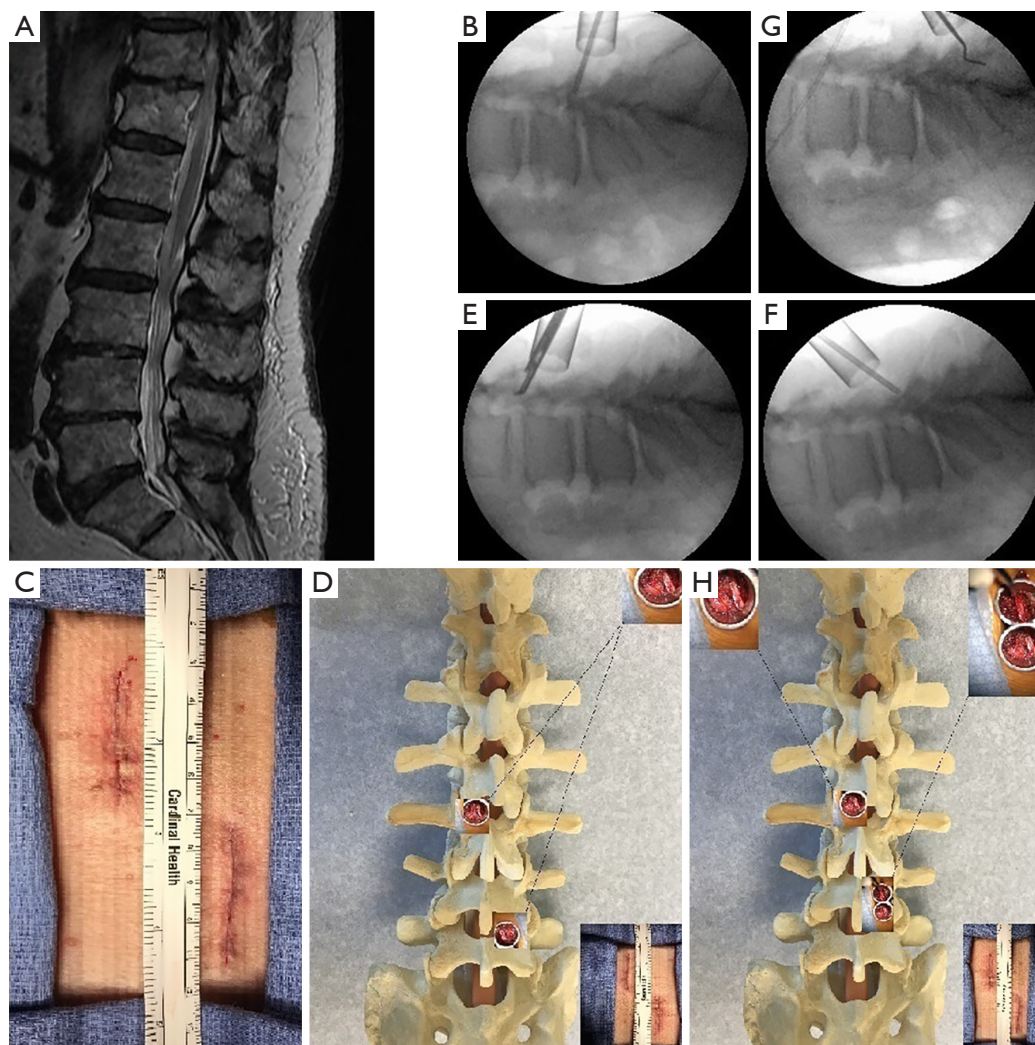
When no preoperative mechanical instability is present, or when the TLIF is performed for recurrent disk

herniations, degenerative disk disease or lateral foraminal stenosis, a unilateral construct, especially in elderly patients, can be biomechanically sound possibly limiting the rate of adjacent disk disease (7-9). In this combined approach the incision used for the TLIF may be extended to allow a more medial fascial incision at the level of the adjacent laminectomy or tailored to the laterality of the compression in case of disk herniation (*Figure 12*). In case of adjacent level central stenosis, we prefer to make a contralateral incision to minimize the degree of unilateral muscle/fascial opening (and relative postoperative unilateral muscle spasms) as illustrated in Case 7, where SPL and lumbar stenosis at the adjacent level were present (*Figure 13*).

