# Thoracic & Lumbosacral Spine Surgery (TECHNIQUES)

Last updated: January 13, 2021

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OUTCOMES, PATIENT SELECTION

- see p. Op260 >>

Timed Up and Go (TUG) test – patient stands up from a sitting position, walks 10 feet, turns around, and walks back to chair, to sit down.
- patient is permitted to use an assistive device if needed and instructed to perform the test as fast as possible

>18.4 sec (15-20 sec) = severe objective functional impairment (OFI) = frailty
N B. Frailty is a different domain from disability and comorbidity
- frail patients have 5-fold increased risk of high-grade* complications after elective thoracolumbar spine surgery within 5 wk of surgery
- grade 1 up using a modified Clavien-Dindo classification validated for neurosurgery patients
- consider prehabilitation in high-risk patients to improve postoperative clinical outcomes

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**TABLE 2. Clavien-Dindo Classification of Surgical Complications**

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<tr>
<th>Grade</th>
<th>Definition</th>
<th>Example</th>
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<td>I</td>
<td>Any deviation from the normal postoperative course without the need for pharmacological treatment or surgical, endoscopic, and radiological interventions. Allowed therapeutic regimens are any drugs such as analgesics, anticoagulants, diametics, electrolytes, and physiotherapy. This grade also includes wound infections opened at the bedside.</td>
<td>Arm flap necrosis</td>
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<td>IIa</td>
<td>Requiring pharmacological treatment with drugs other than allowed for grade I complications. Blood transfusions and total parenteral nutrition are also included.</td>
<td>Pneumonia, urinary tract infection.</td>
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<td>IIb</td>
<td>Surgical, endoscopic, or radiological intervention that does not require general anesthesia.</td>
<td>Laparoscopic cholecystectomy.</td>
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<tr>
<td>IIIa</td>
<td>Surgical, endoscopic, or radiological intervention that is under general anesthesia.</td>
<td>Open thoracic surgery.</td>
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<td>IIIb</td>
<td>Life-threatening complication requiring intermediate care or intensive care unit management, single organ dysfunction (including diabetes, heart, kidney, liver, pulmonary, renal failure, sepsis, stroke, and subendocardial infarct).</td>
<td>Severe sepsis.</td>
</tr>
<tr>
<td>IIIc</td>
<td>Life-threatening complication requiring intermediate care or intensive care unit management, multiple organ dysfunction (including diabetes, heart, kidney, liver, pulmonary, renal failure, sepsis, stroke, and subendocardial infarct).</td>
<td>Septic shock.</td>
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<td>IV</td>
<td>Death of patient</td>
<td>Cardiac arrest.</td>
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**GENERAL PRINCIPLES**

**Surgical Goals**

- Decompress neural elements to relieve symptoms
- Stabilize mobile segments if evidence of instability
- Preserve alignment if maintained after deformity correction

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**OUTCOMES, PATIENT SELECTION**

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**FACE DISLOCATION REDUCTION – see p. TdS9 >>**

---
N.B. all complications were similar between younger and older age groups, except:

— UTI - more frequent in ≥ 70 age group (OR 2.32, P = .009).
— older age group were more likely to be discharged to a rehabilitation facility (OR 3.66, P < .001), rather than home (OR 0.25, P < .001).

N.B. it is likely that the phenotype associated with older age, namely greater comorbid status, is a driving factor in producing greater perioperative morbidity in this patient population (i.e. frailty is more important than the age).

PATIENT and OUTCOME OPTIMIZATION, incl. ERAS protocol

N.B. components are optional – tailored to patient and type of surgery

PREOPERATIVE
1. Cardiopulmonary consult. Pulmonary function tests
2. Plasma albumin, Nutritionist consult – weight loss vs. nutritional support
3. DEXA scan in patients > 60 yo (do not operate if < 2.5), vit. D level
4. Osteoporosis correction - TERIPARATIDE (Forteo), biphosphonates.
5. Anemia – Epogen, autologous blood donation, CellSaver, intraop TXA
6. Correct modifiable factors (stop smoking, BMI goal < 35)
   • nicotine-free for 6 wk before planned surgery - nicotine levels drawn on the morning of surgery - smoking is grounds for the cancellation of elective cases.

INTRAOPERATIVE
1. Skip Foley catheter
2. Prefer Monitored Anesthesia Care (MAC)
3. Transfusion protocol - intraoperative Hb target ≥ 10 g/dL
   • FFP is given after each 3 units of packed red blood cells (PRBC).
   • platelets are given after every 5 units of PRBC for a goal 100 000/microliter.
   • cryoprecipitate is administered for a goal concentration of fibrinogen of <100 mg/dL
4. Epidural analgesia for cases < T10 (not possible in patients undergoing fusion to the mid to high thoracic levels).
   • motor block - reversible bilateral lower extremity weakness that had no structural cause on imaging and resolves before discharge from the inpatient setting after epidural catheter is removed.

POSTOPERATIVE
1. Sit up in bed on POD0
2. Out of bed for every meal
3. Ambulate with PT on POD1
4. DVT prophylaxis – SC on POD0, chemical on POD1
5. Pain management team consult
6. Geriatrics consult

CARDIAC ARREST (INTRAOP, PRONE)
**SPINAL SURGERY – THORACIC & LUMBAR SACRAL**

- Quickly close incision (e.g. cover widely with large Ioban) → roll supine on the bed.
- When flipping the patient is not feasible – do chest compressions (chest support – sternal bar of Jackson table) – both hands over scapulae:
  - If sternal support is not present, surgeon clutches fist and places it under the chest over lower 3rd of sternum and massages chest (better if assistant does that):
  - If unsuccessful – consider prone thoracotomy (cut between ribs) → cardiac massage:

**UNABLE TO VENTILATE IN PRONE POSITION**
- Never roll bed away after flipping patient prone until anesthesiologist confirms bilateral breath sounds.
- Axis table is the worst (consider longitudinal gel rolls).
- Quickly close incision (e.g. cover widely with large Ioban) → roll supine on the bed
  - "If time permits, may place several sutures on fascia and staples to the skin

**LEVEL LOCALIZATION / WRONG LEVEL SURGERY**

See p. Op210+5

**MINIMALLY INVASIVE SURGERY (MIS)**
- Posterior muscle sparing procedure; it is OK to make midline skin incision and then dissect skin flap of fascia → make stab lateral incisions in fascia.

**BONE GRAFTS**
- Compacting bone grafts (vs. placing them loosely) in spine fusions give better fusion rates.

**SPINAL DEFORMITY**

- NREF videos: https://www.youtube.com/playlist?list=PLrYUcBdXzrLc-YauW4ZfoTFBPSWvQjLHU
- Dr. Lenke tips:
  1. Ask patient to get onto the table unassisted and lay prone – if patient is unable to do it = unfit for deformity surgery.
  2. Keep spine flexible – do not fuse if you can! No surgery cures deformity – if patient lives long enough, spine will degenerate above and below.
  3. Deformity spine surgery always posterior approach (since year 2000).

**Prevalence**: up to 68% in patients > 50 yo.
- Plane: Coronal
  - Sagittal
- N.B. be aware of “functional” deformity on scoliosis (spine survey) XR – when patient, despite instructions, leans forward to rest on something due to pain from central stenosis – such “deformity” may well correct after simple central decompression with laminectomy.

**PATHOPHYSIOLOGY**
Etiology
Advanced degenerative disease
Idiopathic scoliosis / kyphosis
Sarcopenia
Iatrogenic

Prep Optimization
- especially important, e.g. ERAS protocol! see above >>

Imaging (scoliosis film, spine survey, 36-inch film)
Practically, every patient should be evaluated for sagittal imbalance before fusion (even single level) – standing 36 inch lateral XR:
- include femoral heads and C7
- patient stands with hips and knees extended
- arms positioned at a 45° angle in front of the body, and both hands resting on the clavicles.

Characteristics of deformity curves (Rigid vs Flexible – determined by:
a) side bending XR (placing bolsters trying to correct curves)
b) simple supine AP XR – eliminates gravity and allows flexible curves to correct (less operator dependent than bending XR); also reflects patient position on OR table (some experts even try prone XR but many deformity patients do not tolerate it).

Sagittal Imbalance
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 segment.
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 segmental imbalances (osteotomy is done at lower spine - greater lever arm correcting axis of view, there are fewer complications related to thoracic viscera and vascular structures, and correction is not hindered by ribs).

- 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.

Osteotomies
- multiple-level posterior osteotomies
N.B. corpectomies and pedicles subtraction osteotomies are usually avoided in these long-segment cases to mitigate excessive blood loss (+ multilevel posterior osteotomies are often sufficient for deformity correction).

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 Bendini® Spinal Rod Bending System – 5000$ disposable).

N.B. 60-70% of lumbar lordosis is normally at L4-S1
Standard stop upper levels for posterior instrumentation – either T10 or T4.

**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 posterosuperior corner of S-1.
- general aim for < 50 mm
  - N.B. there are studies that report significant unreliability of this goal (SVA < 50) when it comes to patient outcomes.
  - Age-related goals:
    - Age 50 yrs - SVA < 50 mm
    - Age 60 yrs - SVA < 60 mm
    - Age 70 yrs - SVA < 70 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 > 10° 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 head and a line connecting to the midpoint of the endplate of S1.

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

TPA < 20°

Do not aim for ideal for elderly patients!

SPINOPELVIC HARMONY
ELDERLY PATIENT

SVA < 80mm  PT < 25°  LL = PI - 15°

Defining Spino-Pelvic Alignment Thresholds

Should Operative Goals in Adult Spinal Deformity Surgery Account for Age?  
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Age group  Number  PT (deg)  P-LL (deg)  SVA (cm)
45-64  218  15.3 ± 2.3  1.7 ± 3.5  3.3 ± 1.2
65-74  172  22.6 ± 1.5  12.5 ± 2.2  7.1 ± 0.8
75-85  75   28.1 ± 0.8  18 ± 1.2  10.9 ± 0.4

Multivariate linear regressions identifying correlations between QOL and alignment by age

SURGEON ERRORS!

- Failure of planning
  - Understanding appropriate age-related alignment goals
  - Failure to address modifiable factors (osteoporosis, BMI, smoking, etc.)

- Failure of execution
  - Over or Under correction
  - Handling of soft tissues and PLC
  - Implant handling/choice
  - Choosing the wrong UIV

There cases that can be done via MIS approach
**Scheuermann’s Kyphosis**
- structural thoracic kyphosis - anterior wedging of $\geq 5^\circ$ in at least 3 adjacent vertebral bodies (differentiate Scheuermann kyphosis from postural round-back deformity).
- “developmental” type of kyphosis - develops over time during periods of bone growth (such as puberty).
- degree of kyphosis operative correction should not exceed 50% of the initial deformity because of an increased risk of proximal and distal junctional failure.

**Proximal fusion level (upper instrumented vertebra, UIV)**
- proximal end vertebra (PEV) or T2 (when it is difficult to determine the PEV especially when the SVA $\geq 50$mm).

