Spinal Surgery – Thoracic & Lumbosacral

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SPINAL TUMORS – see p. Op260 >>

FACET DISLOCATION REDUCTION – see p. T59 >>

CATALOGS

Medronic


METRx® II System - minimally invasive (tubular) spinal approach and techniques >>

MAST Quadrant (retractor system, interbody implant, pedicle screw) >> DePuy

http://www.depuy.com/healthcare-professionals/products?%Search%3Fkeyword%3D%26company%3D250%26specialty%3D0%26categ ory%3D100&%26sortby%3D%26sortint%3D%26sorttype%3D%3Dac%26ja%3D0%26page%3D1%26pixel%26pref%3D0

Expeditum 5.5 (thoracolumbar spine screws and hooks) >>

Pedicle Screw Insert Technique >>

Viper (minimally invasive spine) >>

Stryker

Radius System (posterolateral fusion) >>

Vertebral Body Support System (VB OSS) - vertebral body implants >>

XIA (lumbosacral posterolateral fusion) >>

GENERAL PRINCIPLES

- compacting bone grafts (vs. placing them loosely) in spine fusions give better fusion rates.

SAGITTAL IMBALANCE (FLAT BACK), SPINAL DEFORMITIES

NREF videos: https://www.youtube.com/playlist?list=PL6YtLoB0eAxEg1YsW4ZfvTFBPWqLHU

Practically, every patient should be evaluated for sagittal imbalance before fusion (even single level) – standing, 56 inch lateral XR (to include femoral heads and C7, making sure patient stands with knees not bent).

- spinopelvic alignment is important to postoperative outcome for adult spinal deformity and isthmic spondylolisthesis surgery

- sagittal balance has been found to improve post–lumbar decompression in patients with isolated spinal stenosis.

Sagittal imbalance can be classified into two types:

Type 1 – segmental hyperlordotic or kyphotic segment in which the patient compensates for the imbalance by hyperextension of segments above and below; corrective osteotomy is done at involved segments.

Type 2 – imbalance across significant segment of spine; spine is flat, and there is segmental loss of kyphosis and lordosis - patient is unable to compensate for this imbalance; more amenable to correction with osteotomy than spinal imbalances (osteotomy is done at lower spine - greater lever arm correcting axis of view, there are fewer complications related to thoracic visceral and vascular structures, and correction is not hindered by ribs).

Two alternatives

a) osteotomies - best level is where normally lordosis should be - at L3, 4, 5. see below >>

b) DLIF, XLIF – may achieve impressive lordosis with large grafts (TLIF, PLIF cannot fit such grafts).

- extend fusion beyond where thoracic kyphosis begins (e.g. to T5).

- most critical part is to mold rod; there are machines that can do it for you (e.g. NuVasive BendinOr® Spinal Rod Bending System – 5000S disposable).

TERMINOLOGY

Sagittal vertical axis (SVA) - measured by extending a vertical plumb line from the midpoint of the C-7 vertebral body and measuring the distance between this line and the posteroumerior corner of S-1.

- aim for < 50 mm

- positive SVA following the correction of adult spinal deformity is correlated with suboptimal functional outcome and quality of life
Lumbar lordosis (LL) - the sagittal Cobb angle between the superior endplate of L1 and the sacral plateau S1.

Pelvic incidence (PI) - the angle of a line perpendicular to the S1 endplate at its midpoint and a line connecting to the midpoint of the line connecting the centers of the femoral heads.

- patients with PI-LL mismatch > 10º have a 10-times higher risk of developing adjacent segment disease.

Pelvic tilt (PT) - the angle between a vertical line through the midpoint of the centers of the femoral heads and a line connecting to the midpoint of the line connecting the centers of the femoral head.

Sacral slope (SS) - the angle between a horizontal line and the endplate of S1.

**Adjacent Level Disease**

a) board answer – extend fusion and do decompression.
b) alternative – XLIF and wait – many patient won’t need posterior decompression as XLIF jacks up disk space and unbuckles nerve root compression.

- quantified by Pfirrmann grades

**Osteoporotic Spine** – avoid hardware (if still needed – use more constrained screws – less wobble, less loosening).

**Ankylosing Spondylitis**

Fractures are very unstable until healed!
Thoracic fracture – look at MRI

a) no ligamentous injury – brace
b) ligamentous injury – fusion (fixed-angle screws!!!)

**Redo Cases**

- dissect down to bone far away from dura and neural elements ⇒ work with curette detaching scar from bone (stay always on bone – only safe place) and thus approaching target (in lumbar spine it will help to establish laminectomy level but even then dura sometimes bulges above laminectomy level!)
- doing fusion – expose previous fusion bony mass – will have to connect to new fusion mass.

**Axis Table**

- see p. Op140 >>

Should be ideally used for every thoracolumbar fusion (shoot lateral XR after positioning)!

**Lateral Decubitus Position**

- axillary roll underneath upper chest region – to protect brachial plexus.
- arms are gently flexed at elbow and supported on double arm rest (alternative - lower arm is extended on abducted regular arm board).
- elbows must be well padded (protecting the ulnar nerve)
- lower leg is positioned relatively straight on pillow (protecting peroneal nerve); upper leg is also positioned on pillow with knee and hip flexed and taped down so as to relax ipsilateral psoas muscle for easier retraction during surgery.
- desired level should be placed on break of bed, and table is flexed for optimal access to intercostal interval.
- make sure patient remains at 90 degrees to floor!

FREE RUNNING EMG
- see Medtronic NIM Eclipse system

![FREE RUNNING EMG](image)

femoral adductors, rectus abdominis (T10, 11, 12):

![femoral adductors, rectus abdominis](image)

lateral vastus (L4):

![lateral vastus](image)

extensor hallucis longus (L5) one palm-width above ankle, close to tibia:
**SPINAL SURGERY – THORACIC & LUMBAR SACRAL Op220**

**Surgical Procedure:**

**Medial Gastrocnemius (S1):** One palm-width below popliteal fossa:

**O-ARM**

- Patient tracking clamp is attached to spinous process closest to camera (if planning laminectomy – drill pedicle screw holes, then do laminectomy, then place screws).
- Cover patient with two large sheets that meet in midline so only spinal tracking frame is exposed; open O-arm into C and slide over patient from side; after scan is done, remove O-arm and pull down sheets.
- O-arm spans only 4-5 spinal segments; if need more, move O-arm and scan again – all are imported as separate scan volumes but it is easy to switch between volumes during navigation.

**STEALTH SPINE**

- Instruments come with already attached SureTrak frames.
- Sequence:
  1) With regular Stealth probe identify pedicle screw starting point
  2) Drill cortex with Midas M8
  3) Navigated PowerEase Stryker drill – to drill holes (watch navigation screen)
  4) Ball probe
  5) Navigated tap
  6) Ball probe
  7) Navigated screw driver with screw

**Intraoperative Neurophysiological Monitoring**

See p. D25 >

**Durotomy**

- Dural violation requires primary closure (± under microscopy): running or interrupted 6-0 nylon/Prolene or 4-0 silk suture using Castro-Viejo needle driver or long Ryder needle driver.
- N.B. Use Hemo-Seal (HS-7) needle – needle diameter smaller than suture – dural hole is smaller than suture!
- Need to well expose durotomy (e.g. remove more bone around while protecting durotomy site and nervous elements with the patty).
- If nerve root keeps plugging durotomy hole (preventing placing stitch) → place patient into reverse T and drain some CSF – nerve root now can be easily pushed out of way. May even leave a patty inside the dura for the dural closure start to keep nerves away.
- Tying deep knots:
  a) Knot pusher
b) hold one string with needle driver and push knot with finger (assistant may pull on other string)

check retractor loop with Valsalva maneuver; if leaking – place another suture line.

obligatory reinforcement: Duragen soaked with autologous blood, fibrin glue with Surgicel layers

N.B. Duragen is placed first! ("Duragen goes on dura")

meticulous fascial closure decreases postoperative CSF leaks dramatically.

patient lays flat postop for 1-3 days

Dural defect (unable to close with dural sutures)

use DuraGuard patch and interrupted 4-0 silk sutures; suture through dural edges and keep tagged on mosquitos – then suture each through patch graft edges and again keep tagged on mosquitos – slide graft down and tie each knot separately.

Epidemiology: prognosis

duratomy occurs in 9% of first-time open laminectomies (with or without fusion).

duratomy significantly increased operative duration, operative blood loss, and inpatient stay

duratomy does not have long-term effects (no differences in incidence of nerve root injury, mortality, additional surgeries, or primary outcomes – up to 4 years of follow up)


POSTERIOR MIDLINE APPROACH

MEDICATIONS

preoperative antibiotics before skin incision

ketorolac (Toradol) can be instilled at preoperative antibiotics before

Epinephrine, prophylactic

meticulous f
doing.

skull incision

meticulous f
doing.

Axis / Jackson table

top of chest bar 1-2 fingerbreadths below top of sternal notch

twist prevention

Skin incision

palpate anterior superior iliac crest = L4-5 interspace

preincision needle localization film to determine correct size of exposure.

local anesthetic with epinephrine to preincision needle localization film to determine

make sure the fascia be

after minimal one-sided exposure obtain localizing film

Laminar tie, pedicles – never!

subperiosteal dissection can be done rapidly with open dry sponge raked ventrally and laterally along spinous process and lamina with large periosteal dissector, such as Cobb elevator.