#### *Lumbar spondylolisthesis with stenosis or disk herniation at the adjacent level (with bilateral instrumentation with or without pars defect)*

In the presence of adjacent level stenosis (or disk herniation) to a spondylolisthesis and when a bilateral construct is recommended (mechanical instability, high degree listhesis, need to remove both joints to facilitate satisfactory intraoperative reduction in osteoporotic patients, or when a bilateral pars deficit decompression is planned), the TLIF can be combined with a single tubular laminectomy by extending one of the skin incisions to allow a more medial third fascial incision, or by placing a third separate small incision at the level involved by the adjacent pathology





**Figure 10** Case 4. L2 to S1 stenosis. Tandem Alternating laminectomies were utilized. L3, partial L2, partial L4 laminectomies were achieved using the left cranial incision. L5, partial L4, partial S1 laminectomies were achieved using the right caudal incision. (A) Preoperative T2 weighted sagittal MRI showing the multilevel stenosis; (B,G) Intraoperative X-rays during L5 partial L4, partial S1 laminectomies; (E,F) Intraoperative X-rays during L3, partial L2, partial L4 laminectomies; (C) Incisions after alternating tandem laminectomies; (D) Model for alternating tandem laminectomies; (H) Model for combined “single-double barrel” alternating approach.

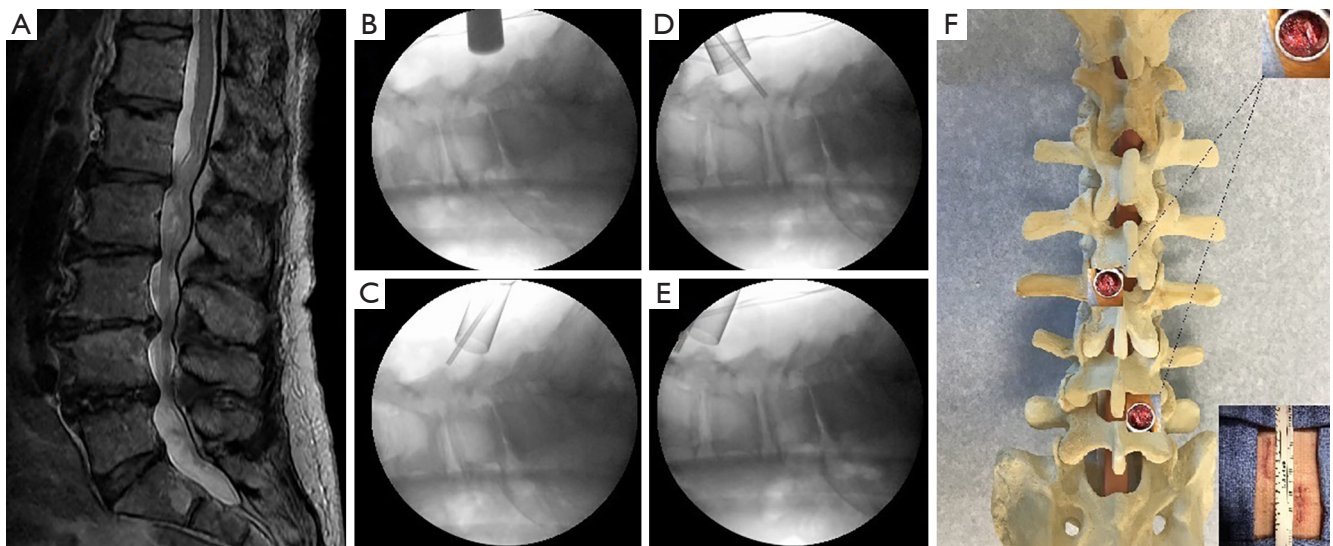
(*Figure 14*). Case 8 illustrates the use of such “one and a half TLIF” combined approach in a case of SPL with bilateral pars defect and adjacent level disk herniation (*Figure 15*).