**Distal fusion level (lower instrumented vertebra, LIV)**
A. Vertebra just below first lordotic disc (FLD) - historical golden standard; due to the often large kyphosis, patients have compensatory hyperlordosis in the lumbar spine making it difficult to truly determine the FLD level ($\Rightarrow$ shorter fusion than necessary)
B. Sagittal stable vertebra (SSV) – much lower (> 4-fold) distal junctional failure & revision rate (Lenke et al. Global Spine J, 2017) at the expense of incorporating additional motion segments in a typically young population.

SSV - the most proximal vertebra touched by a vertical line from the posterior superior corner of S1 FLDS is typically proximal to SSV

L2 is marked by the "*" and represents the distal fusion level (SSV)

N.B. PSF extending to L4 or L5 may cause adjacent segment degenerative disc disease, minimal degeneration occurs with fusions ending more proximally (e.g. Green et al reviewed MRI of 20 scoliosis patients comparing subgroups between LIV = T12 or L1 and LIV = L3 found no significant differences in Pfirrmann scores)

**Coronal Deformity**
- measure coronal offset with plumb line.
- coronal deformity is usually less functionally important than sagittal balance.

Minimally invasive lateral lumbar interbody fusion (LLIF) – can be performed from the concavity or convexity.

- no statistically significant clinical or operative complication rates regardless of a concave or convex approach to the curve.
- clinical outcomes and coronal plane deformity improved regardless of approach side.
- in cases wherein L4-5 is in the primary curve, approaching the fractional curve at L4-5 from the concavity may be associated with a higher complication rate compared to a convex approach.

**Postoperatively**
- see ERAS protocol, see above >>

**Adjacent Level Disease**
- accelerated degeneration of segments adjacent to a lumbar fusion
associated with the increased mobility and stress put on segments neighboring a fusion because of its rigidity. accounts for a significant portion of revision spinal surgery and failed back surgery syndrome and is a major consideration when deciding how many levels to fuse. 25% incidence (requiring reoperation for ALD) after L4-5 fusion over a 10-yr period (131 patient): Prognostic Factors for Adjacent Segment Disease After L4-L5 Lumbar Fusion. Georgios A. Maragkos et al. Neurosurgery, Volume 86, Issue 6, June 2020, Pages 855–842.

### Hounsfield Units

- **Superior endplate**
- **Middle of the vertebral body**
- **Immediately superior to the inferior endplate**

The mean HU value of the four ROIs is defined as the superior endplate, in the middle of the vertebral body, and immediately superior to the inferior endplate. The HU value of < 104 HU at the UIV cutoff value determined by the Youden index was 104 HU (sensitivity 0.840, specificity 0.517) - preoperative L/T spine HU value of < 104 HU may be a risk factor for PJK after ASD correction.

### Adjacent Segment Disease

Risk groups: age > 55, osteoporosis / poor bone density, smoking, long-sagittal fusions from the lower thoracic spine to the sacrum / pelvis, disruption of the posterior ligamentous tissues, overcorrection of sagittal plane deformities because of its rigidity. accounts for a significant portion of revision spinal surgery and failed back surgery syndrome and is a major consideration when deciding how many levels to fuse. 25% incidence (requiring reoperation for ALD) after L4-5 fusion over a 10-yr period (131 patient): Prognostic Factors for Adjacent Segment Disease After L4-L5 Lumbar Fusion. Georgios A. Maragkos et al. Neurosurgery, Volume 86, Issue 6, June 2020, Pages 855–842.

### Classification of PJK

- **Type 1 = disc and ligament failure**
- **Type 2 = bone fracture**
- **Type 3 = implant failure:**

Risk groups: age > 55, postmenopausal women, osteoporosis / poor bone density, obesity, smoking, long-sagittal fusions from the lower thoracic spine to the sacrum / pelvis, disruption of the posterior ligamentous tissues, overcorrection of sagittal plane deformities or residual sagittal imbalance, extreme rod stiffness, combined front-back operations.

### Mechanism of PJK

- **Most common mechanism - fracture of the UV or, less commonly, UV+1, which may be related to low bone mineral density which can be simply measured on CT as Hounsfield units (HU):**

Ellipsoid region of interest (ROI) is used, ideally including the largest possible cancellous bone region while excluding cortical margins, osteophytes, and Schmorl nodes. ROIs are measured in four separate sections of each vertebra: the midsagittal plane, immediately inferior to the superior endplate, at the middle of the vertebral body, and immediately superior to the inferior endplate. The HU value of each ROI is calculated using the PACS. The mean HU value of the four ROIs is defined as the superior endplate, in the middle of the vertebral body, and immediately superior to the inferior endplate. The HU value of < 104 HU at the UIV cutoff value determined by the Youden index was 104 HU (sensitivity 0.840, specificity 0.517) - preoperative L/T spine HU value of < 104 HU may be a risk factor for PJK after ASD correction. A prospective study design was used to test a series of 131 patients, and the association between lower Hounsfield units of the upper instrumented vertebra and proximal junctional kyphosis in adult spinal deformity surgery with a minimum 2-year follow-up. DOI: https://doi.org/10.3171/2020.3.FOCUS20192.

No successful strategy exists to prevent it:

A. Make sagittal balance as neutral as possible.
B. Respect soft tissue - preserve interpinnous ligaments (e.g. leaving top of lamina intact with attached lig. flavum).
C. Vertebral cement augmentation at UV+1 (e.g. if instrumented fusion stops at T10, place cement into T9 body) - unlikely effective.
D. Rib fixation at UV+1.
E. Extend noninstrumented fusion one level above instrumented fusion (leave facets intact)!
F. Sublaminar hooks (instead of pedicle screws) for upper levels.
G. Transverse process hooks
H. Sublaminar bands
I. Spinous process augmentation around UIV and UIV+1 with “Tethers” – Mersilene Tape.
J. Nuvasive VersaTie® – posterior band system that provides distributed loading across the fixation hardware; system’s independent locking connector and advanced tensioning device offers enhanced control.

K. “Soft landing” – avoiding rod being proud (pre-loading) in upper screws (i.e. contour rod so it sits perfectly in upper screw heads without pulling).
L. Flexible rods at the top.
M. Upper screws should be placed not to violate the facet joint above:

N. TLSO brace for 3 months – retrain brain to avoid anteroflexion.

**OSTEOPOROTIC SPINE**

- avoid hardware (if still needed – use more constrained screws – less wobble, less loosening).
- osteoporotic spines are predisposed to screw pull-out, wire cutout, and instrumentation-associated laminar fractures - increasing points of fixation (e.g. 360) may be necessary to offset poor bone quality.
- some experts suggest traditional pedicle screw technique replace with MIDL technique due to the better cortical purchase.
- rigid external orthotics aid in maintaining stability while fusion occurs.
- preoperative - TERIPARATIDE (Forteo), bisphosphonates.

Forteo effect is monitored using P1PN:

P1NP=procollagen type 1 N-terminal propeptide
CTX=carboxy-terminal telopeptide of type 1 collagen.

— Forteo / surgery timeline: surgery after 6 mos of use as Forteo is approved for 2 years – patient can continue postop.

**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!!)

**BROKEN SCREWS**

- distal segments of broken screws are removed utilizing the rreamer (to ream the cuf of bone void around screw shaft), then the reverse-thread female screw driver is applied to undo the screw shaft.

**OBESITY**

Put hoe retrospective subgroup analysis of SPORT
- treatment outcomes for 376 lumbar stenosis and degenerative spondylolisthesis patients.
- incidence of intraoperative complications was significantly lower in the obese patient group,
- trend toward increase rate of wound infection in the obese patient (5% vs. 1%, p=0.051).
- at 4 year follow-up, there was a significantly higher rate of reoperation in the obese patient group (20% vs. 11%, p=0.013).
- at 4 year follow-up in the nonoperative group, obese patients had SF-36 physical function scores that worsened from baseline by a mean of 3.5 compared to a mean improvement of 13.9 points in the nonobese group (p<0.001).
- the treatment effect for the SF-36 Physical Function score was significantly higher for the obese surgical patient group (25.6 vs. 14, p=0.004) suggesting that surgery has a significantly greater benefit (over nonsurgical treatment) of degenerative spondylolisthesis in obese patients.

**PREGNANT PATIENT**
- use open spine table.

**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!

**INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING**
See p. D25 >> (including protocol for intraop spinal cord injury)

**FREE RUNNING EMG**
- see Medtronic NIM Eclipse system >>

![Image of EMG monitoring setup]

femoral adductors, rectus abdominis (T10, 11, 12):
lateral vastus (L4):

extensor hallucis longus (L5) one palm-width above ankle, close to tibia:

medial gastrocnemius (S1) one palm-width below popliteal fossa:
Oxiplex/SP gel

- arms in superman position except for upper thoracic – popoose arms.
- 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 overlap in midline so only spinal tracking frame is exposed (secure sheets with hemostats – easy to undo; if use staples – staples fly everywhere, even into wound); 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.

STEAL THE SPINE

- instruments come with already attached SureTrack 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

DURAL VIOLATION

- dural violation requires primary closure (+ under microsurgery).
- needle driver - Castro-Viejo or long Ryder
- sutures: choices (running or interrupted):
  a) 5-0 nylon/Proline
  b) 4-0 silk
  c) Goss-Tex
  d) metal clips (e.g. AnastoClip GC® Closure System) see p. Op140 >
  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 / piece of Gelfoam inside the dura for the dural closure start to keep nerves away.
- tie deep knots
  a) knot pusher
  b) hold one string with needle driver and push knot with finger (assistant may pull on other string)
  c) use DeBakey to pull loose end
- chock repair line with Valsalva maneuver; if leaking – place another suture line.
- obligatory reinforcement: DuraGen soaked with autologous blood, dural sealant with Surgicel layers
- N.B. DuralGen is placed first! (“DuraGen goes on dura”)
- some experts would add muscle patch or mashed piece of fat (crush wrapped in the gauze)
- 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 again keep tagged on mosquitoes → then suture each through patch graft edges again and keep tagged on mosquitoes → slide graft down and tie each knot separately.