Note: this dissection can be done very rapidly and in case of situs lumbar fusion can be carried out to lateral gutter to rest stop transverse processes of lumbar vertebrae;

Alternatively, Bovie electrocautery done just subperiosteally (“on bone”, “bone is home”) can greatly reduce amount of muscle bleeding encountered during operation; cautery from caudal to rostral removes paraspinous muscular attachments more efficiently and with least blood loss.

bipolar electrocautery can be used for point source bleeding.

N.B. for revision laminectomies, be careful because lamina and all posterior ligamentous structures protecting thecal sac are absent.

CLOSURE

copious irrigation; any bleeding source should be controlled until irrigation is clear.

to ensure deep fascial closure is dry, before placing last fascial stitch, irrigate into deep space and suction out irrigation; this should be clear in color

closure should be meticulous to prevent CSF leak; in event of subclinical violation and to allow for quick and less painful recovery.

interrupted, figure-of-eight. 0-size absorbable sutures to close deep muscle layer is controversial.


Patient is positioned prone on chest rolls on Wilson frame or Jackson table to hold spine in flexion:
• absolutely watertight 0-size interrupted, noninverted layer of sutures at narrow 5- to 8-mm intervals should be completed to achieve completely dry closure.

• superficial fascial closure – 2.0 inverted, interrupted sutures at equally narrow intervals to ensure adequate strength of closure.

• inject local anesthetic into skin – dramatically decreases postop pain!

• skin is closed with either staples or running 4-0 subcuticular stitch.

THORACIC SPINE APPROACHES

• key issue (for selecting approach) – ability to visualize lesion without retraction on already deformed spinal cord (paraplegia can occur from additional traction on already compromised spinal cord!) - imaging requires careful review - particular attention to lesion relationship to midline, dura, disk space, pedicle, and nerve roots.

• radicular arteries variably supply thoracic cord, and watershed infarcts can occur after root sacrifice. H:
  1) delineate with preoperative spinal angiography location of artery of Adamkiewicz.
  2) if nerve root sacrifice is necessary, aneurysm clip should be placed over root sleeve for 10 to 15 minutes with electrophysiologic monitoring before suture ligation

Arrows delineate angle of approach but not location of skin incision:

A. Laminectomy - access to vertebral body and anterior dura is precluded by need for excessive cord manipulation.

B. Transpedicular (s. lateral gutter) approach - bony removal of facet and pedicle to level of posterior vertebral body cortex – most limited access to lateral disk, canal, and vertebral body.

C. Costotransversectomy - disarticulation and removal of proximal 3-5 cm of rib - allows greater visualization of lateral vertebral body, disk space, and neural foramen; anterior decompression is limited to midline.

D. Transpedicular Corpectomy
E. Lateral extracavitary approach - additional 5-7 cm of lateral rib removal + downward pleural retraction allows for greater exposure and more lateral angle of entry, which translates into improved anterior decompression across midline.

F. Transthoracic approach through thoracic cavity - greatest degree of access to vertebral body, providing access to decompress entire anterior canal if needed; posterior elements cannot be addressed.

POSTERIOR LOCALIZATION

- counting from T1 down is the most reliable method; alternative - counting up from T12.
  - anatomically numbered ribs articulate with disk space above correspondingly numbered vertebral body.
  - in the lowest segments of thoracic spine, rib articulations can be found below level of corresponding disk space.
- long cassettes instead of fluoroscopy can be used if necessary.
- alternative - radiology confirmation (e.g. placing localization coil or small amount of cement in pedicle caudal to targeted disk space); also small screw can be placed under CT guidance preoperatively.
- intraoperative confirmation of operative level by multiple techniques in AP and lateral planes is recommended.
INCISIONS

- determined by instrumentation (if needed), degree of intended exposure, and surgeon preference.
  A. Midline - adequacy of exposure, potential for bilateral access, and ease of subsequent instrumentation
  B. Paramedian - used in lateral extracavitary approach
  C. Semilunar - used in lateral extracavitary approach
  B and C incisions need not extend more laterally than articulation of rib head or transverse process
  D. “Hockey-stick” or T in midline - may be added to midline incision if additional rib exposure is required.

THORACIC DISKECTOMY

- use monitoring (motor evoked, SSEP)
- use lateral approach (transpedicular = transthoracic approach):
  a) for paramedian disc - two-level laminectomy and the drill pedicle (e.g. T7-8 disc herniation → T7 and 8 laminectomies, T8 pedicle drill off with M8 and T7 pars removal)
  b) for lateral disc - limited laminotomy just over the disc, facet (and maybe superior portion of pedicle) drill off with M8

Thoracic ventral pathology – laminectomy is harmful (deficits may worsen postop!)

At no point in operation should one attempt to retract cord!

- maintenance of blood pressure is crucial in patients with severe cord compression!
- small cavity can be drilled into body so that disk can be pushed away from cord
- remove disc with reverse-angle curette.
- in case of calcified disk that is adherent to dura, curette / high-speed drill should be used to drill disk off thecal sac, rather than pulling it off with rongeur.

THORACIC LAMINECTOMY

- use drill to make troughs (as for CLAM), alternatively – eggshell drill entire lamina and remove with curettes.

TRANSPEDICULAR APPROACH, THORACIC
• for lateral and paramedian disc herniations.
• use prep CT – see if disc calcified - will be stuck to dura!
• wide 2-level laminectomy with drill.
• drill off pedicle below disc – enter disc space and perform formal discectomy to have space to pull herniated disc down into now empty disc space.
• small cavity can be drilled into vertebral body so that disk can be pushed away from cord.
• remove herniated disc using downdogging curette.
• for calcified central disk, entire width of thecal sac should be visualized to ensure thorough decompression; if fragment is stuck to dura – try to rotate dura and carefully dissect that fragment off dura.
• to ensure complete decompression to contralateral side, contralateral pedicle should be palpated with blunt instrument.
• for unilateral transpedicular approach to midthoracic spine, no need to instrument for stabilization; if bilateral – need to fuse.

**COSTOTRANSVERSECTOMY**

- disarticulation and removal of proximal 3-5 cm of rib - allows greater visualization of lateral vertebral body, disk space, and neural foramen; anterior decompression is limited to midline.

• prone position.
• perform facetectomy.
• pedicle is drilled to level of posterior vertebral body cortex.


• after circumferential dissection from underlying pleura, rib osteotomy is performed distally using rib cutters, Leksell rongeur, or B-1 footplate
• although parietal pleura is typically protected by thin layer of yellow fat, Kerrison rongeur is preferred to Leksell rongeur for removal of rib head to avoid pleural violation.
• downward retraction on pleura with malleable retractor allows visualization of lateral body.
• herniated disc down into vertebral body is useful to avoid segmental vessel or sympathetic trunk transaction.
• approach can be expanded to lateral extracavitary procedure with further distal rib resection, removal of multiple ribs, single-lung ventilation, and more aggressive pleural retraction.

• if decompression is likely to result in significant destabilization, place pedicle screws and provisionally tighten rod on contralateral side before removal of any bony elements; root sacrifice may be needed for cage placement.
• reserve tumor debulking until full exposure has been achieved (early aggressive attempts at tumor resection with inadequate exposure may lead to preventable blood loss).
• Valsalva maneuver under irrigation to evaluate for occult pneumothorax.

TRANSPEDICULAR CORPECTOMY

• often used for acute neurologic decline from epidural metastasis when goal is palliative decompression rather than en bloc resection.
• tumor invasion of pedicle can sometimes soften bone so that suction or pituitary forceps are only tools needed for removal.
• for cases that require bilateral transpedicular corpectomy, contralateral screws and temporary rod should be placed to stabilize spine during corpectomy and cage placement.

TRANSTHORACIC APPROACH

• if neuromonitoring signal changes occur, compression on temporary rod may relieve tension on spinal cord that sometimes occurs as body settles after circumferential bony removal.
double-lumen tube should be used for intubation.

- indication - calcified central disc herniations.
- contraindication: pulmonary pathology such that patient cannot tolerate one-lung ventilation.
- lateral decubitus position; left side up (to avoid aortic arch).
- incision - two rib levels above level of rib corresponding to the affected level.
- intercostal neurovascular bundle is dissected in a subperiosteal fashion using periosteal elevator and Doyen elevator.

- lateral decubitus position, left side up (to avoid aortic arch).
- incision - two rib levels above level of rib corresponding to the affected level.
- intercostal neurovascular bundle is dissected in a subperiosteal fashion using periosteal elevator and Doyen elevator.

- rib is harvested and can be saved for grafting material if needed.

- rib spreader is used as a self-retaining retractor, and lung is deflated.
- vertebral body and disc space are exposed in a subperiosteal fashion.
- rib head should be removed with high-speed drill, osteotome, or rongeur.
- find foramen and pedicle → using high-speed drill, pedicle is thinned, and spinal canal is identified → posterolateral aspect of vertebrae adjacent to disk is removed using drill → disk material is removed using pituitary rongeur, Kerrison rongeur, or high-speed drill.

- for calcified central disk, entire width of thecal sac should be visualized to ensure thorough decompression; → to ensure complete decompression to contralateral side, contralateral pedicle should be palpated with a blunt instrument
- 1-2 chest tubes (28-32 F) are inserted (depending on bleeding during closure) and put on low suction.
- ribs are reapproximated with heavy (No. 2 Vicryl) sutures.

THORACIC CORPECTOMY

- contraindication - limited life expectancy (<3 months)—protracted recovery period may not be justified.
- preoperative angiography may identify artery of Adamkiewicz and vascular flow to tumor (allow for embolization when appropriate).