#### ***Two level “Alternating” tubular TLIF***

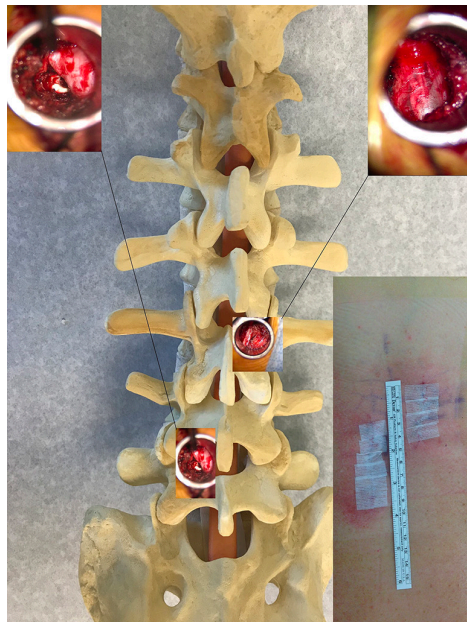
In cases of “staircase” SPL, multilevel degenerative disk disease or combined pathologies, a multiple level minimally invasive TLIF may be indicated.

In these cases, unless a unilateral approach is to be performed (disk herniations on the same side, purely

unilateral symptoms etc.), we prefer to alternate the sides of the TLIF. In our experience this approach minimizes the amount of unilateral postoperative muscle spasms and facilitates the tubular exposure as the retractor does not tend to “slip” toward the previously operated side when performing the second TLIF. An alternating approach may also limit the extent of paraspinal muscle dissection, as the muscles superior to the posterior joint may not need to be dissected using an alternating approach (*Figure 16*). Case 9 is an illustrative example of the use of such alternating tubular approach for a multilevel TLIF (*Figure 17*).



**Figure 11** Case 5. L2 to L4-L5 stenosis. Tandem Alternating laminectomies were utilized. L2, L3 laminectomies were achieved using one incision. L4, partial L5 laminectomies were achieved using the other incision. (A) Preoperative T2 weighted sagittal MRI showing the multilevel stenosis; (B,C) Intraoperative X-rays during L4 partial L5 laminectomies; (D,E) Intraoperative X-rays during L2, partial L4 laminectomies; (F) Model for alternating tandem laminectomies.



**Figure 12** Model for Tandem Alternating laminectomy for stenosis (or disk herniation) and SPL (unilateral instrumentation). “One and a half” approach.

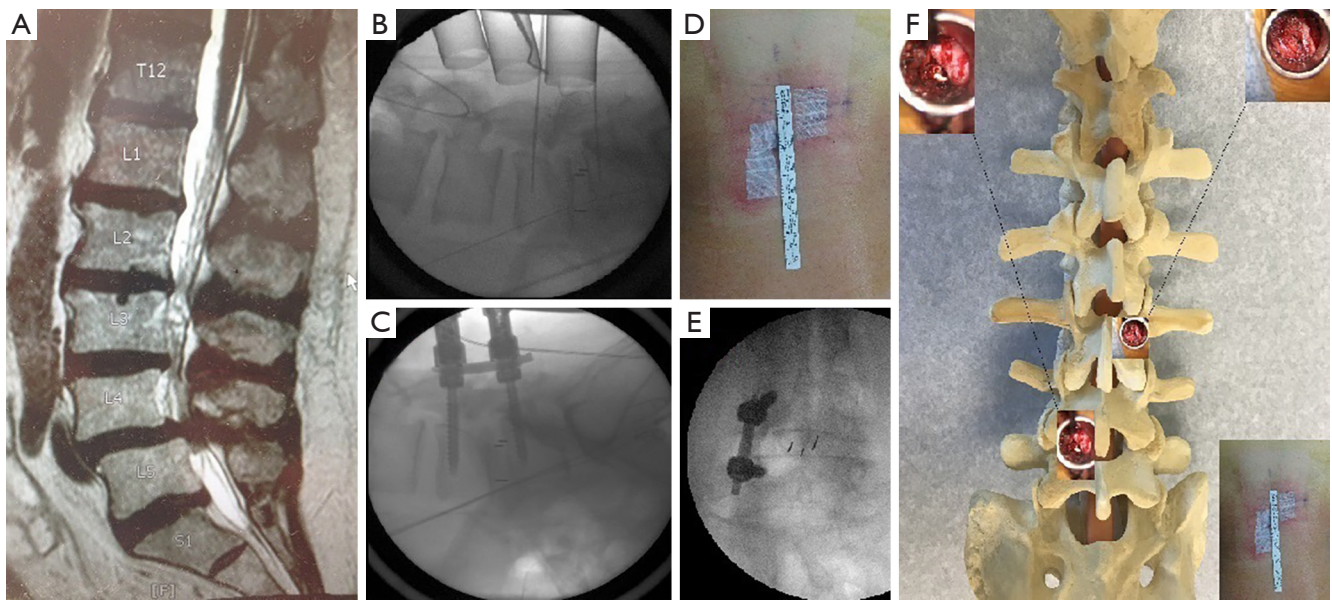
### Multilevel (or holocord) spinal epidural abscess (SEA)

