Cervical Spine Surgery (TECHNIQUES)

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CHOICE OF APPROACH

Surgery must address two PATHOPHYSIOLOGIC COMPONENTS:

Static – surgical decompression
Dynamic – surgical fusion

DECOMPRESS + FUSE

- when choosing which levels to operate, always attempt to correct kyphosis (← puts lots of stress on cervical facets).
- ventral fusion surgery has been shown to yield better quality of life (QOL) outcomes than dorsal fusion surgery.
- when choosing approach, aim to leave **AP canal diameter ≥ 12 mm**.
- complication rates (for rates of specific complications see specific approaches – anterior or posterior).
  a) **ventral fusion surgery** (11-13.6%) – *dysphagia*, esophageal injury, cardiopulmonary events, hoarseness (*n. laryngeus recurrent injury* due to traction), vertebral artery injury.
  b) **dorsal fusion surgery** (16.4-19%) - significant postoperative muscular pain, nerve (C5) palsies, pulmonary complications, hematomas, higher operative blood loss, wound infection.

N.B. complication rates and costs are significantly greater for **dorsal** fusion compared with ventral fusion!

Posterior approach – for ***multilevel*** disease:

1. **Laminectomy ± fusion**
   - laminectomy is fastest way to decompress poor surgical candidates.
   - allows *foraminotomy* (root compression due to osteophytes).
   - not suitable in pronounced cervical *kyphosis* (kyphosis may be exaggerated by doing MRI with pillow under occiput).
   - *wide laminectomy* (over at least 3-5 levels) – standard for *diffuse spinal stenosis*; may be complicated in later years by:
     1) *swan neck deformity* owing to loss of posterior support;
     2) *increased cervical mobility* → increased risk of further spondylosis progression.
        H: **lateral mass fusion**.
        N.B. posterior approach is limited to patients who have either neutral or lordotic alignment!
2. **Laminoplasty** – preserves posterior tension band but still 40% patients need fusion; more suitable for young patients with oncologic indications.

Fusion is preferred in patients with neck pain!

Anterior approach – for more ***focal*** disease with ***less neurological*** deficits:

1. **Discectomy with interbody fusion (ACDF)** – especially suitable for vertebral osteophytic ridges or chronic disc herniations; best decompression for radiculopathies. see p. Spin11 >>
2. **Corpectomy with graft**:
   a) **autograft** (iliac crest) – very rapid fusion (advantageous in *trauma* cases)
   b) **allograft** – no postoperative iliac pain (advantageous in *spondylosis* cases)

- minimal postoperative pain because the only muscle cut is platysma (patients tolerate anterior approach much better than posterior; plus, posterior approach caries higher rate of infection); other muscles are split apart (don't hesitate spilt muscles higher and lower → less traction force required → less postoperative dysphagia and pain).

Fusion rates for 2-level anterior operations (i.e. 2 disc spaces) (***Class III***):

2-level ACDF with anterior plate = 1-level corpectomy with plate > 1-level corpectomy without plate* > 2-level ACDF without plate

* however, the graft extrusion rate is higher for corpectomy than ACDF

Ventral surgery is preferable to posterior surgery in cervical kyphosis > 13° or poor cervical sagittal alignment

Techniques to increase lordosis via ACDF

Taller cages

Bend plate (more lordotic)

360° (circumferential) approach – combination of **anterior** and **posterior** approaches.

Global sagittal plane deformity may go unnoticed if only regional spinal imaging is assessed → unfavorable outcomes.

- maintain a low threshold for obtaining LCRs (long casette standing XR, s. scoliosis film, s. spine survey film) as part of preoperative evaluation for cervical spine pathology – may significantly influence surgical decision-making.

TRIALS

Cervical Spondylotic Myelopathy Surgical (CSM-S) trial

Zoher Ghogawala et al. Effect of Ventral vs Dorsal Spinal Surgery on Patient-Reported Physical Functioning in Patients With Cervical Spondylotic Myelopathy A Randomized Clinical Trial. JAMA. 2021;325(10):942-951. doi:10.1001/jama.2021.1233

- 163 patients 45-80 years with multilevel (≥ 2 levels) cervical spondylotic myelopathy.
- 15 large North American hospitals.
- randomized to undergo:
  a) ventral surgery (ACDF) (n = 63)
  b) dorsal surgery (n = 100) – PCF or laminoplasty at surgeon's discretion (i.e. nonrandomized)
- primary outcome - 1-year change in the Short Form 36 physical component summary (SF-36 PCS) score (range, 0 [worst] to 100 [best]; minimum clinically important difference = 5).
  SF-36 PCS mean improvement was not significantly different between ventral surgery (5.9 points) and dorsal surgery (6.2 points) (estimated mean difference, 0.3; 95%CI, −2.6 to 3.1; P = .86).
- secondary outcomes - 1-year change in mJOA score, work status, sagittal vertical axis, health resource utilization, and 1-2-year changes in the Neck Disability Index and the EuroQol 5 Dimensions score.
  No significant difference between ventral surgery and dorsal surgery
- rates of complications in ventral and dorsal surgery groups, respectively, were 48% vs 24% (difference, 24%; 95%CI, 8.7%-38.5%; P = .002) and included:
  dysphagia (41% vs 0%)
  new neurological deficit (2% vs 9%)
  reoperations (6% vs 4%)
  30-day readmissions (0% vs 7%).
  - there was no significant difference in the risk of **major complications** (22.2% [ventral] vs 17.0%[dorsal]; difference, 5.2%; 95%CI, −7.4%to 17.9%; P = .41),
  - ventral surgery was associated with greater risk of **minor complications** (27.0% vs 7.0%; difference, 20.0%; 95%CI, 7.9%-32.0%; P < .001), of which dysphagia was the most prevalent.

N.B. **laminoplasty** was associated (at 1 year and 2 years) with significantly better patient-reported functioning (SF-36 PCS), significantly fewer complications, and significantly less health service and resource utilization compared with ventral fusion and dorsal fusion.

MOTION SEGMENTS

	Bifid Spinous Process	Transverse Foramen / Vert?	Flexion/ Extension	Rotation	Lateral Bend
Occiput-C1			50	4	8
C1 (Atlas)	None	Yes / Yes	10	50	0
C2 (Axis)	Yes	Yes / Yes			
C3	Yes	Yes / Yes	50 (10/level)	50 (10/level)	60 (12/level)
C4	Yes	Yes / Yes			
C5	Yes	Yes / Yes			
C6	Yes	Yes / Yes			
C7 (VP)	No (95%)	Yes / No			
Total Motion			**110**	**100**	**68**

Motion contribution
Flexion-extension: 50% at occiput-C1
Rotation: 50% at C1-2
Lateral bend: 90% at C3-7

ADJACENT LEVEL DISEASE / ADJACENT SEGMENT DISEASE

- after ACDF, estimated to develop at 3% / year for the next 10 years (operation rate for symptomatic ASD after ACDF at 10 years is 5-20%)
- strategies to decrease the risk – hybrid constructs (e.g. ACDF + TDR)

HARDWARE

- some of the instrumentation systems are currently categorized as class III devices by FDA.
- most internal fixation devices are classified as **temporary devices** - intended to be implanted for > 30 days but *not intended to be implanted permanently*:

- Orthopedic Surgical Manufacturer's Association recommends that, whenever possible and practical, bone fixation devices should be removed when their service as an aid to healing is completed.
- general clinical opinion is that cervical instrumentation that leads to successful fusion without complication does not need to be removed.
- each patient should receive preoperative counseling concerning this difference of opinion.
- when patients understand the risks of repeat surgery yet request removal of hardware after bone fusion has occurred, every attempt should be made to comply with their wishes.

AIRPORT

All spinal implants are undetectable by screening airport scanners except hand-held "wands" (wands can detect all posterior hardware and anterior cervical hardware).

INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING

See p. D25 >> (including protocol for intraop injury, new deficits in PACU)

Practice guideline: Intraoperative electrophysiologic monitoring during surgery for cervical spondylotic myelopathy or radiculopathy
Use of intra-op EP monitoring during routine surgery for cervical myelopathy/radiculopathy is not recommended as an indication to alter the surgical plan or administer steroids since this paradigm has not been observed to reduce the incidence of neurologic injury (***Level D Class III***)

BONE GRAFTS, OSTEOGENESIS, OSTEOCONDUCTION, OSTEOINDUCTION

A) **autografts** - gold standard and associated with the highest rates of fusion.
- have all three features:
  1) **osteogenesis** – native capacity to form bone by osteoblasts living in marrow under the influence of many factors such as bone morphogenetic protein (BMP).
  2) **osteoinduction** – capacity to induce bone formation by osteoblasts; BMP is osteoinducing agent.
  3) **osteoconduction** – physical property present in structural composition of bone graft that acts as a scaffold for new bone to form.
- disadvantages: pain, hematoma, cosmetic deformity, and infection at donor site.
- sites for harvesting:
  1) **local** – drilled osteophytes, uncovertebral joints, manubrium sterni, decompression bone (e.g. laminae - carefully separating all soft tissues and grinding it into a heavy paste)
  2) **iliac crest*** - strongest structural support (stronger than rib)
  3) **posterior ribs*** - somewhat flexible and can be contoured
  4) skull – for young kids
  5) fibula

  *preferred sources of tricortical, bicortical, or cancellous chips; rate of arthrodesis for grafts from ribs or iliac crest is the same, but the rate of complications associated with harvesting a rib is lower.

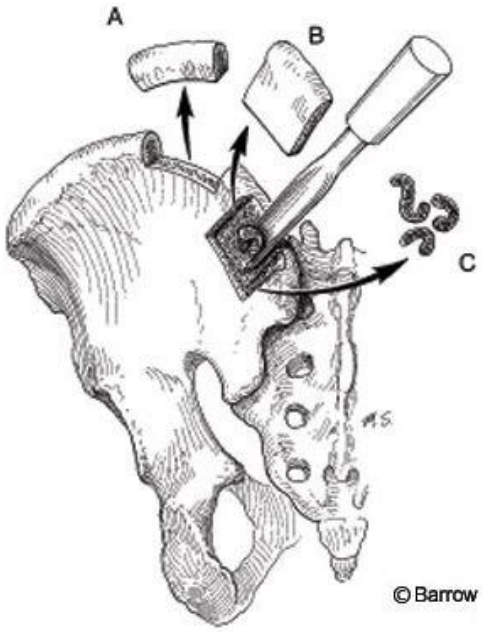
B) **allografts** - revascularize more slowly; bone fusion is slower; and the risk of bone resorption, infection, or rejection is higher.
- allografts act purely as **osteoconductive** material.

- allografts *lack osteogenesis* capacity because the marrow is absent! H: add patient's own marrow aspirate.
- allografts *lack osteoinduction* capacity! H: add BMP.

- **cortical bone** is the strongest form of graft and is typically used when strong structural support is required.
  - graft must be carpentered to maximize bony contact between the surfaces needing to be fused.
    e.g. notch in the bone is often fashioned to allow the graft to "sit" on the spinous process of C2
  - structural grafts should be ***augmented by wiring*** to ensure the bone is under compression.
- **cancellous bone** is quite weak and should only be used in cases that do not require the graft to withstand compressive forces.
  - compacting bone grafts (vs. placing them loosely) in spine fusions give better fusion rates.
- when neither autographs nor cadaveric allograft can be used, **methyl methacrylate** is an option - immediate stabilizing method but *does not lead to bony fusion* (i.e. should be reserved for patients with a short life expectancy).

ILIAC CREST HARVESTING

a) **posterior iliac crest** - source of tricortical grafts, cortical-cancellous plates, cancellous bone strips, or cortical matchstick grafts:

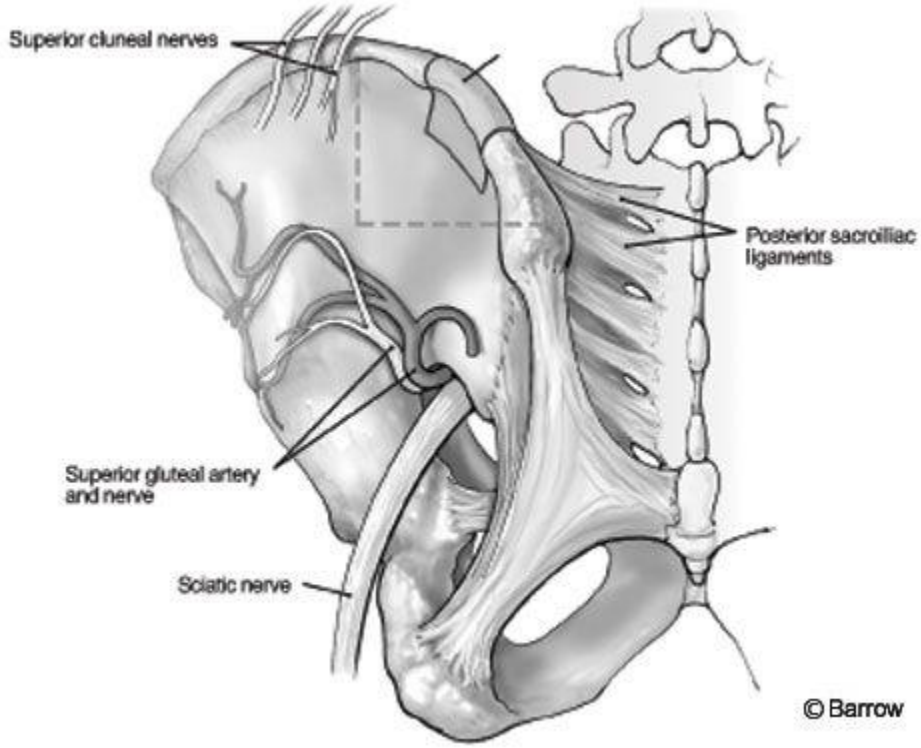


B – unicrestal cortico-cancellous plate may be ideal

- curved skin **incision** beginning at PSIS and extending superolaterally (just above the crest – allows easier dissection on the inner surface of crest) – maximum 8 cm from PSIS - superior cluneal nerves, which course over the crest.
- dissection is carried out through the fascia and opened over the iliac crest.
- dissection is continued subperiosteally to minimize damage to the gluteal artery, sciatic nerve, ureter, and ilioinguinal nerve.
- graft is obtained using osteotomes and bone curettes.
  - do not harvest > 8 cm from iliac crest - to avoid damaging the superior cluneal nerves.
  - do not harvest too medially - can place the sciatic notch and the sacroiliac joint in danger.
- incision is closed in layers.

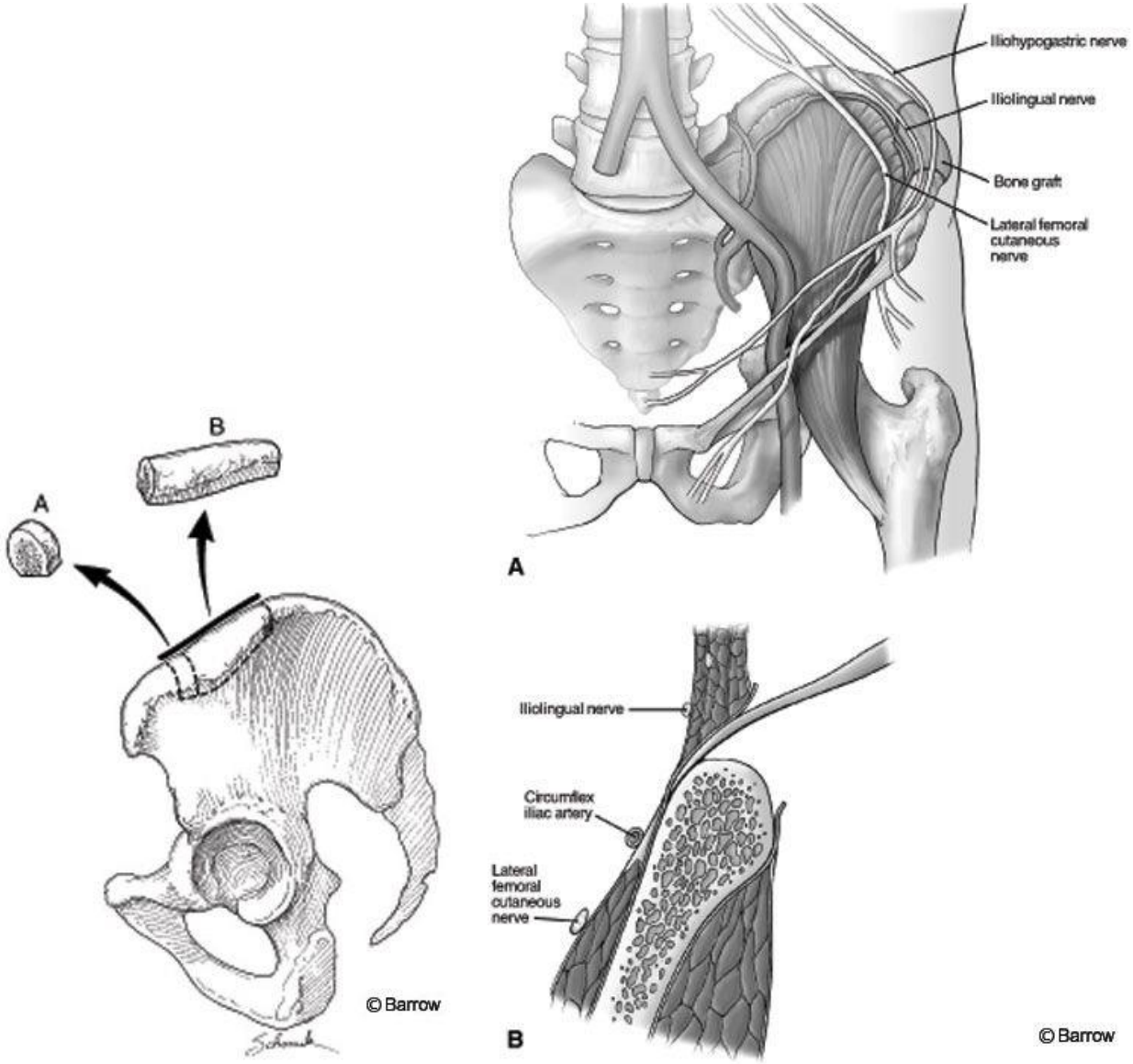
- injury to superior gluteal artery is reported (during exposure with inadvertent placement of a sharp self-retaining retractor into the sciatic notch); H: if vessel is encountered and identified, it should be ligated - usually not possible due to vessel retraction (then operative site should be packed → angiography suite for embolization; primary operation may be completed the following day).

Sacroiliac ligaments (medially), sciatic nerve (caudally), gluteal vessels (caudally and submuscularly), superior cluneal nerves (laterally), and ureter (anteriorly; not shown) should be avoided.



Source of picture: Barrow Neurological Institute

b) **anterior iliac crest** – 2-3 cm lateral to ASIS:
   1) to avoid avulsion/stress fracture (insertion of sartorius muscle, rectus femoris muscle and inguinal ligament)
   2) to avoid inadvertent damage to lateral femoral cutaneous nerve (may have anomalous course).



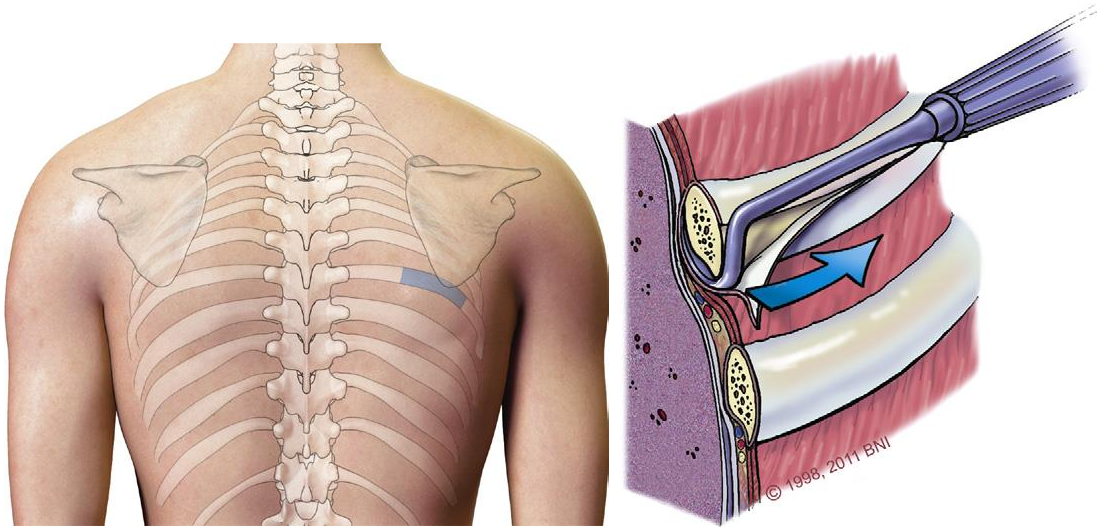
Source of picture: Barrow Neurological Institute

- **sandbag** under ipsilateral gluteal region helps to accentuate ASIS.
- skin is incised and dissection proceeds to the fascia overlying the iliac crest.
- fascia should be opened carefully to ensure complete closure at the end of the procedure.
- <u>when cancellous bone is harvested</u>, a chisel or bone-cutting rongeur can be used to perforate the outer cortex → curettes or gouges are used to scrape the inner graft material.
- <u>tricortical grafts require more dissection</u>:
    - electrocauterization and Cobb elevators are used to perform a subperiosteal dissection of the musculature; the peritoneal cavity on the medial side should not be violated.
    - careless dissection of iliacus can injure iliohypogastric or ilioinguinal nerves as they course over the muscle.
    - once the iliac crest is fully exposed, the size of the graft should be measured carefully in all three dimensions → graft is fashioned with a reciprocating sagittal saw.
    - final removal of the bone may require the use of gouges and chisels to free the bone from attachments in the inferomedial region.
    - **hemostasis** of exposed bony surfaces is achieved using Gelfoam, bone wax, or both (if necessary, **drain** may be left in place overnight).
- <u>reconstruction</u>:

a) only **cancellous** bone removed -empty cavity can be filled with allograft cancellous expander - may promote internal healing and may help the crest to regain a more normal density.

b) large defect after a **strut** is removed can leave a painful and unsightly deformity: gap can be filled with polymethylmethacrylate or absorbable mesh with bone cement - molded to recreate iliac crest anatomy.

RIB HARVESTING



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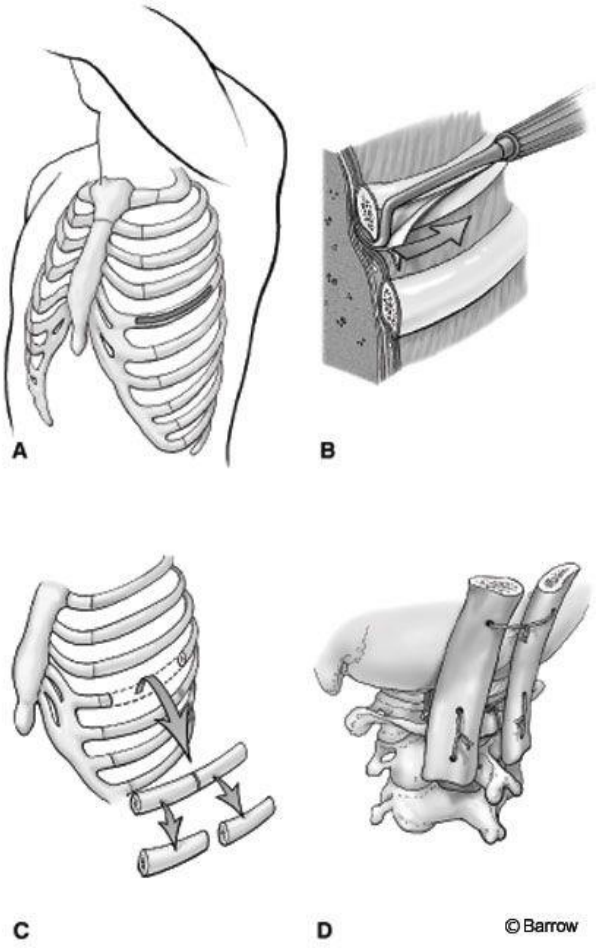


Source of picture: Barrow Neurological Institute

- linear incision is made in the skin over the rib surface (just caudal to scapula tip – usually 7th rib).
- lateral border of the trapezius muscle can be dissected longitudinally and retracted medially.
- erector spinous muscles are transected over the donor rib exposing the costotransverse articulation.
- subperiosteal dissection is performed to expose the bare surface of the rib.

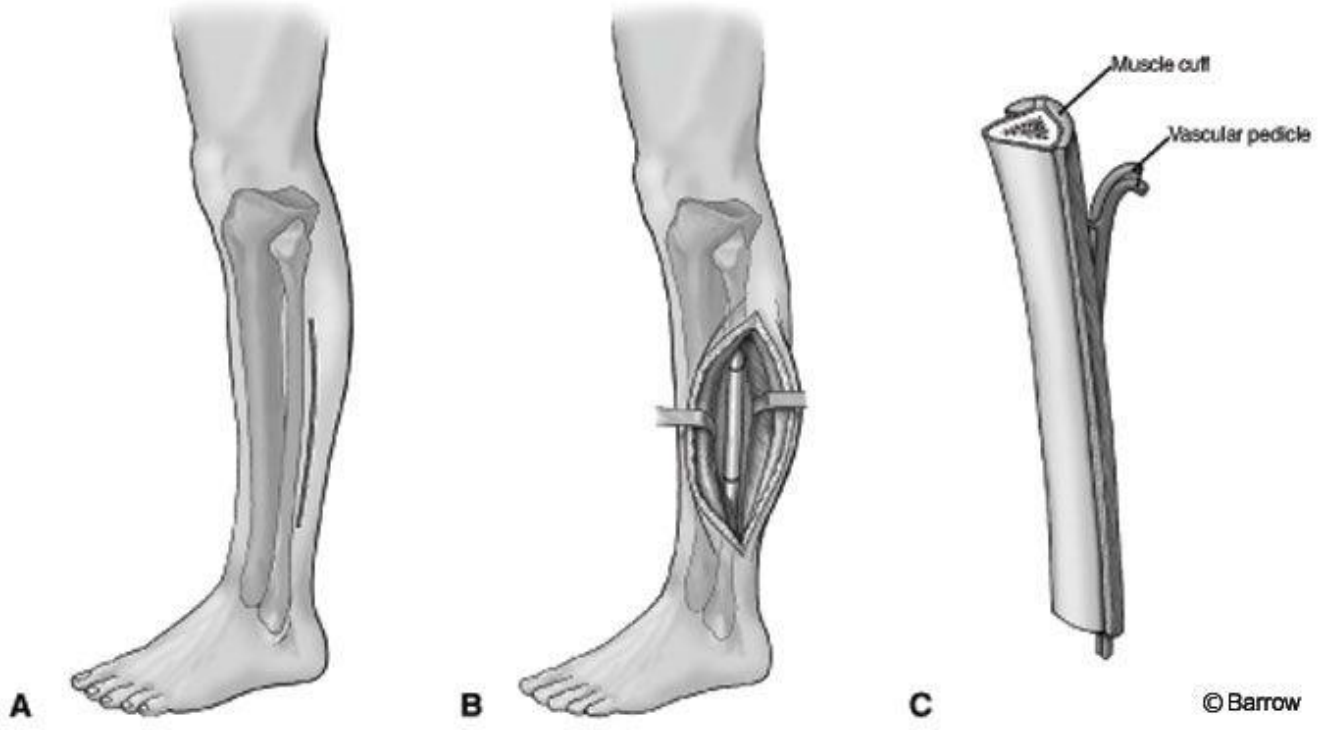
- careful near the inferior aspect of rib to avoid neurovascular bundle.
- blunt dissection with a **Doyen rib dissector** is used to detach the intercostal muscles and parietal pleura from the undersurface.
- rib is transected as medial as possible using a **rib cutter** (avoid it - tends to splinter the rib) or **oscillating saw** to get the greatest curvature for the strut graft.
- laterally the rib is transected as far as possible to procure a rib graft of adequate length.
- ends of the rib are smoothed to avoid a pneumothorax.
- chest wound is then filled with saline, and a Valsalva maneuver is performed to ensure that there is no airleak or pleural fistula (if a hole is made in the parietal pleura, it should be closed by simple suture).
- postop chest XR.

SKULL HARVESTING

- in the young child, the iliac crest is largely cartilaginous and ribs are small.
- bone from the parietal skull can be harvested through a bicoronal flap.
- if identical free flaps are taken and split carefully, half-thickness skull bone replacements at both sites facilitate solid and cosmetically acceptable reconstruction within 3 months.

FIBULA HARVESTING

- may be associated with significant morbidity*, but it also has been associated with high rates of arthrodesis - high ***cortical-to-cancellous bone ratio***.
  *fibula carries 15% of leg axial load and is the origin of many muscles - walking may be uncomfortable for 9 months after surgery (for children, radiographic studies of leg should be performed periodically to assess for development of valgus tilt of the ankle)
- long segments up to 25 cm can be harvested safely.
- **bolster** should be placed under the knee of the donor leg at midcalf so that the foot can rest in a position that keeps the leg flexed at the knee and internally rotated at the hip.
- **tourniquet** is applied to the thigh.
- straight lateral **incision** over the fibula - between peroneal and soleus muscles.
- fibular surface is covered in muscle origins that can be dissected free with electrocauterization using a subperiosteal technique
- midportion of the fibula should be adequate for use in the spine.
  - proximal head of fibula should be avoided to avoid peroneal nerve.
  - to preserve ankle stability, lower 7 cm should be preserved.
- peroneal **muscle** is separated from the ventral aspect of the fibula; muscles of the dorsal compartment of the leg are also dissected free.
- **curved elevator** is used to free the deep surface.
- Gigli **saw** is used to divide the fibula, paying due attention to the peroneal artery and nerve - fibula is elevated in a distal-to-proximal fashion, fibular diaphyseal segment and peroneal vessels are ligated and dissected.
- close with suction drain in place.
  - fascia is not closed to avoid the possibility of compartment syndrome
- in cases of failed fusion, ***vascularized graft*** can be used - preserving a muscle cuff and the peroneal vascular pedicle (pedicle is anastomosed to vessels within the host site).



Source of picture: Barrow Neurological Institute

LEVEL LOCALIZATION / WRONG LEVEL SURGERY

Wrong level surgery

Incidence: 50% at least one wrong level surgery during career (anonymous survey of 415 spine surgeons); true incidence underreported (0.4-4.3%)

Distribution: lumbar (71%), cervical (21%), thoracic (8%)

Risk factors:

1. Difficulty visualizing reference points
2. Unusual anatomy (e.g. rib counting in severe scoliosis)
3. Large body habitus
4. Failure to re-localize after exposure
5. Inconsistent counting methods

PREVENTION MEASURES

Preop

- develop level counting plan preop - obtain **chest XR and CT preop** (esp. prior to thoracic surgery)! - carefully count number of thoracic and lumbar vertebrae - be aware of aberrant anatomy. see below >>

  N.B. make sure MRI scout view shows all vertebrae!
  N.B. count index level same way on preop MRI and intraop XR – either both from C2 down or both from sacrum up.

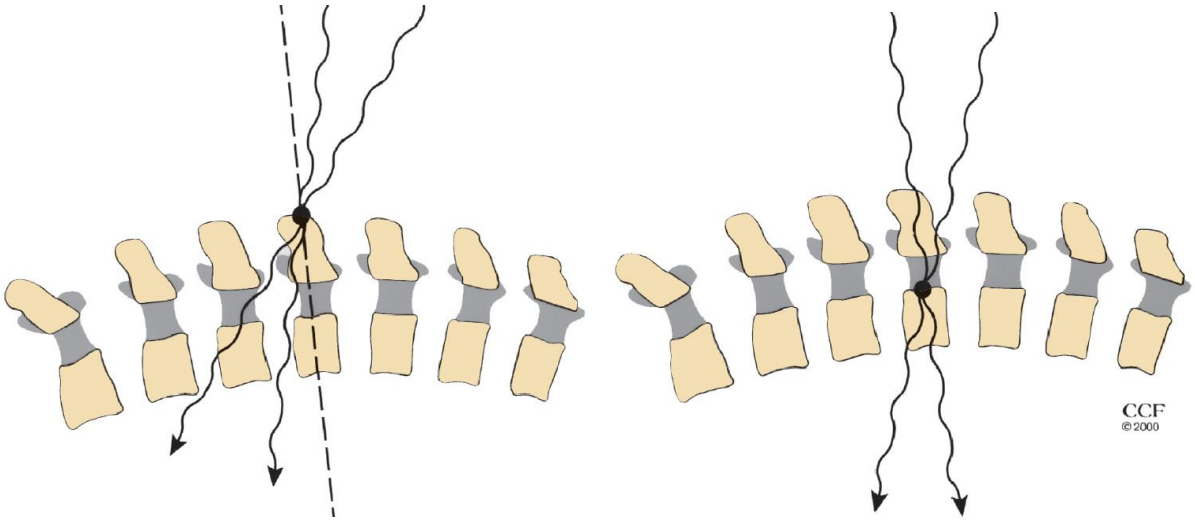
- outpatient preop **interventional radiologist**:
  a) injects methylene blue (0.5 mL into spinous process).
  b) places metal marker (Guglielmi detachable coil, breast cancer surgery wire, screw*) or injects PMMA as close to the index level pedicle as possible.

  *widely used in radiation oncology to localize tumors before SRS.

Intraop

- **attending surgeon present in OR** for skin site marking – "hand-off" effect.
- ***series of needles*** are placed every few levels counting from sacrum in cephalad fashion in lateral views (or from first rib down).
- **attending surgeon scrubbed in** for vertebral marking – "hand-off" effect.
- intraoperative radiographs with ***markers and retractors*** positioned in place.
    - markers must be firmly and **immovably attached** to spine.
    - two forms of site marking required (and must not be mistaken for other objects), e.g. purple permanent marker and hemostat.
- radiographic time-out – do not proceed until two surgeons (at least one – attending; some sites require a second independent non-operating attending to asses – this may be ineffective policy, thus, shift is made towards radiologist verification) independently verbalize marked level (use open-ended questioning during spinal level verification).
    - send* **localization XR to impartial radiologist** and do not proceed until radiologist calls into room to verbally discuss with attending (same as tumor frozen section result) – each OR should have posted on wall the number for radiology reading room that surgeon can call at their discretion to confirm vertebral level.

      *need for WiFi-enabled C-arm
- ideally, use neuronavigation (if there is radiographically-visible distinct bony pathology).
- avoid parallax with localization XR – by placing marker as close to pathology in sagittal plane as possible:



- if difficult to see on intraop XR – use oblique views, spin confirmatory O-arm
- if expected pathology is not found at the expected level, radiographs should continue to be performed with different marking techniques until the surgeon is satisfied that he or she is operating at the appropriate level.
- reliably mark identified level
    a) permanent marking **pen** - may be washed off with blood or irrigation.
    b) **Bovie** marking - may be washed off with blood or irrigation.
    c) small **bite** off the spinous process.
    d) **suture** placed through spinous process.

<u>Other intraop methods</u>

- Kinon et al. - esophageal temperature probe to localize upper- to midthoracic spine - probe is inserted, and radiopaque tip is tracked using intraoperative fluoroscopy - once the correct surgical level is identified, this serves as a reference point during the case.
- Henegar et al. - intraoperative ultrasonography to help localize thoracic intraspinal pathology through interlaminar space.

TRANSITIONAL ANATOMY

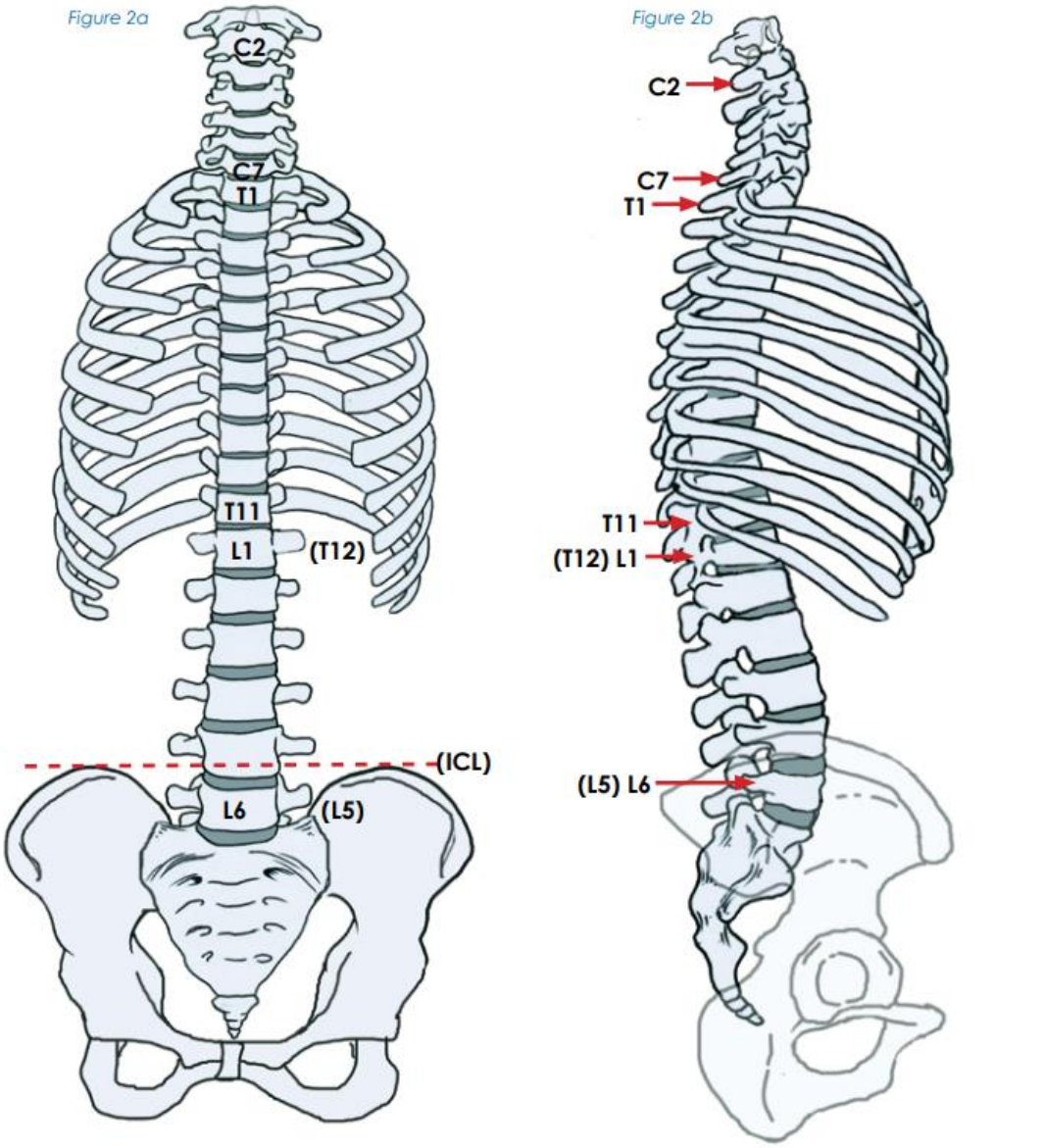
There can be 4 (2.6) and 6 (8.2%) **lumbar vertebrae**.

There can be 11 and 13 pairs of **ribs / thoracic vertebrae**:

Intercrestal line always bisects the lumbar vertebra above the last

N.B. lumbar and thoracic numbers are not related (i.e. one segment addition does not automatically compensate with another segment loss) but 11 thoracic + 4 lumbar vertebrae probably do not exist

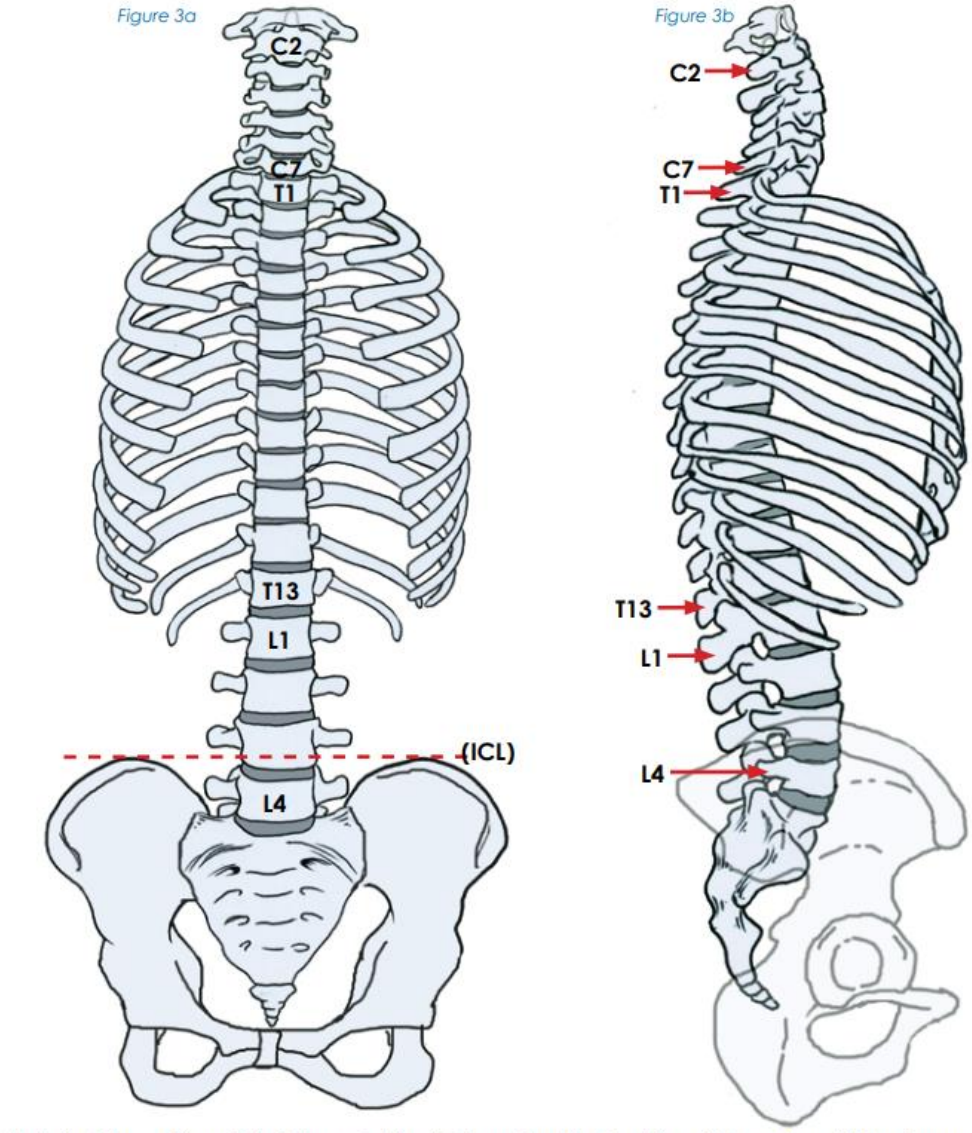
Atypical Anatomy
11 Thoracic and 6 Lumbar Vertebrae*



*If there are 11 definite ribs with 6 vertebrae below and it is not clear if the 12th vertebra has a rib, call it T12 to maintain the 12 Thoracic and 5 Lumbar numbering.

Note that the position of the intercrestal line (ICL) confirms the location of L6 (L5) on AP and lateral x-rays.

Atypical Anatomy
13 Thoracic and 4 Lumbar Vertebrae



Note that the position of the intercrestal line (ICL) confirms the location of L4 on AP and lateral x-rays.

CERVICAL

- XR needle localization of disk level – ***always insert double-bent spinal needle at the highest accessible level*** (if lower – bulky patient's shoulders may obscure XR).
- lateral radiograph is obtained: count down from C1-2 complex; alternative – anterior posterior radiograph – localize 1st rib and count up, then verify with counting down from C2

Drs. Rivet, JRC use fluoro and blunt instrument* (do not use needle! – accelerates degeneration if chose wrong level) *e.g. clamp tip of mosquito on prevertebral fascia.

Dr. Mathern uses straight needle (with hemostat attached for depth gage) – if disc space is obscured, surgeon may judge by needle trajectory

- if disc space is covered with osteophyte ("patella"), do one XR, remove osteophytes with Leksell to see actual disc space – insert needle there and do second XR.
- if shoulders very high (unable to see operative level on lateral XR despite pulling shoulders down with wide tape) – use AP view or localize what you see on lateral view and count down under direct exposure.

THORACIC

Level on MRI is counted from C2 or from sacrum vs. intraop X-ray counting is done using ribs. Reconcile preop MRI level with plain films - to know the number of nonrib lumbar vertebrae + size of 12th rib.

- **long cassettes** instead of fluoroscopy can be used if necessary.
- intraoperative confirmation of operative level by multiple techniques in AP and lateral planes is recommended.
- anterior posterior radiographs are obtained – ribs (heads) are counted - frequently misleading!
- 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.
- large plate lateral radiograph (that includes sacrum) may be used - careful placing an instrument under the lamina due to the narrow spinal canal dimensions (safer, marker may be placed on the transverse process) - counting is performed from the sacrum
- if above fails, marker (Alice clamp) may be placed at the most rostral or caudal level (spinous or transverse process) that is exposed → lateral ***cervical*** or ***lumbar*** radiograph is obtained, which includes the occiput or sacrum, respectively → levels are counted to this marker → lateral ***thoracic*** radiograph is performed, and levels are counted from the prior marked level to pathology.
- alternative - preoperative **radiology confirmation** (e.g. placing under CT guidance of localization coil, small screw, or small amount of cement in pedicle caudal to targeted disk space).

Caveats on using preop MRI and intraop XR

- example of error - suppose MRI demonstrates that there is a thoracic vertebra pathology that is 14 vertebral bodies rostral to the sacrum:
  - if patient has normal 5 lumbar vertebrae and 12 thoracic vertebrae, then the thoracic vertebral pathology would be at T3.
  - if patient has 4 or 6 lumbar vertebrae and 12 thoracic vertebrae, then the pathology would be at T2 or T4, respectively – if surgeon uses a XR localization using C7 spinous process to count down to the pathology solely relying on the MRI that did not include the corresponding cervical levels, then the identification of the pathologic level could be erroneous if the patient had anomalous segmentation vs. if surgeon used a radiologic localization corresponding to the MRI localization and counted from the sacrum up, then this error could be avoided.

LUMBAR

- Alice clamp or sharp towel clip may be placed on **spinous process** along with a Penfield no. 4 or Woodson elevator **under the same lamina** - both directed perpendicular to the spine.
- lateral radiograph is obtained: count up from lumbosacral junction and assume five lumbar vertebrae:
  - most caudal normal disc space is labeled as L5-S1.
  - iliac crest serves as a secondary internal landmark to identify the L4-5 level.

CONGENITAL ABNORMALITIES

- even if bone looks OK, it may not be strong enough to withstand loads, thus, extend instrumentation past congenitally abnormal levels.

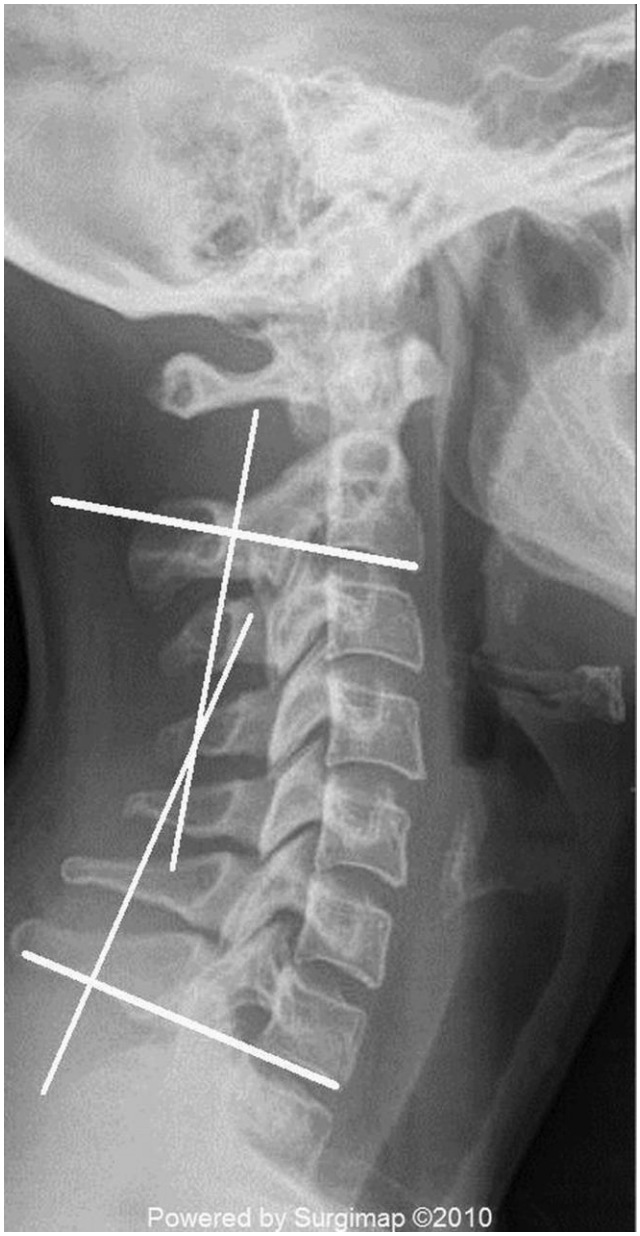
DEFORMITY

- head weight is transmitted through upper cervical spine in a specific fashion:
    1. begins with the load going through the occipital condyles and then to the C1 lateral masses.
    2. goes through the C1-2 joint and becomes divided along the articular pillars of C2.
    3. weight moves from the lateral to anterior column of the cervical spine, including the C2-3 disc as well as the posterior column and C2-3 facets.
    4. rest of head weight is then mostly handled by the posterior columns with 64% load distribution compared with the anterior columns having 36% vs. lumbar spine - most of the body weight load carried through the anterior column (67%-82%) vs the posterior elements having less (18%-33%).
- natural alignment of cervical spine is one in which the person assumes a position of comfort and allows them to maintain a horizontal gaze.
- patients that have a flexible cervical deformity found on supine testing must be ruled out for any of the *various etiologies of camptocormia* (PD, ALS, myopathy, etc).

GENERAL CERVICAL ALIGNMENT PARAMETERS

Cervical lordosis (CL) - Cobb angle measurement (inferior endplate of C2 to inferior endplate of C7 – the farthest endplates) using the 4-line method:

5. surgical goal - general rule of correcting cervical kyphosis is to at least neutral (ideal CL < 32 degrees)
6. normal volunteers, 75-80% of cervical standing lordosis is localized to C1-C2 and relatively little lordosis (15% or 6 degrees) exists in the lower cervical levels (concept is similar in the lumbar spine with the majority of the lordosis being with L5-S1)

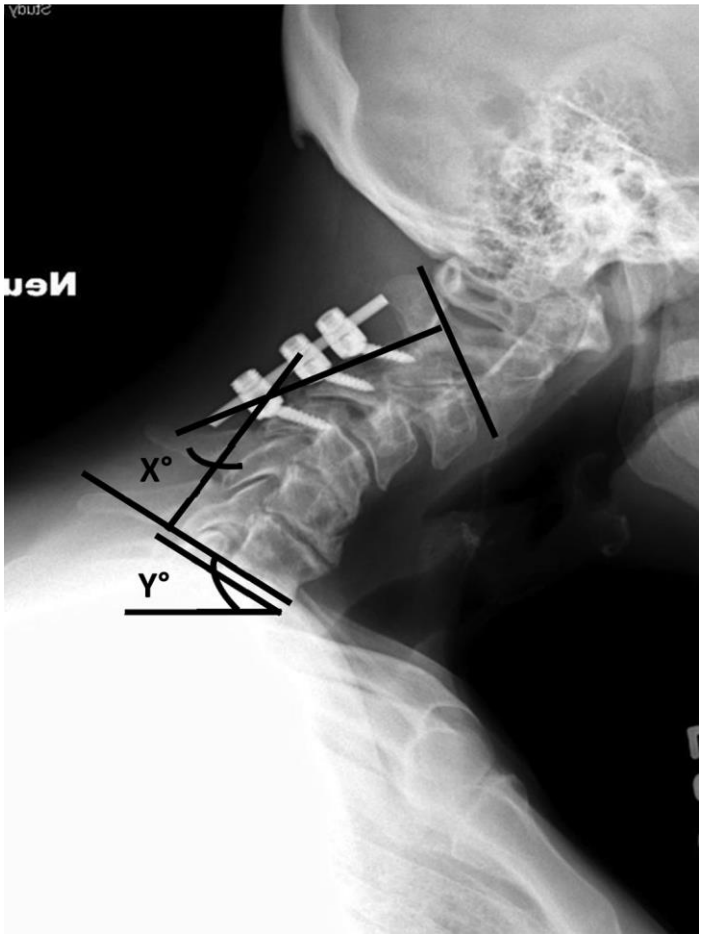


T1 slope (TS) - angle subtended by a line drawn parallel to the superior endplate of T1 and a horizontal reference line.

7. ideally, TS-CL mismatch is < 15 degrees
8. relationship between CL and the T1 slope is analogous to the relationship between pelvic incidence (PI) and lumbar lordosis (LL) in the lumbar spine;
9. PI correlates with LL, LL correlates with thoracic kyphosis (TK), and TK correlates with CL; i.e. increases in PI correlates with increases in LL, which correlates with increases in TK, which then correlates with increases in CL

N.B. always obtain 36 inch standing plain film x-ray

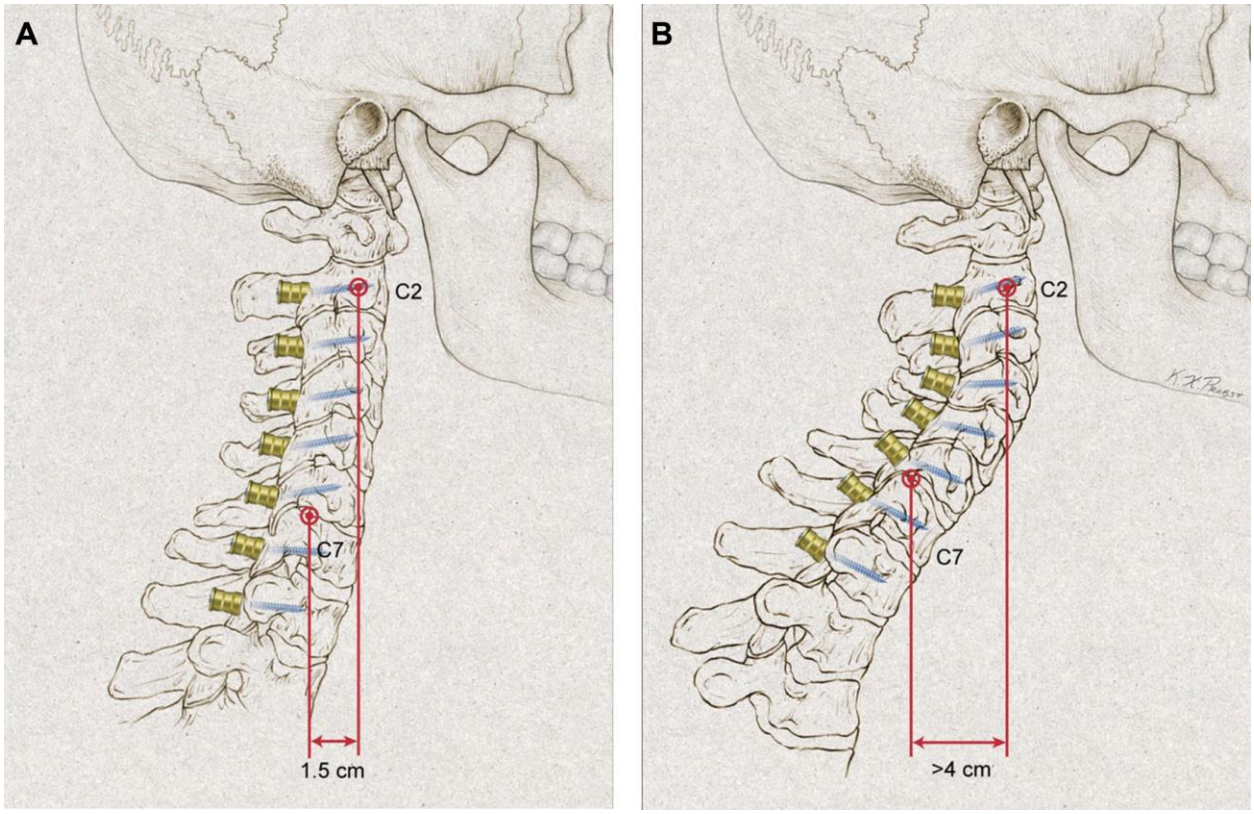
Lateral radiograph showing the method for measuring the T1 slope minus cervical lordosis (TS-CL).



- if need osteotomy, select **T2** (no brachial plexus – can take T2 root, no vertebral artery).