- access below T5: right lateral decubitus position → left-sided thoracotomy
upper thoracic spine (T1-3) - best approached through midline sternotomy or posterior lateral extracavitary approach.
lower thoracic spine (T11 and T12) - combined thoracolumbosacral approach.
self-retaining rib spreader system → ipsilateral lung is collapsed.
transpleural or retropleural plane is developed bluntly through resected rib bed.
pedicle is visualized and drilled off (gives idea of posterior margin for resection).
cranial and caudal disks are removed back to annulus or posterior longitudinal ligament (PLL).
corpectomy is performed with rongeurs and ostiotomes when preserving bone, which may be used later for autograft; high-speed bur is essential for completing corpectomy by drilling out contralateral pedicle and posterior wall back to PLL.

PLL and any bony remnants can be removed off the dura with fine curettes and Kerrison rongeurs.
N.B remove posterior vertebral body from contralateral pedicle toward ipsilateral side; this prevents decompressed dura from expanding into operative field and obscuring visualization.
ALL and lip of bone is left behind anteriorly for stability and to prevent graft kickout (unless curative tumor resection is being performed).
dural injury – attempt to repair; alternative – Duragen, sealants, lumbar drain.

Reconstruction of corpectomy defect
A. Tricortical iliac crest autograft
B. Ceramic or titanium metallic cages packed with bone graft
C. Steinmann pins and polymethyl methacrylate (PMMA).
with or without instrumentation (anterior plating or posterior screw fixation):
compression is applied across cage.
LUMBAR INTERLAMINAR STABILIZATION
— for spinal stenosis with facet disease when fusion would be a consideration.

COFLEX
Paradigm Spine, LLC >> (surgical technique starts at page 28)

Dynamic stabilizer – good alternative to fusion!
- maintains foraminal height, offloads facets and posterior annulus – facetogenic back pain
- compressible in extension - physiological adjacent segment kinematics, maintains sagittal balance
- axial force shock absorption.

Official indication:
- use in one or two contiguous level lumbar stenosis from L1-L5* in skeletally mature patients with at least moderate impairment in function, who experience relief in flexion from their symptoms of leg/ buttock/groin pain, who have undergone at least 6 months of non-operative treatment.
- performed after decompression (flavectomy) of stenosis at the affected level(s).

*S1 spinous process is unpredictable

Technique
- position patient neutral on the table (uncranked Wilson frame is OK).
The patient is placed in prone position on a surgical frame avoiding hyperlordosis of the spinal segment(s) to be operated on. For the surgical decompression as well as for appropriate interspinous distraction, a neutral position or a slight kyphosis may be advantageous
- Paramedian or midline approach is taken with preservation of the supraspinous ligament. The muscle is sharply dissected lateral to the supraspinous ligament preserving the entire thickness of the supraspinous ligament

The basic surgical approach entails a midline incision and reflection of the supraspinous ligament. For a minimally invasive approach, this reflection of tissues extends to the base of the spinous process, which affords microsurgical access through the ligamentum flavum into the spinal canal. For an open approach, this reflection of tissues extends to the facet capsules affording total access to the entirety of the posterior elements. The interspinous ligament is sacrificed and any bony overgrowth of the spinous process that may interfere with insertion is resected.

Ligamentum flavum is resected and microsurgical decompression is performed, relieving all points of neural compression.
The trial instrument is placed to evaluate proper contact with the spinous process and the amount of facet distraction. Some bony resection of the spinous process may be needed to ensure proper contact of the implant.

Prior to insertion, the wings may need to be opened slightly using the bending plier to ensure appropriate depth of insertion.

The implant is introduced via impaction utilizing a mallet.

### Trials

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Material: Medical grade acetal copolymer

### coflex® Implant

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<td>UQ000008</td>
</tr>
</tbody>
</table>

Material: Wrought titanium-6-aluminum-4-vanadium alloy according to ISO 5822-3

The coflex™ implant is delivered in sterile packaging.

- can be implanted either way (i.e. upside down).
• trial should spread spinous processes only 1–2 mm apart.
• max. device height – 16 mm.
• must leave only 1–2 mm gap to dura; i.e. must be implanted rather anteriorly as most stress will be taken by laminar bone (and not spinous process) – wing must contact lamina (prevents anterior migration).

Proper depth is determined if a ball tip probe can be passed freely leaving 1–2mm separation from the dura

By deeply inserting the coflex® implant at the level of the facet joints, the implant counteracts the majority of posterior column forces (interlaminar positioning).

• after device is in situ, compress wings to achieve additional purchase.

Once proper placement has been achieved, it is recommended to securely crimp the wings of the implant using the crimping plier

In case of ligament reconstruction, the fascia and the supraspinous ligament can be closed in one layer over the spinous processes. A surgical drain may be placed as per surgeons' preference. Paraspinal muscles are reattached to the supraspinous ligament. Skin is closed in the usual manner

If a two level decompression is mandated, the Coflex® implants must be sequentially placed to the appropriate depth avoiding an overlap (contact) of one pair of wings upon the other. The Coflex® device is indicated for implantation at 2 contiguous levels

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**LUMBAR LAMINECTOMY**

**INDICATIONS**

1) spinal stenosis
2) contraindications (or medical comorbidities) for anterior approach
3) contraindications for general anesthesia for extended fusion because of increased cardiac risk

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**CONTRAINDICATIONS**

1. Herniated disk - needs additional diskectomy and foraminotomy.
   - Check preop radiculopathy!
2. Pars defects (congenital or acquired) - fusion is required to prevent dynamic instability and spondylolisthesis.

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**PLANNING**

MRI – look for neural foraminal stenosis (→ diskectomy and foraminotomy).

Before any laminectomy (esp. if spondylolisthesis is present) – do flexion and extension XR - dynamic instability? (→ lumbar fusion rather than laminectomy alone).
PROCEDURE

SPINAL SURGERY – THORACIC & LUMBOSACRAL

Op220 (18)

Medications, Positioning, Skin incision, Fascial and Subfascial and Subperiosteal Dissection, Closure - see “Posterior Midline Approach”

SPINAL PROCESS REMOVAL

- when spinal process out to facet is dissected, bony dissection can begin.
- Horsley bone cutter and double-action rongeur can be used to remove spinal process.
- bone can be saved and used for posterolateral in situ fusion if needed.
- cortical bone at base of spinal process may bleed easily, and one should be prepared with bone wax (irrigation can be used to identify further bleeding sites); rather than attempting to place bone wax on bleeding lamina using Freer elevator, small ball of wax can be placed over bleeding site, and dry ½ × ½ cottonoid can be used with bayoneted pickup to compress and mold wax into bleeding sites.

LAMINECTOMY

- when all spinal processes are removed for planned laminectomy, attention can be turned to completing laminectomy with high-speed drill or with various Kerrison rongeurs.
- bone should be removed from caudal to rostral because top of lamina is close to dura (one may encounter dura easily in this location).
- 2-mm side-cutting drill can be used to thin remaining lamina and bone to identify yellow ligamentum flavum without violating dura (while drilling laterally, one can create trough to assist in subsequent completion of laminectomy).
- after thinning lamina sufficiently, 2- to 4-mm up-biting Kerrison rongeurs can be used to remove remaining bone exposing yellow ligamentum flavum.
- sharp right-angled instrument can be inserted into ligamentum flavum and used to pull dorsally away from thecal sac while cutting along instrument using No. 15 blade.
- dissection is carefully continued until whitish blue thecal sac is identified. Careful removal of window of ligamentum flavum can be done with pituitary rongeur.
- after ligamentum flavum is removed, widen laminectomy to medial edge of pedicles.
- lateral gutters contain venous plexus that bleeds quite easily; hemostasis techniques:
  a) place thrombin-soaked Gelfoam → use wet ½ × ½ cottonoid to impress Gelfoam in place; by irrigating on cottonoid and holding suction, Gelfoam shrinks and fits into desired dimensions.
  b) place Avitene Hemostat over bleeding venous plexus → place dry ½ × ½ cottonoid over Avitene Hemostat, and bayonet forceps can be used to hold clot in place.
  c) use bipolar cautery

COMPLICATIONS

Adjacent segment disease (ASD) after lumbar laminectomies without fusion - cumulative incidence of ASD requiring reoperation is 10% (for 1- and 2-level laminectomies) over a mean of 4 years.

*L50% patients require fusion

LUMBAR MICRODISKECTOMY

Used literature:
R. Jandial “Core Techniques in Operative Neurosurgery” (2011)
**PEDIATRIC**
- no free disc fragments – they are continuous with nucleus pulposus
- irrigate disc space to remove inflammatory cytokines

**INDICATIONS**
Foraminal stenosis with radiculopathy (esp. with weakness) that fails to improve with conservative measures (at least 6 weeks).

**CONTRAINDICATIONS**
Large disk herniation causing central canal stenosis - full laminectomy is indicated.

**PLANNING**
MRI – look for level of neural foraminal stenosis.
Flexion and extension XR - dynamic instability? (→ laminar fusion rather than discectomy alone*).
* Discectomy will treat radiculopathic pain but would be unable to treat mechanical back pain.

**PROCEDURE**
Medications, Positioning, Skin incision, Fascial and Subfascial and Subperiosteal Dissection, Closure - see “Posterior Midline Approach”.
- fascial incision is paramedian to ensure midline ligamentous structures are not damaged by dissection.
- for morbidly obese patients use Taylor retractor.
- imaging – lateral XR:
  1) two 18G needles on skin – for incision planning
  2) Penfield #4 under lamina – to verify level
  3) Penfield #4 in disc space (Dr. Broaddus) – to verify correct discectomy.