Epidemiology, prognosis

- durotomy occurs in 9% of first-time open laminectomies (with or without fusion).
- durotomy significantly increased operative duration, operative blood loss, and inpatient stay durotomy 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)

- Ducoat ®/P637: Does Unplanned Durotomy Affect Long-term Outcomes in Cases of Spinal Stenosis?" Neurosurgery March 2015 - Volume 76 - Issue: p.577-583

DURAL SCAR PROPHYLAXIS

Oxiplex/SP gel – barrier gel to coat dura and nerve roots.
ISCHEMIC OPTIC NEUROPATHY (ION)
- the most common pathological diagnosis underlying postoperative vision loss.
- Spine surgery remains one of the largest sources of acute perioperative visual loss!
- two forms:
  a) anterior (AION) - affecting the optic disc
  b) posterior (PION) (58-83%) - affecting the optic nerve proximal to the disc.
- risk factors: fusion, higher number of operative levels, higher blood loss, change in hemoglobin, hematocrit, prone surgery, longer operative time, intraoperative hypotension.
- bilateral (75%).
- only 30% patients demonstrate improvement in visual acuity while the rest remain either unchanged (40%) or worsened (20%) at last follow-up.
- PION is associated with higher odds of severe visual deficit at immediate presentation (odds ratio [OR]: 6.45, confidence interval [CI]: 1.04–34.3, P = 0.04) and last follow-up.
- management:
  1) urgent ophthalmologic examination to ascertain the cause of vision loss.
  2) test pupillary reflex - absence implicates injury of the optic nerve or globe, while presence of a normal pupillary reflex indicates cortical blindness from either stroke or posterior reversible encephalopathy syndrome (PRES).
- prophylaxis:
  - stage the surgery to reduce the duration and intensity of each operative stage.
  - deliberate hypotensive anesthesia must be used cautiously while avoiding prolonged periods of hypotension.
  - soft headrests to avoid undue pressure on the globe vs. pin the head in Mayfield.
  - regular eye checks.

HARDWARE REMOVAL
- removal of rods with laminar hooks: make preop diagram which hooks are facing which direction; then drill lamina along heel of the hook, then rotate hook.

DIFFERENT METALS
- stainless steel (old hardware) should not contact with titanium (vs. stainless steel (old hardware) should not contact with titanium)

SURGICAL SITE INFECTION
- see p. Op120 >>

EPIDEMIOLOGY
- despite appropriate prophylaxis, the rate of surgical site infections in spine surgery is 0.7% - 10% (patients without comorbidities 0.7 – 4.3%; patients with comorbidities* 2.0 – 10%).
- current best practice with antibiotic protocols has failed to eliminate (reach rate of 0.0%) surgical site infections.

*diabetes (level of evidence: III), obesity (level of evidence: insufficient), neurologic deficits, incontinence, hyperglycemia (preoperative >125 mg/dL, postoperative > 200 mg/dL), smoking, nutritional depletion, immunodeiciencies, use of antithrombotic therapies, trauma and prolonged multilevel instrumented surgery.

PROPHYLAXIS
- stage surgeries.
- frequent intraop irrigation.
- vancomycin powder decreases risk 2-fold.
- < 5% BETADINE irrigation before closure.

TREATMENT
- operative washout and drainage: use pulse lavage with liters of bacitracin.
- if in doubt and skin is intact (infection vs hematoma vs seroma vs CSF) – do MRI w/wo, aspirate fluid for analysis.
- infection in the presence of hardware:
  - practically never need to remove hardware; some experts leave even bone grafts in place.
  - stainless steel (typically, old fusion hardware) - needs to be removed as it creates biofilm vs. titanium.
  - index surgery long time ago (do CT to verify fusion) – remove hardware.
  - fresh surgery:
    - Grc cocci – washout, leave hardware
    - Gr. rods – will likely need multiple washouts, even temporary hardware removal (keep patient on bed rest)
  - close incision with retention sutures (esp. in obese patients).
  - place “AquaCel” dressing on incision.
- antibiotics for ≥ 6 weeks (ESR and CRP need to normalize).
- N.B: do not start perioperative antibiotics and do not irrigate with bacitracin until cultures are sent!
- keep drains on suction until output = 0 (it is fine to discharge with drains in).

OSTEODISTOISIS,OSTEOMYELOITIS
Infection likes stability – consider fusion!
- consider BMP (some experts swear it gives good results even if it is formally contraindicated)
- destroyed endplates – place large footprint TLIF graft or 2-level corpectomy through lateral approach (may need vascular surgeon for approach due to chronic infection), then supplement with posterior fusion (consider quad-rods to bridge corpectomy levels).
**POSTERIOR MIDLINE APPROACH**

**MEDICATIONS**
- preoperative antibiotics before skin incision
- ketorolac (Toradol) can be instilled at end of case

**POSITIONING**
Patient is positioned prone on chest rolls on Wilson frame or Jackson table to hold spine in flexion:

- crack frame for discoscopes; frame has to be in neutral position for fusions!!!
- hips flexed (to open interlaminar spaces), legs cannot be overflexed.
- posterior bony hump should hang as freely as possible (to reduce venous hypertension – main cause of severe intraoperative bleeding!)
- pad ulnar nerves at elbow (to prevent neuropathy).

**Axis / Jackson table**
- top of chest 1-2 fingerbreadths below top of sternal notch
- iliac crest at interface of top 1/3 and bottom 2/3 of hip support

**SKIN INCISION**
- palpate anterior superior iliac crest = L4-5 interspace
- obtain precission radiograph with spinal needle (to confirm localization and to determine correct size of exposure; surgeons still operate on wrong level!!!)
- local anesthetic with epinephrine to skin and deeper tissues.

**FASCIAL AND SUBFASCIAL DISSECTION**
- Bovie electrocautery for subcutaneous dissection and for achieving hemostasis.
- thoracolumbar fascia is identified after dissection through subcutaneous fat.
- dry sponge raked along fascia identifies white tissue easily, and periosteal elevator can be used to dissect off subcutaneous fat from fascia beneath (Dr. Graham thinks that it leaves unnecessary dead space).
- self-retaining retractor (such as Gelpi retractor).
- pad to find midline.
- Bovie (on cut) to cut through fascia in midline

- "for microdiscectomy/paramedian fascial incision ensures midline ligamentous structures are not damaged.

**SUBPERIOSTEAL DISSECTION**
- retract paramedial muscles (away from spine and laminae involved).
- after minimal one-sided exposure obtain localizing film
- dry sponge raked along fascia identifies white tissue easily, and periosteal elevator can be used to dissect off subcutaneous fat from fascia beneath (Dr. Graham thinks that it leaves unnecessary dead space).
- self-retaining retractor (such as Gelpi retractor).
- pad to find midline.
- Bovie (on cut) to cut through fascia in midline

- *for microdiscectomy/paramedian fascial incision ensures midline ligamentous structures are not damaged.

**CLOSURE**
- copious irrigation; any bleeding source should be controlled until irrigation is clear.
- 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.
- absolutely watertight 0 subcutaneous stitches 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.
- radical arteries vary widely supply thoracic cord, and watershed infarcts can occur after root sacrifice.
- 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.

Topography of intervertebral foramen:

1: segmental spinal nerve/dorsal root ganglion, 2: sinuvertebral nerves and rami communicantes, 3: spinal branch of segmental arteries, 4: intervertebral vein

Anterior Surgical Approaches to Thoracic Spine:
- T1-2: Anterior neck dissection with or without sternotomy
- T3-4: Anterior neck dissection with partial median sternotomy and anterolateral thoracotomy "trap door" technique
- T5: Transthoracic extra pleural approach
- T11-L2: Retropleural retrodiaphragmatic retroperitoneal approach or transpleural transdiaphragmatic retroperitoneal approach

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

Unilateral

Bilateral

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.

There can be 11 and 13 pairs of ribs.
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 preop 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. *At no point in operation should one attempt to retract cord!*
- 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, disc 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.
- subperiosteal dissection along 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.

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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.
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**TRANSTHORACIC APPROACH**
• indication – calcified central disc herniations.
• contraindication: pulmonary pathology such that patient cannot tolerate one-lung ventilation.
• double-lumen tube should be used for intubation; lung deflated and retracted medially and superiorly during the case.
• steroids and maintenance of MAP > 80 mm Hg are recommended for cord protection.
• thoracic surgical instruments include:
  o rib retractors (e.g., Finochietto retractor)
  o long-bayonetted instruments (Kerrison rongeurs, Leksell rongeurs, bipolar cautery)
  o high-speed drill with long handle
  o self-retaining retractor system
• intercostal neurovascular bundle is dissected in a subperiosteal fashion using periosteal elevator and Doyen elevator.
• rib spreader is used as a self-retaining retractor, and lung is deflated.
• vertebrectomy and disk 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 vertebra 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;
  – 25% of the upper and lower vertebral bodies need to be removed, but the amount of removal needs to be precisely tailored to the pathology encountered.
  – drilling is taken across the vertebral body to the contralateral pedicle.
• under microscope magnification, curettes (forward and reverse-angle) are used to manipulate the vertebral endplates and annulus into the formed cavity.
any disk material around the spinal cord can be gently teased away from it in an anterior direction. This is performed across the entire disk space until the contralateral pedicle is reached.

in cases where the herniated disk is large and calcified, it may be necessary to drill around it first; PLL may be calcified; therefore, it needs careful burring; PLL should be opened sharply above then below the level of the calcified disk protrusion; using microdissectors, the disk protrusion should be teased away from the cord in an atrumatic fashion.

great care should be taken not to retract or manipulate the cord in any way.

direct palpation using microsurgical blunt hooks can confirm the exposure across to the contralateral pedicle (i.e. to ensure complete decompression to contralateral side, contralateral pedicle should be palpated with a blunt instrument).

if a significant amount (> 25%) of the superior and inferior vertebrae has been removed, an instrumented fusion is recommended.

- thoracic corpectomy may occur with little or no morbidity
- chest cavity is then copiously irrigated.
- parietal pleura is closed over the vertebral bodies and the lung expanded.
- 1-2 chest tubes (28-32 F; depending on bleeding during closure) are inserted superior to the incision in the midaxillary line and put on low suction.
- ribs are reapproximated with heavy (No. 2 Vicryl) sutures.

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THORACIC CORRECTOMY

- contraindication - limited life expectancy (<3 months)—protracted recovery period may not be justified
- preoperative angiography / CTA to 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 thoracoabdominal approach.

self-retaining rib spreader system → ipsilateral lung is collapsed.

transpleural or retropleural plane is developed bluntly through resected rib bed.

*parietal pleura is incised longitudinally over the intended vertebral bodies.

segmental vessels: over each body (located in the mid portion of the vertebral body) must be identified, dissected, isolated, and preserved if possible; they can be ligated / clipped if needed, but this should be done anterior (proximal) to the lateral foramen.
N.B. segmental vessels bleed a lot; maybe difficult to control, especially if injured on the contralateral side.
- Cobb elevator is used to retract the parietal pleura posteriorly, and electrocautery is used to subperiosteally strip it off each vertebral body (again – watch for segmental vessels).
- 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) – using osteotome and pituitary rongeurs.
- Corpectomy is performed with rongeurs and osteotomes 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 (high-speed drill (small burr) should be used as it is less traumatic than rongeurs).
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 or lateral 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/ buttocks/ 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.
- 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.