CERVICAL SPINE TRANSLATION IN SAGITTAL PLANE

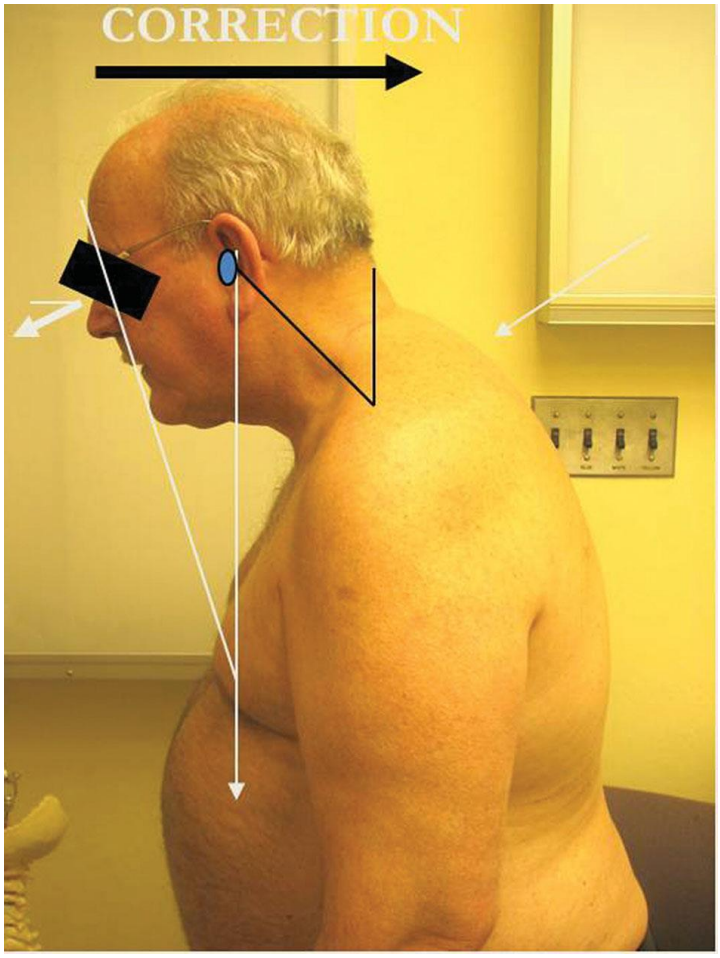
A. **Cervical sagittal vertical axis (cSVA)** (if > 4 cm → increased disability) - distance between a plumb line dropped from C2 centroid and superior-posterior-superior aspect of C7 vertebral body:



B. **Gravity line** is measured by using a plumb line drawn from the center of gravity (COG) of head on a lateral radiograph "by using the anterior portion of the external auditory canal as the initial point for the plumb line"

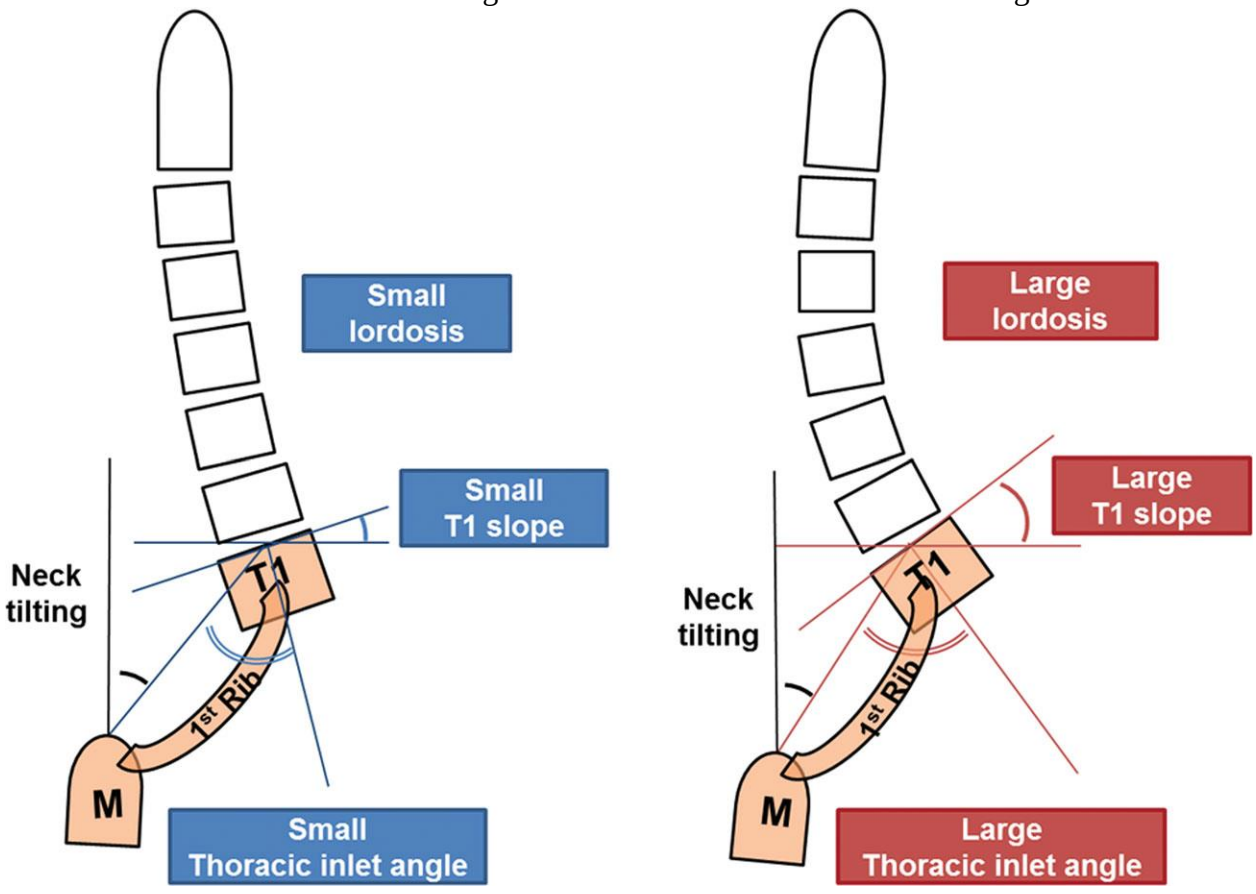
MEASURE OF HORIZONTAL GAZE

(impact the patients' activities of daily living and reduce their quality of life)
- **chin-brow-vertical-angle (CBVA)** (surgical goal is +/- 10 degrees) - "an angle subtended between a line drawn from the chin to the brow and a vertical reference line" - measured on clinical photographs of the patient standing with hips and knees extended and the neck in a neutral or fixed position:

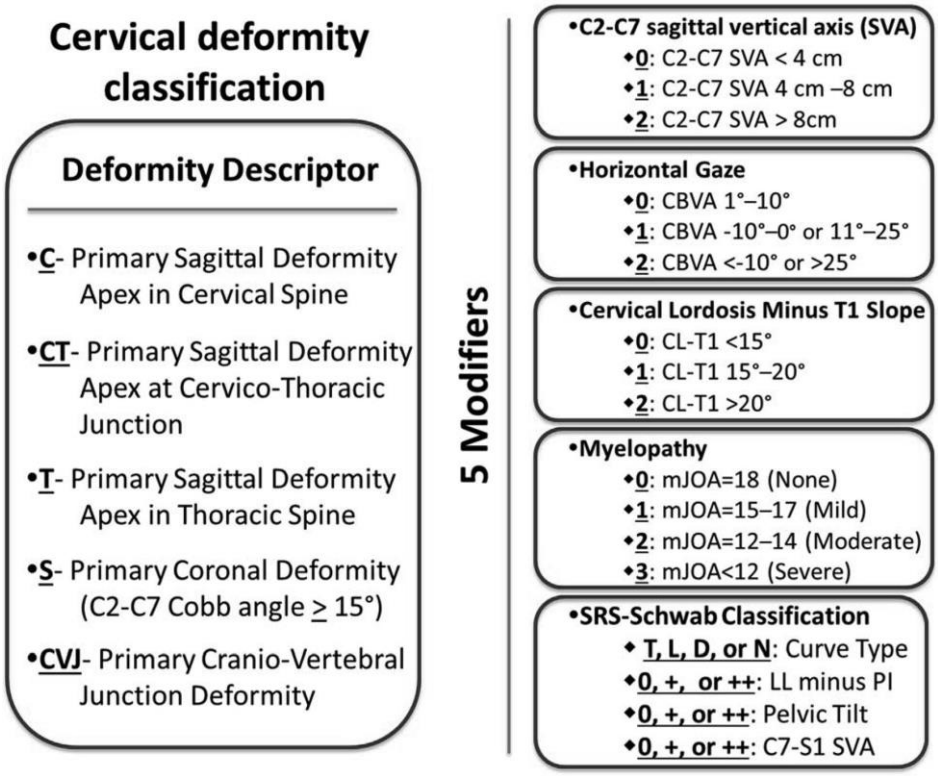


THORACIC INLET

Correlation from the thoracic inlet angle to cranial offset and craniocervical alignment:



CERVICAL DEFORMITY CLASSIFICATION



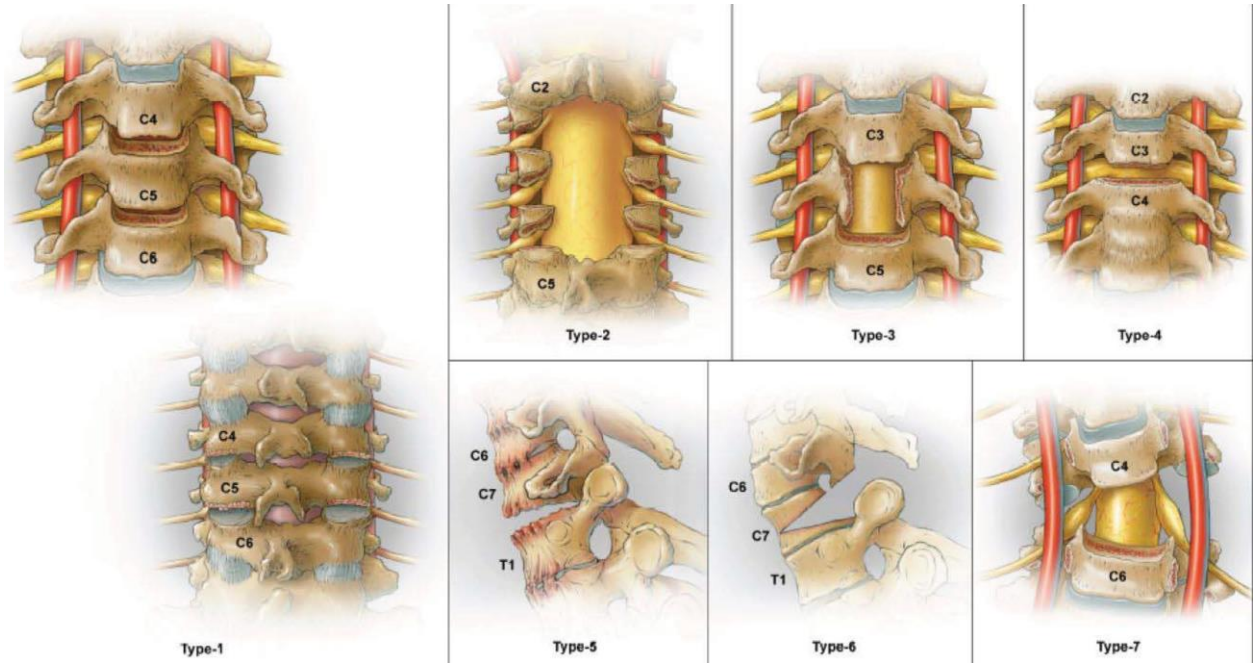
SURGICAL TECHNIQUES

N.B. all-cause **mortality** at 1.2 yr postop was 9.2%.

If the cervical spine is flexible and is not ankylosed, an anterior or posterior-alone correction strategy may be used.
If the spine is rigid without ankylosed facets, an anterior-alone strategy may be sufficient.
If the spine is rigid in the anterior column and with ankylosed facets, a combination of anterior and posterior strategies may be needed to correct the deformity.

- in general, for subaxial cervical sagittal plane deformities (cervical kyphosis), an anterior release and posterior fixation is often most effective.
- for deformity stemming from pathology of the CTJ (high T1-slope, neutral to normal CL), 3 column osteotomy and posterior approach would be the correct strategy.
- prior to surgical correction of a deformity, **cervical traction** may be used for maximum 5 days which may be sufficient to reduce the deformity.

Different osteotomy types that increase in the amount of cervical spine destabilization for deformity correction:



COMPLICATIONS

DYSPHAGIA

Risk factors (displacement of the esophagus with retractors):

at day 1: **C3-C4** (4.11, P < .01), loss of preoperative cervical lordosis (2.26, P < .01), intubation attempts ≥ 2 (3.10, P < .01), left side approach (1.85, P = .02);

at day 7: **C3-C4** (3.42, P < .01), BMI ≥ 30 (2.29, P = .02), length of surgery ≥ 90 minutes (2.97, P = .005);

at day 21: **C3-C4** was kept as a risk factor (3.62, P < .01).

ESOPHAGEAL INJURY

– usually only big hole is visible; 60% cases present > 30 days after surgery (usually due to migrated hardware); mortality 20% if noticed within 24 hours of surgery (otherwise, mortality nearly 50%)

Risk of lethal mediastinitis!

- area of the esophagus most vulnerable to injury, known as **Killian's Triangle**, is formed by the junction of the paired inferior constrictor pharyngeal and cricopharyngeal muscles - anterior to C5-C6 disc (occasionally found more caudally), particularly susceptible to injury since the posterior esophageal mucosa lacks muscle protection (only thin buccopharyngeal fascia separates the esophagus from retroesophageal space).
- dysphagia and odynophagia, followed by fever and cervical edema, unexplained tachycardia, wound drainage + WBC, ESR, CRP

  N.B. wound infection after ACDF is esophageal perforation until proven otherwise!
  - coughing up food = tracheo-esophageal fistula
  - classic triad of vomiting, chest pain, and subcutaneous emphysema (**Mackler's triad**) is seen in only 25% of cases and is more common in thoracic esophageal lesions.
- diagnosis:
  1) *for C1-5* - **ENT eval with endoscopy**; *for below C5* - **contrast esophagogram** (water soluble such as Gastrografin)
  2) **CT with contrast** (free air, abscess)

3) if patient still has a drain – **swallow dye** (e.g. methylene blue) → watch if dye shows up in the drain.

N.B. imaging and endoscopy can have a false-negative rate of 10-46% - if there is high clinical suspicion, patient should be taken back to OR immediately for exploration, preferably with ENT.

- treatment:
  a) **conservative management** - indicated in asymptomatic young patients with lesions smaller than 1 cm.
     Small leaks + no esophageal obstruction may close spontaneously with good nutrition; for Boards – need operative exploration
  b) **surgical treatment** – for infection, fistula, or pseudocyst:
     – *remove all anterior hardware* (replace with iliac autograft → staged posterior supplementation)
     – *primary repair by ENT over bougie* (in delayed-presentation cases, defect is larger – add reinforcement with pedicled muscle – rotate **SCM, sternohyoid, pectoralis major flap** or free omentum – work as a bolster between repair and cervical hardware, helps deliver abx).
     – *PEG + NPO*
     – *broad-spectrum abx*

By time of presentation

A. **Noticed intraoperatively**: primarily repair with interrupted resorbable inverted sutures in a two layers; for anything more than super small injury, reinforce with muscle flap (layer between fresh suture line and bone graft - sternal head of sternocleidomastoid muscle reflected and sutured to contralateral paravertebral muscles), drain → antibiotics and NG tube → esophagram around day 7 - if normal oral feeding may be started.
B. **Noticed postoperatively**: same as above but wound may be left open and consideration should be given to remove spinal implants

POST-OP C5 PALSY

- new weakness (loss of strength by ≥ 1 grade) of **deltoid** and/or **biceps** following cervical spine surgery with no worsening of myelopathy within 6 weeks of surgery (most occur < 1 week post-op).

- other nerve roots may be involved, but C5 palsy is the most common.
- 92% are unilateral.
- no pre-op risk factors have been identified for the posterior approach.
- 50% have motor involvement only (deltoid > biceps)
- incidence: ≈ 3–5% of extensive anterior or posterior decompression (including laminoplasty).
  - incidence is higher after posterior surgery; however, posterior surgery is used more commonly than anterior surgery for myelopathy.
- etiology: unresolved; most theories have been disputed:
  a) traction on the nerve root from posterior migration of the cord after decompression or to bone graft displacement.
  b) heat from the high-speed drill.
  c) increase in lordosis.
  d) pull on intraforaminal tethering ligaments during decompression.
- prevention: no effective preventative measures have been identified (in a series of 52 cases of post-op C5 palsy with *intraoperative neuromonitoring*, none had monitoring changes during surgery).
- prognosis: chances of spontaneous recovery are generally good (most recover in 2 years): 48% of mild cases resolved in < 3 months, whereas 52% of severe palsies persisted for up to 6 months.
  - recovery occurred in 75% of the palsies after anterior approach, and in 89% after posterior approach.

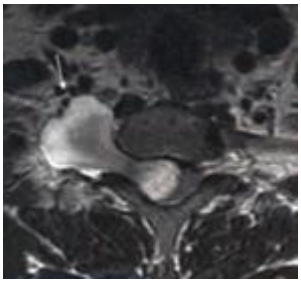
- management: expectant management in most cases.
    - it is critical to ***keep the joints mobile*** to avoid contractures which can diminish the recovery when nerve heals, and can also impede benefits of tendon transfers – PT/OT with attention to fingers is vital
    - may perform EMG (serially or at 6-9 months) to look for reinnervation both for prognostication and to determine if intervention is indicated: if *no reinnervation* on EMG or developing *contractures*:
        a) **nerve transfers** (work better in younger patients): triceps branch → axillary, spinal accessory nerve → suprascapular
        b) **tendon transfers**
        c) **joint fusion**: place arm in a more functional position than dangling limply at the side

VERTEBRAL ARTERY

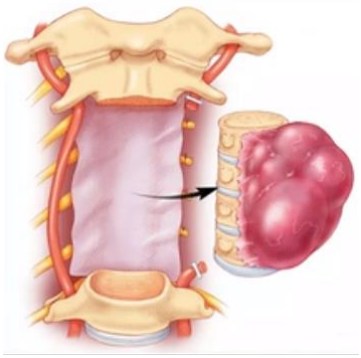
For anatomy and variants – see p. A205 >>

Anticipate need to mobilize in: consider VA occlusion test preop!

1) nerve sheath tumors with paraspinal extension:

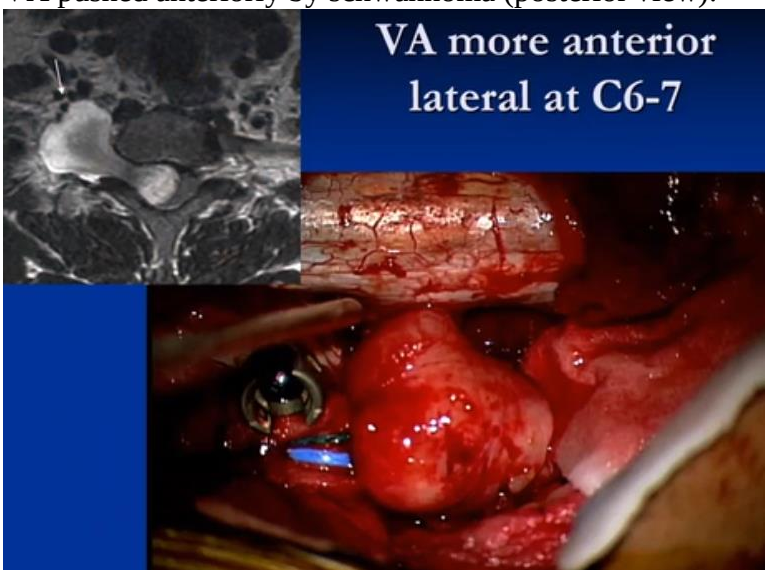


2) en bloc cervical resections:

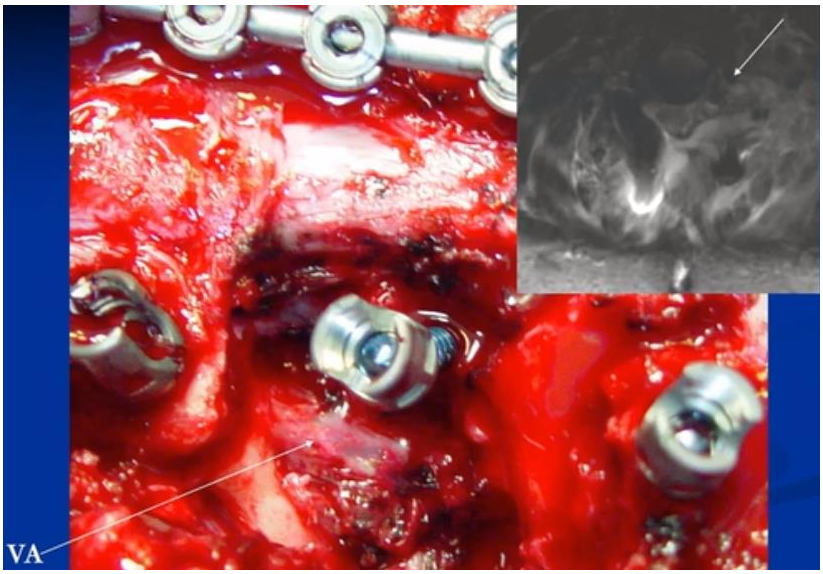


- benign tumors rarely have adhesions to artery (can be aggressive around tumor capsule).
- malignant tumors (see for signs of vertebral bone erosion, tumor enveloping rather than displacing artery) often invade artery.

VA pushed anteriorly by schwannoma (posterior view):



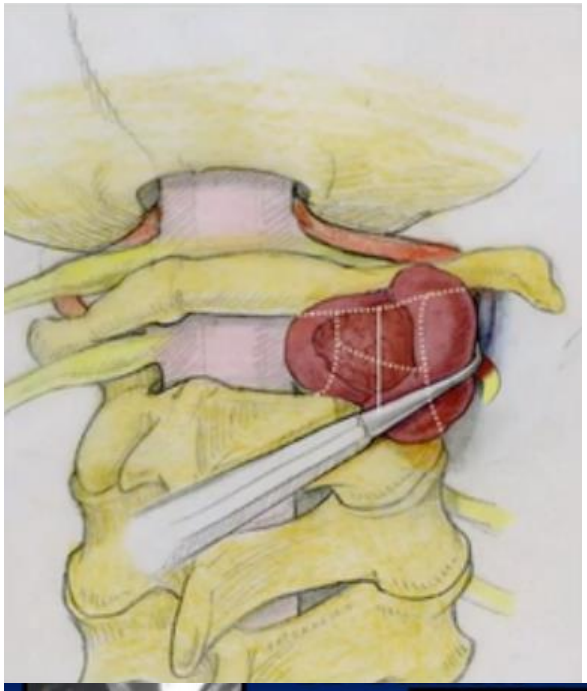
VA visible after tumor resection:

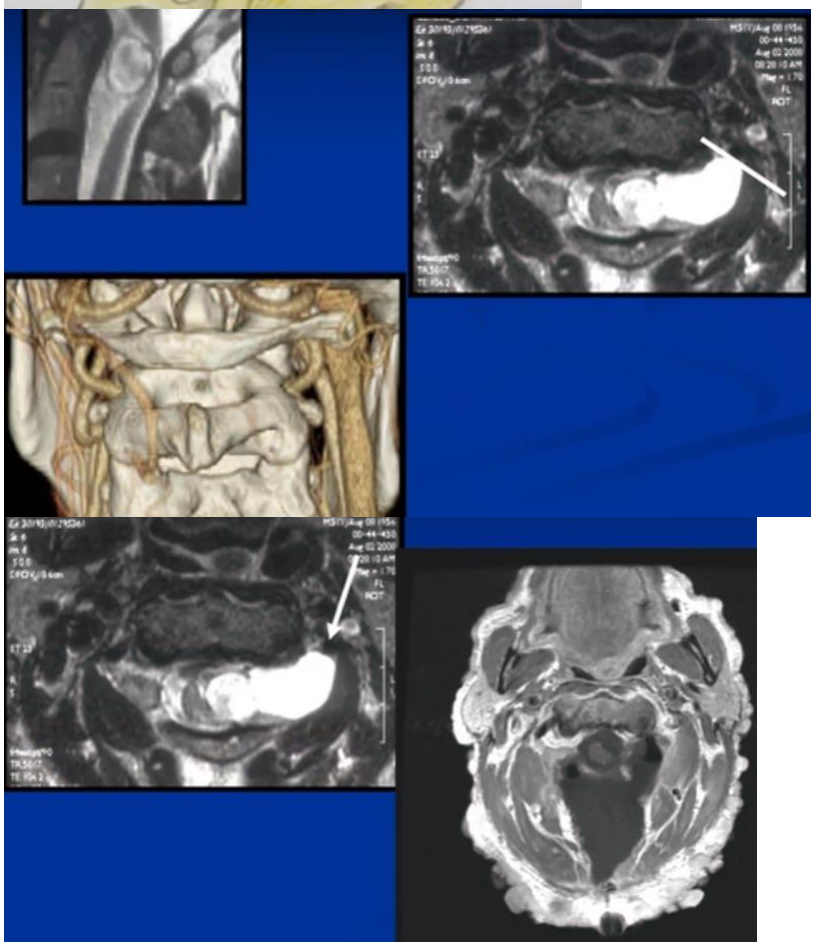


C1-2 NERVE SHEATH TUMOR

Two types:

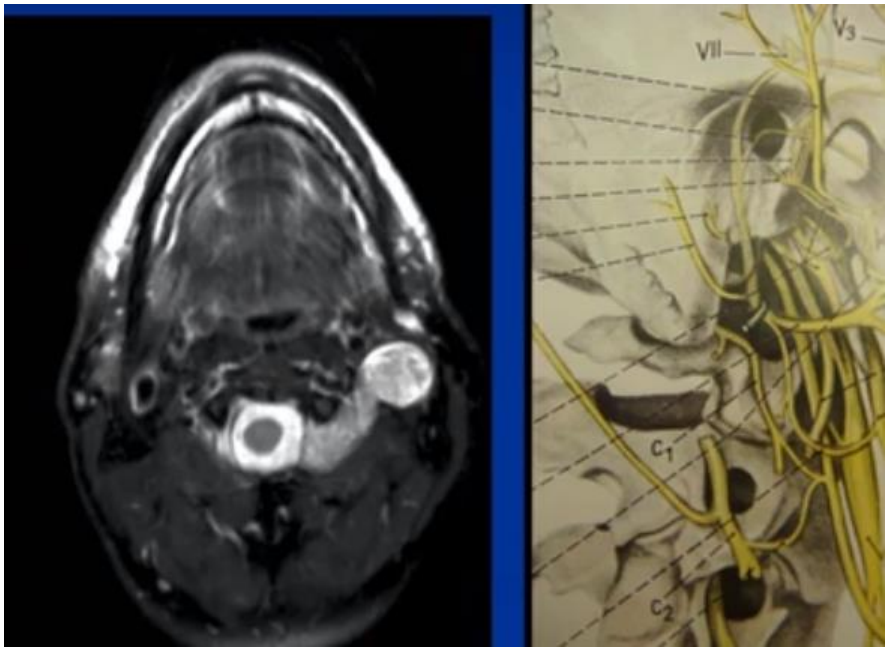
A. **Tumor does not extend laterally to VA** – done in single stage posterior approach;



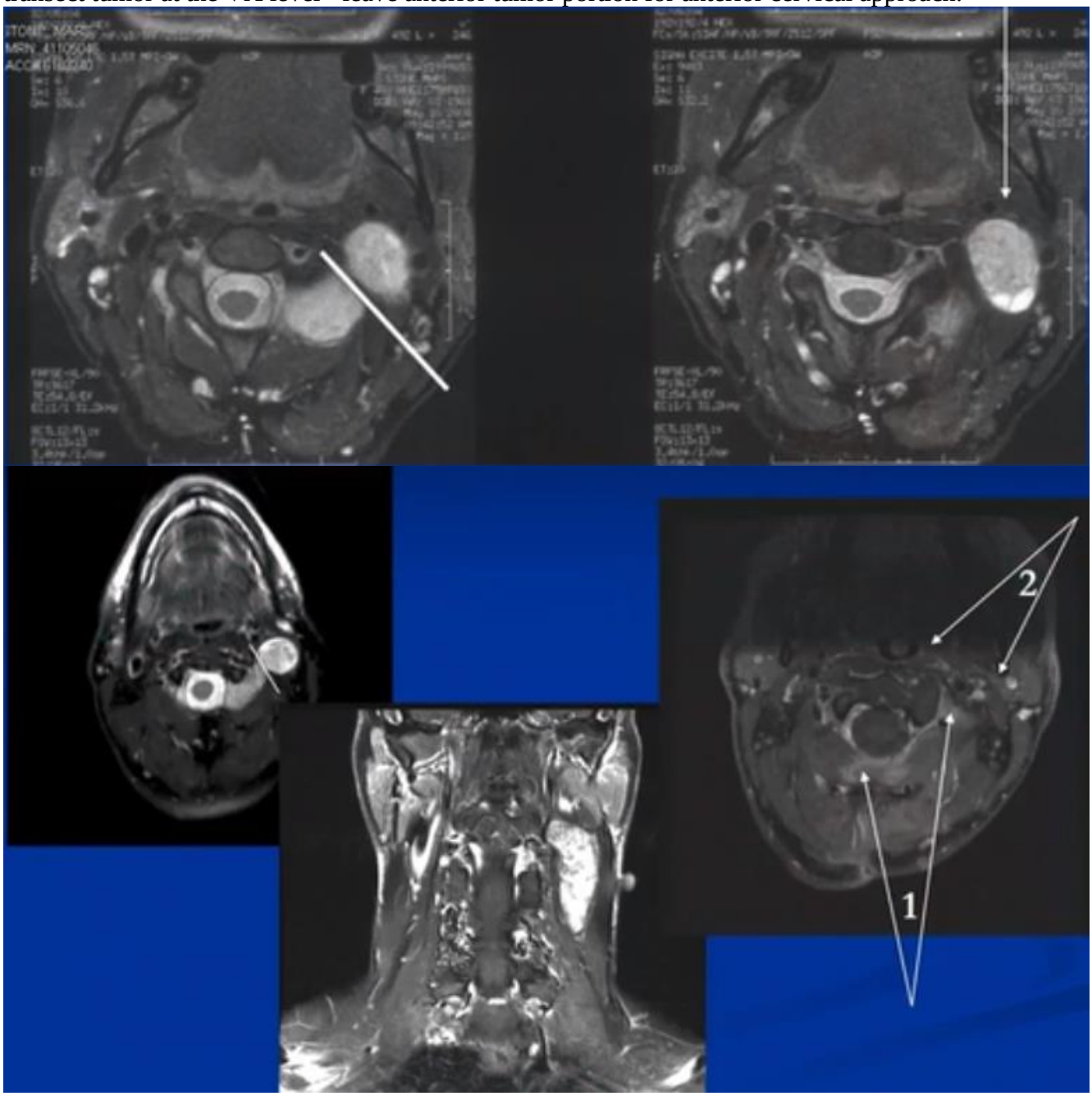


- debulk tumor centrally
- locate C2 pars and C1 lateral mass – transect tumor along this line
- mobilize tumor medially, away from VA
- work within tumor capsule laterally then develop plane around VA
- stay within tumor margin.
- leave thin cuff of tissue around VA.

B. **Tumor extends laterally to VA** along ansa cervicalis – approach in 2 stages



- transect tumor at the VA level - leave anterior tumor portion for anterior cervical approach:



VA INJURY

Vertebral artery can have a variable course!!! For anatomy and variants – see p. A205 >>

AVOIDANCE

- study MRI / CT carefully before surgery – see which VA is dominant, where VA is displaced (e.g. VA medial to pedicle is a contraindication for anterior discectomy)
- have intraop Doppler.
- have microscope available.
- consider VA occlusion test preop.

INCIDENCE

0.07-1.4%.

> *David J. Lunardini et al. "Vertebral artery injuries in cervical spine surgery" The Spine Journal 14 (2014) 1520–1525*
>
> 141 CSRS members responded to the survey (total of 163,324 cervical spine surgeries): the overall incidence of VAI was 0.07%. Posterior instrumentation of the upper cervical spine (32.4%), anterior corpectomy (23.4%), and posterior exposure of the cervical spine (11.7%) were the most common stages of the case to result in an injury to the vertebral artery. Discectomy (9%) and anterior exposure of the spine (7.2%) were also common time points for an arterial injury. One-fifth (22/111) of all VAI involved an anomalous course of the vertebral artery. The most common management of VAI was by direct tamponade. The outcomes of VAIs included no permanent sequelae in 90% of patients, permanent neurologic sequelae in 5.5%, and death in 4.5%. Surgeons at academic and private centers had nearly identical rates of VAIs. However, surgeons who had performed 300 or fewer cervical spine surgeries in their career had a VAI incidence of 0.33% compared with 0.06% in those with greater than 300 lifetime cases (p5.028).

- highest risk in upper cervical spine (cf. subaxial spine) - posterior instrumented upper cervical spine surgery (4-8% incidence vs. 0.3-0.5% for anterior subaxial cervical spine procedures).

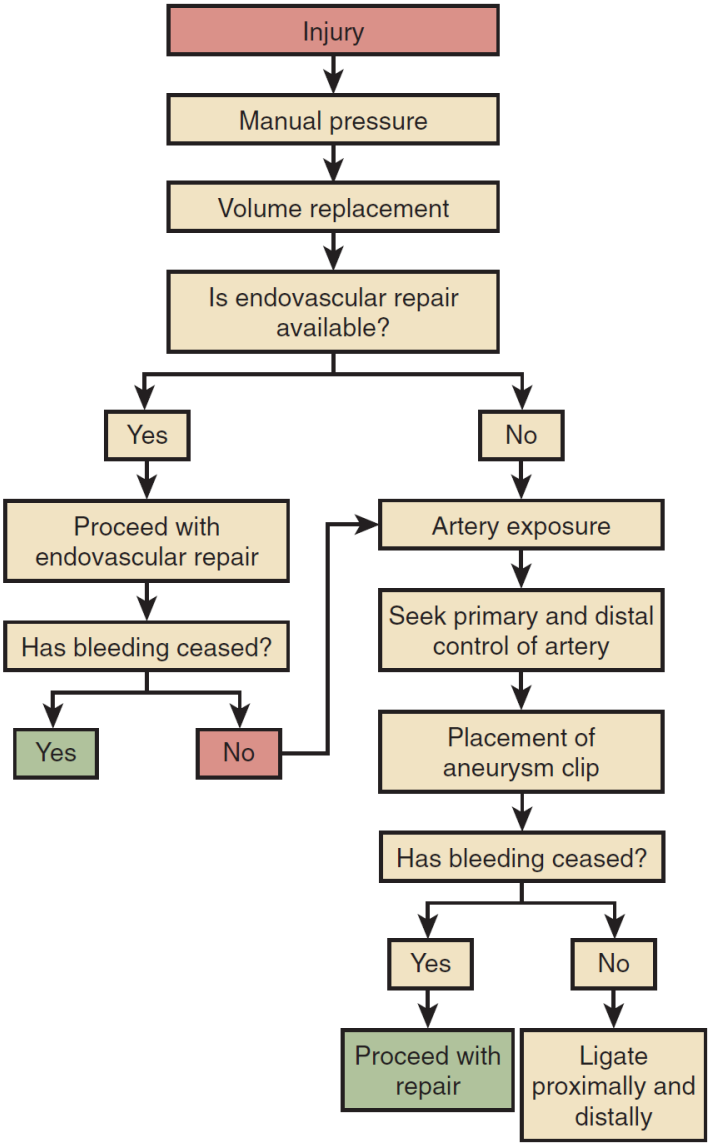
PLAN OF ACTION

(1) Achieve control of hemorrhage.
(2) Prevent acute central nervous system ischemia (lateral medullary (Wallenberg) syndrome, quadriparesis)
   - majority of patients do not get strokes so calm down, on the other hand it may be fatal.
(3) Prevent postoperative complications such as embolism and pseudoaneurysm.

Bleeding control:

- control bleeding with manual pressure and local hemostatic agents: let it bleed and find out where exactly injury is, then control bleeding with cottonoid - keep suction tip over cottonoid over injured artery part (use larger pieces of hemostatic agents so it does not embolize).
- aggressive **fluid and blood resuscitation** communicated to the anesthesia team.
- let NIR team know.
- ensure **head is in a neutral position** (cervical extension and axial rotation can lead to occlusion of the contralateral vertebral artery).
- remove bone to expose VA above and below injury (esp. if manual pressure above and below does not control bleeding.

If bleeding continues, aim for **endovascular repair**; if endovascular repair fails / unavailable → expose artery → proximal and distal control with temporary aneurysm clips / manual pressure – *if bleeding stopped* then repair artery, *if bleeding continues* then ligate proximally and distally.



A. Tamponading

- prepare patch of **Surgicel** with new cottonoid; remove old cottonoid and place Surgicel over injury; ideally, add muscle plug / Gelfoam over Surgicel.
- if injury inside bone (e.g. ponticulus posticus) – place **bone wax**.
- if injury during screw placement, place **shorter screw** (do not want to see screw in the artery on postop CTA) to tamponade and do not place screw on opposite side (use alternative technique, e.g. sublaminar wiring)
- keep working and do not check injury site; at the end, lift cottonoid off, may encase the whole area with **bioglue**.
- some experts think, tamponade alone is not effective in achieving hemostasis, as multiple reports exist of complications after use of this method.
- may use ADENOSINE to pause heartbeat and slow down bleeding.

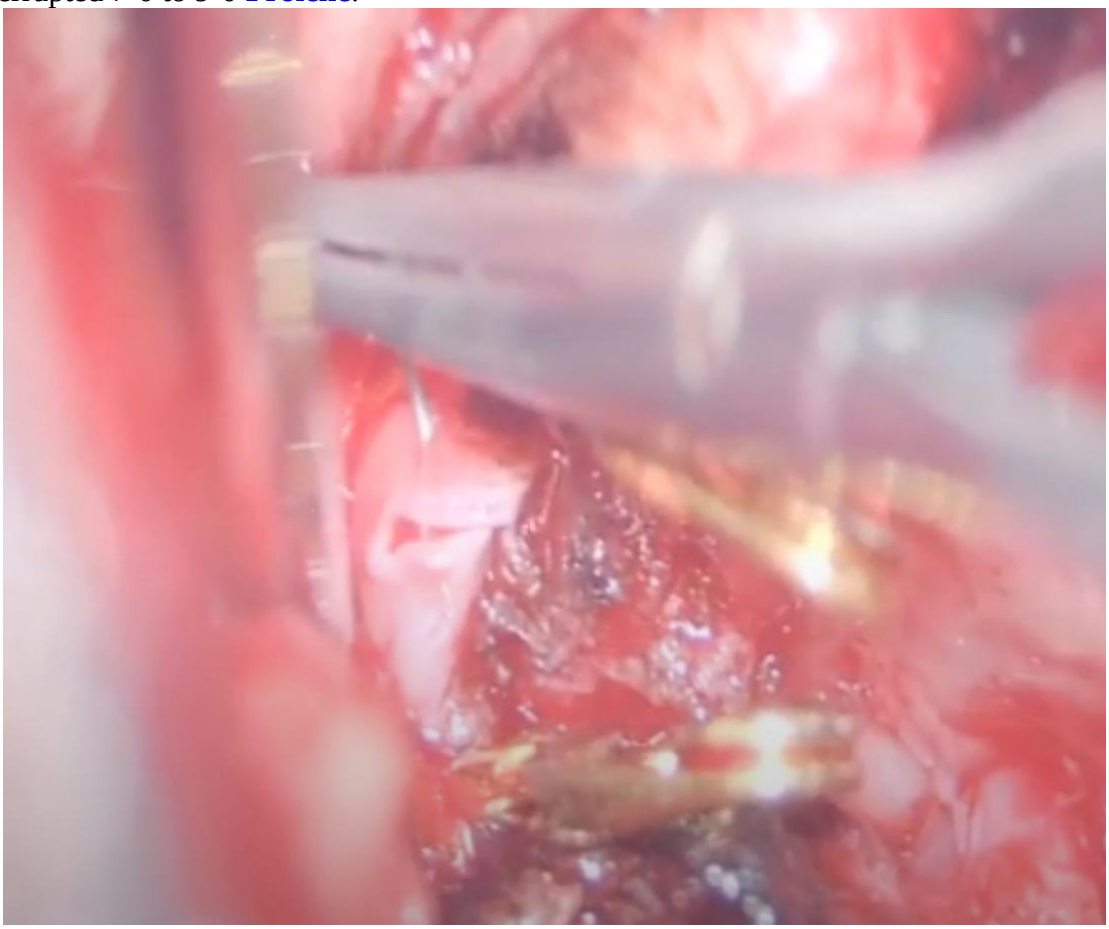
B. Repairing

- if available, consider **endovascular covered stent** (→ dual antiplatelet).
- expose artery through foramen transversarium one level above and below injury with diamond drill bit – see below.

- dissect with nerve hook proximally and distally → apply proximal and distal temporary aneurysm clips (or vessel loops or just manual pressure)
- repair defect with:

a) L-shaped aneurysm **clip** (i.e. incorporate injury into clip jaws parallel to artery (e.g. if injury with Bovie and impossible to repair with sutures)

b) interrupted 7-0 to 9-0 **Prolene**:



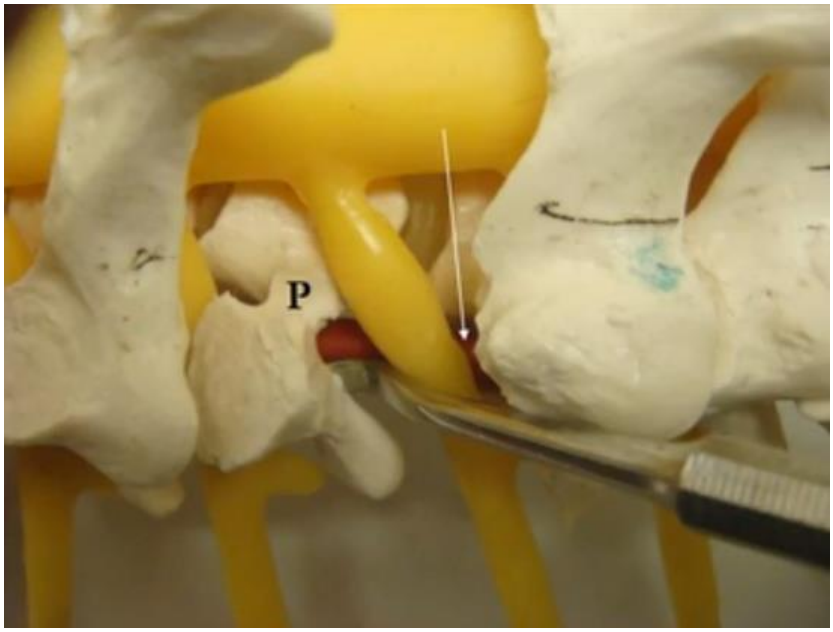
- prior to completion of the repair, temporary clips should be removed to prevent air embolism or the propagation of other emboli.
- check for distal flow with Doppler and neuromonitoring signals.

C. Bypass - if vessel cannot be repaired, and there is poor retrograde flow; the vascular surgeon may choose to perform traditional bypass surgery.

D. Sacrifice / Deconstruction - **ligation** of the vessel should only occur if there is good retrograde flow (and monitoring shows no drop of signals).

- **endovascular coiling** has also been shown to be effective in stopping hemorrhage from a pseudoaneurysm after a vertebral artery injury, but there is no literature on its use intraoperatively immediately after the injury.

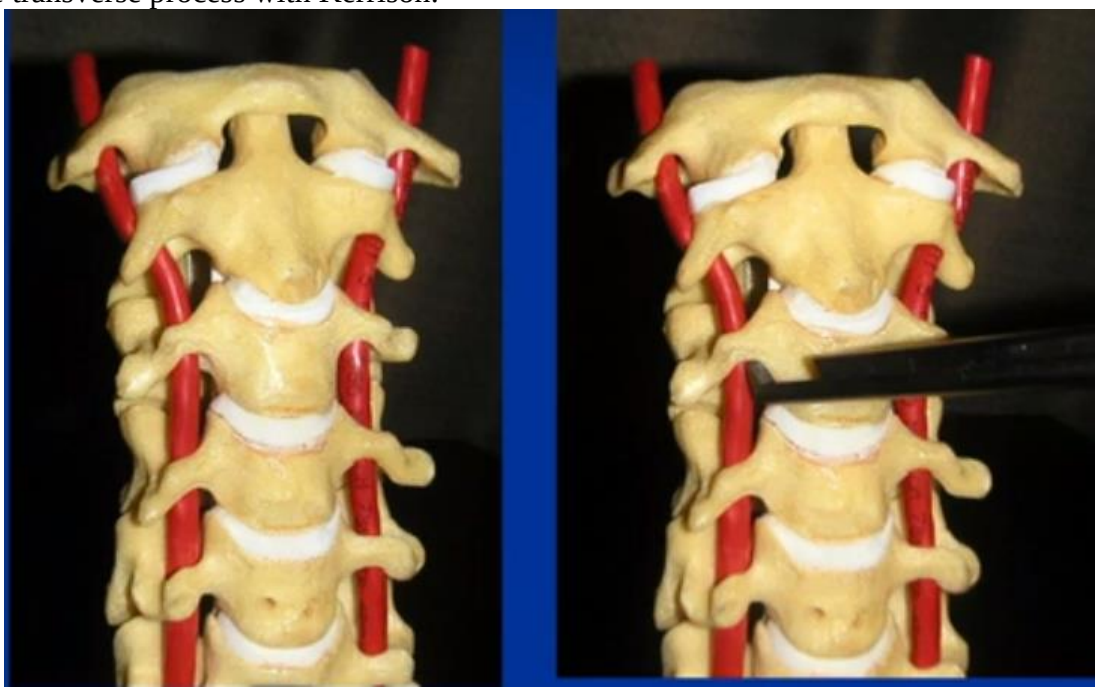
Posterior localization (e.g. for large paraspinal lesions):

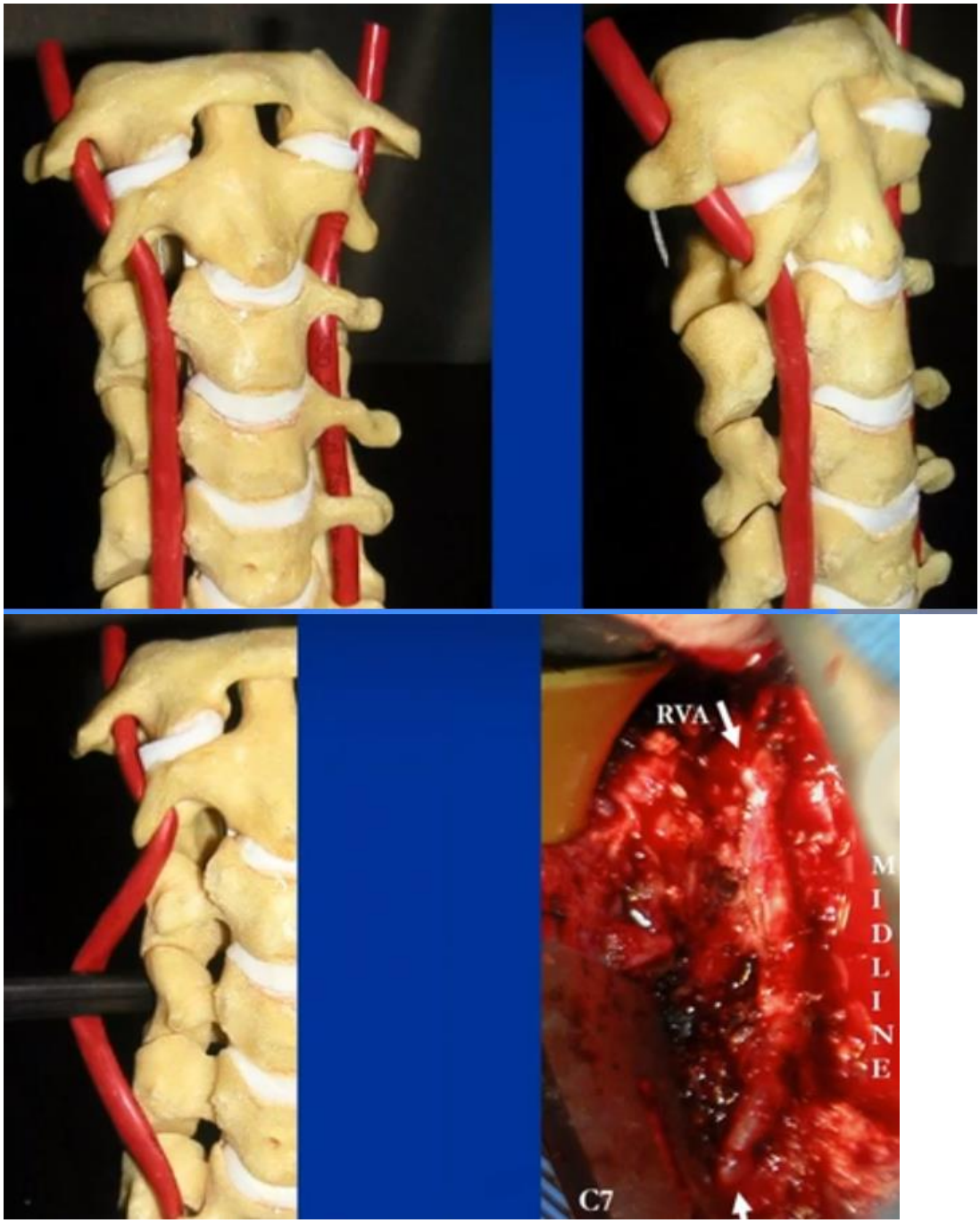


- full width foraminotomy → identify nerve and follow laterally (artery is anterior to nerve and more medial than most surgeons think – it is right at the lateral edge of vertebral body)
- resect pedicle (P) if needed
- encounter robust venous plexus (easy hemostasis with injectable foam)
- for V3 exposure at exit of C2 transverse foramen, need to transect (preganglionic cut – to avoid neuropathic pain!!!) C2 nerve – vertebral artery is in front of ganglion.

<u>Anterior localization</u> (e.g. for spondylectomy lateral mobilization)

- mobilize longus colli up and down over many levels to mobilize muscle laterally (do not cut muscle transversely – risk of Horner's syndrome)
- go with curette laterally at upper level of vertebral body – to encounter transverse process.
- VA is directly under transverse process (dissect fibrous adhesions to nerve root)
- very little epidural bleeding.
- remove transverse process with Kerrison:





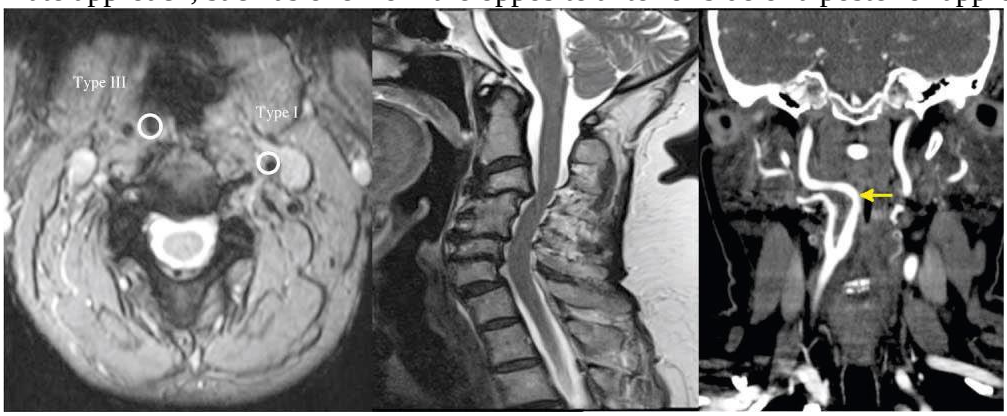
POSTOP

- at the end, transfer patient to angiography suite – VA open, occluded, dissection.
- some experts choose CTA (instead of DSA) if patient is stable.
- start ASPIRIN at 6 hrs postop.
- postop **CTA** before patient discharge – look for:
    1. delayed pseudoaneurysm formation.
    2. arteriovenous fistula (may cause delayed spinal cord compromise from epidural venous engorgement).

CAROTID INJURY

- controlled with direct pressure.
- carotid artery may be shunted or temporarily clamped while a primary or patch repair is performed.

- 12.6% of patients have a medially aberrant carotid artery, and 2.6% have a retropharyngeal carotid vessel (type III) where the artery is found anterior to the midline of the vertebral body – use alternate approach, such as one from the opposite anterior side or a posterior approach.



N.B. manipulation of carotid may result in a stroke secondary to either mechanical compression of artery or dislodgement of debris from a plaque. H: monitor temporal artery pulse after placement of self-retaining retractors (carotid occlusion from retraction)

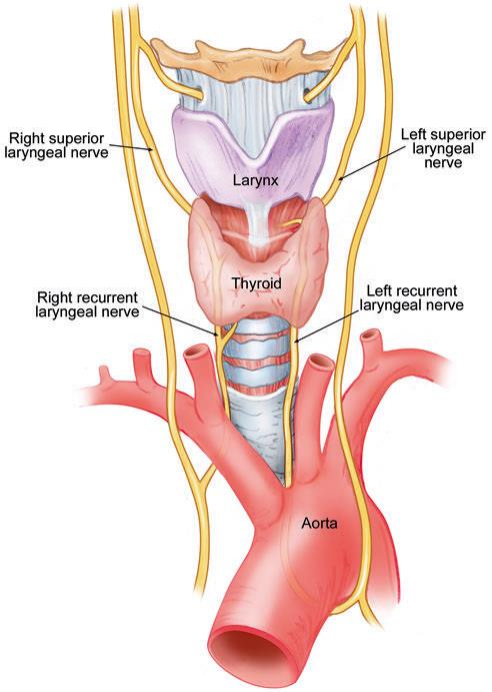
LARYNGEAL NERVE injury

SUPERIOR LARYNGEAL NERVE

- innervates **cricothyroid muscle**.
- **superior thyroid artery**, encountered above C4, is an important anatomic landmark for the superior laryngeal nerve.
- damage to this nerve - hoarseness, easy voice fatigue.

INFERIOR (RECURRENT) LARYNGEAL NERVE

n. laryngeus recurrent injury due to traction (≈ 2.4-3 %), esp. during reoperations;
N.B. minor hoarseness is common (50%) after anterior cervical surgeries!



Anatomy

- on left side, RLN loops under the arch of the aorta and is protected in the left tracheoesophageal groove.
- on right side, however, RLN travels around the subclavian artery, passing dorsomedially to the side of the trachea and esophagus - vulnerable as it passes from subclavian artery to the right tracheoesophageal groove.
  - right **inferior thyroid artery** is an anatomic marker for the RLN (nerve usually enters the tracheoesophageal groove, the point at which the inferior thyroid artery enters the lower pole of the thyroid).
  - anatomic variant (< 1%) where right RLN is **nonrecurrent** - travels directly from vagus nerve and carotid sheath to the larynx; if nonrecurrent nerve is encountered, it may be identified with a nerve stimulator and laryngoscopic examination of the vocal cords; if it cannot be retracted safely, it is best to ***abandon the procedure and use a left-sided approach***!

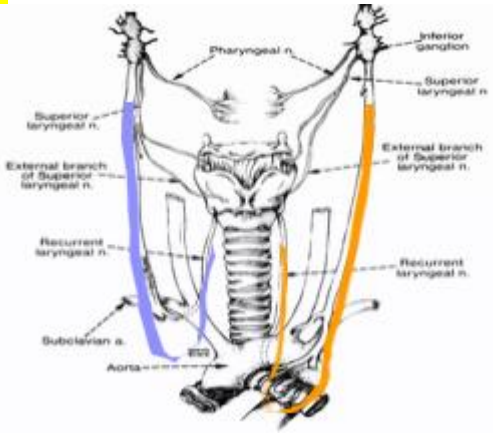
Clinical

- hoarseness, vocal breathiness or fatigue, weak cough, dysphagia, or aspiration.

Prophylaxis

- use nasogastric tube - allows easier identification of esophagus for protection, also allows localization of tracheoesophageal groove
- deflate ET cuff after placing retractor blades (decreased the rate of RLN temporary paralysis from 6.4% to 1.7% in one series)
- before performing reoperation on opposite side, preoperative direct laryngoscopy should be performed to identify existing occult vocal cord paralysis.

  N.B. bilateral recurrent laryngeal nerve dysfunction will result in airway occlusion once patient is extubated!
- do not use Bovie below C6.
- in the past, left-sided approach was preferred (esp. for lower levels) due to more unpredictable and oblique course of right nerve; however, later anatomic studies have refuted this variation, and clinical studies have demonstrated that the choice of operative side had no effect on the incidence of RLN palsy!



Diagnosis

- many patients have some degree of voice change after ventral cervical operations, a thorough investigation is not required in most cases.
- persistent hoarseness → **laryngoscopic examination** (vocal cord fixed in paramedian position).

Treatment

- immediate treatment is not usually required for a paralyzed vocal cord because, in most instances, the nerve has not been severed, and the condition will resolve with time.
- persistent hoarseness after several months can be treated with **injections** into vocal cord:
  1) **hemostatic gelatin (Gelfoam)** - temporary improvement and may be used as an interim measure pending spontaneous return of function.
  2) **Teflon** - permanent treatment if no recovery is expected.

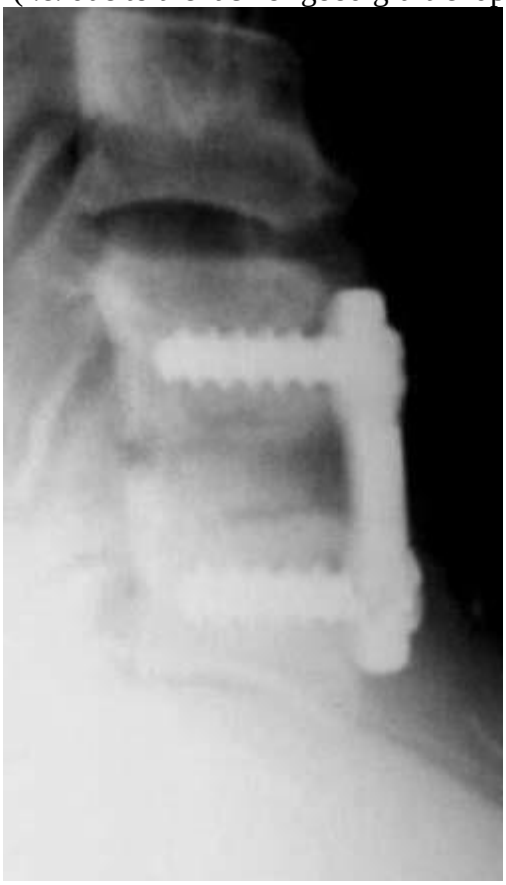
ADJACENT-LEVEL OSSIFICATION DISEASE (ALOD)

- osteophytes develop at the adjacent level

- patients with plates placed < 5 mm from the adjacent level disc have statistically significant increases in the frequency and severity of ALOD.

NONFUSION / PSEUDOARTHROSIS

- most nonunions are not a result of graft collapse but rather of failure of one of the two graft-body interfaces to ossify (i.e. due to the lack of good graft-endplate contact):



RISK FACTORS

1. Multilevel fusions
2. Steroid medication
3. Immunomodulator use
4. Noncompliance with postoperative immobilization
5. Allograft (vs. autograft)
6. Older age
7. Smoking

Martin et al. studied the effect of smoking in patients after ACDF using allograft bone with instrumentation. The reported fusion rate in nonsmokers for single-level procedures was 92%, compared with 85% in smokers. The difference for two-level procedures was more pronounced; the rate of fusion was 72% and 50% for nonsmokers and smokers, respectively. Cauthen et al. reported an overall fusion rate of 85% in nonsmokers and 77% in smokers after single- or multilevel ACDF using autograft and allograft bone without instrumentation. Additionally, Hilibrand et al. showed a 50% nonunion rate among smokers

who underwent multilevel anterior cervical discectomy with interbody fusion using an autograft without fixation, compared with 69% in the control group. Bose and colleagues, however, did not find a significant effect of smoking on fusion rate in their retrospective analysis of 106 patients. They reported a 96.67% and 97.83% fusion rate in smokers and nonsmokers, respectively, after multilevel ACDF with fixation.

Martin G.J. et al. Anterior cervical discectomy with freeze-dried fibula allograft. Overview of 317 cases and literature review. Spine 1999; 24: pp. 852-858
Hilibrand A.S. et al. Impact of smoking on the outcome of anterior cervical arthrodesis with interbody or strut-grafting. J Bone Joint Surg Am 2001; 83-A: pp. 668-673
Cauthen J.C. et al: Outcome analysis of noninstrumented anterior cervical discectomy and interbody fusion in 348 patients. Spine 1998; 23: pp. 188-192
Bose B.: Anterior cervical instrumentation enhances fusion rates in multilevel reconstruction in smokers. J Spinal Disord 2001; 14: pp. 3-9

CLINICAL FEATURES

- **axial pain** may or may not be present: some fibrous unions are stable and, thus, asymptomatic and do not require revision surgery; occasionally, however, enough motion will be present that axial neck pain will be present.
- if ACDF graft subsides, foramina narrow → **radiculopathy**

DIAGNOSIS

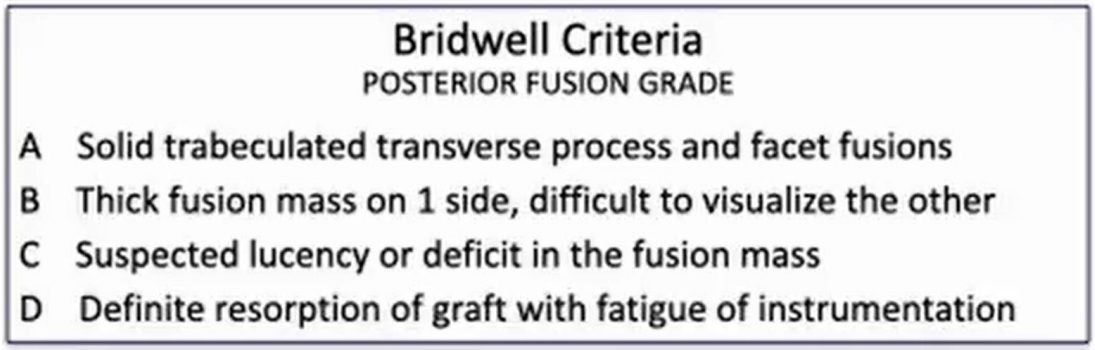
Dynamic X-ray
CT
SPECT (increased focal uptake)
Compare with immediate postop images!

Bridwell grading system – lumbar spine

Interbody fusion

Grade	Description
I	Fused with remodeling and trabeculae present
II	Graft intact, not fully remodeled and incorporated, but no lucency present
III	Graft intact, potential lucency present at top and bottom of graft
IV	Fusion absent with collapse/resorption of graft

Posterior fusion



PROPHYLAXIS

- External stimulator with Pulsed Electromagnetic Field

OrthoFix

Kevin T. Foley et al. Randomized, prospective, and controlled clinical trial of pulsed electromagnetic field stimulation for cervical fusion. Spine Journal, The, 2008-05-01, Volume 8, Issue 3, Pages 436-442

- randomized, controlled, prospective multicenter clinical trial, 323 patients → 163 in stim group (Cervical-Stim; Orthofix Inc., McKinney, TX), 160 in control group.
- patients were either smokers (> 1 pack per day) and/or were undergoing multilevel fusions.
- Smith–Robinson technique with allograft bone and an anterior cervical plate.
- F/U up to 12 months
- conclusions:
  - 6 months, the stim group had a higher fusion rate than the control group (83.6% vs. 68.6%, p=.0065).
  - at 12 months after surgery, the stimulated group had a fusion rate of 92.8% compared with 86.7% for the control group (p=0.1129).
  - there were no significant differences between the stim and control groups with regard to VAS pain scores, NDI, or SF-12 scores at 6 or 12 months.
  - no significant differences were found in the incidence of adverse events in the groups
  - study did not identify smoking to be a risk factor for pseudoarthrosis, as rates of fusion for smokers and nonsmokers were nearly identical in the control group.
  - strong trend toward a lower fusion rate for multilevel versus single-level ACDF in this study (64.5% vs. 84.0%, p=.0623).
  - PEMF stimulation appeared to hasten bone healing; it did not result in a significant advantage in terms of ultimate fusion rates or clinical outcomes in the overall study population.

TREATMENT

A) PCF (esp. for long-segment nonunions) – best solution
B) interfacet spacers (e.g. DTrax via MIS approach)
C) corpectomies and strut grafting.

- try to avoid going back anteriorly, esp. if done in OSH - screws might be stripped (need to drill - avoid metal shavings in esophagus by placing towels and sterile surgical lube), esophagus might be scarred to plate.

VARIOUS UNDERLYING PATHOLOGIES

CORD COMPRESSION

- use awake **fiberoptic intubation** (percutaneous tracheal needle anesthesia)
- **position patient awake** (if in pins, scalp anesthesia)
- use **neuromonitoring** (prepositioning baseline and after positioning) and TIVA (total intravenous anesthesia)
- arterial line - keep **MAP** > 85
- prophylactic **steroids**

OSTEOPOROTIC SPINE

See p. Op220 >>

RA

- cervical spine involvement (17-86% patients) - RA causes erosions in joints, loosening of ligament insertions:

A. **Anterior atlantoaxial subluxation** (most common manifestation of RA – may cause sudden death) – worsens with neck flexion – increased ADI; most important is PADI = posterior ADI (room for cord); indications for C1-2 fusion: PADI ≤ 14 mm, ADI > 6-10 mm, symptomatic
B. **Basilar impression** – needs reduction with halo traction (max 7 days) → decompression [C1, foramen magnum] and occiput-C2 fusion
   N.B. if *unable to achieve reduction* (20% patients) – after fusion proceed with transoral odontoidectomy (patient must be able to open mouth > 25 mm to avoid splitting mandible for access)
C. **C1–2 pannus**: chronic inflammatory granulation tissue - often recedes after surgical fusion (TNF-α inhibitors expedite it)
D. Subaxial subluxation

Cervical myelopathy disability indices for RA patients:

Steinbrocker's grading system for functional disability
I - Complete ability to carry out all the usual duties without handicaps
II - Adequate for normal activities despite handicap of discomfort or limited motion of one of the joints
III - Limited to little or none of the duties of usual occupation or self-care
IV - Incapacitated, largely or wholly bed-ridden or confined to a wheelchair with little or no self-care

Ranawat's neurological classification
I - No neurological deficit (normal neurological condition)
II - Subjective weakness with hyperflexia and dysaesthesia
III A - Objective weakness and long tract signs but able to walk
III B - Quadriparetic and non-ambulatory

What gives cord compression:
A. **Bone** – reducible (by traction) or non-reducible
B. **Soft tissue** – pannus*, lig. flavum infoldings
* may disappear after successful surgical spine stabilization

Treatment
- prognosis is very bad without surgery.
  Cervical instability is the most serious and *potentially lethal* manifestation of RA!
- indications for surgery: instability, myelopathy.
- preop 1 month "holiday" from gold medications (antimitotic → "zero" wound healing).
- rarely, ***transoral approach*** is used (if patient can open mouth to fit 2 fingers; if not – ***endoscopic approach***).