**REMOVAL OF LIGAMENTUM FLAVUM**
- find soft interspace between two laminae of interest.

- sharp right-angled instrument can be inserted into ligamentum flavum and used to pull dorsally away from thecal sac while cutting along instrument using No. 15 blade.
- dissection is continued until whitish blue thecal sac is identified.
- removal of window of ligamentum flavum can be done with pituitary rongeur.
- rest of ligamentum flavum is removed with Kerrison rongeurs to create largest working window possible.
If needed, perform HEMILAMINECTOMY:

- quickly thin bone (e.g. drill or Leksell) past cortical bone in lamina to cancellous bone on other side; up-going curet can be used to remove remaining bone.
- semicircular or square laminectomy can be completed with 1- to 3-mm Kerrison rongeurs and up-going curet.

Dr. Cameron likes to remove top of S1 lamina when operating on L5-S1 disc space

DISCECTOMY

- adequate, counter tension-free traction is achieved with nerve root retractor (in redo cases, nerve root can be retracted distally, thus, retraction can tear dura at axilla) 
- N.B. can place small patties inferiorly and superiorly into gutter – keeps dura pushed away from bone!
- coagulate with bipolar epidural veins.
- single transverse incision is made in annulus with No. 15 blade in medial to lateral direction (to direct sharp end of blade away from dura). *Don't cut window in annulus – will ease reherniation postop; Dr. Graham makes cut vertically
- **pituitary rongeur is used to remove disk material:**
  a) if there is free epidural fragment – remove it and don’t do discectomy at all
  b) if there is only disk bulge – remove only free nucleus pulposus fragments - sequestrectomy (don’t rip all possible disk material)
  c) some experts do formal discectomy, esp. for young people (they have higher rate of recurrences; plus, left nucleus pulposus sets inflammatory reaction – severe postop pain).
- down-going Epstein curet or right-angled Williams instrument can be used to push down paracentral disk material into now decompressed disk space.

Aggressive vs Conservative discectomy

- Controversial; however, there is statistical trend toward limited discectomy so as to cause less discogenic pain subsequently.
- in conservative discectomy, surgeon removes only herniated disk fragment. In aggressive discectomy, large open incision is made on posterior longitudinal ligament with aggressive removal of disk fragments and curettage of disk space.
- both approaches have same recurrence rate.
- conservative discectomy significantly decreased mean operative time and hospital stay.
- level 3 evidence suggests that persistent back or leg pain was increased with aggressive discectomy.
- there was 2-week accelerated return to work and 1-month accelerated return to full-capacity work with conservative discectomy.
- there was statistically insignificant trend toward increased rate of recurrent disk herniation with conservative technique.

TIPS FROM MASTERS

- use straight cupped curet to remove soft tissue to find yellow ligament between two laminae. When ligament is visible, resist temptation to dissect away under inferior aspect of superior lamina in field because this would cause bleeding and ultimately interfere with hemilaminectomy. Using 2-mm side-cutting ‘matchstick’ bur or 3-mm acorn drill bit, drill medially to laterally (from intersection of lamina and spinous process in lateral direction toward facet joint).
Do not drill too far laterally because encountering facet capsule can destabilize joint and cause facet joint pain. Do not drill too far rostrally because this can create pars defect leading to instability. Operating on levels with associated spondylolisthesis may require upfront fusion.

- prospective, randomized clinical trial with 150 patients in each arm compared traditional open microdiscectomies with tubular discectomy 1 year after surgery. Patients in tubular discectomy arm had significantly inferior patient satisfaction scores with microtubular discectomies versus traditional open microdiscectomies.

POSTOPERATIVE

- many patients experience transient radiculopathy flare up at 2 weeks postop (likely due to inflammation).

LUMBAR MICRODISCECTOMY - REDO

Increase laminotomy window – that will also help detach scar tissue from bone edges. Detach scar tissue from dura using curette (same if disk fragment is attached to dura) – always stay on bone (the only safe way).

LUMBAR MICRODISCECTOMY – TUBULAR RETRACTORS

- using Medtronic METRx II tubular retractor system.
- wear lead apron but no loupes
- Wilson frame.
- draped fluoro at the time of patient draping.

INCLUSION

- spinal needle inserted into the paraspinous musculature → lateral fluoroscopy.
- 22 mm vertical skin incision one fingerbreadth from midline with No. 10 blade at the puncture site followed by fascia incision to make tissue dilation easier.

TARGETING

- Syrinx guidewire placed through the incision and directed medially towards lamina under lateral fluoroscopy.
- guidewire is advanced only through lumbar dorsal fascia with great care taken to avoid penetration of the ligamentum flavum and inadvertent dural puncture.
- first cannulated soft tissue dillator inserted over guidewire utilizing a twisting motion; once fascia is penetrated, guidewire is removed and dilator advanced down to the bony anatomy; next series of tubular dilators with increasing diameter are sequentially placed over each other.
- note depth marking on outer dilator – choose length of tubular retractor.
- tubular retractor is placed over sequential dilators and seated firmly on bony anatomy.
- sequential dilators are removed.
- flexible Arm is attached to bed rail and Tubular Retractor.
- all soft tissue exposed in the operative corridor is removed with electrocautery in order to maximize working space.
- that established tubular operative corridor.

DISSECTION

- operating microscope is brought into field.
- hemilaminostomy is performed with a high-speed drill and Kerrison. Nerve root is retracted medially utilizing a Love retractor.
- lateral recess stenosis is addressed with Kerrison.
- annulotomy → loose disc material as well as central subligamentous disk materi is removed with a pituitary rongeur and sharp curette in a standard fashion.
- JRC uses 40 mg of DepoMedrol over exposed nerve root.

CLOSED

- Tubular Retractor is slowly removed inspecting paraspinous musculature for bleeding.
- thoracolumbar fascia is closed with 2-0 Vicryl in interrupted fashion.
- skin is closed with 2-0 Vicryl in interrupted fashion with inverted knots.
- SteriStrips and the sterile Island dressing.

SYNOVIAL CYST EXCISION

Cyst is misnomer - it is usually half of hydrated soft tissue, thus, you will not see fluid-filled sac. Dissect and find where cyst originates (may involve long laminotomy – many patients experience transient radiculopathy flare up at 2 weeks postop likely due to inflammation).

FORAMINOTOMY

- expose lateral edge of pars – will know how far can take pars for decompression without destabilization (safety can remove medial ½ of pars).
- N.B. if doing foraminotomy with microdiscectomy (i.e. with intact spinous process) – will be difficult to achieve angle (Kerrison will rest on spinous process) – risk of inadvertently destroying pars by taking vertical bites on pars (if that happens – decorticate lateral pars surface and place DBX putty, keep patient in simple corset for 6 weeks to remind to prevent bending / twisting motions).
- use 2 mm Kerrison and 45 degree curette to enlarge foramene; check with Woodson probe.

LATERAL FORAMINOTOMY

- if stenosis is created by lateral facet osteophyte – will not reach from medial side; expose lateral side of pars and top of lateral facet; dissect anteriorly; generous venous plexuses – bleed a lot but bipolarizing may irritate dorsal root ganglion (postop neuralgia).
- use drill, pituitary rongeur, 2 mm Kerrison.
MINIMALLY INVASIVE FORAMINOTOMY

Insufficient foraminotomies can lead to persistent radiculopathy.

**Baxano iO-Flex® System**
- for both open and tubular retractor access.
  - All instruments are made that white side (vs. black side) on the handle should be facing surgeon (standing on same side as foraminotomy).
  - difficult on L5-S1 level – iliac crest on the way.
  - use EMG to monitor muscles innervated by nerve root being decompressed (e.g. left vastus lateralis, extensor hallucis longus, medial gastrocnemius);
  - settings: 300-450
  - prone on uncranked (!) Wilson frame
  - perform laminotomy.
  - Probe deploys across foramen (targeting impinging tissue to precisely deliver the wire):

  — **Ipsi Probe 90 & Contra Probe 45** (for contralateral foraminotomy across midline)

  — **Guidewire** is passed and exits through paraspinal muscles and skin (therefore, prep and drape wide) and is grasped with Kocher and then **Distal Handle**.

  — advance **Neuro Check® device** - helps confirm wire is dorsal to nerve root – switch lets stimulate dorsally and ventrally in foramen (difference to obtain EMG response should be > 5 mA):
    — has two radiopaque dots on each side of electrodes (one must be on pars right in foramen, another – extraforaminal)
    — when stimulating dorsally, pull wire against pars
    — when stimulating ventrally, relax wire


- advance MicroBlade Shaver® instrument (comes in three widths – 5.5, 7.5, 10.5 mm) - performs precision removal of impinging bone and soft tissue – by using sawing motion back-and-forth (bimanual reciprocations).

- use lateral fluor to assess progression of decompression:
  - Stenosis prior to reciprocation
  - Removal of impinging tissue following reciprocation

- there is special cannula for FloSeal deposition in foramen (in case bleeding happens).