**MILD (MINIMALLY INVASIVE LUMBAR DECOMPRESSION)**
- percutaneous removal of hypertrophied lumbar ligamentum flavum.

**VERTOS MEDICAL**
Nice video: https://www.youtube.com/watch?v=DE8BMJmJiqM0

**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

**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.

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

**SPINOUS PROCESS REMOVAL**
- when spinous process out to facet is dissected, bony dissection can begin.
- Horsley bone cutter and double-action rongeur can be used to remove spinous process.
- bone can be saved and used for posterolateral in situ fusion if needed.
- cortical bone at base of spinous 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 spinous 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.
• most difficult and time-consuming part - developing plane between dura and ligamentum flavum (frequently hypertrophic and closely adherent to underlying dura - risk of dural lesion with CSF escape).
• 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. N.B. thecal sac may be under pressure; to avoid CSF leak, small ½ × ½ clot is placed in front of each bite with Kerrison rongeur (Kerrison bites clot can be used in place of CSF escape).
• to avoid inadvertent CSF leaks from sharply angled bony spurs, bites with Kerrison rongeur should be kept continuous and overlapping.
• thecal sac should appear relaxed and more pliant before each bite with Kerrison rongeur.

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 MICRODISCECTOMY


DISCECTOMY – one of most commonly performed elective operations in USA (many performed in outpatient setting).

TRIALS

Surgery vs. conservative management (Norwegian study)
• class of evidence III
• statistically significant benefit of surgery at 1 year (p = 0.0015)
• beyond 4 years, although there was a trend towards benefit, the difference was not statistically significant.

<table>
<thead>
<tr>
<th>1 year outcomes</th>
<th>Conservative Management</th>
<th>Surgery</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>36%</td>
<td>65%</td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td>42%</td>
<td>27%</td>
<td>p = 0.0015</td>
</tr>
<tr>
<td>Poor</td>
<td>20%</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Bed</td>
<td>2%</td>
<td>0%</td>
<td></td>
</tr>
</tbody>
</table>
SPORT trial: surgery vs. conservative management (US study)
- class of evidence II
- statistically significant improvement of Sciatica Botherness Index (SBI) in the surgery group at 1 year (p<0.001)
- benefit from both surgery and conservative management but no conclusions regarding the superiority of either can be made on an intention-to-treat analysis (N.B. significant cross-over between groups with 40% of the surgical group, 43% of the conservative group).

Outcomes (12 months) Surgery Conservative management

| Pain (SF-36) | 39.7 | 36.9 | None |
| Physical function (SF-36) | 36.4 | 35.2 | None |
| OSI | −30.6 | −27.4 | None |

CONTRAINDICATIONS
1) unrelenting back pain after bout of sciatica has resolved (discectomy results are not good).
2) patient not provided adequate conservative treatment (e.g. short period of sciatica without bedrest and steroid trial).

INDICATIONS

Clear indications for surgery:
1) cauda equina or conus medullaris syndrome → emergency surgery!
2) acute or progressive myelopathy
3) severe or progressive neurologic (e.g. motor) deficits.
4) intractable pain.

Additional indication: unfruitful factor response within 3-12 weeks of conservative measures.

How urgent surgery must be:
- decision to operate urgently is often based on fear of legal repercussions rather than on scientific evidence.
- ensure completeness of diagnostic workup prior to operation (all surgery can recall several cases in which diabetic plexopathy or epidural metastasis was missed).

NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012):
- preoperative assessment for signs of psychological distress (somatization, depression) is suggested - patients with signs of psychological distress have worse outcomes (Grade of Recommendation: B).
- positive straight leg raise test correlates with better outcomes (Grade of Recommendation: C).

Surgical intervention prior to 6 months is suggested for lumbar disc herniation severe enough to warrant surgery. Earlier surgical intervention (within 6 months to one year) is associated with faster recovery and improved long-term outcomes.

There is insufficient evidence for urgent intervention for motor deficits due to lumbar disc herniation with radiculopathy.

Recovery of ankle dorsiflexion weakness
- patients treated with surgical decompression at various intervals (urgent (<10 days), expedient (<30 days) and routine (>30 days))
- outcomes assessed at 24 months
- ankle dorsiflexion power at the long-term follow-up significantly correlated with the preoperative ankle dorsiflexion power (p = 0.001).

Level IV evidence that timing of surgery does not affect recovery of ankle dorsiflexion.


STRATEGIC PRINCIPLES

See also: Spinal11 >>
PLANNING

MRI – look for level of neural foraminal stenosis.

Flexion and extension XR - dynamic instability? (→ lumbar fusion rather than discectomy alone*)

*discectomy will treat radiculopathic pain but would be unable to treat mechanical back pain

PROCEDURE

POSTERIOR APPROACH

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

Large central disk herniation - full laminectomy is indicated.

- fascial incision is paramedian to ensure midline ligamentous structures are not damaged by dissection.
- for morbidly obese patients use Taylor retractor.
- localizing 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 document 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.
Inferior Hemilaminotomy
- Standard for posterolateral herniation (unilateral radiculopathy).
- Remove portions of lamina with drill or rongeurs (to gain entrance into lateral aspect of spinal canal).
- Operating microscope may now be used.
- Microscope is suggested to obtain comparable outcomes to open discectomy.
- Medial facet is partially resected in most patients (but structural integrity of facet should be preserved).
- NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012): insufficient evidence for or against medial facetectomy to improve the outcomes.

If needed, perform hemilaminectomy:
- Quickly thin bone (e.g. drill or LeKell) past cortical bone in lamina to cancellous bone on other side; up-going curet can be used to remove remaining bone.
- Operating microscope may now be used.
- Medial facet is partially resected in most patients (but structural integrity of facet should be preserved).

If needed, perform laminectomy:
- For central herniation (additional indications - large herniations, free disc fragment).

Disk Herniation
- Adequate, counterclockwise traction is achieved with nerve root retractor (in redo cases, nerve root can be tethered 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!
- Retract affected root medially* and expose disc herniation immediately anterior to it.
- *If hernia is present in axilla between nerve root and adjacent dura, root must be retracted laterally.

Disk hernia impinging on root from directly anteriorly (A), medially (B), and laterally (C):
- 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).
- Retract affected root medially* and expose disc herniation immediately anterior to it.
- *Don’t cut window in annulus – will ease rehydration 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.
• with angled instrument explore nerve root thoroughly along its course to ensure that it is adequately decompressed.
  - if osteophytes compromise neural foramen → FORAMINOITY (resection of anterior and medial segments of facet).
  - intraspinal sonography may help locate disk fragments / osteophytes located anterior to dura or nerve root.

AGGRESSIVE DISKECTOMY VS. CONSERVATIVE DISKECTOMY (IS SEQUESTRCTOMY): - controversial; however, there is statistical trend toward limited diskectomy so as to cause less discogenic pain subsequently.
• there was 2-week return to work and 1-month accelerated with conservative diskectomy.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Sequestrectomy</th>
<th>Aggressive diskectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure operative time and hospital stay</td>
<td>shorter</td>
<td>longer</td>
</tr>
<tr>
<td>Recurrence rate*</td>
<td>12.5% vs. 10%</td>
<td></td>
</tr>
<tr>
<td>Persistent back or leg pain</td>
<td>less</td>
<td>more</td>
</tr>
<tr>
<td>Return to full-capacity work</td>
<td>less</td>
<td>more</td>
</tr>
<tr>
<td>Post-operative disc degeneration and end-plate changes on MRI**</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Overall outcome over time (≥ 2 years)*</td>
<td>better (p = 0.029)</td>
<td></td>
</tr>
</tbody>
</table>

*NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012) when surgery is indicated, either sequestrectomy or aggressive diskectomy is recommended since there is no difference in rates of reoperation (Grade of Recommendation: B); insufficient evidence for or against aggressive discectomy vs. the avoidance for the achievement of chronic low back pain.

LOCAL STEROIDS:
• some experts apply 40 mg of DepoMeth on solution on the nerve root (after finished irrigation, right before closure); others believe that it increases the risk of delayed CSF leak.
• Level II therapeutic evidence that application of glucocorticoids, with or without fentanyl, for or against the application of glucocorticoids, with or without fentanyl, is not suggested to provide long-term relief of symptoms following decompression.

FAT GRAFT: - to reduce the degree of dural scarring.

NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012): insufficient evidence for or against application of a fat graft following open discectomy.

STABILIZATION:
- stabilization role is very unclear (increasing number of patients are having fusions).
  a) rigid fusion: modern trend - INTERBODY FUSION
  b) ARTIFICIAL DISK IMPLANTATION

NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012): insufficient evidence for or against fusion for specific populations with lumbar disc herniation with radiculopathy whose symptoms warrant surgery. — the best available evidence suggests that outcomes are equivalent whether or not a fusion is performed.

TOP TRUMPS:
• 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 entering facet joint 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 spondylothesis may require upfront fusion.

INTRAOPERATIVE COMPLICATIONS
1. Very rarely, anterior annulus is violated and retroperitoneal vessel is injured → close back while vascular surgeon prepares to repair vessel via LAPAROTOMY.
2. Durotomy (risk < 5%)

POSTOPERATIVE COMPLICATIONS
Overall complication rate is 2.4%
1. Postoperative discharge (ESR, fevers, severe localized pain, recurrent symptoms).
• many patients experience transient radiculopathy flare up at 2 weeks postop (likely due to inflammation).
3. Postoperative scar (epidural granulations → mature fibrous tissue) - extradural reactive process; may cause recurrent symptoms - imaging studies show prevalence & severity entirely similar in pain-free patients.

- lumbar epidural fibrosis (scar) is replacement of normal epidural fat with postoperative fibrotic tissue, which is capable of binding dura and nerve roots to surrounding structures anteriorly and posteriorly.

N.B. distinguish from recurrent / residual disc material (MRI is best – accuracy 96-100%) - firm indication for re-operation!!

Scar enhances consistently regardless of time since surgery.

Disc material does not enhance (or has peripheral enhancement) owing to its lack of vascularity.

Recurrence herniation (peripheral enhancement):
4. **Pseudo-meningoceles** (dura breached during surgery) - not of clinical relevance; distinguish from abscess (no communication with thecal space).

5. **Lumbosacral adhesive arachnoiditis** (intradural reactive process) - cause for failed lumbar disc surgery - occurs in only 3%, markedly diminished since abandonment of preoperative myelography using oil-based isopentylate (Myodil, Pantopaque).
   - may be confined to operation site or be more generalized.
   - arachnoiditis is detected with similar sensitivity by both MRI and water-soluble myelography.

6. **Vertebral instability** → **spondylolisthesis** H: fusion.

### POSTOPERATIVE REGIMEN

- **oral narcotics and IV supplementation for pain.**
- **mobilized 4-6 hours after surgery; should be able to void without help.**
- **once patient tolerates fluids, he may leave hospital with ample supply of narcotics, antispasmodics, and stool softeners (rarely, patient may remain in hospital for 2-5 days).**

**Prevention of recurrence:**
1. Low back exercises.
2. Avoidance of certain activities (bending or twisting at waist frequently, lifting heavy objects).

#### FOLLOW UP

- 1st follow-up - 6 weeks after surgery (for uncomplicated cases, patient is then released from surgeon's care).
- return to work after 3-10 weeks of recuperation at home.

### IMAGING POSTOP

**CT**
- not useful soon after surgery - edema and blood eliminate soft-tissue contrast within spinal canal.
- after few weeks - scar tissue (CT attenuation similar to dura matter) is seen; molded to shape of theca which also may be drawn towards it (vs. recurrent disc material indents and displaces dura away).