N.B. keep in halo postop for 2-3 months
N.B. RA cervical pathology may cause VA or anterior spinal artery compression – do CTA preop!

CARROT-STICK FRACTURE (ANKYLOSING SPONDYLITIS)

- routine use of CT and MR is recommended even after minor trauma.
- fractures are ***very unstable*** until healed – typically require surgical stabilization:
  Fixed-angle screws!!!

a) long segment rigid PCF – might preferable, esp. to achieve reduction (reduction under live fluoro using Mayfield, then long segment fusion, e.g. C2-Th2).
b) ACDF + PCF
c) ACDF with 3-level plate (so 4 screws above and 4 screws below fractured level)

N.B. stand-alone **anterior** fusion → **50% failure rate**; it might be difficult to achieve reduction (esp. of large distractions) via anterior approach

- very high (up to 30%) mortality regardless of treatment offered or surgical approach used; most important risk factor – age.

OPLL (OSSIFICATION OF POSTERIOR LONGITUDINAL LIGAMENT)

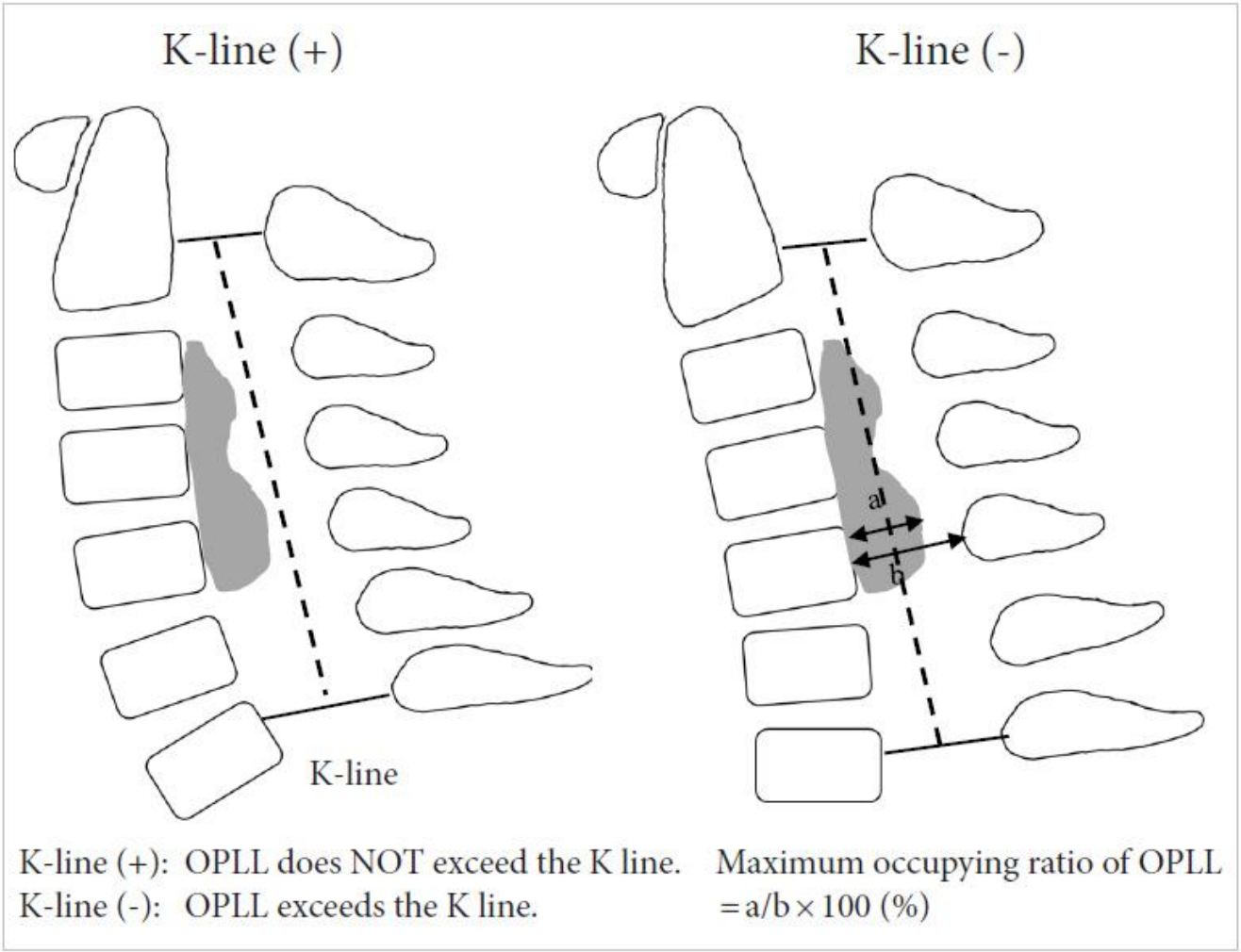
Etiology, clinical features, diagnosis – see p. Spin13 >>

- risk of spinal cord injury during neck positioning for intubation H: strong consideration should be given to awake nasotracheal intubation.
- surgical removal is often difficult – may involve dura (adherent to dura mater – warn patient about CSF leak!) – use cautiously high speed drill (some even leave a thin layer of bone on dura); durotomy incidence 16-25%
- if OPLL extends at C2 and above, impossible to remove calcified ligament – use laminectomy up to occipital bone decompression.
- anterior approach is generally favored, although laminectomy may be acceptable.
    - incidence of pseudarthrosis after corpectomy ranges 5–10% and increases with number of levels fused
    - anterior approach may cause some traction → neurological worsening (up to 10% cases)
- consider SSEP.
- C-collar at least for 3 months postop (halo-vest for > 2 level corpectomies).

Radiological parameters

C2–7 line ("K-line") - straight line connecting midpoints of spinal canal at C2 and C7 on a neutral cervical lateral radiograph.

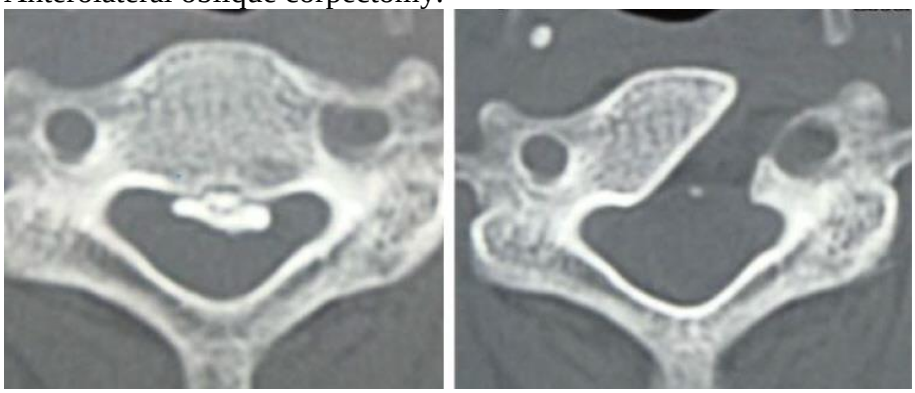
Maximum occupying ratio of OPLL is calculated from a sagittal CT:



Surgical options

A. **Anterior** resection for OPLL with or without wide corpectomy and anterior fusion; risks CSF leakage, spinal cord damage, instrumentation-related complications, and dyspnea or dysphagia.

Anterolateral oblique corpectomy:



B. **Posterior** decompression with or without relatively long fusion; risk of nerve root tethering or cervical foraminal stenosis or additional neurological deficit related to the remaining OPLL.
- in K-line (–), posterior decompression surgery would be unable to achieve a satisfactory posterior shift of the spinal cord and thus satisfactory neurologic improvement.
- poor surgical outcomes for laminoplasty in case of OPLL occupying ratio > 60%, and/or when ossified lesion is hill-shaped with sharp angulation of spinal cord.

C. **Combined** surgery.

DISH

Etiology, clinical features, diagnosis – see p. Spin13 >>
Indication for surgery - dysphagia due to esophageal compression by osteophytes:

a) patient is losing weight + not responding to dietary modifications
b) recurrent episodes of choking or (aspiration) pneumonia

Preop evaluation:

1) speech therapy consult for dysphagia
2) (modified) barium swallow study - site of obstruction
3) DVE (digital video esophagoscopy) - to rule out intrinsic esophageal disease.

Surgery - anterior removal of osteophytes with high-speed drill.

- careful protection of soft-tissue structures (esophagus, carotid sheath).
- no discectomy nor spine stabilization.
- counsel that post-op may be worse (from manipulation of esophagus and possibly disruption of some of the autonomic innervation) - significant chance will need a (temporary) gastrostomy
- improvement sometimes takes up to 1 year to occur.

COINCIDENT CERVICAL AND LUMBAR SPINAL STENOSIS

- usually managed by first decompressing cervical region, and later operating on lumbar region (unless severe neurogenic claudication dominates the picture); it is also possible, in selected cases, to operate on both in a single sitting.

OUTCOMES, PATIENT SELECTION, OUTCOME OPTIMIZATION

For problems **common with lumbar** surgery - see p. Op220 >>
Outcome Optimization (incl. ERAS) - see p. Op220 >>

Nurick grades of disability from cervical spondylosis:

Grade 0 - signs or symptoms of root involvement without myelopathy
Grade 1 - myelopathy, but no difficulty in walking
Grade 2 - slight difficulty in walking, able to work
Grade 3 - difficulty in walking but not needing assistance, unable to work full-time
Grade 4 - able to walk only with assistance or walker
Grade 5 - chairbound or bedridden

ACDF – neurosurgeons vs ortho-spine

Safwan Alomari et al. Early Outcomes of Elective Anterior Cervical Diskectomy and Fusion for Degenerative Spine Disease Correlate With the Specialty of the Surgeon Performing the Procedure. Neurosurgery 90:99–105, 2022

- 21 211 patients (elective ACDF) from the American College of Surgeons National Surgical Quality Improvement Program database (700 hospitals) were reviewed for 30-day outcomes
- propensity score matching was applied - demographic variables or comorbidities were ***comparable between the 2 cohorts*** – neurosurgeons vs ortho spine
- neurosurgeons performed around 3 times as many ACDFs when compared with orthopedic surgeons.
- patients undergoing the procedure by neurosurgeons had significantly more preoperative comorbidities.

In both groups (single-level/multilevel ACDF), patients operated on by neurosurgeons had longer operation time (133 vs 104 min/164 vs 138 min), shorter total hospital stay (24 vs 41

h/25 vs 46 h), and lower rates of return to operating room (0.7% vs 2.1%/0.6% vs 2.4%), nonhome discharge (1.2% vs 4.6%/1.0% vs 4.9%), discharge after postoperative day 1 (6.7% vs 11.9%/10.1% vs 18.9%), perioperative blood transfusion (0.4% vs 2.1%/0.6% vs 3.1%), and sepsis (0.2% vs 0.7%/0.1% vs 0.7%; P < .05). In the single-level ACDF group, patients operated on by neurosurgeons had lower readmission (1.9% vs 4.1%) and unplanned intubation rates (0.1% vs 1.1%; P < .05).

- in 2018, a graduating neurosurgery resident preformed an average of 493 spine procedures which account for 31.3% of total surgical cases, whereas a graduating orthopedic resident preformed 83 spine procedures accounting for 4.9% of total surgical cases.
- orthopedic spine surgeons are subjected to a postgraduate year fellowship intensely focused on spine surgery

AVOIDANCE OF LITIGATION

Eric W. Sankey et al. The medicolegal impact of misplaced pedicle and lateral mass screws on spine surgery in the United States, Neurosurg Focus 49 (5):E20, 2020

1. Very **detailed informed consent**; esp. include foot drop, bone quality may cause screw migration during surgery! Also blindness, metal sensitivity.
2. Do not operate **elective cases at night or with unfamiliar crew** – plaintiff will claim fatigue or unfamiliarity as factors.
3. **Navigated** screw placement (either computer- or robot-assisted)
4. Routine use of **monitoring** and **intraoperative imaging confirmation** (via 3D fluoroscopy or intraoperative CT; or, at the very least, AP and lateral views on XR) → **intraoperative revision**
   Revision may avoid iatrogenic neurological deficits due to prolonged nerve root compression or improved stability of construct!
5. For breaching screws, do not use **terminology** such as "malpositioned" or "misplaced"; instead say "screw migrated / medialized / lateralized [due to bony pathology]"
6. If need to take patient back to OR for revision, state "During surgery everything felt perfect, however, I have concerns [of screw migration] on XR; XR is not a reality but only a hint of reality, thus, need to test in OR" [may give analogy of human silhouette behind shower curtain – only lifting curtain and looking at human allows to identify the person]
   Judge "Who placed the screw?" Answer "Pathology. If not patient's pathology, screw would not be here"

- neurosurgeons spend an average of 27.2% of their careers in an open lawsuit.
- 88% of physicians in high-risk specialties, like neurosurgery, are involved in a lawsuit by age 45, increasing to a 99% by 65 years of age.
- 50% of physicians exhibit at least a temporary loss of self-esteem after a malpractice claim, and at least 25% experience depression.
- median time to judgment is substantial, spanning over 4.5 years from the time of surgery!
- majority of verdicts are found in favor of the defendant (surgeon), but > 30% of cases are in favor of the plaintiff (patient), resulting in average inflation-adjusted payouts of over $1.2 million per claim (in 2020).

ANTERIOR NECK APPROACH

BMP is contraindicated in neck anteriorly!

INDICATIONS

Cervical spondylosis with myelopathy / radiculopathy – see p. Spin13 >>

CONTRAINDICATIONS

Patients whose careers prohibit any risk for voice alterations may best be treated with posterior foraminotomies or laminectomies (left-sided approach has lower risk of recurrent laryngeal injury).

PREOP

- check **vocal cords** if going to operate on someone who had anterior neck surgery on opposite side; alternative – use vocal cord EMG (commercially available ET tube with mounted electrodes).
- Dr. Cameron and Dr. Broaddus give 10 mg of DEXAMETHASONE to everybody – decreases postop dysphagia from 72.5% to 40%; slows down fusion (from 57% to 31% at 6 months) but final fusion rates are the same (74% vs. 72% at 12 months).

  "Dexamethasone Improves Outcomes in Spinal Fusion" Congress of Neurological Surgeons (CNS) 2013 Annual Meeting. Abstract #158. >>

  Dr. Kazemi sprays DepoMedrol on esophagus at the end of case.
- Dr. Rivet uses fluoro and microscope (80% of the time). N.B. fluoro shot for incision planning and leave in (drape together with field draping).

POSITIONING

- slight reverse Trendelenburg position.
- Rick doesn't use esophageal tubes (temperature probe, OG tube) – increases risk of esophageal damage; but orogastric tube can help with identification of esophagus in reoperative cases.
- arms tucked and padded at sides; wrap arms in gel pads to protect ulnar nerve.
- head on padded horseshoe head holder
- head in extended* position (IV saline bag[1] transversely underneath neck** not shoulders[2]).

  *if myelopathic, keeping neck in neutral position without additional manipulation

  **to support neck from behind during procedure (not for extension); therefore, shoulders and neck should be above table

  [1]Dr. Mathern prefers folded towels

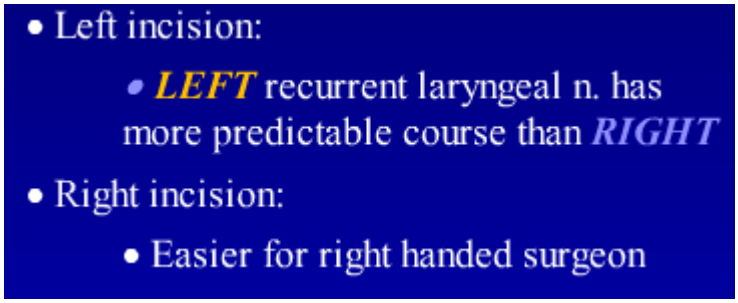
  [2]Dr. Day places roll longitudinally between scapulae - allows shoulders fall backwards.
- Drs. Graham, Ward, Simon, Cameron, Mathern use **5-10 pounds of in-line cervical traction** (not always necessary!!!); pad straps over cheeks to avoid pressure ulcers.

  Dr. Broaddus does not use – due to risk of pressure sores on chin.

  Dr. Cameron does not use – no benefit (unless need to move away "second chin").
- optional - place hemostat on skin (along natural skin crease) → preoperative fluoroscopy shot - to plan skin incision over desired vertebral body.

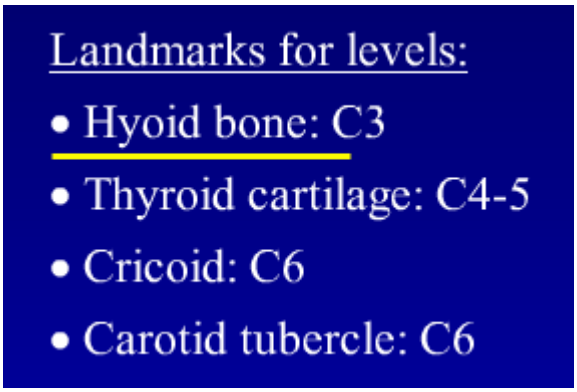
INCISION

- some experts always use **left-sided approach** - lower chances of recurrent laryngeal nerve injury. *see above >>*

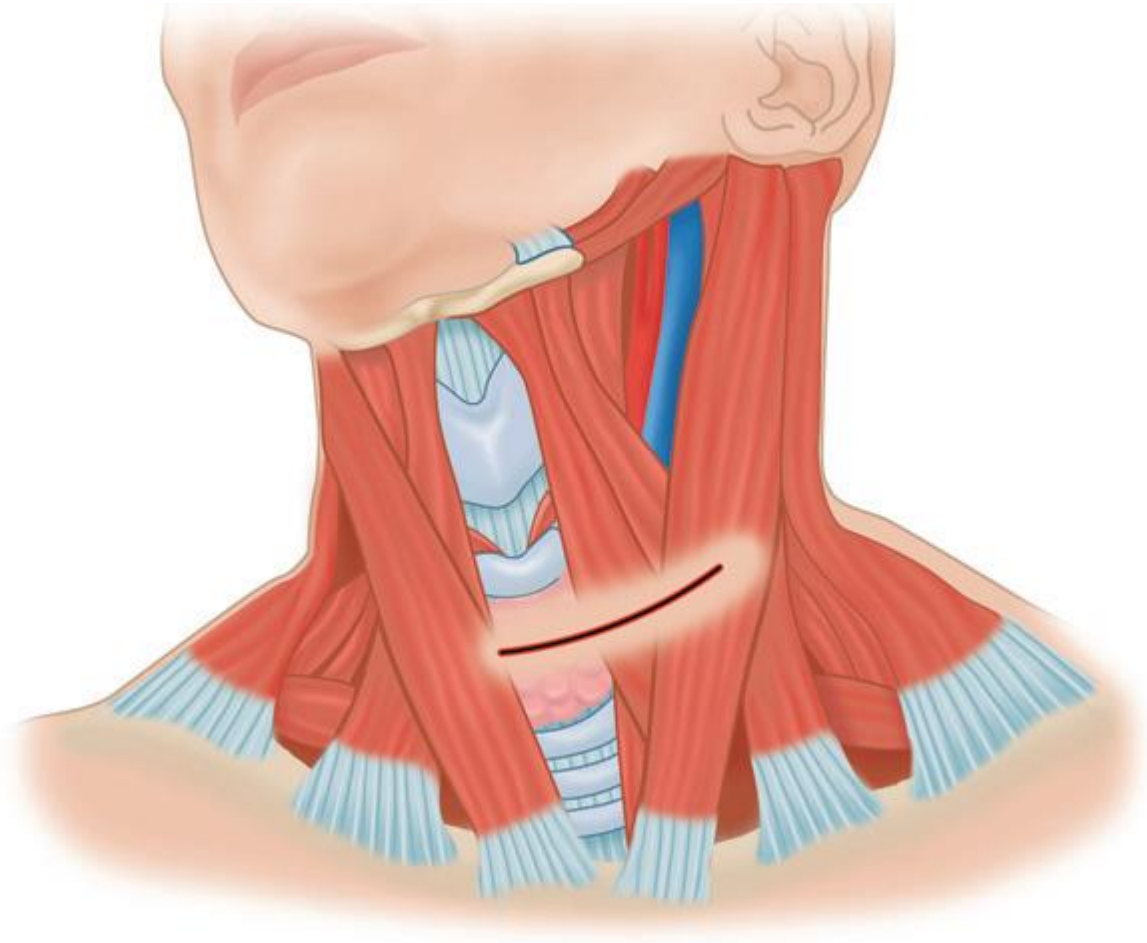


- transverse skin incision along skin crease (suitable for up to 3-level discectomies); may ***palpate carotid tubercle on C6*** to select incision height (also look at MRI – what levels skin folds correspond).
  Dr. Rivet uses incision across midline!
  Dr. Cameron uses "carotid" skin incision along anterior sternocleidomastoid border for 4-level ACDF; opens platysma along fibers
  For ***trauma cases***, try to use "carotid" skin incision (transverse incision may interfere with tracheostomy if patient will need one)

C1-3—1 cm below angle of the jaw
C3-4—hyoid bone
C4-5—top of the thyroid cartilage
C5-6—bottom of thyroid cartilage
C6-7—top of cricoid cartilage
Chassaignac's tubercle on the transverse process of C6
C7-T1—bottom of cricoid cartilage

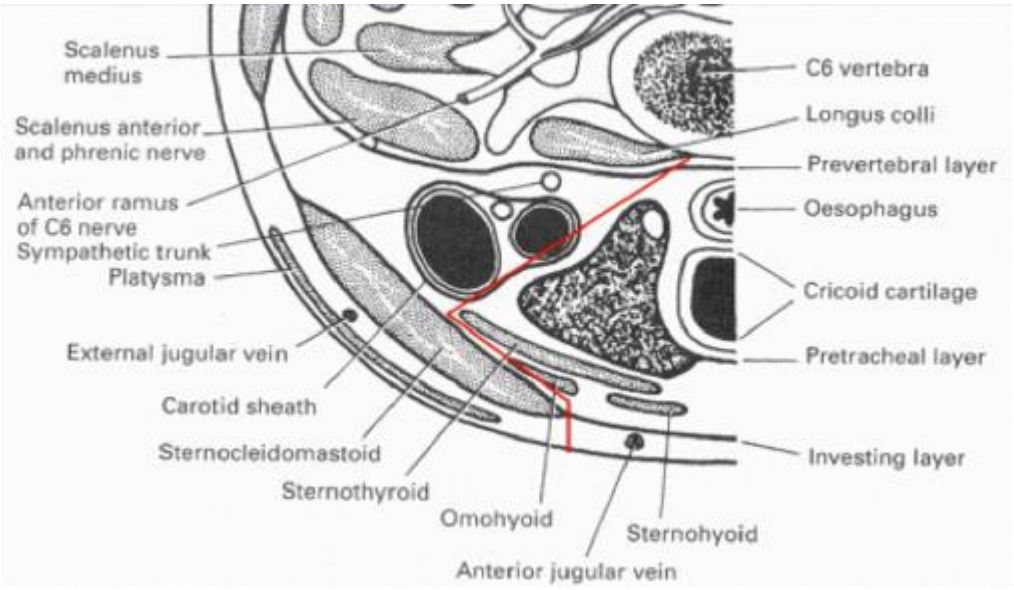


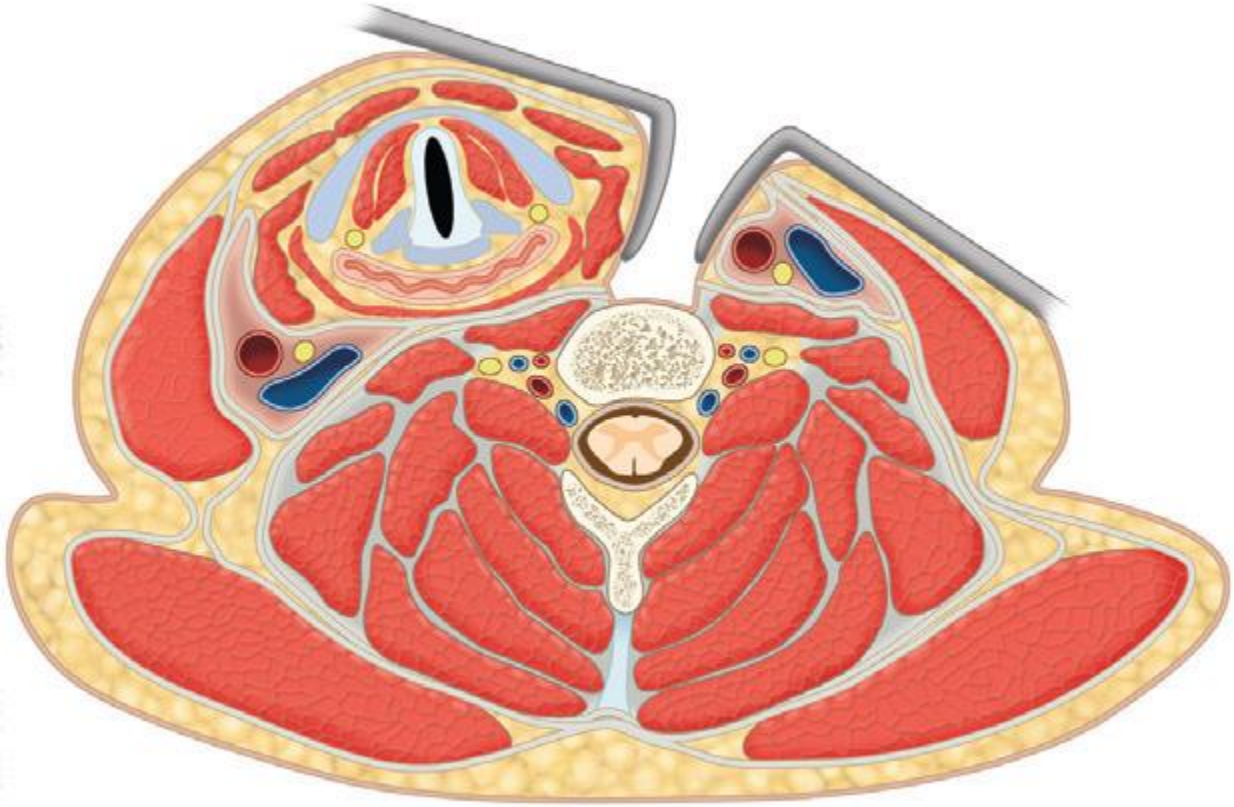
- if it is difficult to ascertain level accurately, mark incision slightly superior to estimated level of pathology; it is easier to expose inferiorly than superiorly.

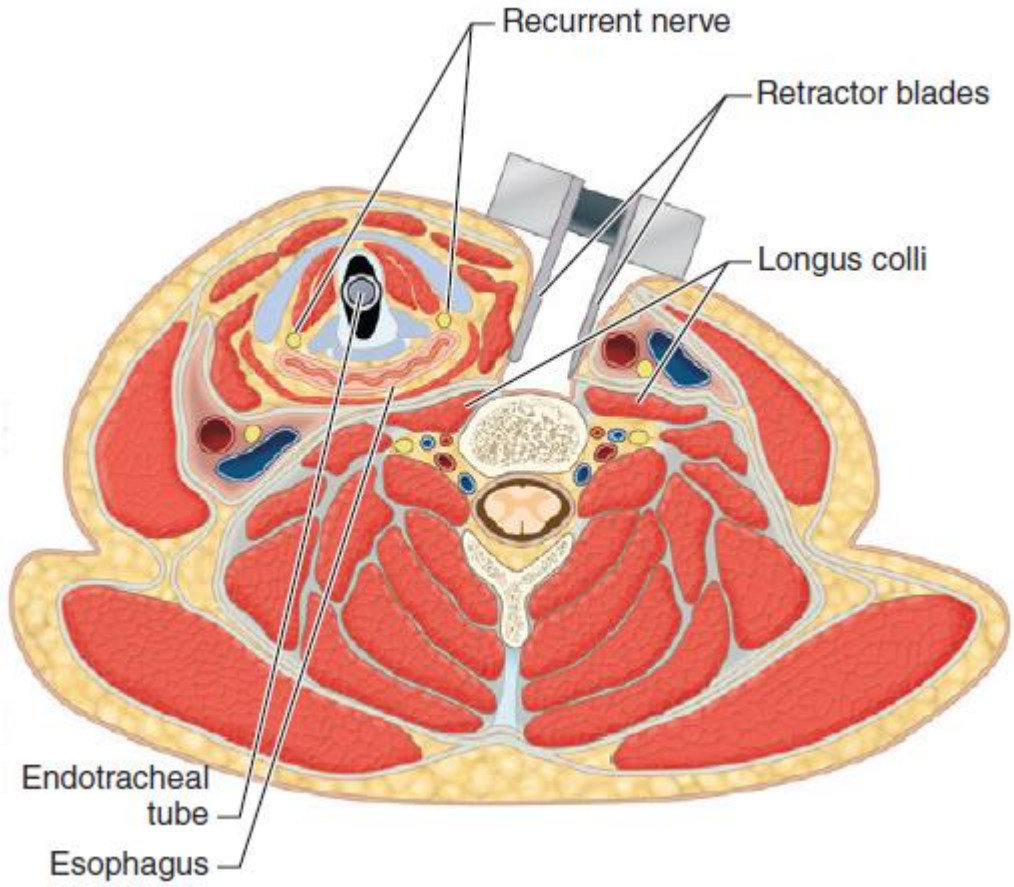


DISSECTION

- dissect subcutaneous tissue down to platysma – with Metz scissors and DeBakey forceps
- split platysma – with scissors or Bovie* (over scissors placed underneath platysma).
  *Dr. Graham likes scissors; Dr. Rivet uses Bovie
- use bipolar cauterization for hemostasis.
- important to mobilize tissue planes (superiorly and inferiorly) below platysma – allow to access more levels via shorter incision.
- sharply dissect avascular plane medial to SCM; if EJ is encountered dissect it from SCM and retract medially (if bleeds → vascular clip / sacrifice).
- blunt dissection with Kittner dissector and Cloward retractor medial to carotid sheath - until anterior vertebral fascia encountered which is swiped with Kittner as well.
  - avoid swiping up and down widely – creates potential space for hematoma
  - for upper cervical levels, make sure you are lateral to strap muscles (otherwise will be difficult to reach those levels).
  - for lower cervical levels, make sure you are inferior to omohyoid (practically, never needed).
- deflate and reinflate the endotracheal tube cuff following retractor placement – helps cuff to reposition (esp. important if using immobile table-mounted retractor).


Scalenus medius
Scalenus anterior and phrenic nerve
Anterior ramus of C6 nerve
Sympathetic trunk
Platysma
External jugular vein
Carotid sheath
Sternocleidomastoid
Sternothyroid
Omohyoid
Sternohyoid
Anterior jugular vein
C6 vertebra
Longus colli
Prevertebral layer
Oesophagus
Cricoid cartilage
Pretracheal layer
Investing layer





LOCALIZATION

- see above >>

CLOSURE

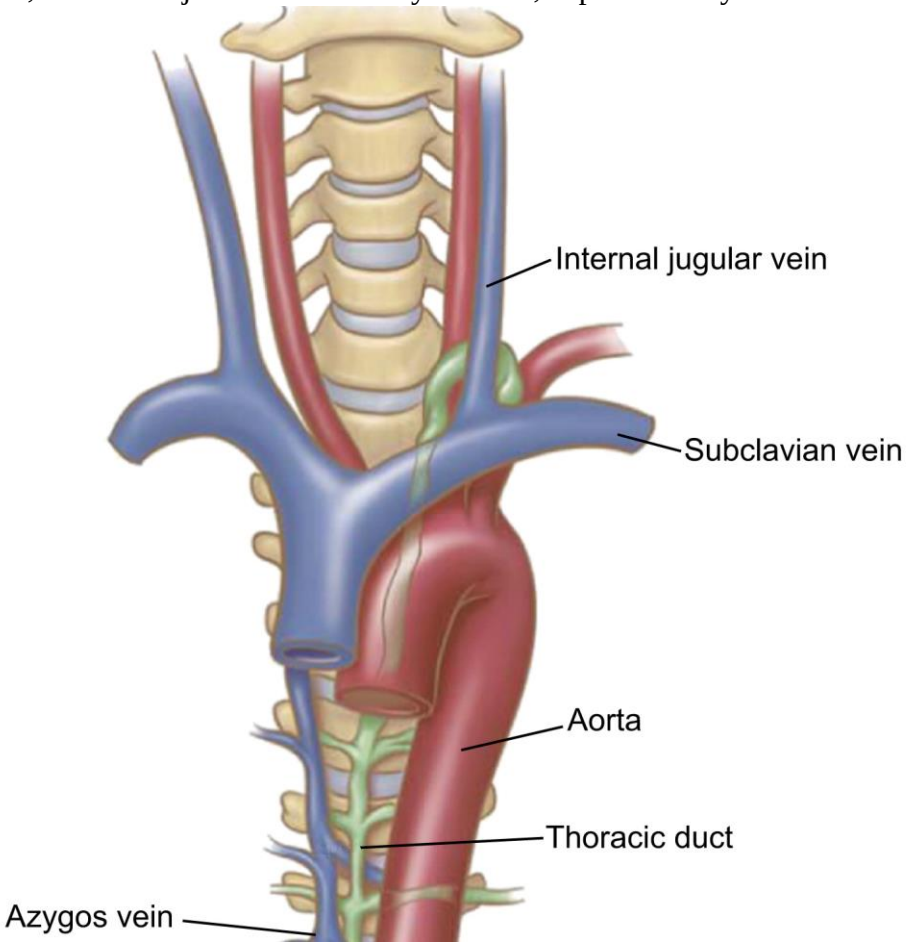
- irrigate with bacitracin-containing solution.
- inspect esophagus – repair if injured.
- drain directly overlying vertebrae, medium Hemovac.
  Dr. Graham likes drain to exit below incision – more comfortable when exits collar
  Dr. Rivet uses drain only occasionally
- platysma reapproximated with 2-0 Vicryl.
- subcutaneous layer with skin closed with rare 4-0 Vicryl in interrupted inverted manner (esp. Dr. Rivet uses thin sutures).
- Mastisol and Steri-Strips.
- Aspen cervical collar for 6 weeks (apply while still intubated); Dr. Simon may not use collar; Dr. Cameron does not use collar for any ACDFs; Dr. Broaddus does not use collar for 1-level ACDFs.

COMPLICATIONS

(11-13.6%)

1) **dysphagia** (2-67%) *see above >>*
2) **esophageal injury** (0.02-4%) *see above >>*
3) hematoma (6%)
4) cardiopulmonary events
5) **hoarseness** (0.21%); *n. laryngeus recurrent injury* due to traction (≈ 2.4-3 %) *see above >>*

6) **thoracic duct**, which if injured results in chylothorax, is present only on the left side:



7) injury to **sympathetic chain** → Horner syndrome. H: do not dissect lateral to longus colli muscles and elevate muscle subperiosteally, do not overdistract.
8) **vertebral artery injury** – study MRI / CT carefully (VA medial to pedicle is a contraindication for anterior discectomy) *see above >>*
9) **carotid injury** *see above >>*

ANTERIOR DISCECTOMY

For indications - see p. Spin11 >>

N.B. preoperatively ***check vertebral artery anatomy*** – at what level enters foramen transversarium, what is the course (if suspicious → order CTA – better than intraop VA injury)!

- intervertebral space is marked with double bent spinal needle → XR → keep eye on needle, take it out and immediately mark disc space with Bovie.
- bilateral longus colli muscles taken out with **protective-tip Bovie** cauterization (Rick leaves tissue line in midline for orientation; Dr. Rivet marks midline while longus colli still intact – midline is very clear) – coagulate anterior disk surface, then between muscle and vertebra (retracting muscle edge laterally with Bovie tip and staying all the time below* muscle).
  *if above – risk of Horner's syndrome (sympathetic chain)
- Shadow-Line / Boss hand-free retractor (serrated blade goes laterally, smooth – medially not to injury esophagus).
  - when retractors are placed, deflate and then reinflate endotracheal tube cuff - recenters endotracheal tube within larynx and may reduce incidence of recurrent laryngeal nerve injury.

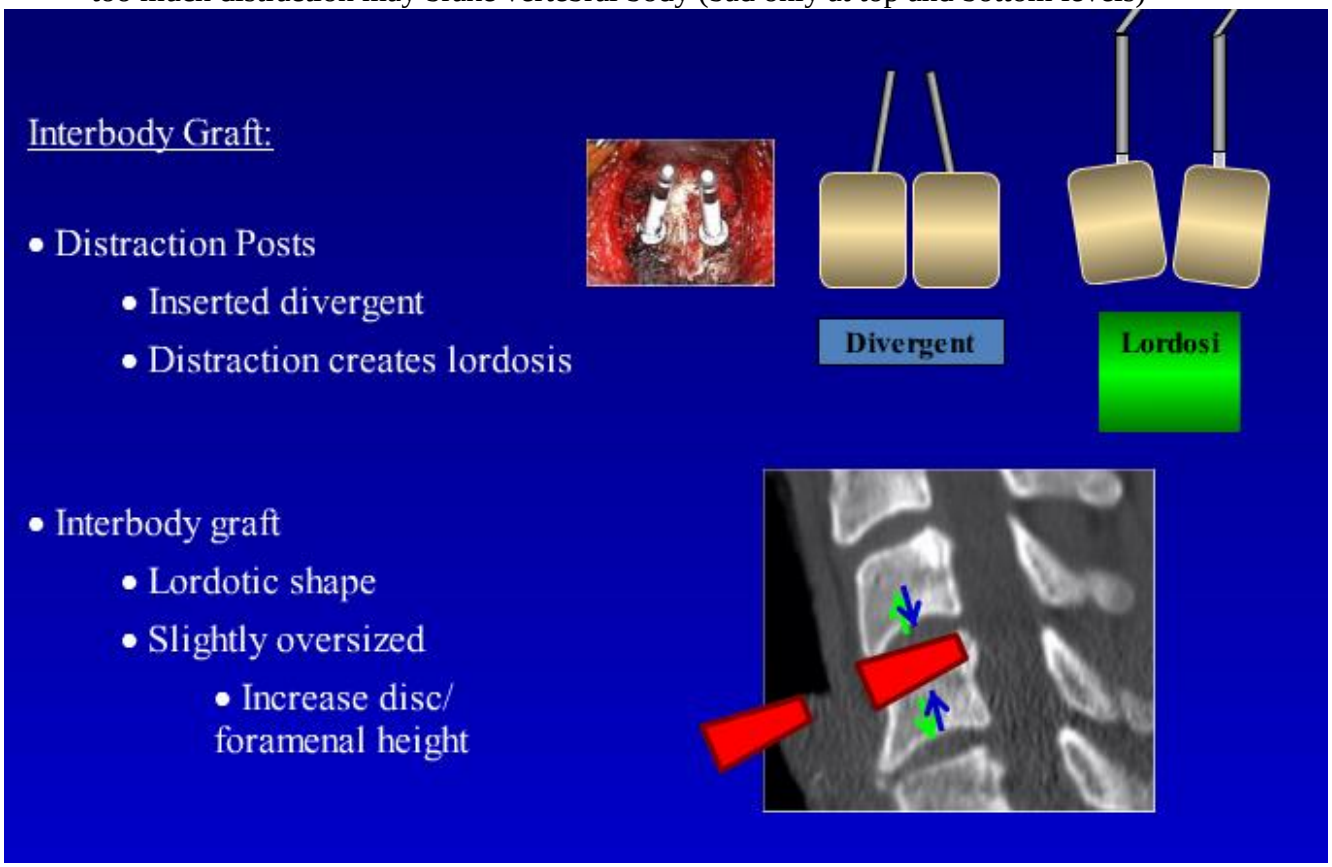
  - when significant retraction is needed, visual inspection of esophageal undersurface can identify small tears that can be primarily repaired with absorbable sutures.
- annulotomy (No. 15 blade; Dr. Rivet never uses blade – too easy to plunge down on the cord) → **superficial diskectomy** (with pituitary rongeur).
- two different techniques for **deep diskectomy**:

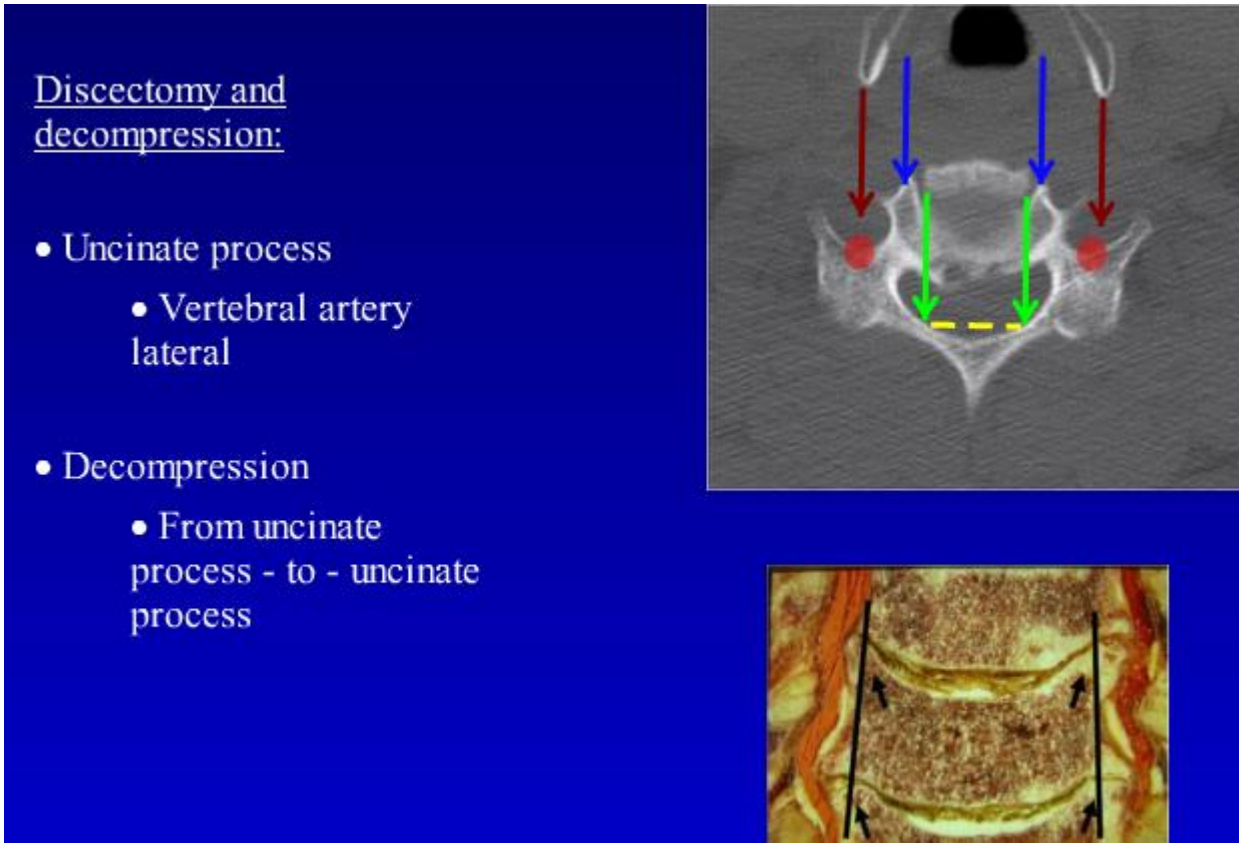
SMITH-ROBINSON TECHNIQUE

(Dr. Ward, Broaddus, Mathern, Simon)

Caspar pins screwed into centers of vertebral bodies → insert Kerrison in disk space and rotate (to loosen disk space and uncovertebral joints) → in situ distraction with Caspar distractor → deep diskectomy with 2-0 and 3-0 curved curette + 2- and 3-mm Kerrison.

- work to well expose posterior lip of vertebral body (and remove osteophytes, if needed)
- place pins in parallel (or slightly convergent at top and bottom levels – upon distraction help to open posterior portion of disc space)
- too much distraction may brake vertebral body (bad only at top and bottom levels)





- average width of the spinal cord is relatively constant in the subaxial spine (13-14.5 mm)
- average interforaminal distance (vertebral artery) increases from C3 to C6 - wider decompression is safer at the more caudal levels.
- since the vertebral artery is located 0.8-1.6 mm from the lateral tip of the uncinate process + decompression to the upward curve of the uncovertebral joint is often sufficient for symptom relief = avoiding aggressive removal of uncinate joint is prudent when pathology is appropriate.

CLOWARD TECHNIQUE

(Dr. Graham in 99% cases, Young)

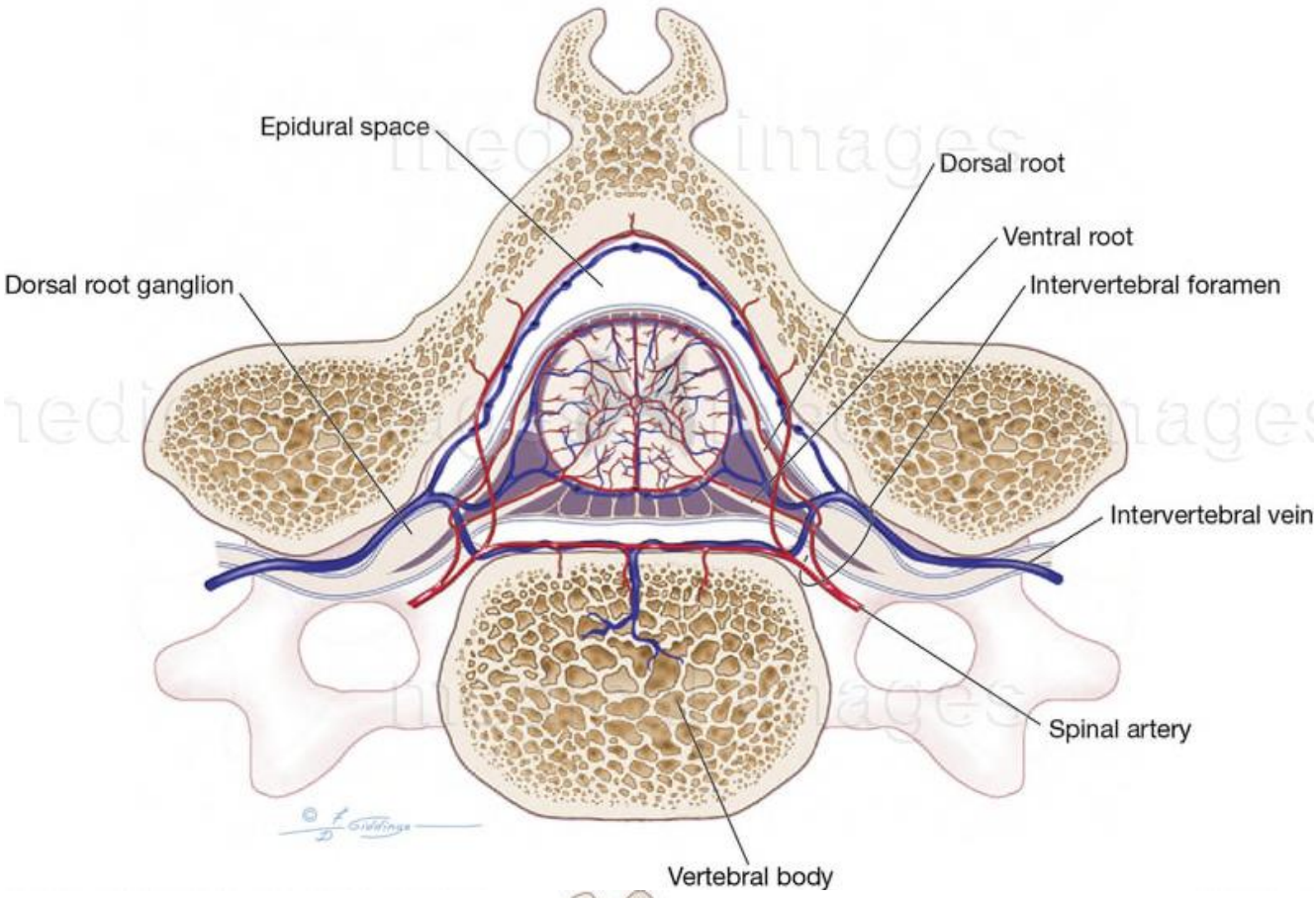
- disadvantages:
  1) more difficult to achieve lordosis than with Smith-Robinson
  2) native bone ingrowth in center of dowel lags a lot (long distance for cells to migrate); sometimes center of dowel disintegrates
- disk space drilling – tuck **Cloward drill guide** over center of disk space (or disk space intersecting between upper 2/3 and lower 1/3 of field seen); may use instrument in disk space while placing drill guide (helps center drill guide; mark midline with pen!!!!) → drill incrementally (first leave 3 threads visible and drill; after removing drill inspect disk space through lumen of drill guide – make sure disk space is in center, plus, if still bone visible; advance by 1-2 mm until no bone visible, i.e. stop within 1 mm of posterior cortical aspect);
- if drill guide becomes dislodged, there is cylinder guide to help reposition drill guide.
- trim cadaver bone dowel to 12 mm length; impact it while anesthesiology applies traction.
- Dr. Mathern - prepare disc space completely in Smith-Robinson way, then use special guiding instrument to guide drill guide and do drilling; dowel has to countersink 2-3 mm.

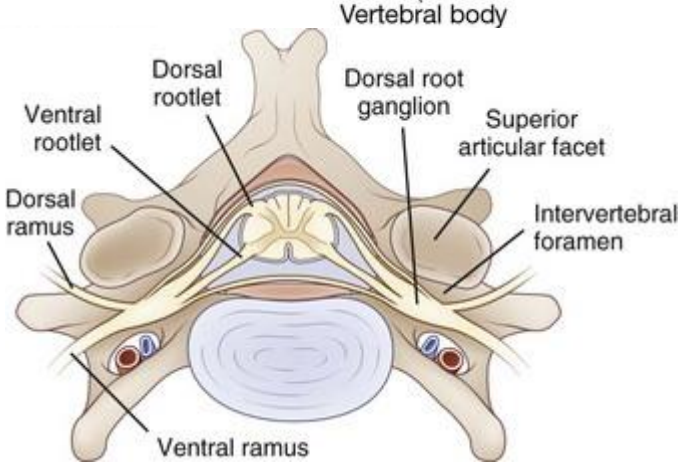
OTHER ASPECTS

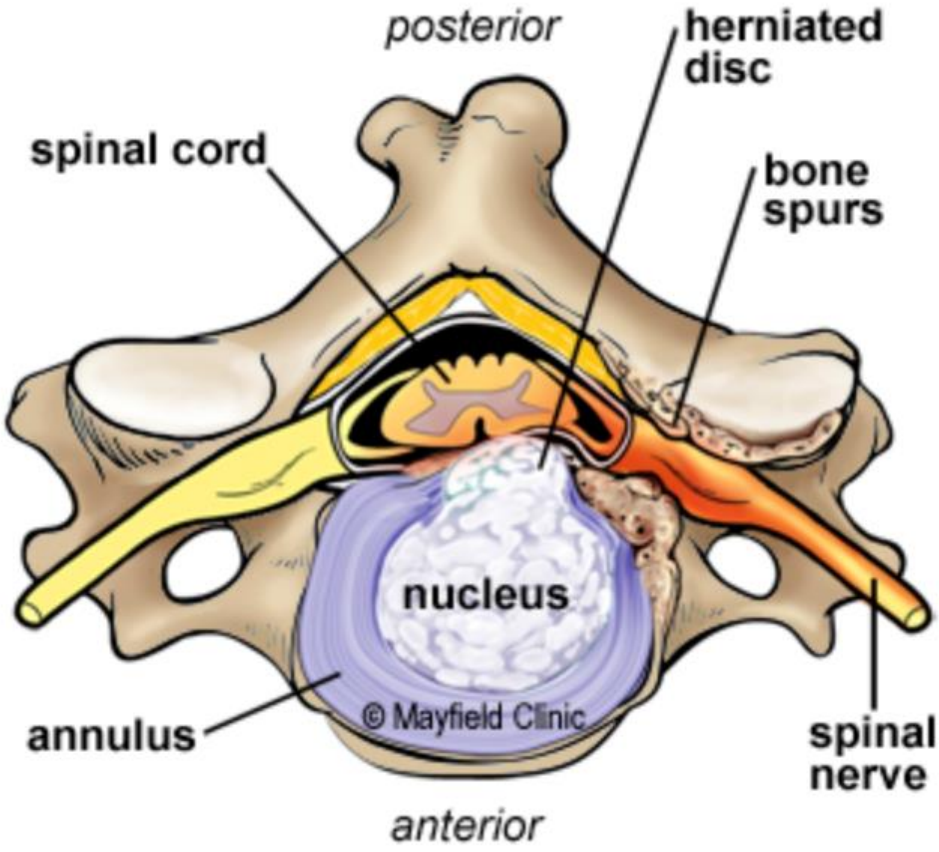
- PLL may be removed, esp. Dr. Simon but not for Dr. Tye; Dr. Mathern, Dr. Cameron try to avoid it to decrease risk of epidural hematoma esp. not to go too lateral into foramen – does not give any benefit (foramen is mainly opened by disk height restoration) - foraminal bleeding plexus is venous

– use FloSeal on both sides of graft; if vertebra is wide then blood should easily escape anteriorly along sides of graft.

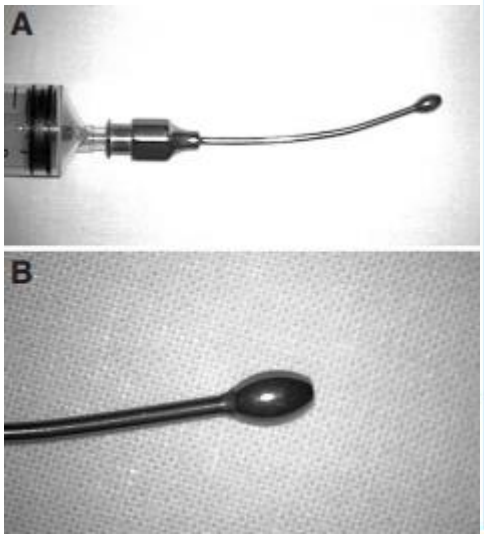
- remove anterior osteophytes with Kerrison / Leksell to provide optimal bone-plate interface
- neural foraminal decompression: use 2 mm Kerrison; check with blunt nerve hook (Dr. Holloway thinks it may damage nerve and discourages that):







- Drs. JRC, Rivet, Simon use microscope.
- Dr. Simon uses SSEP and MEP.
- disc fragments behind vertebral body:
  a) use 45º curette to cut posterior vertebral body; use blunt nerve hook "to fish out" disc fragments.
  b) Cloward technique
  c) corpectomy
- hemostasis for epidural venous bleeding – inject powerfully 5-10 mL of saline into epidural space (between dura and bone) – bleeding stops:



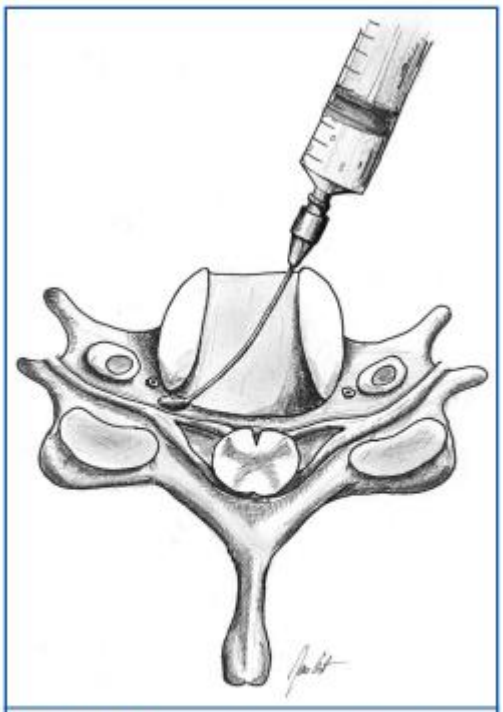


FIGURE 2. *Schematic drawing of the technique showing the atraumatic tip of the cannula being placed between the dura and the bony edge, with the saline being powerfully injected into the epidural space.*

ANTERIOR INTERBODY ARTHRODESIS

NASS Clinical Guidelines for Cervical Radiculopathy from Degenerative Disorders (2010):
The addition of an interbody graft for fusion is suggested to ***improve sagittal alignment*** following ACD. Both ACDF with and without a plate are suggested as comparable treatment strategies, producing ***similar clinical outcomes and fusion rates***, in the treatment of single level cervical radiculopathy from degenerative disorders. The addition of a cervical plate is suggested ***to improve sagittal alignment*** following ACDF (grade of recommendation: B).

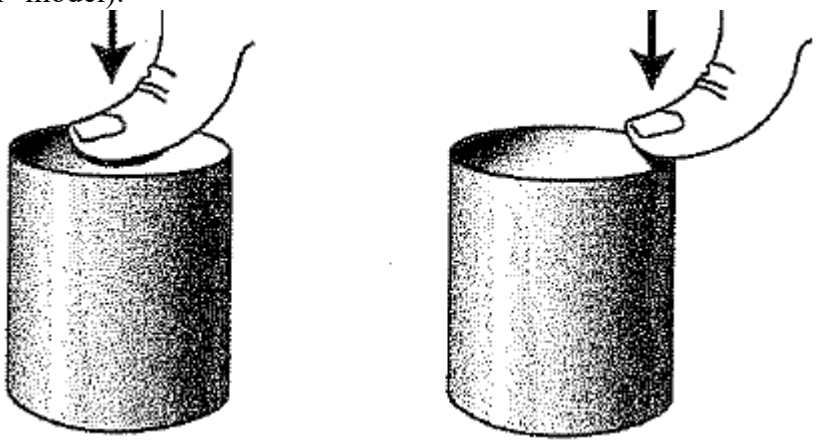
Indications for axial neck pain – see p. Spin19 >>

SMITH-ROBINSON TECHNIQUE

- use curette to scrape endplates; Dr. Rivet uses drill extensively!
- use rasp to make rough surface (release Caspar distraction for this).
  Remove end plates to expose blood-rich cancellous bone!
- remove all bone distraction instruments.
- use trial to find appropriate graft height – do not oversize graft! (easy to do it in trauma cases with disrupted posterior elements – pin head in Mayfield for trauma cases to minimize this!)
- place interbody graft (e.g. Cornerstone graft); if needed, use impactor:

- mechanically, graft should extend as far posteriorly as safely possible.
- release distraction and remove Caspar pins (bone wax – "witch hat / Madonna tits / rat poop" – into bleeding holes).
- if working on > 1 levels, do the same for next level (always start on worst level).

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



MATERIALS FOR CAGES

1. Cadaver bone
2. PEEK
3. Titanium

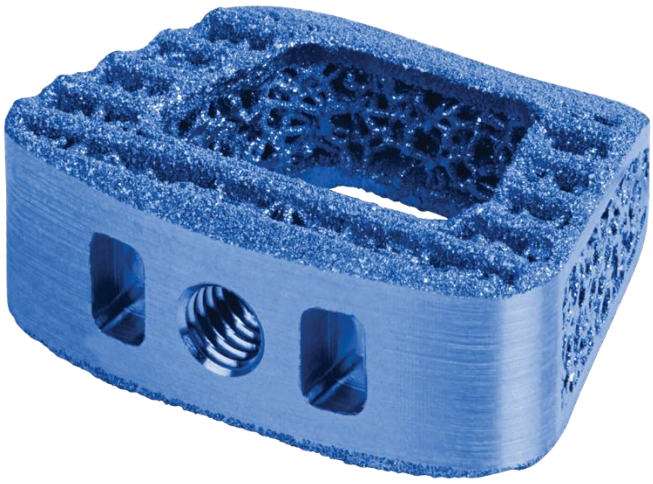
- porous PEEK technology - higher osseointegration capability when compared to solid PEEK, solid titanium and porous titanium in cell culture → higher fusion and quality of fusion grades at 12- and 26-weeks post-op when compared to solid PEEK.

BRANDS OF CAGES

HEDRON C (GLOBUS)

- 3D printed titanium interbody spacers feature a biomimetic porous scaffold:

Footprint: 12x14, 14x16, 15x18 mm
Heights: 5, 6, 7, 8, 9, 10, 11, 12 mm
Lordosis: 0°, 7°, 12°, 15°, 20°



DEPUY

VG2® Cervical Allograft
HEALOS® Bone Graft Replacement

ILIAC CREST

- lateral to anterior superior iliac spine to avoid inadvertent damage to lateral femoral cutaneous nerve.

I-FACTOR™ BONE GRAFT (CERAPEDICS)

- composite bone substitute material consisting of P-15 synthetic collagen fragment adsorbed onto anorganic bone mineral suspended in an inert biocompatible hydrogel carrier.
- results in ACDF - similar outcomes compared to local autograft bone at 2 yr following surgery.

ENDOSKELETON® NANOLOCK (TITAN SPINE)

Barbara Boyan, Ph.D., Dean of the School of Engineering at Virginia Commonwealth University and an investigator in various Titan Spine studies, said, "The nanoLOCK™ surface topography is far different than what is found on titanium-coated PEEK implants. In addition, the nanoLOCK™ surface is not created by applying a coating, but rather is formed by a **reductive process of the titanium** itself. This eliminates the potential for delamination, which is a concern for products with a PEEK-titanium interface."

CLOWARD TECHNIQUE

- **Cloward dowel rod allograft** is soaked for 30 seconds in saline, trimmed (to ≈ 12 mm), and tapped into the defect.
- drill – 10 mm, dowel – 12 mm
- Caspar pins are not used, so to accomplish distraction, may insert 3 mm Kerrison through drill guide, rotate it (so disc space distracts), then tap drill guide into place (this way drill guide spikes engage and keep disc space distracted)
- Caspar pins are not used, so anesthesia pulls on Holter sling during dowel placement.
- bits of bone graft may be packed laterally.

ANTERIOR INSTRUMENTATION

Obsolete technique – **ACDF without instrumentation**; mainly for Cloward technique (Smith-Robinson – risk of graft migration).

PLATE

Examples of plates: http://www.medicalexpo.com/medical-manufacturer/anterior-cervical-plate-7867.html

- select appropriate length of anterior cervical plate:
  When plate is properly sized and positioned:
  - superior screw holes align with inferior 1/3 of superior vertebral body.
  - inferior screw holes align with superior 1/3 of inferior vertebral body.
- plates have oblique holes at top and bottom level, so that even fixed angle screws will go oblique.