LUMBAR TOTAL DISC REPLACEMENT (TDR)

- introduced in the 1980s in Germany
- TDR was compared with lumbar fusion: TDR produced outcomes that were similar or superior to fusion based on a variety of outcome measures, results were maintained during 5-year follow-up.
- ROM preservation: ROM is reduced at 3 months after surgery and increases thereafter; at 5-year follow-up, mean ROM values are at least as much as the preoperative value.
- heterotrophic ossification (HO) – McAfee scale - 5-point system ranging from none to bridging bone across disc space.
- safety of metal-on-metal (MoM) implants:
  - metallic wear debris is less than in total hip replacements
  - serum ion level analysis (cobalt, chromium) found the greatest mean value at any follow-up point was less than 20% of Medicines and Healthcare Products Regulatory Agency recommended minimum value to merit monitoring hip replacement patients
- designs:
  - 1) Kineflex-L (investigational)
  - 2) CHARITÉ

NONINSTRUMENTED FUSION

- advantage – more elasticity in the segment (than with instrumentation) – less risk of adjacent level disease
- good only if segment has started autofuse.
- decorticate and place grafts as for instrumented fusion.
Indications for interbody fusion
spondylolisthesis
Spondylolisthesis should not be considered unstable. Conclusion for fusion

4. Augmenting anterior strut grafting:
3. Unstable fractures.
2. Existing painful spinal instability:
1. Existing painful spinal instability:

INDICATIONS

1. Existing painful spinal instability:
   1) post-laminectomy spondylolisthesis
   2) painful pseudoarthrosis
2. Potential instability:
   1) spinal stenosis
   2) degenerative scoliosis
3. Unstable fractures.
4. Augmenting anterior strut grafting:
   1) tumor
   2) infection
5. Stabilizing spinal osteotomies.

Disadvantages

1. Caudal or medial penetration of pedicle cortex; results in dural or neural injury (n = 36% of cases; N Engl J Med 2016; 374: 1424-34).
2. Rigid fixation can accelerate adjacent motion segment degeneration.
3. Postoperative MRI is obscured by implants.
4. Extensive tissue dissection (to expose entry points + to provide required lateral to medial orientation for optimal screw trajectory) → costly lengthy operation, significant blood loss.
5. Stabilizing spinal osteotomies.

Technique

Using O-arm and navigation – see above >>

L5-S1 is technically most difficult level to fuse properly (esp. if using spondylolisthesis reduction).

Levels, fusion extensions

never stop at thoracolumbar junction (ie. L1) – extend fusion to T11.

to extend previous fusion:
   a) remove old rods (≥ pedicle screws – if suspicion for being loose) and place longer rods
   b) use rod-to-rod connectors to attach to old rods; need at least 1 cm between screw heads to attach connector (loosening set screws may help to move heads apart to gain some width).

pedicle: strong, cylindrical, anatomic bridge between dorsal spinal elements and vertebral body; consists of strong shell of cortical bone and core of cancellous bone

dissection with Bovie to extend previous fusion

See Table below for key differences.

Pedicle screws traverse all three columns of vertebrae - can rigidly stabilize both ventral and dorsal aspects of spine.

pedicle also represents strongest point of attachment of spine:
   — significant forces can be applied to spine without failure of bone-metal junction.
   — allows for incorporation of fewer normal motion segments in order to achieve stabilization of abnormal level.

pedicle screw fixation does not require intact dorsal elements - can be used after laminectomy or traumatic disruption of laminar, spinous processes and/or facets – less requirements for postoperative bracing and improvements in fusion rates.

Indications for fusion – (predisposition for instability)

1) unstable on dynamic imaging (> 10 degrees of angulation or > 4 mm of relative motion) 2) facet-joint edema - joints are likely to be unstable, even if they appear stable on dynamic imaging.

Spondylolisthesis should not be confused with "instability" – there are obvious differences between spondylolisthesis patients.

a) large disk, bulky fluid-filled facets, and dynamic instability → decompression with fusion.
b) collapsed disk with fixed spondylolisthesis – despite slip progression, a stable degenerative spondylolisthesis can be adequately treated with decompression alone, albeit with a 34% rate of reoperation surgery (vs. 14%* or 22%** if fusion was used).


N.B. the results of reoperation may be worse than the results of the original surgery, and the health care costs may be high, especially considering that most patients with lumbar stenosis are elderly!

Indications for interbody fusion – see PLIF >>

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BRIEF HISTORY

1. Direct puncture approach:
   — prone on chest rolls (longitudinal or transverse) / Jackson table ensuring anatomical nonflexed position.
2. Indications for spondylolisthesis:
   — spondylolisthesis should not be considered unstable. Conclusion for fusion

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LAMINECTOMY

- may not be indicated if operating for trauma with no canal stenosis.
- if burst fracture with retropulsion – use Woodson / bone tamp to push retropulsed fragments ventrally.

SCREWS

N.B. do not use polyaxial screws for trauma (one of AO principles!)
Measure pedicle widths on CT scan!

Thoracic – 4.5-6.5 mm
  - at T1-3, 4.5 mm diameter screws that are 25-30 mm in length are usually recommended. At T4–T10, screws are usually 4.5 mm in diameter and 30-40 mm in length.

Lumbar – 6.5-7.5 mm

Sacral – 7.5 mm

- if replacing old hardware screws (recommended always, unless fusion is very fresh and screws feel tight) – use screws 1 mm larger in diameter into old trajectories
- use largest acceptable diameter (as screw bending strength Z increases by cube degree to screw diameter D):

\[
Z = \frac{\pi D^3}{32}
\]

e.g. difference in strength between 5.0 mm and 6.0 mm core diameter screw is nearly twofold (125 versus 216).

Screw pullout resistance:

- major screw diameter
- thread depth - screw pullout resistance is proportional to volume of bone between threads.
- cortical purchase - treads nearest screw's head bear most of load transferred from bone during pullout stressing
- N.B. proximal cortical "purchase" is very important regarding pullout resistance!
- depth of screw penetration - secondary importance

Pedicle width increases in lower lumbar spine and is variable in thoracic spine:

- pedicle width is more important than pedicle height for pedicle screw placement.
- pedicle width is narrower than pedicle height except in lower lumbar spine.
- pedicle width increases from L1 to S1
- most pedicles below T10 are >7 mm in width and most below L1 are >8 mm.
  N.B. place largest possible pedicle screw! Only disadvantage – if patient will need revision in the future, the larger diameter screws may be needed!

POLYMETHYL METHACRYLATE
- used as implant material that conforms to contours of bone.
  N.B. loosening of acrylic-bone interfaces is common - some surgeons have found acrylic to be useful as spinal implant, however, others have found it to have little utility!

Common misconceptions:
1) acrylic usually does not conform precisely to bone because of blood interfacing between acrylic and bone (H: injection under pressure)
2) bone does not bond to acrylic - osseointegration between surfaces does not occur.

Pressurized injection of polymethylmethacrylate into screw hole causes acrylic to penetrate into bony interstices (G) - this effectively increases screw diameter (H).
If non-pressurized injection is used (I), acrylic penetration into bone interstices does not occur; in fact, acrylic may clump around screw, thus decreasing its efficacy (J):
- drill cortical bone at it until see cancellous bone (but only screw core diameter – cortical bone is important structure!); - awl would be advantageous as it compacts cortical bone but usually cortex is too sclerotic to penetrate with awl!

- put towel clamp on spinous process of vertebra above – move to see where joint line is.

**THORACIC SPINE**

- transverse process commonly does not align with pedicle in axial plane (TP is rostral to pedicle in upper thoracic spine → crossover at T6-7 → TP is caudal to pedicle in lower thoracic spine) - fluoroscopic guidance or direct vision and pedicle palpation via laminotomy is highly recommended.

- Dr. Mathern removes transverse processes because they will interfere with screw trajectory; then decorticates facet joints to see joint line; then places screws into lateral facets (transverse process is no longer good guide – lots of anatomical variations)

- Dr. Graham does not use fluoroscopy – uses only anatomical landmarks and CT images – both in axial plane (where starting point is on U shape surface of dorsal lamina) and sagittal plane (where starting point is regarding visible joint line – you can see it easily; usually need to drill off a little bit of proximal facet joint “lip” to uncover pedicle starting point)
**LUMBAR SPINE**

- Muscle dissection is performed as lateral as possible to allow palpation of transverse process – one has to be persistent and patient; have some good retractors.
- At junction of lateral facet and transverse process (or bisection of vertical line through facet joints and horizontal line through transverse process), esp. at L4; Dr. Graham, Dr. Mathern uses mamillary process (“gift of nature”) as entry point (thus, dissect that area thoroughly to see bone anatomy).
- Above L4, midline of TP is rostral to pedicle.
- At L5, it is 1.5 mm caudal to pedicles.
- If patient has distorted anatomy (e.g. previous fusion mass – remove it with Leksell), then may use AP fluoroscopy to find starting points.
- Leksell rongeur / drill to remove inferior cortical surface at junction of superior facet, transverse process, and pars (to create room for screw head); at fusion level, can remove dorsal parts of both (medial and lateral) facets – screw starting point in lateral facet immediately adjacent to joint space.
  - In L5-S1 facet, as facet hypertrophies and overgrows dorsally, facet joint line tends to move laterally – thus, remove facet almost flush with sacral surface to see true joint line.

**TRAJECTORY**

- Curved or straight Lenke probe is passed through cancellous bone by generous bidirectional rotation down pedicle (before that may verify with Woodson probe position of pedicle - must medial point – gives sagittal and lateral angles) but not further (i.e. Lenke is for pedicle only + slightly into vertebral body – typically 30 mm total) → ball probe to verify intactness of trajectory.
**S**PINAL **S**URGERY – **T**HORACIC & **L**UMBOSACRAL

Op 220 (bottom and pedicle part only; may suction on hole – see if epidural blood is sucked in) → tap for entire (?) trajectory (except last 5 mm)

*Thoracic is straight (esp. Dr. Mathern)*

• Curved tip is facing laterally (to avoid medial breech) and, once passed pedicle, flipped to face medially
  - thoracolumbar junction (Th10-L2) pedicles are almost strictly sagittal (or 3-5 degrees per Dr. Mathern); for all other direct screws slightly medially;
  - sudden plunge suggests breaking out of pedicle laterally;
  - increase in resistance indicates abutment against pedicle or vertebral body cortex.