Spinal epidural abscesses involving multiple levels or encompassing more than one spinal region, may pose a surgical challenge as treatment with extensive open multilevel decompressive laminectomies in an urgent setting may not be inconsequential.

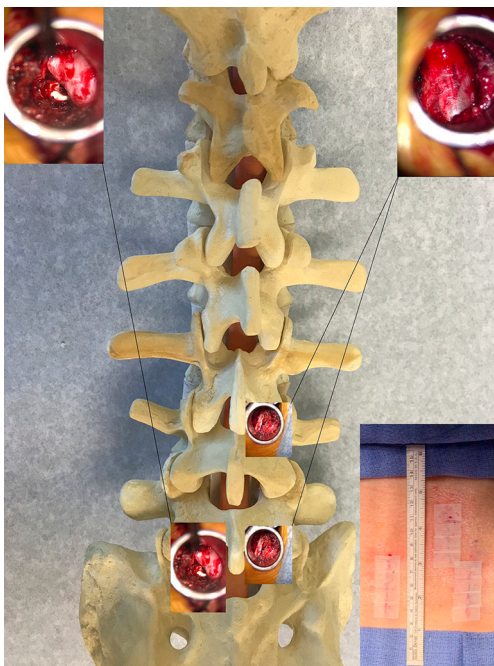
The use of tandem alternating tubular laminectomies tailored on preoperative imaging can facilitate a relatively quick and bloodless surgical drainage with decompression of the epidural space.

In such cases, we prefer to tailor the level of the laminectomies to the sagittal length of the SEA, while the laterality of the incisions for the tubular approach is guided by the radiological extension of the fluid collection on the axial plane (*Figure 18*). Case 10 describes the use of tandem alternating laminectomies for the urgent treatment of a rare holocord SEA (*Figure 19*).

The use of similar “skip” laminectomies for the treatment of multilevel spinal hematomas was also recently described (10).



**Figure 13** Case 7. L4-5 SPL with adjacent L2-3 stenosis, treated with minimally invasive left L4-5 TLIF/laminectomy and alternating incision L2-3 tubular laminectomy (“one and a half” TLIF with UNILATERAL instrumentation). (A) Preoperative T2 weighted sagittal MRI showing the L4-5 SPL and L2-3 stenosis; (B) Intraoperative X-rays during the L3, partial L2, partial L4 tubular laminectomy achieved with the alternating incision; (C) Intraoperative X-rays (lateral) during the minimally invasive L4-5 TLIF; (D) Intraoperative X-rays (a/p) after the minimally invasive L4-5 TLIF; (E) Incisions after “one and a half” TLIF with unilateral instrumentation and adjacent level laminectomy; (F) Model for the alternating tubular TLIF-adjacent level laminectomy.