**MRI**
- MRI is preferable for postoperative lumbar spine evaluation (determining cause of “failed back”) - gadolinium-enhanced images with fat signal suppression reliably distinguish recurrent / residual disc material (lack of enhancement) from epidural scar (strongly enhances).
- scar enhancement diminishes over 2 years, but persists for many years.
- signal change in damaged spinal cord usually regresses when functional outcome is good, but persists when it is poor.

### PEDIATRIC ASPECTS

- no free disc fragments – they are continuous with nucleus pulposus.
- irrigate disc space to remove inflammatory cytokines.

### FAR LATERAL LUMBAR DISKECTOMY

**NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012): insufficient evidence for or against the specific surgical approach for far lateral disc herniations.**

- **A)** complete facetectomy
- **B)** laminotomy with medial facetectomy
- **C)** intertransverse discectomy
- **D)** lateral transmuscular approach
- **E)** combined medial/lateral (interlaminar/paraisthmic) approach

#### LUMBAR MICRODISKECTOMY - 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 MICRODISKECTOMY – MIS (TUBULAR RETRACTORS)
- using Medtronic MISTRX II tubular retractor system; introduced to increase rate of recovery – studies do not confirm it!

**Exposure**
- Spinal needle inserted into the paraspinal 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**
- Styman guidewire placed through the incision and directed medially towards lamina under lateral fluoroscopy.
- Guidewire is advanced only through lumbodorsal fascia with great care taken to avoid penetration of the ligamentum flavum and inadvertent dural puncture.

**Discectomy**
- Operating microscope is brought into field.
- Hemilaminotomy 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 material are removed with a pituitary rongeur and sharp curette in a standard fashion.
- JRC uses 40 mg of DepoMedrol over exposed nerve root.

**Closure**
- Tubular Retractor is slowly removed inspecting paraspinal 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.
- Durotomy (CFS leak) – no need to attempt repair – after Tubular Retractor is removed, muscles collapse and seal the potential space.

**Outcome Trials**
- Prospective, randomized clinical trial (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.
- NASS Clinical Guidelines for Lumbar Disc Herniation with Radiculopathy (2012): insufficient evidence for or against tubular discectomy compared with open discectomy to improve the outcomes.

**Synovial Cyst Excision**
Cyst is misnomer – it is usually ball of hydrated soft tissue; thus, you will not see fluid-filled sac. Dissect and find where cyst originates (may involve long laminotomy; usually need also superior laminotomy of lower vertebra – to expose entire pedicle and medial facet).

**Foraminotomy**
- Expose lateral edge of pars – will know how far can take pars for decompression without destabilization (safely 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 foramen; check with Woodson probe.

**LATERAL FORAMINOTOMY**

- if stenosis is created by lateral facet osteophyte – will not reach from medial side; expose lateral 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);
  - 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)

- Guide exit (should be without resistance) to the number 3-4 on the handle.

- **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 fluoro 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) / ARTHROPLASTY

• introduced in the 1980s in Germany
motion preservation - keeps adjacent segments from significantly progressive degeneration.

in 2019, 65% of insurance providers cover single-level lumbar arthroplasty.

**DESIGNS**

**Core material:**
A) metal-on-metal – may cause gross metallosis around device
B) polyethylene core – may cause osteolysis

**Core can be:**
A) mobile (unconstrained)
B) fixed to one of the end plates (constrained)

- biomechanical studies show no significant advantage of constrained (ProDisc-L) over an unconstrained device (Charité).
- unconstrained devices had higher ROM for axial rotation and lateral bending and lower ROM for flexion and extension.

- constrained prostheses with a small radius of curvature cause increased facet joint loads in extension while unconstrained prostheses that are free to translate during extension might find an equilibrium point between facet joint compression and capsuloligamentous tension.

- constrained device would cause increased facet loads caused by impingement during flexion and extension of the motion segment, whereas an unconstrained device would unload the facet joint.

- loading forces are absorbed in a constrained prosthesis, resulting in long-term facet preservation, whereas an unconstrained LDR, lacking inherent shear stability, would make the facets and posterior ligaments subject to increased forces resulting in an increased incidence of degenerative facet changes.

1. **CHARITÉ (DePuy Spine)** - made up of plastic core sandwiched between two metal endplates.

2. Kineflex-L

3. **activL** - third-generation device (FDA approved in 2015)

**INDICATIONS**

Even precise placement of the implant and excellent surgical technique will not overcome poor patient selection for the procedure!

- ideal candidate is early on the Kirkaldy–Willis degenerative timeline than a typical patient for fusion.

- failure of 6 mo of conservative therapy, symptomatic DDD at one level (L3-S1), skeletally mature patient, and no more than a grade I spondylolisthesis.

- best results are obtained in patients:
  - younger than 40 yrs
  - single-level disc degeneration
  - > 50% remaining disc height (at least > 4 mm).

- not contraindications: microdiscectomy, prior fusion with adjacent segment disease, and disc replacement below a previous long-segment fusion for scoliosis

N.B. 2-level replacements having higher revision rates!

**CONTRAINDICATIONS**

1) spondylolisthesis
2) spondylolisthesis
3) spinal fracture
4) posterior element disease such as a significant facet joint arthropathy or previous facet joint removal
5) central or lateral recess stenosis
6) extruded nuclear pulposus with a radiculopathy
7) nonmobile segment
8) osteoporosis
9) metal allergy (for metal-on-metal implants)
10) infection

**BIOMECHANICS**

- Pedicle screws traverses all three columns of vertebrae - can rigidly stabilize both ventral and dorsal aspects of spine.
- Pedicle also represents aspects of pedicle screws instrumentation) was introduced by Cotrel and Dubousset (Clin Orthop 227:10-23, 1986).
- Roy Boucher in 1959 was first to use pedicle screws.
- First descriptions of use of bone screws to obtain internal spinal fixation at time of fusion were by St. Louis and St. Paul in 1953.
- Each screw can increase forces 2.5 times more than the intact segment, and posteriorly located devices correlate with smaller facet loads.
- Efforts should be made to have a centralized device (ideally, an implant has maximum coverage over the endplates)
- It is important to select the appropriate height to preserve mobility and prevent over distraction of the facet, which can initiate the facets and nerve roots (traction on the dorsal ramus from over distraction are suspected sources of pain).

**COMPLICATIONS**

- Excessive facet distraction → facet joint degeneration and acquired spondylosis
- Pedicle fracture
- Device dislocations
- Vertebral body split fractures (specifically with devices that have keels)
- Development of sclerotic deformities and spontaneous fusion secondary to malpositioned implants.
- Endplate violation → 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 in total hip replacements
  - Serum ion levels 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
- Approach related, retrograde ejaculation (0.42% from injury to the superior hypogastric plexus), ureteral injury, and vascular injury (prior anterior approaches) → adhesions of the iliac vessels making retraction difficult thus increasing the risk of vascular injury.

**OUTCOMES**

- All current studies have generated a large body of evidence on the safety and efficacy of arthroplasty, and overall noninferiority to fusion.
- 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.
- Adjacent level disease: 2 randomized controlled trials showed that the difference in ASD etalon becomes more significant after 5-year follow-up and that with in 5 yr, the rates overall are similar.
- Index level facet joint degeneration was higher than other levels with ProDisc at an average of 53% more follow-up (rate of facet degeneration was significantly higher at the L5-S1 level than other levels).
- Resorption rates were higher in the 2-level arthrodesis group at 5-year follow-up vs. 2-level LDR.

**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.

**PEDICLE SCREWS & POSTEROLATERAL FUSION**

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

**BRIEF HISTORY**

- First descriptions of use of bone screws to obtain internal spinal fixation at time of fusion were by Tornney in 1943 and King in 1944.
- Bouchez in 1959 was first to use pedicle screws.
- Roy-Camille was first to use pedicle screws connected to dorsal plate (Clin Orthop 203:7-17, 1986).
- First system using both screws and hooks connecting them with rods or plates (i.e universal spinal instrumentation) was introduced by Cotrel and Dubousset (Clin Orthop 227:10-23, 1988).

**TECHNIQUE**

- Inserted via anterior approach (as for ALIF)
- XL TDR (NuVasive) and Triumph ( Globus Medical) - insertion techniques via lateral and posterior approaches, respectively – important for L2-4 levels!
- Dissection is performed and the endplates are prepared with a variety of curettes and Kerrison rongeurs.
- N.B: Too extensive of a preparation and thinning of the bony endplates can increase the risk of implant subsidence and migration or cause heterotopic ossification.
- Flat-end plates (type I, by Yu-Bertagnoli classification) make implantation easier: vs. end plates that exhibit a type II or type III morphology require, respectively, either a keel or a spike mode of endplate stabilization.
- Studies show anteriorly placed disc replacements load the facets 2.5 times more than the intact segment, and posteriorly situated devices correlated with smaller facet loads.
- Efforts should be made to have a centralized device! (ideally, an implant has maximum coverage over the endplates)
**DISADVANTAGES**

1. Causal or medial penetration of pedicle cortex can result in dural or neural injury (nerve root or spinal cord injury).
2. Screw placement can be checked electrophysiologically with direct stimulation of pedicle probe or screw producing electromyogram (EMG) response peripherally; if this response occurs below threshold expected for intact cortical bone, screws may be redirected or removed.
3. Extensive tissue dissection to expose entry points + to provide required lateral to medial orientation for optimal screw trajectory → costly lengthy operation, significant blood loss.
4. Rigid fixation can accelerate adjacent motion segment degeneration.

**INDICATIONS**

1. 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.

**Definition of instability, Principles of spondylolisthesis treatment**

**Indications for fusion (− predisposition for instability)**

1. Unstable on dynamic imaging (> 10 degrees of angulation or > 3.4 mm of relative motion)
2. facet-joint edema - joints are likely to be unstable, even if they appear stable on dynamic imaging
3. large disk
4. sagittally-oriented facets

Spondylolisthesis should not be confused with “instability” - there are obvious differences between spondylolisthesis patients:

a) large disk, fully fluid-filled facets, and dynamic instability → decompression with fusion.

b) collapsed disk with fixed spondylolisthesis → despite slip progress, a stable degenerative spondylolisthesis can be adequately treated with decompression alone, albeit with a 34% rate of revision surgery due to development of instability (vs. 14% or 22% if fusion was used).

**NASS Clinical Guidelines for Degenerative Lumbar Spondylolisthesis (2nd ed., 2014)**

There is the lack of uniform reference standards to define instability.

**Direct surgical decompression alone may be considered** for symptomatic stenosis associated with low grade degenerative lumbar spondylolisthesis when symptoms have been recalcitrant to a trial of medical/interventional treatment (grade of recommendation: C)

- insufficient evidence for or against indirect surgical decompression (e.g. X-STOP device),
- decompression with fusion is suggested to improve clinical outcomes compared with decompression alone or compared to medical/ interventional treatment alone (grade of recommendation: B)
- may be considered as a means to provide satisfactory long-term (> 4 yx) results (grade of recommendation: C).