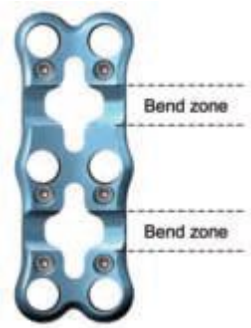
Plate lengths:
1-level Cloward (Dr. Graham) – use 23 mm
1-level – start with 20 mm
2-level – start with 40 mm
3-levels – start with 60 mm
4-level – start with 75-80 mm

DEPUY SKYLINE PLATE

For C2 to C7 (i.e. 1-5 levels)
Thickness = 2.5 mm Width = 16 mm Waist = 14 mm
Length 12 to 105 mm
Plate contouring:

- SKYLINE plate is pre-lordosed, reducing need for contouring.
- additional contouring may be accomplished by inserting plate into plate bender and squeezing handles.

- SKYLINE plate is provided with bend zones and may not be bent across CAM LOC mechanism



- plates should be bent in one direction, kyphosis or lordosis only.
- never reverse bend as this may create micro fractures that will weaken plate.
- short plates of each level do not have bend zones and therefore cannot be bent.

ATLANTIS VISION PLATE (MEDTRONIC)

- older; locking less robust and gives some excuse for missed screw angles.

ATLANTIS ELITE PLATE (MEDTRONIC)

- newer (locking screw same driver as for screws)

ZEVO (MEDTRONIC)

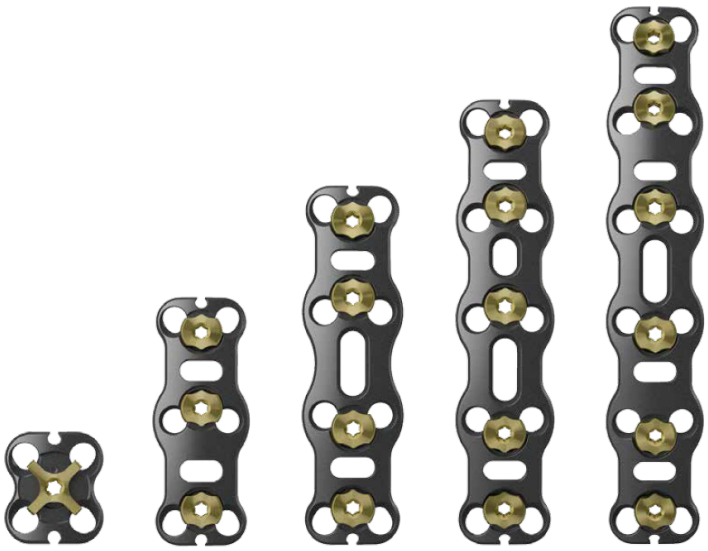
Zevo

Anterior Cervical Plate System

Find a New Direction

Over 30 years of experience in the cervical market combined with current treatment trends has been designed into the new Zevo Anterior Cervical Plate System:

- Combination of short-plate options and hyper-screw angulations to avoid impingement on adjacent levels
- Low-profile plate thickness allowing for treatment of up to 5 levels of degenerative pathologies
- Cortical screw technology designed to maximize bone purchase; featuring an enhanced driver interface
- Versatile design featuring visualization windows,* slots for additional screw fixation, and unique pre-fixation options
- Instrumentation designed in parallel with implants to take advantage of the system features
- Visual, tactile lock

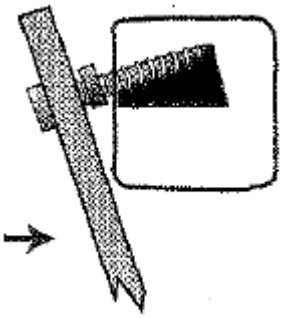


DIVERGENCE™ ACF SYSTEM (MEDTRONIC)

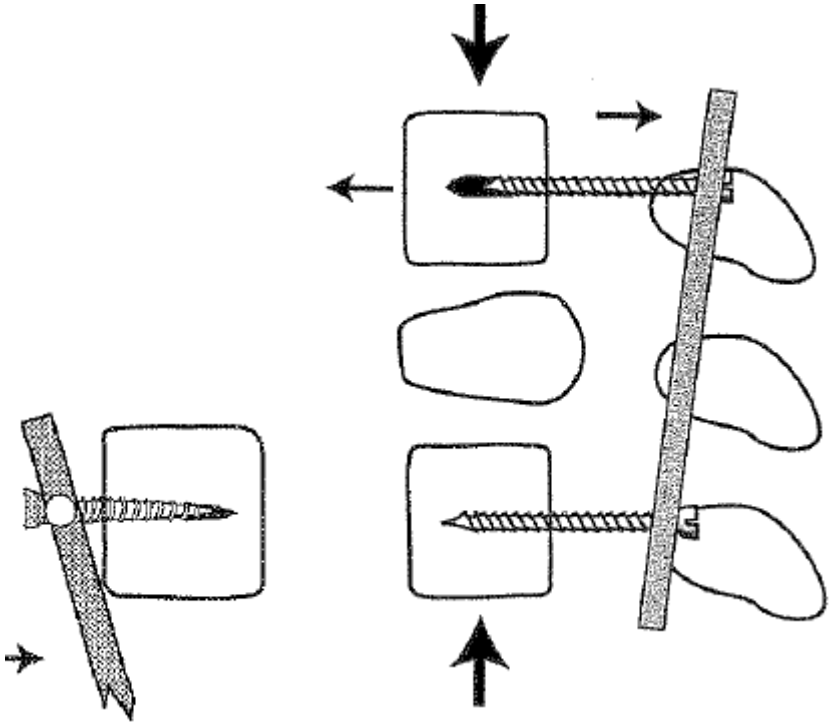
- for one level ACDF - plate and interbody cage in one.
- ***laterally-divergent screws*** - requires less retraction compared to the traditional medially-convergent screw insertion techniques.

SCREWS, TRAJECTORIES

Constrained screws provide less angulation and construct is more rigid (resist axial loads well) but less load sharing with the graft (important for fusion) and prone to screw cut-out:

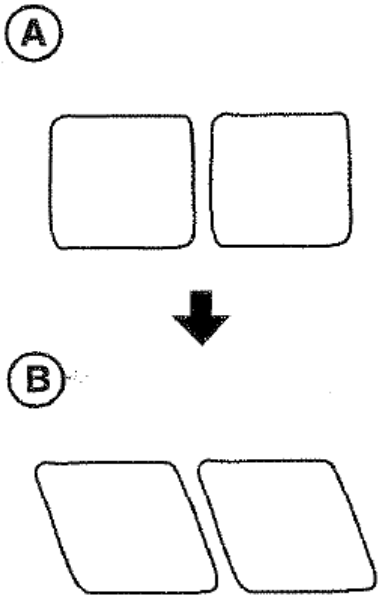


Variable screws provide more angulation and construct is more dynamic but prone to screw pull-out:

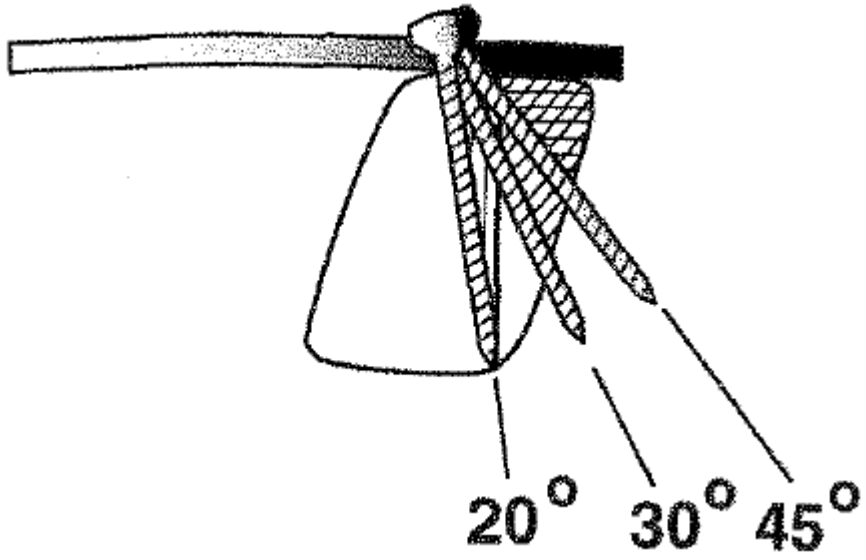


- variable (v) screws go into upper levels to allow for subsidence* and then constrained (c) screws into lower levels for stability (e.g. v-v-c or v-c-c).
  *allows load-sharing with interbody graft: **Wolff's law** - weight sharing helps stimulate fusion
- 3.5 mm **diameter**; larger for rescue screws.
- **screw length** (mostly 12-14 [women] and 14-16 [men] mm for adults); if need to measure:
  a) use axial CT; plain XR magnification is unpredictable (if needed, use the coin taped to skin at spine plane)
  b) use vertebral body height measurer
- Dr. Cameron uses ***all fixed*** self-tapping* screws (*to avoid cost of drill): 16 mm for all men, 14 mm for all women.
- Dr. Mathern uses ***variable for top level*** (or top two levels for 4-level ACDF) and fixed for other levels; he uses longer screws for top and bottom level (because screws go oblique, i.e. plate has oblique holes at top and bottom level);
  e.g. 16v-14f-16f OR 16v-14v-14f-16f
- Dr. Broaddus uses ***all fixed*** and same length (15 mm for males).
- Dr. Graham uses ***all fixed*** and same length (15-16 mm for males, 14 mm for women).
- Dr. Rivet, Ward uses variable for top, fixed for bottom rest, prefer self-tapping screws.
- Dr. JRC uses top variable and others fixed (all fixed for one level **trauma**).
- if ACDF for trauma – aim for bicortical screws!

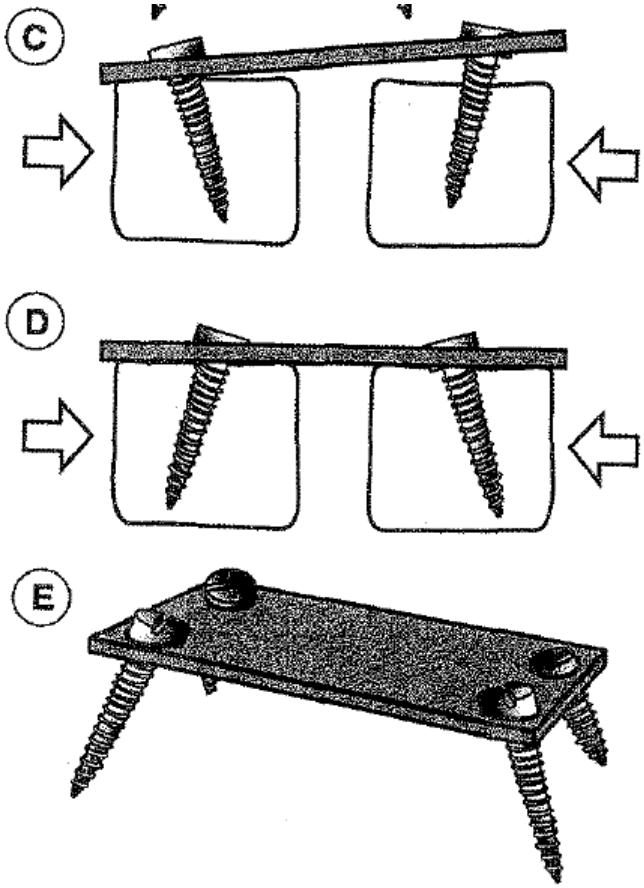
Triangulation effect – see p. Op220 >>
N.B. cervical vertebral body should not be considered to be cube (A), but rather as flattened parallelogram shaped cylinder (B):



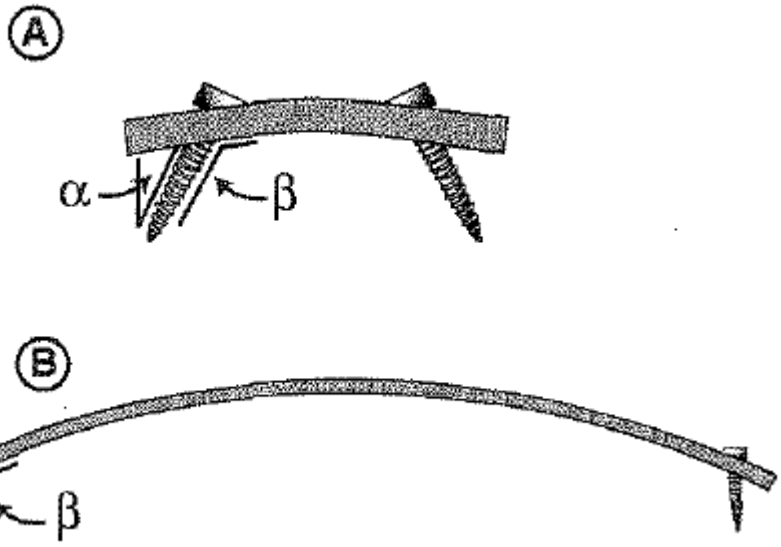
Thus, lesser angle (than otherwise optimal 45°) may provide greater triangulation effect (note difference of shaded areas). Furthermore, lesser angles (e.g. 20°), caudal dorsal corner of vertebral body may be purchased (bicortical purchase improves pullout resistance - angling screws toward endplate provides longer screw paths and improved pullout resistance):



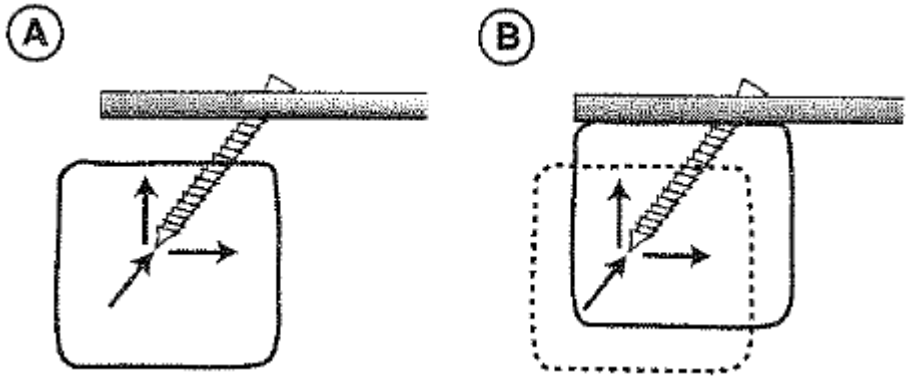
Resistance to axial load (toe-out is better here!):



Effect of plate length:



Compression effect (Dr. Graham technique):
Two component vectors are applied when angled screw is tightened. One brings bone to plate and other moves bone along long axis of spine (compression) (A). This may be used to apply compression forces (B):



N.B. to allow this effect ***screw starting points in bone must be further apart than screw holes in plate***; after first hole, do not tighten first screw and let plate stick out a little bit – will allow "to reach" for another hole – then, tightening both* screws, will allow compression!

*start with topmost screws – if plate does not conform perfectly with anterior vertebral bodies, it will make plate sit flush with vertebral body superiorly (and stick out inferiorly) – theoretical advantage to prevent dysphagia from prominent plate corner

DEPUY SCREWS

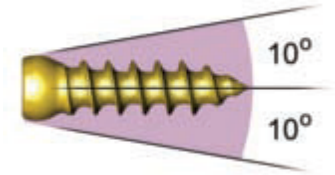
- neutral angle of SKYLINE Screw is 10° rostral /caudal and 5° medial.

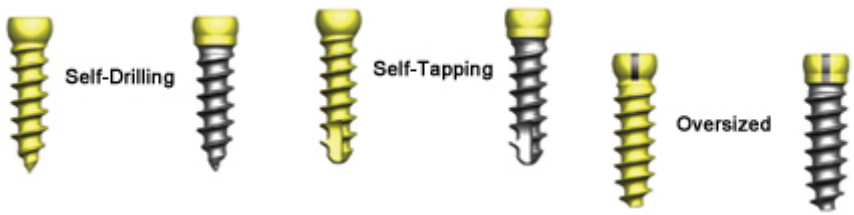
Constrained screws provide up to 5° cone of angulation in coronal (axial?) plane while maintaining sagittal trajectory (easier screw placement without affecting stability);

- constrained screw can pivot 2.5° medial/lateral from neutral angle

Variable screws provide up to 20° of angulation;

- variable screw can pivot 10° in all directions from neutral angle (20° cone of angulation).

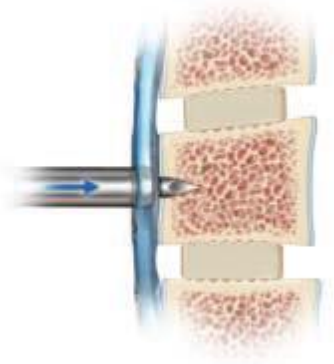




	Color Code		4.0mm Self-Drilling	4.0mm Self-Tapping	4.5 mm Oversized
10mm	Green	•		•	
12mm	Blue	•	•	•	•
13mm	Violet	•	•	•	
14mm	Gold	•	•	•	•
15mm	Light Blue	•	•	•	
16mm	Magenta	•	•	•	•
17mm	Light Green	•	•	•	
18mm	Titanium	•	•	•	•
20mm	Titanium	•		•	
22mm	Titanium	•		•	
24mm	Titanium	•		•	
26mm	Titanium	•		•	

- place temporary fixation pins* → lateral x-ray (to check adequate length of plate).
  *into one of cephalad and one of caudad screw bores of plate

- **unicortical screw fixation** - place variable* screws at upper level, then constrained-angle screws into other vertebral bodies.
  *will allow subsidence as time passes
- for trauma cases – use **bicortical screw fixation**
- break anterior vertebral body cortex with awl then drill* (may drill all way down planned screw tract)
  *self-drilling screws do not normally require predrilling, however, awl should be used to perforate cortex to provide starting point for screw insertion
- self-centering awl can protrude into bone up to 7 mm (to penetrate dense cortical bone, strike handle of self-centering awl with mallet)



- when using **constrained screw**, ***constrained single barrel drill guide*** must be used (tip of guide mimics head of constrained screw in order to ensure drilled hole is within functional range of constrained screw):

- insert tip of single barrel drill guide into bore of screw and orient as desired.

Drill Bit Selection

SKYLINE System provides 12 mm (blue), 14 mm (gold), and 16 mm (magenta) fixed depth drill bits:

- self-retaining screw-driver may be used to remove desired screw from screw caddy.
- insert screw into screw bore and advance it into vertebral body.

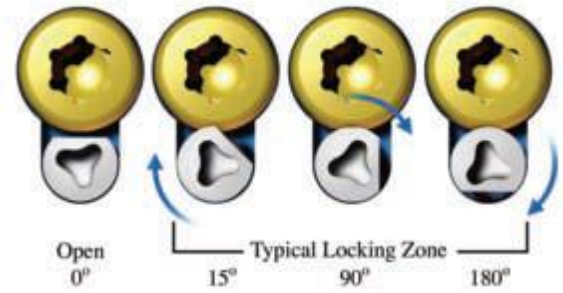
LOCK SCREWS INTO PLACE

- all screws should be placed before beginning locking procedure.
- use fluoroscopic imaging to confirm final trajectory of screw and plate position before screws are fully tightened and secured.

DEPUY

Tri-Lobe CAM LOC™ mechanism - provides audible, palpable, and visual confirmation of screw lock.

- rotate CAM tightener clockwise. Resistance will be felt as CAM contacts screw head.
- CAM tightener incorporates torque-limiting feature (0.78 Nm) that will release when appropriate torque level is achieved. When this occurs, audible click will be heard.
- lock is obtained when CAM tightener torque limit releases or when CAM is positioned within typical locking zone (do not rotate CAM past 270°).
- exact position of locked CAM may vary within typical locking zone depending on screw angulations:



ZERO-PROFILE

- may be implanted adjacent to prior fusion
- in general, mechanically inferior to conventional plates (zero-P was invented when BMP was still used for ACDFs).

ROI-C (LDR, ZIMMER BIOMET)

Technical manual >>

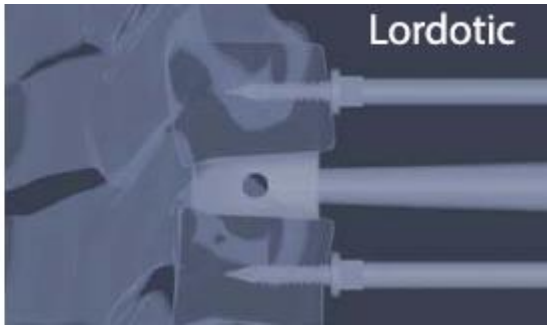
Anatomic

Lordotic

Anatomic implant has 6 degrees of lordosis, lordotic – 7 degrees of lordosis.

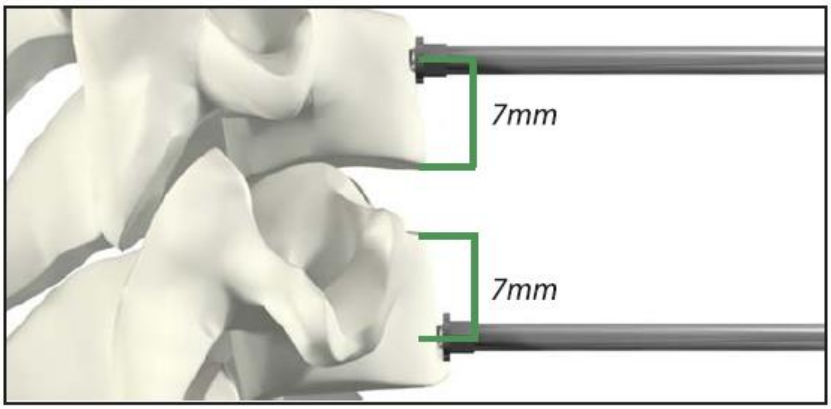
- use fluoroscopy.
- use Depth Gauge to choose cage **depth** – 12 or 14 mm (cage should leave 1 mm from anterior* and posterior vertebral edges).

  *corresponds to depth stop (on implant holder) set to 0 mm
- cage **width** – should reach uncinate processes but not ride on them.
- cage **height** – use trial – height should not exceed the height of adjacent heathy discs.
  - if trial sits straight, the hole in the center will look perfectly round

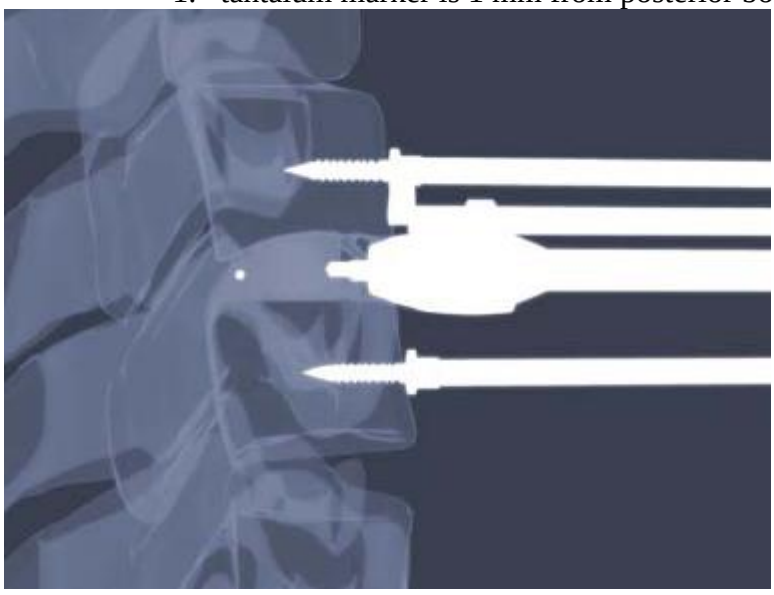


- Caspar pin must be ≥ 7 mm* from endplate to avoid contact with locking plate.

*or remove Caspar pin before insertion



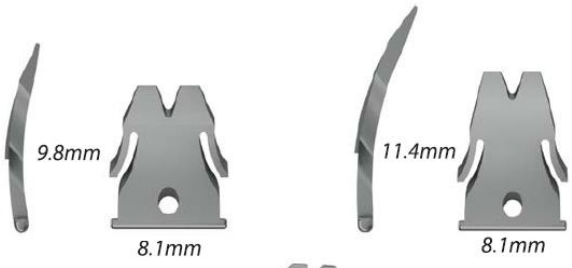
- cage is filled with DBX putty paste before putting into disc space.
- cage alignment is more challenging – holder obstructs view, holder holds cage straight (so holder needs to be in sagittal plane but holder abuts trachea-larynx); X-ray verification is mandatory:
  1. tantalum marker is 1 mm from posterior border of PEEK cage

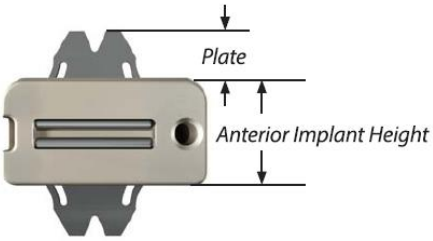


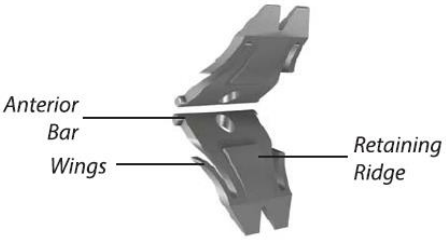
- prior to plate insertion release distraction on Caspar pins.
- if plate does not go in with simple hammer (bone too sclerotic), then use awl plates.
- insert plates in any order (e.g. cranial first, then caudal; or the opposite).

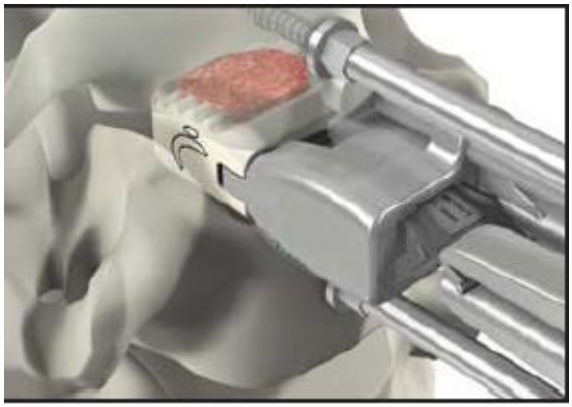
VERTEBRIDGE PLATE SELECTION

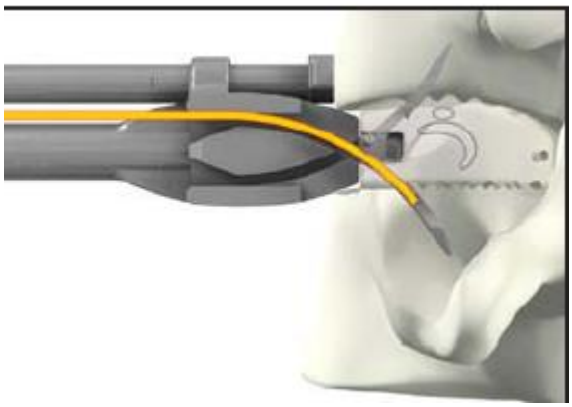
Select the plate length according to the height of the implant besing used. Use the ROI-C Standard Plate (MC1005T) with heights 5-7mm and the ROI-C Long Plate (MC1006T) with 8-10mm heights.







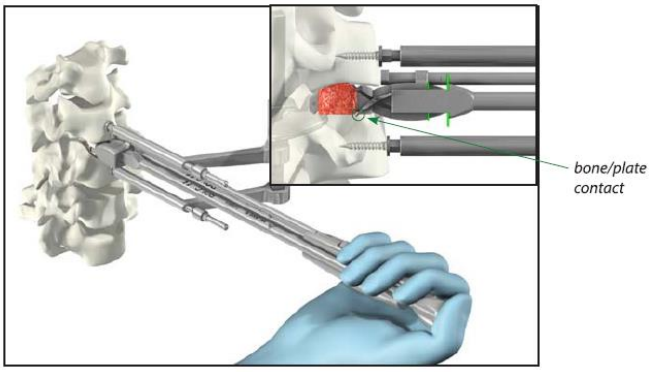


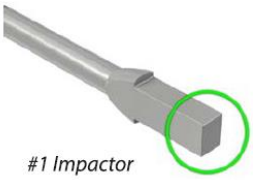


ADVANCE FIRST PLATE

Using thumb pressure, insert the #1 Impactor (MC9092R) to advance the first plate until it touches bone.* Take a lateral radiographic image to verify the plate is touching the bone.

**Note: If the plate does not advance with thumb pressure, confirm the plate is properly loaded in the Holder and that the Holder is aligned with the PEEK.*




#1 Impactor

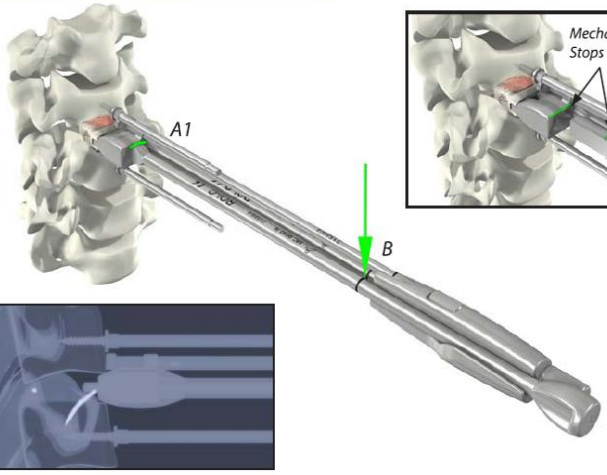
ADVANCE FIRST PLATE CONTINUED

Use a mallet to impact the first plate into the bone. The plate is fully advanced when the:

- Mechanical stop on the Impactor meets the mechanical stop of the Implant Holder (A1/A2).

Do not proceed to the #2 Impactor until proper placement of the implant and first plate are confirmed via fluoroscopy or x-ray (C).

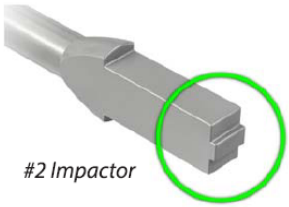
**Note: The impaction lines (B) will allow visualization of the plates' advancement and the mechanical stops should make contact when the lines appear aligned.*



FINALIZE FIRST PLATE POSITION

Once position is confirmed, use the #2 Impactor (MC9093R) to finalize the advancement of the first plate. Again, the plate will have advanced completely when the mechanical stop on the #2 Impactor meets the mechanical stop on the Implant Holder.

Take a lateral radiographic image to ensure proper implant and plate position.


#2 Impactor

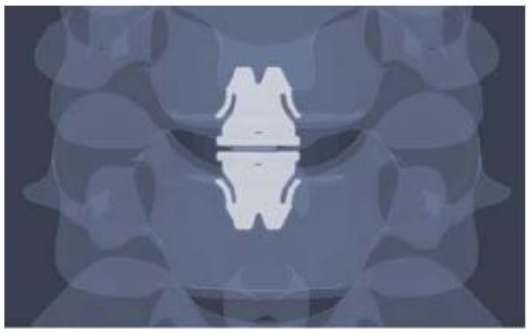
**Note: The plates must be advanced and finalized using this sequence:*

1st Plate
- *Advance with thumb pressure*
- *#1 Impactor*
- *#2 Impactor*

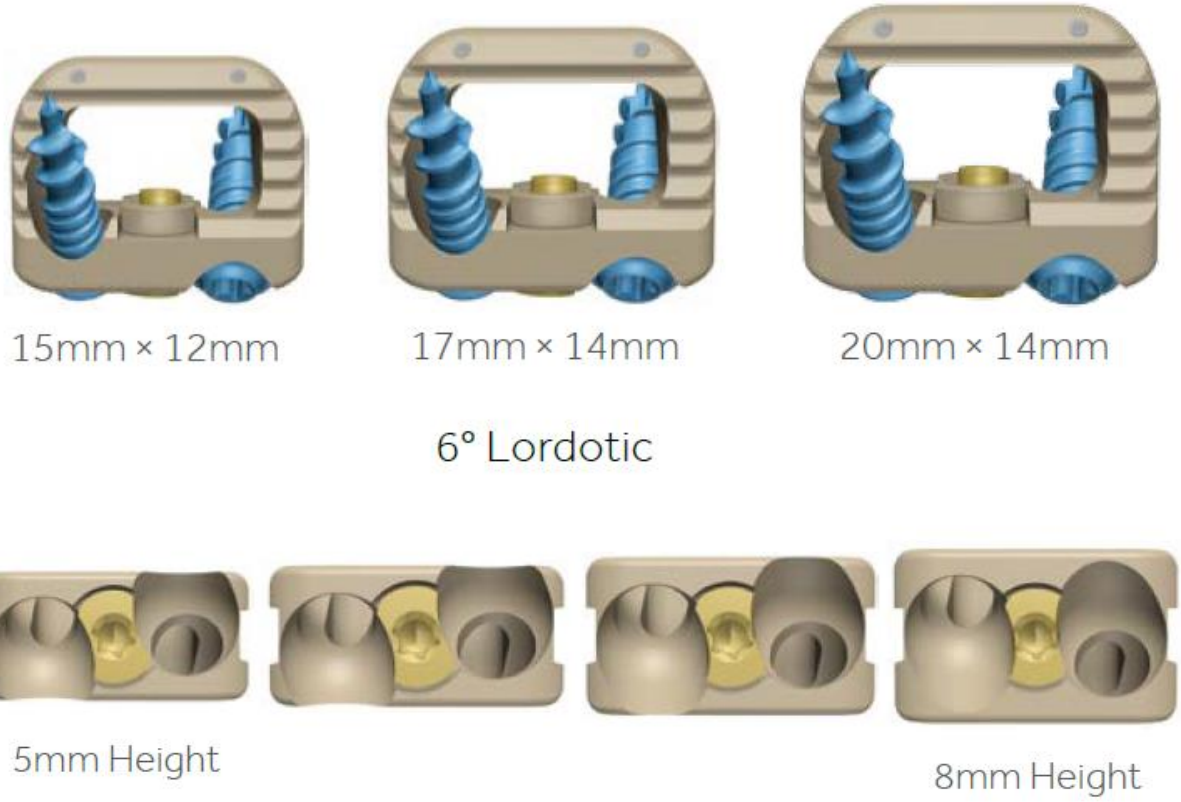
2nd Plate
- *Advance with thumb pressure*
- *#1 Impactor*
- *#2 Impactor*

- confirm there is tiny separation between tips of plates on X-ray:



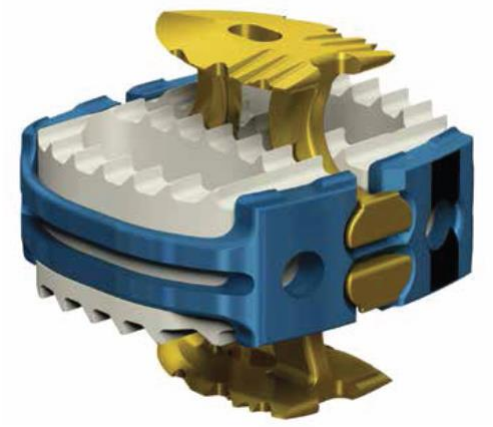

DIVERGENCE stand-alone interbody cage (MEDTRONIC)



COALITION (GLOBUS)

AERO-C (STRYKER)

Stryker Aero-C (cervical zero profile) >>



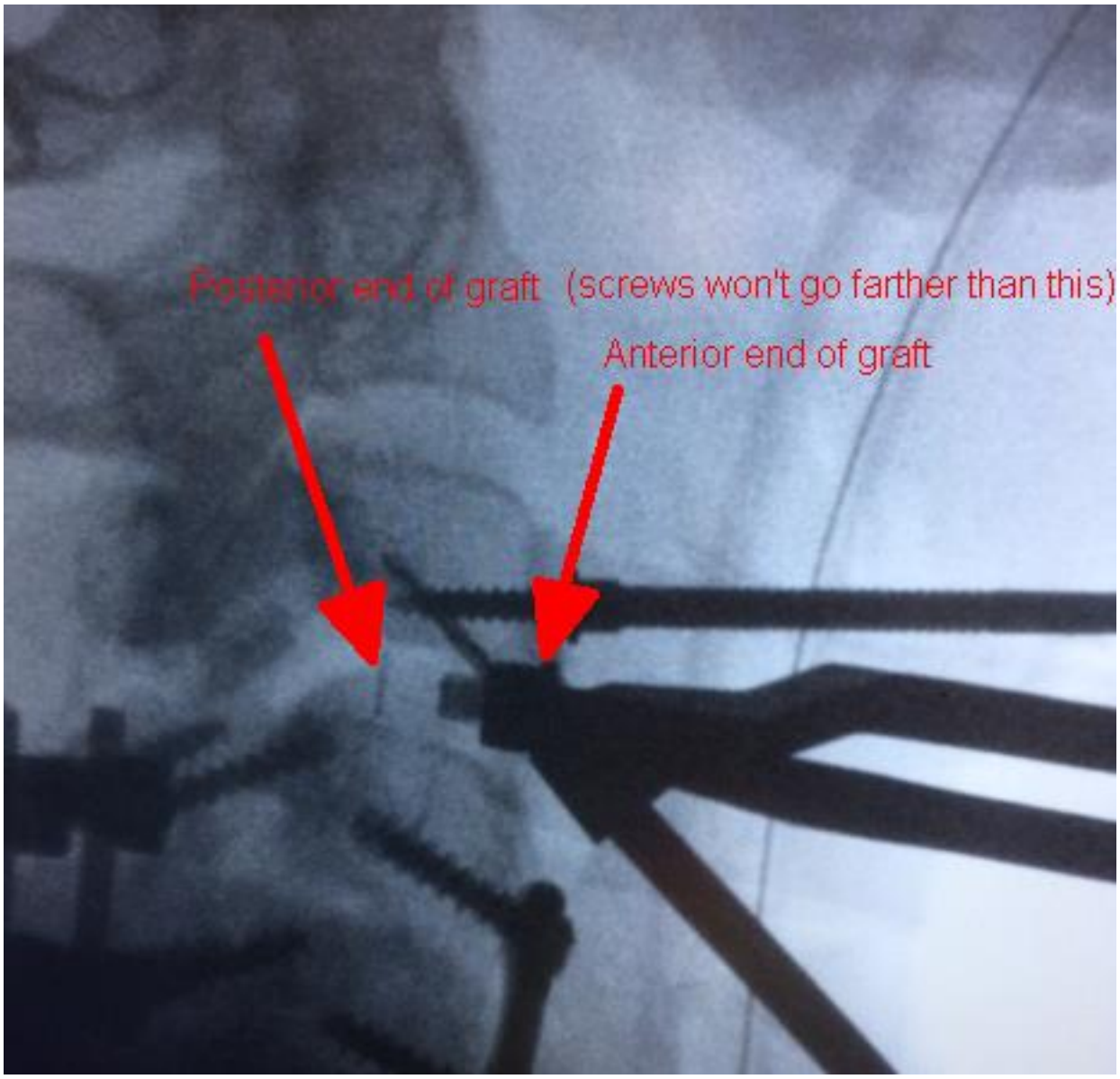
ZERO-P AND ZERO-P VA (SYNTHES)

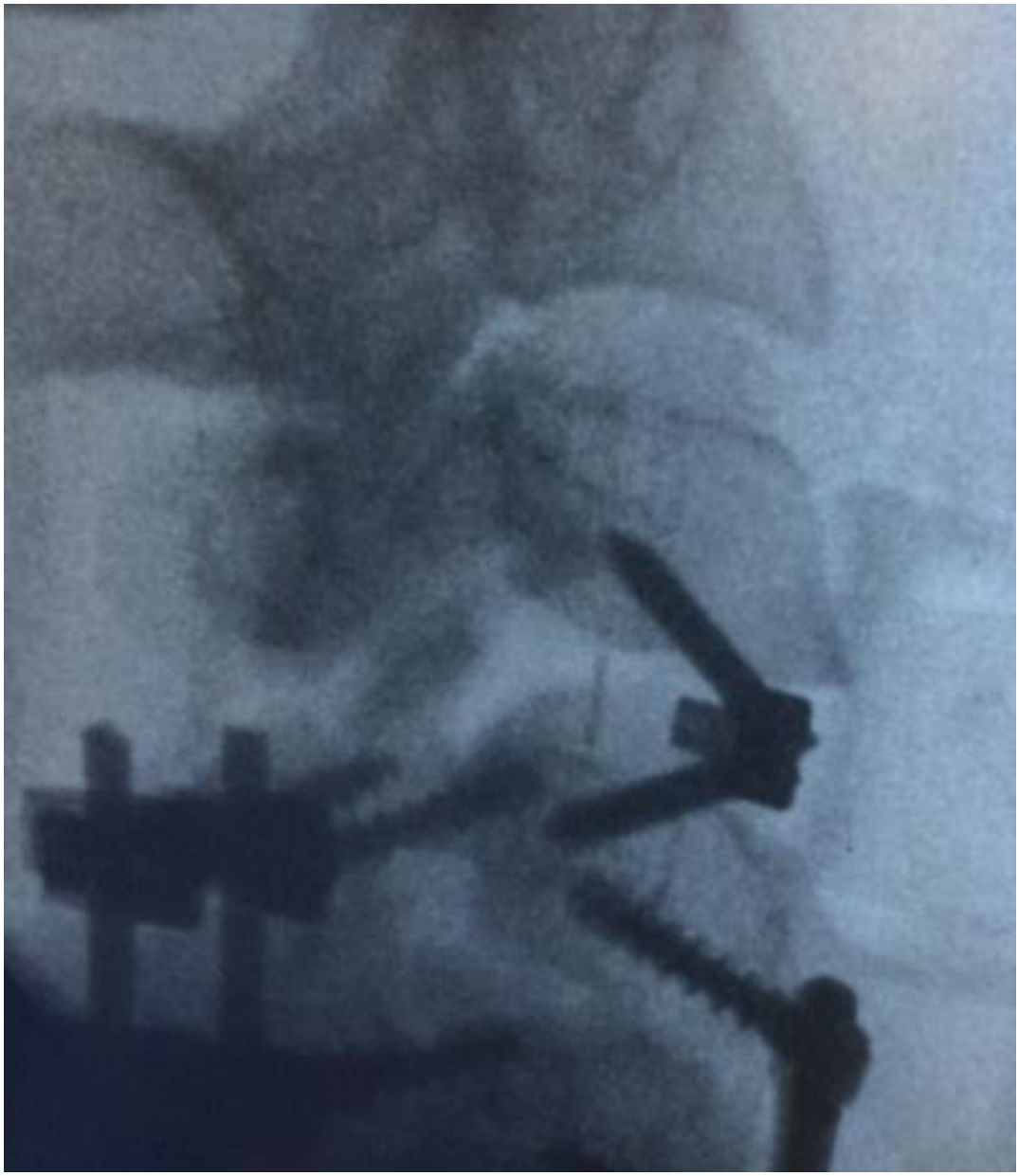
Synthes - Zero Profile anterior cervical fusion >>
Synthes - Zero P Quick Reference guide >>

- preassembled implant (Titanium plate and PEEK spacer).
- available in multiple configurations: lordotic, parallel, and convex profiles.
- full range of heights: 5 mm to 12 mm.
- no need to rasp disk space.
- fill PEEK spacer with DBX paste ± auto bone chips.
- use either fixed drill guide or angled awl.
- can drill all holes through fixed drill guide and can put first (lateral) screw through it
- wider screws go on the side of previous ACDF plate.
- screw head has smaller step thread – locks itself by "crossthreading"

Zero-P

Zero-P VA - variable angle screws offer a wide range of screw trajectories.


Posterior end of graft (screws won't go farther than this)
Anterior end of graft



Zero P Natural >>
- it has bone allograft instead of PEEK

CORPECTOMY

Used sources:
Jandial "Core Techniques in Operative Neurosurgery" (2011): Procedure 60
Nader "Neurosurgery Tricks of the Trade – Spine and Peripheral Nerves" (2014), Ch. 8
Fessler, Sekhar 'Atlas of Neurosurgical Techniques Spine and Peripheral Nerves' 2nd ed (2016), Ch. 28

INDICATIONS

- **posterior osteophytes / ossified posterior longitudinal ligament** (PLL) that often bridges past disk spaces and cannot be adequately removed with diskectomies alone
- **osteomyelitis** that fails nonoperative management

- vertebral body **tumor**
- vertebral body **burst comminuted fracture**
- if bone is good quality, no risk factors, then 2-level corpectomy may not need posterior stabilization; corpectomies > 2 levels need PCF.

Two-level corpectomy +/- PCF

Bayerl SH et al. Two-level cervical corpectomy-long-term follow-up reveals the high rate of material failure in patients, who received an anterior approach only. Neurosurg Rev. 2019 Jun;42(2):511-518. doi: 10.1007/s10143-018-0993-6. Epub 2018 Jun 18.

- 21 patients, choice over the surgical procedures was exercised by every surgeon individually.
- both groups benefitted from surgery concerning pain, disability, and myelopathy.
- while all patients of the ANT/PCF group showed no postoperative instability, one third of the patients of the ANT group exhibited instability and clinical deterioration - revision surgery with secondary posterior fusion was needed.

  N.B. patients with a sole anterior approach demonstrated a very high rate of instability (33%) and clinical deterioration in a long-term follow-up. Therefore, we recommend to *routinely perform an additional posterior fusion after two-level cervical corpectomy*.

Two-level corpectomy (ACCF) versus three-level discectomy (ACDF) for multilevel cervical spondylotic myelopathy

Lau D, Chou D, Mummaneni PV. Two-level corpectomy versus three-level discectomy for cervical spondylotic myelopathy: a comparison of perioperative, radiographic, and clinical outcomes. J Neurosurg Spine. 2015 Sep;23(3):280-9. doi: 10.3171/2014.12.SPINE14545. Epub 2015 Jun 19.

- 20 patients underwent 2-level ACCF, 35 patients underwent 3-level ACDF; preoperative Nurick scores were higher in the ACCF group (2.1 vs 1.1, p = 0.014), and more patients underwent PSF in the 2-level ACCF group compared with patients in the 3-level ACDF group (60.0% vs 17.1%, p = 0.001).
- two-level ACCF was associated with greater EBL (382.2 ml vs 117.9 ml, p < 0.001) and longer hospital stays (7.2 days vs 4.9 days, p = 0.048), but a subgroup comparison of patients without PSF showed no significant difference in length of stay (3.1 days vs 4.4 days for 2-level ACCF vs 3-level ACDF, respectively; p = 0.267).
- perioperative complication rates were similar in the 2 groups when patients underwent anterior decompression without PSF.
  - there was a trend toward more complications in the 2-level ACCF group (20.0%) than the 3-level ACDF group (5.7%; p = 0.102), but a subgroup analysis that excluded those who had second-stage PSF no longer showed the same trend (2-level ACCF, 0.0% vs 3-level ACDF, 3.4%; p = 0.594).
- both groups obtained similar postoperative cervical lordosis, operative ASD rates, radiographic pseudarthrosis rates, neurological improvement, and pain relief.
  - no significant differences (ACCF vs. ACDF) in terms of postoperative sagittal Cobb angle (7.2° vs 12.1°, p = 0.173), operative ASD (6.3% vs 3.6%, p = 0.682), and radiographic pseudarthrosis rate (6.3% vs 7.1%, p = 0.909).
  - similar improvement in mean VAS neck pain scores (3.4 vs 3.2 for ACCF vs ACDF, respectively; p = 0.860) and Nurick scores (0.8 vs 0.7, p = 0.925).

CONTRAINDICATIONS

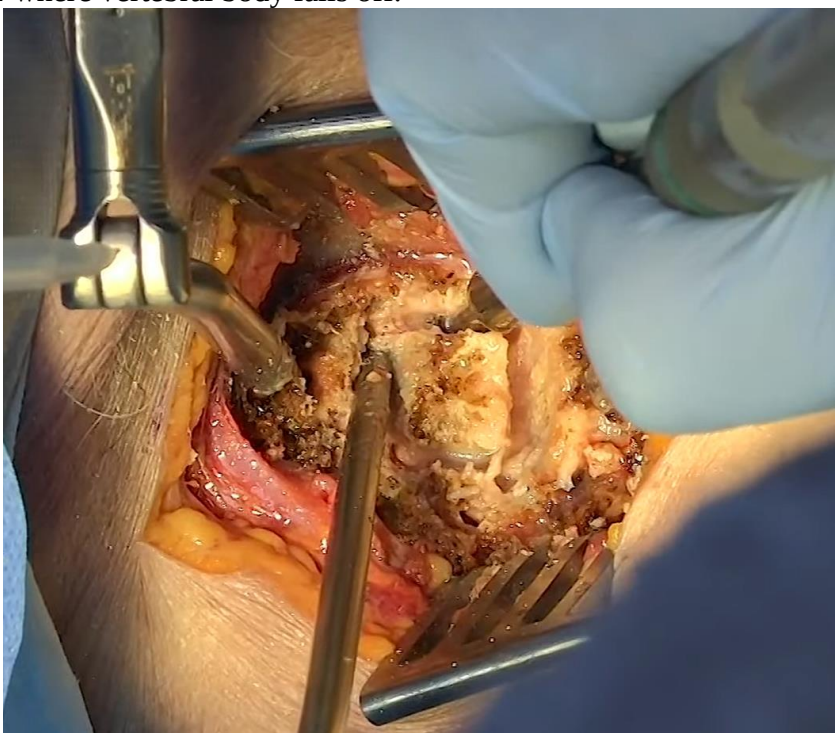
- aberrant vertebral artery* is relative contraindication and requires attention to width of corpectomy trough.

  *i.e. aberrant VA passing medial to pedicle precludes corpectomy at that level.

  - average interforaminal distance (VA) increases from C3 to C6 - wider decompression is safer at the more caudal levels - properly performed multilevel corpectomies usually result in a ***trapezoidal-shaped decompression***.
  - one potential pitfall from the use of operating microscope is the potential for an asymmetric decompression (i.e. oblique or asymmetrical decompression during a corpectomy may put the vertebral artery at risk, especially if a tortuous path is missed); H: symmetric and stable patient placement on a head holder and positioning of the microscope perpendicular to and over the center of the wound.
- chin on chest deformity (best treated with cervicothoracic fusion and T1 osteotomy)
- anterior bony ankylosis

TECHNIQUE

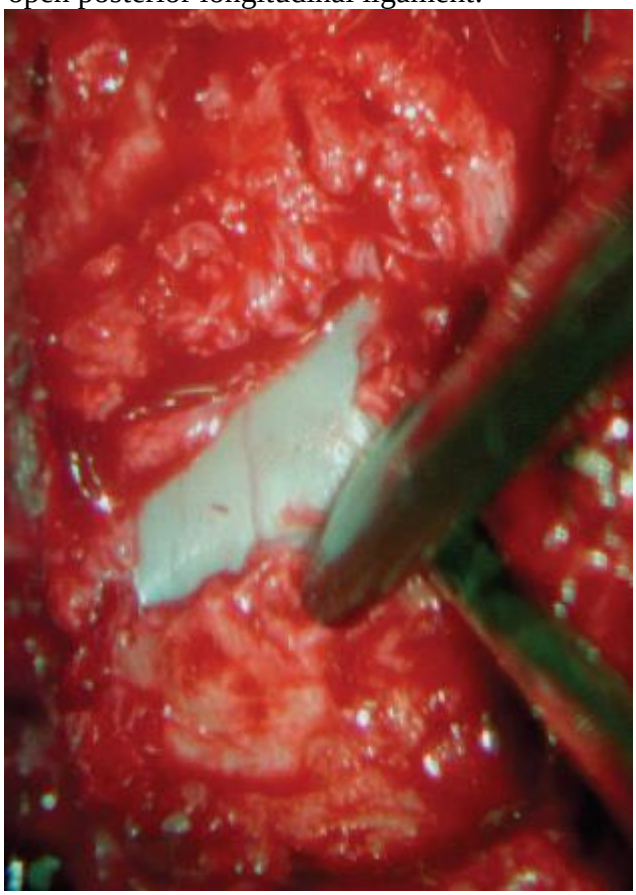
- recommend **monitoring** with MEP and SSEP.
- use fiberoptic intubation.
- use **RADIOLUCENT Mayfield frame** – so can do AP X-ray and see midline marked with Caspar pins (to avoid oblique corpectomies)
- ***complete discectomies*** above and below (but do not spend time on removing PLL, decompressing foramina – easier to do once vertebral body is removed); do not destroy endplates (to avoid subsidence, telescoping)!!!
- corpectomy is done:
  - drill troughs on anterior vertebral body cortex (e.g. with drill) - ***midline*** and then ***lateral edges of corpectomy*** (along medial edge of each uncinate process); may palpate with Penfield #4 where vertebral body falls off.



    - width of corpectomy should not exceed 15 mm to avoid vascular injury (classically, distance between vertebral arteries is 20 mm) and allow lateral walls to help with bony fusion.
  - anterior 3/4 – remove using Leksell (to collect bone);
  - deepest 1/4 – using high speed drill with coarse 3-4 mm diamond burr – to drill trough just wide enough (1.5 cm; wider has risk of vertebral artery damage) to fit cage (may leave bone lips posteriorly to avoid posterior graft migration):

- residual posterior cortex is then isolated circumferentially with Kerrison rongeur; then PLL is disconnected at both ends and bone-ligament island is removed away from the canal to avoid potential cord injury.
- palpate posterior bone lips to make sure decompression is complete.

- optional* - open posterior longitudinal ligament:

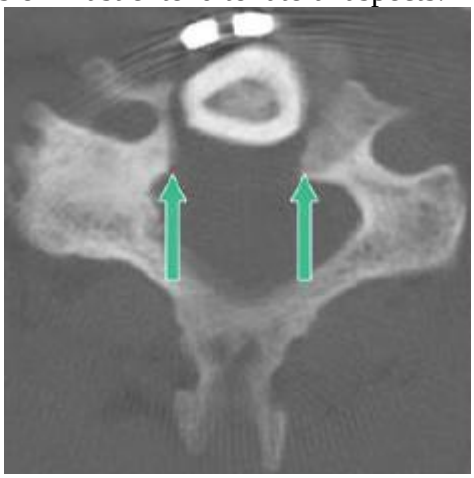


*PLL is removed only if torn or in the presence of sequestered disk because PLL removal may be associated with increased risk of C5

stretch injury, or CSF leak (especially in cases of infection or irradiated tumor).

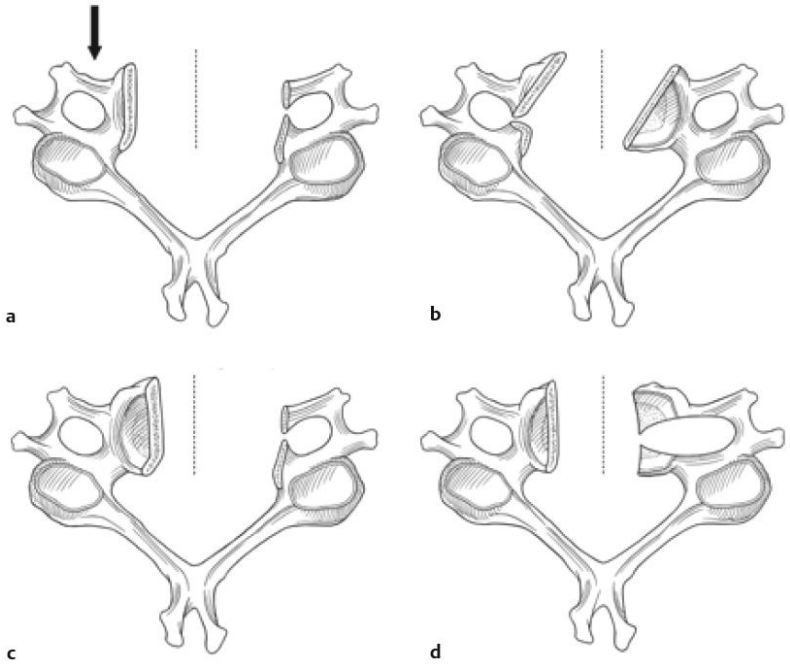
- dura must be visualized (makes sure that decompression is complete):

- decompression must extend to lateral aspects:

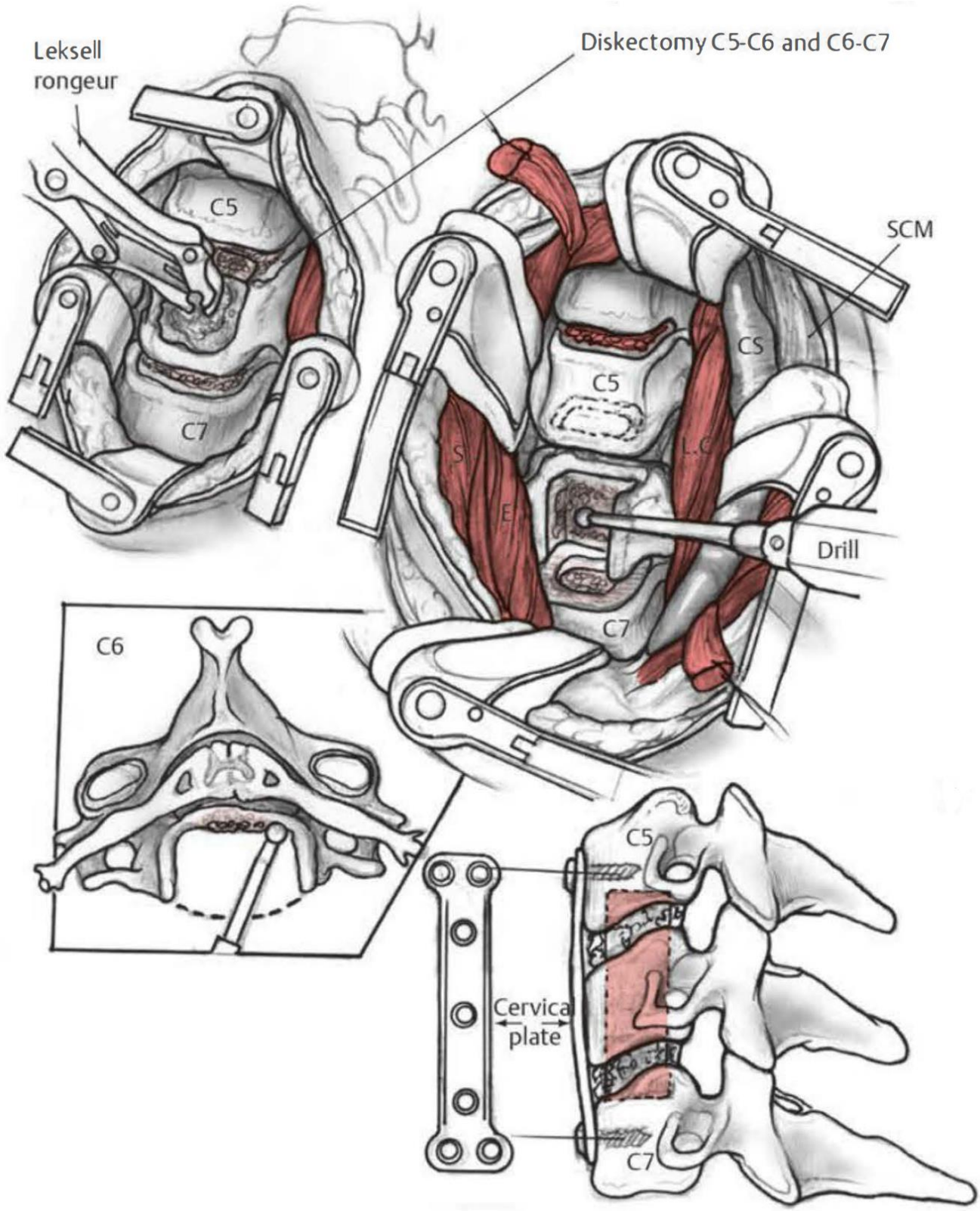


Risk factors for vertebral artery injury (dashed line indicates midline, costal process indicated by arrow):

(a) Excessively wide corpectomy.
(b) Oblique corpectomy – common error: retractor blades sit at oblique angle, so natural tendency is to perform corpectomy in line of vision (i.e. oblique); H: perform O-arm scan at the end of corpectomy to verify decompression.
(c) Off-center corpectomy.
(d) Tortuosity of vertebral foramen, causing vertebral artery to be located within vertebral body.



- 1- to 2-mm posterior shelf of bone may be created in superior aspect of vertebral body below to prevent posterior graft migration.



Source of picture: R. Nader "Neurosurgery Tricks of the Trade – Spine and Peripheral Nerves" (2014), ISBN-10: 1604069147, ISBN-13: 978-1604069143 >>

- distraction using Caspar distraction posts or standard handheld distractor helps to correct kyphosis and facilitates graft placement.
- for strut graft reconstruction, endplates must be parallel or slightly narrower posteriorly.

CAGES

N.B. use neutral (zero) degree endcap **cranially** and lordotic **caudally** (else, cage will sit in position prone to kickout!)

Complications:
1) subsidence (thus, preserve endplates)
2) kick out

- graft height is calculated under traction.

A. **Titanium** mesh (e.g. Medtronic Pyramesh, DePuy Bengal) - ideal for long segments (has lots of space inside cage – accommodates plenty of autograft (i.e. bone chips); trim length to fit exactly; Dr. Cameron uses circular (vs. oval)
B. **Titanium** cage – static or expandable
C. **PEEK** cage – static (may be stackable) or expandable
    - PEEK has similar elasticity to bone, with a good combination of strength, stiffness, and toughness.
    - PEEK is more elastic than titanium - ↓risk of graft subsidence, especially in osteopenic and osteoporotic patients.
    - PEEK has no MRI artifact.
    - PEEK is radiolucent.
D. **Methyl methacrylate** – as a preshaped block or inside Silastic tubing (e.g. thoracic drain) - used in oncology patients with a limited life expectancy (< 6-12 months) as this construct is less expensive, resists tumor destruction, and loses its compressive support after 1 year.