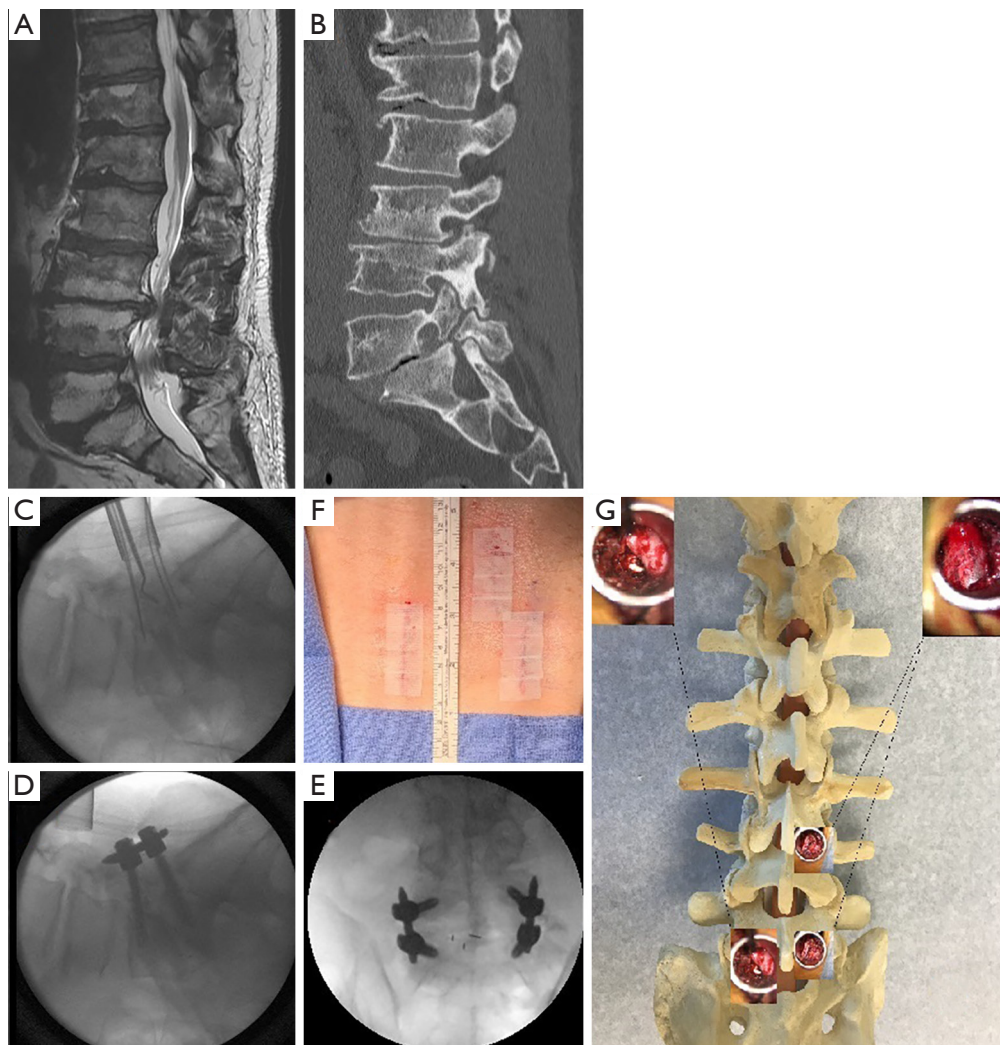
**Figure 14** Model for Tandem Alternating laminectomy for stenosis (or disk herniation) and SPL (bilateral instrumentation). “One and a half” approach.

## Discussion

With the acquisition of long term outcome data and the evolution of instrumentation and procedures, surgeons have become more acquainted with the use of less invasive spinal techniques, which has led to a gradual expansion of their surgical indications.

The use of minimally invasive techniques in spine surgery has proven to positively affect length of stay, surgical blood loss and need for postoperative opioids, without compromising long term surgical outcome (11,12) and tubular approaches have now becoming part of the surgeons’ armamentarium for the treatment of numerous spinal conditions (13-24).

Minimally invasive muscle sparing techniques and other minimally invasive procedures have also proven to be cost effective in recently published cost-utility analysis (25,26). The amount of muscle injury from tubular approaches also positively compares with open techniques when MRI postoperative studies are analyzed (27). Despite some of the advantages introduced by the use of lesser invasive procedures, there are drawbacks that should be considered when selecting such approaches. The learning curve