- insufficient evidence for MULTILEVEL spondylolisthesis:
  - for symptomatic single-level degenerative spondylolisthesis that is low-grade (< 20%) and without lateral foraminal stenosis, decompression alone with preservation of midline structures provides equivalent outcomes when compared to surgical decompression with fusion (grade of recommendation: B).
  - addition of instrumentation is suggested to improve fusion rates but is not suggested to improve clinical outcomes for symptomatic low-grade stenosis and degenerative lumbar spondylolisthesis (grade of recommendation: B).
  - insufficient evidence for or against the use of spondylolisthesis reduction with fusion.
  - insufficient evidence for or against the use of autogenous bone graft or bone graft substitutes in posterolateral fusions.
  - conflicting evidence which technique leads to better outcomes - minimally invasive or open decompression and fusion, with or without instrumentation.
  - insufficient evidence for or against decompression with posterolateral fusion vs. 360° fusion (vs. for isthmic spondylolisthesis).

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.

N.B. flex-ex radiography has low accuracy (measurement errors of up to 4 mm)

- there is no clear evidence that radiologic instability is associated with pain and impaired function in the individual patient.

NASS Clinical Guidelines for Adult Isthmic Lumbar Spondylolisthesis (2014):

- Insufficient evidence for or against surgical treatment as compared to medical/ interventional approach.

Fusion is suggested to provide long term clinical improvements when symptoms have been recalcitrant to a trial of medical/interventional treatment (grade of recommendation: B).

- Insufficient evidence to indicate that fusion leads to improved long term outcomes as compared with a directed exercise program.

- Insufficient evidence to recommend one surgical fusion technique over another to improve long term outcomes.

- For grade 1 isthmic spondylolisthesis, the addition of instrumentation to posterolateral fusion may not improve outcomes (grade of recommendation: B).

- 360° fusion is recommended to provide higher radiographic fusion rates compared to posterolateral fusion; there is conflicting evidence whether 360° fusion provides better clinical outcomes than posterolateral fusion alone.

- ALIF may be considered as an option to indirectly decompress foramen stenosis (grade of recommendation: C).

- Insufficient evidence to make a recommendation regarding which prognostic factors have been associated with good or poor surgical outcomes.
**TECHNIQUE**

Using O-arm and navigation – see above >>

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

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 Rovie to fully expose transverse processes – at junction of pars and superior facet;  
- do not violate superior most facet (it is OK to cut lateral facet joint – i.e. facet process of vertebra involved in fusion); other facets can be denuded by dissecting on bone (as intention is to fuse them)
- dissect on lateral surface of facets
- ideally expose intertransverse membrane (careful – nerve root is beneath it)
- may excise (esp. with Dr. Mathern) paraspinal muscles to create space for bone grafts.
- transverse process only anatomical guide and does not contribute much to fusion.
- Dr. Cameron uses large Gelpi retractors!

**LAMINECTOMY**

- may not be indicated if operating for trauma with no canal stenosis.
- if burst fracture with retroplulsion – use Woodson / bone tamp to push retroplused 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 - threads 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!

**DUAL-HEADED SCREWS**

Globus CREO (modular screw):
Surgical procedures for spine surgery include thoracic and lumbar sacral operations. Medtronic DRMAS (5.5, 6.5, and 7.5 mm diameter) uses polymethylmethacrylate (PMMA) as implant material that conforms to contours of bone and is also used for cannulated screws.

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).

BlackArmor® implant material (Icotec-Medical Ag):

**CAUTION**
- artifact-free imaging enables for unobstructed post-operative diagnostic assessment and patient follow-up.
- easy planning of dosage for radiation treatment for more accurate dose delivery.
- reduced scattering and shielding of radiation beam protects adjacent tissue and allows...
Titanium screw and rod vs. BlackArmor® VADER® one screw and BlackArmor® rod:

**STARTING POINT**
- 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 → TP is caudal to pedicle in lower thoracic spine);
- neuronavigation or fluoroscopic guidance or direct vision and pedicle palpation via laminotomy is highly recommended.
- starting point is the highest (most cranial) at T6, then it migrates caudally when moving towards T12 and towards T1.
- trajectory angle medial-to-lateral gradually changes from 45 degrees at T1 to 0 degrees at T12.
- before placing screw, drill off medial-superior part of transverse processes because it will collide with screw head, then decorticate facet joints to see joint line.
- review anatomical landmarks on preop 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 upper facet joint “lip” to uncover pedicle starting point):
  - **red** starting point – for oblique screw trajectory
  - **green** starting point – for horizontal screw trajectory
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 use 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.
- At S1, entry point is inferior portion of lateral (S1) facet.
- 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 – most 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 intamctness of trajectory (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 breach) 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.
  - L4 has unique trajectory – very inward and very towards feet (almost 45 degrees towards floor).
  - thin thoracic pedicles – may use parapedicular trajectory (in-out-in).

A - pedicle width
B - transverse (coronal) pedicle angle
C - sagittal pedicle angle

**Transverse pedicle angle** (A), coramal angulation (how medial?) decreases as one descends caudally until lumbar region (from 0-15° at T1 to 5° at T12) → angle increases approximately 5 degress 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:
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 100% (on lateral fluoroscopy it seems as 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 (screw tip barely penetrates promontory).

**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 screw 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.)
**Tips** - in cancellous bone, tapping weakens implant-bone interface:
- Tapping decreases pullout resistance in osteoporotic bone.
- Do not tap vertebral body (cancellous bone) – tap only pedicle (ideally carves threads inside cortical bone but in practice pedicle screws rarely obtain cortical purchase within pedicle).
- For sacrum if planning bicortical, make sure, when approaching anterior (beak) cortex that tap is advancing (tap tip may hit hard cortex with increased resistance – if will keep spinning tap, it will strip!!!)
- If pedicle is very sclerotic, screw (normally, 1 mm larger diameter than tap) may break pedicle; H: tap such pedicle with same diameter as screw (but only for pedicle part; cancellous bone of vertebral body is still tapped with 1 mm less diameter tap).

**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 bone fusion mass.
- Multiangle screws are placed.
- Rods are used to connect pedicle screws.
- Place set screws (locking caps) with “stick” instrument then tighten with final tighter
  - Only finger tightening – prevents cross-threading
- Final tighten N.B. if operating for fracture – tighten central caps (over the fracture) last – minimizes stress of tightening on fractured segment
- Fluoroscopy see below
- Irrigate
- Pack posterolateral gutters with morcellized bone grafts (± wrapped into) BMP, Medtronic MagniFuse. See p. Op140 >>
- May place DuraGen on exposed dura – to make dural scar smooth.

**RODS**
- A) Cobalt-chromium – stiffer (use for spondylolisthesis, scoliosis reduction)
- B) Titanium
- C) PEER – flexible
- For long constructs, use rod cross link
- Do not bend rod in coronal plane!
- Instrumentations along junctions (a-c, C-C-T) tend to break rods - some people place 3 or even 5 rods.

**OUTRIGGER (QUAD) RODS**
- Added medially or laterally to main rods.
- Outrigger rods may capture screws that main rods may not due to severe deformity.
- Indications – poor bone quality, extensive osteotomies, rod extensions (to bridge old and new rod junction)
- Use side-to-side connectors on existing rods and dual-headed screws >>

**KICKSTAND ROD**
- A supplement to quad-rods in coronal deformity surgery:

**FIGURE 13-10**
- A screw tap (A). Note the tapered tip and the full-length flute. A self-tapping screw (B). Note the leading-edge flute that does not extend the length of the screw. Inset: An end-on view of the tip.
REDOING SPONDYLOLISTHESIS

- Check if there is mobility at the level.
- Use cobalt-chromium rod.
- Counter-lever technique: place and final tighten cap to lock rod into lower screw (rods sit pride – away from upper screw seat – distance depends on how much reduction one is expecting).
- Using tower, pull upper screw towards rod (do both sides simultaneously while checking on fluor – 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 fluor (XR only final – lateral and AP to document screw placement).

FUSSION REVISION / EXTENSION

Quad (outrigger) rods – see >>
Dual-headed screws – see >>

- Never stop at thoracolumbar junction (ie. L1) – extend fusion to T10-11; next level – T4, then C2.
- To extend previous fusion – depends on status of fusion below:
  a. Solid fusion – 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).
  b. Poor fusion – remove old rods (a pedicle screws – if suspicion for being loose) and place longer rods.

CONNECTIONS

Medtronic Domino
End-to-end – span 22 mm total (in lower thoracic, lumbar – enough space may place between screws; in upper thoracic – may need to skip one screw)
Side-to-side

Globus Revere Addition system – see >>

So called Z-rods or Rescue® Implants:

**In-Line Extension Clamp**
- Attaches to existing Global® REVERSE®, CREO®, REACOM®, or PROTECT® hardware
- Provides direct in-line coupling
- Integrated rod for stabilization
- Easier access to tighter areas (ideal for smaller stature patients)

**The Strength is in the Radius**

The offset coupling of the rod meets the clamp (the radius) is mechanically stronger than a typical tension connector

**Offset Extension Clamps**
- Attaches to existing REVERSE™, CREO®, REACOM®, or PROTECT® hardware
- Provides 7mm offset coupling
- Integrated rod for extension
COMPLICATIONS

- **screw breakage** - has been reported as high as 60%
- **fusion failure** – risk factors:
  1) multilevel fusion (esp. > 3 disc levels)
  2) allograft (vs. autograft), esp. for > 1 level fusion
  3) long-term smokers
  4) diabetes
  5) long-term steroid use

POSTOPERATIVE

Dr. Cameron – upright XR before patient leaves hospital.

DYNAMIC STABILIZATION

- “flexible fusion”, dynamic stabilization without arthrodesis.

**Dynexys (Zimmer Biomet)**

Dynexys® Dynamic Stabilization Product Family (LIS, Top-Loading, & Zimmer® DTO®)

- holds the segments in a more natural anatomic position using non-rigid materials
- preserves natural anatomical structures as much as possible
- constrains spinal motion (“internal splint”)

PELVIC FIXATION

**ILIAC SCREWS**

- 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 results in the most significant decrease in the strain on S1 screws).

N.B. goal of iliac screws is to offload S1 screws!
**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.

N.B. in long T3-L5 constructs add L4-L5 interbodies to prevent rod fractures

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; thighs are maintained in extension to maximize lordosis; 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.

- **posterior superior iliac spine** is identified by finger palpation → slightly oblique incision is then carried through the lumbosacral fascia over the posterior superior iliac spine; Cobb may be used to peel the soft tissue at the outer end plate of the iliac bone up to the sciatic notch, to ensure that the pathway of the screw is superior to the notch.

**Galveston technique**

- **start at posterior superior iliac spine (PSIS)** – bite with rongeur 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** (aiming 35 degrees caudad) – 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.
- bone graft is applied after bone decortications.

**SACRAL-ALAR-ILIAC (SAI) SCREW, S. S2-ILIAC SCREWS**

Starting point – lateral border, midway between S1 and S2 dorsal foramena:
Perioperative considerations:

- feel some resistance while crossing SI joint.

* Screw sizes:
  - At least 90 mm length
  - Diameter 8-10 mm

** Iliosacral Screws **

- **starting point** is scored at the outer aspect of the ilium, just distal to L5-S1 facet.
- **second entry point** is marked 10 mm anterior to the posterior superior iliac spine at the posterior gluteal line.
- **screw trajectory** is toward the L5-S1 facet joint (same trajectory as for a medially placed S1 pedicle screw); guidewire is passed through the iliac wing toward the sacrum to the body of S1; connector is then threaded onto the guidewire as it passes the ilium; screw path is drilled over the guidewire.
- **typical screw length** is 60-80 mm.

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=8CKKSqDFt4U
Medtronic - CD HORIZON SEXTANT System >>

Prerequisites:
- pedicles should be well seen on AP fluoroscopy

- 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 TRAJECTORY)**
4 points of contact:

- **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) – some experts believe it is better for elderly osteoporotic spine (with age, vertebral body bone marrow becomes porotic, but pedicle & periarticular bone becomes sclerotic).
  - bone density heat map:
    - best for L2-5
    - sizes: 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 untouched)
      - screw insertion through medial starting point enables less tissue dissection and retraction for reduced muscle disruption – expose as for laminectomy
      - direction away from neural elements provides safety and lower incidence of postoperative radiculitis.

- **Improved bone purchase vs. conventional technique:**
  - Reduced screw loosening >69%\(^{11}\)
  - Significantly increase in pull-out resistance >30%\(^{21}\)
  - Strong anteroposterior spondylolisthesis correction, -83% slope\(^{31}\)

- **Potential for a lower adjacent segment disease (ASD) vs. conventional technique:**
  UP TO -71%

- **Less coagulation near blood vessels / dorsal branch = less damage to the adjacent (cranial) segment**
• starting point - junction of center of superior articular process and 1 mm inferior to inferior border of transverse process.

N.B. best is to use AP fluoro or CT-based navigation – starting point is at 5 o'clock for L side (and 7 o'clock for R side); therefore, important to do AP fluoro 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 medial-lateral line of starting point.
  - some experts say that tapping is a must (triple tapping – e.g. with 4 mm then 5 mm then 6 mm taps).

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 spondylolisthesis
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

for long fusions (thoracic-sacrum) always add L(4/5)-S1 interbodies! (Dr. Lenke)

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 Love nerve root retractor
  1) increasing sizes of Extractors (starting at 6-8 mm) under XR control (should reach anterior annulus)

N.B. make trajectory holes before laminectomy; then laminectomy, PLIF, etc; place screws at the end.
• 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 – **apophyseal ring** ("tin can" model).
WAVE D (MEDTRONIC)

Brochures >>

2975 USD

- 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
- radiolucent for postoperative diagnosis
- audible click sound made when device is fully expanded

6° Options

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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.

**ELEVATE (MEDTRONIC)**

Brochures >>

3737 USD

**TLIF (TRANSFORAMINAL LUMBAR INTERBODY FUSION)**

http://www.neurosurgicalatlas.com/grand-rounds/transforaminal-lumbar-interbody-fusion-tlif

- first described by Harms et al in 1982 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 crests); H: PLIF

**Kambins Triangle**

- graft placed obliquely or, more recently, curved graft rotated into position.
- removal of pars interarticularis, lamina, and inferior and superior articular processes.
radical diskectomy 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 (MEDTRONIC)
Brochures >>
WAVE O Spinal System Animation >>

CONCORDE BULLET (DEPUY)
CONCORDE Bullet >>
TLIF Surgical Technique >>
TLIF >>

ROB-T (LDR)

**MIS-TLIF**

• in the early 2000s, Foley et al introduced a minimally invasive (MIS) modification of the TLIF surgical technique.
• interbody fusion is supplemented with posterolateral instrumentation.
• success of MIS-TLIF relies on a solid interbody fusion since a posterolateral fusion is difficult to achieve given the limited exposure - MIS-TLIF procedures often are done with rhBMP.

Entry point – intersection between disc space and facet joint line; incision length ≈ 1 inch

Insert tubular dilators:

Drill facet joint (save bone shavings for grafting)
SPLINAL SURGERY – THORACIC & LUMBOSACRAL

Op.220 (72)

OUTCOMES
• MIS TLIF has similar fusion rates and complication rates compared to open TLIF surgery - regardless of graft material used (utilization of autologous local bone in combination with both bone extender and rhBMP showed the highest fusion rate with a 98.8% at 12-mo follow-up.
  isolated use of local bone resulted in the lowest fusion rate of 91.8% at 12-mo follow up. The highest fusion rate without the use of BMP was seen with autologous local bone plus bone extender - 93.1%.

ALIF (ANTERIOR LUMBAR INTERBODY FUSION)

Rationale:
Weight-bearing distribution
  o 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%
  o with aging and degenerative cascade, including reducing disk height, weight-bearing distribution shifts to posterior column.
  o 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) neurological injury
5) abdominal muscle damage
6) mobilization of sympathetic plexus can result in high rate of localized lower extremity sympathetic dysfunction - asymmetric feeling of “cold leg” or “warm leg.”

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
DETAILED

- For lower disk levels (L4-5, L5-S1), the patient is supine.
- An inflatable bladder is placed under the small of the back to increase or decrease lordosis as necessary.
- A cell saver is in place to handle large quantities of blood loss from vascular injury.
- A pulse oximeter is placed on each lower extremity (e.g., each big toe) to monitor for ischemia during vessel manipulation and retraction.
- The correct disk space is localized using fluoroscopy, and the skin is marked appropriately.
- Incisions - midline, paramedian, Pfannenstiel.
- Approach:
  a) Transperitoneal approach - may be used to access L4-5 and L5-S1.
  b) Muscle-sparing retroperitoneal approach is 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 the 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, illolumbar 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.

discectomy ("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 interpace; 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.

Posterior enforcement
- supplemental posterior percutaneous pedicle screws lead to comparable clinical outcomes to those undergoing open posterior instrumentation.

addition of fusion levels (cephalad, caudal or iliac) in the setting of a high grade isthmic spondylolisthesis in adult patients improve outcomes.

CAGES
ROI-A ALIF CAGE (LDR)

AxiaLIF

growing evidence of complications and biomechanical failures as well as the publishing of revision strategies for failed AxiaLIF → the technique ultimately fell into disuse.
LATERAL APPROACH INTERBODY FUSION

- always approach from left side (regardless of scoliosis curve).

APPROACHES

A. Anterior-to-psoas (ATP), e.g. OLIF – mandatory for L4-5 level (trans-psoas may cause severe femoral nerve injury and “high-riding” ilium is often in a way for LLIF), optional for L3-4
B. Trans-psoas, e.g. DLIF, LLIF – acceptable for L1-3 levels (lumbosacral plexus is not well formed yet); some say it has higher risk of plexus injuries others say it is the same.

- check for major vessel position on preop MRI.

NAVIGATED

It can be done with modern neuronavigation – avoids fluoro exposure to surgeon.

- start with the level furthest from tracking frame – to maintain accuracy.
- reference frame pin in ASIS*; start at the farthest level from reference frame.
- *if frame may get into way, place into PSIS

- one O-arm “spin” can include 4 levels (e.g. L1-5).
- use navigated pointer to project skin incision, then to traverse psoas.

Multi-function tool:
1. Navigation pointer
2. Nerve stimulator
3. Initial retractor dilator
• navigated Cobb for contralateral release:

• navigated cage trials:

• can do OLIF as well:

**COMPLICATIONS**

**Subsidence**
- risk if graft is oversized.
- Globus expandable cage claims less subsidence
Plexus injury
- highest risk at L3-5 levels, thus, prefer to use OLIF
- monitor patients with stim probe (directional stim probe) + motor evoked potentials
- avoid breaking the table – flat Jackson table, just place a roll under the patient
N.B. experts avoid breaking the table as it stretches lumbosacral plexus (more susceptibility to retraction injury)
- avoid fixed (locked to vertebra) retractors

DLIF (DIRECT LATERAL INTERBODY FUSION)
http://www.youtube.com/watch?v=3C2fcmDqgfc
http://www.youtube.com/watch?v=7juZ2kl6cfw
DLIF procedure (Bangkok Medical Journal - Sept 2012) >>
http://www.spineuniverse.com/professional/research/treatment/surgical/procedure-description-direct-lateral-transpsoas-lumbar

- usually as two stage procedure:
  first day – DLIF → bed rest with head of the bed up to 45 degrees
  second day – posterolateral fusion
dissection and “unlocking” of facets by Smith-Peterson osteotomies, so lets to
  distract disc space, may be done on first day – practically only if it is revision
  surgery and need to remove posterior old hardware
- NIM-SPINE free-running EMG monitoring needle electrodes placed into bilateral leg muscles –
  see above
- 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)
Others do in prone position (if DLIF fails, straight proceed to posterior fusion).

— 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)

N.B. always approach from left side (right side – liver and vena cava)

For L.2-1 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 flous field) - lateral disc entry point is localized, guidewire needle advanced through probe lumen into disc space and increasing diameter DLF dilators are inserted.

— if doing open approach, after disc 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 DLF 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 lumbarosacral plexus nerves are trapped (this step is not needed for open approach).

— there are directional stimulation probes that help to determine where plexus is.

— goal is to keep plexus posterior

— docking screw is placed through retractor blade hole (check using NIM-PAK Needle that spot too) – place in blade which does not need more movement (so when opening retractor, the other blade will move).

— resect with Knife / blunt just enough psoas for discectomy exposing disc annulus.

— annulotomy using a 15-blade scalpel – discectomy with pituitary rongeurs and curettes (others use Box Cutter, Kittner)

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.

— 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 disc 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)

— too big graft may damage endplate; even if endplate is not damaged, too big graft will subside

— N.B. discectomy just to create channel for graft cage and no more.

— 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 interbody graft – it is lordotic so has “ANTERO” edge marking

— retractor is removed.

— closure without drain; suture muscle fascia together.

— posture – bed rest (may sit up to 45 degrees) until posterolateral fusion is done (other experts do not limit activity and even discharge patient home till the second stage); Dr. Mathews likes postop thoracolumbar CT (after second stage, activity as tolerated, scoliosis XR during follow up).

GRAFTS / CAGES

GLOVES

Calibrated testing shows that expandable spaces help preserve minute spaces during implant insertion, with 50% greater resistance to subsidence compared to static spaces. Additionally, repeated truing with static spaces may lead to more uniform endplate damage, resulting in less indirect decompression and may postpone the operative level to subsidence.1

Substance has been reported in up to 24% of clinical cases in which static spaces are used, wherein C causes proximal migration.1

XLIF (eXtreme Lateral Interbody Fusion)

— same as DLF just by different company (NuVasive®)

AVENUE L (LDR)

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 spondyolisthesis.