**T1** has unique trajectory – very inward and very towards feet (almost 45 degrees towards floor)

- pedicle width
- transverse (coronal) pedicle angle
- sagittal pedicle angle

Transverse pedicle angle: s. coronal angulation (how medial?) decreases as one descends caudally until lumbar region (from 10-15° at T1 to 5° at T12) → angle increases approximately 5 degs per level from L1 to sacrum (L1 medial angulation is 5-10°):

N.B. wider coronal angle is necessary to avoid lateral pedicle penetration in lower lumbar spine.

Sagittal pedicle angle increases from 0° at T1 to 10° at T8 and then decreases to 0° at T12.

• L4 sagittal pedicle angle is 0° and subsequent rostral and caudal levels are associated with progressively greater sagittal angles.

**TRIANGULATION**

N.B. screws must be on same rigid implant (cross-fixed) for triangulation to work:

Tied-in (A) and toed-out (B) screws:
Optimal orientation of screw for pullout resistance via triangulation effect is 180 degrees (A). This angle does not apply to loads applied along long axis of screw (B). Optimal triangulation effect that accommodates forces applied in all planes is 90 degrees (C).

**DEPTH**
- ideally 50-80%
- penetration > 80% of vertebral body on lateral X-ray raises concern of ventral penetration of vertebral body cortex
- for sacrum it is OK bicortical (but barely)

**TAPPING**
Use 1 mm smaller taps than planned screw diameter (e.g. 5.5 mm for lumbar pedicles, 6.5 mm for S1 pedicles)

Two characteristics of screw tap are fundamental:
1) tapered tip - helps to align screws in desired direction by directing it down predrilled hole
2) full-length flute - gathers bone debris carved from wall of drill hole (facilitated by periodic loosening of screw by approximate one quarter to one half turn during tightening, which allows bone debris to collect in flute):

![Tapping Diagram](image)

**STIMULATION**
- stimulate pedicle screws up to 30 mA (if cortical bone is intact, EMG response should occur at > 14 mA; threshold to suspect breach is 6 mA).
- EMG muscles – see above >>

**FUSION**
- posterolateral gutters are sharply decorticated to see bleeding cancellous bone (i.e. before placing screws – will be difficult to reach then):
  - if redo case (fusion extension), then decorticate also superior and lateral aspects of previous bony fusion mass.
  - multangle screws are placed.
  - rods are used to connect pedicle screws.
  - place set screws (locking caps) with “stick” instrument then tighten with final tighten
  - final tighten
- fluoroscopy see below
irrigate
pack posterolateral gutters with morcellized bone grafts (n wrapped into) BMP, Medtronic MagniFuse
may place DuraGen on exposed dura

**RODS**
- cobalt-chromium – stiffer (use for spondylolisthesis, scoliosis reduction)
titanium
- for long constructs, use rod cross link
- do not bend rod in coronal plane!

**REDUCING SPONDYLOLISTHESIS**
- check if there is mobility at the level.
- use cobalt-chromium rod.
- place and final tighten cap to lock rod into lower screw (rods sits pride – away from upper screw seat – distance depends how much reduction one is expecting).
- using tower, pull upper screw towards rod (do both sides simultaneously while checking on fluoro – do not strip screws if reduction is not progressing), engage set screws, then final tighten (to finalize reduction).

**FLUOROSCOPY**
- lateral view during the case
- AP view at the end – to check for:
  1) too lateral placement – main goal of AP
  2) too medial placement – screws should not be crossing
- Dr. Graham uses no fluoro (XR only final – lateral and AP to document screw placement).

**COMPLICATIONS**
- screw breakage - has been reported as high as 60%

**POSTOPERATIVE**
Dr. Cameron – upright XR before patient leaves hospital.

**ILIAC SCREWS (PELVIC FIXATION)**
- large biomechanical stress - fixation between the mobile lumbar spine and the far less mobile sacrum.
- rigid fixation to the pelvis is crucial when maintaining sagittal alignment.
- sacral pedicle screws alone, such as those at S1 and S2, are prone to failure under less load than when they are used in combination with additional pelvic fixation (addition of iliac screws resulted in the most significant decrease in the strain on S1 screws and significantly increased the load to failure).

Hardware systems
Isola (DePuy)
Xia (Stryker)

**INDICATIONS**
1. Long segment fusions to the sacrum, particularly in patients prone to L5-S1 pseudarthrosis, such as patients with global or lumbar sagittal imbalance or bony deficiency.
2. Degeneration caudad to long segment fusions.
3. High-grade spondylolisthesis
4. Correction of pelvic obliquity
5. Correction of flat back syndrome requiring osteotomy

**PROCEDURE**
- position – prone on Jackson table; adding slight relative kyphosis in the sagittal plane allows for better access to the structures of the lower lumbar spine and pelvis.
- iliac screws should be placed last, after all other pedicle screws have been placed; be aware of screw alignment in longer constructs.
- extensive exposure is required increasing the amount of blood loss.

Galveston technique
- start at posterior superior iliac spine (PSIS) – bite a 1-2 cm chunk off to accommodate screw head – screw should be recessed more than the remaining bone anterior and posterior to the PSIS to decrease the chance of hardware prominence.
- target trajectory towards:
  a) superior rim of the acetabulum – places the hip joint at risk and is less desirable.
  b) anterior inferior iliac spine (AIIS) – accommodates a longer screw and is safer; use live fluoroscopy aiming from PSIS towards femoral trochanter (typically aiming 25 degrees lateral from the midline and 30 degrees caudad) – should see “teardrop” - screw goes perfectly along this view.
• iliac screws measure 7.5-8.5 mm in diameter; length at least 80 mm.
• Tomlinson et al have shown that little difference exists in construct stiffness and lumbosacral motion between unilateral and bilateral iliac screws when screw length is at least 80 mm.
• connection to the rest of fusion rod usually requires offset connector.

PERCUTANEOUS SCREWS
- it is stabilization (not fusion) for trauma (i.e. internal brace); so, after healing of fracture (6-9 months), hardware needs to come out (as screws will become loose due to movement of nonfused segments and will cause pain).
• use it only if see enough bone on X-ray so it will heal (soft tissue components prevent healing – may need fusion).

Medtronic Sextant system: https://www.youtube.com/watch?v=8CKKSqDTtU
Medtronic - CD HORIZON SEXTANT System >>
pedicles should be well seen on AP fluoro
no need to decompress canal (if yes, then need open approach with laminectomy)
no injury to ligamentous structures necessary for stabilization (ligaments do not heal – instability will remain even after bone healing)
difficult for thoracic spine as pedicles rather thin.

MIDLF (S. MIDLINE LUMBAR FUSION WITH CORTICAL BONE SCREW TRAJECTORY)
Cortical Bone Trajectory (CBT): 8-9° mediolateral 25-26° caudocephalad (more for top level as need to avoid facet joint; less for bottom level as incision doesn’t allow to achieve angle)

- engaging with cortical bone maximally from pedicle to vertebral body, i.e. increased cortical bone contact, providing enhanced screw purchase (up to 30% increased pullout strength but it is unproven).
- best for L2-L5
- screws: smaller diameter than would be analogous level pedicle screws.
- length is 30-39 mm.

- indications:
  1) rescue when pedicle was destroyed
  2) adjacent level disease (may leave old hardware in untouched)
- direction away from neural elements provides safety and lower incidence of postoperative radiculitis.
- starting point - junction of superior articular process and 1 mm inferior to inferior border of transverse process:

N.B. best is to use AP fluor - starting point is at 5 o’clock for L side (and 7 o’clock for R side); therefore, important to do AP fluor before even incision - if cannot see pedicles, won’t be able to do MIDLF!

*probably not as it is easy to convert to regular pedicle screws intraop

- mark with M8 drill bit all starting points on AP fluoroscopy; then create trajectories using monitored Stryker power drill using lateral fluoroscopy.
- often starting points need to be adjusted as they don’t look right on lateral fluoro; so AP fluoro value is mostly to define mediolateral line of starting point.

N.B. make trajectory holes before laminectomy; then laminectomy, PLIF, etc; place screws at the end.

PLIF (POSTERIOR LUMBAR INTERBODY FUSION)

Used resources:
- Jandial - Procedure 73

INDICATIONS
1. Spondylolisthesis (symptomatic, progressive, or requiring decompression that necessitates stabilization)
2. Correction of degenerative scoliosis
3. Pseudarthrosis of previous intertransverse fusion that requires fusion technique with higher success at achieving solid arthrodesis
4. Degenerative disk disease with low back pain that can benefit from fusion
5. Recurrent disk herniation

CONTRAINDICATIONS
1. Osteoporotic end plates that may not hold interbody graft, leading to subsidence
2. Disease at or above conus medullaris – TLIF should be considered to avoid thecal sac retraction.