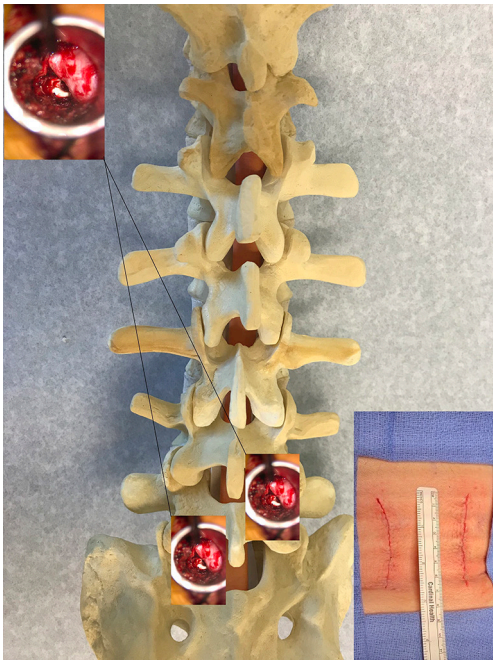


**Figure 15** Case 8. L5-S1 SPL with bilateral Pars defect and adjacent L3-4 HNP, treated with minimally invasive bilateral L5 pars fractures decompression, L5-S1 TLIF and alternating incision L2-3 tubular discectomy/laminectomy (“one and a half” TLIF with BILATERAL instrumentation). (A) Preoperative T2 weighted sagittal MRI showing the L5-S1 SPL and L3-4 HNP/stenosis; (B) Preoperative Sagittal CT showing the pars fracture; (C) Intraoperative X-rays (lateral) during the minimally invasive pars decompression; (D,E) Intraoperative X-rays after the minimally invasive L5-S1 TLIF; (F) Incisions after “one and a half” TLIF with bilateral instrumentation and adjacent level discectomy); (G) Model for the alternating tubular TLIF, bilateral pars fractures decompression-adjacent level laminectomy/discectomy.

associated with becoming proficient with these procedures can in fact be steep and lengthy (28). Also the need for dedicated instrumentation, the lack of familiarity with the surgical anatomy that a tailored but limited tubular dissection can expose and the anatomical distortion created by the pathology at hand, may all add challenges that even experienced spine surgeons should keep into consideration before planning an operation.

Iatrogenic durotomy and subsequent CSF leak is

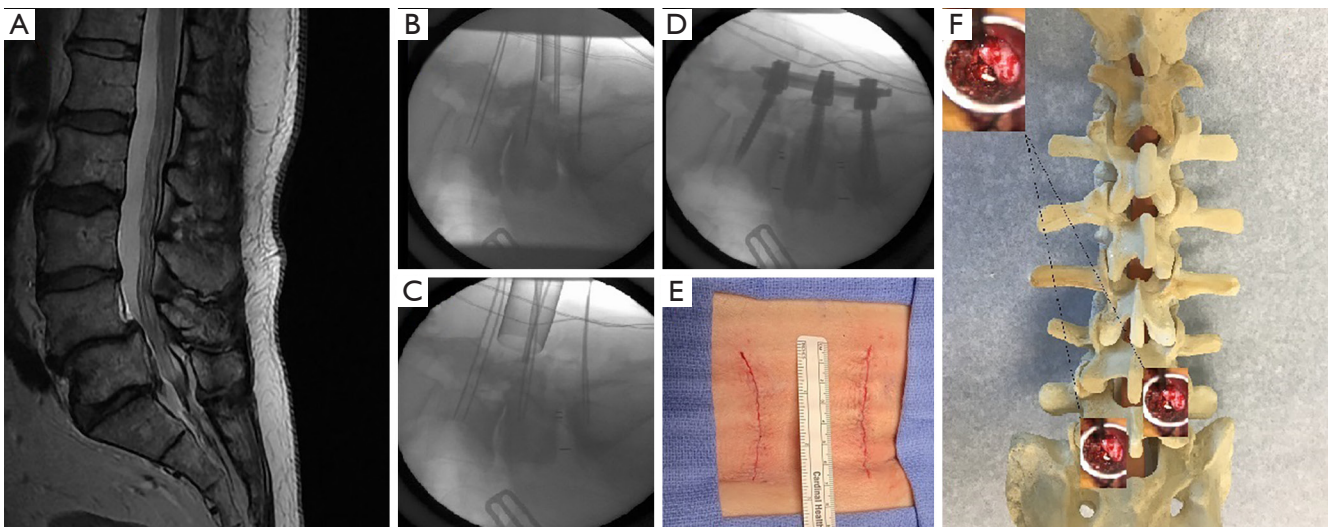
unfortunately not uncommon during minimally invasive spine surgery. In light of the limited exposure provided by the tubular approach, a CSF leak occurring at the beginning of the procedure can add additional challenges to the procedure and lengthen the duration of the surgery. In the presence of an active leak, the dural sac may deflate and venous bleeding from the epidural plexus may start clouding the surgical field. The presence of blood next to a durotomy may also increase the risk of adhesive arachnoiditis in the