30% GREATER RESISTANCE TO SUBSIDENCE

WITH THE GLOBUS EXPANDABLE PLATFORM

EDTRONIC PEEK cage filled with BMP and wrapped with silk tie to keep BMP in place}
- uses much larger grafts and may achieve impressive lordosis. N.B. Leave ALL intact to prevent graft migration (some experts recommend to cut some ALL fibers – but only under direct vision to avoid vascular injury; reminder of ALL fibers will stretch naturally).
- there grafts also for scoliosis correction.

**OLIF (Oblique Lumbar Interbody Fusion), ATP (Anterior To Psoas)**

https://www.youtube.com/watch?v=XhsOa23fpmk&feature=youtu.be&list=PLyptnEaqO5f6_ue9U_io_UfYy1Ro9BqjQ

Avoids psoas muscle – less potential for lumbar plexus injury.
Osteotomies

Spinal osteotomies are generally needed when the deformity is not correctable with the use of instrumentation alone or when facet or ligament releases are insufficient to gain enough flexibility.

- try to avoid osteotomies if you can

Classification #1


In order of increasing complexity:

1. Smith-Petersen osteotomy (SPO) - posterior column osteotomy in which the posterior ligaments (supraspinous, intraspinous ligaments and ligamentum flavum) and the facet joints (inferior facets of the upper vertebra + superior facets of the inferior vertebra).
   - correction is performed through the disc space - mobile anterior disc is essential.
   - both coronal and sagittal correction can be achieved.
   - best in patients with +6-8 cm C7 plumbline.
The spinous process and facets of the upper vertebra are removed in addition to the superior facets of the inferior vertebra; areas to be removed are painted in red.

IAP, inferior articular process of the superior vertebra; SP, spinous process; SAP, superior articular process of the inferior vertebra.

- In 1945, Smith-Petersen et al. reported the first spinal osteotomy.
- Most studies reported the correction in ankylosing spondylitis patients with osteoarthritis.
- Ponte described similar bone resection and mobility through an open disc space.
Ponte/Smith-Peterson Osteotomy

- SPO allows for 10° per level
- Remove supraspinous, intraspinous, and ligamentum flavum with facetectomy to produce a posterior release.
- Ensure exiting nerves are decompressed
- Posterior compression of the osteotomy brings about kyphosis correction
Pedicle subtraction osteotomy (PSO) - posterior elements and pedicles are removed.

- then a triangular wedge through the pedicles is removed:
  a) de-cancellation technique ("eggshell" technique - 1985 Heining et al)
  b) osteotomy (1985 first by Thomsen et al)
- then posterior spine is shortened using the anterior cortex as a hinge (i.e. may be used in patients both with open or fused disc space).
- most useful if done at the apex of the deformity.
- although originally defined in the lumbar spine, the technique can be used in all regions of the spine above or below the conus including cervical and thoracic areas.
- ideal candidates are patients with a severe sagittal imbalance (SVA > 12 cm)
- single level osteotomy can produce 30° - 40° of correction.
- single level osteotomy at L3 may restore global sagittal balance by an average of 9 cm with an upper limit of 19 cm (if more correction is needed, the osteotomy level can be changed to L4, or in some cases a two-level osteotomy may be planned)
- up to 2 litres of blood may be lost during (Cho et al compared three levels of SPO with single-level PSO in a series of 71 patients, and found that single-level PSO caused nearly twice as much bleeding than three levels of SPO).
- incidence of neurological injury is 3.6-12%.
- in order to avoid pseudarthrosis (rate up to 29%) interbody arthrodesis above and below the osteotomy can be carried out (either TLIF or ALIF)
- laminectomy sites may be closed with a cortical strut allograft both to increase mid-line fusion and to prevent any dural complications if revision surgery is needed.

Technique:
- instrumentation should be done before any osteotomy attempt - standard pedicle screws are used at least three levels above and below the level of osteotomy.
- laminectomy should be one level above and below the planned osteotomy level - to prevent buckling of the spinal cord;
- buckling becomes a more severe problem, especially in cases where a previous laminectomy has been done - peridural fibrosis prevents the gliding movement of the dura as the osteotomy gap is closed.
- in addition to laminectomy, laminar undercutting should be done to widen the spinal canal from within to prevent infolding of ligamentum flavum and bony surfaces.
- all or half of the transverse processes should be removed to gain access to the lateral aspect of the vertebral bodies.
- half of the inferior articular process of the upper vertebra and half of the superior articular process of the lower vertebra can be removed to help create a single foramen to accommodate two nerve roots after completion of the procedure.
- after defining the foramen above and below the pedicles to be excised, the nerve roots with their perineural fat tissue should be protected with a dural retractor.
- pedicles on both sides can be removed using an osteotome or a burr.
- body can then be removed in a wedge-shaped fashion either using the "eggshell" technique or using an osteotome.
- transient rod is placed to prevent sudden collapsing of the spine during these maneuvers (classically, a unilateral rod is used; however, in severe angular kyphotic or kyphoscoliotic deformities, bilateral rods are recommended to prevent spinal subluxation).
- posterior cortex is finally removed before closure of the osteotomy and after the osteotomy is completed including the lateral walls of the vertebral body.
- nuts holding the transient rod are loosened and the osteotomy gap is closed by bending the operating table opposite the deformity.
- rods should be angulated acutely at the level of osteotomy and should sit freely in the grooves of the screw heads. Otherwise, when there is a fused spine above and below the osteotomy line, as in ankylosing spondylitis or previous fusion cases, as the rod is not as acutely angulated as the spine, it does not sit into the grooves and pulls the screws just above and below the osteotomy line and causes loss of correction.

a) L3 pedicle subtraction osteotomy plan from the lateral view. Note that a wedge reaching to, but not crossing, the anterior cortex is to be removed. The parts of the laminae painted in red may be preserved if they do not interfere with closure of the osteotomy gap.

b) While planning an osteotomy, laminectomy of the upper and lower vertebrae should be done to prevent buckling of the spinal cord after correction of the deformity. Again, the area painted in red may not be removed if enough decompression is done and these structures do not prevent closure of the osteotomy. SP, spinous process; L, lamina; TP, transverse process; VB, vertebral body; P, pedicle.

- Pedicle subtraction osteotomy was first described by Thomsen in 1985
- This is an extension of the SPO, and involves resection of the posterior elements and vertebral body
- Particularly useful when anterior approach is not possible
• Set up
• Neuromonitoring
• Measure pre-op, must include pelvic parameters
  • Plan, plan, plan.
• Expect blood loss:
  • Cell saver, coagulant (TXA, Amicar), blood products
• Typically performed in the lumbar spine
  • Larger correction
  • Can shorten cauda
• Less often in cervical and thoracic spine
• Bony resection determines final alignment

Exposure
• Careful with blood loss
• TXA is MUST
• Place screws first
• If excessive bleeding (>2L, before PSO, plan on staging)
• Instrumentation removal etc…
• Dura will buckle
• Verify nerves are free in new foramen
• Feel under the dura
• Check signals
  • Stimulate nerves?

• Neuromonitoring is a must!
• Be careful with shortening the spinal column
  • Duraplasty
  • May want cage in osteoporosis
• Translation causes paralysis!
  • Less of an issue if PSO is in lumbar spine
  • Temporary rods
• Pre-operative planning is the key
  • measure twice and cut once.

Quad-rod technique – two short rods for PSO level, long rods for long support.
3. **Bone-disc-bone osteotomy (BDBO)** - osteotomy done above and below a disc level (resection includes the disc with its adjacent end-plate(s))
   - correction rates 35° - 60°
   - main indications are deformities with the disc space as the apex and severe sagittal plane deformities.
   - etiology must be kept in mind when selecting the type of osteotomy (e.g. BDBO may be impossible in ankylosing spondylitis when the anterior annulus is ossified).

**Technique**

- pedicle screws are placed at least two levels below and three levels above the planned osteotomy level, followed by wide laminectomies of the vertebrae above and below the disc space planned to be resected.
- wedge osteotomy including the disc end-plate(s) with or without the pedicle(s) is then performed and the wedge including the disc is removed.
- titanium mesh cage can be placed anteriorly if lengthening of the anterior column is desired.
- osteotomy site is closed bone-to-bone to decrease the risk of pseudoarthrosis.

a) Spine from the lateral view. Upper end-plate of T10 and lower end-plate of T9 were included in the area to be resected. Resection should also include the disc space.

b) Spine from the posterior view. Lower facets and spinous process of the upper vertebra and upper facets of the lower vertebra should be removed to gain access to the area to be resected. SP, spinous process; L, lamina; IF, inferior facet; SF, superior facet; PIC, postero-inferior corner; PSC, posterosuperior corner; D, disc.
4. **Vertebral column resection (VCR):**
   a) circumferential
   b) posterior only (PVCR)
   - indicated for rigid multi-planar deformities, sharp angulated deformities, hemi-vertebra resections, resectable spinal tumours, post-traumatic deformities and spondylolisthesis (main indication for a VCR is fixed coronal plane deformity).
   - if you don’t start VCR by 1 pm, then you should stage the procedure.

a) Lateral view. Lower facets of the upper and upper facets of the lower vertebrae should be removed to allow removal of the laminae and pedicles of the vertebra to be resected. Discs should also be resected and this should be followed by end-plate preparation for a successful fusion.

b) AP view of the anatomical structures to be resected during a PVCR operation. IAP, inferior articular process; D, disc; SP, spinous process; SAP, superior articular process; VB, vertebral body; L, lamina.
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Classification #2

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 Modifications</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>Resection of the inferior facet and joint capsule at a given spinal level, including the lamina, and the spinous processes may also be resected</td>
<td>A/P 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 column with pedicles</td>
<td>P (posterior approach only)</td>
</tr>
<tr>
<td>4</td>
<td>Pedicle/partial body</td>
<td>Complete resection of the posterior vertebral body and a portion of the posterior vertebral column with pedicles, and inclusion resection of at least a portion of 1 vertebral body adjacent to the adjacent transverse process</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Complete vertebrae and discs</td>
<td>Complete resection of a vertebra and both adjacent discs: Isch resection in the sacral region</td>
<td>P (posterior approach only)</td>
</tr>
<tr>
<td>6</td>
<td>Multiple vertebrae and discs</td>
<td>Complete resection of a vertebra and both adjacent discs: Isch resection in the lumbosacral region</td>
<td>P (posterior approach only)</td>
</tr>
</tbody>
</table>
ostotomies cause large blood loss.
best level for osteotomies is where normally lordosis should be – at L3, 4, 5.
patient is placed prone on Jackson table – it must be possible to provide extension of spine and hips to close osteotomy sites.
rods are placed, compression and cantilever manipulation helps close osteotomy sites.

GRADE 1 OSTEOTOMY (PARTIAL FACET JOINT RESSECTION, S. SMITH-PETERSON OSTEOTOMY, OPENING WEDGE 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 RESSECTION)
- 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 ligamentum 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.

- 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:

**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.
  - 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).

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).

**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-T12 vertebral resection by using posterior approach, classified 6P.