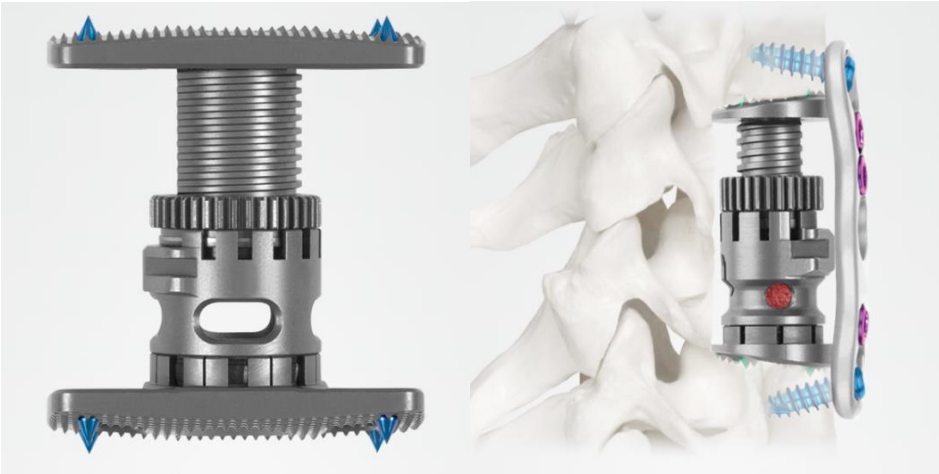
STATIC CAGES

Globus NIKO - static PEEK; comes with 12x14 mm footprint for cervical spine (height 15-33 mm in 2 mm increments)

EXPANDABLE CAGES

Medtronic STRATOSPHERE – has articulating endplates that better conform to anatomy – can match anatomy very well but very little space inside to fill with bone graft.

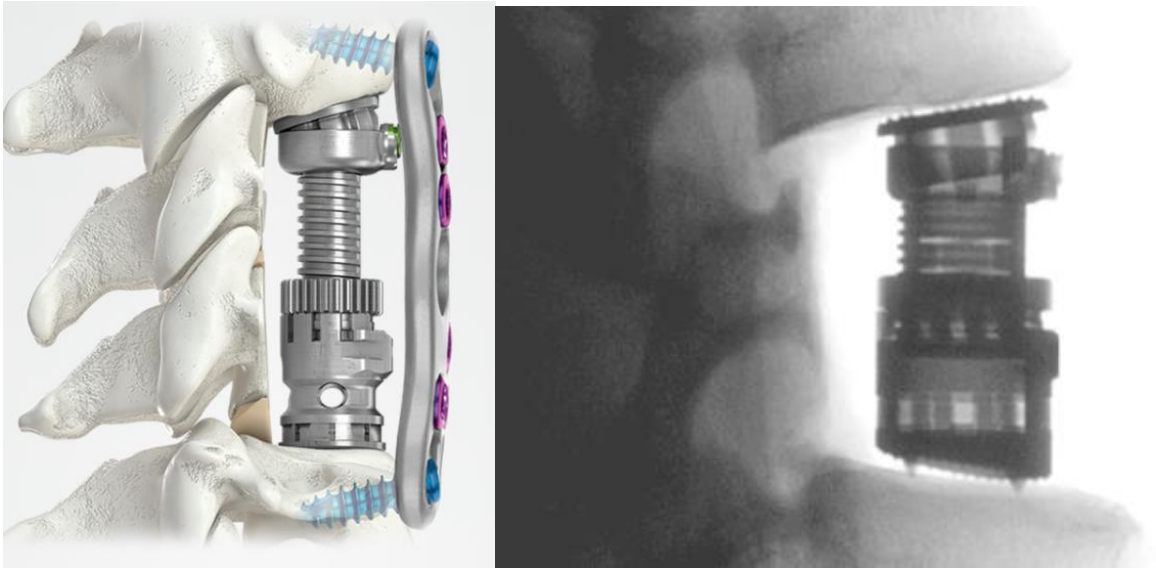
Globus FORTIFY series:
A. FORTIFY (PEEK or titanium):



Spine Levels	Cervical (C2-T1)
Device	FORTIFY® (Titanium)
Footprints	12x14 mm, 14x16 mm, 15x18 mm, 16 mm Round
Heights	Up to 74 mm (Core and Endplates)
Lordosis	Up to 14° Total

Endcap options: 0, 3.5, 7 degrees

B. FORTIFY VA - self-aligning superior endplate (needs anterior supplemental fixation):



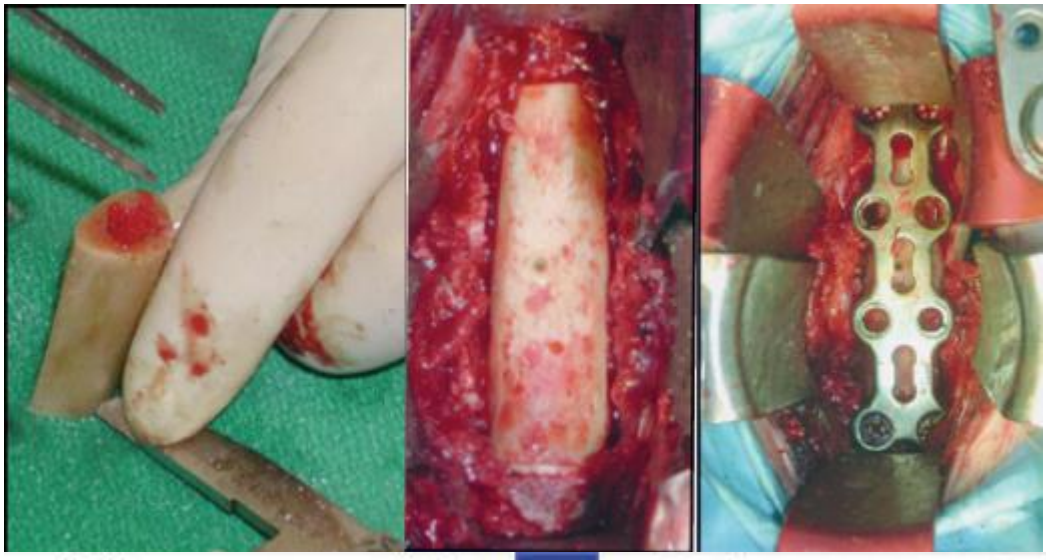
Smallest starting height – **23 mm** (i.e. articulating cap takes space) – may not be feasible for 1-level cervical corpectomy.

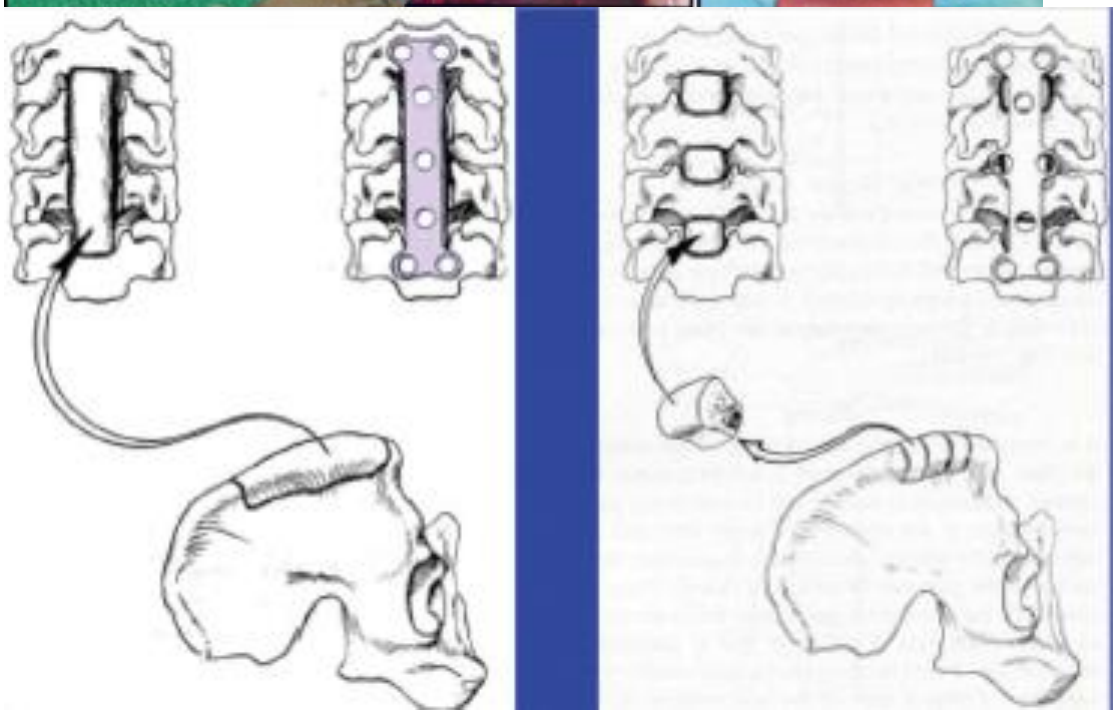
C. FORTIFY I (PEEK or titanium) - integrated titanium plates and screws for additional stabilization:

BONE GRAFTS

- better fusion but more frequent dislocation:

A. **Iliac crest** autograft offers a decreased risk of infection and a better fusion rate at the cost of donor site morbidity and limitation to two-level reconstruction.
B. **Fibula strut** allograft eliminates donor site morbidity at the cost of an increased rate of infection and nonunion.





ANTERIOR PLATE

- instrumentation with anterior plate and screw fixation provides immediate stability, obviating the need for postoperative rigid external immobilization, increasing fusion rate, and acting as a buttress to prevent graft extrusion.

  N.B. it has no proven impact on clinical outcome!
- if one wants to avoid plate, may cut titanium cage the way that anterior edge is longer and overlaps anterior cortex of vertebrae above and below – may place screws through mesh holes.

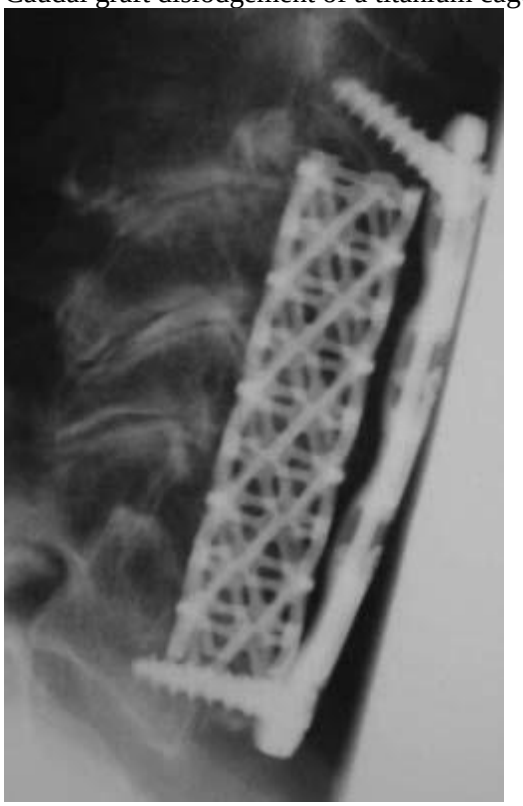
COMPLICATIONS

Hematoma – corpectomy surfaces are very prone for oozing – hemostasis has to be excellent!
Pseudoarthrosis
Adjacent level disease (e.g. 35% incidence of accelerated spondylosis rostral to the uninstrumented motion segment).
Graft fracture

Graft pistoning
Graft dislodgement (incidence as high as 29%; 9% rate for two-level corpectomies, 50% rate for three- and four-level corpectomies)

- can lead to catastrophic sequela: neurological injury, airway compromise, or esophageal injury.
- prophylaxis – anterior plating.

Caudal graft dislodgement of a titanium cage:



Witwer et al. (2007)

TRANSORAL ODONTOIDECTOMY

Used sources:
R. **Jandial** "Core Techniques in Operative Neurosurgery" (2011): Procedure 57

Suggested reading:
Crockard H.A.: The transoral approach to the base of the brain and upper cervical cord. *Ann R Coll Surg Engl* 1985; 67:321-325.
Hadley M.N., Spetzler R.F., Sonntag V.K.: The transoral approach to the superior cervical spine: a review of 53 cases of extradural cervicomedullary compression. *J Neurosurg* 1989; 71:16-23.
Menezes A.H.: Surgical approaches: postoperative care and complications "transoral-transpalatopharyngeal approach to the craniocervical junction". *Childs Nerv Syst* 2008; 24:1187-1193.
Menezes A.H., VanGilder J.C.: Transoral-transpharyngeal approach to the anterior craniocervical junction: ten-year experience with 72 patients. *J Neurosurg* 1988; 69:895-903.
Mummaneni P.V., Haid R.W.: Transoral odontoidectomy. *Neurosurgery* 2005; 56:1045-1050.

Rhoton collection – Anterior Skull Base, part 2 >>

Very morbid operation – check if posterior decompression is not a better alternative (degenerative retrodental pannus involutes after stabilization)

INDICATIONS

- compression of cervicomedullary junction:

1. Irreducible atlantoaxial subluxation
2. Unstable odontoid fractures
3. Ventrally located pathology of the lower clivus or atlantoaxial complex
4. Os odontoideum

CONTRAINDICATIONS

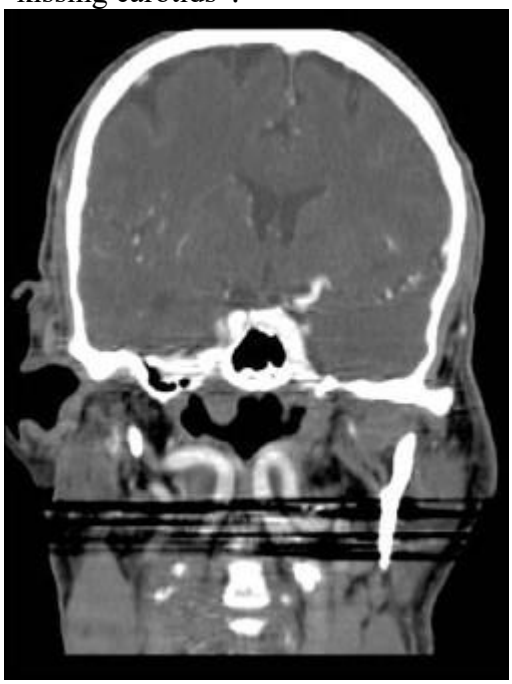
1. Trismus (H: splitting of mandible)
2. Oropharyngeal infection
3. Low-riding hard palate - requires a more extensive approach (e.g. palate split)
4. Certain vascular aberrations - "kissing carotids", single median vertebral artery
5. Intradural lesions - better approached from a lateral approach

PLANNING

MRI - ligamentous complex and soft tissue masses
CTA - level of hard palate, position of carotid arteries
Dynamic radiographs - to evaluate craniocervical stability

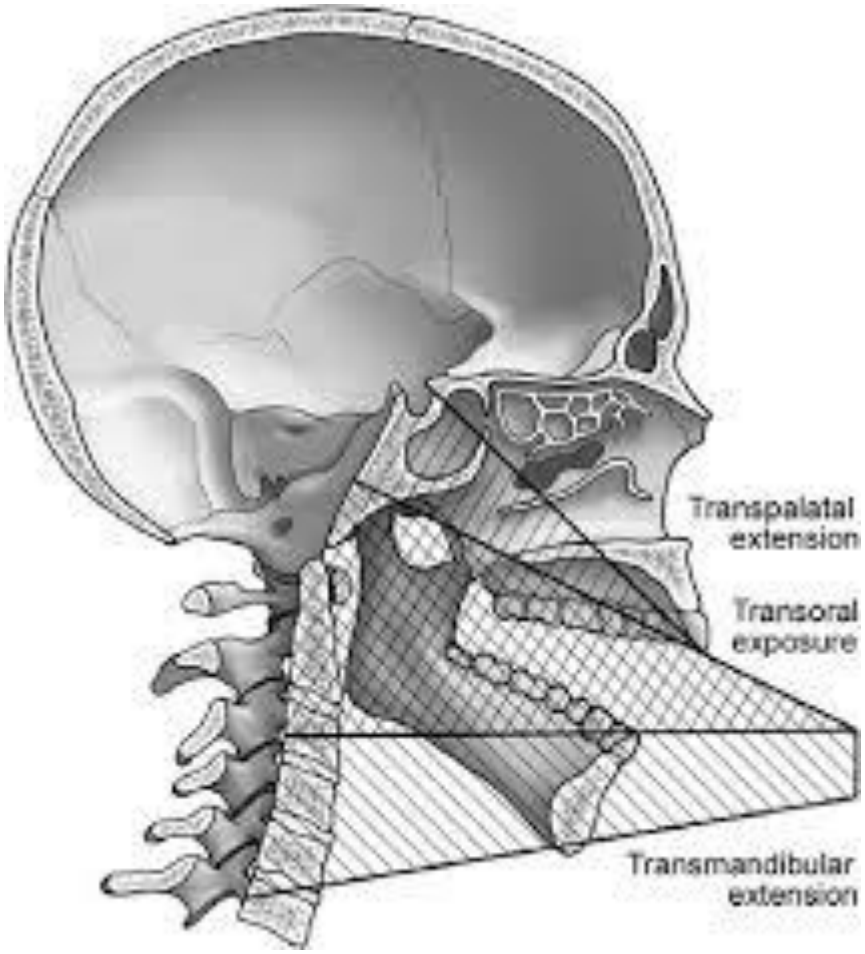
- epidural retrodental pannus causing cord compression - first thought might be to decompress posteriorly (at least as first stage) – error! – cord gets even more deformed and patient deteriorates! H: always decompress from compressing side! vs use reduction first with halo traction
- it is essential to know the location of carotid arteries; otherwise, catastrophic injury could result!

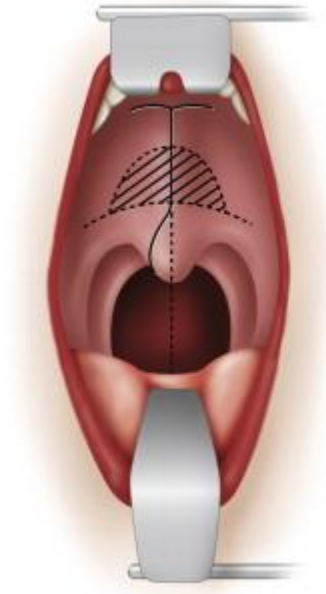
"kissing carotids":

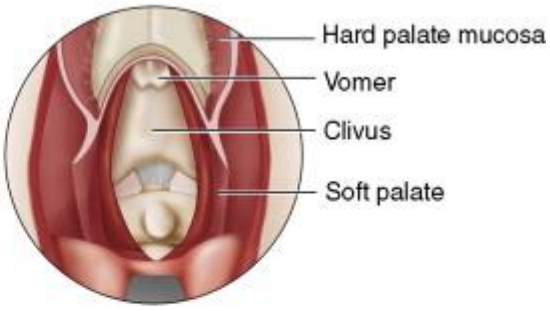


Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- hard palate dictates rostral access (superior border and extent of exposure and resection); if visualization is inadequate:
  a) soft palate split
  b) mandibular split
  c) endonasal approach (independently or combined) for compression above hard palate





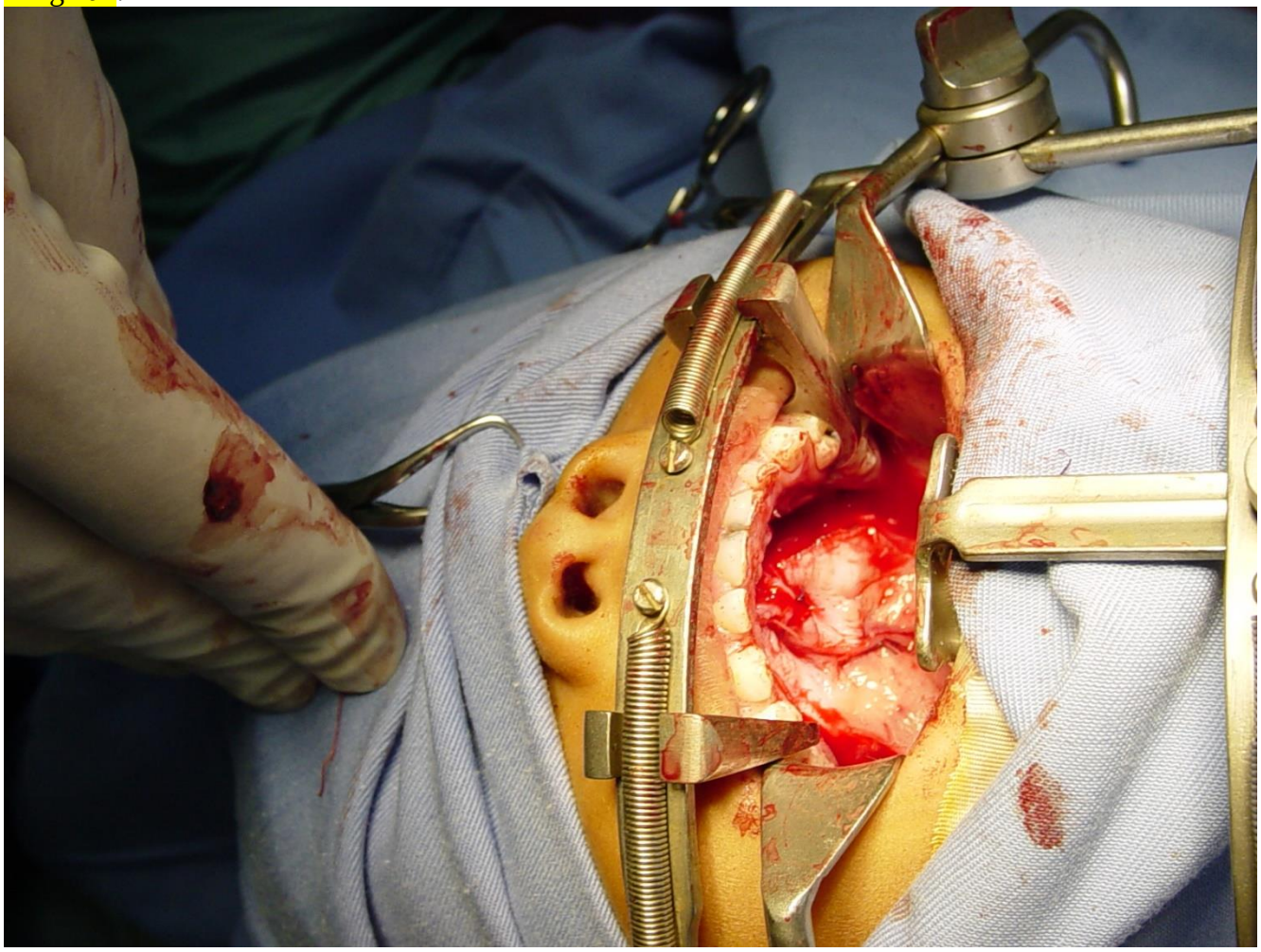


Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

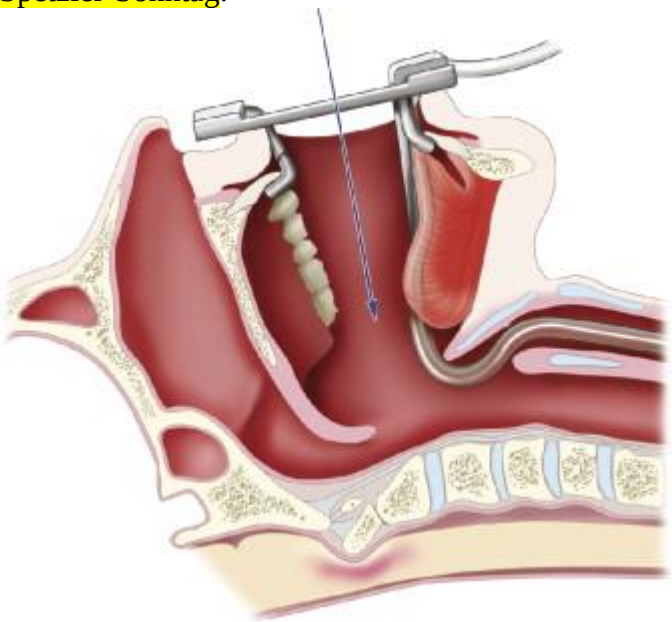
PROCEDURE

- **microscope** or **endoscope**
- **neuronavigation** or **lateral fluoroscopy**
- optional preoperative ***tracheostomy*** - if splitting of mandible is required to facilitate exposure.
- disruption of anterior osteoligamentous complex may destabilize spine, H: dorsal arthrodesis (e.g. occipito-C3 fusion)
- keep MAP > 85 mm Hg
  Patients with severe cord compression may be subject to ischemic injury during positioning or intraoperative fluctuations in mean arterial pressure
- antibiotics should cover mouth flora (e.g. CLINDAMYCIN)
- 10 mg of DEXAMETHASONE
- position:
- supine
- table rotated 180º away from anesthesia (so can work with microscope and fluoroscopy)
- head in a Mayfield head holder in slight extension (alternative – halo crown attached to Mayfield via adapter)
- retractor (ensure that tongue and endotracheal tube are behind the retractor!; release tongue pressure as often as you can – reduces tongue swelling but still typically need to keep intubated for 24 hrs or more):

Dingman:

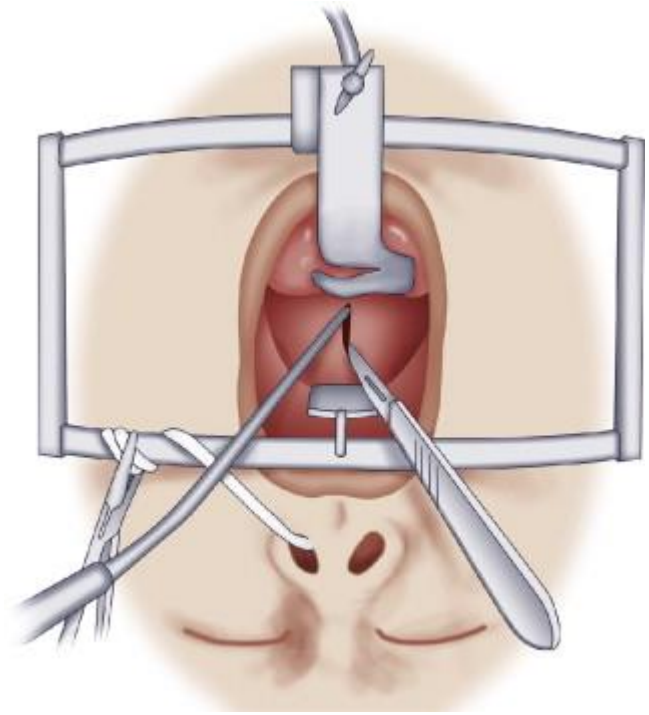


Spetzler-Sonntag:



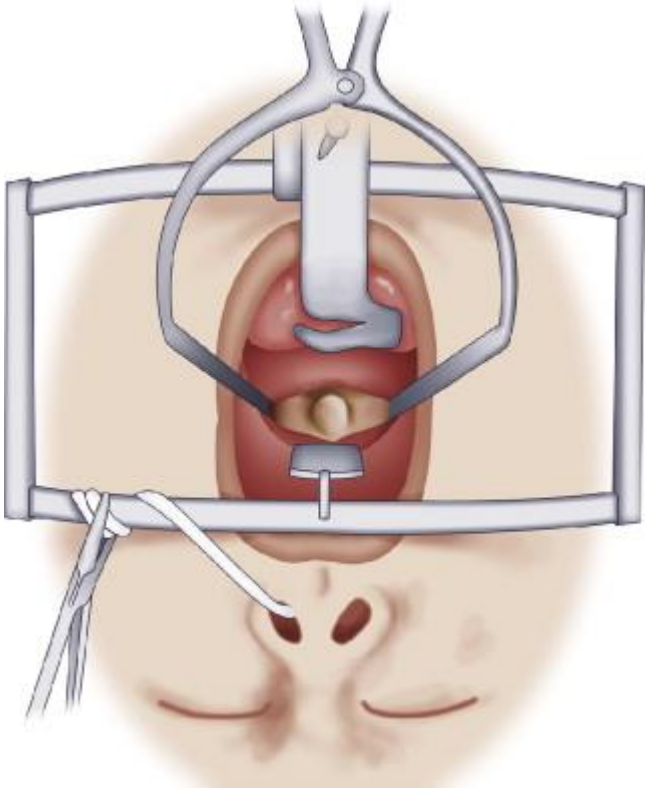
Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- advance Foley catheter through each nostril into oral cavity and then grab and secure tight both ends with hemostat – retracts soft palate
- linear incision is made in pharyngeal mucosa (stick needle into superior and inferior ends of planned incision and check with lateral fluoroscopy if it is enough; may also palpate anterior C1 tubercle through mucosa):



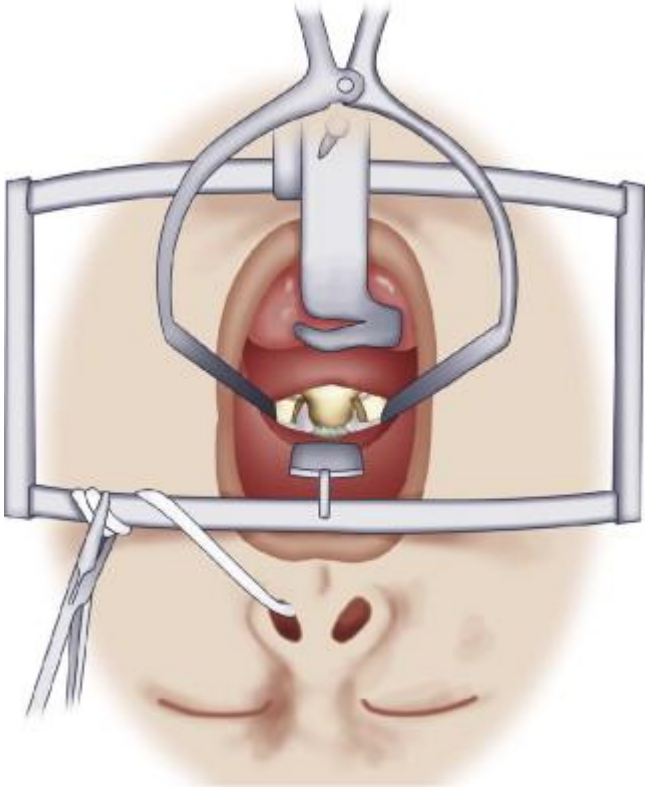
Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- mucosa is opened with Bovie to expose anterior ring of C1:



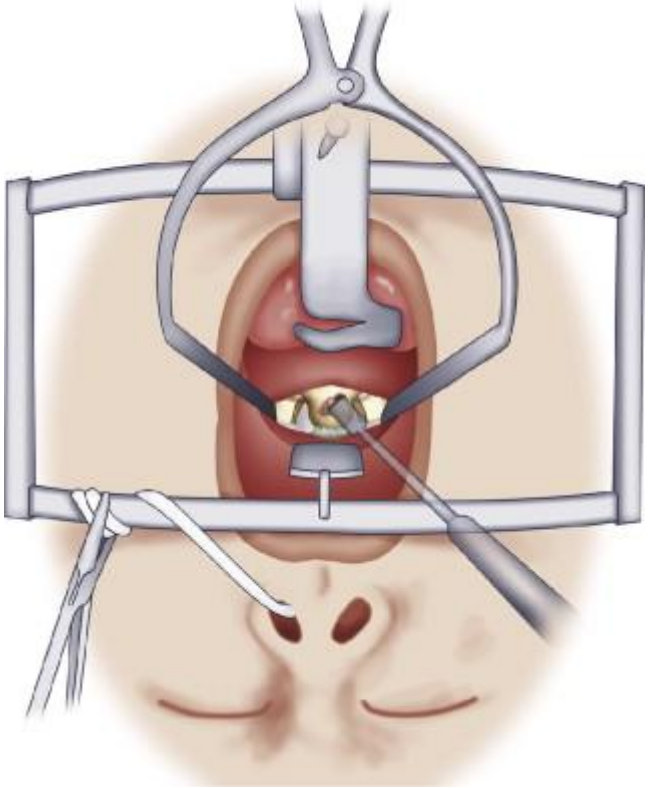
Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- C1 ring is removed with high-speed bur (e.g. M8):



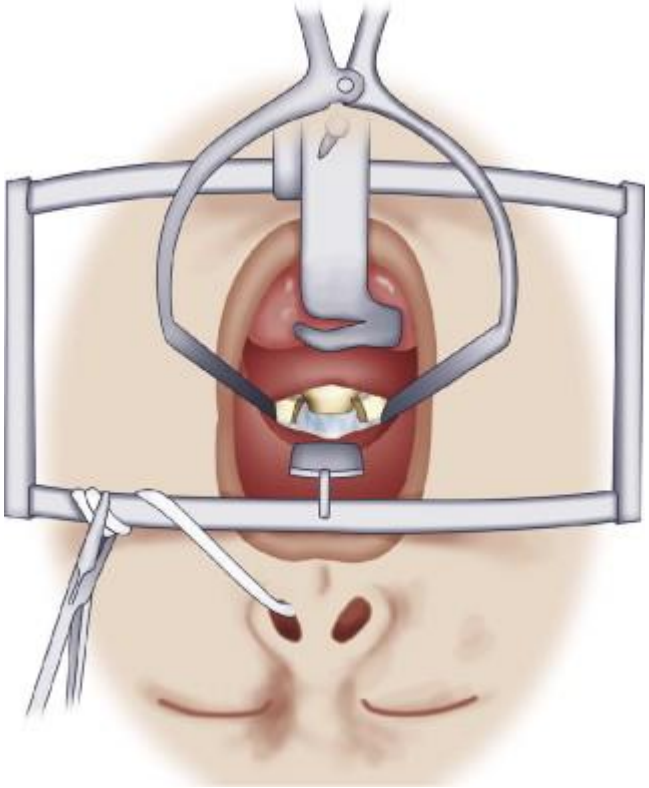
Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- odontoid is removed using combination of electric drills and hand tools:



Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- decompression has been completed when dura has been identified:



Source of picture: R. Jandial "Core Techniques in Operative Neurosurgery: Expert Consult - Online and Print", 1st ed (2011), Saunders; ISBN-13: 978-1437709070 >>

- to achieve successful decompression, it is important to ensure adequate lateral extension of bone removal (avoid injury to hypoglossal nerves, vertebral arteries, and carotid arteries!!!)
- close mucosa with interrupted 0 Vicryl sutures

POSTOPERATIVELY

- keep NPO for 7 days (to protect mucosa healing) – so place NG tube in OR and suture it to nasal septum.
- keep intubated overnight (plus, steroids for 24 hours).

COMPLICATIONS

1. Durotomy - risk of meningitis from - oropharyngeal flora.
- watertight dural closure with addition of fascial graft and lumbar drainage may help prevent CSF fistulas
2. Care must be taken during resection at lateral margin of exposure to avoid injury to hypoglossal nerves, vertebral arteries, and carotid arteries.
- pathology situated lateral to hypoglossal nerves and vertebral arteries may be better accessed via anterolateral, lateral, or posterolateral approaches
3. Patients with severe canal compromise may be subject to ischemic injury during positioning or intraoperative fluctuations in mean arterial pressure.

POSTOP OF ANTERIOR APPROACHES

FOLEY

Pull at 5 am on POD#1 – may discharge home early if voids.

C-COLLAR

- for 6 weeks after fusions.
No C-collar for 1-2 level ACDF: Dr. Cameron
2-weeks for 1-level: Dr. Holloway.

IMAGING

No imaging – Drs. Graham, Mathern, Holloway
Routine imaging – Drs. Cameron, Broaddus, JRC, Ward

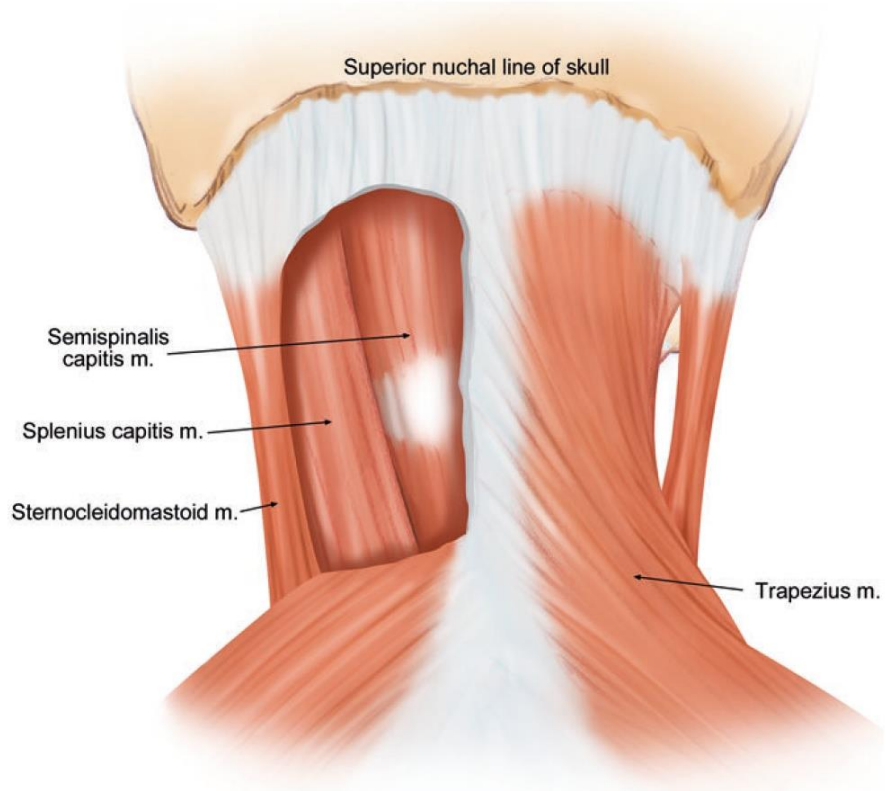
FOLLOW UP

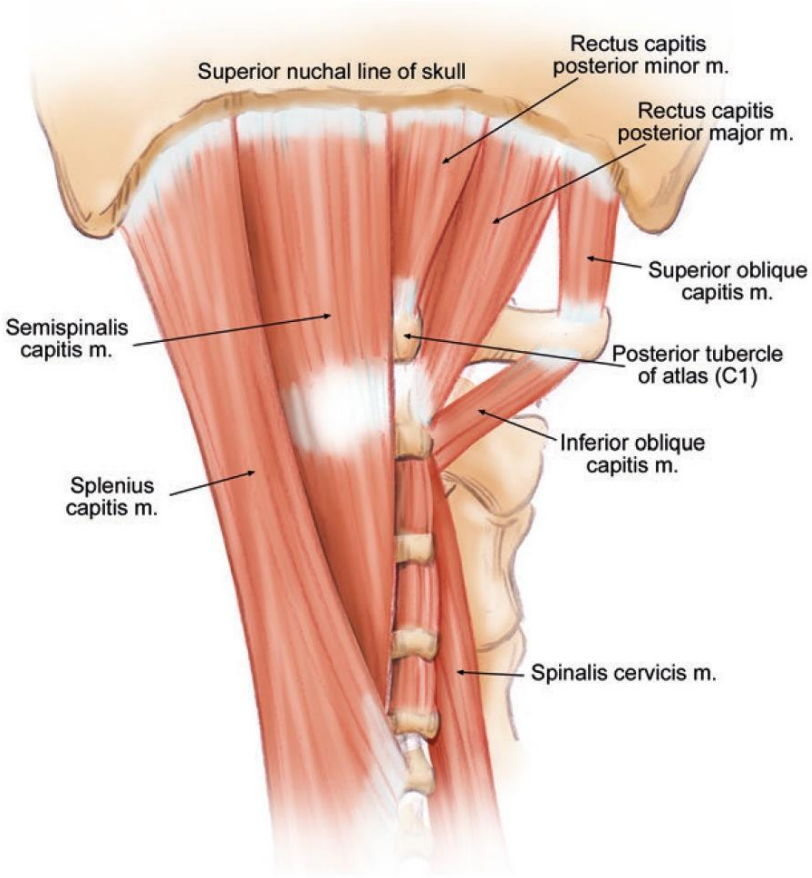
1) **6 weeks** - do XR (not for fusion but for any unexpected findings) and take off C-collar.
2) **3 months –** may do flexion-extension XR
3) **6 months**
4) **12 months** – time to diagnose "nonfusion" (only if symptomatic; some people never have radiographic fusion but remain asymptomatic); H: OrthoFix.

- if patient is symptomatic, especially if with SCI (e.g. central cord syndrome), consider MRI to check for decompression and syrinx development.

POSTERIOR NECK APPROACH

ANATOMY





- **suboccipital triangle** consists of inferior oblique muscle (inferiorly), the superior oblique (laterally), and the rectus major muscle (superiorly).
- suboccipital nerve and vertebral artery pass through suboccipital triangle as they perforate posterior atlanto-occipital membrane.

TECHNIQUE

PATIENT POSITION

N.B. avoid neck flexion or extension in myelopathy!
N.B. keep head neutral (look from side at positioned patient) if fusing; tendency to flex neck – unable to swallow postop (use XR to measure occipital-C2 angle)

- gel rolls longitudinally or white Wilson frame; tuck arms at sides.
- table is placed in a ***reverse Trendelenburg position*** - to decrease intraoperative bleeding and intraocular pressure.
- if neck is bulky with thick skin folds, may use towel clamps on skin to pull caudally:

APPROACH

- midline skin incision is made with a full-thickness scalpel cut, down into subcutaneous fat.
- incision is deepened with electrocautery.
- self-retaining retractors aid in hemostasis.
- once below subcutaneous fat, it is very important to carefully stay in midline (actual median raphe may deviate from actual physical midline by quite a bit but is visible by carefully using electrocautery on cut rather than coagulate; median raphe usually looks like a white band of fascia approximately 3 to 4 mm wide)
- care is used to avoid dissecting into paraspinal muscles, which would lead to greatly increased bleeding and postoperative pain.
- crossing bleeders from venous plexus can be coagulated.
- separation between paraspinal muscles can sometimes be very fine when they merge centrally in raphe.
- at level of spinous processes, muscles span tips and can be preserved in performing unilateral foraminotomy/discectomy without fusion.
- when the plan is to fuse or dissect previously fused levels, interspinous tissue can be taken with lateral soft tissue flaps so that only bone remains - this will minimize bleeding by staying out of vascular muscle.
- levels are localized:
    a) spine needles on spinous processes percutaneously prior to incision – rarely needed
    b) towel clamp on exposed spinous process with intraoperative lateral radiograph.
- once subperiosteal dissection has been completed with electrocautery down to level of lamina, Cobb elevator is used to strip soft tissues laterally with scraping technique.
- only expose enough of lateral masses to place lateral mass screws and no further, as beyond the lateral masses, one encounters venous plexuses that bleed profusely + dorsal nerves innervating the paraspinal muscles may be injured and can result in substantial muscle atrophy.

O-ARM

- the easiest for O-arm to move is Jackson / Axis table (but Mayfield adaptor is rather bulky and patient positioning is tricky).
- spin O-arm early – helps to orient to anatomy and amount of dissection needed.

- spin O-arm again after screw placement (obviates the need for postop CT) but before rod placement (so can revise screws if needed).

CLOSING

- removal of the dorsal portion of a prominent C7 and/or T1 spinous process can be extremely helpful for limiting wound tension in slender patients.
- #1 absorbable suture is used for fascia and muscle.
    - if local irradiation has been performed or is anticipated, nonabsorbable suture should be considered, at least for the fascial closure.
- numerous sutures with small bites are placed in fascia of paraspinal muscles deep in attempt to bring muscles back together - this combats incision's tendency to invaginate during healing.
  N.B. some experts do not close muscles to prevent necrosis at stitches!
- some experts divide the bifid spinous processes with a bone cutter during approach, keeping the paraspinal muscles attached; these are tagged, facilitating bone-to-bone closure at the conclusion of the operation - prevents having to suture into muscle, which obligates necrosing the captured muscle.
- it is helpful to tag clamp sutures in same layer and then tie them before proceeding to more superficial layer.
- meticulous hemostasis and closure of dead space along with drains help to prevent postoperative wound complications that are inherent to this approach.
- drain is highly recommended:
  — deep subfascial drain is placed.
  — superficial subdermal drain is added if the adipose layer is > 3 cm.
- skin is closed with staples or running Monocryl (Dr. Graham prefers Steri-Strips if skin is in reasonably good condition).

COMPLICATIONS

(16.4-19%)

1) significant postoperative muscular pain
2) nerve (C5) palsies – use intraop EMG! *see above >>*
3) pulmonary complications (4.6%)
4) hematomas (3.22%), operative blood loss (significantly [$p < 0.01$] greater in dorsal approach compared with ventral approach)
5) wound infection (4.7% vs. 0.6% with ventral surgery)

LAMINECTOMIES (CLAM)

- indications - see p. Spin15 >>
- for decompression, some recommend cervical laminectomy extending one or two levels beyond stenosis above and below.
- C3–6 laminectomy is often considered a **"standard" laminectomy**; **"extended" laminectomy** includes C7 and/or C2.
- CLAM is contraindicated in the kyphotic spine (loss of cervical lordosis)
- complications:
  1) if stenosis severe, decompress several levels as cord tends to "herniate / bow" posteriorly – risk of SCI, C5 palsy (use intraop monitoring!); plus, OPLL tends to progress postoperatively.

2) in cases of hyperlordosis, posterior cord migration (following an extensive laminectomy) → increased tension on nerve roots and blood vessels (→ possible neurologic worsening); H: limited laminectomy just where cord is compressed.
3) delayed formation of postlaminectomy membranes → recompression of the spinal cord dorsally over the site of the laminectomy.
4) increased cervical mobility (esp. at lower levels of CLAM) → kyphosing (long term risk up to 47% but not everybody needs treatment for this)

Witwer et al. (2007)

To avoid significant destabilization of cervical spine:

- do not remove soft tissue overlying facet joints (to preserve their blood supply)
- laminectomy only as far lateral as the extent of spinal canal, carefully preserving facet joints (use keyhole laminotomies where necessary)
- avoid removing a total of one facet at any given level.

LAMINOPLASTY (S. EXPANSIVE LAMINOPLASTY)

References:
R. Jandial "Core Techniques in Operative Neurosurgery" (2011) – procedure 61

ADVANTAGES

OVER ACDF / CORPECTOMY

- much lower complication rate and greater functional recovery for long segment pathologies.
  Edwards CC 2nd et al. Corpectomy versus laminoplasty for multilevel cervical myelopathy: An independent matched-cohort analysis. Spine 27:1168–1175, 2002

OVER LAMINECTOMY

- preserves posterior tension band – ***prevents loss of sagittal balance*** (lordosis).

- preservation of the lamina provides an anatomic barrier ***preventing the formation of postoperative scar*** over the dura mater (postlaminectomy membrane).

Controversies (laminoplasty vs. PCF)
Expansive laminoplasty (EL) or laminectomy followed by fusion (LF), are usually performed in patients with multilevel (≥ 3) cervical spondylotic myelopathy (CSM). However, the superiority of either of these techniques is still open to debate.
7 studies comprising 302 (EL) and 290 (LF) patients:

- both groups were similarly improved in JOA grade (MD 0.09, 95% CI -0.37 to 0.54, p = 0.07) and neck pain VAS score (MD -0.33, 95% CI -1.50 to 0.84, p = 0.58).
- both groups evenly lost cervical lordosis; in the LF group lordosis seemed to be preserved in long-term follow-up studies, although the difference between the 2 treatment groups was not statistically significant.
- ***both EL and LF lead to clinical improvement and loss of lordosis evenly*** - no evidence to support EL over LF in the treatment of multilevel CSM (LF shows favorable long-term results).

Lee CH "Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: a meta-analysis of clinical and radiological outcomes." J Neurosurg Spine. 2015 Jun;22(6):589-95.

INDICATIONS

(same as for laminectomy) – cervical stenosis: see also p. Spin15 >>

1. **Multilevel (≥ 3)** cervical stenosis with **preserved lordosis or straight spine** (laminoplasty is contraindicated in the kyphotic spine).
   N.B. to qualify for laminoplasty, ***patient needs to have minimal lordosis***
2. Diffuse ossification of posterior longitudinal ligament (**OPLL**).
   N.B. OPLL is Japanese original indication; Dr. Chapman thinks that OPLL is contraindication as motion is a signal for OPLL to grow!
3. Posterior cord compression resulting from buckling ligamentum flavum.
4. Posterior exposure of intraspinal pathology (tumor, vascular malformation, infection, hematoma.
5. Factors limiting anterior neck dissection, including short neck, scarring from previous anterior neck dissection or radiation.

Dr. Chapman does C3-7 to restore good CSF sleeve around the cord.

CONTRAINDICATIONS

1. Straightening of normal cervical lordosis or kyphosis.
2. Cervical instability (from trauma, tumor invasion, or connective tissue disorder).
3. Broad-based ventral pathology that may not be readily accessed from posterior approach.

POSITION

- prone on chest rolls or wide Wilson frame.
- head in pins – only slightly flexed and translated posteriorly.
  N.B. avoid neck flexion or extension in myelopathy!

TYPES and TECHNIQUE

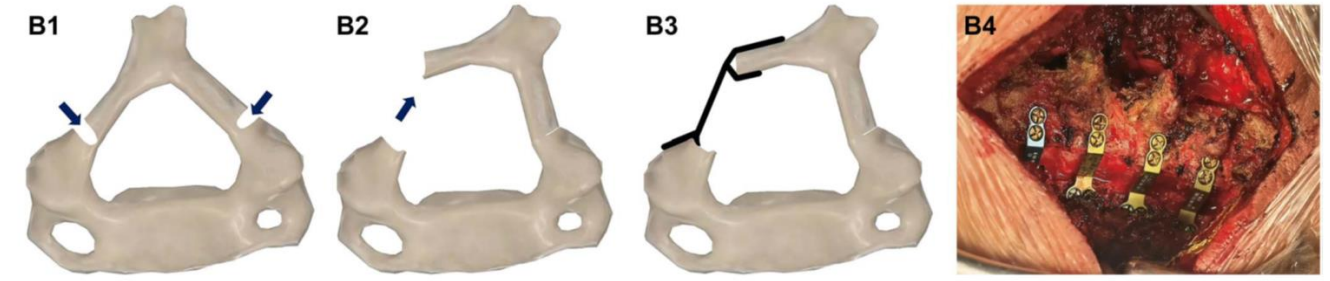
A) **single-door (open-door) laminoplasty** - spinal canal is opened on 1 side and hinged on the other → asymmetrical opening
B) **double-door (French-door) laminoplasty** - opening the "door" in the midline and placing hydroxyapatite blocks as spacers between the opened laminas → symmetrical expansion.

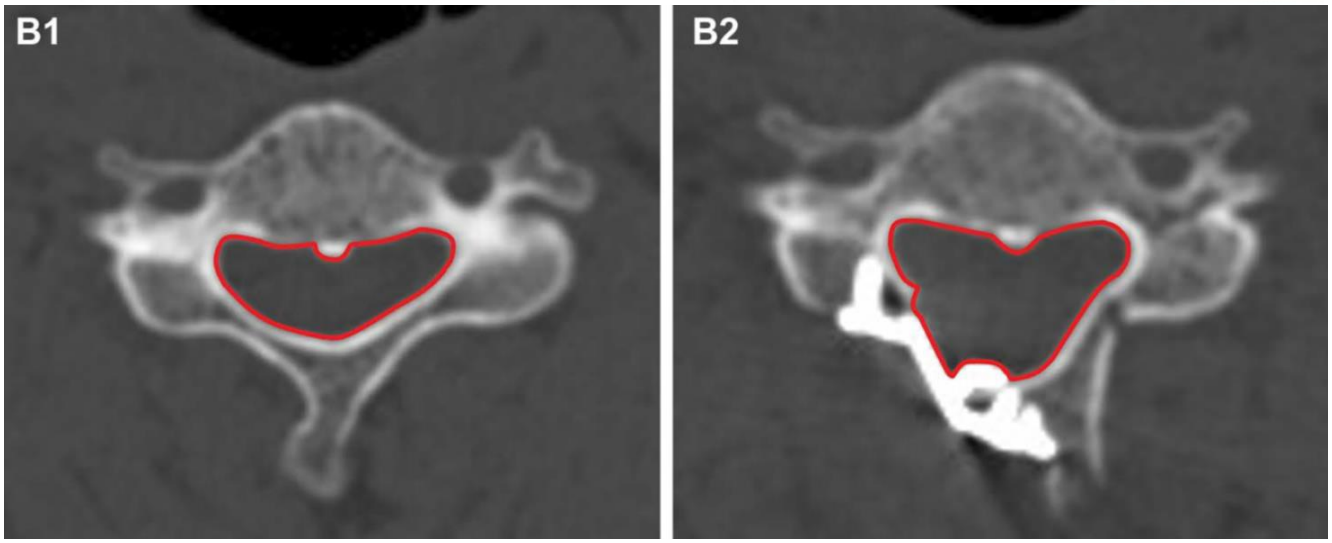
- standard posterior midline incision down to the tips of spinous processes.
- preserve muscles attached to C2 and C7 spinous processes.
- ***leave interspinous ligament intact (even nuchal ligament can be left intact)*** - undisturbed posture tension band.
- paraspinal muscles are dissected laterally, exposing the lamina out to the mid-portion of the lateral masses (i.e. exposure stops medial to facets) - this is motion-preserving procedure - arthrodesis is to be avoided.

  Muscle origins and insertions over the lateral half of the lateral masses are preserved!
- may use navigation to make precise lamina cuts (otherwise, "drill in the valley" – flexion point where lamina meets lateral mass).

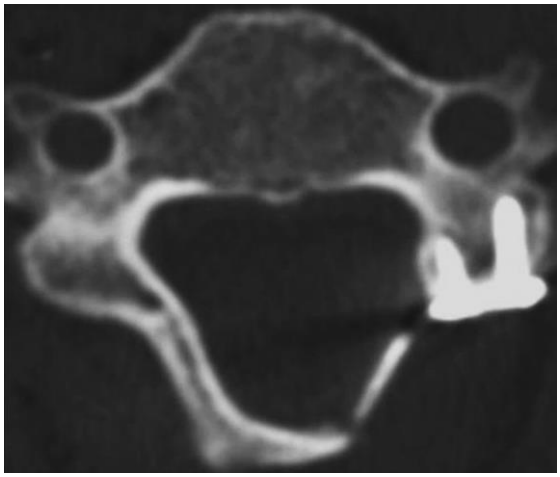
  N.B. better drill more medial – avoids going into lateral mass – more bane left for plate screws, also tiny ledge of lamina allows better plate kickstand / graft purchase

A. SINGLE-DOOR MINIPLATE



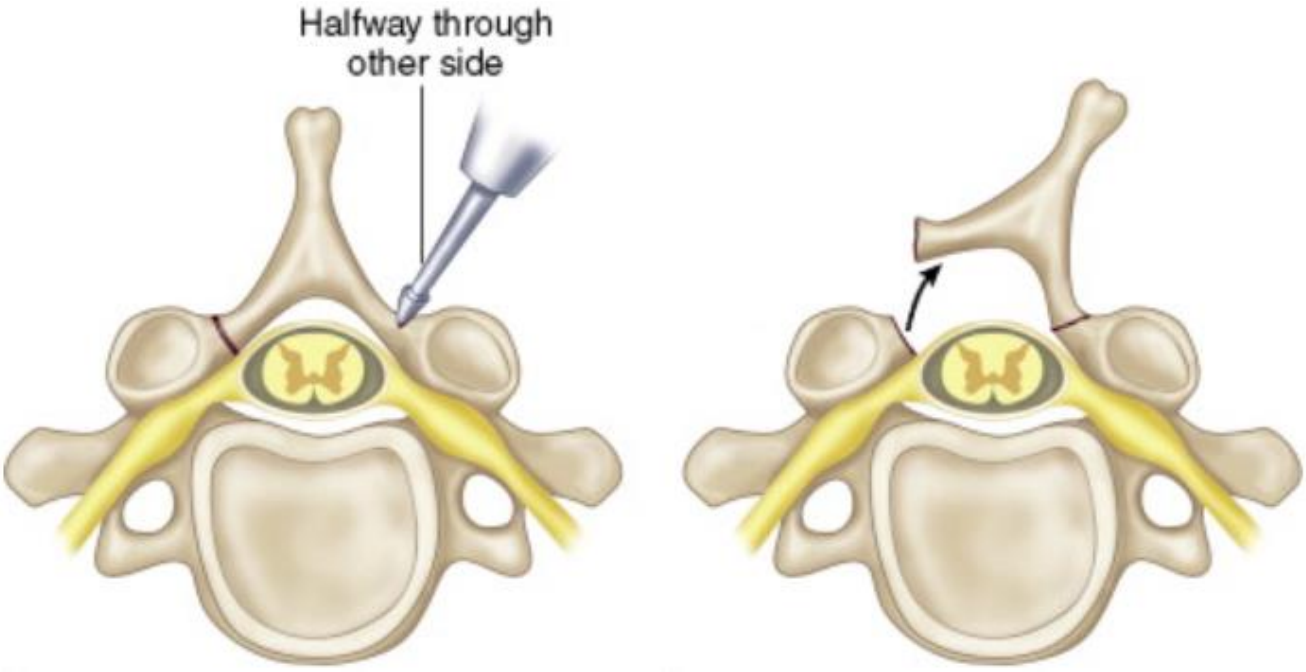


At 6 months:



Collect bone dust during drilling for autograft packing!
Dr. Chapman:
- fully preserve interspinous ligaments;
- drill at the valley – junction of lamina to lateral mass;
- use M8 Matchstick drill and #9 suction tip;
- very low threshold to do C4-5 foraminotomy (on both sides) to minimize C5 palsy risk;
- may need to carve dome in C2 to give room for C3 opening (if C3 lamina is wedged under C2).

- **complete (bicortical) longitudinal troughs** are drilled on laminae on one side (more ***stenotic / symptomatic side***, also if ***foraminotomy*** is needed on that side)
  - at lamina–lateral mass junction, 3-mm cutting bur drill bit is used to make small laminotomy hole at inferior aspect of the inferiormost lamina → cut cephalad with Medtronic B-1 bit (low-profile footed drill bit).
    - caution is warranted at C7, when included, because of its unique angle.
  - alternatively, drill a small trough (using the 3-mm cutting bit) on opening side and complete opening with 2-mm Kerrison (use small curette to release lig. flavum at each level – it would interfere with door opening).
  - bone wax is avoided!
- **partial depth (unicortical) V-shaped longitudinal troughs** are drilled on the laminae with a matchstick drill bit on the other side.
  - **aim 3 mm medially** from the junction of the facet joint and lamina.
  - do not breach anterior cortical bone (Dr. Chapman makes rather deep cut – leave only thin wafer as it will heal; even if completely breaks, it is not a problem – it will heal without any plate!).
  - surgeon should ***err on the side of leaving more bone***, as fine-tuning can be done once every level is at, or close to, the desired thickness.



- Kim CH et al 2020 in RCT compared ***regular drill bit vs. ultrasonic bone scalpel (UBS)***: hinge union rate was inferior in the UBS group at 6 mo postoperatively, but UBS was efficacious in reducing dural injuries and bleeding.
- using 2 mm Kerrison, **divide ligamentum flavum** at both ends of planned laminae-spinous process complex.
- laminae-spinous process complex is **hinged**.
  - controlled pressure is applied to spinous process toward hinged side to expand opening (may use vertebral body spreader for that).
  - sometimes one must resect ligamentum flavum, as pressure is applied to the spinous process, to open the door.
  - if hinge fails to bend despite resection of what seems to be adequate amount of bone, check to be sure that the bone was completely divided on open side.
  - foraminotomies, if indicated, are now performed (do not to destabilize facets!); may need to use **lateral hole plate** then (as cranial-caudal diameter of lateral mass gets shortened).
- if hinge side is fractured (risk of ventral subluxation into foramina, esp. if door is opened too widely), three simple solutions are available:
  a) often no change in operative plan is necessary because the posterior elements remain in position by wedging the graft in position and its fixation on the open side.
  b) entire hinge side can be opened, in the same technique as the open side, and grafts can be placed.
  c) **trough (s. hinge) plate** can be placed across fracture line (Dr. Chapman thinks it is not necessary):

- laminae-spinous process complex is **fixed** in new position with plates laid on posterior surface of lateral mass and lateral edge of lamina;

  N.B. most common reason for failure of laminoplasty has been restenosis due to hinge closure!

  — may use graft to restore bony arch.

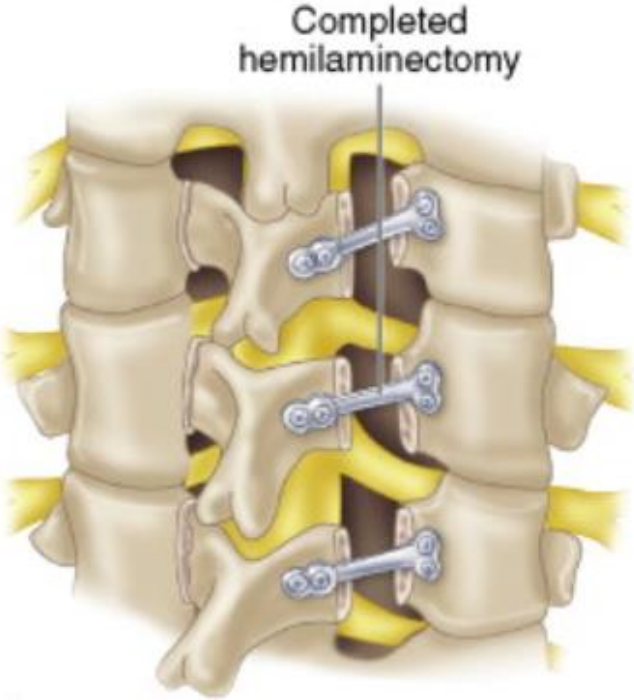
  N.B. do not place any graft across interlaminar spaces to ensure no fusion occurs across levels!

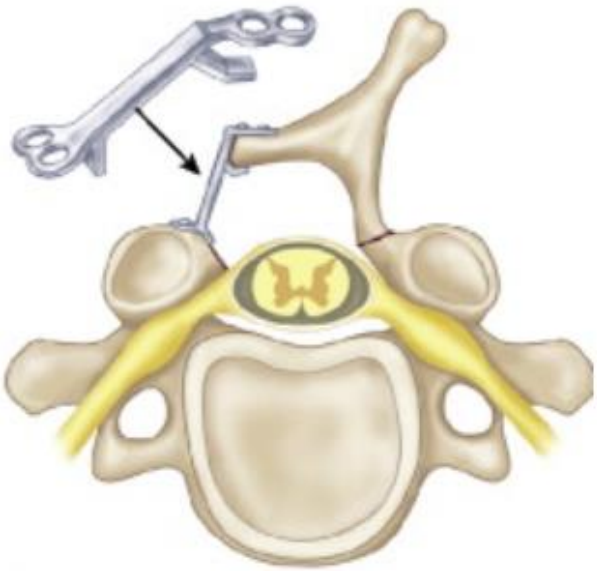
  — use **smaller plates** (6-10 mm or even specially designed oblique grafts) at the top and bottom, **bigger plates** (8-12 mm) in middle segments; some experts do not do large openings (not needed, plus, ↑risk of C5 palsy).