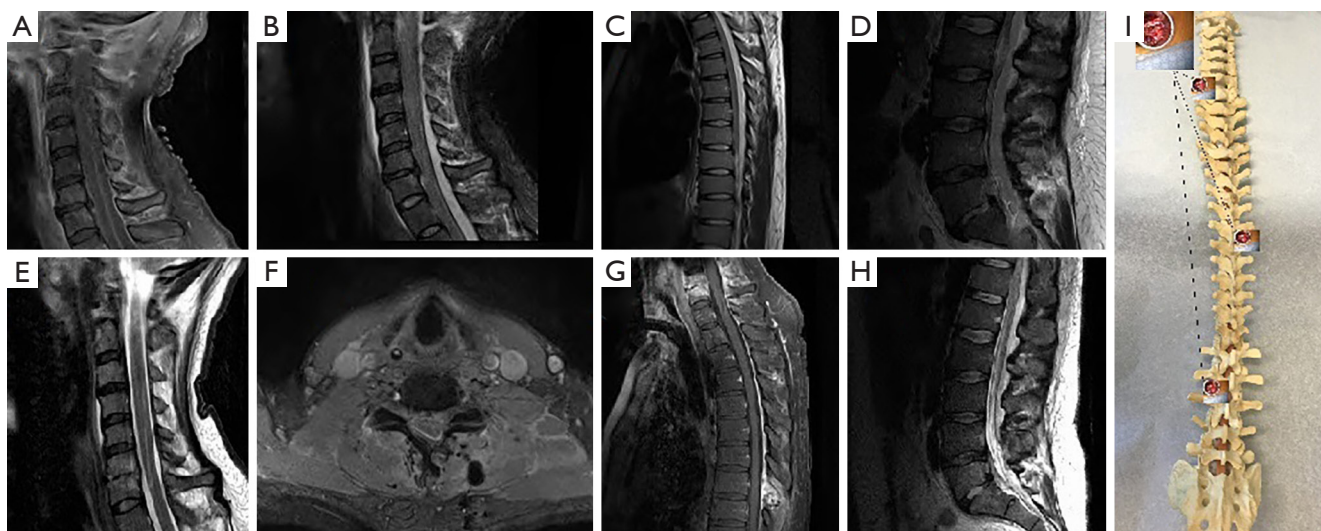
**Figure 16** Model for Alternating 2 Level TLIF for stenosis-SPL (bilateral instrumentation).



**Figure 18** Model for Tandem Alternating laminectomies for multilevel SEA-hematomas.



**Figure 17** Case 9. L4-5 SPL with adjacent L5-S1 degenerative disk disease (DDD), treated with minimally invasive right L4-5 and left L5-S1 alternating TLIF's and bilateral instrumentation. (A) Preoperative T2 weighted sagittal MRI showing the L4-5 SPL and L5-S1 severe DDD; (B,C) Intraoperative X-rays during the alternating TLIF's and L4-5 and L5-S1; (D) Intraoperative X-rays (lateral) after the TLIF/instrumentation; (E) Incisions after the alternating sides minimally invasive tubular TLIF's with bilateral instrumentation; (F) Model for the alternating tubular TLIF's.



**Figure 19** Case 10. Rare Holocord SEA, treated with urgent minimally invasive tubular laminectomies at C6-7, T8 and L4 with catheter assisted drainage-irrigation of the epidural space. (A) Preoperative T1 weighted sagittal MRI with contrast showing large cervical posterior SEA; (B) Preoperative T2 weighted sagittal MRI with showing large cervical posterior SEA; (C) Preoperative T2 weighted sagittal MRI showing large thoracic posterior SEA; (D) Preoperative T2 weighted sagittal MRI showing large lumbo-sacral posterior SEA; (E) Postoperative T2 weighted sagittal MRI showing good decompression of cervical SEA after alternating tubular laminectomies and catheter-assisted drainage; (F) Postoperative T1 weighted axial MRI at the level of the cervical laminectomy, showing good decompression of SEA after alternating tubular laminectomies and catheter-assisted drainage; (G) Postoperative T1 weighted sagittal MRI with contrast showing good decompression of thoracic SEA after alternating tubular laminectomies and catheter-assisted drainage; (H) Postoperative T2 weighted sagittal MRI showing good decompression of SEA after alternating tubular laminectomies and catheter-assisted drainage; (I) Model for the alternating tubular cervico-thoracic-lumbar laminectomies.

postoperative period. In some instances, nerve rootlets may also protrude from the arachnoid opening and be exposed to involuntary iatrogenic injury during the procedure. Direct coagulation of the epidural plexus is usually poorly effective and may result in worsening of the venous oozing due to dural shrinkage, while the use of powdered hemostatic agents directly over a durotomy should be avoided. In these cases we have found useful to temporarily repair the leak with some subcutaneous fat graft and fibrin glue, so that the leak can be controlled, the dural sac can gradually re-expand and good hemostasis can be facilitated. Final repair can be then performed at the end of the procedure.

In our experience with the use of tubular laminectomies, direct suturing of iatrogenic durotomies has not been necessary, as CSF leaks are successfully repaired with the use of autologous fat graft and fibrin glue.

Among the benefits offered by minimally invasive tubular approaches in fact, is that iatrogenic CSF leaks are usually contained by the spontaneous closure of the paraspinous

muscles (which are not removed/detached during the approach), when tubular retractors are removed.

Depending on the degree of central stenosis an “over the top” tubular laminectomy may be needed, so to reach and decompress the contralateral neural elements (6). Tilting the tubular retractor toward the contralateral joint will allow visualization of the contralateral foramina and bilateral decompression can be achieved via a unilateral approach. If such contralateral decompression is planned, we suggest to perform it near the end of the procedure so if a durotomy occurs, the repair is easier and no significant time is added to the duration of surgery.

In cases where a bilateral joint removal is planned/needed (e.g., pars defect with SPL, in need of reduction), a bitubular approach is utilized. Otherwise, an effective bilateral decompression can be achieved with an “over the top” laminectomy by tilting the tube toward the contralateral side while using a 45-degree Kerrison to perform a contralateral foraminotomy.

Depending on the nature and extent of the pathology

at hand, as well as patients' comorbidities, the use of open multilevel laminectomies may not always be inconsequential, with the morbidity associated to a lengthy and extensive open surgery, especially if in an urgent setting (SEA, cauda equina syndrome etc.), that are well known to the surgeons (29). Significant blood loss, extensive paraspinal muscles trauma, long incisions in bedridden patients and risks of postoperative progressive spinal deformity, should all be factored in when planning and selecting the best surgical operation to treat multilevel spinal conditions. Furthermore, treatment of non-adjacent pathologies such as tandem stenosis involving distinct spine regions (30), can sometimes be facilitated by the use of less invasive procedures.

With the introduction of tubular dissection techniques, many surgical variations have been reported and terms such as "skip", "apical", "alternating sides", "double-triple barrel" laminectomies have been introduced (4,31-33). The use of "skip" laminectomies with alternating side incisions for unilateral approaches and bilateral decompression, was introduced with the goals of minimizing soft tissue trauma, muscles imbalance as well as iatrogenic postoperative instability (33). Aside from facilitating daily postoperative wound care, the use of level-skipping muscle sparing procedures can minimize intraoperative blood loss also reducing postoperative pain and overall time in the operative room (34).

Tandem or alternating laminectomies can be utilized for the treatment of multiple degenerative conditions such as tandem stenosis, multilevel disk herniation and multilevel spinal stenosis. Combination of tubular procedures is safe and feasible and such approaches can be tailored to patients' need on a case by case bases.

## Conclusions

Minimally invasive techniques are part of the spine surgeons' armamentarium and treatment of severe degenerative conditions such as multilevel spinal stenosis, tandem stenosis, combination of spondylolisthesis and stenosis/disk herniation at adjacent spinal levels, as well as multilevel spinal epidural abscesses, may require a tailored multilevel surgical approach. Minimally invasive tubular laminectomies can be safely utilized and combined to provide safe and effective treatment of many multilevel spinal conditions. We presented a schematic, case-based, illustrative review of tubular minimally invasive techniques, based on our personal experience with these approaches

that may be used to facilitate the preoperative selection of such procedures or their use in combination.

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