TECHNIQUE

POSITION
- a) Jackson table – often makes spondylolisthesis to reduce
  - b) chest rolls – longitudinal or transverse (more lordosis)
  - c) Wilson frame (Dr. Graham)

MONITORING
- neurophysiologic monitoring (incl. SSEPs and EMG) is routinely used (Dr. Cameron uses EMG)
- EMG:
  - 1) medial gastrocnemius (S1)
  - 2) EHL (L5)
  - 3) lateral vastus (L4)

DISK PREPARATION
- expose disk space laterally – complete laminectomy, drill pars & medial facet as much as needed; removal of pars interarticularis with chisel (e.g. Smith-Peterson osteotomies or removal of Gill fragments) can be performed for greater exposure of nerve root and disk space + unroofing neural foramen + allows compression of screws / disk space
- perform annulotomies on both sides with No. 15 blade – clean with pituitary.
- thorough complete diskectomy (DRS) thecal sac is carefully retracted with Lave nerve root retractors
- increasing sizes of Exc extractors (starting at 6-8 mm) under XR control (should reach anterior annulus)
optional - insert supplemental pedicle screw and rod fixation on contralateral side to maintain distraction in situ during disc space preparation and to facilitate graft placement; provisionally tighten construct

2) **Rotating Cutters or Shavers** (1-2 mm smaller than planned graft - to preserve endplates) to remove cartilaginous end plate (remove end plate fragments with pituitary rongeurs) → *"paw"* curettes to remove cartilaginous end plate

3) Trial with *Sizers.*
• use A/P and lateral fluoroscopy to confirm proper placement and trajectory

**GRAFTS / CAGES**

a) **PEEK:** put some BMP inside graft and between grafts (anteromedially); cage is impacted into disk space until 3 mm below posterior margin of annulus under fluoroscopic guidance and then rotate 90 degrees into final position (graft tends to back out during rotation, so push forward during rotation)

b) **cadaveric bone dowels** – 12 mm diameter for lumbar spine (Dr. Graham) trimmed to appropriate length – use increasing sizes of reamers from 7.5 mm to 10 mm, then scrape endplates with curettes; disk space filled medially with morcellized laminar bone autografts; grafts gently impacted into disk space until 5 mm below posterior margin of annulus

• before inserting the graft, place autograft anteriorly and contralaterally or in the bone construct central cavity.
• mechanically, graft should extend as far anteriorly as safely possible.
• if grafts cannot be placed, bone autograft, allograft, or osteoinductive materials may be placed into disk space instead.
• interbody construct is supplemented by pedicle screws and intertransverse fusion.
• PLIF for spondylolisthesis - compress screws at the end - will create lordosis ± prevents graft migration posteriorly.

Ideally, graft should extend to vertebral body edges where resistance to compression is highest ("tin can" model):

- **Brochures**
- **X-ray Marker Location**
bullet tip device with lordotic expansion of 6 and 12 degrees
- MAST® compatible
- ability to postpack device with autograft using funnel and tamp after expansion
- radiolucency for postoperative diagnosis
- audible click sound made when device is fully expanded

X-ray Marker Location

Use Rotating Distractor for distraction and sizing.
Fixation of the Cage on the Inserter:

Application of the Impactor Cap:

Marking for lateral side of the Cage:

Advance the implant anteriorly so that the leading tip of the implant rests on the anterior apophyseal ring:
Remove the Impactor Cap after completed implantation and screw the Distraction Rod into the cage distraction plug:

Fill the disc space and the cage with autograft, BMP:

**TLIF (TRANSFORAMINAL LUMBAR INTERBODY FUSION)**

- introduced by Harms and Jeszenszky in 1998.
- it is alternative to PLIF for lesions at or above conus medullaris because retraction of thecal sac is not an option.
- not feasible at L5-S1 (iliac crest): H: PLIF
- graft placed obliquely or, more recently, curved graft rotated into position.
- removal of pars interarticularis, lamina, and inferior and superior articular processes.
radical discectomy is performed to cross midline and ensure that contralateral disk is removed:

allows disc space to be accessed without need for nerve root retraction, but corridor that is created remains constrained by exiting and traversing roots - size of interbody graft is inherently limited; thus, amount of disc space covered is also limited → resurgence in bilateral access to place bilateral grafts; alternative – unilateral approach with sequential grafts (nested interbody spacers):

goal is to place graft in middle of disk space and as anterior as possible

if disk space is significantly collapsed, pedicle screws can be used with distraction retractors to heighten interbody space and enable larger graft placement.

do on more symptomatic side – if will damage root, it is already worse side; on the other hand, it is greater chance of helping that side by better distraction.

Graft / cages

WAVE O Mentorship
Brochures >>

CONCORDE Bullet (DRX)
CONCORDE Bullet >>

TLIF Surgical Technique >>

ROI T LDR >>
ALIF (ANTERIOR LUMBAR INTERBODY FUSION)

Rationale:
Weight-bearing distribution
- in normal lumbar spine in upright standing position, anterior and middle weight-bearing columns support 80% of spinal load, and posterior column supports approximately 20%
- with aging and degenerative cascade, including reducing disk height, weight-bearing distribution shifts to posterior column.
- ALIF, redistributes weight-bearing distribution to original ratio.

Advantages over TLIF:
1) superior height restoration (additional 5-10 degrees).
2) sparing of paraspinal musculature
3) no need to enter spinal canal – less risks, less scarring

Disadvantages over TLIF: worse cost, blood loss, and operative time

Complications
1) implant migration - observed in majority of patients
2) retrograde ejaculation and sterility (1-5%) - from injury of superior hypogastric sympathetic nerve plexus (particularly when operating at L4/L5); H: avoid using Bovie (use bipolar!)
3) vascular injury (more common when operating at L4/L5 and above)
4) genitourinary anatomic abnormalities, such as an ipsilateral single ureter or kidney
5) patients who are unwilling to assume risk of retrograde ejaculation
6) severe osteoporosis

INDICATIONS
1) chronic, incapacitating low back pain secondary to degenerative disk disease or degenerative spondylolisthesis in absence of severe neural element compression + at least 6 months of conservative nonsurgical therapies have failed.
2) ALIF may also be used in cases of failure of previous posterior approach lumbar surgery.

CONTRAINDICATIONS
1) conditions that limit retroperitoneal access to the lumbar spine: morbid obesity, retroperitoneal scarring from a previous surgery, or a large infrarenal aortic aneurysm
2) neural element compression requiring direct decompression (exception - radicular foraminal compression at level of operation secondary to disk collapse, which may respond to distraction and restoration of disk height).
3) history of previous retroperitoneal surgery
4) genitourinary anatomic abnormalities, such as an ipsilateral single ureter or kidney
5) patients who are unwilling to assume risk of retrograde ejaculation
6) severe osteoporosis

DETAILS
- for lower disk levels (L4-5, L5-S1), patient is supine.
- inflatatable bladder is placed under the small of the back to increase or decrease lordosis as necessary.
- cell saver in event of large quantities of blood loss from vascular injury.
- pulse oximeter is placed on each lower extremity to monitor for ischemia during vessel manipulation and retraction.
- correct disk space is localized using fluoroscopy, and skin is marked appropriately - incision is centered at this location and marked.

- incisions - midline, paramedian, Pfannenstiel
- approach:
  a) transperitoneal approach - may be used to access L4-5 and L5-1
b) muscle-sparing retroperitoneal approach has become more popular - lower rates of postoperative ileus, easier control of intraperitoneal structures, ability to sweep sympathetic plexus bluntly to the right of disk space

- approach from left side is generally performed (gentle manual retraction of aorta is more safely performed than retraction of inferior vena cava, which can be difficult to repair surgically in event of vessel wall injury).

- at L5-S1, mobilization of large vessels is usually unnecessary because approach can be taken through vascular bifurcation; pubic symphysis is access-limiting structure (explore imaging preop).
- at L4-5 level, iliolumbar vein enters common iliac - avulsion at this anastomosis can lead to aggressive, unnecessary bleeding.
- L3-4 disk requires more significant mobilization and retraction of iliac vessels and aorta.
- disectomy ("as for ACDF")
  - symmetric incision of anterior disk annulus is performed, taking care to leave lateral annular walls intact.
  - avoid disruption of posterior annulus (→ injury to contents within vertebral spinal canal).
- use graft with significant lordosis, particularly at L5-S1 interspace, graft with 10-15 degrees of lordosis is reasonable.
- anterior plate provides minimally increased biomechanical rigidity, but it can be useful to prevent anterior expulsion of intervertebral spacer in stand-alone ALIF.
**DLIF (DIRECT LATERAL INTERBODY FUSION)**

[http://www.youtube.com/watch?v=3C2fcmDqc0c](http://www.youtube.com/watch?v=3C2fcmDqc0c)
[http://www.youtube.com/watch?v=w7JnZezL6ws](http://www.youtube.com/watch?v=w7JnZezL6ws)

**DLIF procedure (Bangkok Medical Journal - Sept 2012)**


- **usually as two stage procedure:**
  - first day – DLIF → bed rest with head of the bed up to 45 degrees
  - second day – posterolateral fusion

- **NIM-SPINE** free-running EMG monitoring needle electrodes placed into bilateral leg muscles

- **right lateral decubitus position on Axis table;**
  - shoulder roll in axilla
  - maximum lateral flexion at the intended DLIF level (check with your hand if there is space between ilium and ribs)
  - pelvic ring stabilized between posterior and anterior lateral positioners
  - make sure patient’s back is absolutely vertical (if needed for added stability, may also stabilize chest between lateral positioners)

- **For L1-2 need open thoracotomy approach to dissect diaphragmatic crus (along with rib resection – will be used for second day surgery)**

- **fluoroscopy to determine incision - in left flank, oblique (along Langer lines), 5 cm length.**
  - mark two lines: one parallel to disc spaces at intended work level; second running parallel to spine long axis and splitting vertebral bodies into anterior 2/3 and posterior 1/3; center incision where those two lines cross

- **dissection down through subcutaneous tissue.**

- **blunt dissection (finger, Kittner) to split abdominal muscles.**

- **use NIM-PAK Needle probe (holding with Kocher / radiolucent holder so your hand is not in fluoro field) - lateral disk entry point is localized, guidewire needle advanced through probe lumen into disk space and increasing diameter DLIF dilators are inserted.**
  - if doing open approach, after disk entry point localization (with simple spinal needle) use Kittner to split psoas along fibers.