  — Dr. Chapman places ***medial screws first***, then assistant pushed spinous process towards operator and operator places lateral mass screws under compression (from assistant push) – you want grafts be under compression!

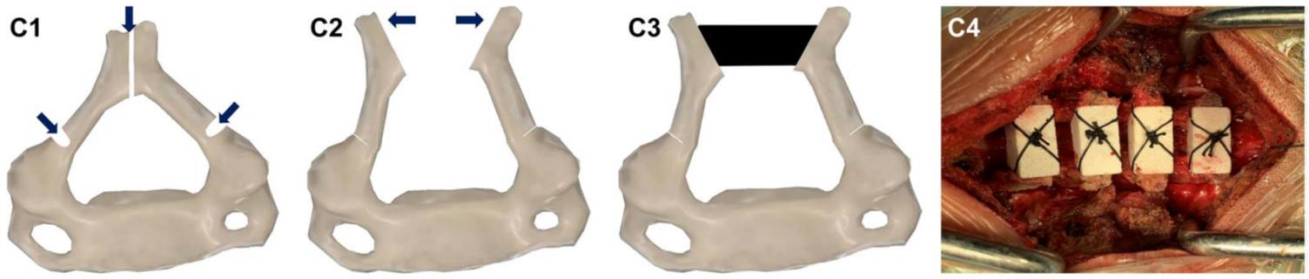
  N.B. place lateral mass screws into upper half of lateral mass (else risk of screws extending into facet joints); this makes plate to extend to upper half of lamina, but plate could be bent (plate easily conforms to bone surface upon screw tightening).

  — if fixation *feels suboptimally strong*, may add **hinge plate** to opposite side.

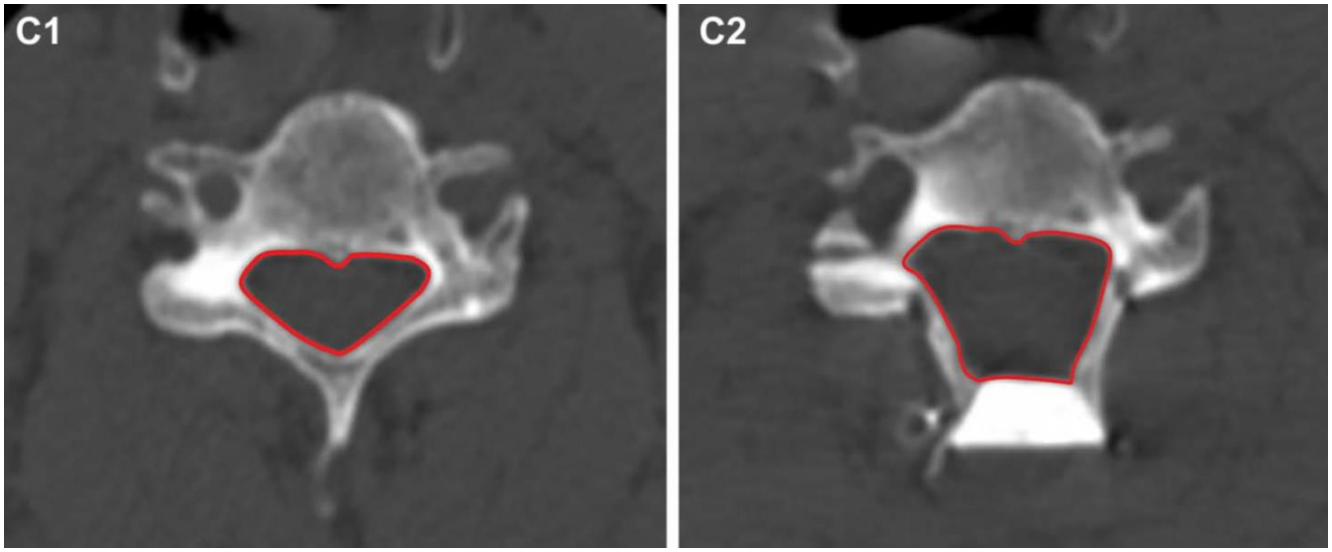




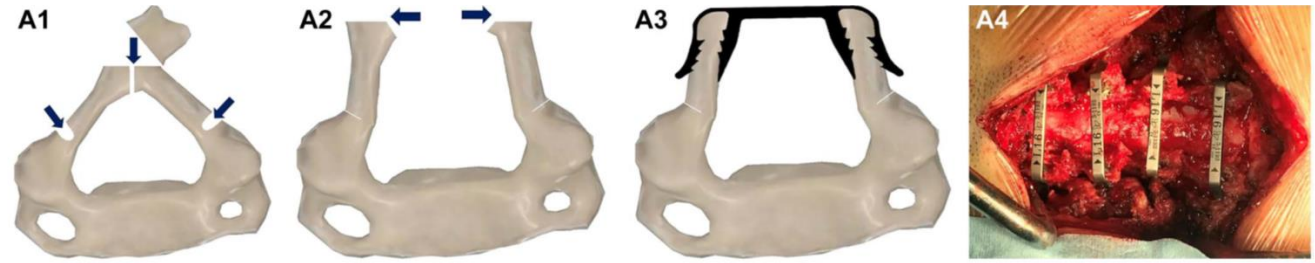
B. DOUBLE-DOOR SPACER



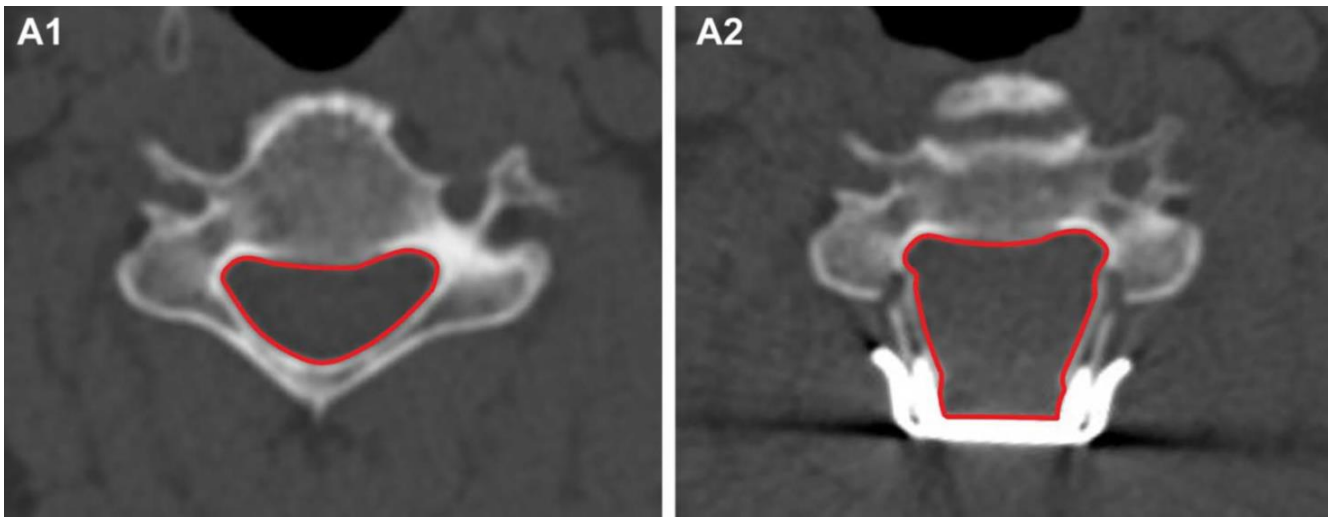
- split laminae at the center.
- bilateral gutters made using a high-speed drill.
- place hydroxyapatite blocks as spacers between the opened laminae.
- spinous processes anatomically reattached onto the spacers using ordinary suture.



C. DOUBLE-DOOR STAPLE



- split laminae at the center.
- bilateral gutters made using a high-speed drill.
- place lamina staple (e.g. Beijing FITO Medical Co, Ltd) between the opened laminae to keep them open; no screws needed!



POSTOPERATIVELY

- soft* or rigid collar for comfort (begin isometric neck exercises while wearing the collar) → ROM exercises started at 2 weeks (flex and extend their necks as much as possible).

*Dr. Chapman choice

OUTCOMES

- postoperative **cervical ROM** (flexion–extension, lateral bending, and rotation) – inferior in singled-door miniplate vs. double-door spacer (difference was not statistically significant).
    - contracture of paraspinal muscles and facet joints is a potential cause of reduced cervical ROM after laminoplasty.

Meta-analysis

complication rate:

single-door laminoplasty - 18.72%
double-door laminoplasty - 8.13%

C5 palsy rate:

single-door laminoplasty - 7.69% on the opened lamina side (asymmetric decompression effect)
double-door laminoplasty - 2.60%

postop axial neck pain in single-door laminoplasty – due to lack of reattachment of the spinous process and associated muscles; vs. double-door laminoplasty have the advantage of the anatomic reattachment procedure.

Outcomes by different types

Chao Li et al. Comparison of Clinical Outcomes of Cervical Laminoplasty for Cervical Spondylotic Myelopathy: Double-Door With Lamina Staple, Single-Door With Miniplate, and Double-Door With Spacer—A 2-Year Follow-Up Study. Neurosurgery 2023 Jun 1;92(6):1259-1268

- 166 patients with cervical spondylotic myelopathy (CSM) and canal < 13 mm AP
- C3-6 laminoplasty
- all operations are performed by the same experienced spinal surgeon at a single center
- three techniques were regularly alternated between each consecutive week (i.e. patients underwent only 1 of the 3 techniques each consecutive week).
- 52 patients underwent double-door staple, 63 patients underwent single-door miniplate, and 51 patients underwent double-door spacer.
- outcomes:
    - in all groups, **JOA score** was significantly better postoperatively than preoperatively ($P < .05$).
    - **operation time** was significantly shorter in double-door staple (123.1 ± 22.6 minutes) and single-door miniplate (123.3 ± 32.4 minutes) groups vs. double-door spacer group (152.1 ± 33.5 minutes) ($P < .005$).
    - **estimated blood loss** was significantly more in the single-door miniplate group (188.9 ± 24.1 mL) than in double-door staple (138.1 ± 22.7 mL) and double-door spacer (129.1 ± 21.9 mL) groups ($P < .005$).
    - **expansion ratio of cervical intraspinal cross-sectional area** decreased in the order of double-door staple (136.8%) > double-door spacer (107.9%) > single-door miniplate (93.3%).
    - **expansion ratio of dural sac cross-sectional area** (MRI on POD1) - no significant differences among 3 groups: double-door staple group (57.6% ± 28.1%), single-door miniplate group (45.6% ± 26.7%), double-door spacer group (51.4% ± 23.4%) ($P > .05$).
    - **postoperative complications** - no significant differences among groups ($P > .05$).
    - no patients required **reoperation**.
- conclusion - double-door staple is a safe and innovative choice.

SYSTEMS

DEPUY SYNTHES

ARCH laminoplasty system

MEDTRONIC

CENTERPIECE™ Plate Fixation System

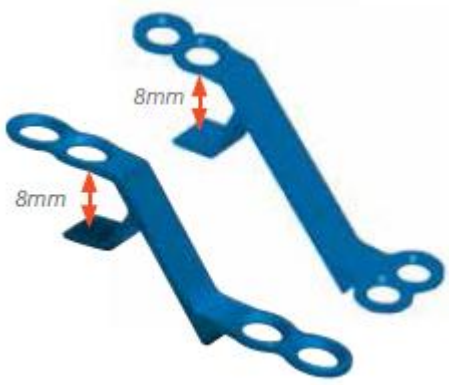
Catalog >>

A. **Open Door Plates** - laminar shelf on plate, available in 8-18 mm sizes in 2 mm increments

B. **Graft Plates** - available in 8 mm to 18 mm sizes in 2 mm increments

C. **Lateral Hole Plates** (in Open Door and Graft Plate Designs) – medial/lateral lateral mass screw holes allow for flexible screw placement

D. **Wide Mouth Plates** - wider laminar shelf to accommodate thick laminae:



E. **Trough Plates** - small, angled plates provides fixation for floppy or displaced hinge:

Grafts (optional)

Top View Side View

- all cortical graft, freeze-dried, curved edges
- predrilled center screw hole allows for immediate access for screw insertion
- available in 8 mm to 18 mm sizes in 2 mm increments

Figure 15a

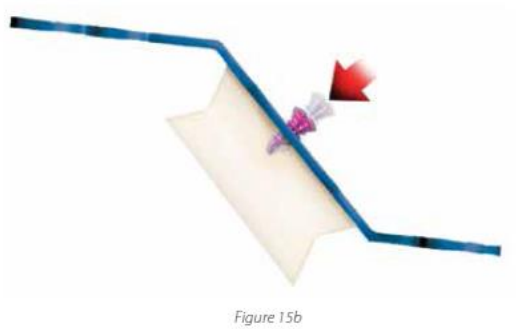


Figure 15b

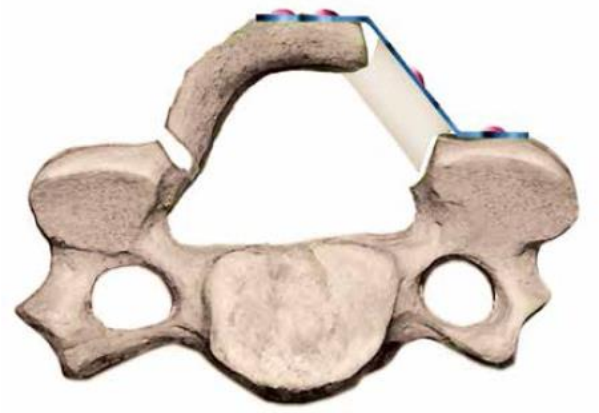


Figure 16

GLOBUS

CANOPY™ System brochure >>

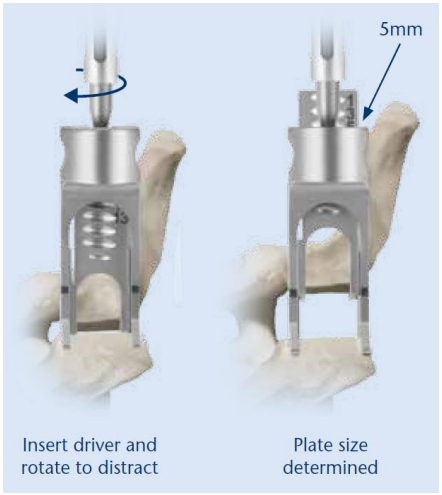
Indicated for levels C3-T3 (for levels T1-3 use with ELLIPSE® polyaxial screws).

Optional - **Open Door Distractor** (alternative – use conventional vertebral body spreader) – goals:

Open Door Distractor 6102.1020
Open Door Distractor Holder 6102.1021
(Assembled)

1) to lift lamina and measure plate size:

Distractor placement



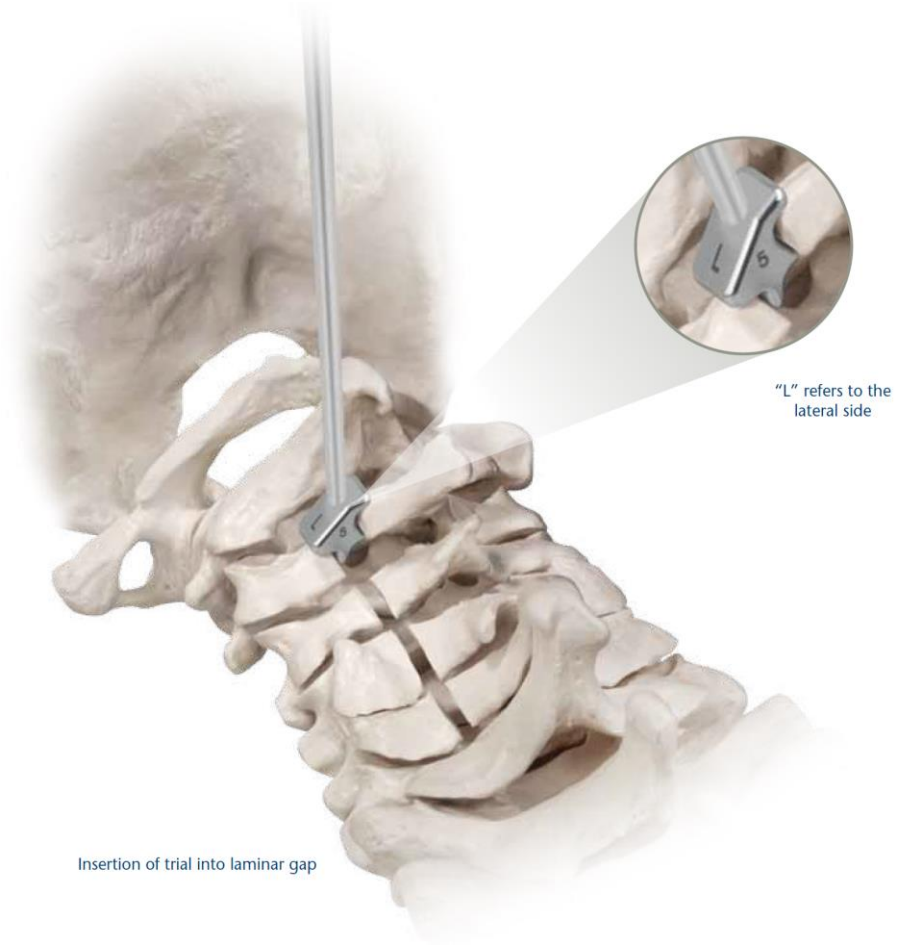
Insert driver and rotate to distract

Plate size determined

2) to maintain intralaminar opening during the insertion of a shelf plate:

Plate Holder, Internal Grip inserting shelf plate

Insert **<u>Trial</u>** into laminar gap on Open Door side (err on the slightly bigger trial – later always can trim more lamina to accommodate too big plate / graft):



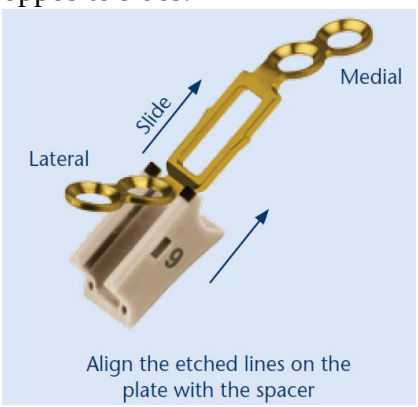
A. <u>Graft Plates</u> – do not have kickstands (rely on spacer to keep door open):

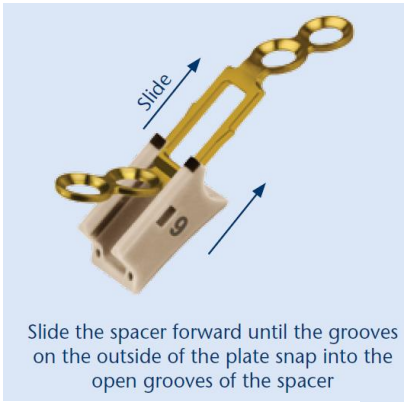
- available in 5–13 mm sizes (in 2 mm increments).
- **in-line** and **adjacent** screw hole configurations:

N.B. **in-line screws** risk breaching lateral part of lateral mass.
N.B. lower screw (in **adjacent screws** plate) risks going into facet – make sure both screws are placed in upper half of lateral mass (i.e. upper screw is next to upper facet joint line – may need to contour plate to get optimal landing on lamina as you now are at the top of lamina)!

- spacer options - used with **PEEK spacer** or **allograft**:

A) assembling Graft Plate and slide-on radiolucent **PEEK Spacer** (with chamber for allograft or autogenous bone graft packing); black line on the plate and black dots on the graft at the end are on opposite sides:



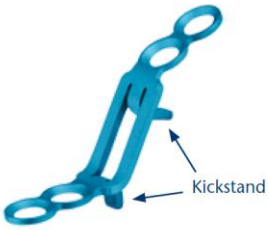


B) assembling Graft Plate and **Allograft** (2.6x5 mm **graft screw** on Pushbutton Hex Driver, 2.0 mm) - align with the plate and insert the screw through the window of the plate into the spacer:

B. <u>Shelf Plates</u>

- available in 5–13 mm sizes (in 2 mm increments).
- **in-line** and **adjacent** screw hole configurations:

- additional plate contouring may be required.
- if desired, the plate may be cut between the screw holes using the Cutter to best fit patient anatomy.



<u>Hinge Plates</u>

- designed to accommodate an unstable hinge (so do not overdistract open door! – better trim the lamina PRN); may also be used if open door side feels somewhat unstable.
- **in-line** and **adjacent** screw hole options:

Plate Holder options:

Plate Holder, External Grip 6102.1000

Drill-Through Plate Holder 6102.1001

Plate Holder, Internal Grip 6102.1004

Articulating Plate Holder, External Grip 6102.1006

The **Drill-Through Plate Holder** stabilizes the implant and allows simultaneous drilling or screw insertion.

The **Plate Holder, External Grip** attaches to the outside edges of the graft plates and shelf plates.

The **Articulating Plate Holder, External Grip** attaches to the outside edge of the plates and articulates to the desired angle.

Internal holder is used for **shelf plates** with **open door distractor**:

The **Plate Holder, Internal Grip** grips the central opening in the shelf plates.

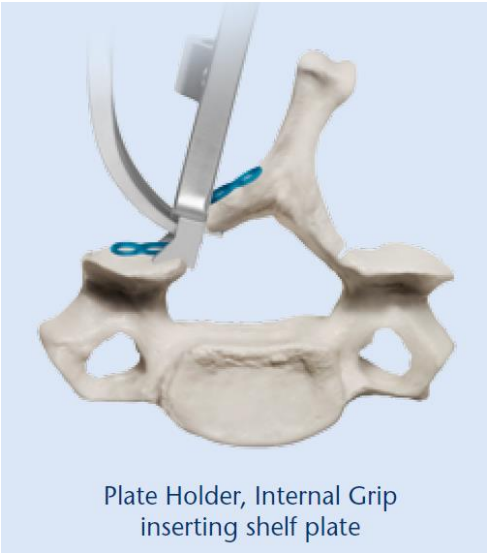


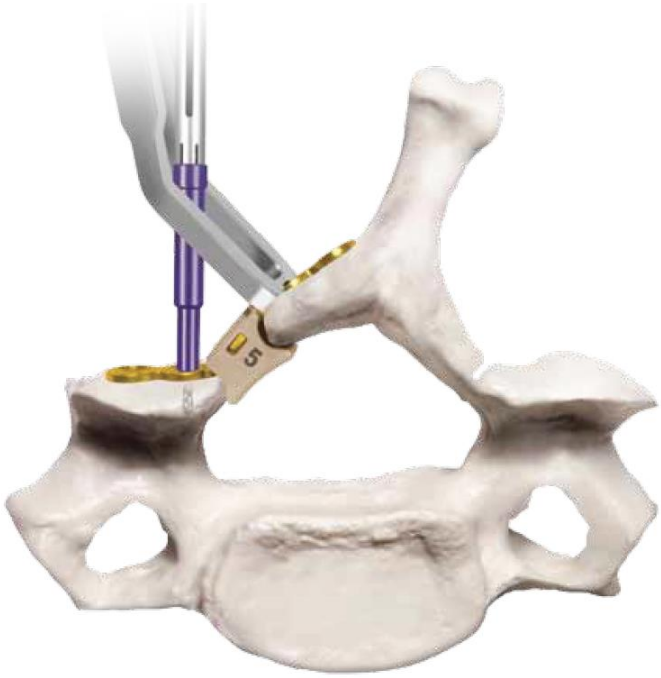
Plate Holder, Internal Grip inserting shelf plate

Bone screws:

- 2.2 mm and 2.6 mm diameter self-drilling or self-tapping.
- 3.0 mm diameter self-tapping rescue screw.
- lengths 4–12 mm (in 2 mm increments).
- color-coded **screw** lengths match drill **Depth Sleeves**.

Screw Hole Preparation

- 1.3 mm **Awl** is used to perforate the cortex at the site of screw placement.
- for self-tapping screws, pilot hole may be drilled using 1.4 mm **Drill Bit** and **Depth Sleeve**:
    - place the tip of drill bit and depth sleeve assembly into the desired plate hole – depth sleeve centers drill bit in the plate hole.
    - drill to the stop.
    - Depth Gauge may be used to verify depth.



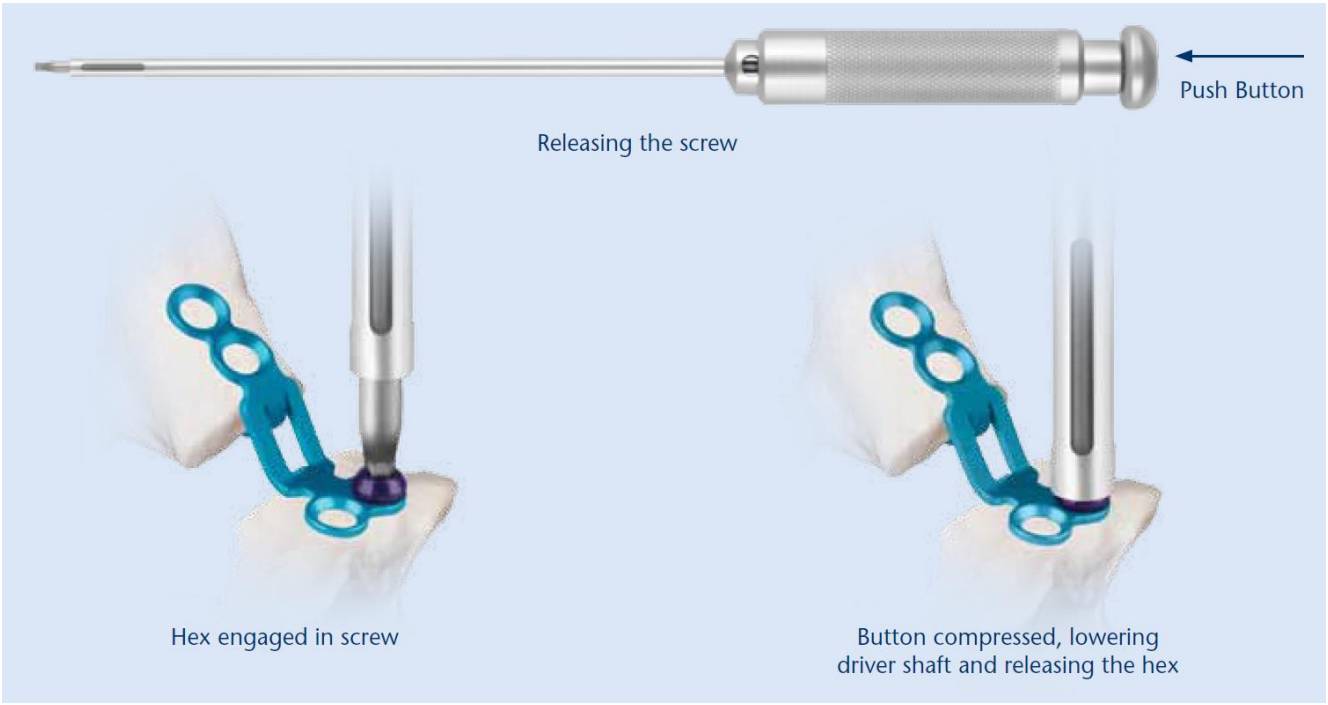
Slide the depth sleeve over the tip of the drill bit

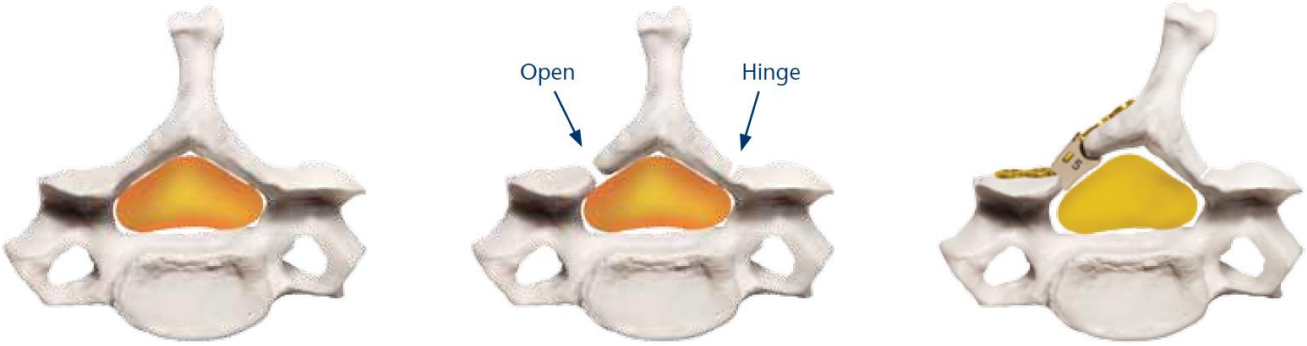
Push the depth sleeve forward to snap onto the drill bit

The depth sleeve is spring loaded to cover the tip of the drill bit and retracts only as it is advanced through the screw hole

Screw Placement

- screw is loaded on Pushbutton Hex Driver, 2.0 mm.
- press the button at the distal end of the driver to release screw.


Push Button
Releasing the screw
Hex engaged in screw
Button compressed, lowering driver shaft and releasing the hex

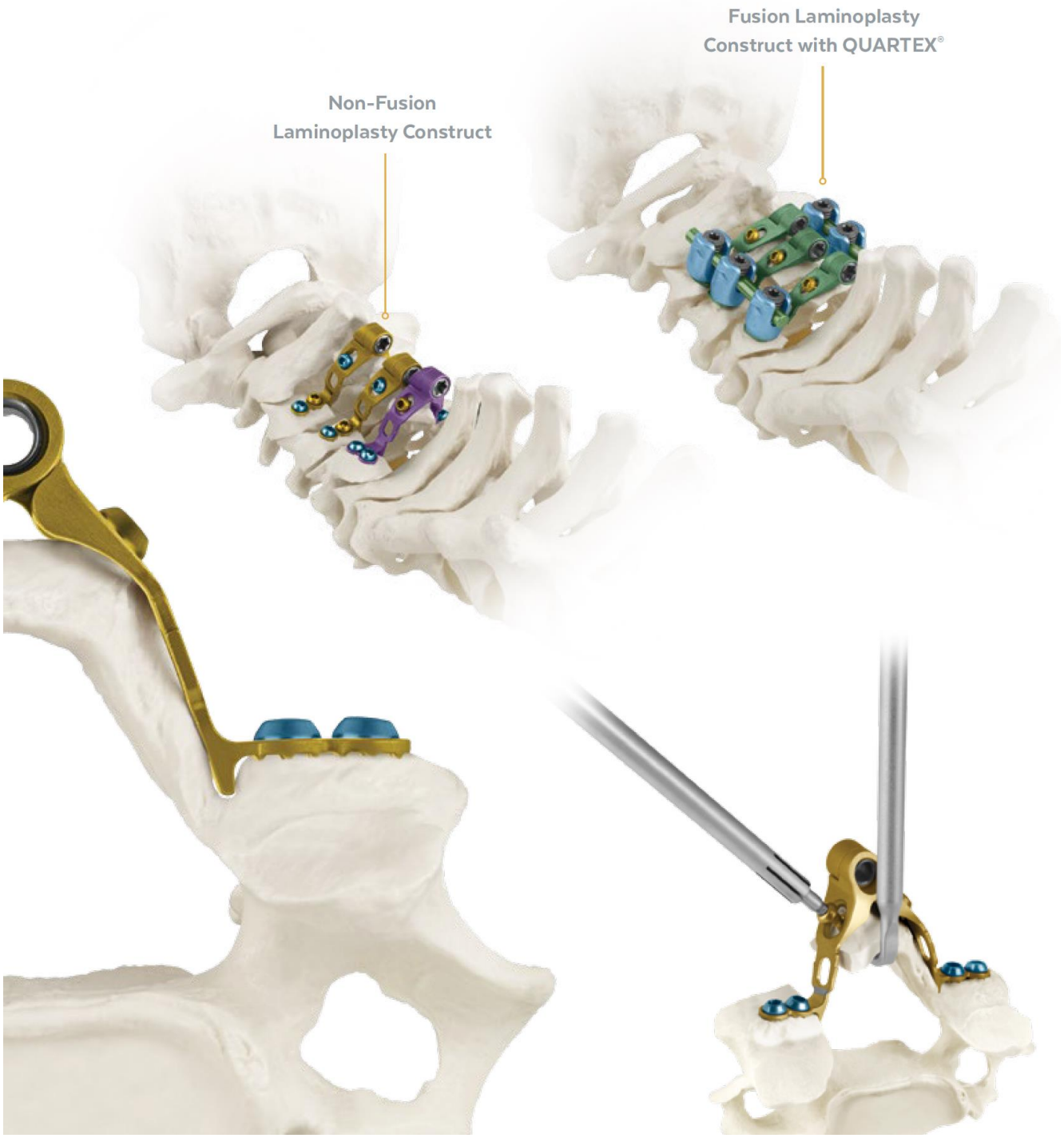

Open
Hinge
Spinal cord compressed
Laminoplasty
CANOPY™ inserted

Implant Removal

- plate holder to grip the plate during screw removal

HAVEN™ System brochure >>

- dual plate laminoplasty system that offers bilateral lamina support.
- may be used with or without posterior cervico-thoracic fusion systems.
- see more in the brochure.



PCF (Posterior Cervical Fusion)

Indication – adjunct to laminectomies to prevent kyphosis (check CT – if significant anterior osteophytes are present, patient may not kyphose without PCF)

Contraindications: aberrant vertebral artery, fractured lateral mass.

- prone on chest rolls or wide Wilson frame.
- head in pins – translated posteriorly (but keep neck neutral for fusion; too much flexion – difficulty swallowing; too much extension – difficulty walking).

- Dr. JRC likes fluoro (vs regular XR) – to have XR whenever needed; others use navigation (to minimize radiation exposure to surgeon and maximize screw accuracy and length).
  - fluoroscopy should be used to confirm proper cervical alignment if PCF is part of either occipitocervical fusion or cervicothoracic fusion

ALIGNMENT PARAMETERS

1) cervical lordosis
2) cervical sagittal vertical axis (SVA)
3) T1 slope

ARTHRODESIS

- look at flexion-extension films – try to create extension with fusion (improve sagittal balance to minimize persistent chronic pain).
- facet joints are exposed and the joint cartilage is denuded with curettes or small rasps or drill.
- joint space is packed with autologous bone chips; alternatively, machined interfacet allograft spacers can be used to augment posterior cervical fusion (see below).

Cervical interfacet spacer (CIS)
- see below >>

- addition to posterior cervical fusion
- allograft technology to provide indirect neuroforaminal decompression while simultaneously enhancing fusion by placing the allograft in compression.

CERVICOTHORACIC JUNCTION

- posterior approaches (vs. ACDF):
  - disrupt posterior tension band (muscle dissection, laminectomies, violation of ligamentous structures and facets).
  - lack anterior column support.
  - provide less restoration of cervical lordosis.
- constructs ending at the cervicothoracic junction (CTJ) may lead to higher rates of adjacent segment disease (prevalence of clinical adjacent segment disease (ASD) after cervical fusion ending at C6 or C7 is quoted from 16.0% to 38.1% at 10 yrs).
- if stopping short of the CTJ, do not to disrupt the facets and interspinous ligaments.
- as of May 2020, there are 5 retrospective clinical studies: 3 recommend crossing the CTJ and 2 found no difference in outcomes.

  Crossing CTJ is recommended in smokers and osteoporosis (and others with increased risk of pseudoarthrosis); not recommended in frail patients

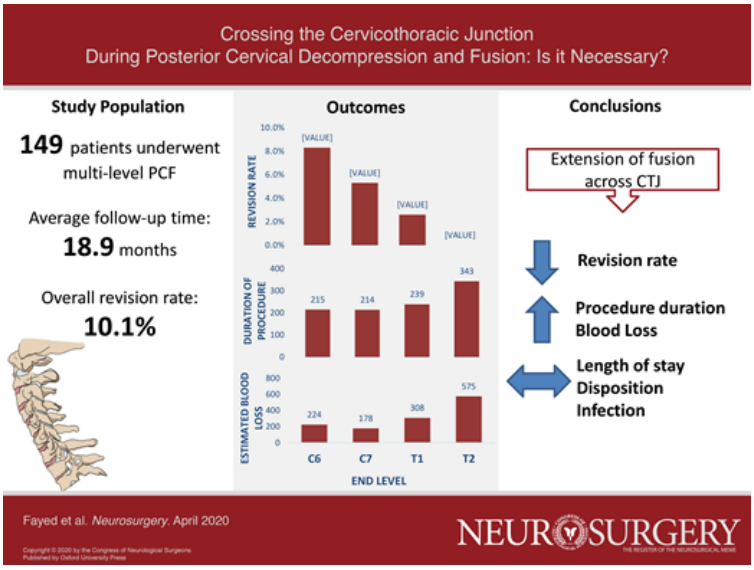
For thoracic pedicle screws use **navigated awl** – much stiffer – more accurate trajectory (than using long drill bit that tends to bend and navigation less accurate → higher rate of needing screw revision).

Case series

Islam Fayed et al. Crossing the Cervicothoracic Junction During Posterior Cervical Decompression and Fusion: Is It Necessary? Neurosurgery 0:1–7, 2020

- retrospective review of 149 multilevel (≥ 3 levels) PCF adult patients with a mean follow-up of 18.9 mo.

— 79 (53.0%) constructs ended in the cervical spine and 70 (47.0%) constructs ended in the thoracic spine.
— 15 (10.1%) early revisions, 7 (4.7%) were related to the construct.
— C6 → T2:



- 5 (8.3%) revisions were performed for constructs ending at C6, 1 (5.3%) at C7, 1 (2.6%) at T1, and none (0%) at T2 (P = .035).

  Extending fusion to T1-2 decreases revision risk 5-fold
- mean procedure duration: 215 min at C6, 214 min at C7, 239 min at T1, and 343 min at T2 (P = .001).
- mean estimated blood loss: 224 mL at C6, 178 mL at C7, 308 mL at T1, and 575 mL at T2 (P = .001).
- no difference in length of stay, disposition, surgical site infection, or radiographic parameters.

  T1 may be the optimal end level when taking revision rate, procedure duration, and EBL into consideration

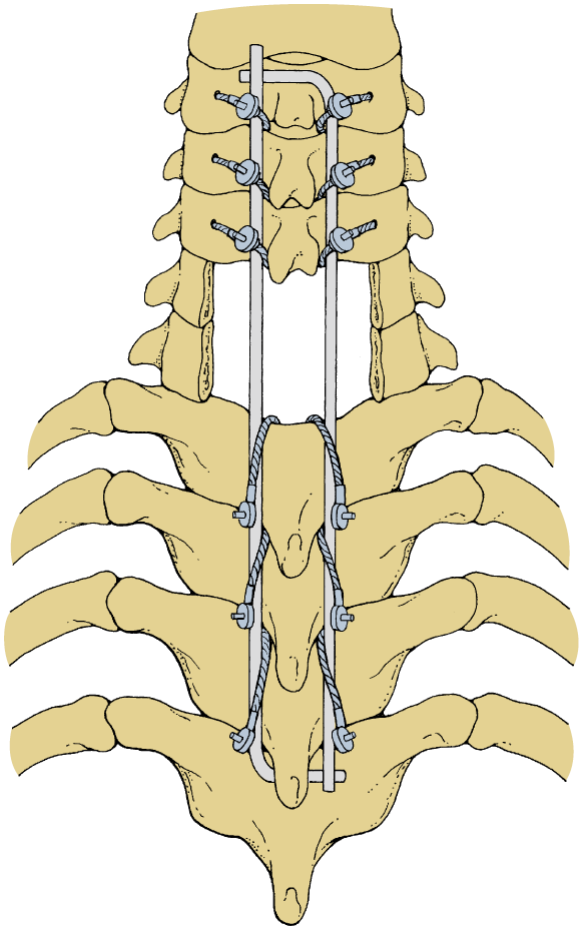
INSTRUMENTATION

- fixation at **C1** can be achieved by screws placed in the **lateral mass**. *see below >>*
- fixation at **C2** can be achieved by screws placed in the **pars, pedicle, or lamina**. *see below >>*
- **lateral mass** screws are used for fixation **from C3 to C6**; whereas **pedicle screws** are typically used for fixation at **T1-2**.
- largest lateral mass – C3; smallest – C7.
- **C7** lateral mass is rather small and at steep angle; options:
  a) use C7 pedicle screw (screw head may or may not collide with C6 screw head so may need to skip C6)
  b) C7 fixation is skipped to facilitate screw fixation into T1.
  c) C7 lateral mass screw is placed using the "down and out" technique
- additional sublaminar hooks or translaminar screws can be used at the caudal part of the construct to reinforce the screw fixation if necessary.

N.B. use **drill guide (tube)** – *drill bit is thin and easily bends* (especially if levering against skin edge) → unreliable navigation!

LUQUE L-RODS AND LUQUE RECTANGLES

Read Benzel (2012) ch. 147

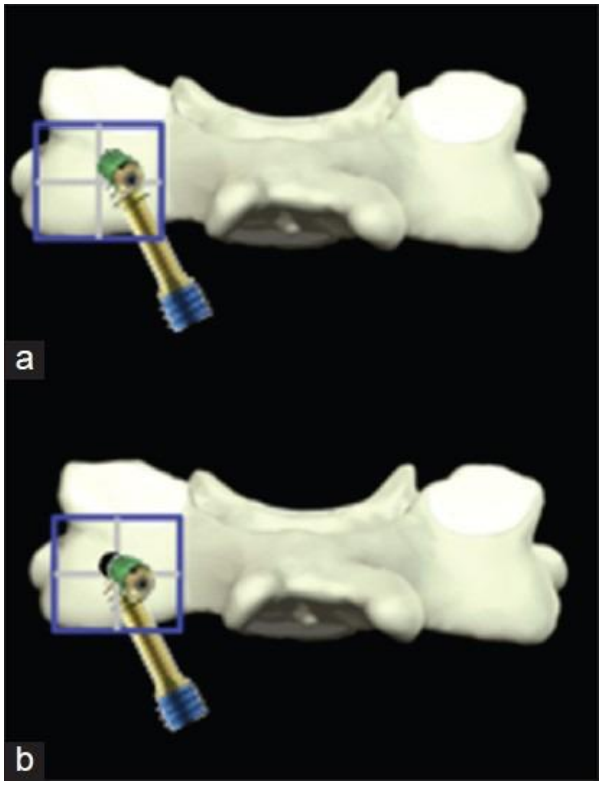


LATERAL MASS FIXATION

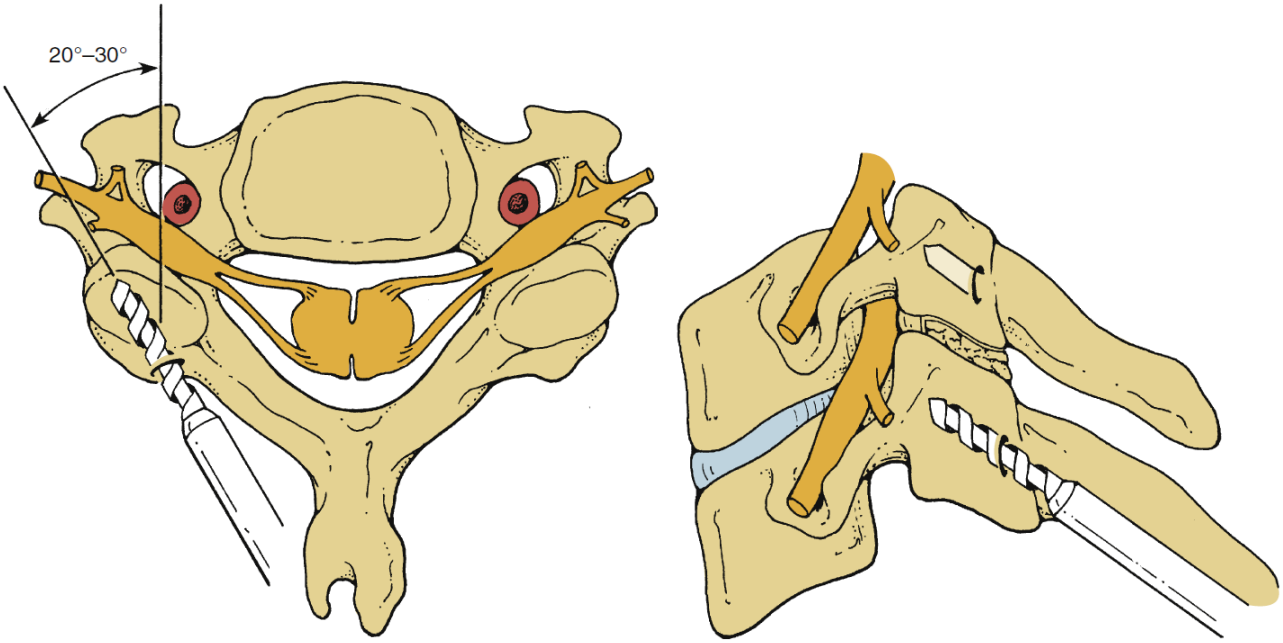
Medtronic - Vertex (older system), Infinity (newest system)

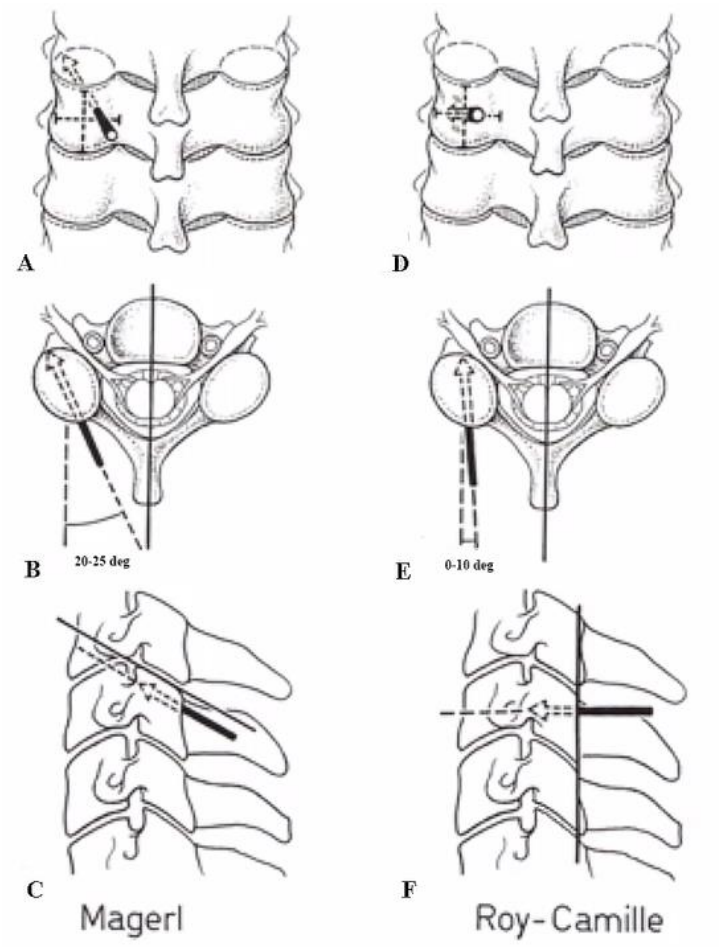
- expose entirely posterior surface of lateral masses.
- ***place screws before laminectomy*** to protect spinal cord from instrument passing above exposed dura.
- ***screws*** are 3.5 mm diameter, 14-16 mm length.
  - "favored-angle screws" - allow for fewer angulations in certain planes and a bias in the way the screw saddle sits on the screw.
- ***rods*** are 3.0-3.5 mm diameter.
  - lateral offset connectors can be placed if a screw is significantly outside the rod longitudinal axis, as sometimes occurs with the transition from lateral mass screws to thoracic pedicle screws.

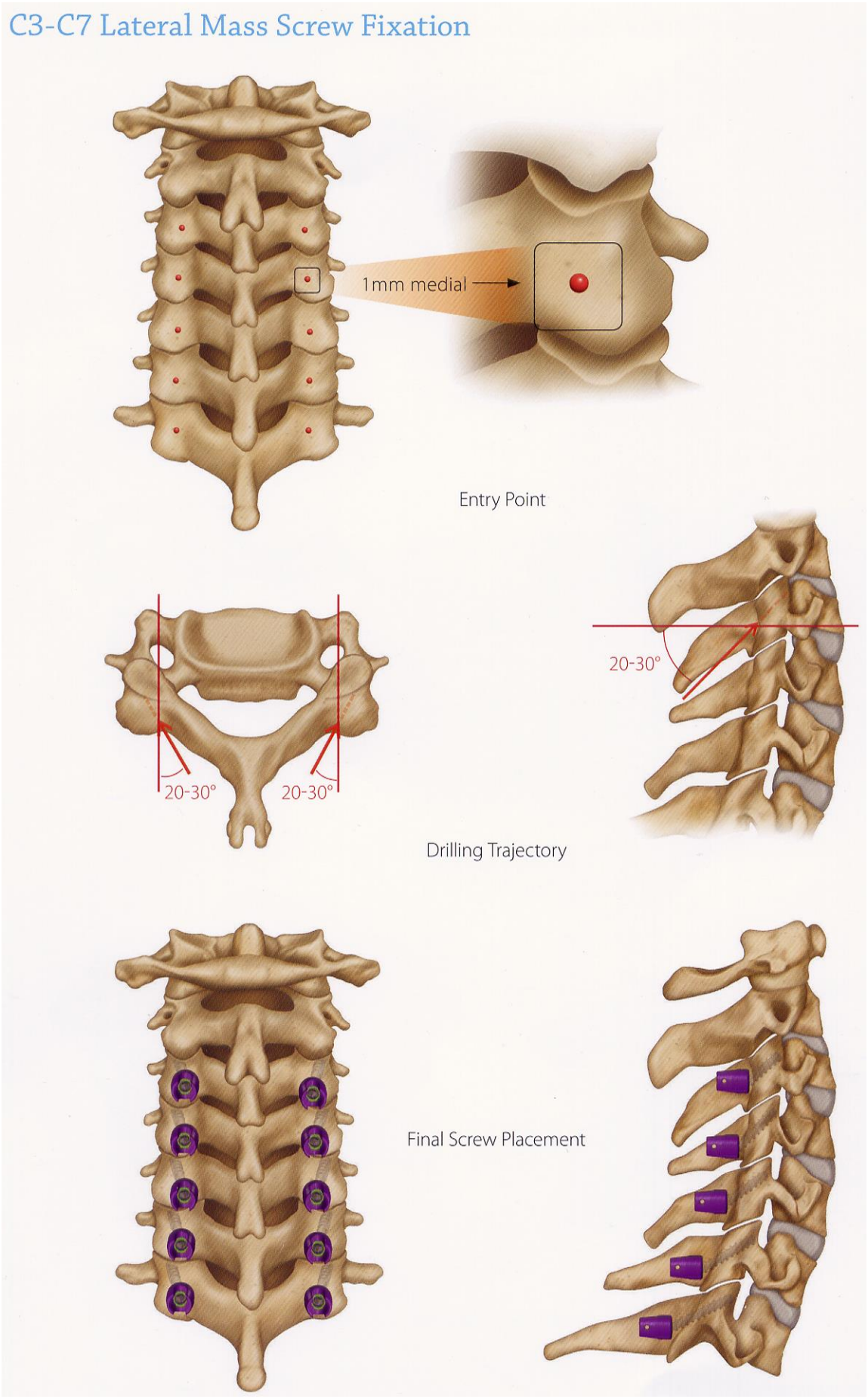
Starting points for the (a) Magerl and (b) Roy-Camille lateral mass screw:



Standard Magerl technique:




A
D
B
20-25 deg
E
0-10 deg
C
Magerl
F
Roy-Camille



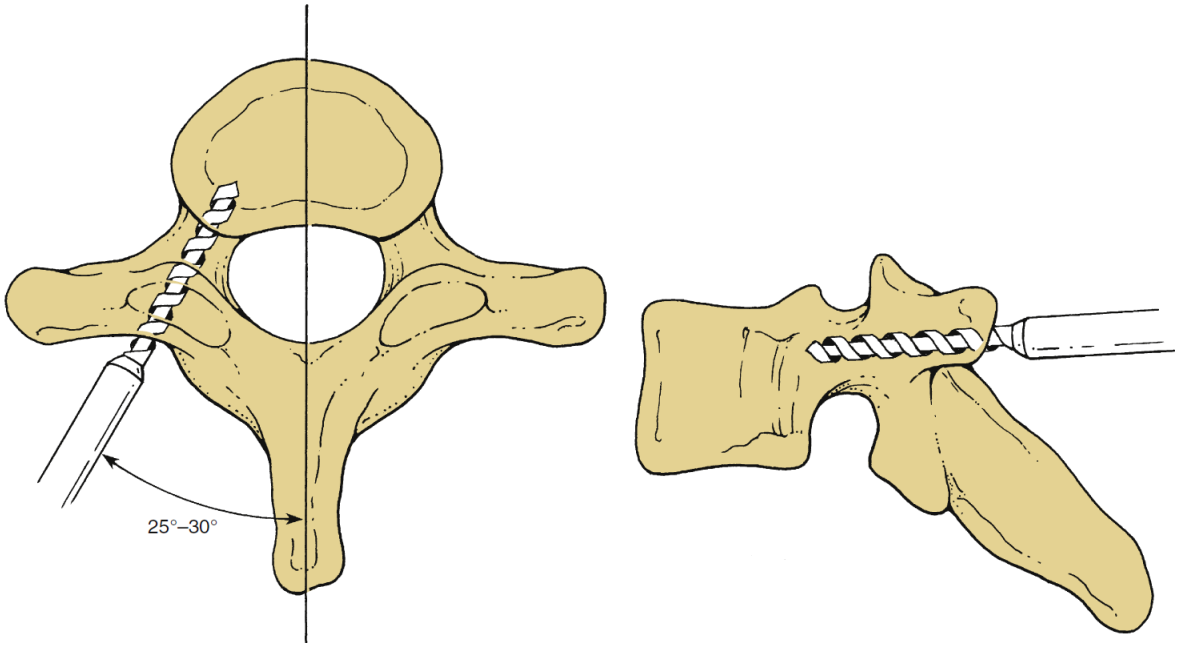
- divide mentally posterior surface of lateral masses into quadrants; drill with matchstick starting hole at medial-inferior corner of lateral mass center.

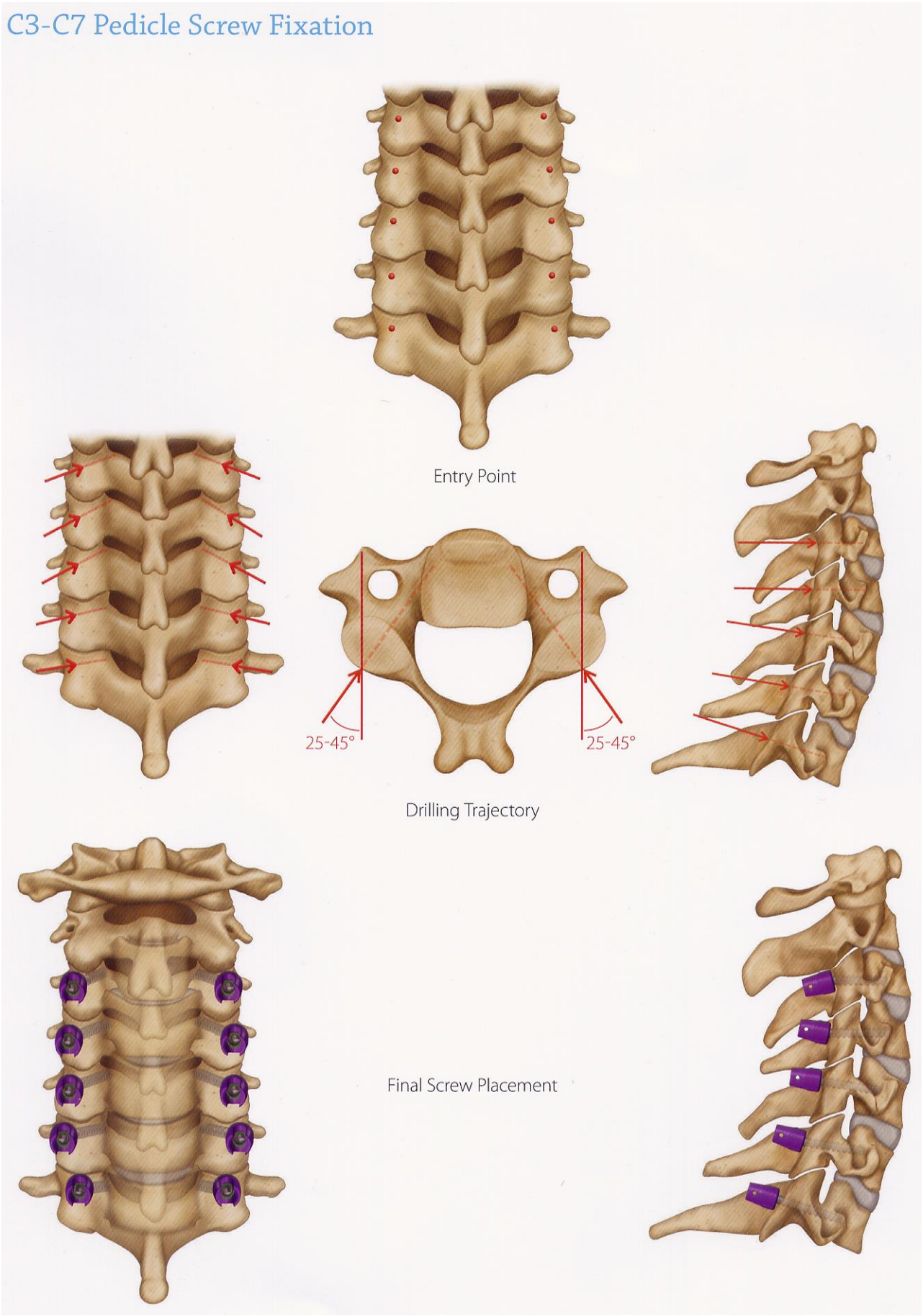
  - looking globally at starting points of posterior cervical screws, particularly in a long segment fixation incorporating occiput, C1, or C2, can help prevent unnecessary contouring during rod placement
- drill hole aiming up (to avoid nerve root) and out (to avoid vertebral artery); best way to achieve trajectory is to rest drill shaft on Cn-1 spinous process tip (as Dr. JRC noticed – you always need steeper trajectory than that).
  - if vertebral artery is encountered, place bone wax in hole → insert shorter salvage screw for tamponade, avoid placement of screws on contralateral side (alternative methods of fixation should be pursued if necessary, such as laminar screws); if the bleeding is refractory to these measures, it may be necessary to expose the vertebral artery for primary repair or occlusion. *see above >>*
- if screw is not self-tapping, then tap but just the beginning of canal (just to engage tap); ± check with ball probe (practically not needed as bicortical fixation is considered superior to unicortical fixation; if vertebral artery is injured – will see bright red blood through hole immediately).
- options for stripped screw:
  a) larger diameter rescue screw
  b) small amount of polymethylmethacrylate placed into hole before screw
  c) trans-facet screw
- decorticate ***posterior surface of lateral masses*** and ***facet joint spaces***
- place screws and rods.
  - for lowest levels may be difficult to achieve trajectory; options: a) extend incision, b) make a stab skin incision to pass screw driver, c) skip C7 and place T1 pedicle screws (unique trajectory – very inward and very towards feet, almost 45 degrees towards floor).
- if needed, perform laminectomies.
- place grafts into lateral gutters ± facet joint spaces.

PEDICLE SCREW FIXATION

- pedicle is entered 1 mm caudal to the facet joint.
- drill aiming medially 25-30 degrees; orientation is perpendicular to the long axis of the spine at C7, T1, and T2.
- use either navigation or verify the position of the pedicle by palpation through a small laminoforaminotomy prior to drilling.
- ***screws*** are 4.0-5.5 mm diameter.
- lateral mass screws are preferred for C3-6; main indication – trauma, when stronger posterior purchase is needed.

T1 pedicle screw:


25°–30°



INDUCING LORDOSIS

- even with lordotic rods and compression, it is not uncommon to achieve inadequate lordosis, especially if the construct includes the upper thoracic spine.
- solution - use of spinous process cables or a third rod fixed into the spinous processes of C2 and thoracic vertebrae with subsequent compression to create additional lordosis.
- spinous processes should be no more than 1 cm apart to create adequate lordosis.

  N.B. excessive neck extension may cause iatrogenic compression of the nerve roots, especially if there is radiographic foraminal stenosis preoperatively. H: ***prophylactic foraminotomies*** (if there are flexible segments with foraminal stenosis, the patient can be placed supine in the clinic and asked to maintain the neck extension for 10-15 min - if the patient develops any numbness, paresthesia, pain, or weakness in the arms, then a prophylactic foraminotomy should be performed).
- for fixed deformity cases, **Smith-Petersen Osteotomy** and **Pedicle Subtraction Osteotomy** can be used.

Cervical Spine Deformity—Part 3: Posterior Techniques, Clinical Outcome, and Complications. Lee A Tan, MD K Daniel Riew, MD Vincent C Traynelis, MD Neurosurgery, Volume 81, Issue 6, 1 December 2017, Pages 893–898, https://doi.org/10.1093/neuros/nyx477 Published: 31 October 2017

FUSION EXTENSION

Globus
ELLIPSE® ADDITION®-C:

POSTERIOR FORAMINOTOMY, DISCECTOMY

Used literature:
Benzel "Spine Surgery: Techniques, Complication Avoidance, And Management" 3rd ed.– chapter 76

Pending reading
Greenberg 469-470

INDICATIONS

Lateral disc herniations without significant uncovertebral spurring - see p. Spin11 >>

CONTRAINDICATIONS

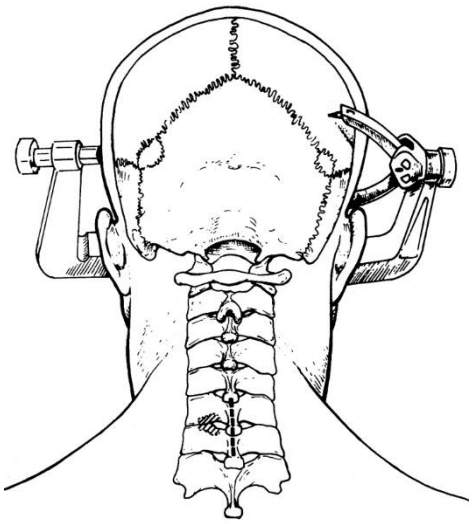
Central disc herniations and "disc-osteophyte complexes".

INTRAOPERATIVE

Position

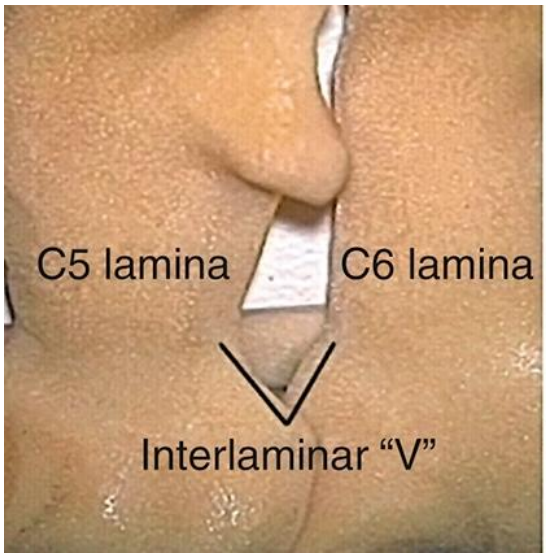
- prone in pins, neck in flexion
- Gardner-Wells tongs may be used to apply traction (10-20 pounds) via flexion vector
- maximum reverse Trendelenburg position (minimizes venous bleeding)
- shoulders may be taped down using 3-inch silk tape from around the acromioclavicular joint, down the arms (supporting them from falling downward), then around the foot of table. Overstretch with excessive force can cause a brachial plexus injury.
- Dr. Broaddus uses **microscope**; Drs. Cameron, Graham don't.
- in personal observance, *high risk of nerve damage* – use **intraop free-running EMG**.

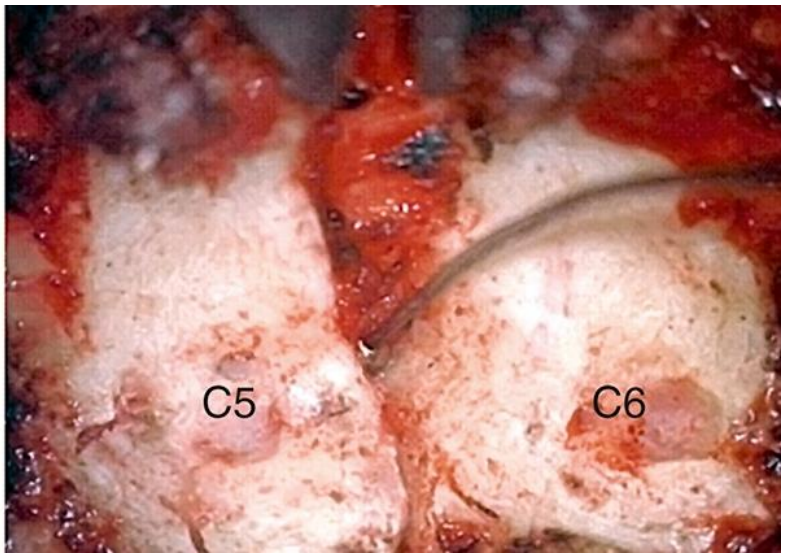
Posterior approach for C_{6-7} herniation on left; interrupted line - skin incision; oblique lines - area of bone removal that exposes left C_7 nerve root and disc herniation.



Foraminotomy

- **interlaminar V** is starting point (check it with ballprobe):

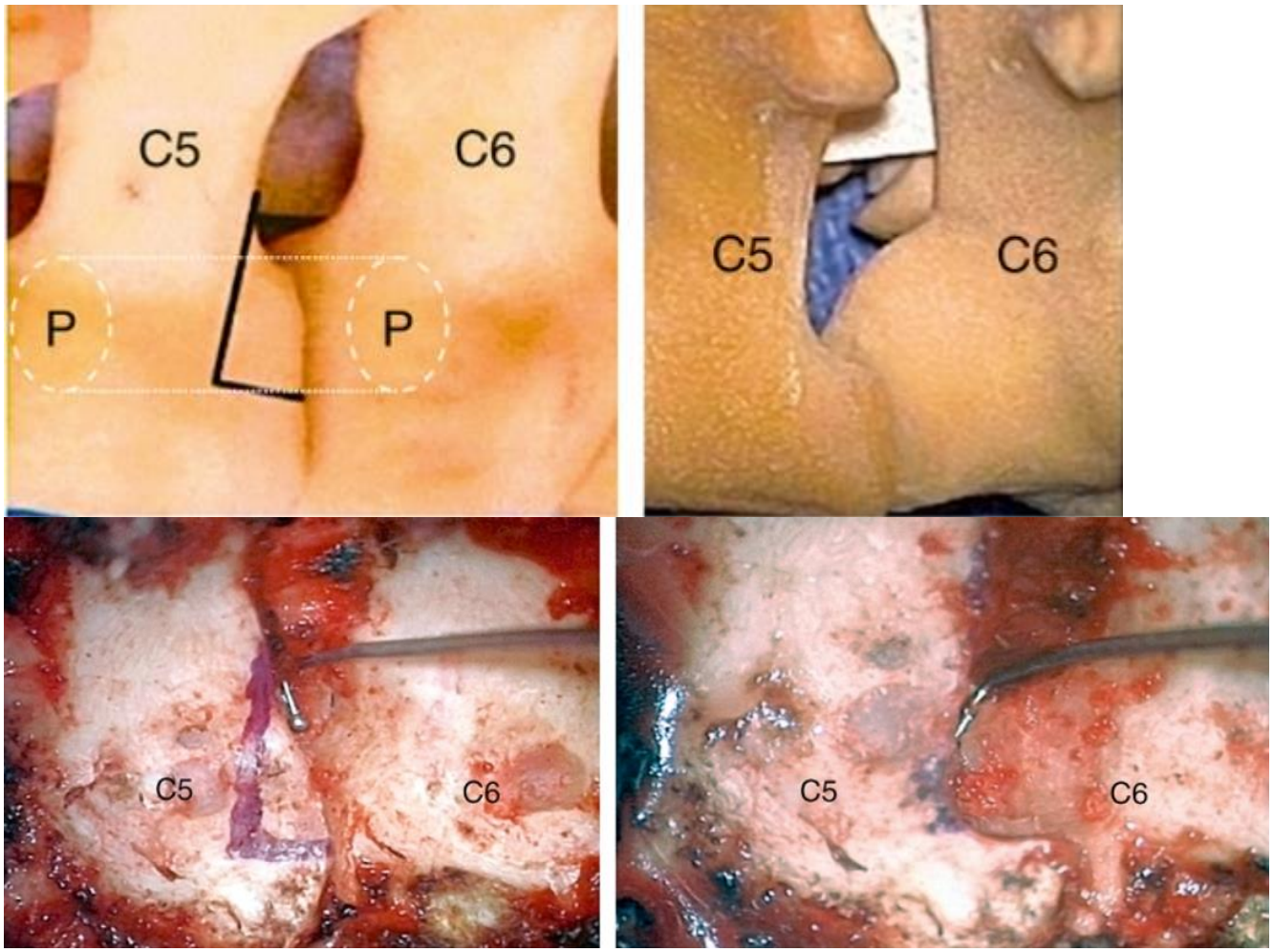




Source of picture: Benzel "Spine Surgery: Techniques, Complication Avoidance, And Management" 3rd ed. (2012), Saunders; ASIN: B00E6TO0MK >>

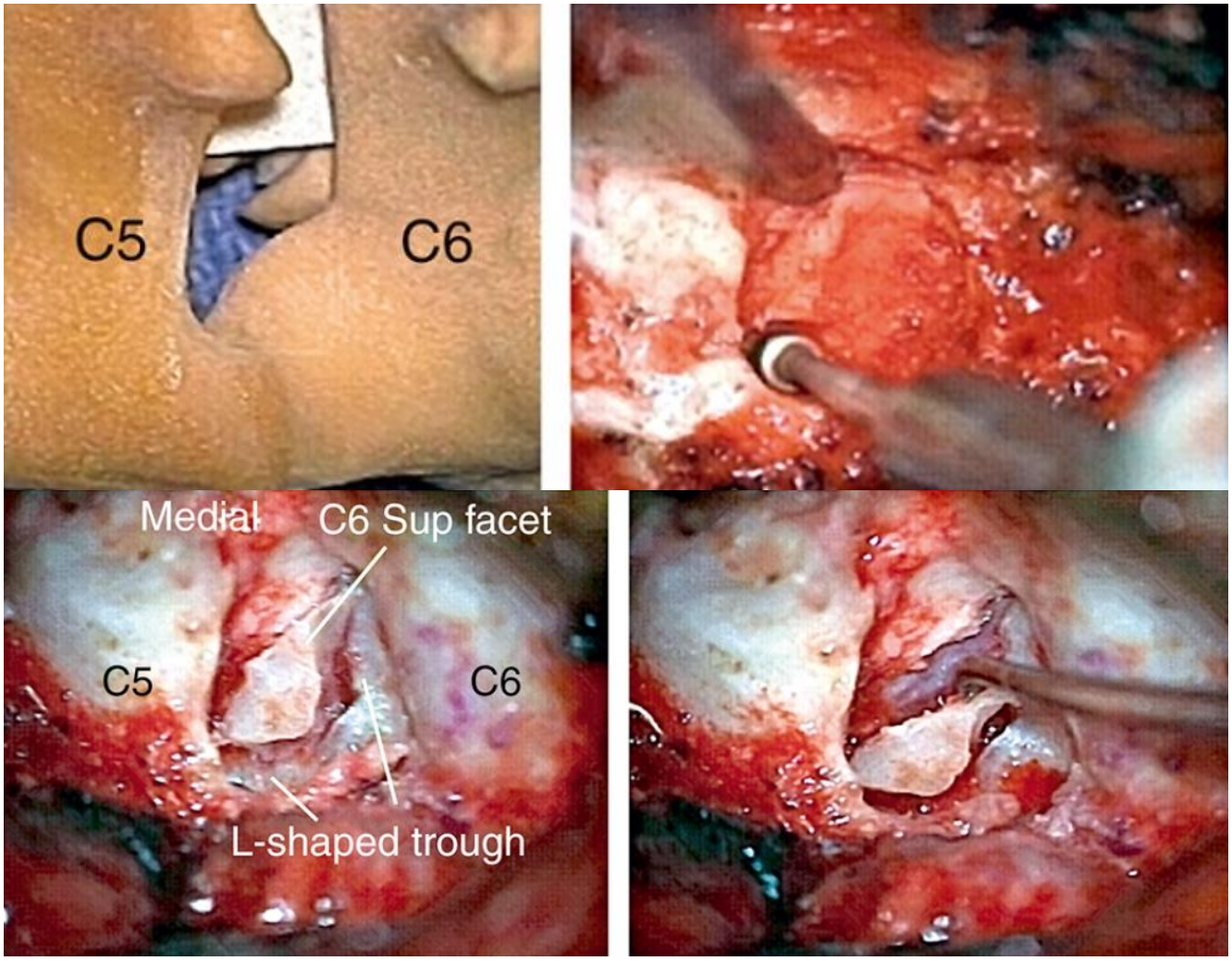
- Dr. Broaddus uses high-speed ***irrigating diamond bur*** (thermal damage may be detrimental) - held like a pencil as close to the bottom of the bur as possible for better control - surgeon's fingers should point down into the wound as a result; the other hand holds a small Frazier suction tip.
- Drs. Cameron, Graham use ***matchstick drill bit***.
- drill bit is maneuvered in small, circular motions, getting gradually deeper (ventral); in-and-out motions are to be avoided.
- inferior articular process of superior vertebra is burred away in L-shaped resection (resect 50% of distance between interlaminar V and lateral margin of facet – this is where lateral margin of pedicle is*), leaving superior articular process of inferior vertebra:

  *foramen is bounded by pedicles; if one performs decompression lateral to pedicle, foramen will be completely free!



Source of picture: Benzel "Spine Surgery: Techniques, Complication Avoidance, And Management" 3rd ed. (2012), Saunders; ASIN: B00E6TO0MK >>

- if facet joints are arthritic and have large spurs, foraminotomy hole can become quite deep.
- burring is stopped once soft tissue is seen protruding through remaining bone at "floor" or on "walls" of foraminotomy or bone takes on translucent appearance from becoming so thin.
- any bone that is overlying C6 pedicle is then removed with 1 mm Kerrison (careful – don't lever Kerrison heel against nerve root – may easily permanently damage it):

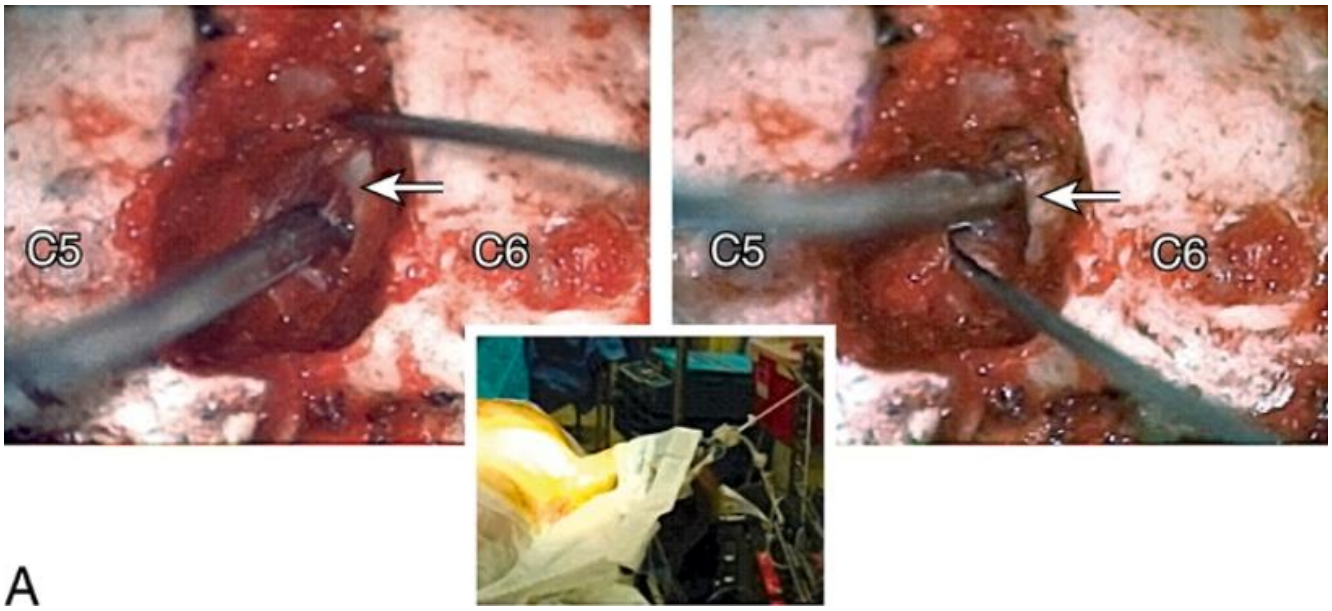


Source of picture: Benzel "Spine Surgery: Techniques, Complication Avoidance, And Management" 3rd ed. (2012), Saunders; ASIN: B00E6TO0MK >>

- it is preferable to complete drilling laterally first, rather than medially, because if medial cortex is perforated first, engorged vein underneath protrudes while surgeon is trying to complete lateral drilling and causes considerable bleeding and difficult visualization.
- cord protection: suction tip is maintained in interspace when drilling, to protect the soft tissue overlying the cord in case of a sudden drill "kick" or movement. Alternatively, curette can be placed into interspace, hooked into foramen, to protect cord. Codman-Karlin 2B curette is ideal tool, since it can be held like a pencil, and with a pulling motion, the bone overlying the foramen can be lifted out; 1-mm Kerrison rongeur is also useful.
- vein that overlies nerve root tends to bleed profusely, so it is important to understand maneuvers that can decrease bleeding. Reverse Trendelenburg positioning with the abdomen hanging freely is used to decrease venous pressure. Thrombin soaked hemostatic gelatin (Gelfoam) and cottonoid patties are packed into the bleeding foraminotomy site.
- thoroughness of decompression is assessed by palpating superior and inferior pedicles with tip of Codman curette or nerve hook or Penfield #4 - once entire interpedicular region has been unroofed, bony decompression is done.

Figure 76-10

A, The arrows point to the C6 pedicle. The nerve is retracted cranially, and a right-angled ball-tipped probe is utilized to hook the herniated disc fragment. If there is no disc fragment and one is just performing a foraminotomy, after making sure that the foramen is completely open, one should recheck with the neck in full extension. This ensures that even with the patient's neck in full extension, the foramen is still wide open. It should also be noted that the entire foraminotomy and discectomy procedure should be performed with the neck in maximal flexion, which opens up the foramen. B, The root is retracted cranially, and the small pituitary rongeurs are used to remove the disc fragment.



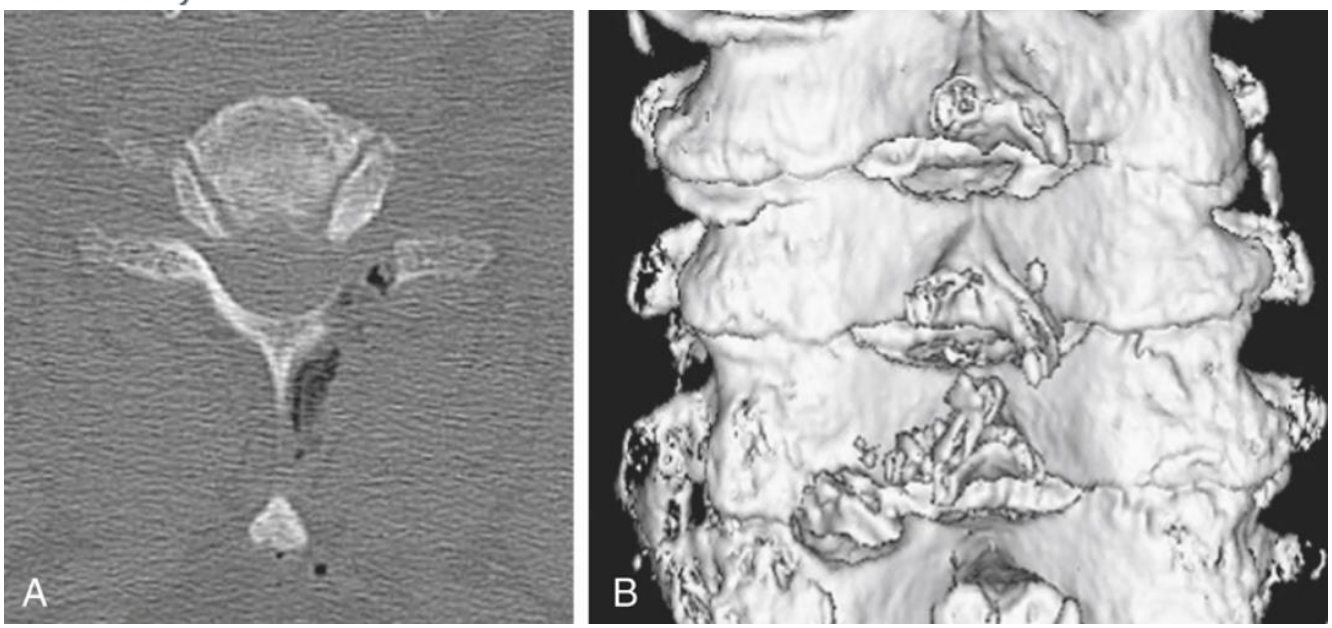
A

Source of picture: Benzel "Spine Surgery: Techniques, Complication Avoidance, And Management" 3rd ed. (2012), Saunders; ASIN: B00E6TO0MK >>

- resecting 50% of cervical facet does not typically require fusion or stabilization.
- at the end, adequacy of foraminal decompression can be checked with the patient's neck extended.

Figure 76-11

A, Postoperative CT showing a foraminotomy at C6-7. B, Three-dimensional reconstructed image of the foraminotomy.



Discectomy

- find nerve root axilla – reach for disc there; may need to bipolarize veins there.
- nerve root can be gently retracted superiorly and disc material removed with reverse angle curette.

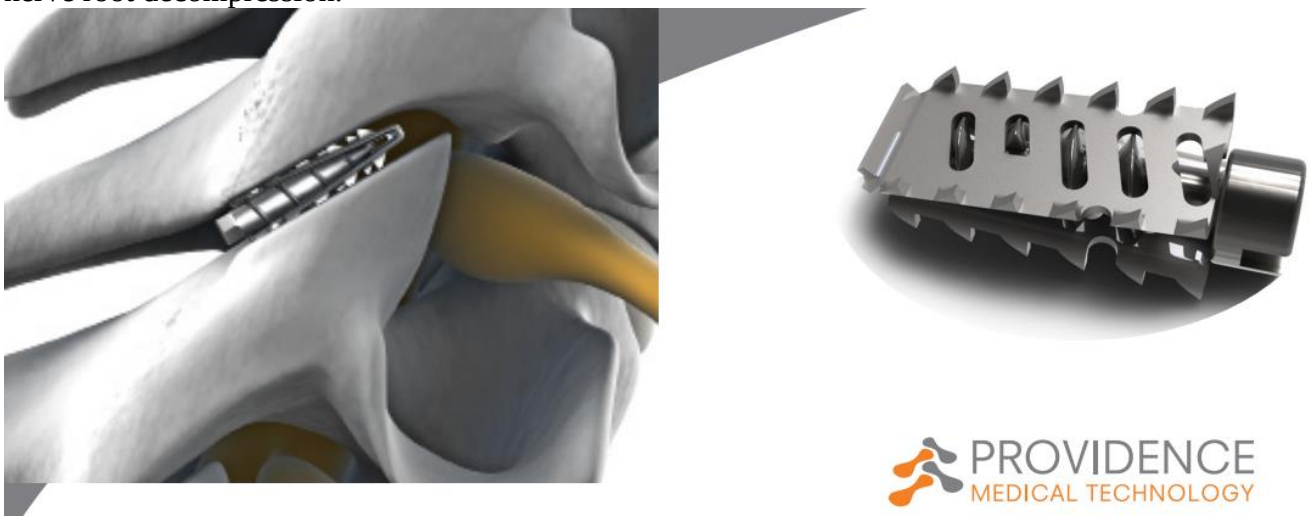
COMPLICATIONS

4) neurologic deterioration
5) dural injury → pseudomeningocele (H: fibrin sealant or tissue graft and tight wound closure)
6) inadequate decompression with persistent or recurrent symptoms.
7) air embolism

Percutaneous Foraminal Decompression & Fusion (s. Cervical Interfacet Spacer)

DTRAX FACET SYSTEM (PROVIDENCE MEDICAL TECHNOLOGY)

- minimally invasive approach - distraction of the facet joint to increase neural foraminal volume for nerve root decompression.



- titanium implant inserted percutaneously from a posterior approach under fluoroscopic guidance through 1cm working channels.
- DTRAX increases foraminal volume more than 17%
- DTRAX had minimal effect on cervical lordosis:
  Change in overall cervical lordosis = 1.9 degrees
  Change in segmental lordosis at the treated level = 1.1 degrees
- main indication – treatment of post-ACDF pseudoarthrosis.

OCCIPITOCERVICAL FUSION

DePuy Synthes
SYNAPSE system >>

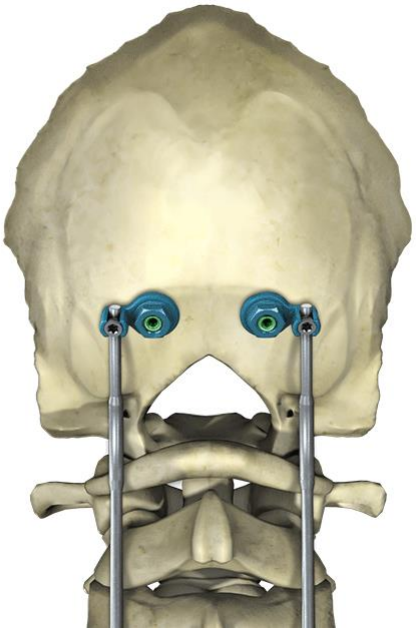
DePuy
MOUNTAINEER (Occipito-Cervico-Thoracic Spinal System) >>

Stryker
Oasys (occipito-cervico-thoracic system) >>

Medtronic
Vertex system >>

Globus
Quartex

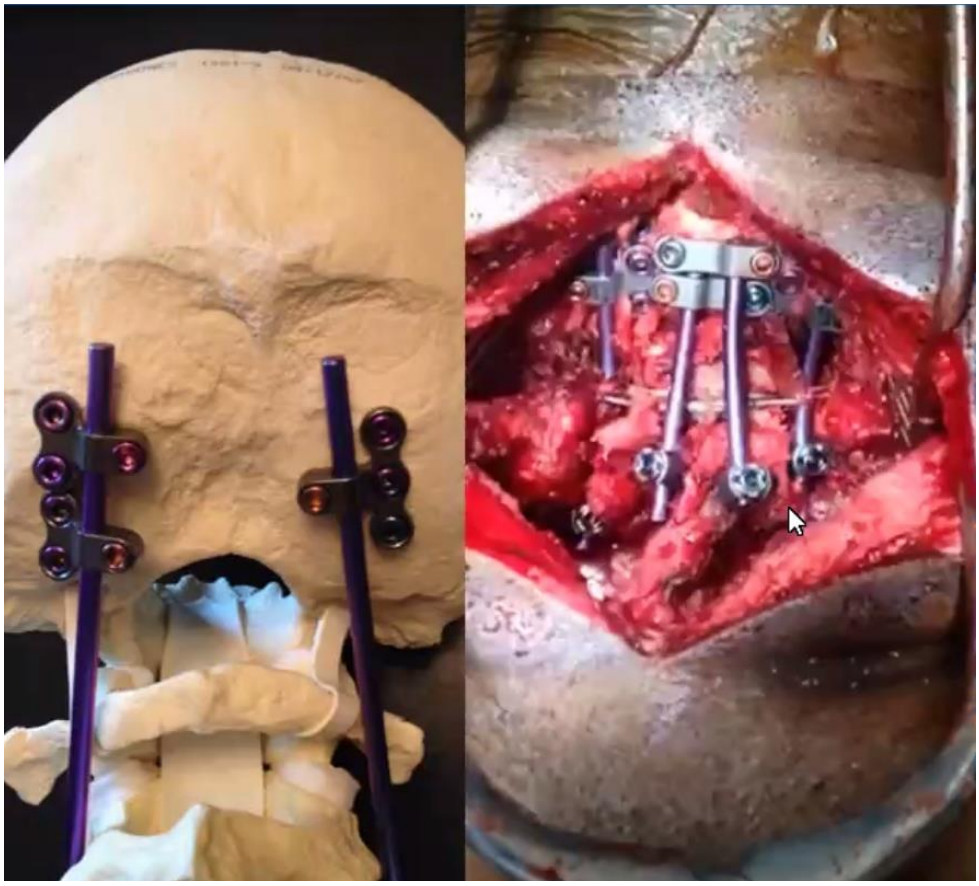
K2M / Stryker
CASPIAN® Occipital Anchor – biomechanically analogous to occipital plate



N.B. take meticulous attention not to rotate head in relation to body.

- instrumentations along junctions (occ-C, C-T) tend to break rods - some people place 3 or even 5 rods.
- always put crosslink at C1-2 level.
- if using ***structural graft***, it should be fashioned so that there is solid contact with skull*, C1, and C2 - by cutting an oblique angle into the graft and drilling a trough into the suboccipital bone into which graft is wedged.

  *for this reason some experts do not like occipital plates as they cover large area of skull that could be used for fusion; they rather use occipital buttons and iliac autograft and long C1 screws as rods will be difficult to contour:



PATIENT POSITIONING

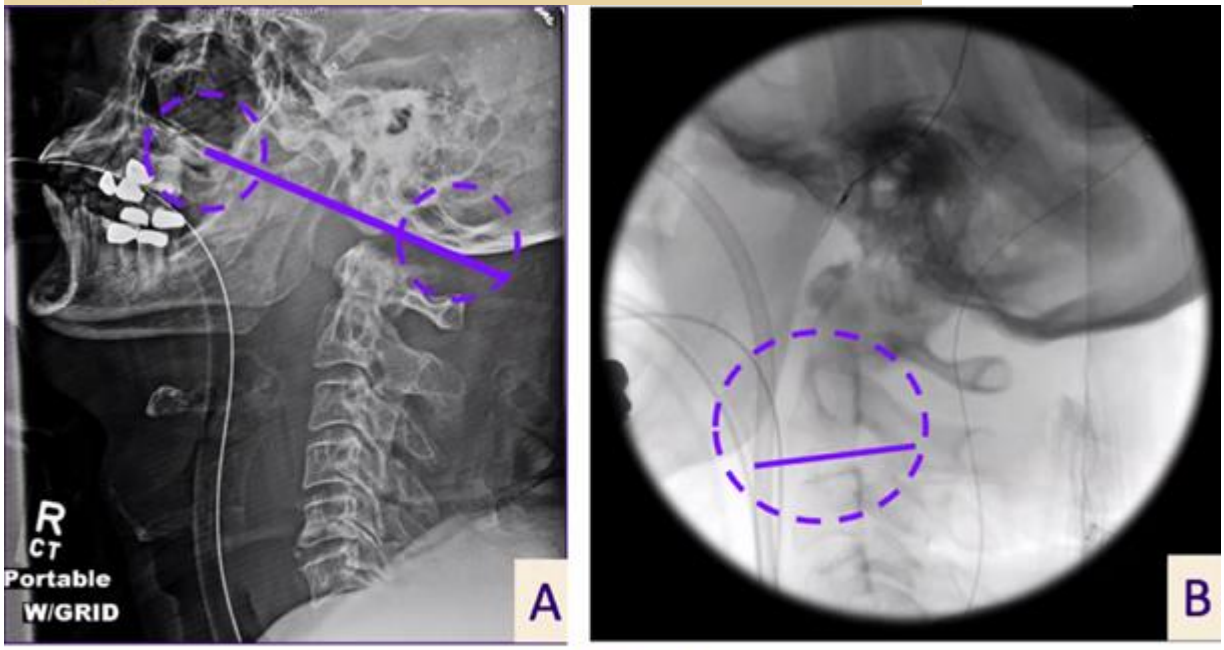
N.B. take **lateral XR preop with patient standing in neutral position** – note the angle between C-spine and cranium – use same angle when positioned on the table (otherwise, might be hard to judge correctly); too much flexion – unable to swallow food!

Occipito-cervical angle (OCCa) s. occipito-C2 angle (OC2A)

Radiographic Data	Male (n = 75)	Female (n = 75)	*P*
OC2A (mean ± SD) (deg.)	14.8 ± 3.1	14.2 ± 4.3	0.861

> The occipitocervical angle (OCCa) is currently the gold standard radiographic measurement that helps clinicians estimate neutral craniocervical (CC) alignment in patients.

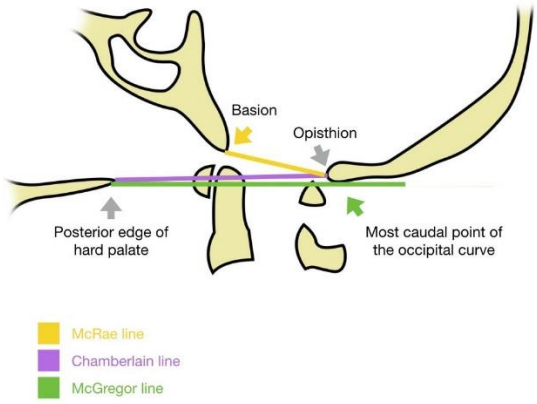
> The OCCa is useful due to its high interobserver reliability and because of the correlation of its angular value with surgical outcomes.



OCC Angle

The OCC angle is measured between the McGregor line (A) and a line parallel to the inferior endplate of C2 (B).

McRae line, McGregor line & Chamberlain line



C2-Mandible angle – lines have to be almost parallel:

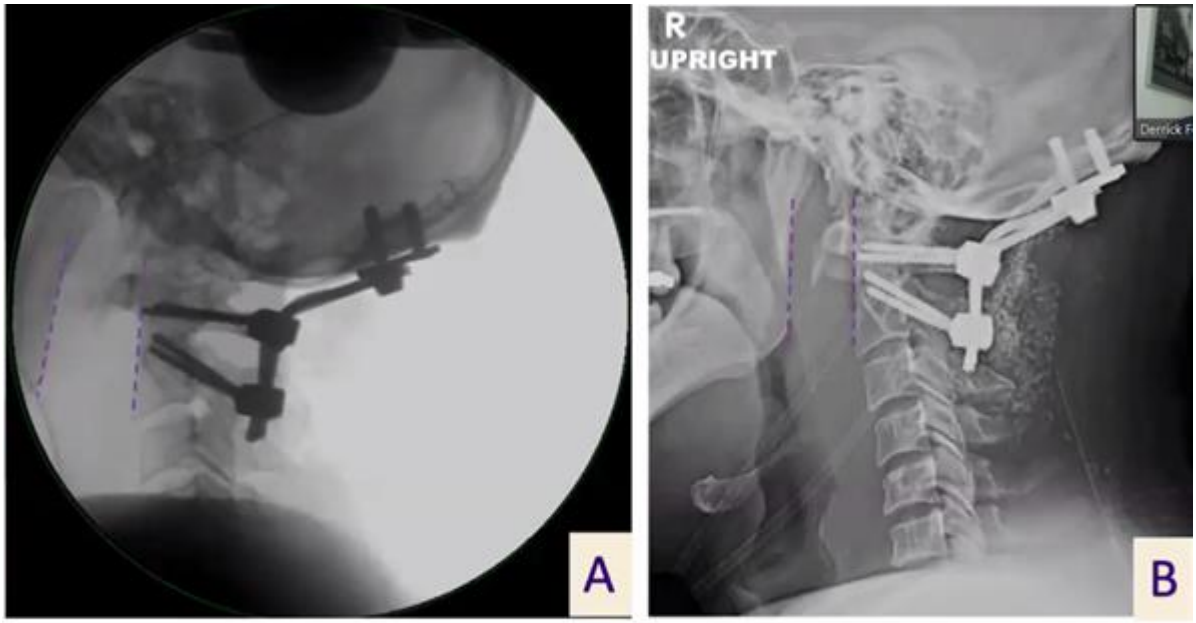


Fig 2: The C2 M angle is defined as the angle measured between a line parallel to the anterior C2-body/dens complex and a line parallel to the posterior mandible line of the mandibular ramus.

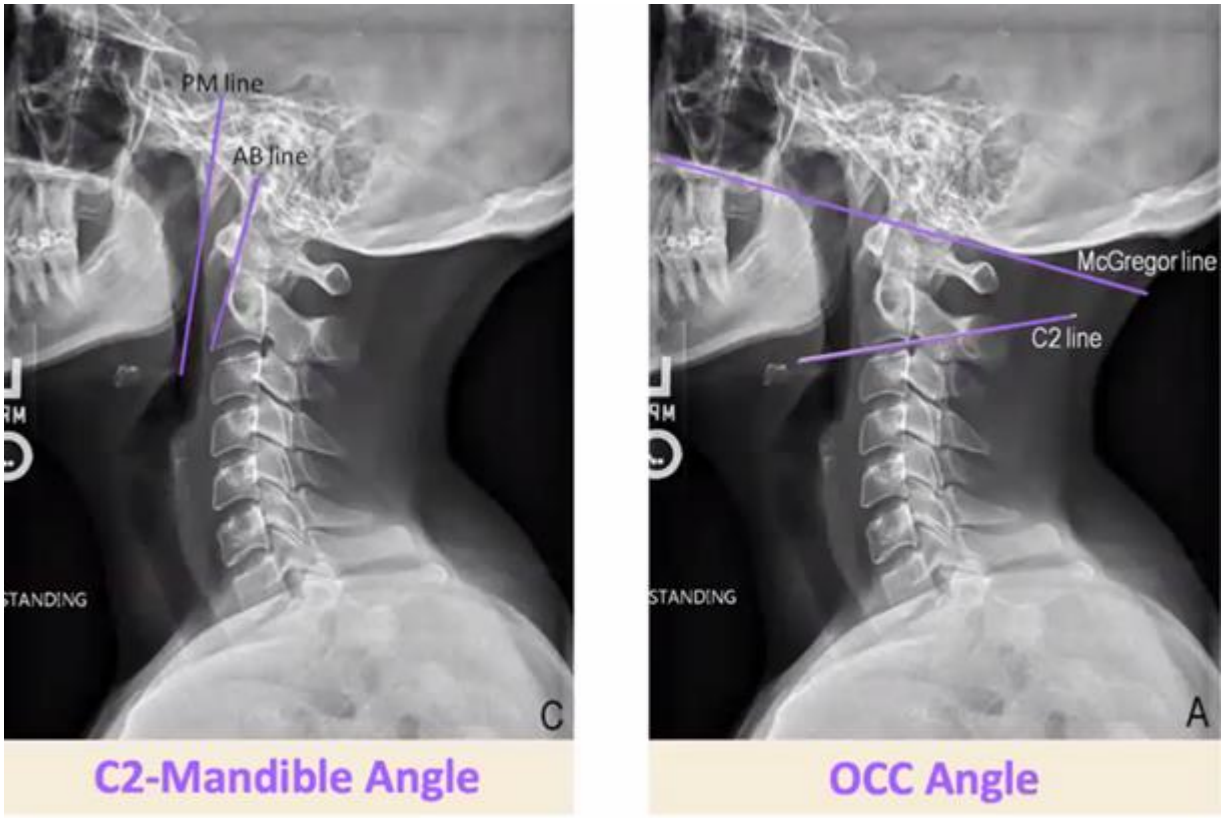


Fig. 1 The C2 M angle is measured between a line parallel to the anterior C2-body/dens complex and a line parallel to the posterior mandible line on the mandibular ramus. The OCC angle is measured between the McGregor line and a line parallel to the inferior endplate of C2.

C1-C2 INSTRUMENTED FUSIONS

Good articles:
http://www.medscape.com/viewarticle/468465
http://www.medscape.com/viewarticle/405704

O-arm use >>

Three options:

A) sublaminar wiring
B) laminar clamps
C) screw fixation

- to reduce risk of vertebral artery injury, electrocautery is not used more than 15 mm lateral to midline when performing subperiosteal dissection of superior posterior ring of C1.

- if indication is odontoid fracture in young patient, months later (if CT shows healed fracture), may remove C1-2 instrumentation to restore ROM.

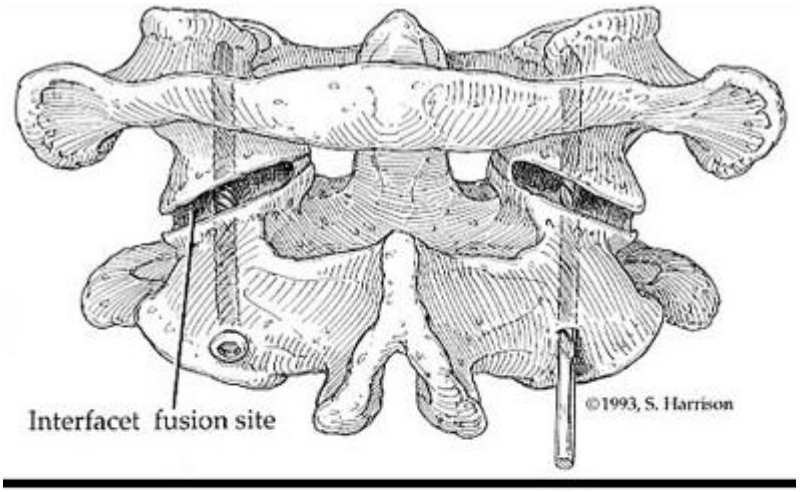
SCREW FIXATION

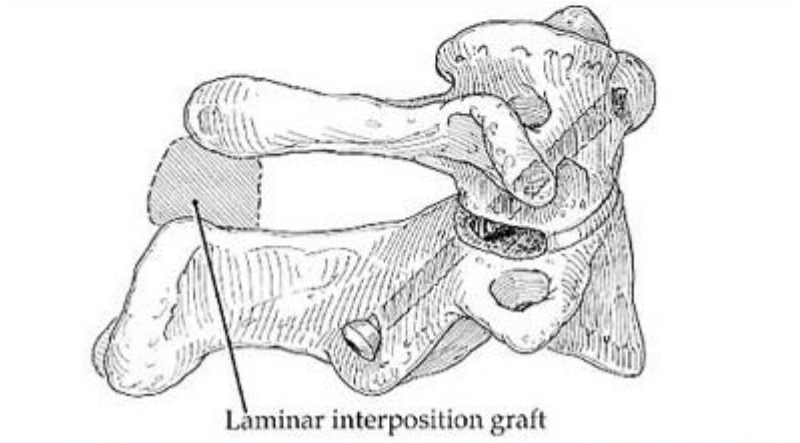
TRANSARTICULAR SCREWS (C1-C2)

Risk of vertebral artery injury – check on CT how much bone is available at C2 transverse foramen level.

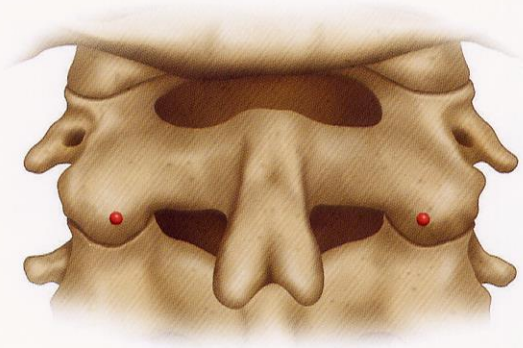
- in 23% of patients, C2 isthmus is too small to accommodate a unilateral 3.5 mm transarticular (Magerl) screw, and in 6% of patients it cannot accommodate a screw on both sides - placement of a transarticular screw would put VA at an increased risk of injury.

Technique described by Foley and Fassett and Apfelbaum: also see Medtronic Vertex manual

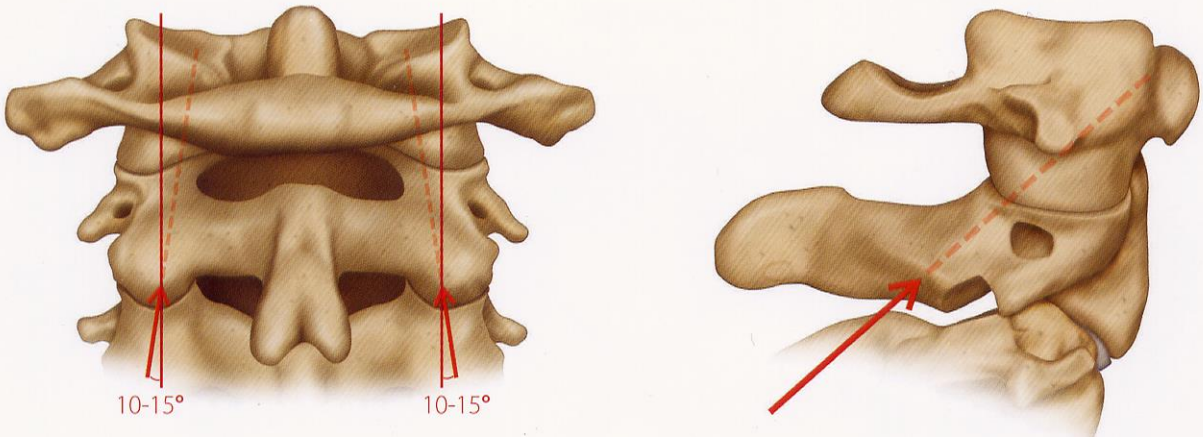

Interfacet fusion site
©1993, S. Harrison


Laminar interposition graft

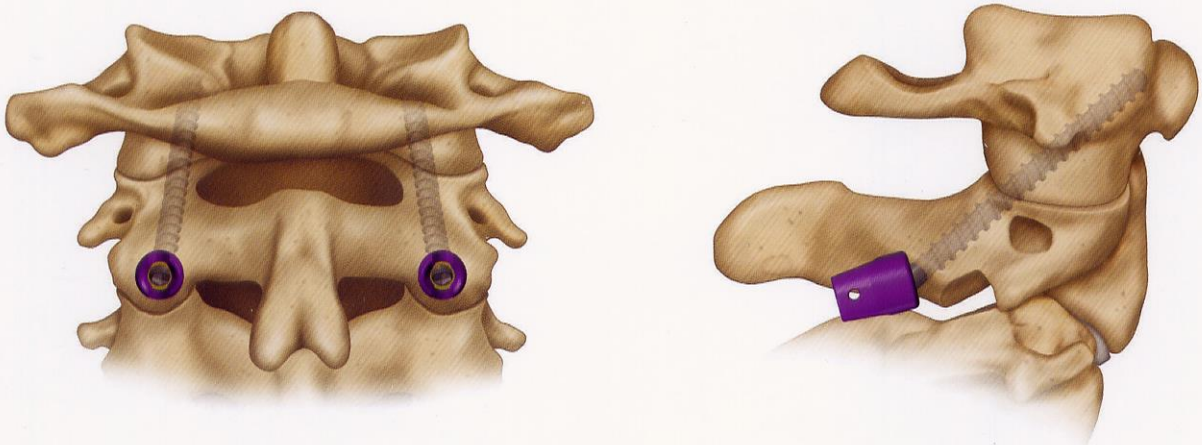
C1-C2 Transarticular Screw Fixation



Entry Point



Drilling Trajectory



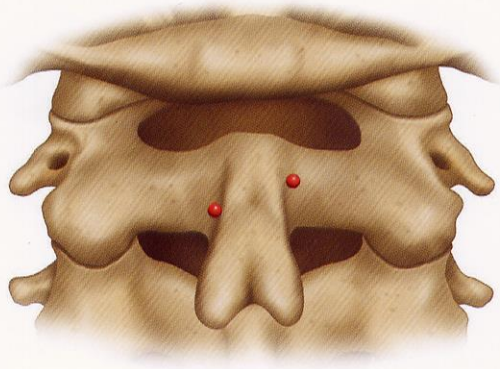
Final Screw Placement

TRANSLAMINAR SCREWS (C2)

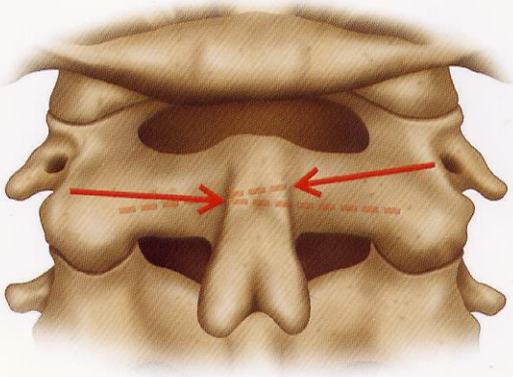
Technique described by Wright – see Medtronic Vertex manual

- bilateral crossing C2 laminar screws - alternative technique for C2 fixation - reserve this technique when other types of C2 fixation are not possible or as a bail-out maneuver.
- drill is used to place a pilot hole pointed opposite the lamina to be fixated.
- hole is drilled to a depth of 20-28 mm
- 3.5- or 4.0-mm polyaxial screw is advanced into the lamina.
- ensure that any possible cortical breakthrough is pointed dorsally through the laminar surface as opposed to ventrally into the spinal canal:
  - trajectory for screw insertion is kept less than the downslope of the lamina.
  - dental instrument is placed under the lamina during screw insertion to help detect any breakouts.
- in its correct final position, the head of the screw is at the base of the spinous process while lying flush within the lamina.
- **second screw** is placed from the opposite base of the spinous process into the lamina similar to the first screw.
- disadvantages: early hardware failure, breach of the dorsal lamina or ventral canal, and difficulty in bone graft or rod placements due to the position of the screw heads.

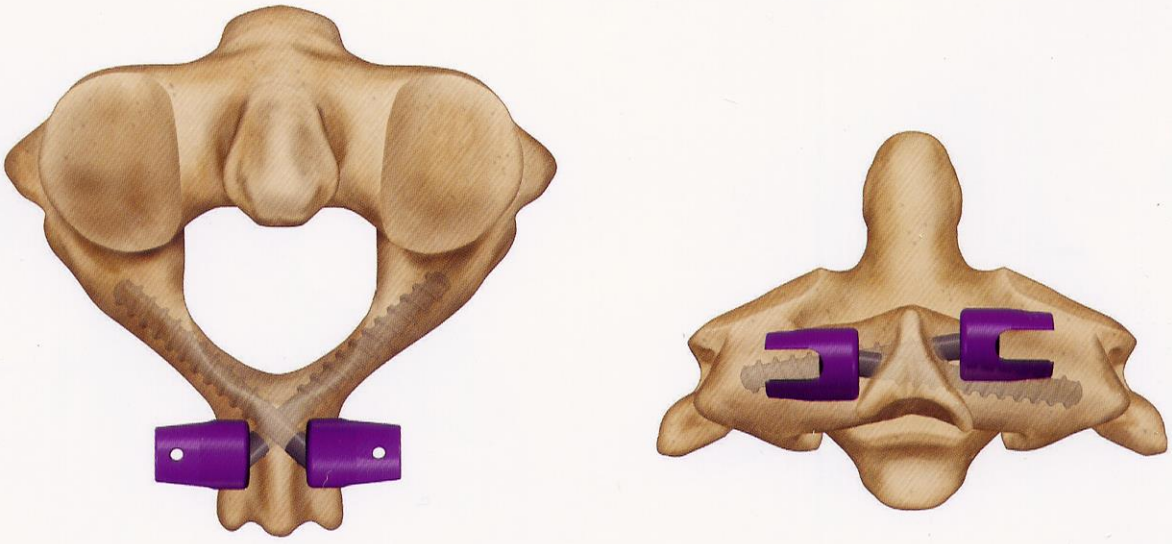
C2 Translaminar Screw Fixation



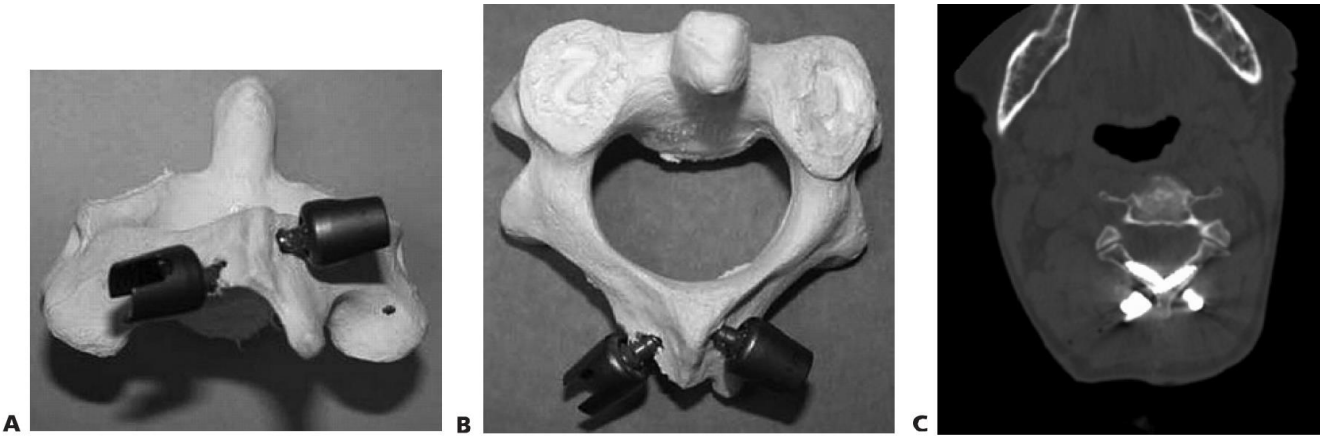
Entry Point



Drilling Trajectory



Final Screw Placement



LATERAL MASS SCREWS (C1)

For VA anatomy and variants – see p. A205 >>

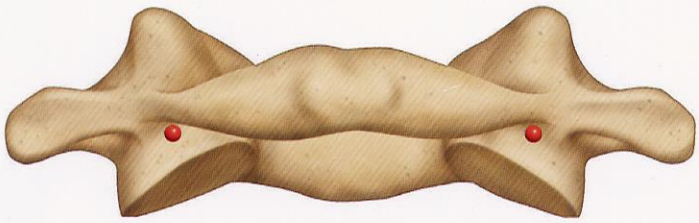
Beware of posterior looping, intersegmental / fenestrated VA, extracranial PICA origin!

Technique described by Harms and Melcher

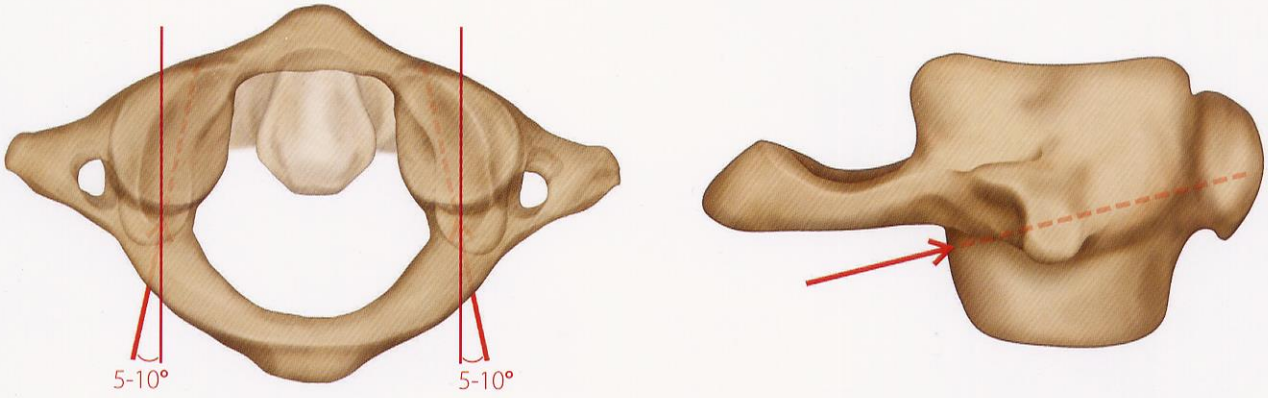
Harms, J., & Melcher, R. (2005). Posterior C1 and C2 Screw Fixation. Spinal Instrumentation Surgical Techniques (pp. 292-298). Thieme.

Harms, J., & Melcher, R. (2001). Posterior C1-C2 Fusion With Polyaxial Screw and Rod Fixation. SPINE, 26(22), 2467-2474

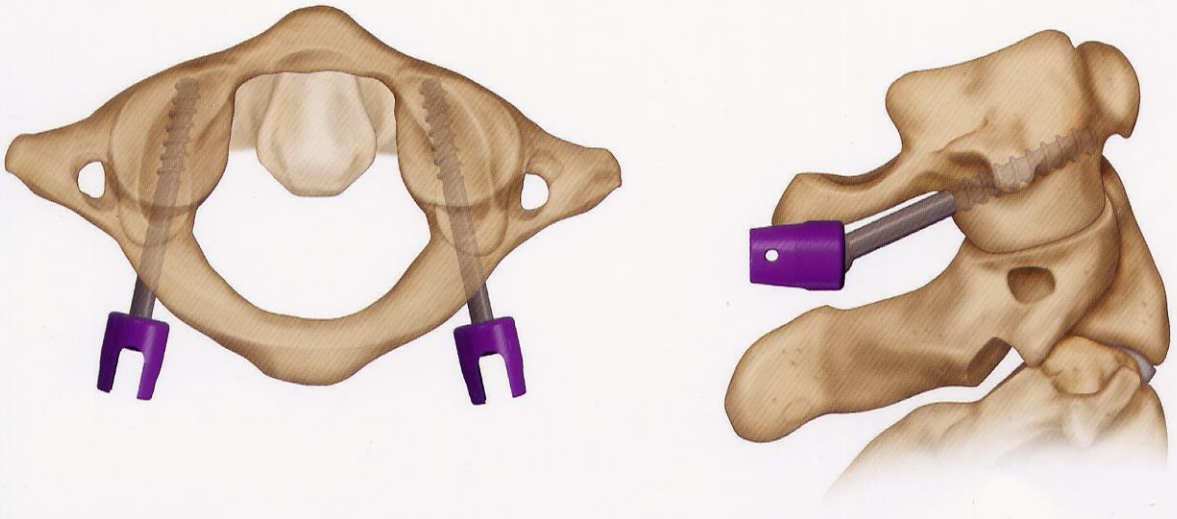
C1 Lateral Mass Screw Fixation



Entry Point



Drilling Trajectory



Final Screw Placement

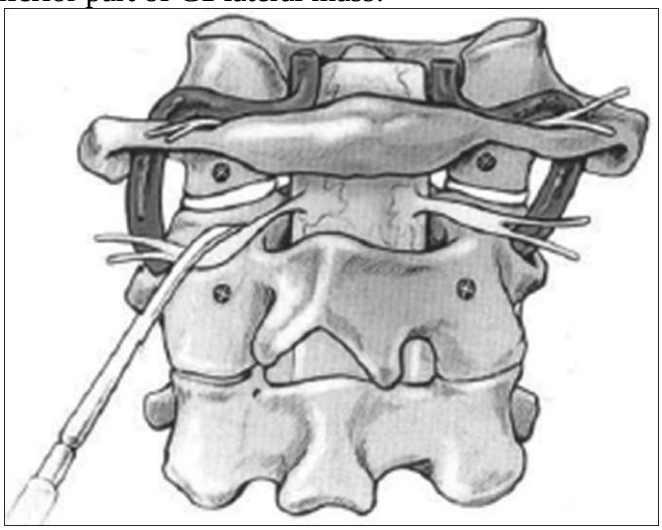
N.B. 3.5 mm lag screws (4.0 mm are used for rescue)

- reverse Trendelenburg position to minimize bleeding!
- head and neck in as neutral position as possible (but it is OK to flex slightly to open C1-2 space, then extend neck back when ready to place rods).

- bulk of upper torso retracted caudally with the use of wide tape attached to the skin.
- expose posterior arch of C1, laminae of C2.

  N.B. lateral dissection on C1 should be limited to 15 mm lateral to the midline; since VA runs along the superior aspect of C1 posterior ring, dissection along the inferior aspect is safest; no dissection should occur on the superior edge of C1 more than 8 mm lateral to the midline.
- expose inferior part of posterior surface of C1 lateral mass through C1-2 interspace.
- retract C2 root with DRG caudally (if need to sacrifice* → occipital anesthesia)

  *cut preganglionically – avoid burning deafferentation pain
- may encounter very large engorged venous plexuses on both sides (hemostasis achieved with Gelfoam packings and bipolar) – may lose lots of blood; H: subperiosteal dissection – with small curette lift periosteum from C1 arc root.
- C1 lateral mass screws:
- **entry point** is the middle of the junction of C1 inferior aspect of posterior arch and midpoint of posterior inferior part of C1 lateral mass:

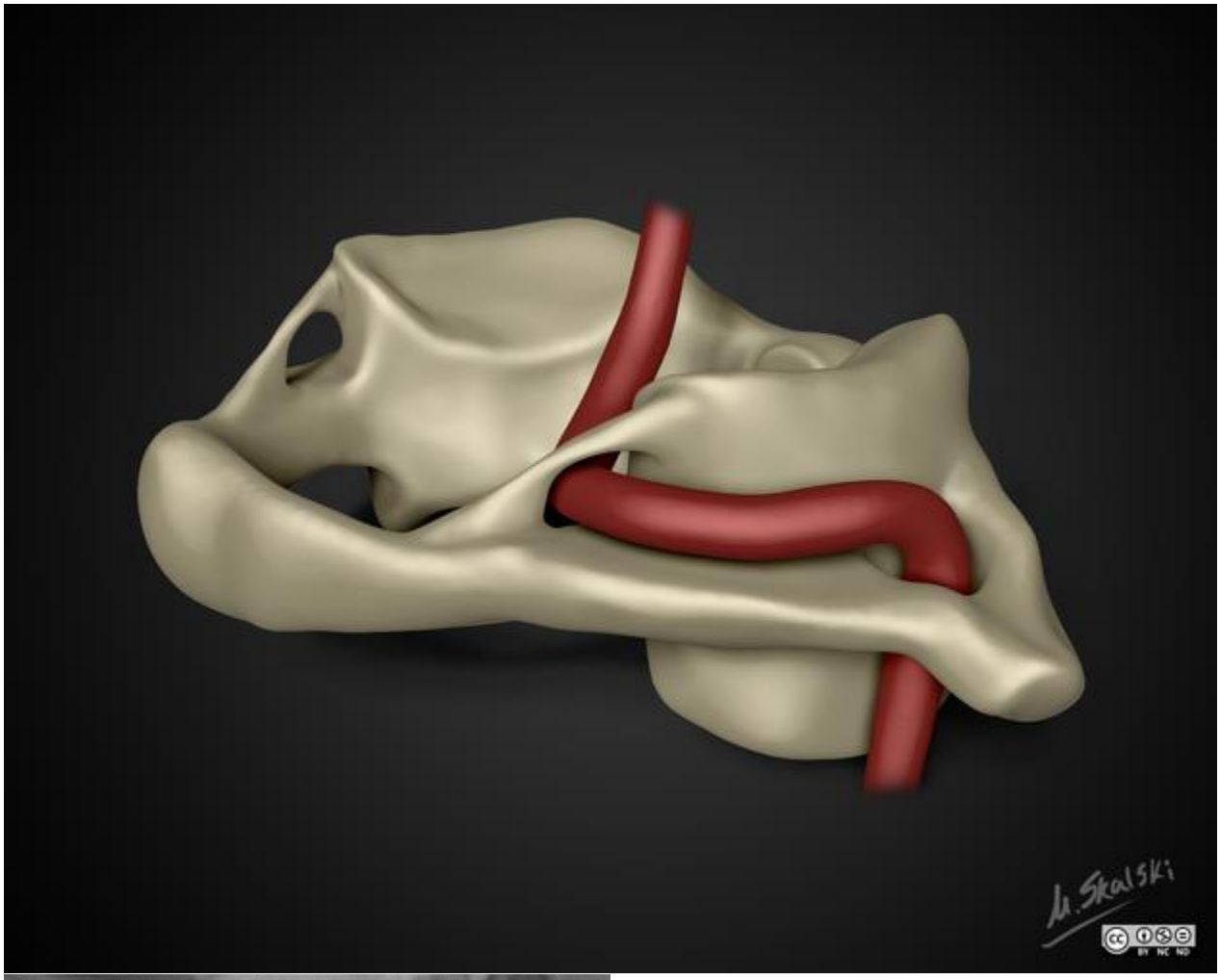


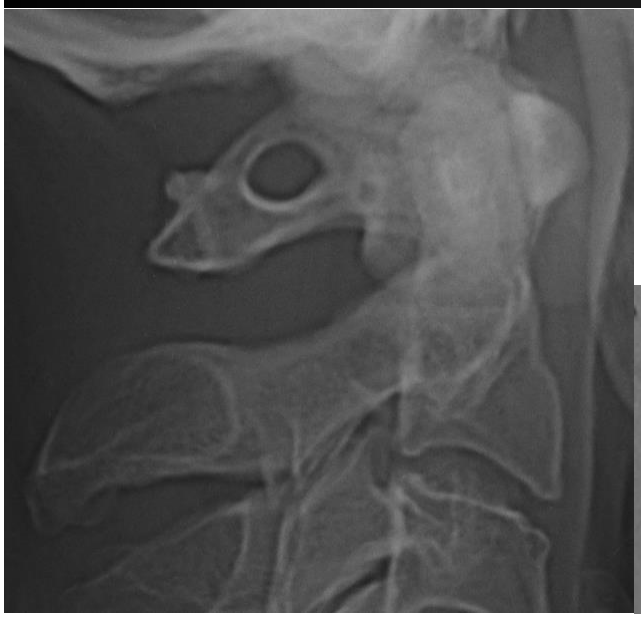
  — to facilitate exposure, the overhang of the C1 arch must be removed at times to ensure a proper starting point.
- **trajectory**: drill bit should be angled straight or slightly convergent, approximately 5-10˚ medial, and parallel to the underside of the C1 posterior arch. When drilling under fluoroscopic control, additional orientation can be obtained by directing the tip of the drill bit toward the caudal half of the anterior tubercle of C1.
- palpate with curette the lateral mass → Midas Rex drill used to drill through the cortical surface of C1 lateral mass and then manual drill used to drill along the pedicle under fluoroscopic guidance to achieve bicortical purchase (ball probe used to feel the trajectory of the screw) → polyaxial screws placed on either side of C1.