- **lateral fluoroscopy to obtain appropriate trajectory (center of graft is between 2/3 anterior and 1/3 posterior; however, more anterior is desirable to correct kyphosis) and placement of retracting system.**

- **tubular DLIF retractor on FlexArm are then docked and attached to table.**

- **NIM stimulation using NIM-PAK Needle checks 4 quadrants inside retractor to make sure no lumbosacral plexus nerves are trapped (this step is not needed for open approach).**

- **resect with Bovie / blunt just enough psoas for discectomy exposing disk annulus.**

- **annulotomy using a 15-blade scalpel – discectomy with pituitary rongeurs and curettes.**

- **N.B. do not damage endplates by too vigorous curettage!!!**

- **N.B. do not damage ALL (or graft will migrate anteriorly).**

- **N.B. discectomy just to create channel for graft cage and no more.**
SPINAL SURGERY – THORACIC & LUMBOSACRAL

**Op220**

- Contralateral annulus is disrupted using Cobb elevators along each endplate – advance Cobb until it is beyond vertebral body on AP fluoro; some surgeons do it along each endplate but it is enough just in one spot – to allow to distract disc space.
- Trial placed into disk space → appropriate graft size is chosen to maximally distract disk space.
  - Too big graft may damage endplate; even if endplate is not damaged, too big graft will subside with time (BMP softens bone and promotes that)
- Interbody graft (PEEK cage filled with BMP and wrapped with silk tie to keep BMP in place) is placed under AP → lateral fluoroscopy guidance
  - e.g. Medtronic Clydesdale PEEK cage → it is lordotic so has “ANTERIOR” edge marking
- Retractor is removed.
- Closure without drain; suture muscle fascia together.
- Postop – bed rest (may sit up to 45 degrees) until posterolateral fusion is done; Dr. Mathern likes postop thoracolumbar CT (after second stage, - activity as tolerated, scoliosis XR during follow up).

**COMPLICATIONS**

- Globus expandable cage claims less subsidence

**GRAFTS / CAGES**

- Globus

  - Brochure
  - 0 or 6 or 12 degrees lordosis
  - Indications: one or two contiguous levels from L2 to S1; patients may also have up to Grade I spondylolisthesis.

- Avenue L (LDR)

**XLIF (eXtreme Lateral Interbody Fusion)**

- same as DLIF just by different company (NuVasive®)
- uses much larger grafts and may achieve impressive lordosis; N.B. leave ALL intact to prevent graft migration.
- there grafts also for scoliosis correction.

**OLIF**

https://www.youtube.com/watch?v=XhsOn23bfm&feature=youtu.be&list=PLypmlaqO56t_ue9U_io_UFY1RQh8yQ
OSTEOTOMIES

Osteotomy classification: grades 1 to 6 according to anatomic resection:
<table>
<thead>
<tr>
<th>Grade</th>
<th>Anatomic Resection</th>
<th>Description</th>
<th>Surgical Approach Modifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Partial facet joint</td>
<td>Resection of the inferior facet and joint capsule at a given spinal level</td>
<td>P (posterior approach only)</td>
</tr>
<tr>
<td>2</td>
<td>Complete facet joint</td>
<td>Both superior and inferior facets at a given spinal segment are resected with complete ligamentum flavum removal; other posterior elements of the vertebra including the lamina, and the spinous processes may also be resected</td>
<td>P (posterior approach only) A/P (anterior soft tissue release combined with posterior resection)</td>
</tr>
<tr>
<td>3</td>
<td>Pedicle/partial body</td>
<td>Partial wedge resection of a segment of the posterior vertebral body and a portion of the posterior vertebral elements with pedicles</td>
<td>P (posterior approach only) A/P (both)</td>
</tr>
<tr>
<td>4</td>
<td>Pedicle/partial body/disc</td>
<td>Wider wedge resection through the vertebral body: includes a substantial portion of the posterior vertebral body, posterior elements with pedicles, and includes resection of at least a portion of 1 endplate with the adjacent intervertebral disc</td>
<td>P (posterior approach only) A/P (both)</td>
</tr>
<tr>
<td>5</td>
<td>Complete vertebra and discs</td>
<td>Complete removal of a vertebra and both adjacent discs (in resection in the thoracic region)</td>
<td>P (posterior approach only) A/P (both)</td>
</tr>
<tr>
<td>6</td>
<td>Multiple vertebrae and discs</td>
<td>Resection of more than one entire vertebra and adjacent discs. Grade 5 resection and additional adjacent vertebral resection</td>
<td>P (posterior approach only) A/P (both)</td>
</tr>
</tbody>
</table>
Grade 1 osteotomy (partial facet joint resection, s. Smith-Petersen osteotomy, opening wedge osteotomy, Chevron osteotomy, extension osteotomy)

- resection of inferior facet and joint capsule at given spinal level.
- limited deformity correction and is often applied to offer limited change in alignment and potential for fusion through cartilage removal of the superior facet.
- anterior column mobility (nonfusion) is a prerequisite for performing a grade 1 osteotomy.
- done by using posterior approach only (modifier P).
- 5-10° of correction can be achieved at each level, but lack of anterior column mobility can lead to vascular and neurological sequelae.

Grade 2 osteotomy (complete facet joint resection)

- both inferior and superior facets of articulation at given spinal segment are resected (i.e. beyond what was described by Smith-Petersen), as well as ligamentous flavum.
- other posterior elements of vertebra including lamina, or spinous processes, may also be resected.
- similar to grade 1, grade 2 osteotomies require preexisting anterior column mobility (i.e. adequate disk height are required for this type of correction because posterior segment of disk acts as pivot point).
- any osteotomies that remove bone from the vertebral body are excluded from this grade.
- commonly done by using a posterior approach alone (modifier P), but may also involve a combined anterior soft tissue (anterior longitudinal ligament and/or disc) release and may be further denoted by the modifier A/P.
- in polysegmental osteotomy, bone is removed from articular processes and interlaminar space adjacent to articular processes at multiple levels to create gradual lordosis.
- Ponte procedure - resection of multiple facets along with the resection of spinous processes and involves substantial amount of bone and ligament resection to afford deformity correction.
Pre- and postoperative aspect of multiple lumbar complete facet joints resections by using a posterior approach, classified 2P.

Grade 3 osteotomy (pedicle and partial body resection, s. pedicle subtraction osteotomy, PSO, closing wedge osteotomy, transpedicular wedge resection)
- Wedge resection of posterior and middle portions of vertebral body and posterior elements with pedicles + both sets of articular processes and detachment of transverse processes.
- Portion of vertebral body and discs above and below level of osteotomy remain intact.
- Further described as involving only posterior approach (P) or combining approaches (A/P).
- No anterior column lengthening is performed.
- 25-35° of correction can be reasonably achieved at any given level.
- Of note, PSO that extends into adjacent disc spaces would be termed grade 4P resection.
Circumferential wedge bone resection - variant with wedge-shaped apical vertebral body bone resection in addition to apical laminectomy and laminectomies of vertebrae directly superior and inferior to apex; apical facets and pedicles are removed completely.

Closing opening wedge osteotomy (posterior approach that provides more sagittal alignment correction than PSO): resection of posterior elements while initially preserving anterior, posterior, and lateral cortices of vertebral body; posterior cortex is then pushed into body, and anterior and lateral cortices are removed. This allows hinging to be over posterior vertebral body rather than anterior cortex, resulting in greater correction.

Pre- and postoperative aspect of L3 PSO by using posterior approach, classified 3P:

- Less aortic or inferior vena cava obstruction secondary to stretching.
- Portion of vertebral body at level of osteotomy remains intact, but anterior support may be necessary in cases of marked shortening.
- Further labeled as posterior release (P) or both (A/P).

Grade 4 osteotomy (pedicle, partial body and disc resection)
- Wider (than for grade 3) wedge resection through vertebral body; includes posterior vertebral body, posterior elements with pedicles, and sufficient body resection such that an endplate and at least portion of 1 adjacent disc (associated with rib resection in thoracic region) is removed.
- Portion of vertebral body at level of osteotomy remains intact, but anterior support may be necessary in cases of marked shortening.
- Further labeled as posterior release (P) or both (A/P).

Pre- and postoperative aspect of L4 PSO including disc by using combined approach, classified 4A/P:
Grade 5 osteotomy (complete vertebra and discs resection)
- complete removal of vertebral level and both adjacent discs (+ rib resection in thoracic region).
- because of anterior shortening, anterior support is frequently applied.
- most commonly approached through posterior approaches only (modifier P).

Pre- and postoperative aspect of L4 vertebral resection by using combined approach, classified 5A/P:

Grade 6 osteotomy (multiple adjacent vertebrae and discs resection)
- resection extends focally beyond scope of grade 5 resection - removal of several adjacent vertebrae, at least 1 complete vertebral body and partial or complete second vertebra.
- commonly, osteotomy will involve multiple complete vertebrae, some of which may be only partially developed (e.g. congenital malformation) or partially present (e.g. infection/tumorous destruction or remodeling).
- posterior-only approach is possible (modifier P).
- substantial coronal and sagittal plane correction can be achieved.
Pre- and postoperative aspect of T11-12 vertebral resection by using posterior approach, classified 6P.