  N.B. C1 needs bicortical purchase! (vs. C2; although Nader recommends bicortical for C2 as well)

Beware of **arcuate foramen** (**foramen arcuale atlantis, ponticulus posticus** or **posterior ponticle,** or **Kimerle anomaly**) - frequently encountered normal variant of the atlas - atlantic portion (V3) of the vertebral arteries pass through this foramen – can be injured if surgeon tries to drill C1 lamina to better accommodate C1 screw head.

- incidence is ~ 8% (range 1-15%) and it is more common in females.
- variable morphology, can be complete or incomplete and may be unilateral or bilateral.





LATERAL MASS: PEDICLE AND PARS SCREWS (C2)

- give marginally better fusion rate
- risk of vertebral artery injury – check on CTA how much bone (isthmus) is available at C2 transverse foramen level; artery is most vulnerable as it traverses through foramen transversarium of C2

N.B. always can place C2 pars screws but not always pedicle screws!

Technique for C2 pedicle screw fixation described by Dickman.

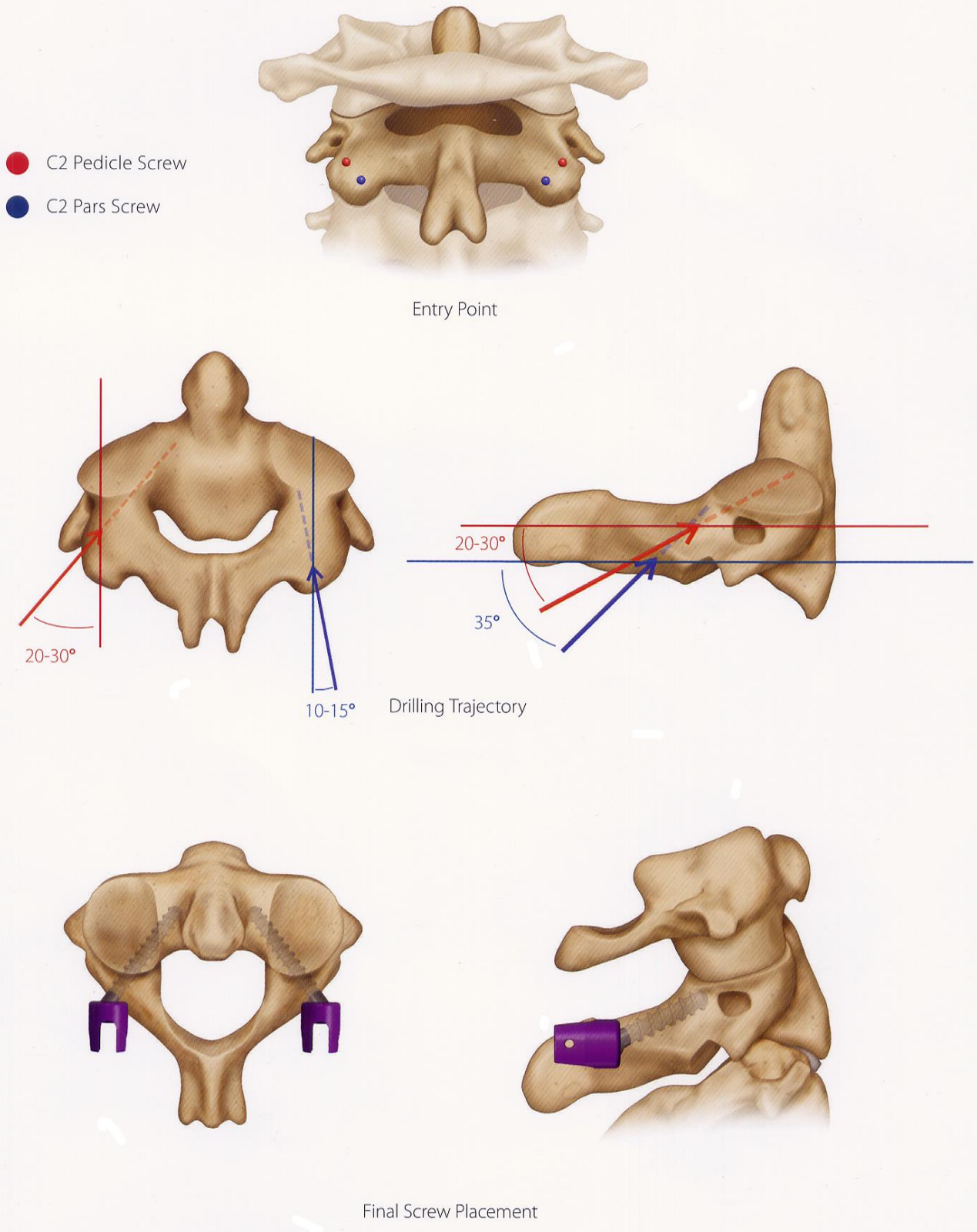
Dickman, C., Sonntag, V., & Marcotte, P. (n.d.). Techniques of Screw Fixation of the Cervical Spine. BNI Quarterly, 9(4), 27-35

Technique for C2 pars interarticularis screw fixation described by Mummaneni and Foley.

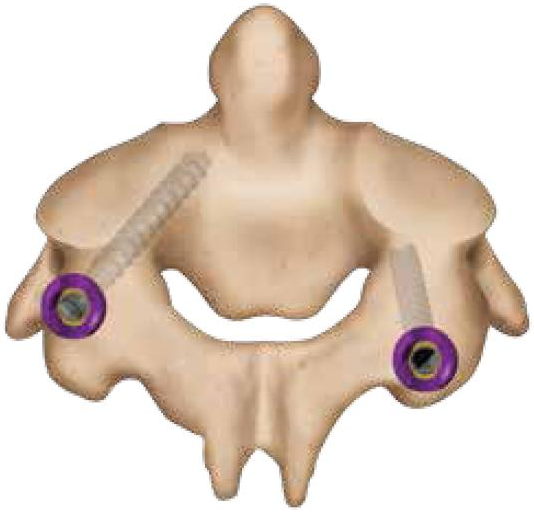
Mummaneni, P. (2002). Posterior cervical fixation using a new polyaxial screw and rod system: Technique and surgical results. Neurosurgery Focus, 12(January), 1-5.
Foley, K. (2004). Atlantoaxial Fixation. Manual of Cervical Spine Internal Fixation. LWW.

C1-C2 posterior screw-rod fixation technique is reversible, and is especially applicable to active patients with healed odontoid fractures!

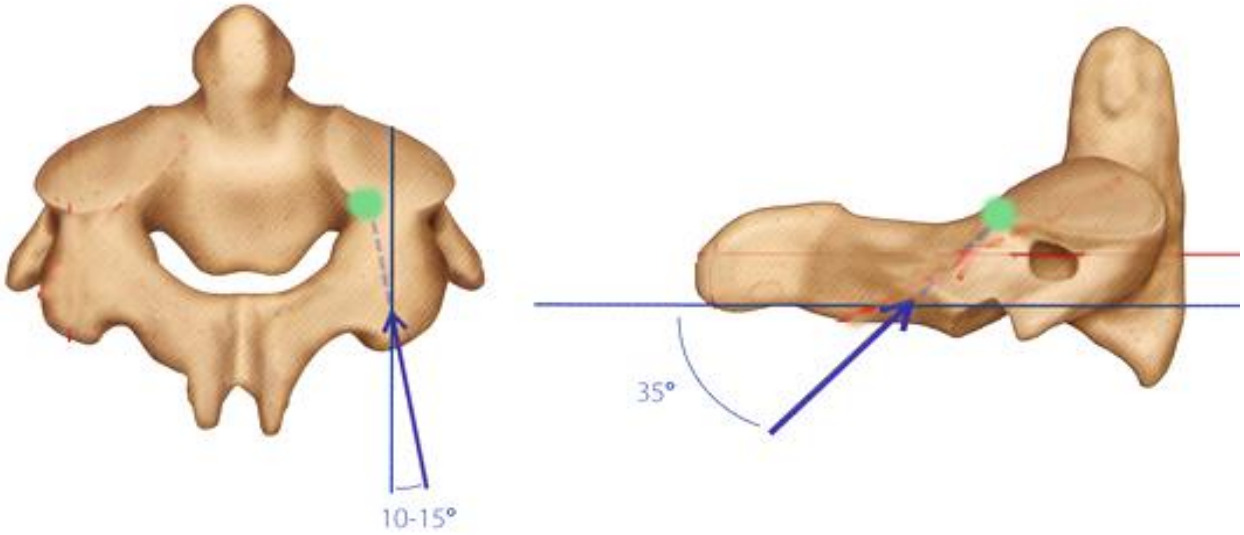
C2 Pedicle and Pars Interarticularis Screw Fixation



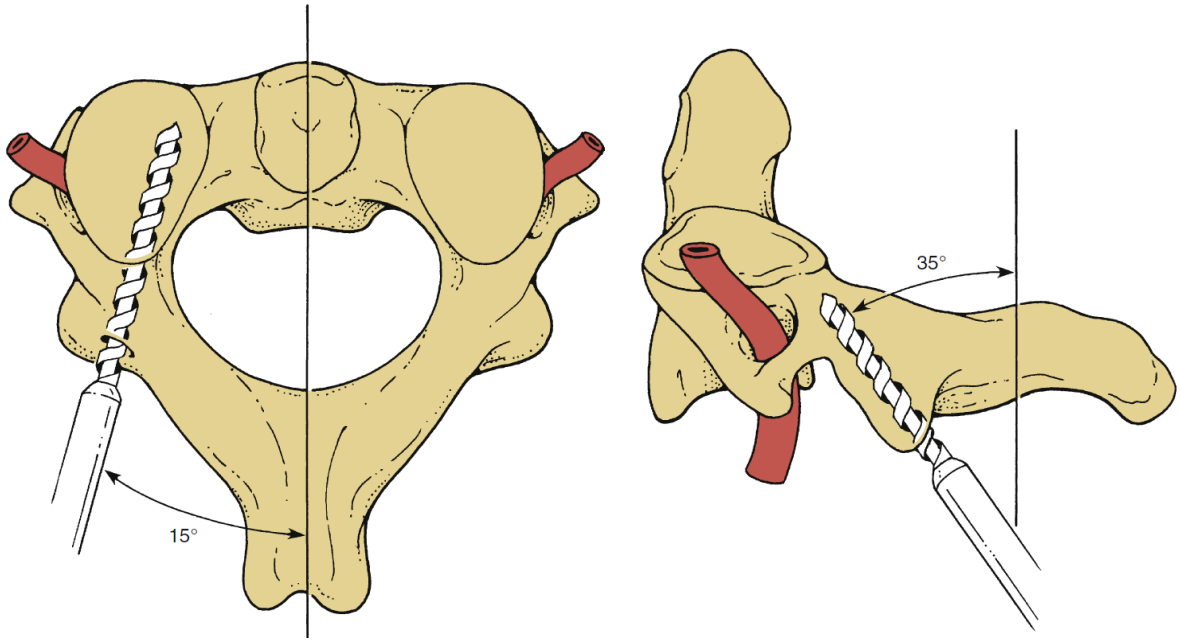
C2 Pedicle Screw



Aiming target for pars screws (small laminotomy allowing direct palpation of medial pedicle wall may be helpful):



C2 pars screw:



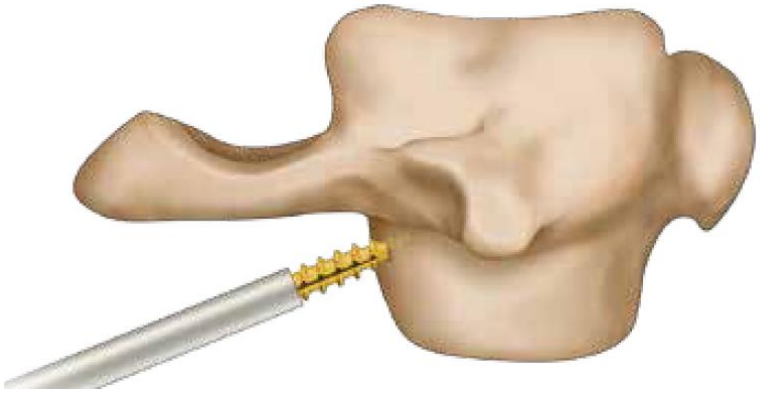
- start point (start in cortex with C1 drill bit) –posterior surface of lateral mass:
  - for pedicle screw: the entry point is 3-4 mm above the C2 inferior facet
  - for pars screw: the entry point is 3 mm superior to the C2-3 facet joint line and 3 mm lateral to the lamina-lateral mass junction; N.B. do not start too high (i.e. too far from C2-3 joint) – screw will go too close to superior cortex (screw may get exposed during decortication at the end).
- trajectory – superomedially (to avoid vertebral artery) along medial border of pars (thus, feel with Penfield 4 or curette medial border of superior facet of C2) towards posteromedial tubercle of facet joint; use 2 mm drill bit

  N.B. use **drill guide (tube)** – *drill bit is thin and easily bends* (especially if levering against skin edge) → unreliable navigation
  - for pedicle screw: the drill bit should be angled 20˚-30˚ medial and directed into the central axis of the C2 pedicle. In the sagittal plane, the drill bit is angled approximately 20˚-30˚ cephalad.
  - for pars screw: the drill bit should be angled slightly medial (10˚-15˚). In the sagittal plane, the drill bit is angled approximately 35˚ cephalad, assessed fluoroscopically by aiming toward the anterior tubercle of C1.
- decorticate C1-2 joint space with small M8 bit and stuff it with bone shavings.

VERTEX (MEDTRONIC)

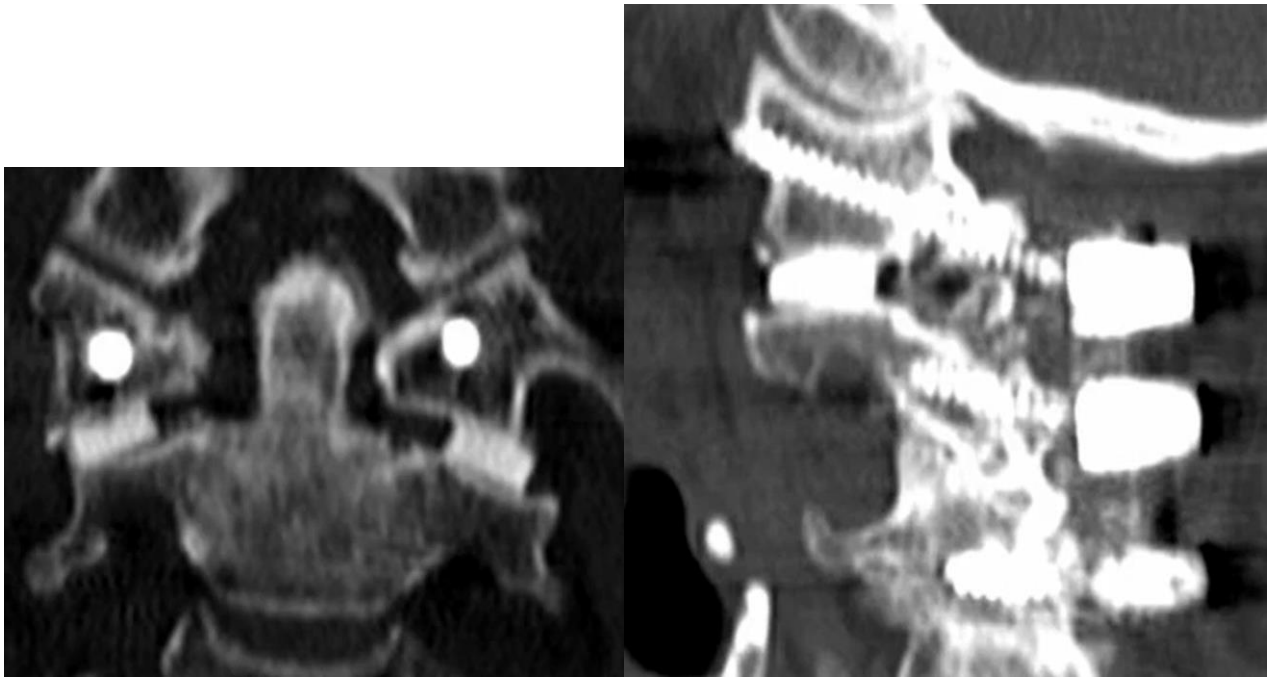
- the Adjustable Drill Guide can be used for drilling the desired depths from 6 mm up to 52 mm.
- the depth of the Drill guide can be adjusted in 2mm increments to allow for desired drill depth that will correspond with the lateral mass screw length.
  - it may be impossible to use drill guide at C1-2 interspace if it is narrow – use "naked" drill.
- the drilling depth is adjusted by pressing the slide forward while adjusting the measuring tube to the desired drill depth. Once the slide reaches the desired depth, rotate the slide into the locked position and prepare the pilot hole in the desired trajectory

- Vertex screws are self-tapping, therefore this surgical step is considered optional. If tapping is desired, place the Tap Sleeve over the end of the Tap Shaft to visualize the depth of the tap in bone. The trajectory of the tap should follow the same trajectory as outlined for drilling
- gold anodized tip of the tap represents the first 10 mm of thread



- ball-tip Pedicle Feeler may be used to gently palpate the bone of the C1 lateral mass

C1-2 INTRA-ARTICULAR GRAFT



- place a graft into C1-2 joint space after reaming it (e.g. using instruments from intrafacet spacer toolkit).
- routinely not necessary but might be helpful adjunct in revision cases, esp. with incompetent posterior C1 arch, osteoporotic bones.

WIRING / CABLE

Dickman CA, Sonntag VK, Papadopoulos SM, Hadley MN: The interspinous method of posterior atlantoaxial arthrodesis. J Neurosurg 74(2):190–198, 1991
Dickman CA, Crawford NR, Paramore CG: Biomechanical characteristics of C1-2 cable fixations. J Neurosurg 85:316–322, 1996
Naderi S, Crawford NR, Song GS, et al: Biomechanical comparison of C1-C2 posterior fixations. Cable, graft, and screw combinations. Spine (Phila Pa 1976) 23:1946–1955, 1998
Songer MN, Spencer DL, Meyer PR, jr, Jayaraman G. The use of sublaminar cables to replace Luque wires. Spine (Phila Pa 1976) 1991 ; 16 Suppl: S41 8-S42 1

Biomechanics – fixation is only semirigid - rarely used stand-alone (needs either screw supplementation or rigid external support)

- wiring acts primarily as a tension band - outstanding resistance to **flexion**.
- graft between the dorsal elements of C1 and C2 serves to limit **extension**.
- axial **rotation** is resisted mostly by friction between the cable and dorsal elements.

Contraindications

- fractures of the C1 or C2 posterior elements (including hangman's or Jefferson's fracture)
- when posterior decompression of the C1-C2 complex is required
- significant osteoporosis

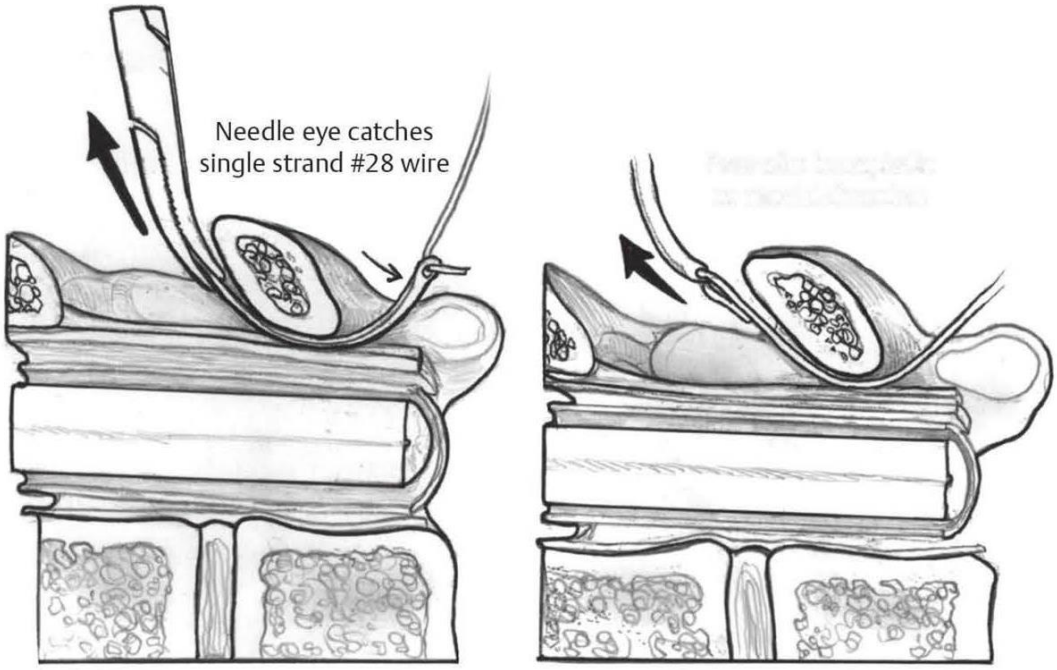
- modern usage – as a supplemental technique or as a bailout.
- allows fixation of atlantoaxial instability via preparation of C1-2 dorsal laminae and preservation of C2-3 interspinous ligament.
- initially, the inferior aspect of C1 and superior aspects of C2 are roughened with a drill to create a suitable interface for fusion.
- Kerrison punch is used to notch the inferior C2 hemilamina to accommodate loop of cable.
- loop of cable is passed under dorsal arch of C1 in a caudal to rostral direction.

N.B. passing sublaminar wires should always be from caudal to cephalad direction with continuous tension on laminar undersurface to avoid canal encroachment

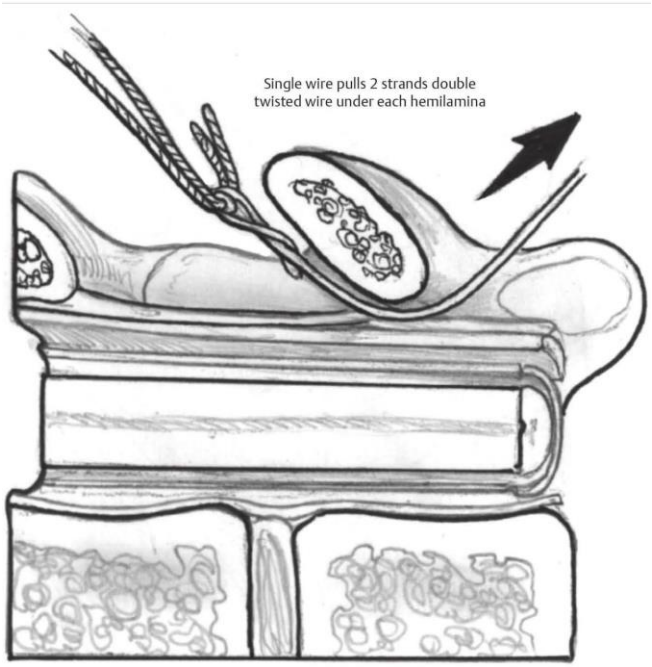
- meticulous dissection of the dura mater from the lamina should prevent dural laceration
  N.B. sublaminar wiring in subaxial cervical spine may injure the cord!
- rectangular graft, approximately 1.5 cm × 3.5 cm, is then harvested (dorsal rib is now used instead of iliac crest) and trimmed to fit snugly between C1 dorsal arch and C2lamina.
  e.g. notch in the bone is fashioned to allow graft to "sit" on C2 spinous process; small grooves are placed on superior and inferior edges of graft to hold cables in place
- cancellous (not cortical!) side of graft should face native decorticated bone (for the best uptake).
- loop of cable is drawn over C2 spinous process and its ends are tightened.
  N.B. this one-point fixation construct does not counter rotatory or translatory movements – combine with another form of fixation (e.g. C1-2 transarticular screws or C1-2 lateral mass screws).
- halo or hard collar for ≥ 6 weeks.

Cable sublaminar passing technique:

- chin has to be tucked in.
- ligamentum flavum between C1 and the occiput and also between C1 and C2 is sharply divided.
- Woodson probe is used to confirm that there are no dural adhesions in sublaminar space.
- interlaminar space is widened to the medial edge of the facet joint using a high -speed drill.
- small curettes are used to develop plane under C1 lamina
- partially flattened uterine trochar needle is passed under the hemilamina at the laminotomy site in a cephalad direction to grasp a single strand of #28 wire.
- single-strand #28 wire is threaded through the needle eye and then pulled under the hemilamina caudally, thus positioning the sublaminar passing wire.



- passing wire is used to pull two double-twisted #28 wires under the hemilamina in a caudal to cephalad direction - this may be performed separately at each hemilamina bilaterally.



CABLE SYSTEMS

18 gauge (Songer)
20 gauge (Codman)

- each system is available in **stainless steel** (avoid it – incompatible with MRI) or **titanium**, with specific force application limits that are dependent on the specific type of metal:
  stainless steel cables – maximum 60 pounds
  titanium alloy cables – maximum 35 pounds
- braided character of cable markedly improves strength and malleability and reduced risk of sublaminar passage (some surgeons prefer the less malleable Luque wire, especially when applying compression techniques with spinous process wiring).
- do not sharply bend cables! – unable to straighten back!
- cable is tightened with the Tensioner-Crimper.
  N.B. avoid hyperextension by overtightening cable!

MULTISTRANDED TITANIUM BRAIDED CABLES

- systems have a variable angle eyelet crimp at one end that allows passing the other end through it.

Songer® cable system (Synthes Spine)

- available in titanium (1.3 mm diameter) and steel (1 mm diameter).
- available in single-loop and double-loop configurations.
- can be tensioned and secured using a single instrument.
- known level of tension can be achieved using the Torque Driver

ATLAS® cable system (Medtronic)

Technique manuals: 1>> 2>> 3>>

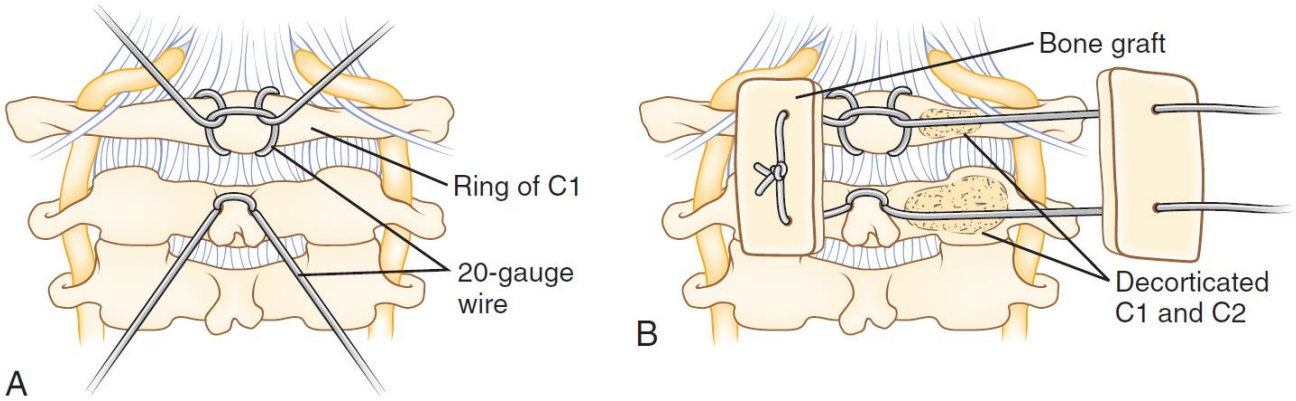
Sof'wire cable system (Codman, Johnson and Johnson)

TECHNIQUES

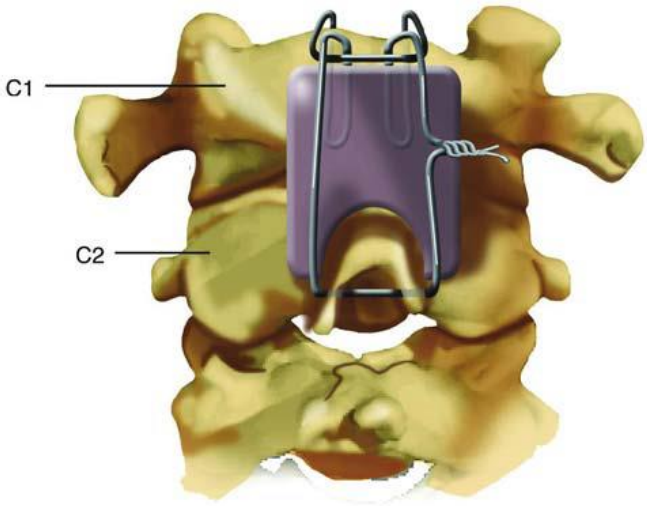
GALLIE (1939)

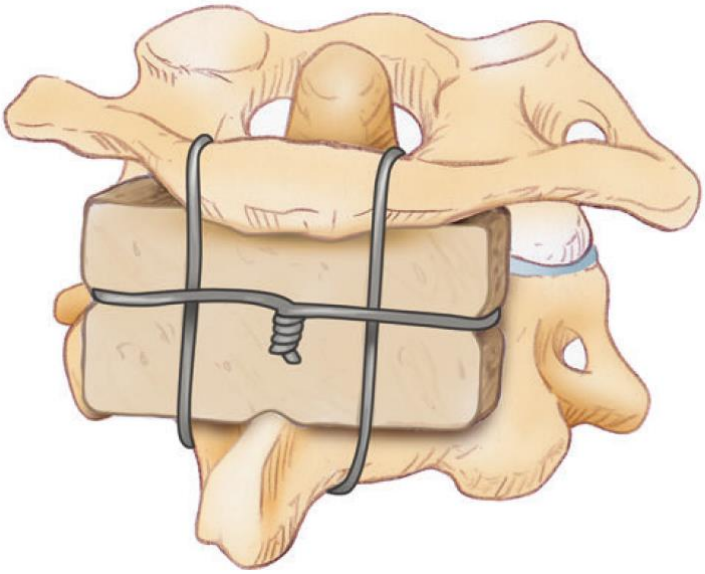
- fastened C1 and C2 vertebrae together with a fine steel wire passed beneath C1 dorsal arch and around C2 spinous process → tricortical bone graft in an **onlay** fashion.

- small **curettes** can be used to develop the plane under the C1 ring for wire passage.
- a loop is created with a 20-gauge wire with the tip contoured for safe passage under the C1 ring.
- a **nerve hook** is used to engage the loop and pull it through approximately 2 cm → free ends of the 20-gauge wire are fed through the loop, and the wire is cinched down tightly onto the C1 ring at the midline.
    - alternatively, sutures may be passed underneath C1 with a **Mayo needle** placed in a reverse manner with the blunt end from caudad to cephalad → wires are placed within the suture loops and passed underneath the lamina as the sutures are withdrawn caudally.
- bur hole is made at the base of C2 spinous process, and a second 20-gauge wire is passed through the hole and looped beneath the spinous process and through the hole again to provide stress distribution.
- two rectangular blocks of corticocancellous iliac crest bone graft are placed over the laminae of C1 and C2 on either side of the midline.
- grafts should be near full–thickness to allow for tightening of the wires with less risk of breaking through the fragile bone.
- wires are tightened over the graft while watching closely to prevent wire breakthrough.
  N.B. tightening wires tends to subluxate the C1 ring posteriorly (H: Brooks technique)
- cancellous chips can be placed around the bone blocks and especially on the ring of C1, where nonunions tend to occur.



Source of picture: Herkowitz "Rothman-Simeone THE SPINE" 6th ed. (2011)



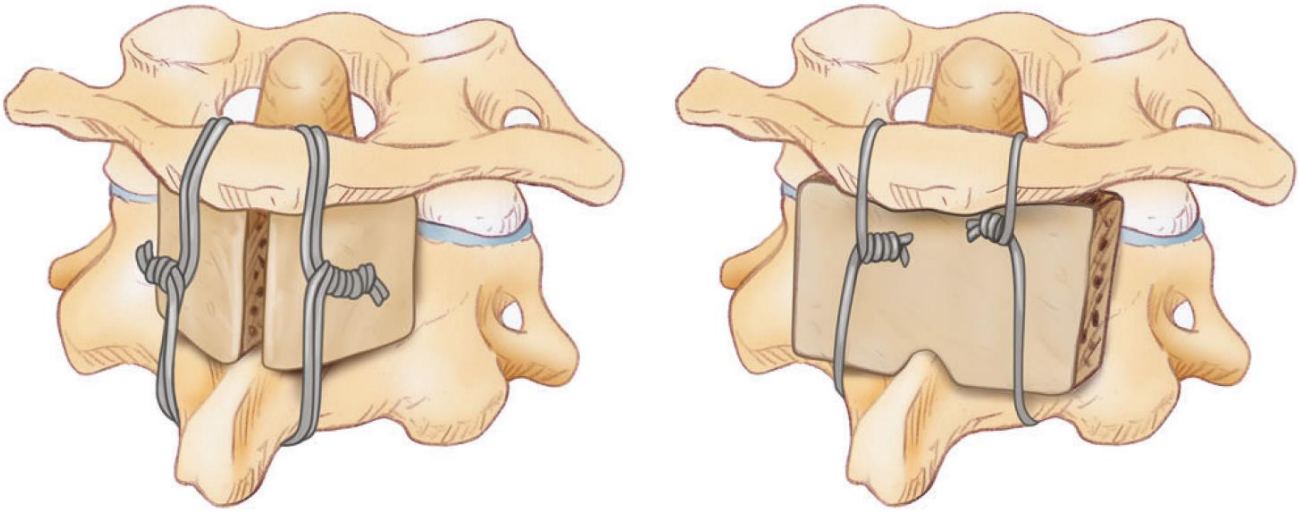


BROOKS AND JENKINS (1978)

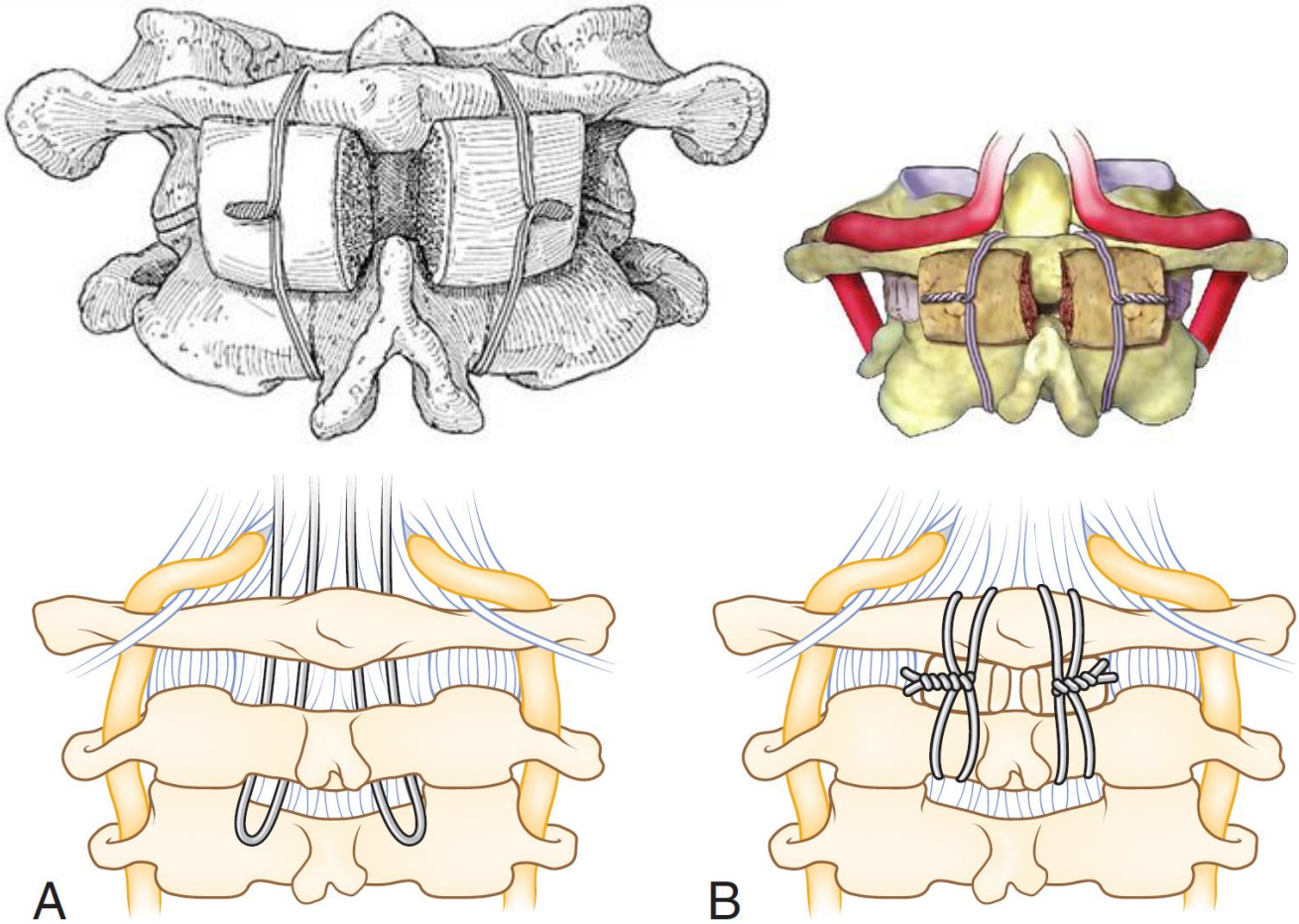
- described a wedge compression arthrodesis by placing sublaminar wires beneath C2 lamina and C1 dorsal arch bilaterally + two separate bone grafts (sculpted in wedge shape) were placed on each side of the midline and secured separately

- provides more rotational stability over Gallie technique because of fixation on both sides of midline.
- Brooks originally used two doubled 20-gauge stainless steel wires passed under each side of C1 arch followed by C2 with the aid of a no. 2 Mersilene suture in a cephalad-to-caudal direction; modern use - pairs of braided titanium cables rather than stainless steel wire!

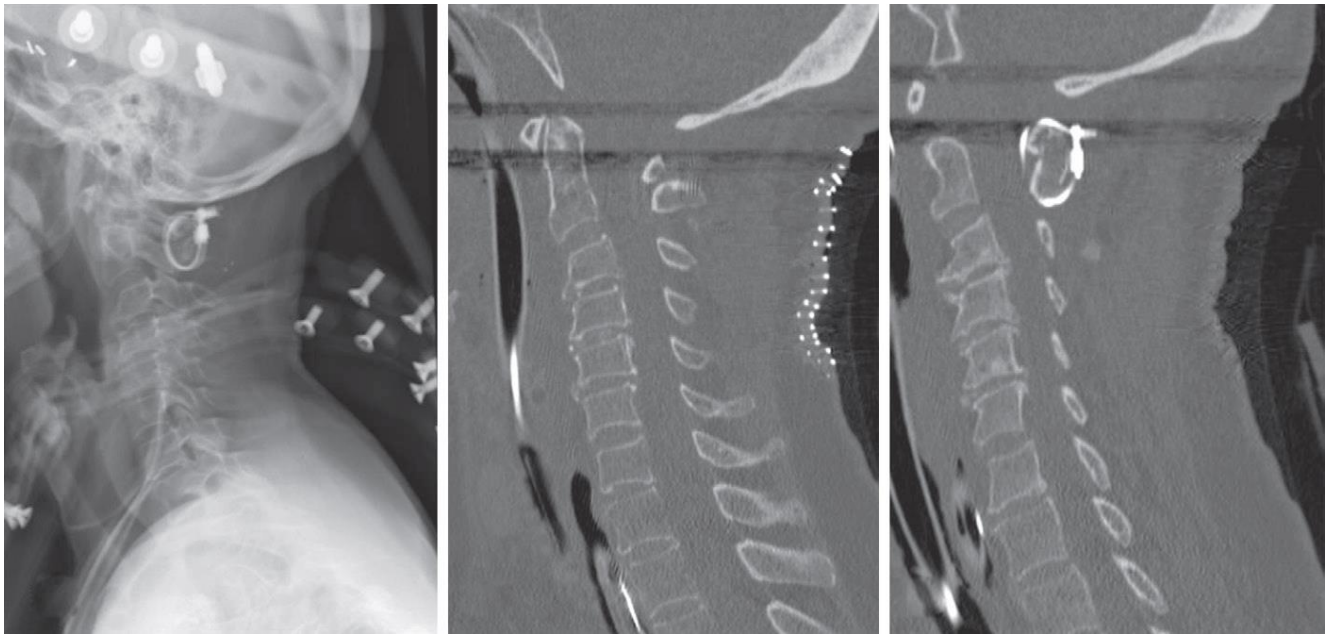
Original and modified Brooks-Jenkins technique:



C1-2 fusion using bone graft (laminotomy may be done between C2 and C3 to facilitate wire passage):



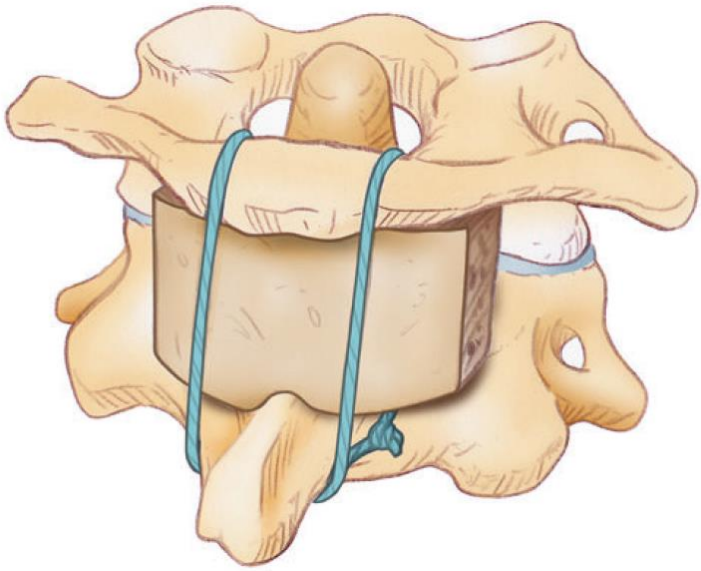
Source of picture: Herkowitz "Rothman-Simeone THE SPINE" 6th ed. (2011)



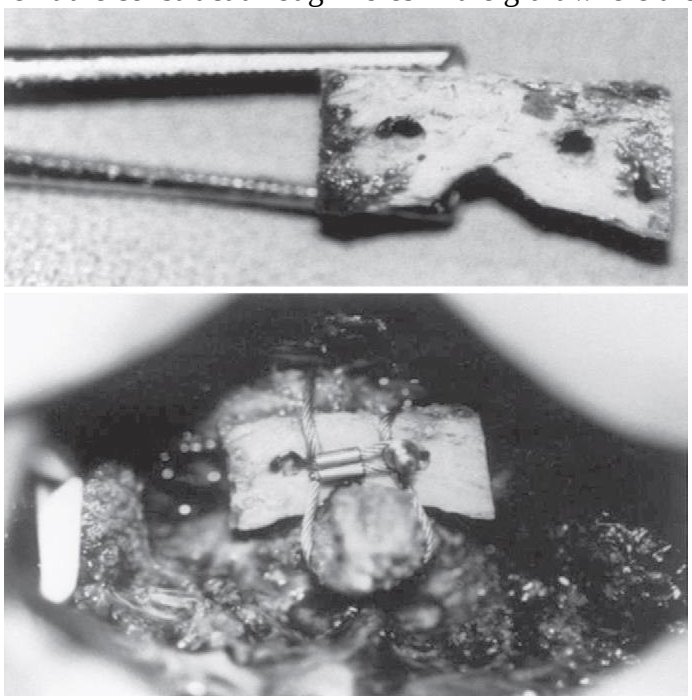
DICKMAN AND SONNTAG (1991)

- described a modification to Gallie technique providing improved rotational stability without a C2 sublaminar cable (needed for Brooks technique).

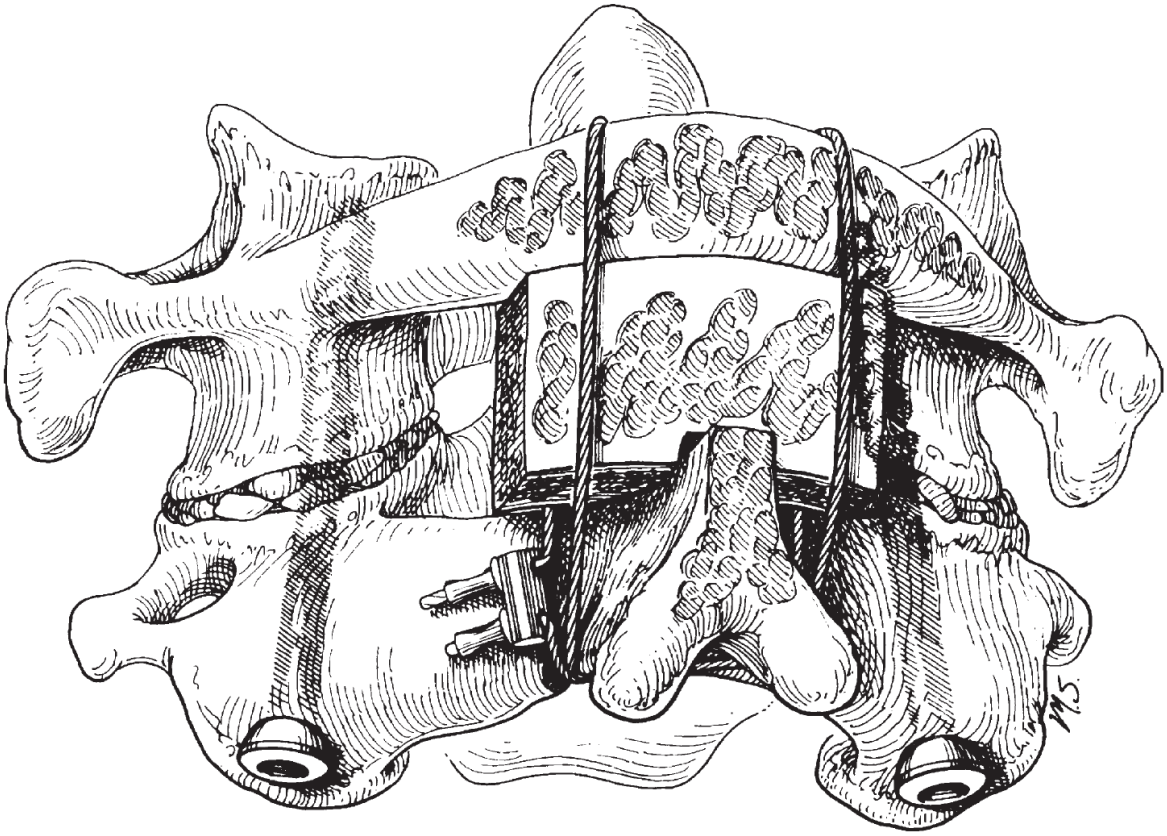
- place a 0 Vicryl suture beneath arch of C1 by sliding blunt end of needle beneath lamina → suture is tied to loop of cable and is used to pull the cable under the C1 lamina from a superior to inferior direction (alternatively, sublaminar cable loop is passed under C1 dorsal arch from caudal to rostral).
- bicortical iliac crest or rib **graft** (cortex on ventral and dorsal surfaces) is fashioned in **H configuration** and interposed between C1 dorsal arch and C2 spinous process - to compress graft between two bony surfaces of dorsal elements.
- notch is created at C2 spinolaminar junction bilaterally with Kerrison rongeur, providing a slot for seating the wire at C2 level.
- loop of cable is brought over bone graft and fixed to C2 spinous process, i.e. cable loop is dorsal to the graft, and cable free ends run ventral to the graft (this ensures that the graft does not migrate dorsally or ventrally) and hug the base of C2 spinous process.
- cable overtightening around the graft can lead to graft erosion and loosening.
- in the presence of dorsal subluxation of dens, there is a risk of pulling the dens dorsally into the spinal cord during wire tightening; H: use larger wedge of bone between the dorsal elements of C1 and C2.
- graft prevents extension, cable prevents flexion.
- Sonntag has reported 97% fusion rates when using a halo vest for 3 months → hard collar for 2-3 months.



Bicortical bone graft harvested from the iliac crest to be interposed between the arch of the atlas and the spinous process of the axis. Holes in the graft allow for the cables to pass through and add further stability to the construct.
Autogenous bicortical iliac crest graft is compressed between the dorsal elements with a Songer cable; free cable ends exit the construct through holes in the graft where they are secured



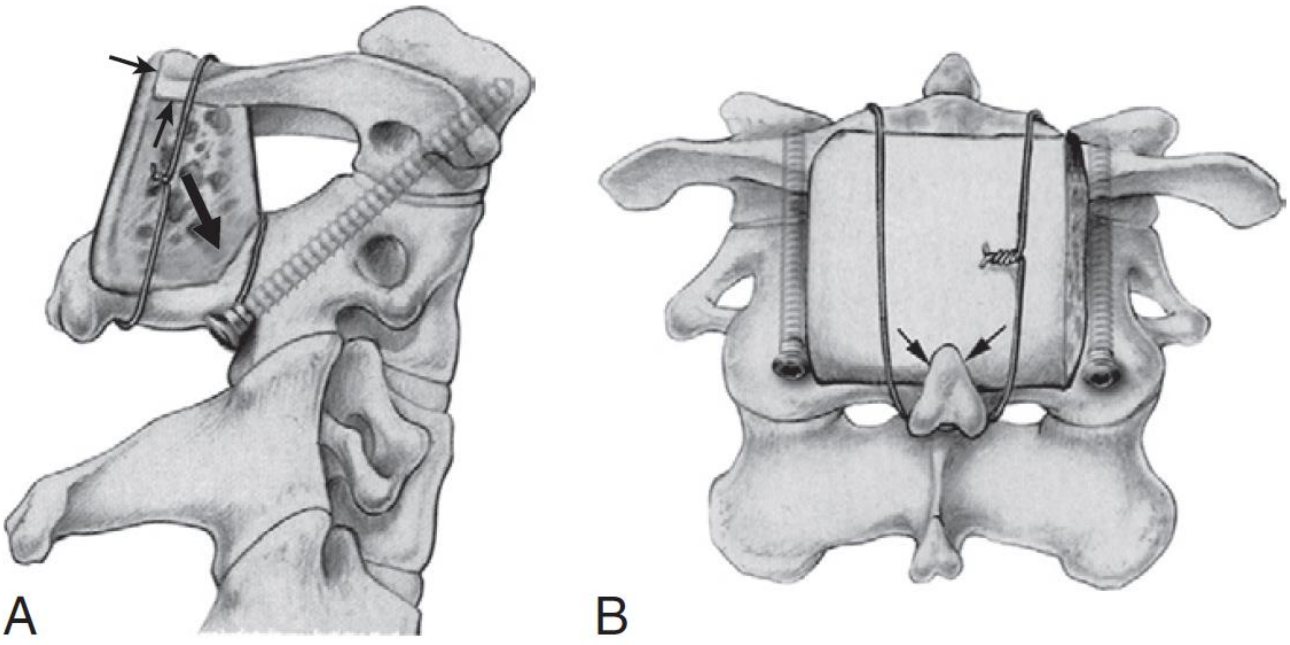
Always add transarticular C1-2 screws if possible (to stabilize rotation moment):



Technique to further increase graft contact:

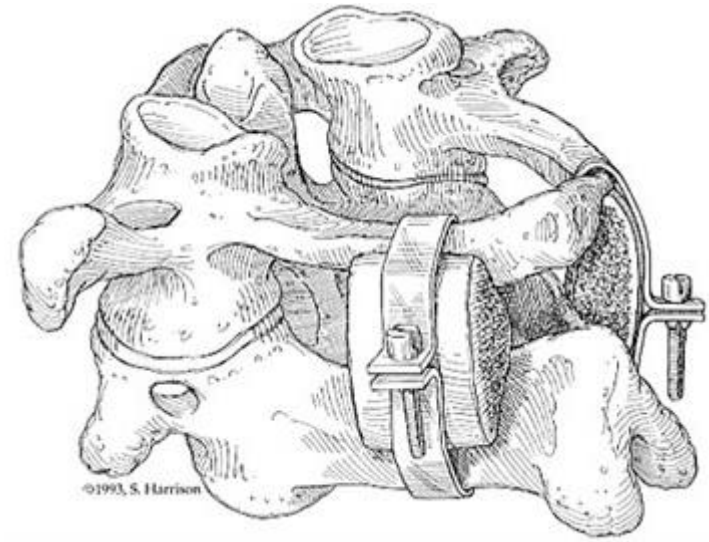
- along inferior aspect of C1 ring and its dorsal aspect (small black arrows in A) - both of these surfaces of C1 are decorticated and flattened to maximize graft contact.
- bicortical graft is mortised into decorticated lamina of C2 (large black arrow in A) and contacts the decorticated spinous process of C2 (arrows in B).

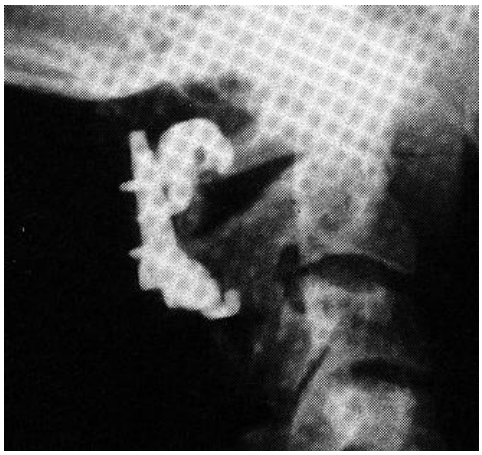
(artist has shown wiring, but braided titanium cable is used and placed as described by Dickman et al. enveloping the graft anteriorly and posteriorly with a cable that passes under the C1 posterior ring and behind the spinous process of C2. Leaving C2-3 interspinous ligaments intact on the spinous process of C2 (not shown) helps retain the cable)



HALIFAX INTERLAMINAR CLAMPS

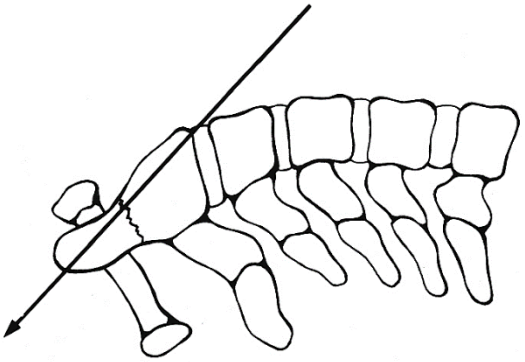
(1984, Holness et al. originally developed in Halifax, Nova Scotia, Canada)
- solution in RA when ventral pannus causes canal stenosis, so passing sublaminar wires causes danger to cord.





Not recommended – do not control rotational movement → poor results!

ODONTOID SCREW



Outcomes (fusion rates) - see p. TrS9 >>

Contraindications

- fracture > 6 weeks old.
- disrupted transverse ligament (TL holds distal fragment in place while placing screw).
- look at apical ligament before surgery (if calcified*, aseptic necrosis will happen and odontoid screw will not work).

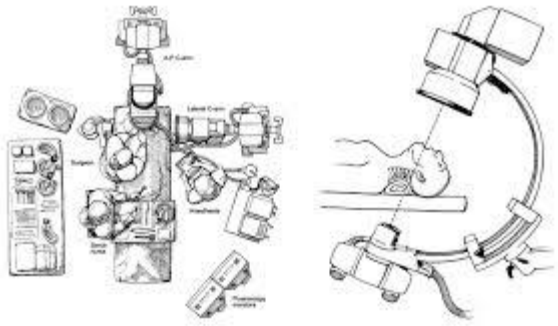
*distal dens blood supply is coming through apical ligament

- difficult if patient has prominent chest (hard to achieve angle).

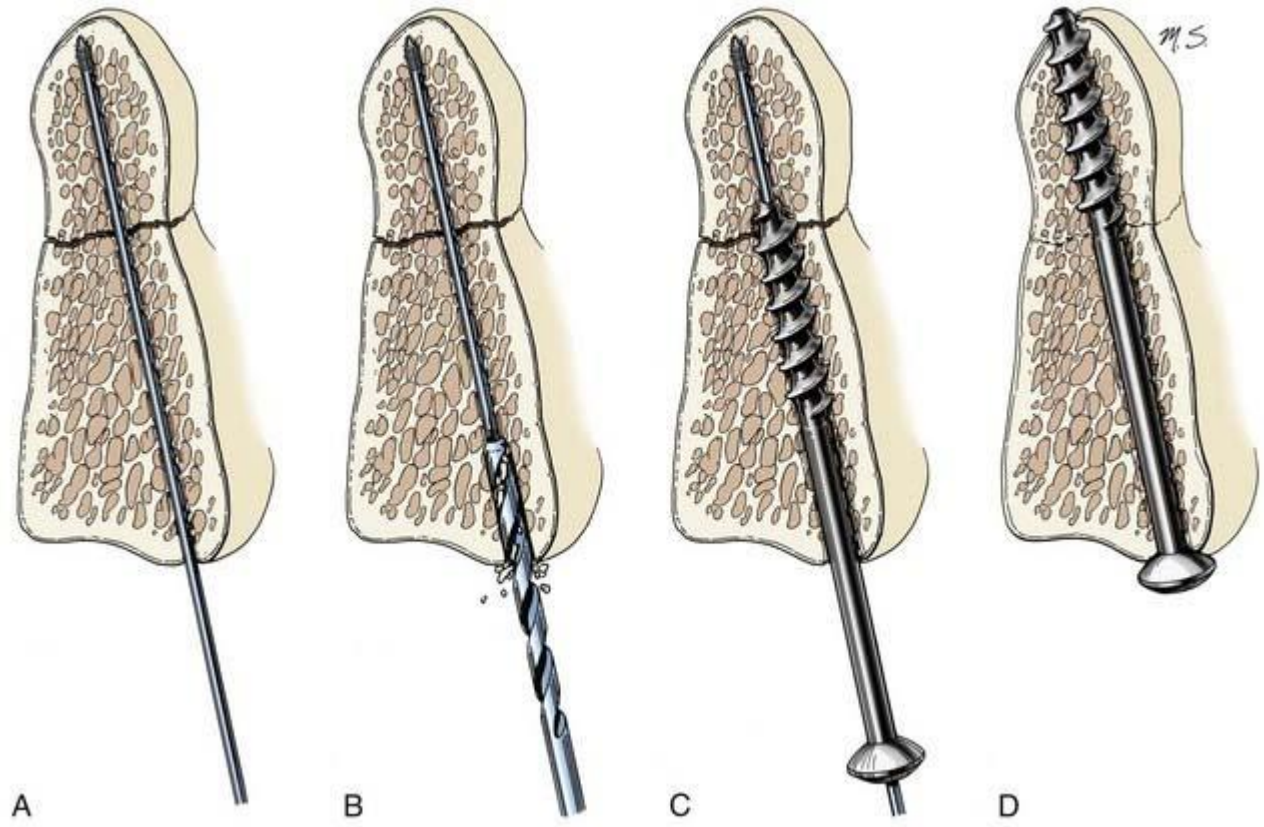
TECHNIQUE

Anterolateral approach – incision at C5 level.

- **biplane fluoroscopy** (make sure everything is visible – place bite block to keep mouth open, make sure head support is not in a way [Mayfield frame is obstructive]):



- drill off the superior anterior corner of C3 (also violates anterior part of C2-3 disk)
- wire pin inserted under fluoroscopy is replaced by **lag screw** over it (1 or 2 screws have same success):



- lag-screw effect can be obtained by drilling near bone fragment hole to diameter greater than, or equal to, outer diameter of a screw: