

Vertebral Column Injury (SPECIFIC INJURIES)

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VCT – vertebral column trauma.
 SCI – spinal cord injury.

N.B. MRI can directly image ligamentous damage! (best sequences: STIR > T2) - normal ligaments are dark, linear structures (on both T1 and T2); when acutely injured, they are outlined by bright edema or blood, making torn ends quite conspicuous.

The primary management of spine injuries consists of **realignment** (when necessary), **decompression** of the neural elements (when indicated), and **stabilization**.

- if the spine is in good alignment and no decompression is necessary, external immobilization may be all that is required to protect the neural elements while healing occurs:
 - this is particularly true when the major cause of the instability is **bony injury**.
 - primary **ligamentous instability** is much less likely to resolve after immobilization → early surgical stabilization.

FRACTURES ACCORDING TO MECHANISM

Any combination of forces may occur in any single case!

Flexion

1. Compression (wedge) fracture
2. Flexion teardrop fracture
3. Clay shoveler's fracture
4. Anterior Subluxation
5. Transverse ligament disruption, Anterior atlantoaxial dislocation ± odontoid fracture
6. Atlantooccipital dislocation

Flexion-Distraction

1. Distractive flexion fracture, s. Chance ("seat belt") fracture
2. Bilateral facet dislocation

Flexion with Lateral component

1. Odontoid fracture with lateral displacement
2. Fracture of transverse process
3. Lateral flexion fracture

Flexion-Rotation

1. Unilateral facet dislocation
 2. "Slice" fracture-dislocation, s. torsional injury
 3. Rotary atlantoaxial dislocation
- failure of *POSTERIOR* and *MIDDLE* columns with varying degrees of *ANTERIOR* column insult – due to combination of:

- 1) **rotation** (→ disruption of **posterior ligaments** and **articular facet**)
 - 2) **lateral flexion**
 - 3) \pm **posterior-anteriorly directed force**.
- uncommon in **thoracic** region due to limited range of rotation (at thoracic facet joints).

Extension

1. Posterior neural arch fracture
 2. Hangman's fracture (s. traumatic spondylolysis of C2)
 3. Extension teardrop fracture
 4. Distractive extension injury
 5. Posterior atlantoaxial dislocation \pm odontoid fracture
 6. Whiplash injury (s. cervical sprain, hyperextension injury)
- most common in **neck**.
 - most are stable as long as vertebral column is flexed.
 - if ligamentum flavum buckles into spinal cord → **central cord syndrome**.
 - **prevertebral (retropharyngeal) swelling** may be the only sign (hyperextension injuries may reduce spontaneously or when spine is placed in neutral position by paramedical personnel).

Vertical (axial) compression

1. Burst fracture of vertebral body
 2. C1 fracture, incl. Jefferson fracture
 3. Lateral mass fracture (C1)
 4. Isolated fractures of articular pillar and vertebral body
- force is applied from either above (skull) or below (pelvis).
 - fractures occur in **cervical** and **thoracolumbar junction** regions – they are capable of straightening at time of impact.

Shearing (by horizontal force)

1. Translational fracture-dislocation
2. Lamina fracture

MECHANICAL STABILITY

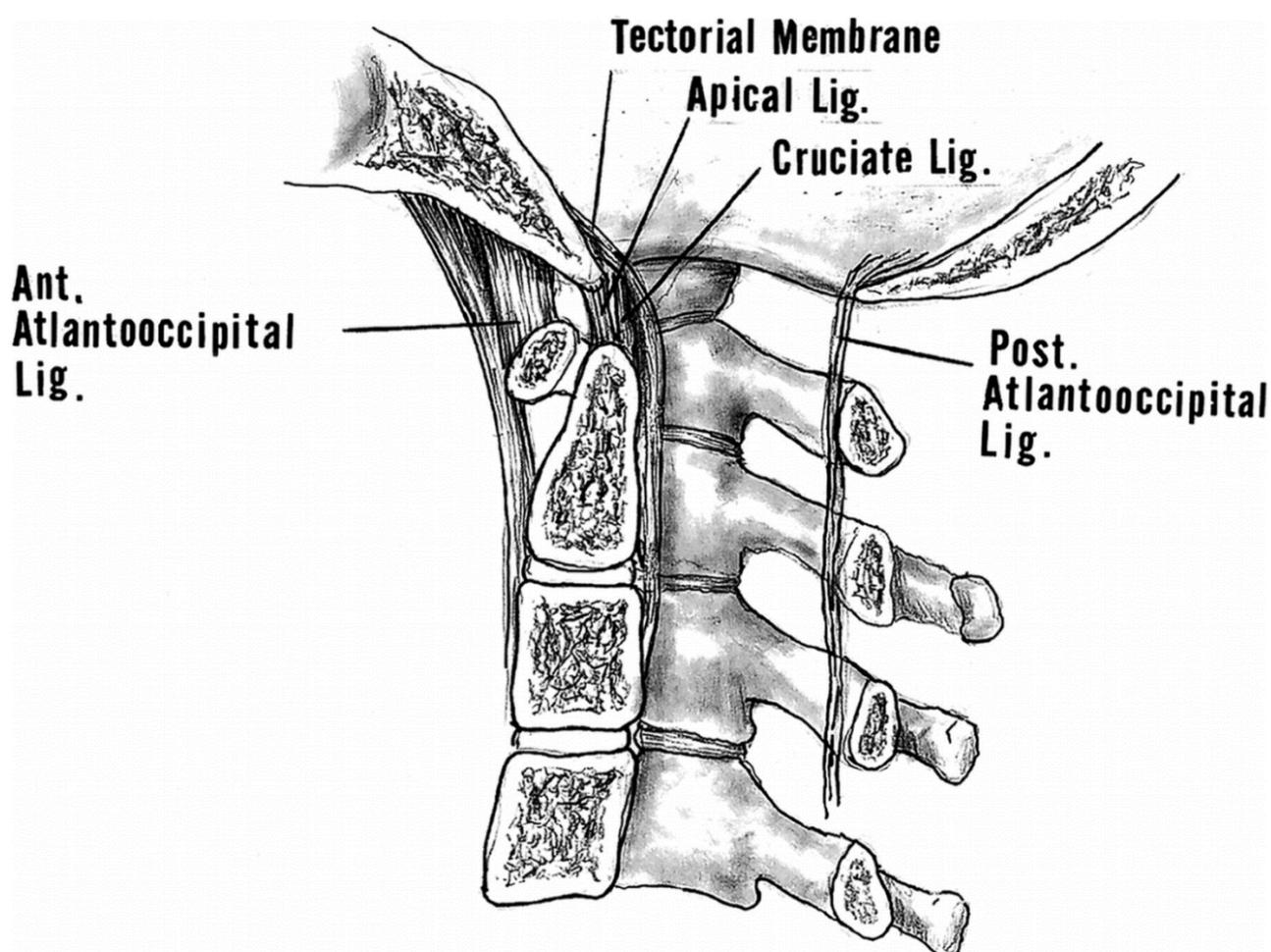
Cervical spine injuries in order of instability (most to least unstable):

1. Rupture of transverse ligament of atlas
2. Odontoid fracture
3. Flexion teardrop fracture (burst fracture with posterior ligamentous disruption)
4. Bilateral facet dislocation
5. Burst fracture without posterior ligamentous disruption
6. Hyperextension fracture dislocation
7. Hangman fracture
8. Extension teardrop (stable in flexion)
9. Jefferson fracture (burst fracture of ring of C1)
10. Unilateral facet dislocation
11. Anterior subluxation
12. Simple wedge compression fracture without posterior disruption
13. Pillar fracture
14. Fracture of posterior arch of C1
15. Spinous process fracture (clay shoveler fracture)

CERVICAL SPINE (C1-2)

Upper neck anatomy is specific - fractures are different from other parts of vertebral column! (> 85% cervical fractures occur below C₃, except in infants and young children)

Rule of thirds - **dens**, **spinal cord**, and **empty space** each occupy approximately 1/3 of spinal canal at arch of atlas.



AOSPINE UPPER CERVICAL CLASSIFICATION SYSTEM (2018)

Dr. Vaccaro explanation:

https://www.youtube.com/watch?v=KyUYfa_JMb4

Injury site vertically (bone and subjacent articulation):

- Type I - occipital and craniocervical region
- Type II - atlas and atlantoaxial joints
- Type III - axis and C2-3 joints

Injury type:

- A – bone injury (clearly stable)
- B – ligamentous injury \pm bone (potentially unstable – MRI is indicated)
- C – translations (clearly unstable)

A Type injuries

- Bony injury only without significant ligamentous, tension band, discal injury
- Most often stable injuries
- Non-operative, conservative management is most often appropriate

B Type injuries

- Tension band/ligamentous injury with or without bony injury
- May be unstable or stable depending on injury specifics
- No complete separation of anatomic integrity
- Management may be operative or non-operative depending on injury specifics

C Type injuries

- Any injury with significant translation in any directional plane and separation of anatomic integrity
- Unstable injuries
- Often requires operative management

Modifiers

- M1 - potential for **instability**
- M2 - high risk of **nonunion** (such as an odontoid waist fracture)
- M3 - high-risk **patients' characteristics** (age, comorbidities, and bone diseases)
- M4 - **vascular** injury or abnormality

M1: Injuries at high risk of non-union with nonoperative Tx

- i.e. Type II odontoid fractures

M2: Injury with significant potential for instability

- i.e. Midsubstance injury to transverse ligament
- i.e. Displaced C1 unilateral lateral mass Tx
- i.e. >6.9 mm displacement of C1 lateral masses

M3: Patient specific factors affecting Tx

- Age, comorbidities, neuro status, smoking, other injuries, ankylosing spondylitis (AS)

M4: Vascular injury or abnormality affecting Tx

N0: Neurologically intact

N1: Transient neurologic deficit that has completely resolved by the time of clinical examination (usually within 24 h from the time of injury)

N2: Radiculopathy

N3: Incomplete spinal cord injury

N4: Complete spinal cord injury

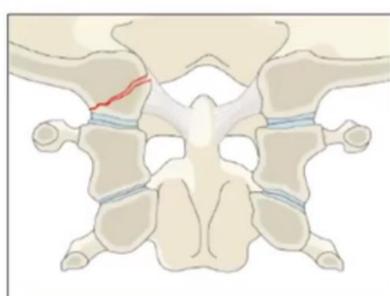
Nx: Unexaminable patient

+: Continued spinal cord compression

I INJURIES

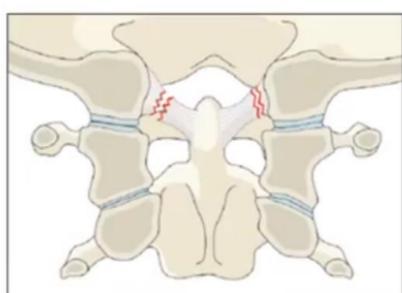
Occipital condyle injuries

- Type A–Isolated bony injury (condyle)
 - Simple or comminuted
 - i.e occipital condyle Type A injury



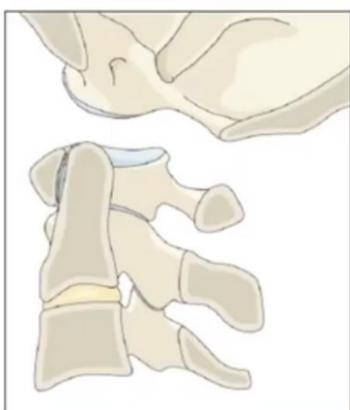
Occipital condyle injuries

- Type B–Non-displaced ligamentous injury (craniocervical)
 - Signs of ligamentary injury with or without condyle fracture without any signs of displacement between occiput and C-Spine



Occipital condyle injuries

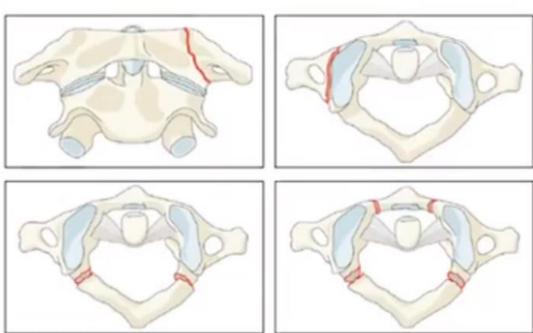
- Type C
 - Any injury with displacement on spinal imaging
 - i.e. occipital cervical Type C injury



II INJURIES

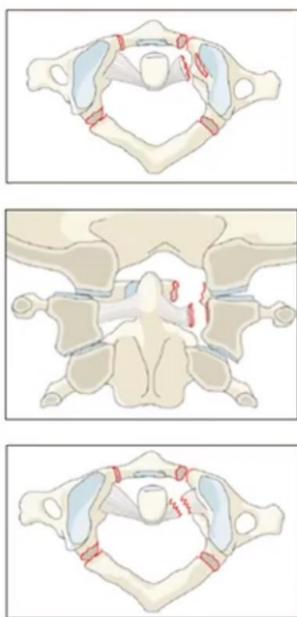
C1 ring and C1-2 joint

- Type A–Isolated bony only (arch)
 - Anterior/Posterior/Combined arch fracture
 - Lateral Mass/Transverse process



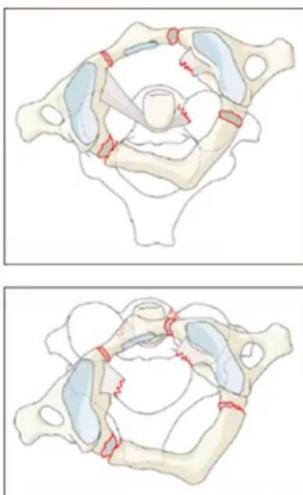
C1 ring and C1-2 joint

- Type B–Ligamentous injury (Transverse Atlantal Ligament)
 - TAL injury +/- bony injury, without acute signs of C1/C2 instability



C1 ring and C1-2 joint

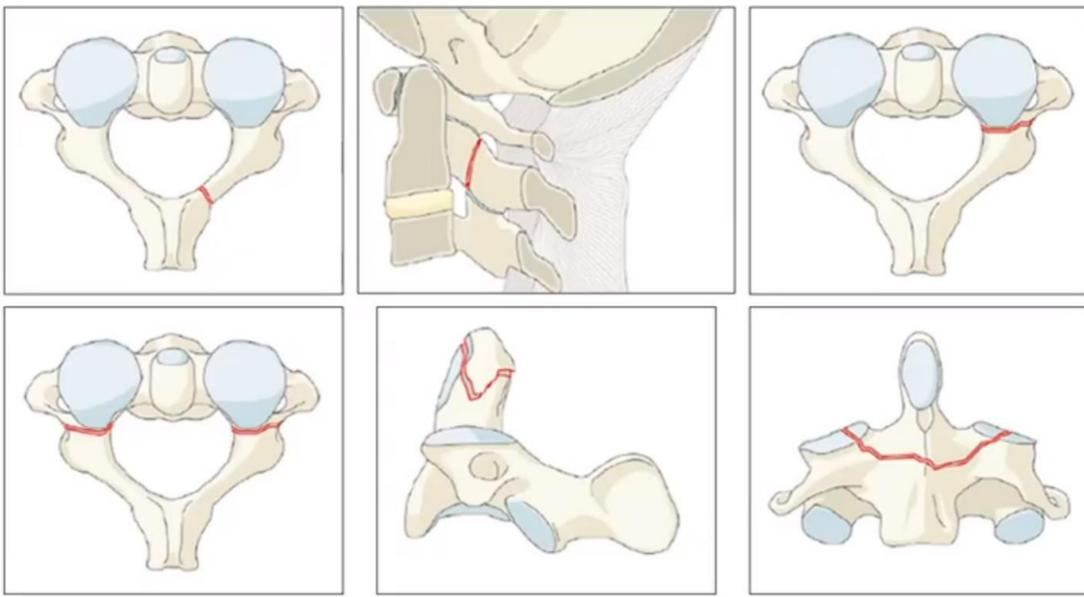
- Type C–Atlantoaxial instability: Translation in any plane
 - Any injury with obvious C1/C2 Instability
 - C1/C2 translation, C1/C2 joint distraction or disruption, Jefferson + Capsule disruption etc.



III INJURIES

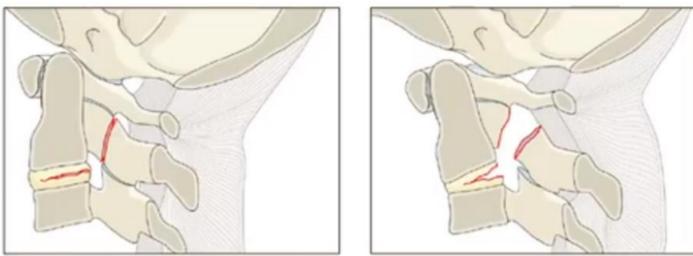
C2 body and C2/3 joint

- Type A–Bony injury only without ligamentous, tension band, discal injury
 - E.g. Type 1-3 Anderson D'Alonzo odontoid fractures; C2 body fractures (axial, sagittal or coronal): Benzel 1-3, Fujimura I-IV



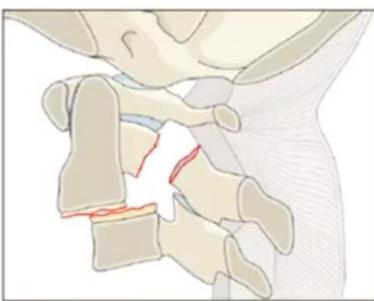
C2 and C2/3 joint

- Type B–Tension band/ligamentous injury with or without bony injury
 - E.g. Type IIA Hangmans fracture



C2 and C2/3 joint

- Type C–Any injury that leads to vertebral body translation in any directional plane
 - E.g. Type II Hangmans fracture, unilateral or bilateral facet dislocation



OCCIPITAL CONDYLAR FRACTURES

See p. TrH5 >>

ATLANTOCCIPITAL DISASSOCIATION

(unstable)

- may be complete (dislocation) or incomplete (subluxation)
- occurs predominantly in **children** - pediatric occipital condyles are small and almost horizontal & lack inherent stability.
- **usually** but not invariably **fatal** due to respiratory arrest caused by injury to lower brain stem (complete disruption of all ligamentous relationships between occiput and atlas → brainstem stretching).
- caused by **severe hyperextension with distraction**; non traumatic causes - Down's syndrome, RA.
- along w/ joint capsules, tectorial membrane is torn.
- 48% patient have cranial nerve deficits at presentation; 20% are normal at presentation.

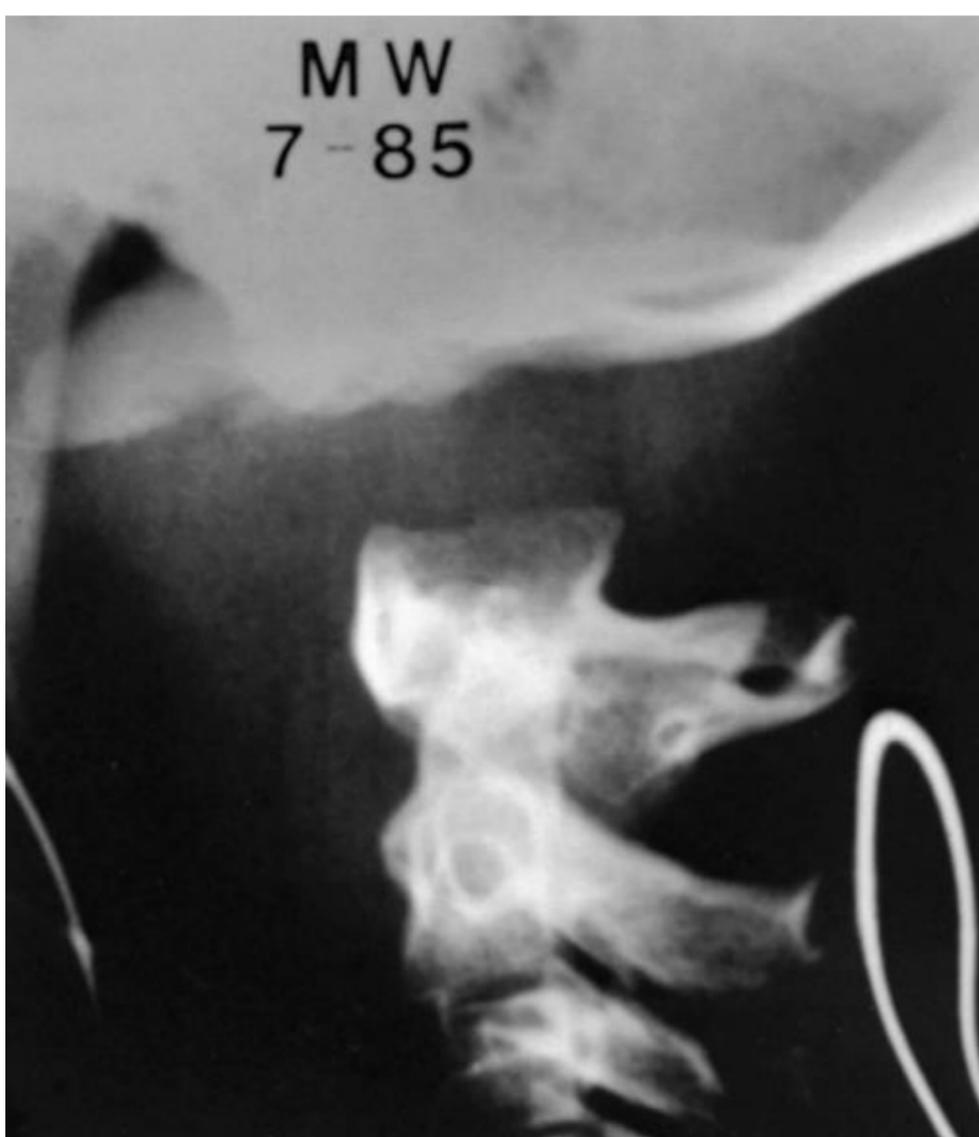
RADIOLOGY

(detection is difficult in cases of partial disruption or if reduction occurs after initial subluxation; **plain XR** has only 50% sensitivity)

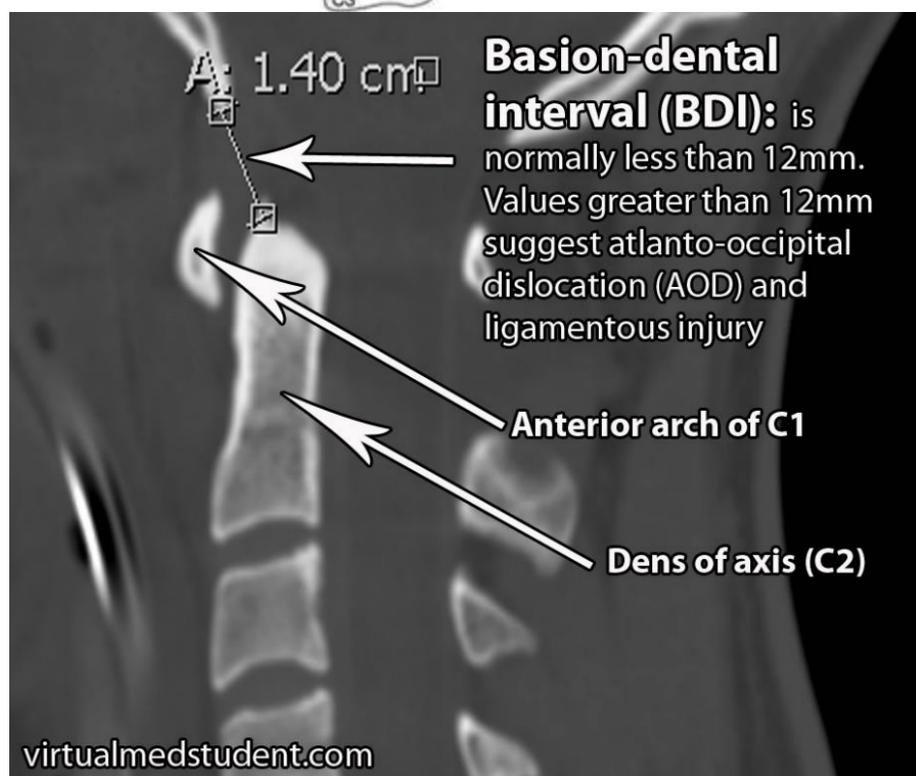
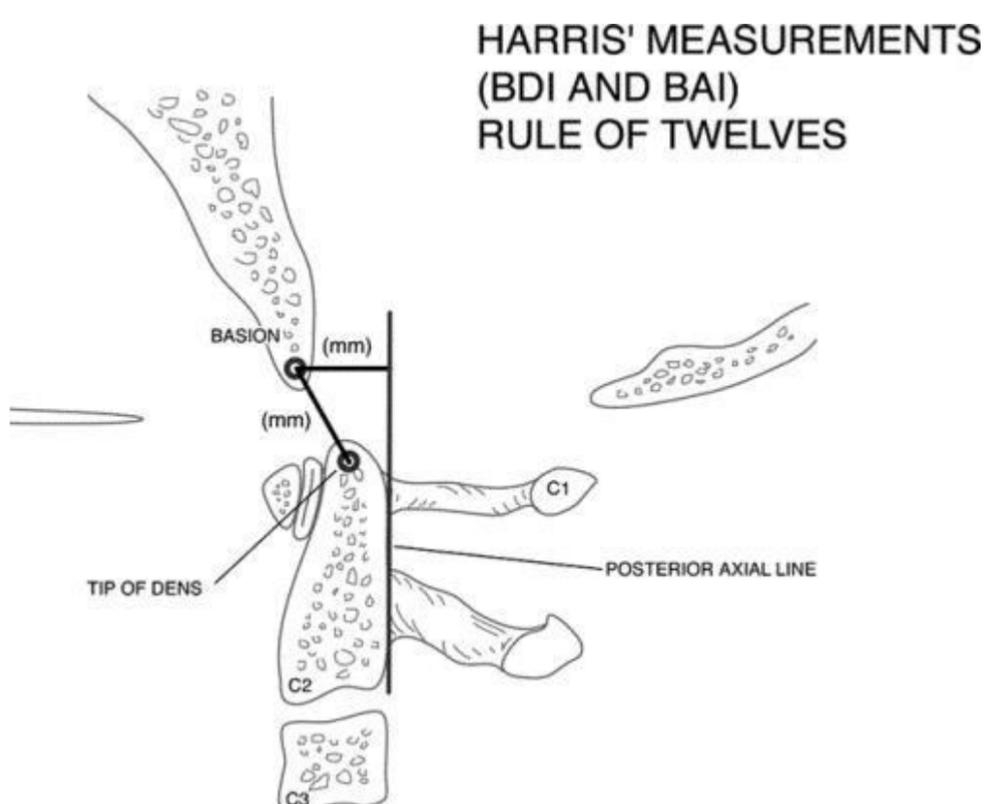
- A. **Condyle-C1 interval (CC1)** determined on **CT** has 100% sensitivity and 100% specificity in pediatric patients (Class I evidence); **distance between occiput & atlas > 5 mm at any point in joint**

N.B. **atlanto-occipital condyle distance should be < 5 mm regardless of age!**

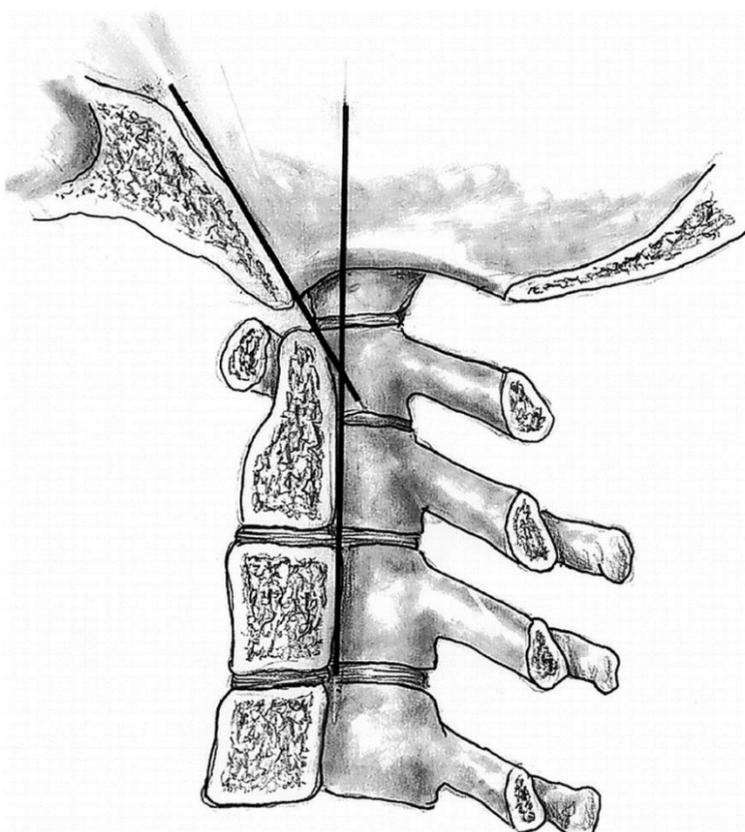
Lateral radiograph of pedestrian struck by car who sustained fatal atlantooccipital dislocation. Note marked widening of space between base of skull and atlas:



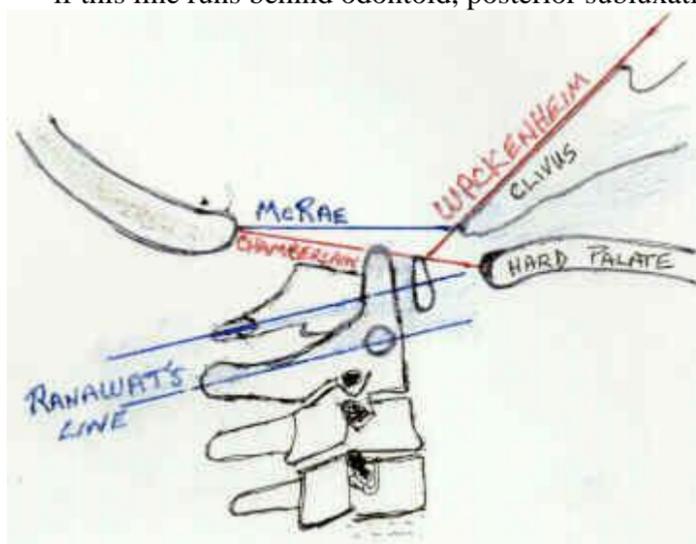
B. CNS/AANS recommended method (proposed by Harris et al, 1994) - most sensitive and reproducible radiographic parameter: on lateral XR - increased distance between clivus & dens – **basion-axial-interval-basion dental interval (BAI-BDI)**:



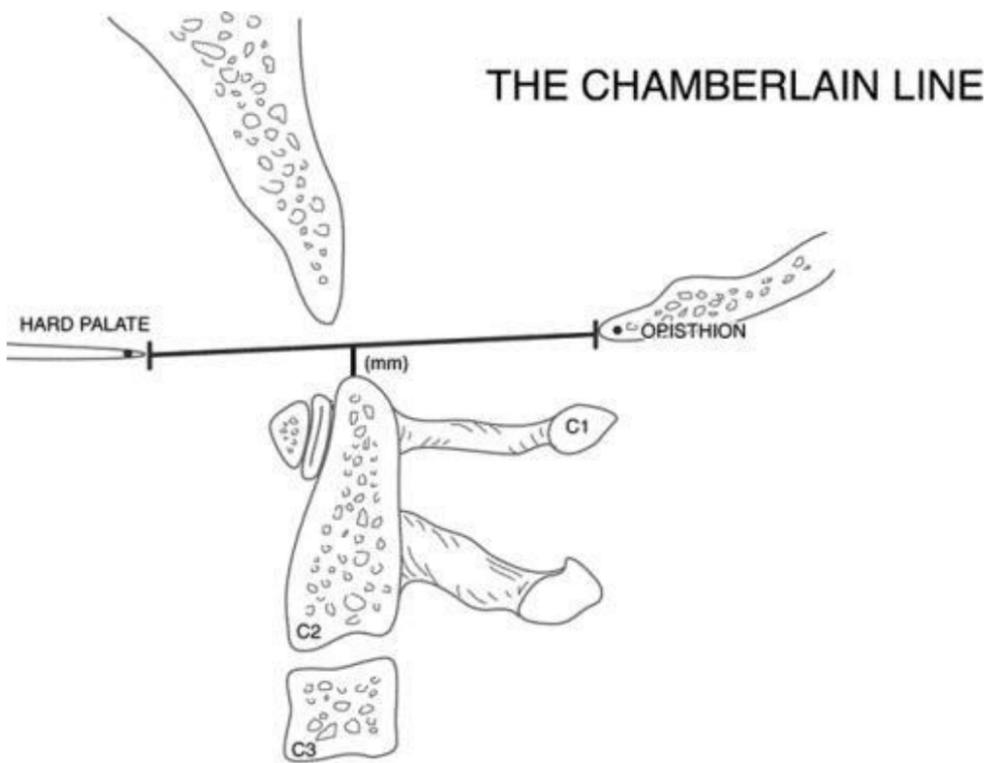
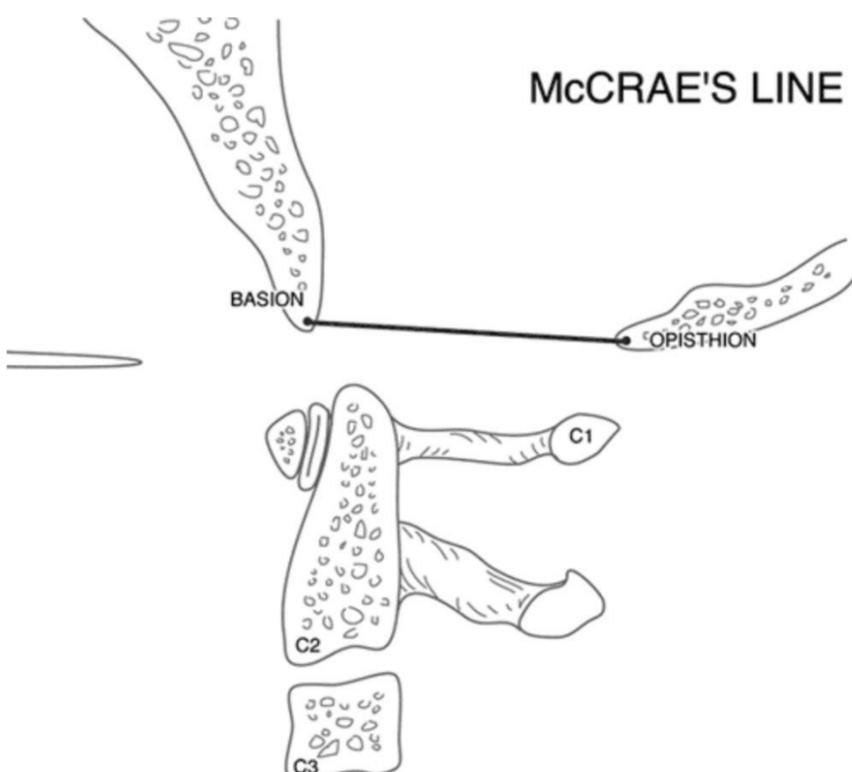
C. Disruption of basilar line of Wackenheimer (**anterior / posterior subluxation**); **WACHENHEIM'S line** - drawn down posterior surface of clivus and its inferior extension should barely touch posterior aspect of odontoid tip;



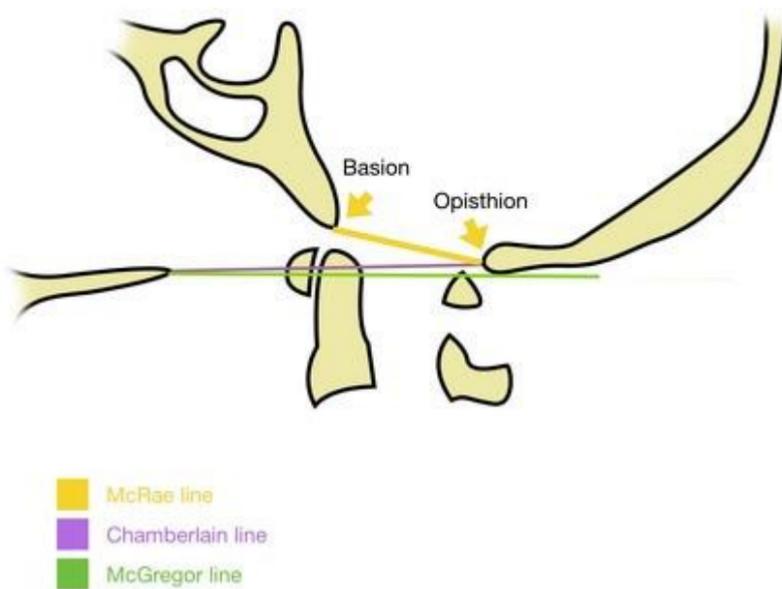
- this relationship does not change in flexion and extension
- if this line runs behind odontoid, posterior subluxation has occurred and vice versa;



Opisthion - the midpoint on the posterior margin of the foramen magnum.
Basion - the midpoint on the anterior margin of the foramen magnum.



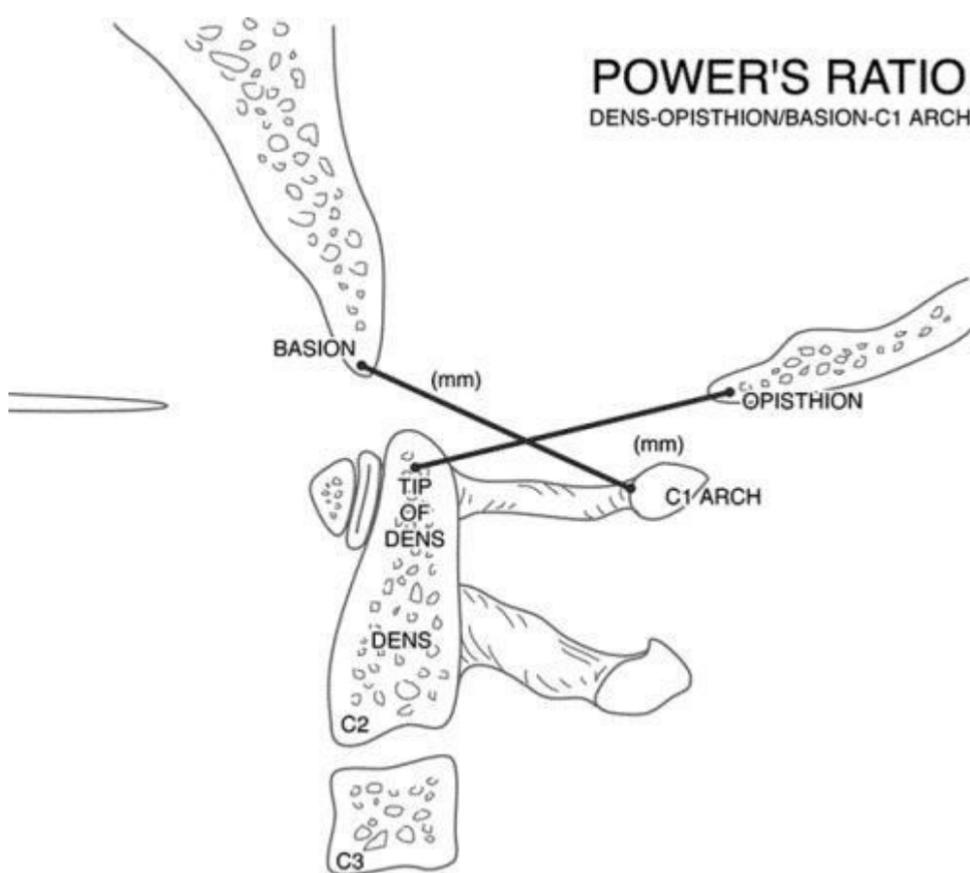
McRae line



D. Powers ratio > 1 (anterior subluxation)

POWERS ratio = BC/OA

BC - distance from basion to midvertical portion of posterior laminar line of atlas;
 OA - distance from opisthion to midvertical portion of posterior surface of anterior ring of atlas.



E. Prevertebral soft tissue swelling (70% patients)

TREATMENT

- avoid flexion of C-spine (can occur on standard adult trauma boards!) - ensure that mattress allows child's head to remain in anatomic position; head is immobilized w/ sandbags.
- **cervical traction is absolutely contraindicated** (→ stretching of brainstem and vertebral arteries!!! - 10% patients experience neurological deterioration).
- definitive treatment - **occiput to C2 fusion**.
 - rigid immobilization in halo allows adjustment to obtain reduction, & maintains position during and after operation.

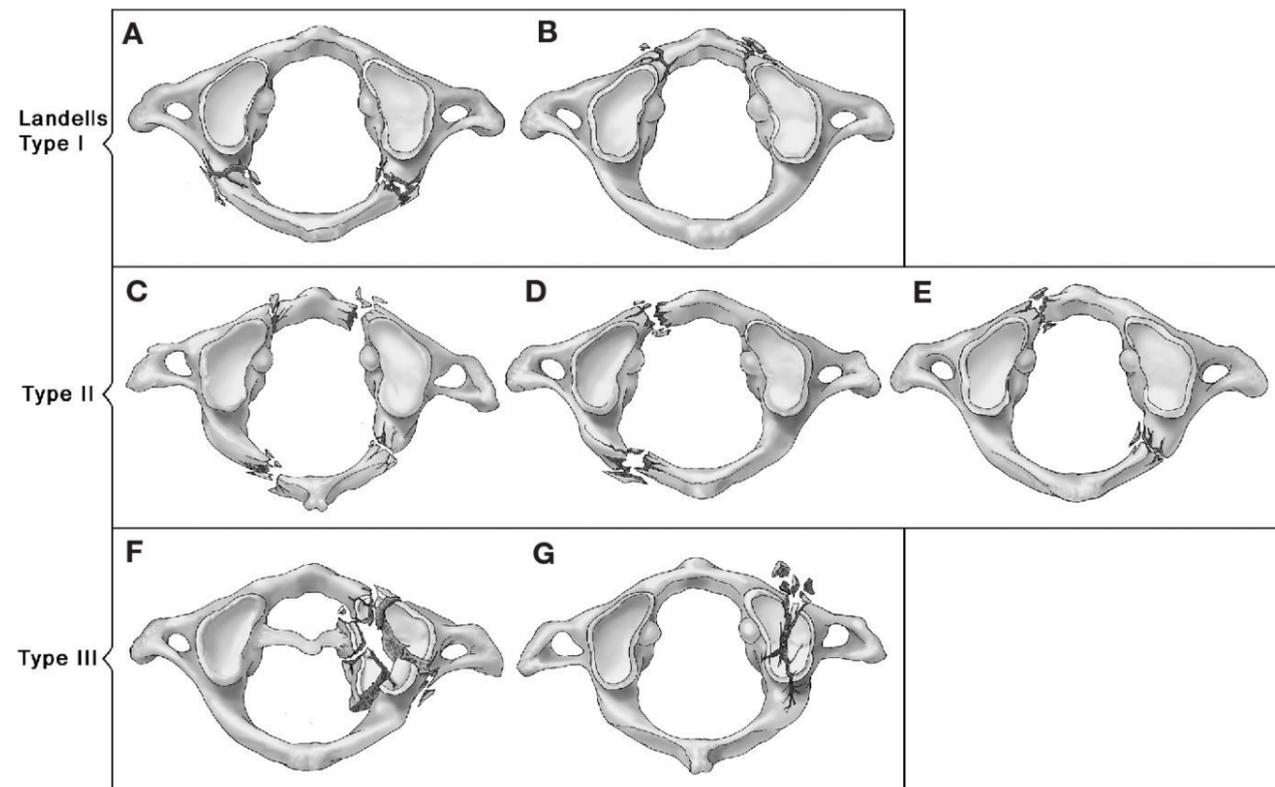
ATLAS FRACTURES

Landell type 1 (stable) – isolated fracture of anterior arch OR posterior arch. see below >>

Landell type 2 – burst fracture of C1 ring (Jefferson fracture). see below >>

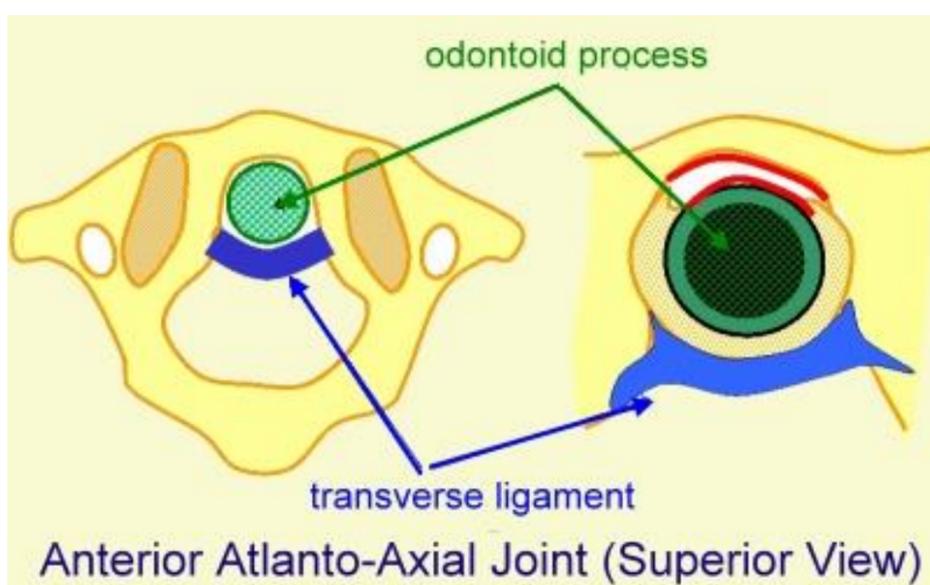
- a) transverse ligament intact (stable)
- b) transverse ligament disrupted (unstable)

Landell type 3 (stable) – fracture through lateral mass of C1. see below >>



- rarely associated with neurological sequelae

Spinal Canal - **Steele's rule**: 1/3 cord, 1/3 dens, 1/3 empty



GENERAL TREATMENT

No Class I or Class II medical evidence!

Intact transverse ligament → collar or halo [for Jefferson] for 8-12 weeks

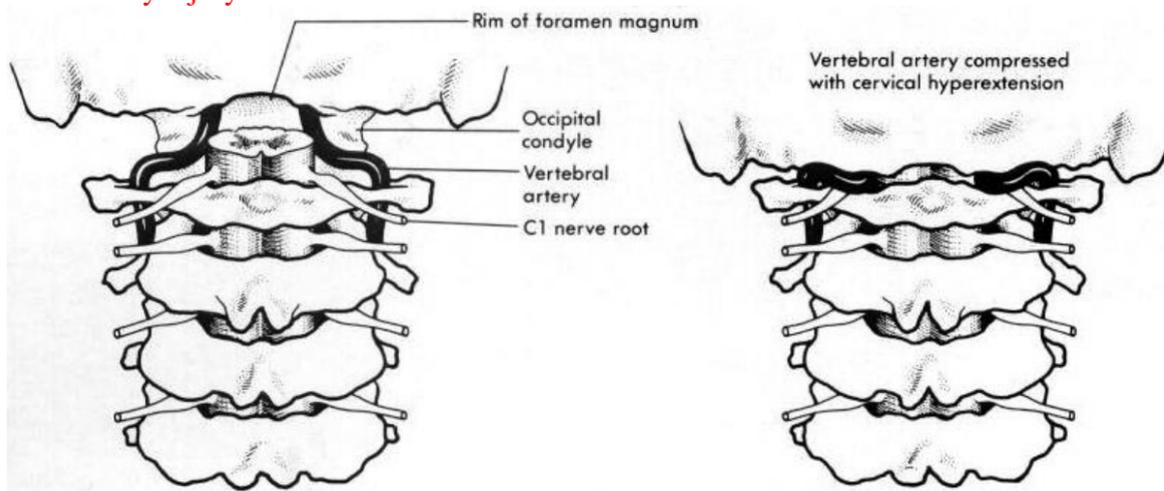
Disrupted transverse atlantal ligament:

- a) halo for 10-12 weeks
- b) C1-2 fusion

POSTERIOR NEURAL ARCH FRACTURE (C₁)

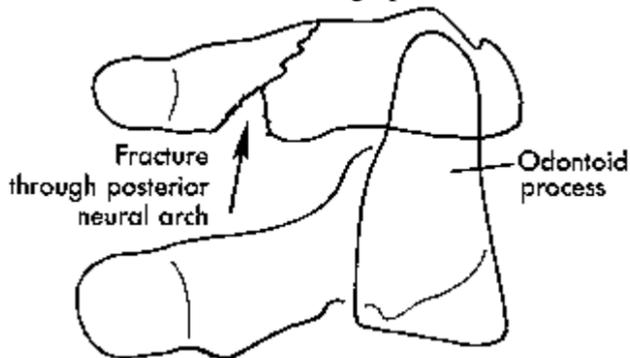
(potentially unstable – because of location – but otherwise stable because anterior arch and transverse ligament remain intact; posterior C1 arch is routinely removed during Chiari decompression)
 - forced neck extension → compression of posterior neural arch of C₁ between occiput and heavy spinous process of axis.

Vertebral artery injury:

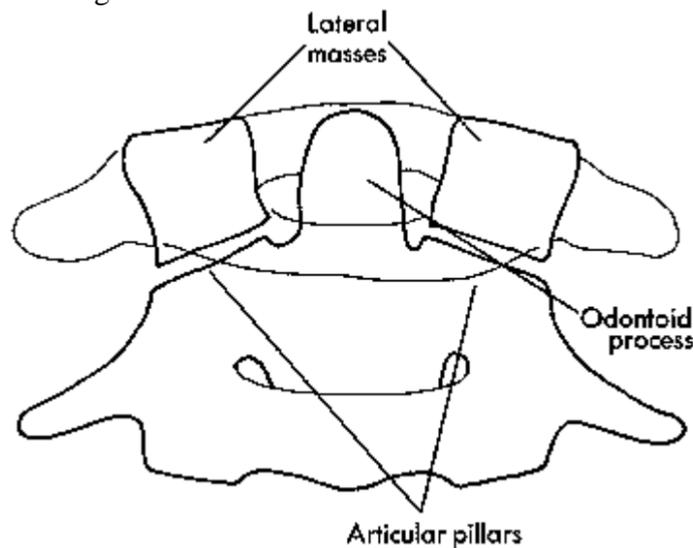


RADIOLOGY

LATERAL VIEW - fracture line through posterior neural arch



ODONTOID VIEW - lateral masses of C₁ and articular pillars of C₂ fail to reveal any lateral displacement - differentiating from Jefferson fracture.



TREATMENT

C-collar (after differentiation from Jefferson fracture).

C₁ BURST FRACTURE (JEFFERSON FRACTURE)

Classic **JEFFERSON fracture (s. C₁ burst fracture)** – burst fracture of C₁ ring in 4 places** ± disruption of transverse ligament:

- *vertical compression force** (transmitted through occipital condyles to superior articular surfaces of lateral masses of atlas) *drives lateral masses laterally*.
- extremely unstable if transverse ligament is disrupted.
 - *e.g. in diving accidents
 - **or at least in two sites - one anterior and one behind lateral masses.

- usually spinal cord is not damaged - canal of atlas is normally large (fracture fragments spread outward to further increase canal dimensions).
- fractures in other parts of cervical spine are found in 50% patients!!!

RADIOLOGY

X-ray - difficult to recognize if fragments are minimally displaced; H: CT

LATERAL view:

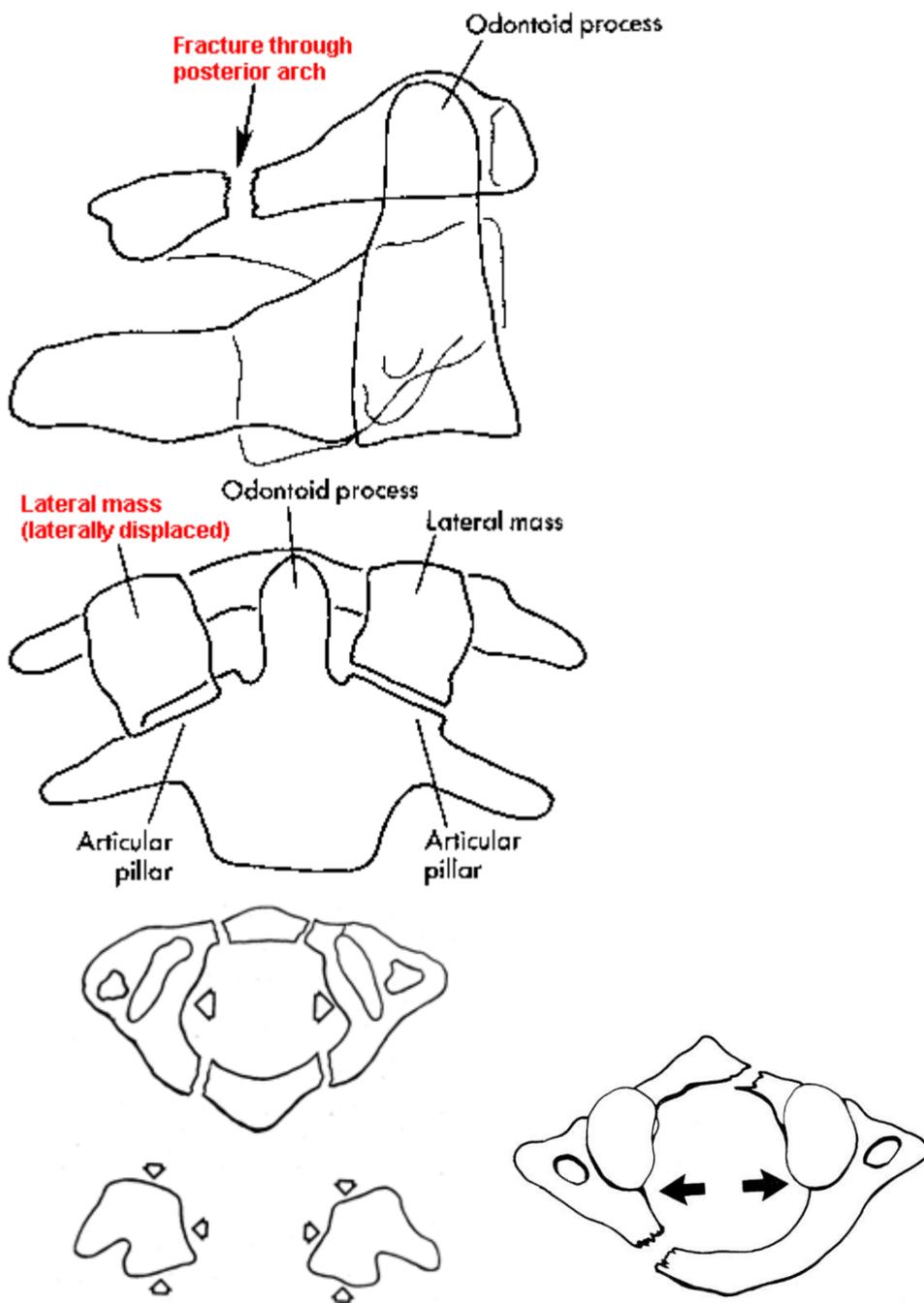
- 1) widening of atlantodental interval *see below*
- 2) prevertebral hemorrhage & retropharyngeal swelling.

ODONTOID view: margins of lateral masses (of C1) lie lateral to margins of articular pillars (of C2) – Spence's rule. *see below*

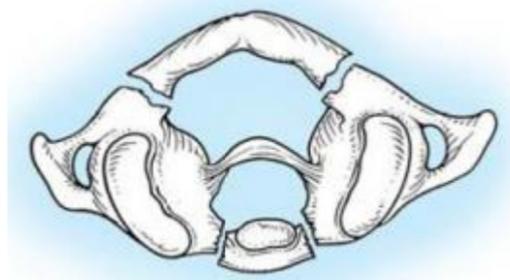
CT is best for diagnosis.

Diagnosis of TRANSVERSE ATLANTAL LIGAMENT RUPTURE – 3 criteria:

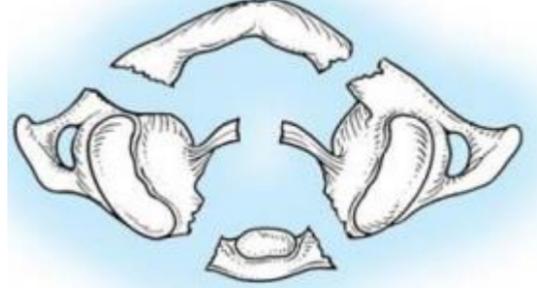
- 1) MRI – most sensitive test (more sensitive than rule of Spence)
- 2) SPENCE'S rule: $\geq 7\text{ mm}$ (sum of bilateral distances between dens and lateral mass) displacement of lateral masses in coronal CT view (or $> 8\text{ mm}$ on plain XR open-mouth view to consider effects of radiographic magnification)
- 3) widening of atlantodental interval (ADI, s. predental space) in sagittal CT view (or lateral XR view): $> 3\text{ mm}$ in adults ($> 2.5\text{ mm}$ in females), $> 4-5\text{ mm}$ in children.
 N.B. if $> 12\text{ mm}$ - rupture of all ligaments about dens.
 Some experts say $> 5\text{ mm}$ in adults.



Axial view of stable Jefferson fracture (transverse ligament intact):



Axial view of unstable Jefferson fracture (transverse ligament ruptured)

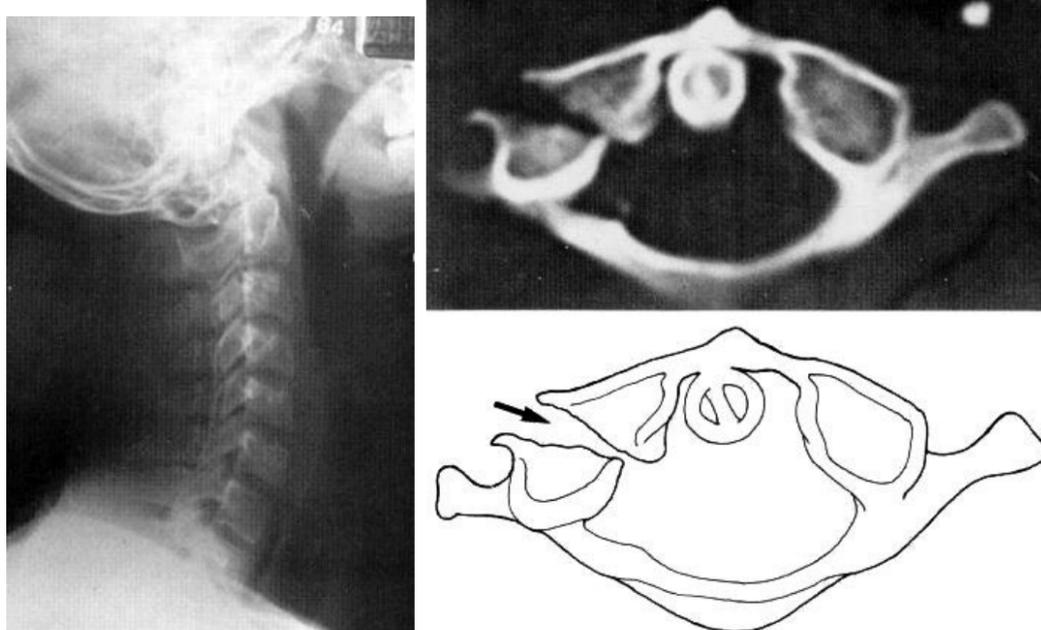


TREATMENT

- A. **No transverse ligament injury** → long-term (10-12 weeks):
 - a) C-collar
 - b) halo (with mild cervical traction);
- B. **Transverse ligament damage:**
 - a) halo (12 weeks) - discomfort of prolonged immobilization + poor healing/union rate
 - b) occ-C2 fusion → halo.

LATERAL MASS FRACTURE (C1)

- A. Normal lateral cervical spine.
- B. Axial CT - slightly displaced lateral mass fracture:



TREATMENT

Comminuted fracture – collar, halo
 Transverse process fractures – collar

ROTARY ATLANTOAXIAL DISLOCATION (S. ATLANTO-AXIAL ROTATORY FIXATION)

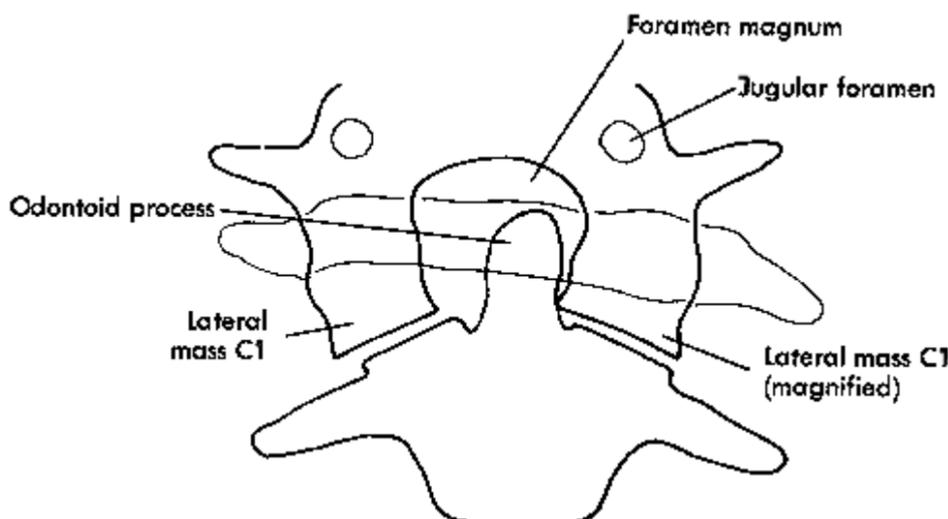
(unstable - because of location - despite fact that facets may be locked)
 - specific type of **unilateral facet dislocation at C1-C2 level** (rotational injury usually without flexion).

ETIOLOGY

- 1) trauma
- 2) Grisel syndrome – see below
- 3) abnormal ligament laxity, e.g. Down syndrome, connective tissue diseases, osteogenesis imperfecta, neurofibromatosis type 1

RADIOLOGY

(ODONTOID view) - **asymmetry** between odontoid process and lateral masses of C1, unilaterally **magnified lateral mass** (wink sign).
 N.B. considerable care during interpretation of odontoid views - if skull is shown obliquely (asymmetrical basilar skull structures, esp. jugular foramina), there is false-positive asymmetry between odontoid process and lateral masses of C1. H: **three-position CT with C1-C2 motion analysis**.



- > 5 mm of anterior displacement of arch of C-1 indicates disruption of both facet capsules as well as transverse ligament (Fielding type III)

TREATMENT

- subluxation is reduced in:
 - a) **halter traction** (if < 4 weeks duration)
 - b) **tong/halo traction** (if > 4 weeks duration)
- specific forms of immobilization are recommended to ensure ligamentous healing:
 - Fielding Type I (transverse ligament intact and **bilateral facet capsular** injury) - **soft collar**
 - Fielding Type II (**transverse ligament + unilateral facet capsular** injury) - **Philadelphia collar** or **SOMI brace**
 - Fielding Type III (**transverse ligament + bilateral facet capsular** injury) - **halo**
- following 6-8 weeks of immobilization, stability is assessed by flexion-extension XR; recurrence or residual instability → **posterior atlantoaxial (C1-2) arthrodesis**.

GRISEL's syndrome

- unilateral or bilateral subluxation of atlanto-axial joint from inflammatory ligamentous laxity
- etiology - **inflammatory process in head and neck** (e.g. upper respiratory tract infections, retropharyngeal abscess, tonsillectomy / adenotonsillectomy, otitis media)
- causative organisms: Staphylococcus aureus, Group B streptococcus, oral flora.
- anatomic studies have demonstrated existence of periodontoidal vascular plexus that drains posterior superior pharyngeal region; no lymph nodes are present in this plexus, so septic exudates may be freely transferred from pharynx to C1-C2 articulation → synovial and vascular engorgements → mechanical and chemical damage to transverse and facet capsular ligaments.
- rare cause of torticollis
- usually occurs in **infants / young children**
- neurological complications (occur in 15% of cases) range from radiculopathy to death from medullary compression.
- treatment – manual reduction under sedation and collar; if recurs - traction brace; residual subluxation after 8 weeks of treatment or neurological symptoms may require operative treatment (posterior atlantoaxial arthrodesis).

ODONTOID (DENS) FRACTURES

≈ 10% of cervical spine fractures.

Anderson and D'Alonzo (1974):

J Bone Joint Surg Am. 2004 Sep;86(9):2081. Fractures of the odontoid process of the axis. 1974. Anderson LD, D'Alonzo RT.



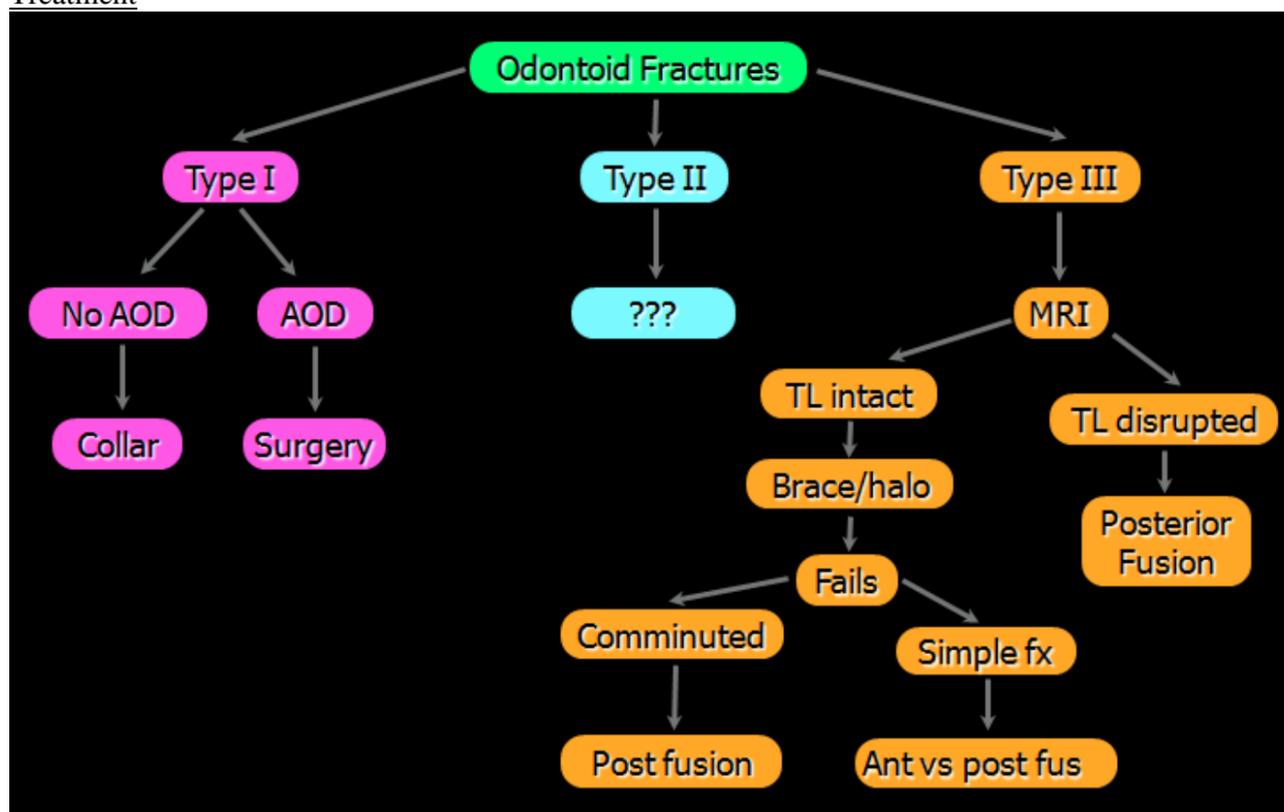
Type I – oblique fractures through **upper portion** of dens.

Type II – fractures across dens base **near junction with axis body**.

Type IIA (Hadley, 1988) - comminuted dens base fracture with free fracture fragments

Type III – dens fractures that **extend into axis body**.

Treatment



AOD – atlanto-occipital dislocation
TL – transverse ligament

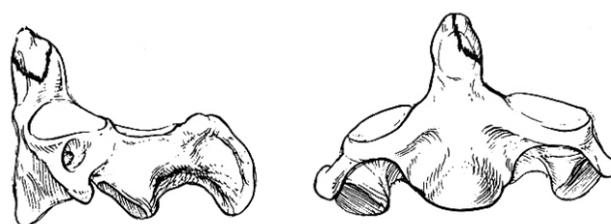
- all odontoid fractures are often effectively managed with external cervical immobilization, with understanding that failure of external immobilization is significantly higher for type 2 - *type 2 has lowest rate of union* (healing).
- management of odontoid fractures in *elderly patients* is associated with increased failure rates, and higher rates of morbidity and mortality irrespective of treatment offered.
- union is verified with **CT** (historical alternative – **dynamic XR**).

Indications for surgical fusion:

1. Type 2 fracture in patient **> 50 yrs**
2. Type 2 or 3 fracture with dens **displacement ≥ 5 mm** post attempted reduction (or inability to maintain alignment* with external immobilization); some experts say even > 2 mm
*e.g. **> 5° angulation** between supine and upright films
3. Dens **comminution** (type 2A fracture)
4. **Transverse ligament** disruption
5. Atlanto-occipital dislocation

TYPE 1

(stable) - fracture across **tip of dens**;



- treated with cervical **collar** (successful in 100% cases).
- may be associated with life-threatening **atlanto-occipital dislocation** (H: **fusion**).

TYPE 2

(most unstable type!) - fracture at **base of dens**; most common type;



- *odontoid process* develops embryologically as body of atlas; during development, body becomes separated from ring of atlas and fuses to body of axis - cartilaginous material at site of fusion is present until maturity is reached - separation at base of odontoid may occur with relatively slight injury to head during childhood (resulting bony segment is *os odontoideum*).

Embryologically – fracture line corresponds to fetal intervertebral disc!

TREATMENT

- **unfavorable healing potential:**
 - 1) considerably less trabecular bone at the base of the odontoid
 - 2) the distractive forces from the apical ligament
 - 3) dens is surrounded by synovial cavities, resulting in diminished periosteal blood supply
- patients rarely seen initially with significant neurological deficits, but risk of posterior displacement - managed with **halo vest** for 3-6 months → flexion-extension XR to confirm stability; inability to maintain dens displacement < 5 mm is indication for surgery.

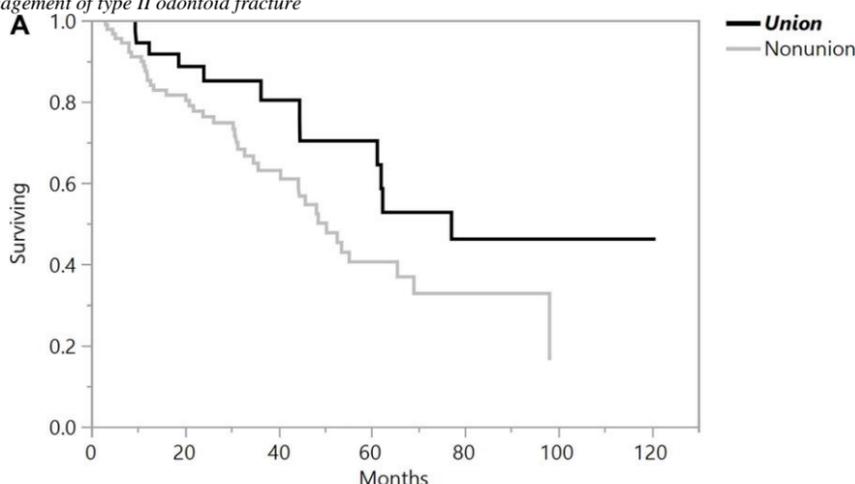
- limited vascular supply, small area of cancellous bone - high prevalence of **nonunion** (43-47% for collar; 16-35% for halo or surgery) and **ischemic necrosis** of odontoid; risk groups - elderly patient*, delay of treatment, failed reduction or secondary loss of reduction; H: **operative fixation**:
 *N.B. consider surgical fusion for type II odontoid fractures in patients > 50 yrs!
 (age > 50 yrs increases nonunion risk 21-fold when treated in halo!; reported union rates in elderly patients treated with halo vary between 20% and 100% in literature; plus, **elderly mortality rates as high as 26-42% with use of halo** have been reported)

Implications of nonunion - type II dens fractures in elderly > 65 yo treated in C-collar (3 months)

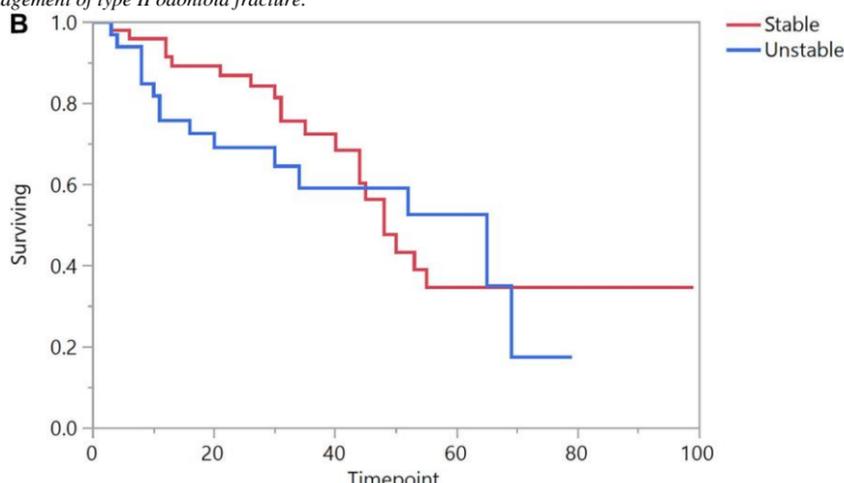
Suzanne McIlroy et al. Conservative Management of Type II Odontoid Fractures in Older People: A Retrospective Observational Comparison of Osseous Union Versus Nonunion. Neurosurgery 87:E648-E654, 2020

- 125 patients
- **29% demonstrated osseous-union**, 71% had nonunion (of which 40% had radiological instability but none of these complained of pain or neurological symptoms).
- no patient developed myelopathy.
- no statistically significant differences in pain, disability, or quality of life.
- 42% mortality rate (union: 33%; nonunion: 46%; median time to death was 30 mo); median length of survival was 77 mo for osseous-union vs 50 mo for nonunion but no significant effect of osseous-union status (P = .22) on Cox proportional hazards modelling*.
 *the cause of the nonunion (eg, frailty, comorbidities) may be the cause of the reduced survival length rather than the nonunion itself.

Kaplan-Meier curves demonstrating the probability of survival (months) for patients with osseous-union and nonunion following conservative management of type II odontoid fracture



Kaplan-Meier curves demonstrating the probability of survival (months) for patients with stable and unstable nonunion following conservative management of type II odontoid fracture.



Conclusion: management with a semi-rigid collar in older people with type II odontoid fracture is safe and associated with low levels of pain and disability without statistically significant differences (incl. length of survival) between those demonstrating osseous-union or stable or unstable nonunions – C1-2 fusion may not be necessary for patients who fail to achieve union through conservative management!

(e.g. only 25% of UK surgeons advocating surgical management in older patients with nonunion)

- A. **C1-2 FUSION** via **posterior approach**: see technical details at p. Op210 >>
- C1 and C2 screws**; if C2 posterior elements are fractured – add **C3** (same with C1 – add occiput);
 - quick alternative - **wiring** between C₁ lamina and C₂ spinous process + iliac **grafts** or methylmethacrylate (between decorticated spinous processes); (historical - fixation with Halifax clamps – poor results)
 - transarticular C1-2 screws** - no longer popular alternative

There studies showing that for odontoid fractures with intact transverse ligament, **C1-2 temporary fixation (without fusion)** has same odontoid healing rates but **better functional outcomes** than **C1-2 fusion**

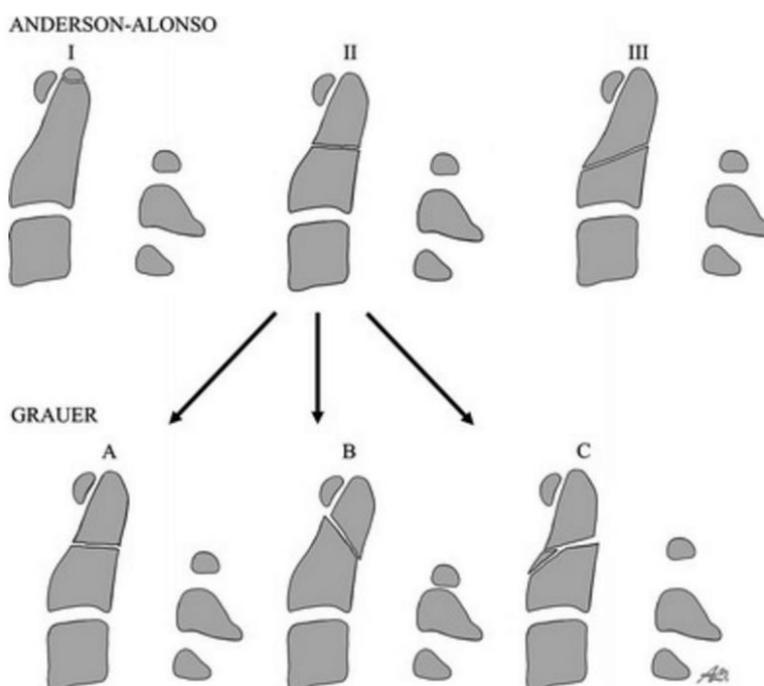
Guo QI et al. Comparison of Clinical Outcomes of Posterior C1-C2 Temporary Fixation Without Fusion and C1-C2 Fusion for Fresh Odontoid Fractures. Neurosurgery. 2016 Jan;78(1):77-83.

- B. **ODONTOID SCREW** via **anterolateral approach** (preserves rotation motion!); high fusion rates (87-100%)* if performed **during first 6 weeks after fracture** – odontoid screw works best if placed early!
 see technical details at p. Op210 >>
 *fusion rates in elderly may be as low as 60% (same as with halo) – age is important factor but not all studies agree with that (plus, fibrous union with radiographic stability may be a suitable outcome in elderly patients)

Contraindications: comminuted odontoid fracture, Grauer type IIC fracture, transverse ligament rupture, nonreducible fractures, nonunion persisting > 3 months, osteoporosis, barrel chest, short neck, severe thoracic kyphosis

Grauer treatment-oriented subclassification of type 2 dens fractures

Grauer IN, Shafi B, Hilibrand AS, et al. Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J. 2005; 5(2): 123-129



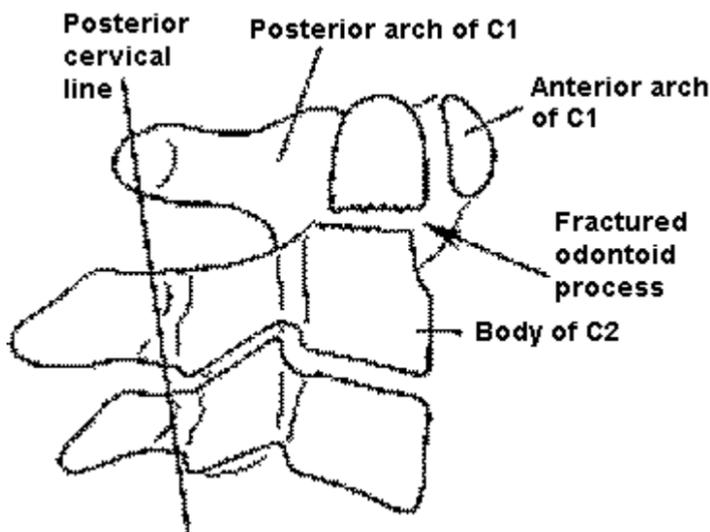
- Type IIA** - horizontal fracture pattern and < 1 mm of displacement → external immobilization
- Type IIB** - oblique fracture extending from the anterosuperior to the posteroinferior portion of the dens → anterior screw fixation
- Type IIC** - oblique fracture beginning anteroinferiorly and extending posterosuperiorly and associated with significant anterior comminution → posterior C1-2 fusion

TYPE 2 WITH TRANSVERSE LIGAMENT DISRUPTION

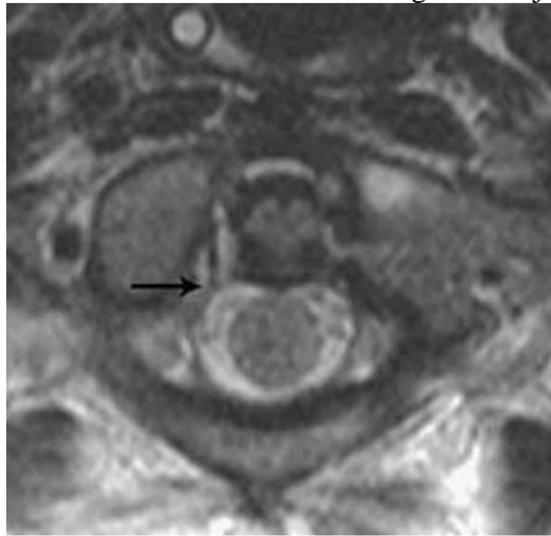
- (unstable because of transverse ligament disruption)
- a) transverse or alar ligament ruptures are uncommon unless there are predisposing factors (rheumatoid arthritis, posterior pharyngitis, ankylosing spondylitis, etc).
 - b) transverse ligament rupture (with intact odontoid) can cause immediate death from respiratory failure (cord compression between odontoid and posterior arch of C1).

Radiology

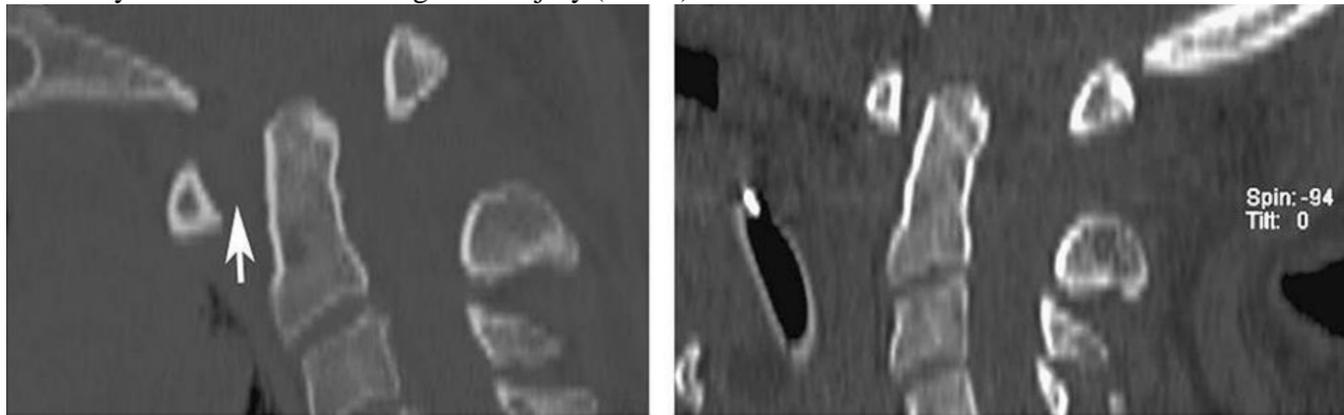
- i. predental (ADI) space ↑ see above >>
- ii. disrupted posterior cervical line
- iii. retropharyngeal swelling.



T2-MRI - traumatic transverse ligament injury (arrow):



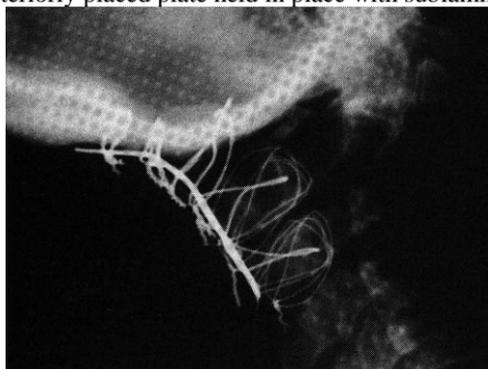
Flexion and extension dynamic CT - craniovertebral junction instability (atlanto-dens interval > 3 mm) caused by traumatic transverse ligament injury (arrow):



Treatment

– traction (with neck in extension) → C1-C2 fusion (as for type 2 odontoid fracture); odontoid screw is contraindicated in transverse ligament disruptions!

Fixation with posteriorly placed plate held in place with sublaminar and occipital wires:



- on occasion, reduction is impossible and odontoid must be removed by drilling (through transoral or anterolateral approach) → fusion.

TYPE 3

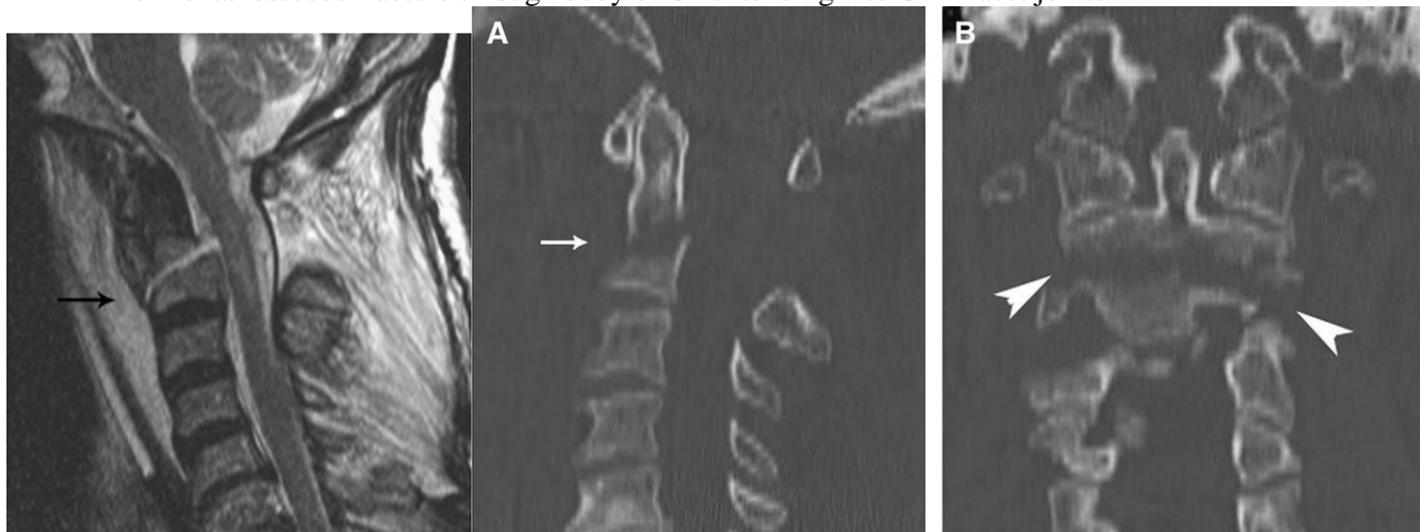
- fracture extending into body of C₂.



- treatment:
 - a) collar (fails in 35-50% cases).
 - b) halo vest (fails in 1-16% cases)

TYPE 3A

- horizontal osseous fracture through body of C₂ extending into C1-2 facet joints:



- associated with circumferential (atlantoaxial ligament, tectorial membrane, interspinous and capsular joints) ligament avulsion - **highly unstable!!!**
- described by Jea et al.

Jea A, Tatsui C, Farhat H, Vanni S, Levi AD. Vertically unstable type III Odontoid fractures: case report. Neurosurgery. 2006;58(4):797-798

OS ODONTOIDEUM

Definition - ossicle with smooth circumferential cortical margins representing odontoid process that has no osseous continuity with body of C₂.

Etiology - remains debated in the literature with evidence for both acquired and congenital causes.

Clinical features:

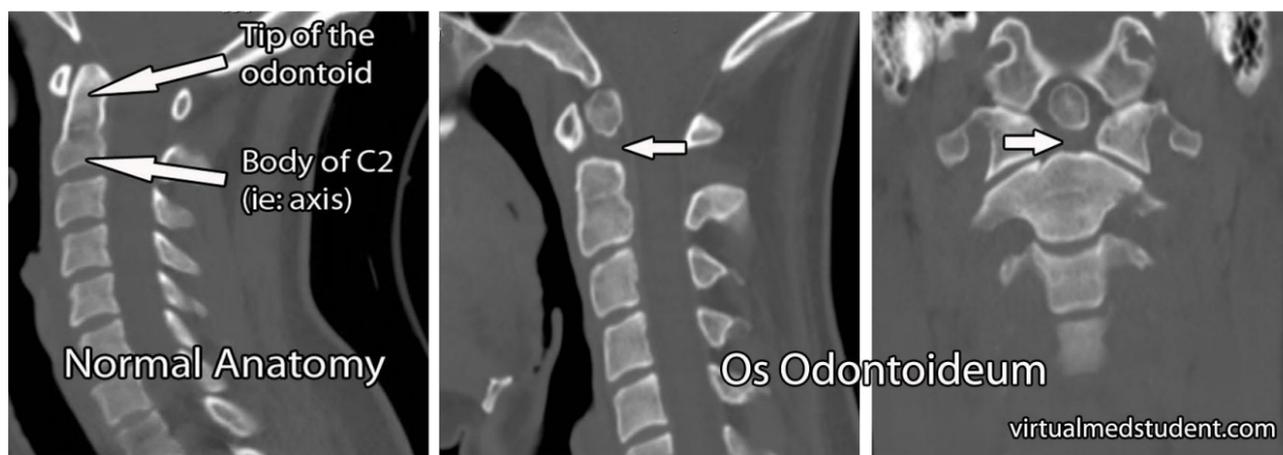
- 1) **occipital-cervical pain**
- 2) **myelopathy** - transient (commonly after trauma), static, or progressive.
- 3) **vertebrobasilar ischemia**
 - **sudden spinal cord injury** in association with os odontoideum after minor trauma have been reported.

Evaluation – flexion-extension lateral XR.

- most often, there is **anterior instability**, with os odontoideum translating forward in relation to body of C₂.
- at times, one will see either **no discernible instability** or “**posterior instability**” with os odontoideum moving posteriorly into spinal canal during neck extension.
- **degree of C1-C2 instability** on XR does not correlate with presence of myelopathy; **sagittal diameter of spinal canal at C1-C2 level < 13 mm** does correlate with myelopathy detected on clinical examination.

Classification - 2 anatomic types:

- Orthotopic** - ossicle that moves with anterior arch of C1.
- Dystopic** - ossicle that is functionally fused to basion; dystopic os odontoideum may sublux anterior to arch.



Management – indications for surgery:

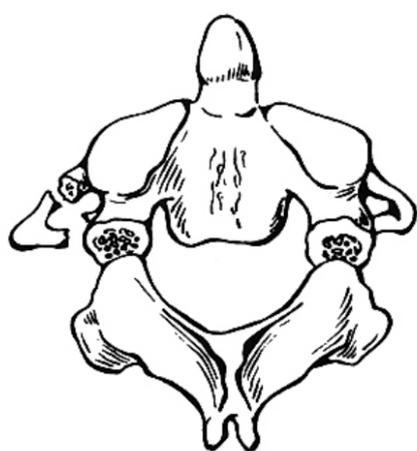
- 1) neurological symptoms → **C1-2 fusion**
- 2) irreducible DORSAL* cervicomedullary compression → **occipital-cervical fusion ± C1 laminectomy**
- 3) associated occipital-atlantal instability → **occipital-cervical fusion ± C1 laminectomy**
 *vs. irreducible VENTRAL cervicomedullary compression → **ventral decompression.**

N.B. odontoid screw fixation has no role!

HANGMAN’S fracture (s. TRAUMATIC SPONDYLOLYSIS of C₂)

(unstable - but **cord damage is rare** because AP diameter of neural canal is greatest at C₂ level and because bilateral pedicular fractures permit spinal canal to decompress itself with forward displacement of C₂ body)

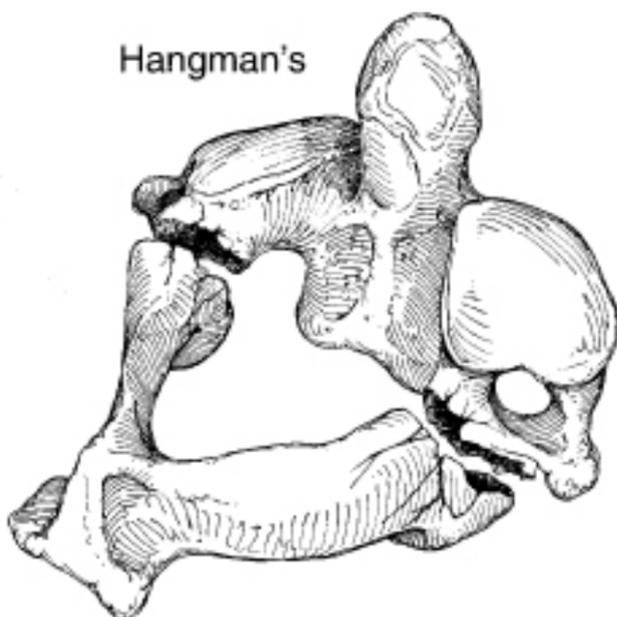
- abrupt deceleration (e.g. hanging with knot in submental position, striking chin on steering wheel in head-on automobile crash) → **cervicocranium** (skull, atlas, and axis functioning as unit) is thrown **into extreme hyperextension** → **bilateral pedicle fractures of axis** (± broken subjacent disc bond → forward subluxation of C₂ on C₃).
- cervical spine / spinal cord damage happens in only those hangings that involve fall from distance greater than body height.



Potential dislocation:



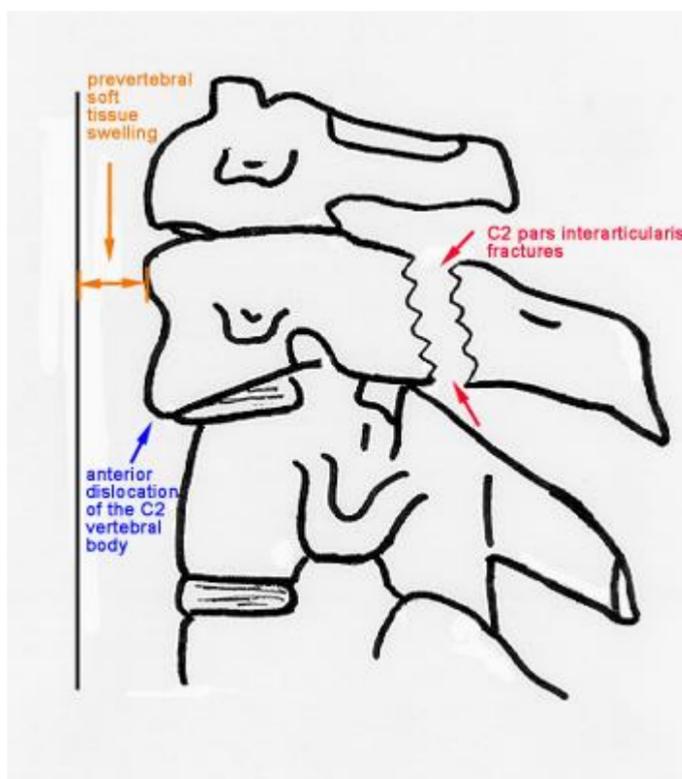
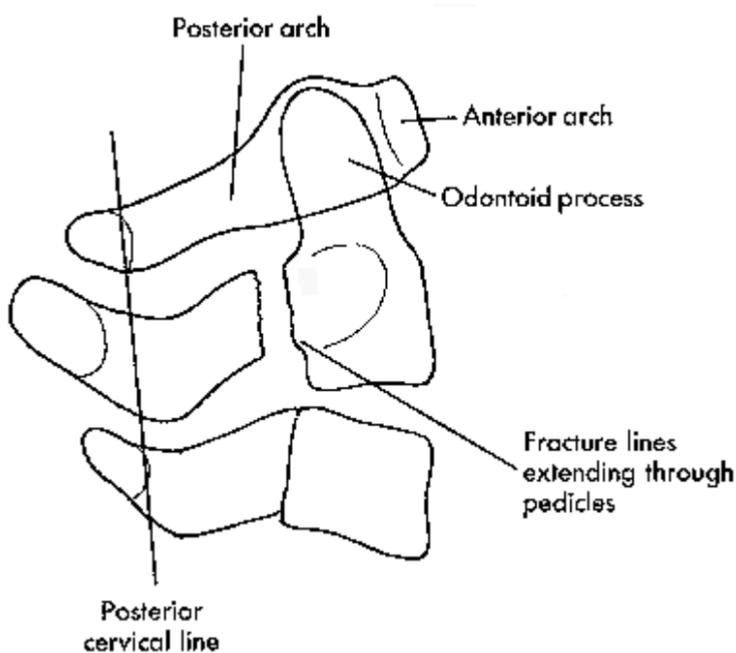
Hangman's



Copyright © 2004

RADIOLOGY

- 1) fracture lines extending through pedicles of C₂ (i.e. anterior to inferior articular facets).
- 2) disrupted **posterior cervical line** (base of C₂ spinous process lies > 2 mm behind posterior cervical line).
- 3) prevertebral swelling (may cause respiratory obstruction!).



CLASSIFICATION AND TREATMENT

Effendi classification:

Fractures of the Ring of the Axis: A Classification Based on the Analysis of 131 Cases. Effendi B, Roy D, Cornish B, Dussault RG, Laurin CA. JBJS 63-B(3):319-327, 1981



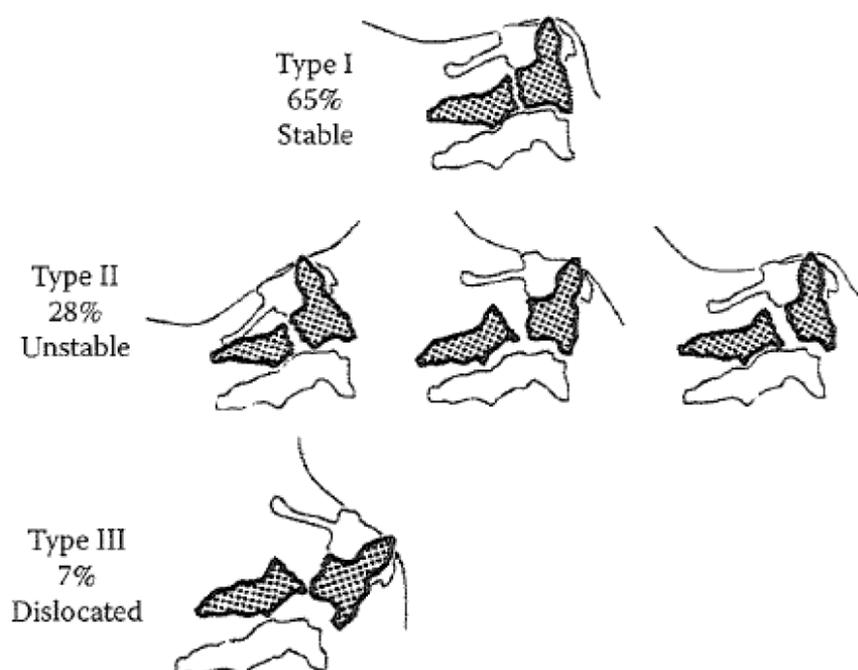
Effendi Typ I
AO 50-B1.1



Typ II
AO 50-B1.2



Typ III
AO 50-B1.1



Type I (stable): isolated hairline (< 1 mm) fracture of axis ring with minimal displacement of C2 body associated with axial loading and hyperextension → 6 weeks C-collar.

Type II (unstable): fractures of axis ring with **displacement** (> 1 mm) of anterior fragment with **disruption of disk space** below axis associated with hyperextension and rebound flexion → 12 weeks of halo → if instability on dynamic XR then add C2-3 fusion.

Type III (unstable): fractures of axis ring with displacement of axis body in flexed forward position (**angulation**), in conjunction with **C2-3 facet dislocation** associated with primary flexion and rebound extension → open reduction and C2-3 fusion → halo for 12 weeks.

Francis classification - grades of increasing severity of displacement and angulation of C2 on C3:

Grade I: fractures with 0-3.5-mm displacement and/or C2-3 angulation < 11°

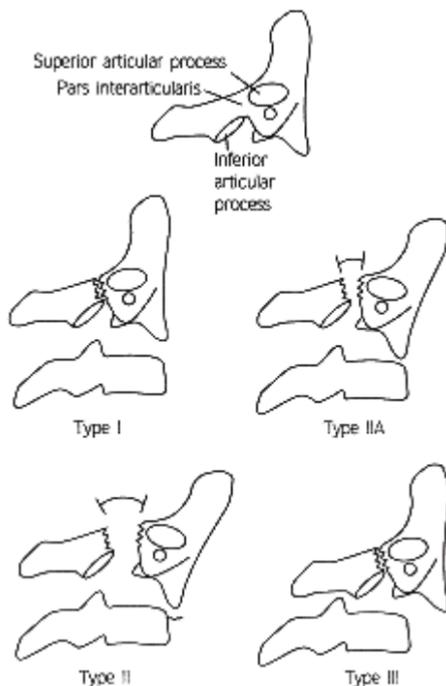
Grade II: fractures with displacement < 3.5 mm and angulation > 11°

Grade III: fractures with displacement > 3.5 mm but less than half of C3 vertebral width and angulation < 11°

Grade IV: fractures with displacement > 3.5 mm but less than half of C3 vertebral width with angulation > 11°

Grade V: fractures with complete C2-3 disk disruption.

Levine and Edwards classification (modification of Effendi classification with added flexion-distraction as a mechanism of injury (type IIA)):



type 1 (stable) - hyperextension and axial loading → C2/3 disc remains intact (stable) – **no change in anatomy**: insignificant displacement (< 3 mm horizontal displacement) or angulation.

Treatment: **rigid cervical collar** / **occipital-mandibular brace** for 4-12 weeks

type 2 - initial hyperextension and axial loading followed by hyperflexion → C2/3 disc and PLL are **disrupted** with vertical fracture line (unstable): **significant horizontal translation (> 3 mm) and angulation (> 11°)**

Treatment:

< 5 mm displacement → reduction with traction + **halo** for 6-12 weeks.

> 5 mm displacement → consider **surgery** or **prolonged traction**.

Usually heal despite displacement (autofuse C2 on C3).

type 2A - results from flexion-distraction → horizontal fracture line: **no translation but severe angulation (> 11°)**

Treatment: reduction with hyperextension + **halo** immobilization for 6-12 weeks. Avoid traction! (*type 2A fractures experience increased displacement in traction but are reduced with gentle extension and compression in halo vest*)

type 3 (grossly unstable) - results from flexion-compression → Type I fracture with **unilateral or bilateral C2-3 facet dislocations**.

Treatment: **surgery** - reduction of facet dislocation followed by stabilization required.

N.B. **C2-3 disc disruption (C2 translation > 3 mm over C3) requires surgery**

- C2-3 ACDF – 100% fusion at 6 months, helps to remove herniated disc fragments but risk of dysphagia (dissect neck tissues well and avoid too much traction).
- C1-3 PCF – helps to achieve facet reduction directly but risk of vertebral artery injury.

- union occurs within ≈ 3 months, with spontaneous anterior interbody fusion.



Resume - indications for surgery (anterior or posterior C2-3 fusion):

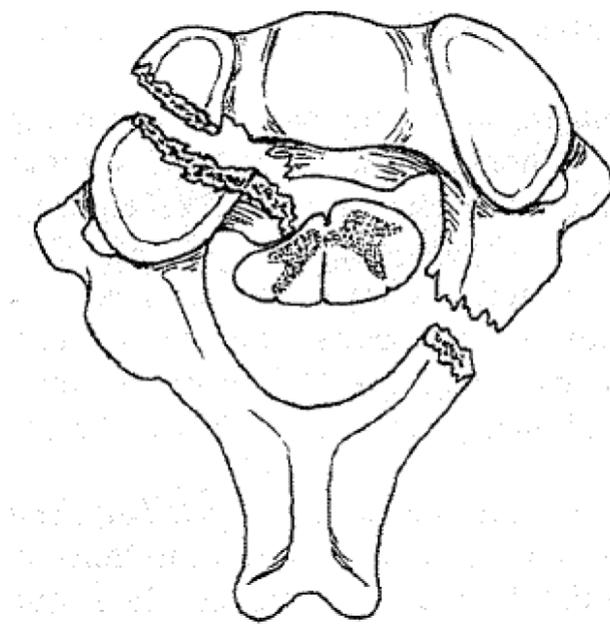
- severe **angulation** (Francis grade II and IV, Effendi type II)
- severe (> 5 mm) **translation**
- C2-3 **disc disruption** (C2 translation > 3 mm over C3) (Francis grade V, Effendi type III)
- facet **dislocations**
- failure of external immobilization** - inability to achieve or maintain fracture alignment.

FRACTURES OF AXIS BODY

comminuted fracture – evaluate for vertebral artery injury.

Fractures of the ring of the axis are typically associated with low rates of neurological injury as displacement of most fracture patterns results in spinal canal expansion;

- fractures involving the posterior cortex of C2, when accompanied by translation, can result in canal compression causing neurological dysfunction:



TREATMENT

- **external immobilization.**

- indications for surgery:
 - severe ligamentous disruption
 - inability to achieve or maintain fracture alignment with external immobilization.

COMBINED C1-C2 FRACTURES

- increased incidence of neurological deficit compared with either isolated C1 or isolated C2 fractures.
- management decisions must be based on characteristics of axis fracture.
- historically, as proposed by Levine and Edwards, combination fractures of C1 and C2 have been managed sequentially, allowing 1 fracture to heal (usually atlas) before attempting definitive management of axis injury.
- rigid external immobilization** is typically recommended as initial management for majority of patients
- modern approach:
 - atlas fractures in combination with type II or III odontoid fractures with **atlantoaxial interval > 5 mm** → early surgical management
 - atlas fractures in combination with Hangman fracture with **C2-C3 angulation > 11°** → surgical stabilization and fusion
- surgical options:
 - posterior C1-2 internal fixation and fusion
 - combined anterior odontoid and C1-2 transarticular screw fixation with fusion.

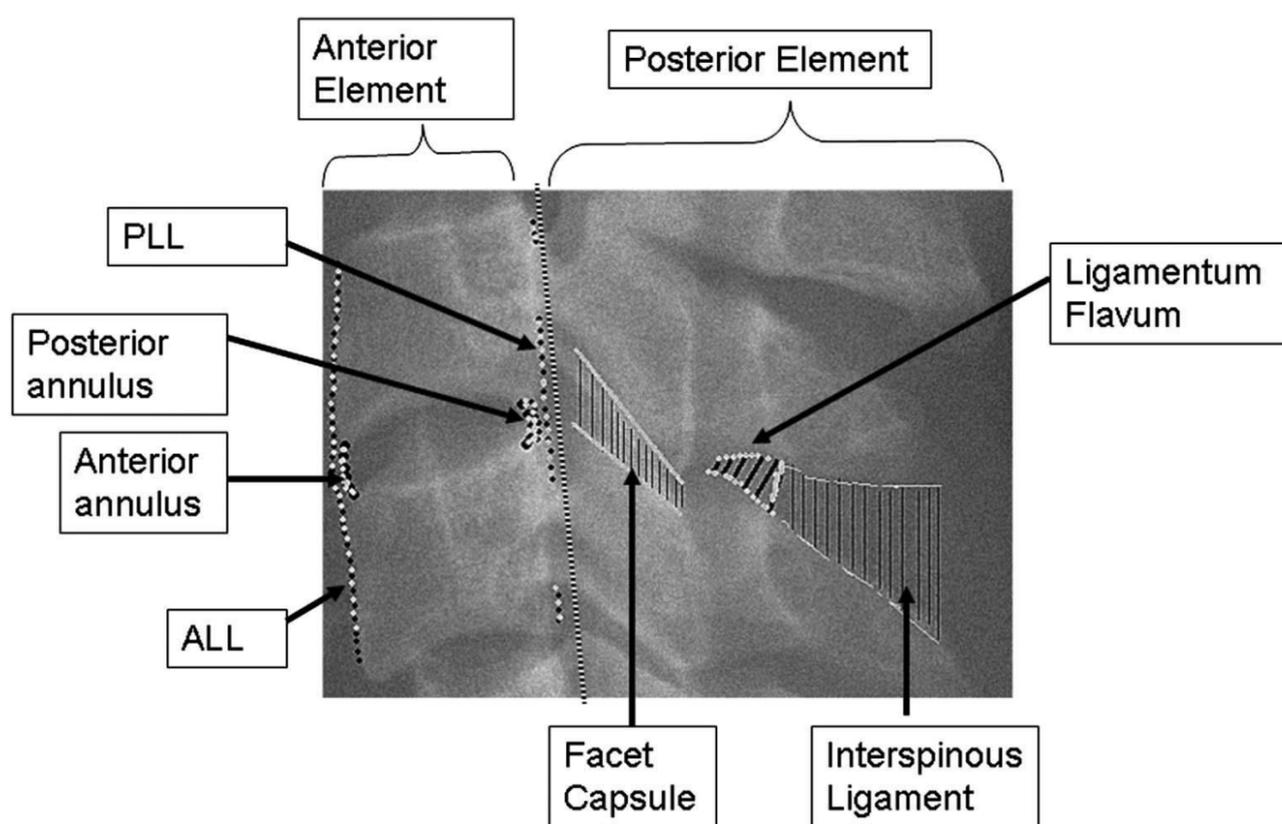
CERVICAL SPINE (SUBAXIAL)

Specificities for ANKYLOSING SPONDYLITIS

- see p. Op210 >>

BIOMECHANICS

Lateral cervical spine - anatomical location of main discoligamentous structures contributing to physiological stability of a single motion segment:



CLASSIFICATIONS

SLIC (Subaxial Injury Classification) and CSISS (Cervical Spine Injury Severity Score) classifications are recommended (Level I)

SLIC (SUBAXIAL INJURY CLASSIFICATION)

by Vaccaro and Colleagues

Patel AA, Hurlbert RJ, Bono CM, Bessey JT, Yang N, Vaccaro AR. Classification and surgical decision making in acute subaxial cervical spine trauma. *Spine (Phila Pa 1976)*. 2010;35(21 suppl):S228-S234.

Vaccaro AR, Hurlbert RJ, Patel AA, et al; Spine Trauma Study Group. The subaxial cervical spine injury classification system: a novel approach to recognize the importance of morphology, neurology, and integrity of the disco-ligamentous complex. *Spine (Phila Pa 1976)*. 2007;32(21):2365-2374.

MORPHOLOGY	
No abnormality	0
Compression	1
Burst	+1 = 2
Distraction (facet perch, hyperextension)	3
Rotation/translation (facet dislocation, unstable teardrop or advanced stage flexion compression injury)	4
DISCO-LIGAMENOUS COMPLEX (DLC)	
Intact	0
Indeterminate (isolated interspinous widening. MRI signal change only)	1
Disrupted (widening of disc space, facet perch or dislocation)	2
NEUROLOGICAL STATUS	
Intact 0	0
Root injury 1	1
Complete cord injury 2	2
Incomplete cord injury 3	3
Continuous cord compression in setting of neurological deficit (NeuroModifier)	+1 = 1

Signs of major **disruption of anterior or posterior ligamentous complex**:

- Horizontal sagittal plane translation > 3.5 mm (or > 20% of AP diameter of involved vertebrae)
- Sagittal plane rotation (angulation) > 11 degrees

CT evidence of **facet joint disruption**:

- articular apposition < 50%
- diastasis > 2 mm through facet joint

SLIC scores:

- 1-3 → non-surgical management
- ≥ 5 → surgical fixation.
- 4 → either non-operative or operative approach.

TREATMENT PRINCIPLES

- decompression /restoration** of spinal canal is the goal.
- internal fixation** or **external immobilization** is recommended (to allow for early mobilization and rehabilitation); **failure rates**:
 - internal fixation – 9%
 - external immobilization only (traction or orthosis) - 30%; risk factors: **vertebral compression ≥ 40%, kyphosis ≥ 15%, vertebral subluxation ≥ 20%**
- either **anterior** or **posterior** fixation and fusion is acceptable in patients not requiring particular surgical approach for decompression of spinal cord;
 - complication rates**:
 - anterior fusion – 9%
 - posterior fusion** – 37%
 - advantages**:
 - anterior approach - safe and straightforward patient positioning (no need to turn patient prone with potential of unstable injury), dissection along defined tissue planes with little if any iatrogenic muscle injury.
 - posterior approach - superior biomechanics, straightforward reduction of facet dislocations.
- prolonged bed rest in traction** is recommended if more contemporary treatment options are not available.

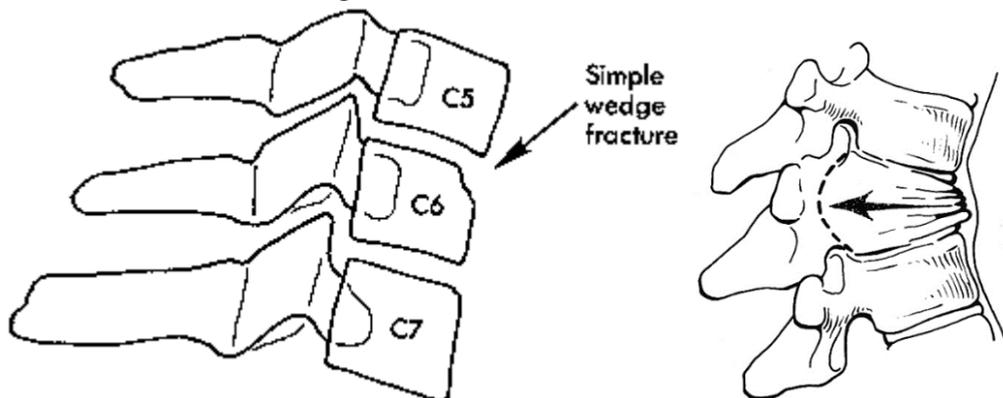
COMPRESSION (WEDGE) FRACTURE

- (mechanically stable - intact posterior column)
 - during flexion, longitudinal **pull is exerted on strong posterior ligaments** (tolerate longitudinal pull very well - usually remain intact) → **most of force is expended on vertebral body anteriorly** → **simple wedge fracture**.
- fragment of posterior vertebral body may be displaced into spinal canal.

RADIOLOGY

- anterior border of vertebral body - decreased height (> 3 mm than posterior border) and increased concavity.
- increased density of vertebral body resulting from bony impaction.

- 3) slight separation of spinous processes (exaggerated in flexion films)
- 4) prevertebral soft-tissue swelling.



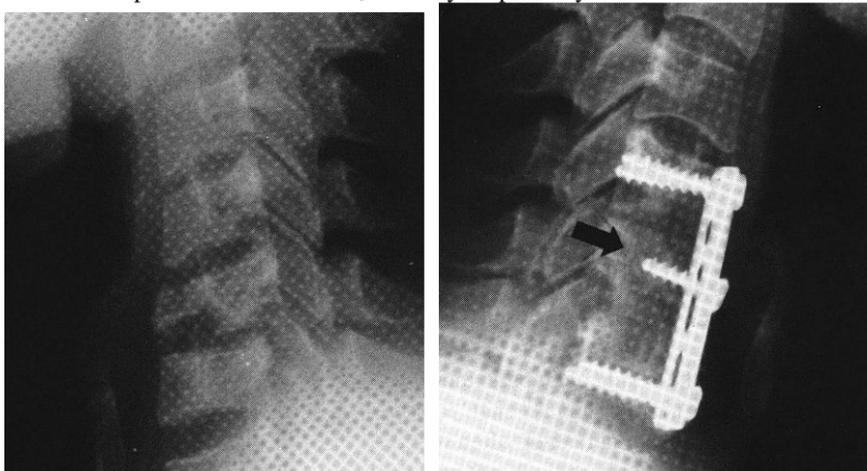
Reconstructed sagittal CT - compression of anterior element and failure of middle element (displacement of superior posterior lip of vertebral body into spinal canal):



TREATMENT

- a) wedge fractures (not associated with neurologic impairment / additional radiographic abnormalities) can be managed on *OUTPATIENT* basis with **orthosis** (soft or hard cervical collar).
- b) **bone / disk impingement** on spinal canal → **decompression** via anterior approach (corpectomy);

Flexion compression fracture of C5 fixed by corpectomy and fusion maintained with Caspar plate:



- c) **injury to posterior ligaments** can be fixed with **Halifax clamps** and fusion:



BURST FRACTURE OF VERTEBRAL BODY

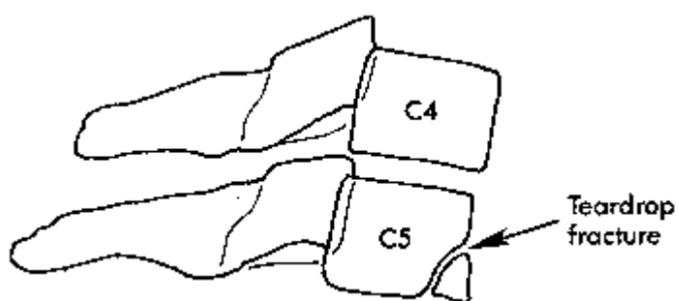
see THORACOLUMBAR >>

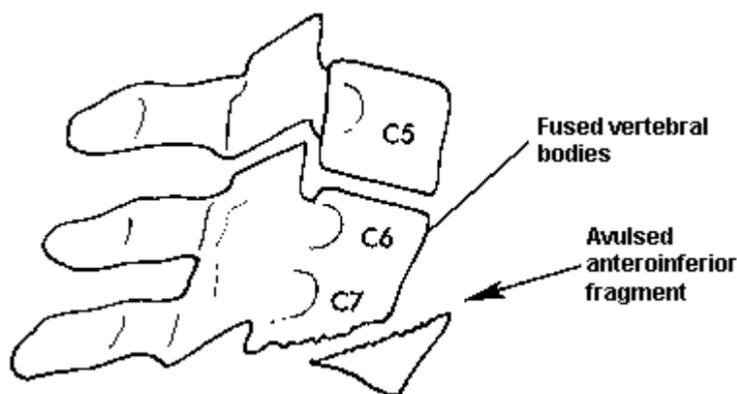
TEARDROP FRACTURE

Teardrop fracture is marker of **potential for high instability** (may be stable or highly unstable)

Two trauma mechanisms:

- A. **Flexion** (+ vertical compression) force fractures (bursts!*) vertebral body - wedge-shaped fragment (resembles teardrop) of **anteroinferior portion of vertebral body** is displaced anteriorly (indicates anterior longitudinal ligament disruption); at same time posterior ligamentous disruption happens (± posterior column fracture – rest of vertebral body may be posteriorly dislocated) - disruption of all 3 columns → **frequent neurologic damage**.
- B. Forced abrupt **extension** (e.g. diving accidents) → dense anterior longitudinal ligament pulls anteroinferior corner of vertebral body away from remainder of vertebra → classic innocent-appearing triangular-shaped fracture (true avulsion); no subluxation!!! (vs. flexion teardrop fracture) but anterior ligament may be disrupted (stable in flexion; highly unstable in extension)
 - often occurs in **lower cervical vertebrae** (C5-C7).





Diagnostic work up – flexion-extension XR to document stability

Management

- a) no ligamentous damage – cervical collar for 3-4 months
- b) ligamentous damage – surgical fusion

DISTRACTIVE EXTENSION INJURY

- rarely demonstrates significant damage by X-ray:



ANTERIOR SUBLUXATION

(stable in extension but potentially unstable in flexion)

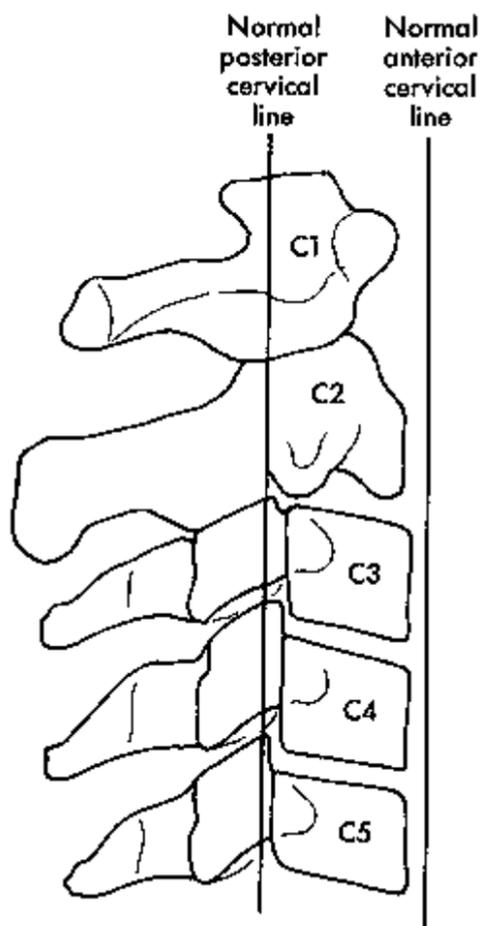
- posterior ligamentous rupture without bony fracture.

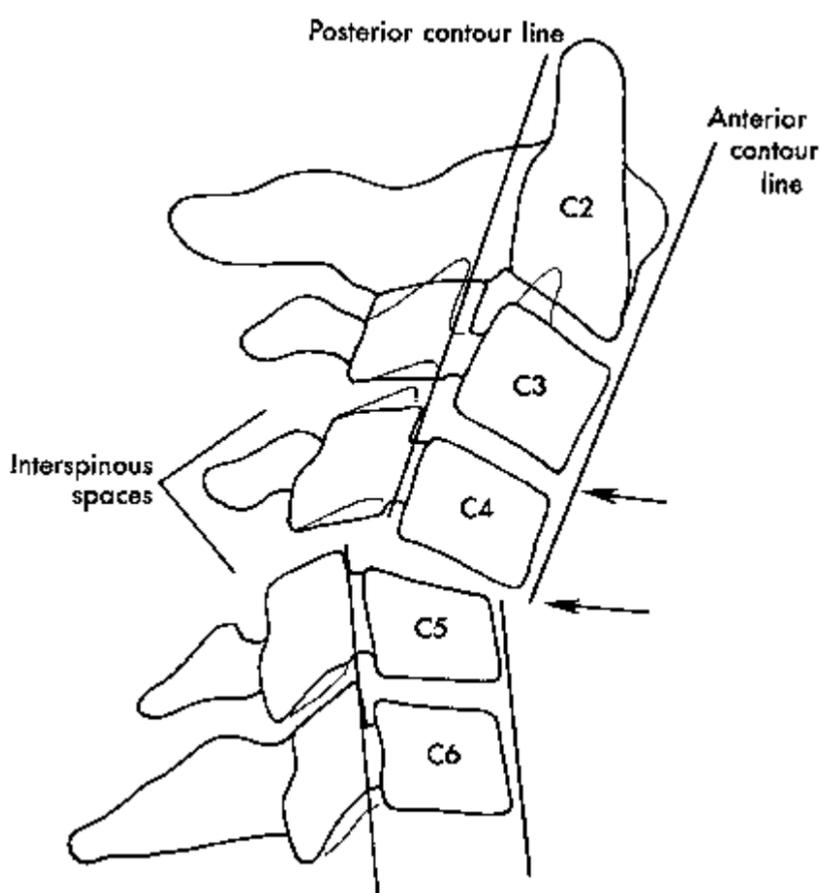
- injury begins posteriorly in nuchal ligament and proceeds anterior to involve other ligaments to varying extent.
- anterior longitudinal ligament (anterior column) remains intact - rare neurologic sequelae.
N.B. significant displacement can occur with flexion → very rare cases of neurologic deficit!

RADIOLOGY

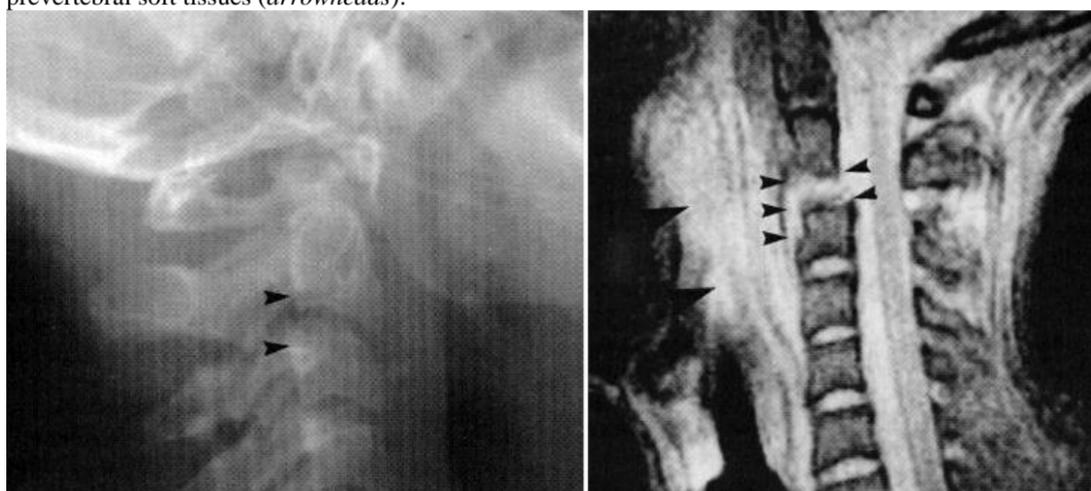
– in order of evaluation:

1. LATERAL RADIOGRAPH (neck in neutral position) - subtle findings (often missed if flexion / extension views are not obtained):
 - widening of interspinous space
 - gapping of intervertebral space posteriorly.
2. OBLIQUE VIEWS - widening or abnormal alignment of facets.
3. LATERAL RADIOGRAPH (flexion / extension views - risk of causing neurologic injury!!! – perform only if above views cannot confirm subluxation) - disrupted anterior and posterior contour lines.
4. MRI can visualize ligaments





A. Lateral cervical X-ray - prevertebral soft tissue swelling and slight C2 subluxation over C3 (arrow).
 B. Sagittal T2-MRI demonstrates ligamentous disruption (double arrows) with blood tracking along both ligaments and prevertebral soft tissues (arrowheads):



C4-C5 fracture subluxation (MRI) - 50% anterolisthesis of C4 on C5; fracture of posterior C4 vertebral body; interruption of normally black anterior longitudinal ligament at C4-C5 disc space; bright signal in spinal cord is combination of edema and hemorrhage.

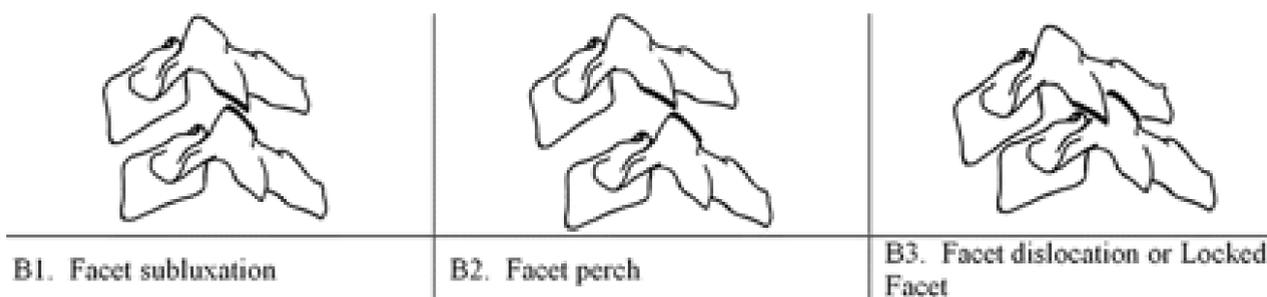


FACET SUBLUXATION / PERCH / DISLOCATION

UNILATERAL

(stable)

- **rotation** about one of facet joints (acts as fulcrum) + simultaneous **flexion** → contralateral facet joint dislocates with superior facet riding forward and over tip of inferior facet and coming to rest within intervertebral foramen (*mechanically locked* in place - stable injury even though posterior ligament complex is disrupted).
- neurologic deficits are rare.



BILATERAL

(always unstable)

- **extreme form of anterior subluxation**: flexion (± axial distraction) causes soft-tissue disruption to continue anteriorly to involve **annulus fibrosus** and **anterior longitudinal ligament**; forward movement of spine causes inferior articulating facets to pass upward and over superior facets of lower vertebra (anterior displacement of spine above level of injury).
- high incidence of **spinal cord injury!!!**

High level of suspicion for vertebral artery injury (esp. in bilateral jumped facets) – consider **vascular imaging** (CTA or MRA)!

RADIOLOGY

UNILATERAL

Plain films

AP view - disrupted line bisecting spinous processes, asymmetry of uncovertebral joints.

Lateral view:

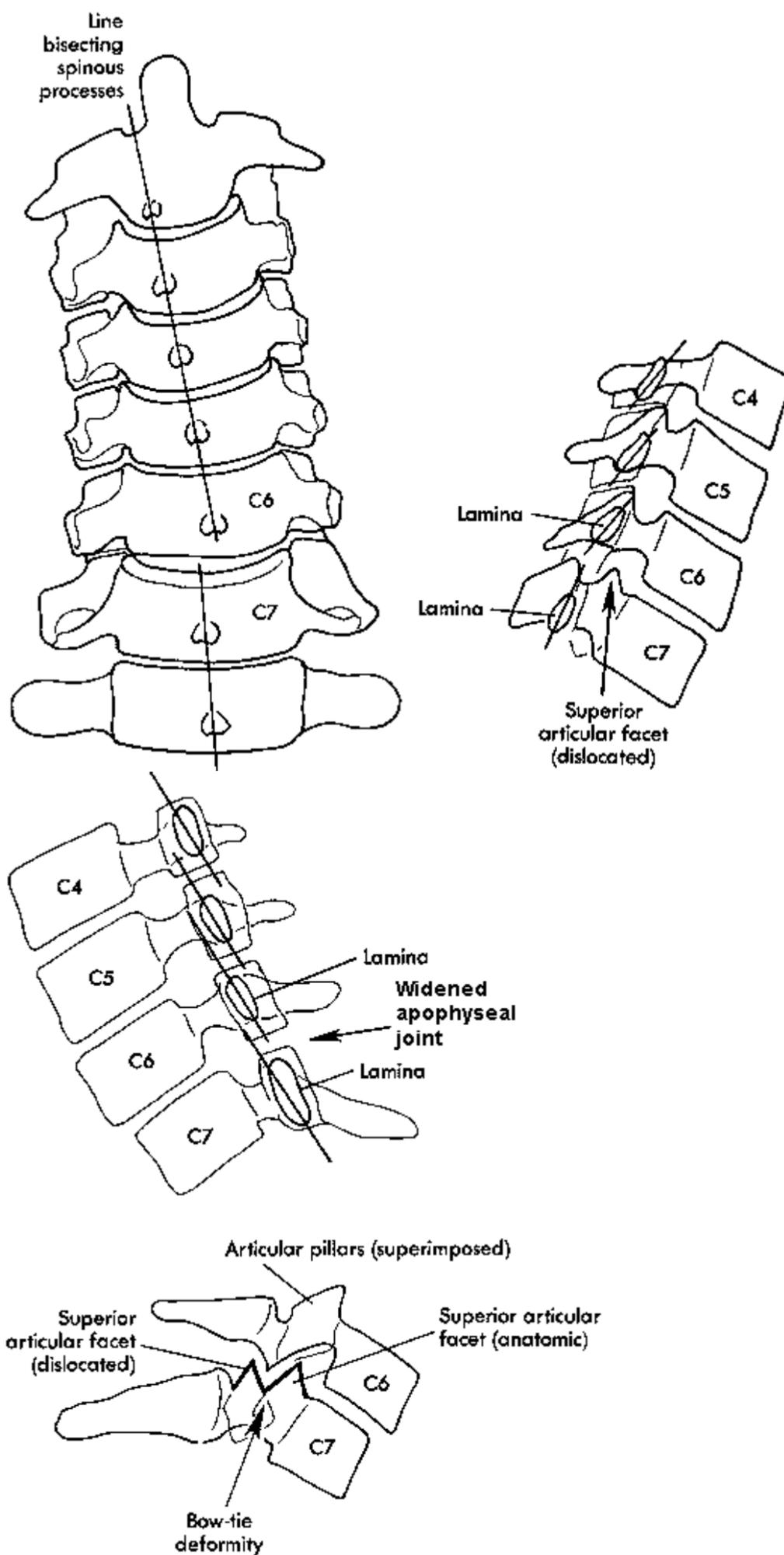
- 1) dislocated superior articulating facet forms **"bow tie" deformity** with nondislocated superior articulating facet.

- 2) upper vertebral body is anteriorly **subluxed / anterolisthesis** ($\leq 25\%$ of AP diameter of vertebral body; vs. $\geq 50\%$ in bilateral facet dislocations).

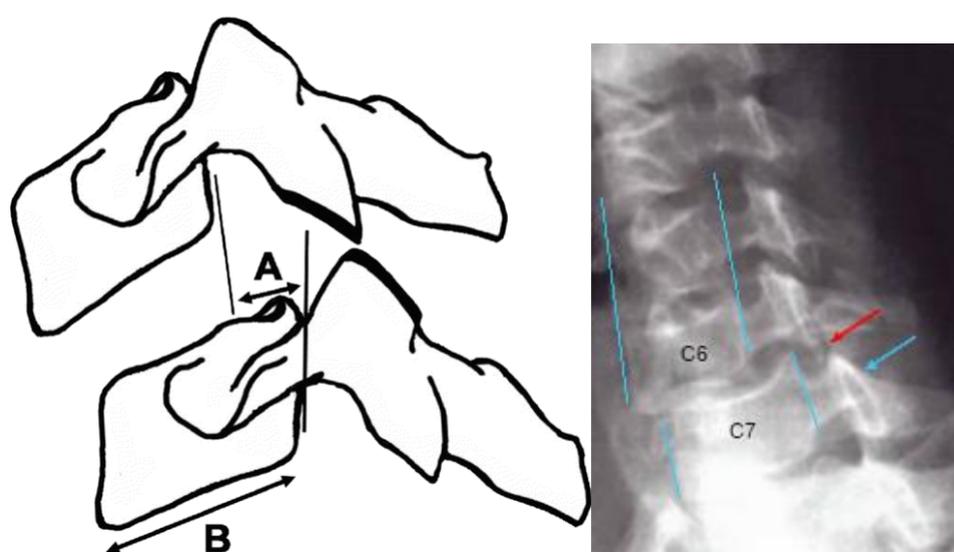
Oblique view:

- 1) superior articulating facet projects within neural foramen.
- 2) expected tiling of laminae is disrupted.
- 3) widening of apophyseal joint (may be strongest differentiation from torticollis!).

CT – “empty facet” sign.



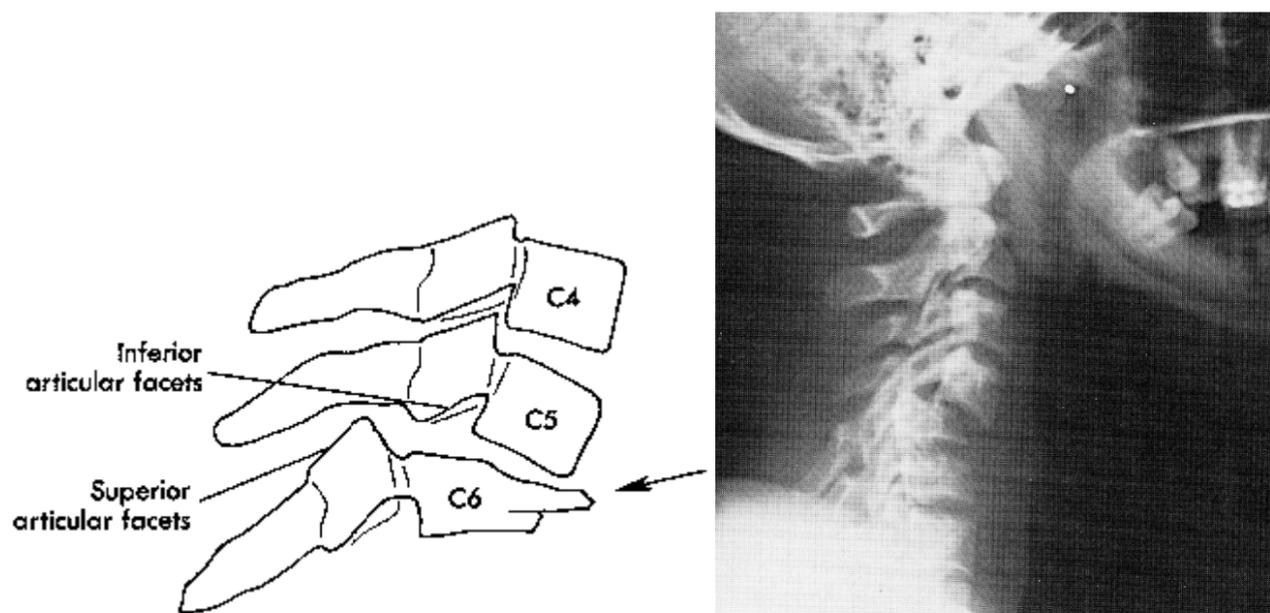
PERCHED FACET



BILATERAL

LATERAL view - vertebral body subluxed anteriorly with **displacement greater than 1/2 of AP diameter** of lower vertebral body; lower vertebral body may be compressed.

AP view - widening of intervertebral disc space at joint of Luschka.



TREATMENT

- keep in C-collar until reduction attempts.
- reduction is safest in **cooperative examinable patient** – therefore is best with skeletal traction.
- reduction under anesthesia is less safe (at least use monitoring).
- **jumped facets**:
 - intact patient → MRI → closed reduction* → **ACDF**
 - SCI, cooperative patient → closed reduction* → MRI → **ACDF**

N.B. it is too easy to oversize ACDF graft due to facet injury – be cautious! Also chances of CSF leak (use dural sealant and HOB up postop)

*if unsuccessful, proceed with open reduction via posterior approach (drill off facet) → **PCF**; some experts recommend **360 fusion** for bilateral jumped facets

CLOSED REDUCTION WITH SKELETAL TRACTION

- prior to attempted reduction ensure that diagnosis is correct;
 - pure cervical distraction injuries** (at first glance can resemble facet dislocation) - should not be managed traction since this would be expected to only worsen the injury.
- alert and cooperative patient → immediate reduction w/o MRI;
 - N.B. some experts recommend **MRI before reduction or operative intervention** is attempted - significant number of bilateral facet dislocations are accompanied by **disk herniation*** - catastrophic compression of spinal cord may occur if injured disk retropulses during cervical traction! (monitor reposition clinically)
 - *in this case, consider ACDF followed by posterior fusion;
- patient must be admitted to ICU with one to one nursing care to monitor his neurologic status preferably when patient is awake and alert.

N.B. prior to traction / operative manipulation on obtunded patient, ensure (e.g. with MRI) that no concomitant **disc rupture** has occurred (present in 30-50% patients with fracture dislocation); if yes → perform discectomy first! (otherwise, increased neurological deficits can result during manipulations).

N.B. prerotation MRI is not necessary if patient is awake and can be examined during reduction and traction application.

Fragment posteriorly – careful with closed reduction (might be OK in awake cooperative patient but avoid manipulative reduction, just let weight to do its job), do not do posterior approach but proceed with ACDF with discectomy, then reduction:



Methods of traction

- TONGS** (Gardner-Wells tongs, Crutchfield tongs) – 2 screws into outer table of skull. see p. TrS5 >>
- HALO** fixation – 4-6 screws; very rigid external immobilization; may be used for *cervical traction* in recumbent position or *attached to body jacket* lined with sheepskin (patient may be ambulatory in halo cast or vest). see p. TrS5 >>>
- sterilized **FISH HOOKS** applied to posterior zygomas - for patients with severe skull injuries.

Traction Force (needed amount is variable) - weight is added incrementally, X-rays being made after each addition

begin with: 10 lbs is added for occiput; additional 5 lbs for each vertebra to level of injury (but begin with < 20 lbs)

re-evaluation: after placement of weight, check lateral X-ray & full neuro exam; if reduction does not occur, weight is then **added in 5 lbs increments, in approximate half hour intervals**, being certain to repeat lateral X-ray and neuro exam after each weight increase.

max amount of traction weight that can be applied safely is unknown (up to one third of body weight may be required; reports include up to 60-75 lbs)

up to 20 lbs can be applied to C1 & C2;

up to 50 lbs can be applied in lower cervical region (C3-C7)

- **weights** aid in spinal realignment:

Rule of thumb - **5 pounds (2,25 kg) for each cervical level** is required for reduction

(e.g. to reduce C₅ dislocation – start with 25 pounds; if insufficient, additional weight increments are applied every 20-30 minutes until reduction is attained).

- weight is increased by 5-pound increments.
 - in routine clinical practice (especially for injuries such as bilateral facet dislocations) weights in excess of 50 pounds may be necessary to achieve reduction.
 - maximal weight that can be safely applied to Gardner-Wells tongs is 80-90 pounds (36-40 kg) or 2/3 of body weight.
- head of bed elevated enough to counter weight of traction.
 - traction is best accomplished in rotating bed* (to minimize risks of decubiti and to help mobilize respiratory secretions). *e.g. RotoRest

During traction

- when traction is applied, patient is **continually monitored** (radiographically and clinically) for reduction success - overdistracted may cause cranial nerve deficits or neurological worsening.
- **muscle relaxants** (e.g. scheduled **DIAZEPAM**) - reduce spasm, which may inhibit reduction efforts.

If reduction is achieved → traction weight is reduced to 20 lbs (9.1 kg) or less to maintain alignment (redislocation is prevented with moderate cervical extension)

- some experts would apply **halo**, others would go to **ACDF** (esp. with bilateral facet dislocation – all ligaments and disc are disrupted – will not heal without arthrodesis).

If reduction does not occur, closed reduction attempts are discontinued when:

- > 1 cm of distraction occurs at site of injury
 - maximum amount of weight is applied
 - neurological status deteriorates
 - unsuccessful reduction by 3-6 hrs after trauma with neurological deficit present
- proceed to MRI → open reduction in OR

- if reduction is not achieved, **bony or soft tissue interposition** should be suspected.

OPEN REDUCTION

First try to reduce manually after patient is under general anesthesia and complete paralysis (remove C-collar and apply Holter traction* in preparation for ACDF):

*may have halo crown ready in OR in case will need more manipulation

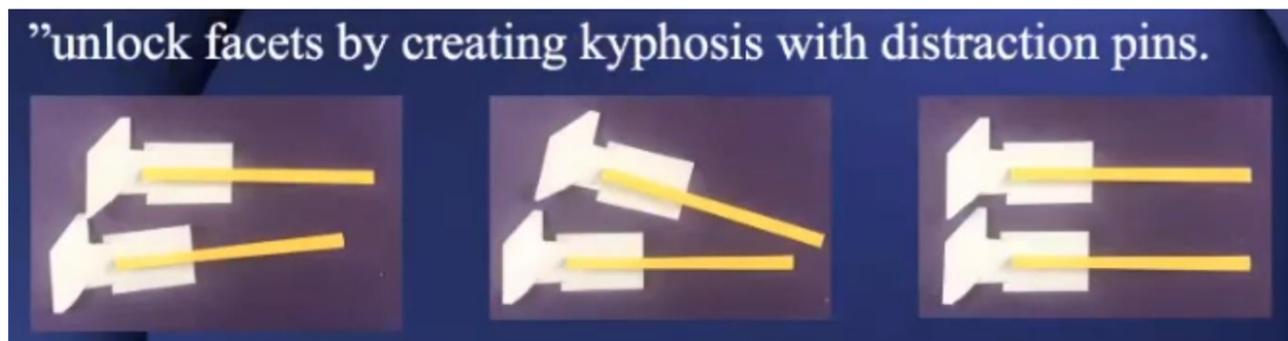
- under live fluoroscopy: apply axial traction and gentle neck flexion (lever action allows superior facet to go over the top of inferior facet) → maintain traction and extend neck by gradually minimizing axial traction (superior facet lands behind inferior facet) → proceed to surgery (ACDF).

Surgical open reduction options:

- posterior approach** is gold standard for straightforward open reduction of facet dislocations; some experts would use **pedicle screws** to gain more strength:



- ACDF** to reduce dislocation and open foramen (going from posterior cannot place pedicle screw because of fracture; would need screws level above and level below); some experts think it is equally acceptable alternative to posterior approach:



- some experts recommend **360° fusion** for bilateral facet dislocations (alternative – after ACDF, flex neck and do XR – if spinous process space widens, add PCF; if not – keep in C-collar)

FACET FRACTURE

- unilateral – may cause subluxation up to 25%
- bilateral – may cause subluxation up to 50%

TREATMENT

- if no subluxation or nerve root dysfunction → **C-collar** with XR in collar and then follow up in 2 weeks – if subluxation or nerve root dysfunction (that happens quite often) → one-level **ACDF**.

Cervical subaxial nondisplaced unilateral facet fractures

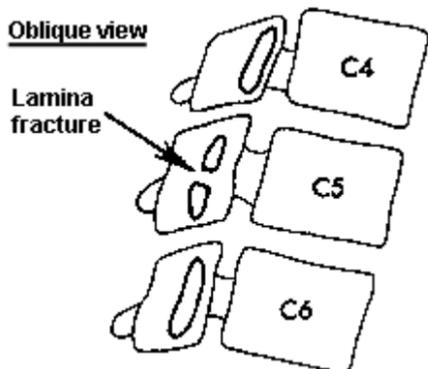
Vedantam A et al. Management of Acute Unilateral Nondisplaced Subaxial Cervical Facet Fractures. Operative Neurosurgery, Volume 14, Issue 2, 1 February 2018, Pages 104–111

Facet fractures were classified:

- type A1 fractures: superior facet fracture of caudal vertebra
- type A2: inferior facet fracture of rostral vertebral
- type A3: floating lateral mass (fracture of pedicle and vertical lamina fracture).

- all patients were given a **trial** of hard cervical collar.
- mean **follow-up** was 2.7 ± 0.4 mo.
- outcome: nonoperative management was successful in 82.9% patients** (others developed instability requiring surgery); no significant association was found between the type of facet fracture and outcome (Fisher's exact test, P = 0.18).

LAMINA FRACTURE



- evidence of nerve root dysfunction → surgical decompression.

FRACTURE OF TRANSVERSE PROCESS

(stable)

- if above C7, need CTA to check for VA injury

CLAY SHOVELER'S FRACTURE

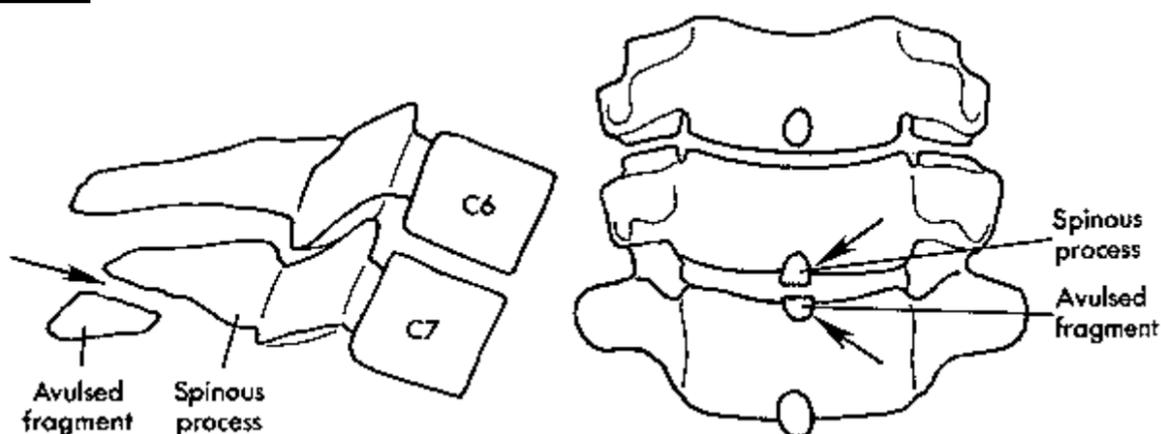
(mechanically stable)

- **oblique fracture of spinous process base** in one of lower cervical vertebrae.

- commonly occurred in **clay miners (Australia during 1930s)** - when miner lifted heavy shovelful of clay, abrupt flexion of his head, in opposition to stabilizing force of strong supraspinous ligament, resulted in spinous process avulsion.

H. **modern etiology:**

- direct trauma** to spinous process.
- forced neck flexion** (e.g. sudden deceleration in motor vehicle crashes, direct trauma to occiput).

RADIOLOGY**TREATMENT**

- as for cervical sprain - **soft orthosis** for comfort (2-3 months).

WHIPLASH INJURY (s. CERVICAL SPRAIN, HYPEREXTENSION INJURY)

- **cervical myofascial injury**.

- **mechanism** - different sequences and combinations of flexion, extension, and lateral motion.
Most common* mechanism - **hyperextension followed by flexion** (motor vehicle is hit from behind by another vehicle, i.e. rear-end collisions).
*cause 85% whiplash injuries
- ≈ 1 million cases per year in USA.
- women* > men. *narrower neck with less muscle mass supporting head
- **pathology** – multifactorial: muscle tears (microhematomas → fibrosis), rupture of ligaments, retropharyngeal hematoma, nerve root damage, cervical sympathetic chain injury, hemarthrosis of facet joints, disc injuries.
N.B. cases with fractures, disk herniations, head injuries are excluded; hyperextension may cause central cord syndrome due to spinal cord damage.

Clinically:

1. Persistent **neck pain** without objective findings.
 - **onset** within 24 hours (in 93% cases).
 - can **persist** for months (in minority of patients – for years).
 - risk factors for more severe symptoms - unprepared car occupant, rotated or inclined head position at moment of impact.
 - psychosocial factors, negative affectivity, and personality traits are not predictive of symptom duration.
 - despite common belief that pending litigation is responsible for persistent symptoms, most patients are not cured by verdict.
2. Possible **concomitant symptoms**:
 - 80% patients complain of **headaches** (muscle contraction type ± greater occipital neuralgia, third occipital neuralgia*).
*i.e. pain referred from C₂₋₃ facet joint innervated by 3rd occipital nerve
 - **neck stiffness** in one or more directions of motion.
 - localized areas of muscle tenderness (**trigger points**) in posterior musculature may develop.
 - **dizziness** is common complaint (dysfunction of vestibular system / cervical proprioceptive system / brain stem / cervical sympathetic nerves).
 - **paresthesias** of upper extremities.
 - **cognitive impairment** is controversial topic (attention deficits present in 18% patients 2 years after injury).
 - **interscapular pain** (20%), **low back pain** (35%).
- rare sequelae - cervical dystonia or torticollis.

Diagnosis – cervical spine MRI (if abnormalities are present, possibility that they are pre-existent should be considered!).

Differential – psychological problems, malingering.

TREATMENT

Instruct patient that complete resolution of symptoms may require 6-12 weeks!

- 1) ice → heat
 - 2) NSAIDs, muscle relaxants.
 - 3) try to avoid soft cervical collars (esp. after first 2-3 weeks) → gentle stretching & early mobilization, range-of-motion exercises, physical therapy, trigger point injections, TENS
- if pain persists > 12 weeks, patient has cervical disc degenerative disease.

THORACOLUMBAR SPINE**CLASSIFICATION**

Classification system should:

- 1) **enhance communication** among clinicians with varying degrees of experience
- 2) reliably **guide treatment**
- 3) **predict the outcome** of various treatment options

Historical **Denis classification** (3-column concept) provided level III evidence and became a popular scheme in North America. However, the system does not clearly identify injuries, which may or may not require operative intervention.

- clinicians thought that if ≥ 2 columns were involved then the patient needed surgical intervention. However, McAfee quickly determined, there were burst fractures which were stable and could be treated nonoperatively.

CNS Evidence-Based Guidelines for Thoracolumbar Spine Trauma (2019)

Insufficient evidence to recommend a **universal classification system or severity score** that will readily guide treatment of all injury types and thereby affect outcomes.

Grade B Recommendation - a **classification that uses readily available clinical data** (e.g. CT with or without MRI) should be used to improve characterization of injuries and communication among treating physicians:

1. **Thoracolumbar Injury Classification and Severity Scale (TLICS)** - cannot yet be adapted to predict management in all populations (there is still wide variation in treatment recommendations) >>
2. **AO Spine Thoracolumbar Spine Injury Classification System** >>

Thoracolumbar injury classification & severity score (TLICS) – 3 components:

TABLE 1: The TLICS system*

Variable	Points
injury morphology	
compression	1
burst	+1
translation/rotation	3
distraction	4
neurological status	
intact	0
nerve injury	2
cord, conus medullaris	
incomplete	3
complete	2
cauda equina	3
PLC integrity	
intact	0
indeterminate†	2
injured	3

* As reported by Vaccaro et al.¹¹

† For patients with suggested ligamentous injury on STIR imaging or T2-weighted MRI.

Injuries with ≤ 3 points = non operative

Injuries with 4 points = nonop vs op

Injuries with ≥ 5 points = surgery

Fundamental issues of TLIC:

- 1) evaluation of the PLC requires MRI which may not be available in all centers around the globe and may be quite subjective.
- 2) operative management is likely to vary based on the country, resources, and perceived clinical condition of the patient.

AO Spine Thoracolumbar Spine Injury Classification System

(AO- Arbeitsgemeinschaft fur Osteosynthesenfragen, 1994)

- it is derivative of *Magerl's Comprehensive Classification*: type A-axial compression, type B-distraction of anterior and/or posterior elements, and type C-axial torque leading to anterior and posterior element disruption with rotation.
 - many observers believe that identification beyond the three basic types (A, B, or C) is confusing, and the AO system does not specifically include the degree of neurological injury.
 - inclusive of all injury patterns observed at the thoracolumbar junction, it did not help guide treatment.

Type A injuries - compression injuries with injury of the anterior elements and preservation of the posterior ligamentous complex: A0 fractures represent transverse or spinous process fractures; A1 are wedge compression fractures of 1 endplate without involvement of the posterior wall of the vertebral body; A2 are split or pincer fractures with involvement of both endplates; A3 are incomplete burst fractures which involve the posterior wall of the vertebral body but only 1 endplate; and A4 fractures are complete bursts, which involve both endplates and the posterior wall.

Type B injuries - failure of the posterior or anterior tension band in distraction: B1 injuries are transosseous monosegmental failure of the posterior tension band; B2 are bony and/or ligamentous failure of the posterior tension band in conjunction with an A fracture of the vertebral body; B3 injuries are hyperextension injuries through the disc space or bone as commonly seen in ankylosing spondylitis. There is some confusion because the first iteration of this new AO Classification System included these injuries under type C. However, for the purposes of this guideline, the authors will include them as type B as this is the classification which has been investigated for internal and external reliability.

Type C injuries suffer disruption of all elements with displacement or dislocation of the cranial spinal elements relative to the caudal elements. There are no subtypes any longer for this injury pattern.

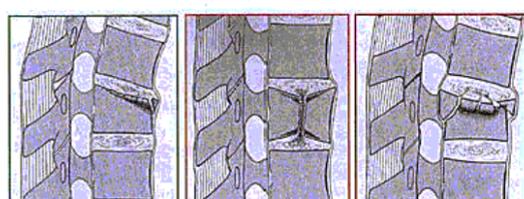
In addition to the morphological classification, there is also a neurological grading component (N0 = intact, N1 = transient symptoms, N2 = radiculopathy, N3 = incomplete or cauda injury, and N4 = complete) and case-specific modifiers.

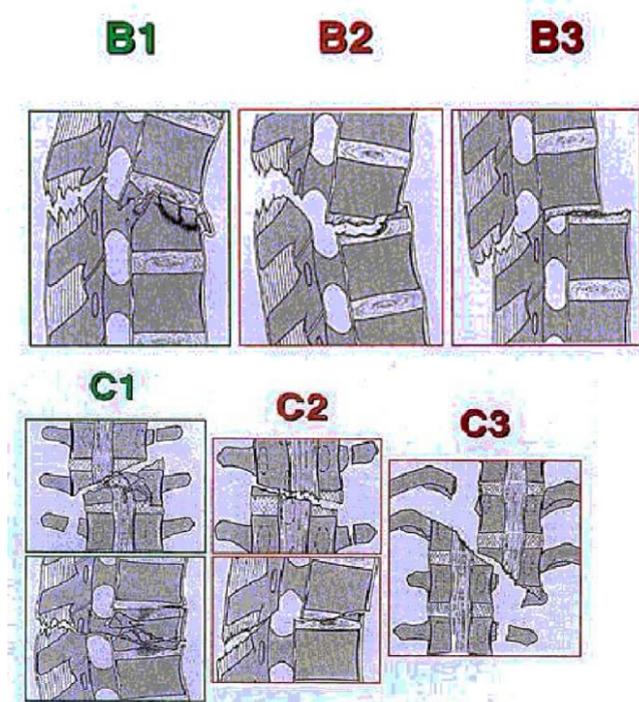
Types	Groups	Subgroups	Specificastions
A compression	A1 impaction	A1.1	
		A1.3	A1.2.1, A1.2.2, A1.2.3
		A1.3	
	A2 split	A2.1	
		A2.2	
		A2.3	
	A3 burst	A3.1	A3.1.1, A3.1.2, A3.1.3
		A3.2	A3.2.1, A3.2.2, A3.2.3
		A3.3	A3.3.1, A3.3.2, A3.3.3
B distraction	B1 post ligamentous	B1.1	B1.1.1, B1.1.2, B1.1.3
		B1.2	B1.2.1, B1.2.2, B1.2.3
	B2 post osseous	B2.1	
		B2.2	B2.2.1, B2.2.2
	B3 anterior	B2.3	B2.3.1, B2.3.2
		B3.1	B3.1.1, B3.1.2
B rotation	C1 A with rotation	B3.2	
		B3.3	
	C2 B with rotation	C1.1	
		C1.2	C1.2.1, C1.2.2, C1.2.3, C1.2.4
	C3 shear	C2.1	C2.1.1, C2.1.2, C2.1.3, C2.1.4
		C2.2	C2.2.1, C2.2.2, C2.2.3
	C2.3	C2.3.1, C2.3.2, C2.3.3	
	C3.1		
	C3.2		

A1

A2

A3





RADIOLOGICAL EVALUATION

CNS Evidence-Based Guidelines for Thoracolumbar Spine Trauma (2019)

Grade B Recommendation: MRI has been shown to influence the management of up to 24% of patients - providers may use MRI to assess posterior ligamentous complex integrity, when determining the need for surgery.

Insufficient evidence that radiographic findings can be used as predictors of clinical outcomes.

COMPRESSION (WEDGE) FRACTURE

ETIOPATHOPHYSIOLOGY

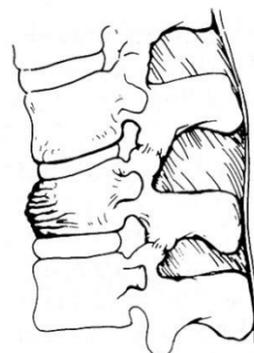
- results from *compression-anterior flexion* mechanism (middle column remains intact and acts as hinge) → **ANTERIOR WEDGE FRACTURES** (most common type of thoracolumbar fractures!)
N.B. traumatic compression fracture in young patient - suspect possible flexion-distraction (Chance) fracture!
- often as **PATHOLOGIC FRACTURES** (esp. elderly white women). *see* PATHOLOGIC FRACTURES >>

CLINICAL FEATURES

→ *see* PATHOLOGIC FRACTURES >>

RADIOLOGY

anterior column failure (stable) - wedging of anterior component of vertebral bodies (loss of anterior vertebral body height is < 50%), soft tissue swelling, anterior superior cortical impaction, buckling of anterior cortex of vertebral body, trabecular compaction, endplate fractures, disk-space narrowing.



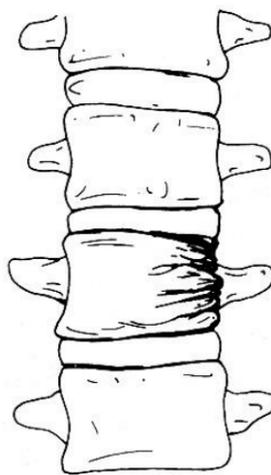
anterior column failure & posterior column ligamentous failure (possibility of being unstable) - anterior wedging (loss of vertebral body height > 50%*) + increased interspinous distance. – *see* FLEXION-DISTRACTION fracture >>

* > 50% loss of vertebral body height in wedge fracture → **CT** to rule out middle column and burst fractures (up to 25% fractures diagnosed initially as wedge fractures are actually burst fractures)

failure of all 3 columns (unstable!!!) - anterior wedging + varying degrees of posterior vertebral body disruption. – *see* FLEXION-DISTRACTION fracture >>, BURST fracture >>

Anterior **wedging > 50%** or **multiple contiguous** anterior wedge compression fractures = **CHRONIC INSTABILITY** (progressive angulation may occur with time!!!).

- 8-14% are asymmetric – caused by *compression-lateral flexion* (stable **LATERAL WEDGE FRACTURES**).



- **DENIS classification** system:
 - type A - involvement of both endplates
 - type B - involvement of superior endplate
 - type C - involvement of inferior endplate
 - type D - buckling of anterior cortex with both endplates intact.
- compression fractures can be devastating for 2 reasons:
 - 1) **bony pain** (from fracture itself) sometimes does not resolve.
 - 2) fracture can **alter mechanics of posture** → increase in kyphosis (sometimes to point that patient cannot stand upright → hip flexor contractures [due to iliopsoas shortening], secondary pain in hips, sacroiliac joints, spinal joints).

TREATMENT

Best **MANAGED** in **HOSPITAL**:

- 1) patients have **marked discomfort**, often requiring parenteral narcotics.
- 2) associated **intrathoracic / abdominal injuries** should be considered.
- 3) often associated with **prolonged ileus** (secondary to hemorrhage of sympathetic ganglia), requiring continuous nasogastric suction.

- for malignant causes – emergent radiotherapy, steroids.
- for infectious causes – antibiotics.

Analgesia (avoid NSAIDs) and **muscle relaxants**

N.B. bony and neuropathic pains are treated differently!

- if pain is not improving with bracing over 2-12 weeks → kyphoplasty or vertebroplasty.

Bracing (for 8-12 weeks) to prevent progressive angulation:

- custom made TLSO (body cast)
 - “off-the-shelf” adjustable TLSO
 - no bracing
- extension brace is best – prevents kyphosing.
 - young people heal very well but many refuse brace (H: percutaneous stabilization).
 - bracing is more prone to fail at high stress areas (e.g. **thoracolumbar junction**) – follow up with new X-ray in 2 weeks (the older is fracture, the more difficult is to reduce it once kyphosis happened)
 - bracing is more prone to fail in **obese** patients.
 - bedrest is not benign - bone density declines approximately 2% per week, muscle strength declines 1–3% per day or 10-15% per week

Early rehabilitation - become ambulatory as soon as comfortable (increased incidence of thromboembolic events!)

- restrictions for 8 weeks: forward bending, hip flexion < 90°, lifting / carrying ≤ 5 kg.
- first 4 weeks simply walking → isometric spine stabilization exercises for 4 weeks → isotonic exercises.

Radiographic monitoring (some fractures can worsen over ensuing months - might require surgical stabilization).

Serial radiographs for 1 year - progressive kyphosis can occur!

INDICATIONS FOR SURGICAL STABILIZATION:

- inability to wear external brace or external brace failure
 - kyphosis > 30°** - indicates instability
 - major **anterior column comminution** with **height loss > 50%** - indicates instability
N.B. vertebral body **comminution** is risk factor per se that bracing will fail as bone fragments will keep “floating”
 - significant **posterior element disruption** - indicates instability
 - neurological deficits** - add **DECOMPRESSION** to **FUSION**
- percutaneous screws (“internal brace”) may suffice if no need to decompress and enough fractured bone contact to heal (esp. young people) – see p. Op220 >>
 - postoperative TLSO bracing (10-12 weeks).

PERCUTANEOUS VERTEBRAL AUGMENTATION (PVA)

INDICATION

- symptomatic* osteoporotic and neoplastic fractures (also see p. Onc56 >>)
- *RTCs of PVA showed statistically significant improvement in pain and function, particularly ambulation

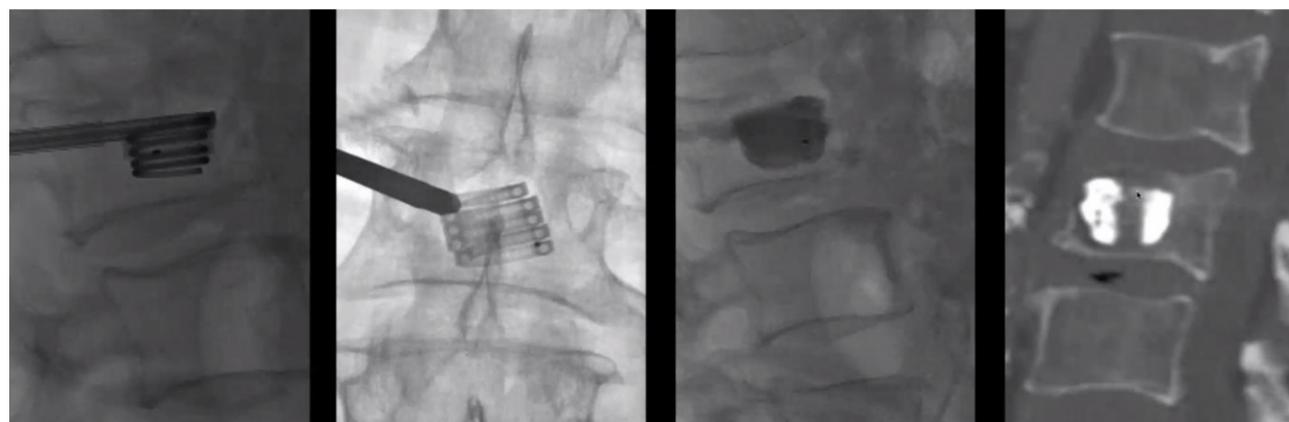
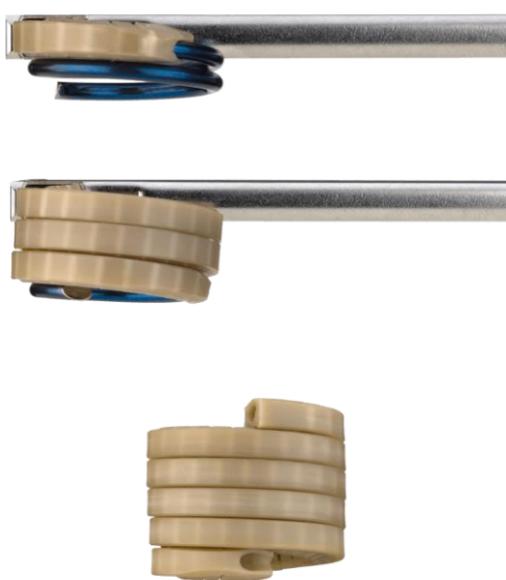
Fracture age requirement – look for **STIR signal** (vertebral body edema) on MRI* (absence of STIR signal means fracture has healed, thus, fracture age limit is probably near 6 months).

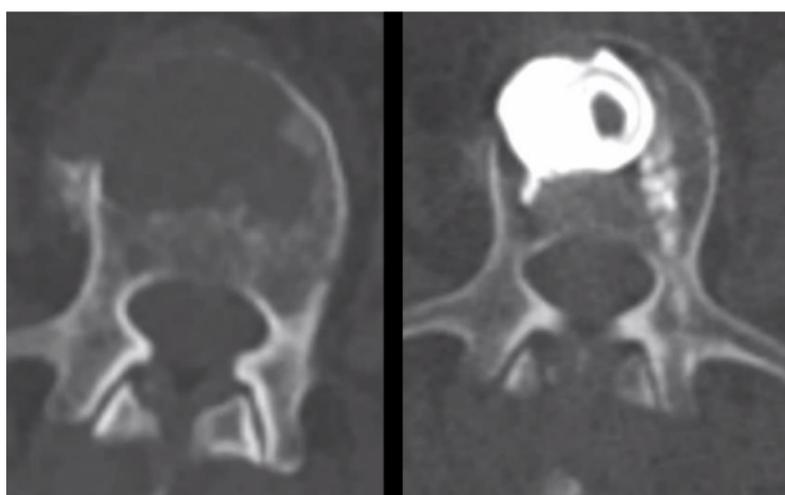
*if MRI is contraindicated, may do **nuclear study** to show ongoing metabolism

CONTRAINDICATIONS

- split fracture
- complete burst fracture with posterior wall compromise** – now it is only a **relative contraindication** – modern devices* able to contain cement
- pedicle fracture
- high-energy trauma
- asymptomatic
- spinal cord compression or canal compromise requiring decompression

*KIVA – PEEK coil with holes on the inside – contains cement:





DETAILS, TYPES

- mostly outpatient procedure.
- under MAC or general anesthesia.
- cement – viscous (different degrees of viscosity) **polymethylmethacrylate**

Vertebroplasty – high-pressure injection of **cement polymer** into fractured vertebral body → better vertebral body resistance to upright loads → decreased pain.

- fluoroscopy guidance.
- percutaneous trocar or large needle is introduced into fractured body through pedicle, and cement is injected.
- complications:
 - 1) cement spread to neural structures
 - 2) adjacent-level vertebral body fractures! (risk increased > 4 times).

Kyphoplasty - similar to vertebroplasty, except **balloon** is used to expand volume of fractured segment → **cement polymer** is delivered under **low-pressure*** into closed balloon (less likely extrusion of cement into spinal canal!)

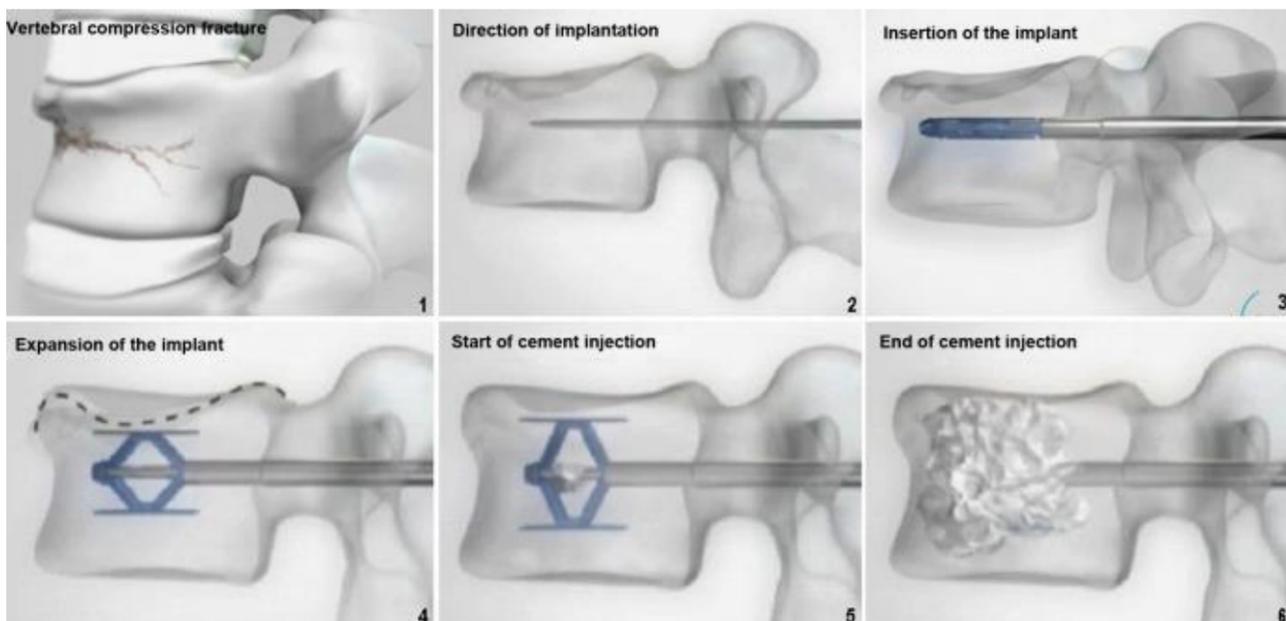
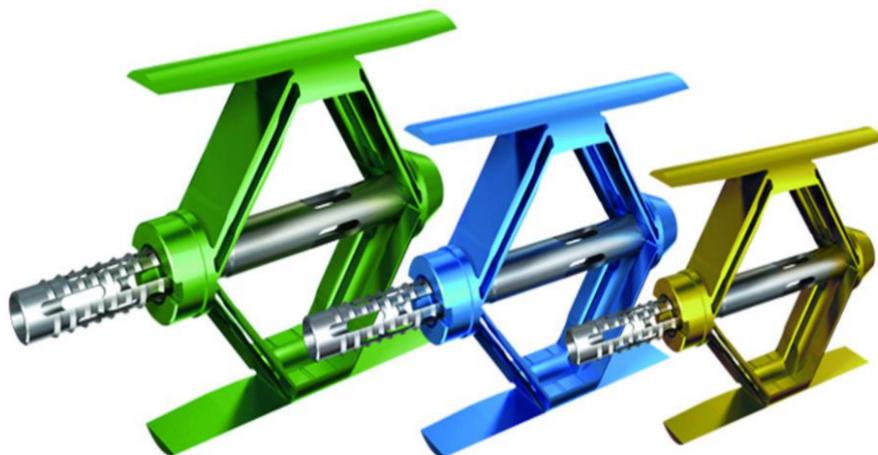
*much lower complication rate

- canal compromise contraindicates kyphoplasty (and sometimes vertebroplasty).
- ideal for cancer pain (pathologic fractures due to metastases)!!!; indicator – STIR signal on MRI.



SpineJack (Stryker)

- mechanical kyphoplasty with height restoration; FDA approved for osteoporotic (non-oncologic) compression fractures



EVOLVE Trial

Prospective and Multicenter Evaluation of Outcomes for Quality of Life and Activities of Daily Living for Balloon Kyphoplasty in the Treatment of Vertebral Compression Fractures: The EVOLVE Trial. Douglas P Beall et al. Neurosurgery, Vol 84, Issue 1, Jan 2019, Pages 169–178

- first large prospective on-label as-treated clinical trial designed to include patients commonly seen in clinical practice.
- 354 patients with 1 to 3 painful vertebral compression fractures (VCFs) **from T5 to L5** due to **osteoporosis** or **cancer**.
- study demonstrates that kyphoplasty is a safe, effective, and durable procedure for treating patients with painful VCF due to osteoporosis or cancer.

Percutaneous vertebroplasty (PVP) and kyphoplasty (PKP) have widely gained acceptance as a line of treatment in symptomatic osteoporotic vertebral fractures and osteolytic primary or secondary lesions in the spinal column.

The introduction of vertebroplasty by Galibert et al. in 1984 and kyphoplasty by Garfin et al. in 1997 offered two simple, fast, and minimally invasive treatment modalities for these conditions.

Vertebroplasty consists of injecting polymethylmethacrylate (PMMA) into the vertebral body through a transpedicular or extrapedicular approach bilaterally or unilaterally. Through bone biopsy needles, which allow better maneuverability within the pedicle to the middle third of the vertebral body, the procedure is done under image intensification. Ideally, two perpendicular C-arms, or as recommended by some, CT-guidance is used. PMMA is injected carefully and under continuous radiographic monitoring in 0.5 mL bolus to enable immediate interruption of the procedure when there are radiographic signs of cement extrusion as PMMA flows into a blood vessel or toward the posterior cortical margin.

Likewise, kyphoplasty is done with the same radiographic setup. An inflatable balloon is introduced through a compatible pedicular needle through a transpedicular or extrapedicular approach. The balloon is then mechanically inflated by a piston and filled with radiopaque liquid. It is then deflated and removed and the resulting void with compressed peripheral bone in the vertebral body is subsequently filled with PMMA. In contrast to vertebroplasty, kyphoplasty allows for direct correction of sagittal plane deformity and, to a much lesser degree, of the coronal plane deformity.

Kyphoplasty Systems

Based on an expandable polymer device, the Sky Bone Expander System (Disc-O-Tech Medical Technologies Ltd, Herzeliya, Israel) represents one such kyphoplasty system. The KIVA VCF treatment system (Benvenue Medical Inc., Santa Clara, CA, USA) consists of a spiraled coil implant made of PEEK-OPTIMA, that is introduced in a transpedicular manner over a shaped memory nitinol coil. After withdrawal of the guidewire, the looped PEEK implant is filled centrally with PMMA. A recent technique is radiofrequency-targeted vertebral augmentation (RF-TVA) which was developed to overcome some of the limitations of balloon kyphoplasty while preserving the advantages of PVP and PKP. The Shield Kyphoplasty System (Soteira, Inc., Natick Mass., USA) uses a 10-mm diameter cement director made of braided nitinol, which is impermeable to cement except for holes located anterosuperiorly and anteroinferiorly. It allows for better application of highly pressurized cement after the creation of a cavity by a curved cavity creation device through a unilateral transpedicular approach. A different approach is the use of two expandable titanium mesh implants which might be filled with PMMA or a suitable bone substitute introduced percutaneously by a transpedicular approach.[9] The SpineJack® (Vexim SA, Balma, France) uses two jacks to mechanically restore vertebral height, which is then maintained by PMMA. Analogous to PKP, the above-mentioned systems allow for restoration of the vertebral body height and are often referred to as third generation vertebroplasty.

Bone Fillers

PMMA is the current filler material employed in almost all vertebral augmentation procedures and was approved by the Food and Drug Administration in 2004. Its mechanical strength, stiffness, biocompatibility, and reasonable price are clear advantages. Disadvantages include its absent biological potential, absent osteoconduction and osteoinduction capability, overt stiffness, high polymerization temperature, and monomer toxicity. Cement and barium sulfate particles have been identified in vertebral vascular spaces reflecting the serious potential for embolization of large vessels, the heart, and the lung. Therefore, PMMA should be injected with low pressure.

The mechanical strength of PMMA is lowered by the addition of radiopaque agents and antibiotics. Less than 2 g of antibiotic powder added to a standard packet of PMMA, however, showed no adverse effect. However, aqueous gentamycin had in comparison to powder gentamycin a negative effect on mechanical cement properties. It was also shown that the antibiotic elution rate was higher in greater surface area-to-volume patterns. Antibiotic bactericidal concentrations eluded for 30 days were found to be longer in hydroxyapatite cement than from PMMA.

Barium sulfate is found in a concentration of 10% by weight in arthroplasty PMMA; however, this is not sufficient for fluoroscopic visualization and so tantalum powder, tungsten, barium sulfate, or zirconium dioxide have been added to PMMA. Bone resorption has been associated with zirconium dioxide and barium sulfate but this has not been clarified.

Because of its osteoconductive property, calcium phosphate cement has the ability to be resorbed and replaced by new bone. This has been shown in several animal models and human treatment series for distal radial fractures.

Different proportions of calcium sulfate and hydroxyapatite or tricalcium phosphate (HA/TCP) composites have been tested. The latter is used to reduce the rates of dissolution, with no negative effect on bone formation, whereas higher proportions of calcium sulfate are still associated with rapid dissolution and less net mineral content.

Disadvantages of calcium phosphate and sulfate compounds are their high costs, low viscosity and their bad handling characteristics. Being true thixotropic cements the suspensions dehydrate when they are exposed to pressurization within the delivery tube forming chalk, thus hindering it to advance through the tube or to interdigitate with the vertebral bone. Moreover, clinical and biomechanical studies revealed their inferiority to PMMA regarding shear, traction, and flexion forces with subsequent loss of vertebral height.

However, calcium phosphate cement can be made osteoinductive by the increase of growth factors like bone morphogenetic protein-2 (BMP-2), transforming growth factor-beta (TGF-beta), platelet-derived growth factor (PDGF), and basic fibroblast growth factor (bFGF). This is based on the macroporous scaffold-like structure of calcium phosphate and the ability to control its pH quite accurately.

Being radiopaque and showing outstanding mechanical properties, composite materials (acrylic cement in conjunction with ceramics) are attractive candidates to replace PMMA in future cement augmentation procedures. Cortoss (Orthovita, Malvern, PA) consists of a terpolymer resin reinforced with combeite glass-ceramic particles and was approved in Europe in 2003, but its biological effect in humans treated for osteoporotic vertebral compression fracture (OCVF) has not yet been sufficiently described in the literature.

Pain Reduction

The mainstay of treatment for osteoporotic vertebral compression fractures is thought to be conservative when pain can be controlled and no mechanical or neurological instability is present in an otherwise healthy patient. Cement augmentation, however, is indicated in patients with intractable pain. The reduction of pain is believed to be from inhibition of fragment micromotion and a thermal and a chemical effect of PMMA. The latter two theories have been disputed because there are no or few intraosseous nerve endings and similar pain reduction has been observed after injection of calcium phosphate cement that crystallizes at body temperature. Mechanical rigidity is achieved by either the formation of a hard mass (PKP) or by interdigitation in the bony trabeculae (PVP), thus preventing nerve irritation in the periosteum, bone marrow, or the haversian system. Furthermore, a placebo effect, the action of the local anesthetics and the natural history have been hypothesized. PKP techniques offer the ability to directly correct fracture induced kyphosis. On the contrary, by lordotic patient positioning and strategically placing pillows, vertebroplasty can indirectly help to a lesser degree in vertebral height reduction. In the presence of neurological symptoms, spinal stabilization with sagittal plane and sometimes coronal angular plane correction and decompression are necessary. In a meta-analysis, Liu et al. found no difference comparing pain relief between PVP and conservatively managed groups at 2 wk and 1 mo postoperatively. Nevertheless, at 3 mo, 6 mo, and 12 mo there was a significantly higher pain reduction in the PVP group. From 2 wk to 6 mo, no difference regarding pain reduction was found among the PVP and sham injection groups. This might be explained by the action of local anesthetics in the latter and a placebo effect attributable to both the PVP and sham injection procedures.

In a meta-analysis by Hulme et al., vertebroplasty offered an immediate reduction of pain scores (53%), although, after 6 wk patients treated conservatively or with PVP had similar pain scores and functional ability. Kyphoplasties in chronic painful vertebral fractures offered at 6 mo substantially better pain relief than other modalities.

Gill et al. showed in their metaanalysis of 21 included studies containing 1046 vertebroplasties and 263 kyphoplasties that both techniques had a decrease of five points in their respective visual analog scores in the immediate postoperative period. The long-term follow-ups showed no further substantial improvement of the visual analog score at follow-up. This was also confirmed by Dong et al. emphasizing that there was no statistical relation between vertebral body height restoration and obtained pain reduction.

Barr et al. reported in their series of 38 consecutive patients with 70 osteoporotic vertebral fractures treated with PVP initial pain relief of 95%. After 18 mo, pain relief was 94%. However, this group also treated eight patients with 13 vertebrae with neoplasms with the primary goal of spinal stabilization and not pain relief. Substantial pain reduction was reached only in 50% and mechanical stability in 88%.

PKP has been found superior to conservative management and at least equal to PVP regarding pain reduction in a meta-analysis by Taylor et al. Pain reduction by PKP also is superior in younger vertebral fractures than in older vertebral fractures.

Cement in Osteolytic Lesions

The primary aim of cement augmentation in primary and secondary osteolytic vertebral lesions is palliative pain relief, and various studies have reported a consistent and sustained reduction of preprocedural pain independent of the type of underlying malignancy. Controversially discussed issues when comparing PVP and PKP use in osteolytic lesions are the optimal filling volume of cement, safety regarding extravasation, and pain reduction. For fear of intraspinal cement escape, some authors consider a posterior wall defect to be a contraindication for cement application; however, others claim good results when done carefully. Other authors have combined radiofrequency ablation with vertebroplasty and report similar pain relief and complication rates when compared to PVP or PKP. The concept relies on tumor dissolution rather than displacement, theoretically reducing the incidence of cement extravasation. Gu et al. reported good pain relief in 94% of their 31 patients with metastatic spinal tumors and malignant vertebral compression fractures treated with interventional tumor removal followed by percutaneous vertebroplasty. Fractured osteoblastic lesions usually are stable and most authors do not recommend cement augmentation. Nonetheless, Camels et al. treated 53 vertebrae with pure osteoblastic and 50 vertebrae with mixed blastic and lytic lesions with vertebroplasty. They reported a good to excellent analgesic effect in 92% at 6 mo and that the occurrence of complications was not related to the nature of the lesion. Nevertheless, a filling failure occurred in five vertebrae, all being osteoblastic.

A new interesting approach is the incorporation of 13.7% holmium and 8.9% samarium phosphates by weight with calcium phosphate bioceramics, thus marking the advent of radiovertebroplasty. After neutron activation, the Ho-166 and Sm-153 bioactive powder emitted 14.5 and 32.5 MBq/mg, respectively. However, its in vivo applicability and efficiency have yet to be proven.

BURST FRACTURE OF VERTEBRAL BODY

- vertebral body end plate(s) fracture → nucleus pulposus is forced into vertebral body → **body is shattered outward from within** (*burst fracture*).
- failure of the anterior and middle columns by axial loading → circumferential expansion of entire involved vertebra.
- fracture of the posterior vertebral body wall leads to retropulsion.
- retropulsed bone splinters and disc material may impinge on ventral surface of spinal cord (with dural laceration) → **anterior cord syndrome** → immediate decompressive surgery (via anterior approach)!
- attempted weight bearing without surgical fixation → severe neurologic injury can be expected.

MCAFEE classified burst fractures:

STABLE burst fractures - posterior column is intact;

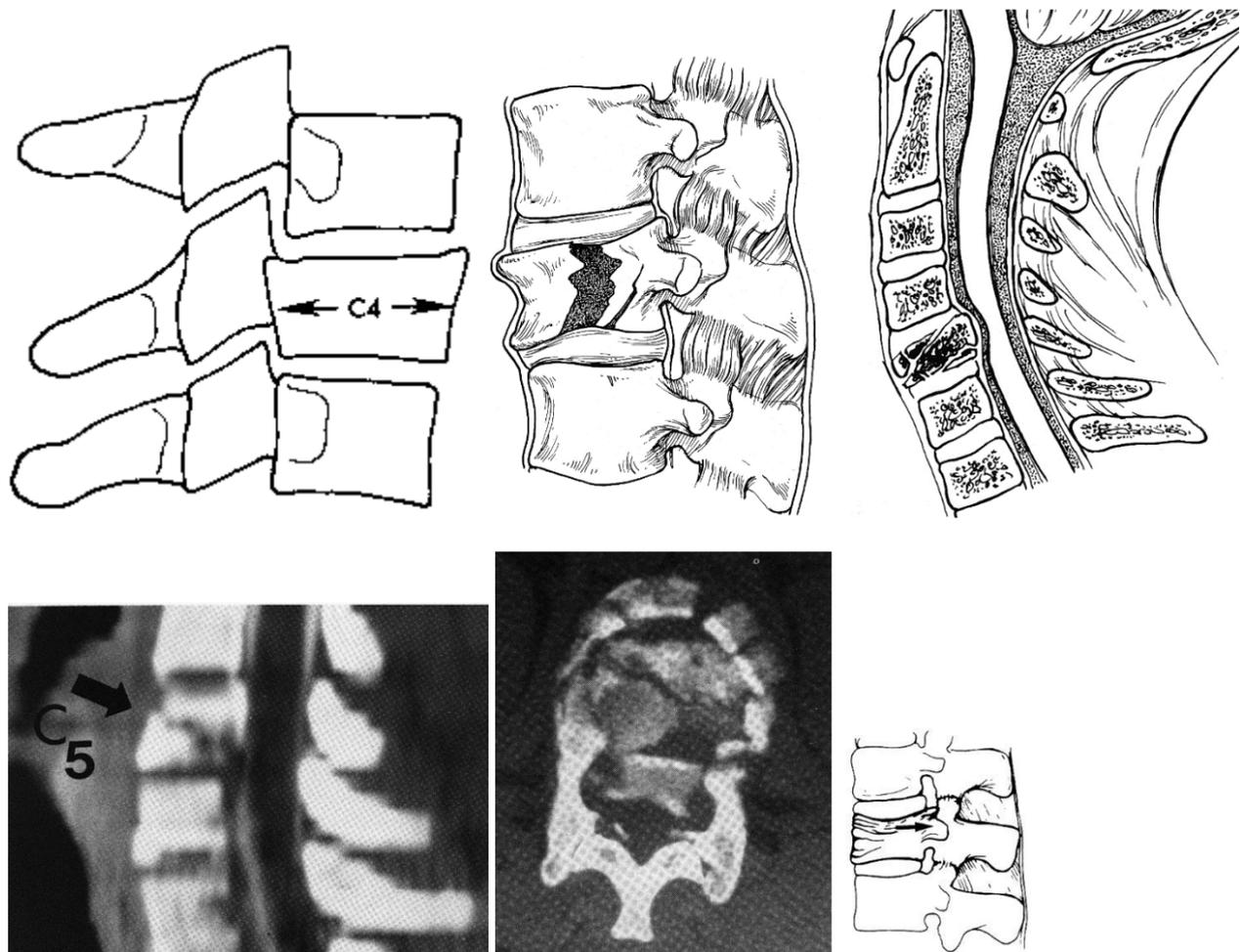
UNSTABLE burst fractures - posterior column has sustained significant insult (*dural tears* are frequent - portions of cauda equina can herniate through dural defect - if not repaired → scarring and chronic pain).

RADIOLOGY

LATERAL view - **comminuted vertebral body**, loss of vertebral height (> 50%), **retropulsion of bone fragments** (canal narrowing > 30%), kyphotic angulation (> 20%).

AP view - characteristic **vertical fracture of vertebral body** (helps differentiate from simple wedge fracture and flexion teardrop fracture); **widened interpedicular distance** (indicates instability).

Always perform **CT / MRI** to document amount of bone retropulsion.



Burst fracture of T12 - anterior deformation, comminution, retropulsion of bone fragments into spinal canal:



TREATMENT

- TL burst fractures in neurologically intact patients are considered to be inherently stable, and responsive to nonsurgical management.
- burst fractures with significant **vertebral collapse, angulation, canal compromise**, or associated **neurologic deficit** are considered to be unstable and necessitate surgical intervention.

Stable / neurologically intact: see also conservative treatment under compression fractures >>

A. **Bed rest** on **firm mattress** (6-12 weeks) – in third world countries

B. **TLSO brace** (custom made molded polypropylene body jacket or “off-the-shelf” adjustable brace) – required to be worn at all times except when lying flat in bed

Kirkham Wood, MD (chief of orthopedic spine service at Massachusetts General Hospital and associate professor of orthopedic surgery at Harvard Medical School) - surgical vs. nonsurgical treatment for neurologically intact and stable burst fractures of the thoracolumbar junction:

- years ago, burst fractures were traditionally operated on; now most clinicians no longer offer surgery to the majority of their patients.
- at 4 years, patients who received surgery (either posterior or anterior arthrodesis), had higher complication rates but there was little difference in outcomes.
- at 15 years later, there was no statistical difference in kyphosis or pain scores but 30% operated patients showed significant segmental degeneration immediately caudal to their fusion, plus, disability (Oswestry Disability Index, Roland and Morris Disability Questionnaire) showed statistically significant advantage for nonoperative group (more patients in nonoperative group were working while 4 times as many operated patients were using narcotics).

Sonali R. Gnanenthiran “Nonoperative versus Operative Treatment for Thoracolumbar Burst Fractures Without Neurologic Deficit: A Meta-analysis”

- Level II Evidence: **operative management** of thoracolumbar burst fractures without neurologic deficit **may improve residual kyphosis**, but **does not appear to improve pain or function** at an average of 4 years after injury and is associated with higher complication rates and costs

- brace is worn for 8-12 weeks when out of bed. External bracing may provide needed patient assurance to promote early mobilization and participation in physical therapy.
- patients treated without brace are encouraged to return to normal activities at 8 weeks.
- pain continues to improve for first 6 months.

C. **No bracing**

Bailey CS “Orthosis versus no orthosis for the treatment of thoracolumbar burst fractures without neurologic injury: a multicenter prospective randomized equivalence trial.” Spine J. 2014 Nov

AO-A3 burst fractures T11-L3, skeletally mature, age > 60 years, kyphotic deformity < 35°, no neurologic deficit: TLSO is equivalent to no bracing at 3 months postinjury (health-related quality of life outcomes, satisfaction, and length of stay).

CNS Evidence-Based Guidelines for Thoracolumbar Spine Trauma (2019)

Grade B Recommendation - **external bracing** in the nonoperative treatment of **neurologically intact** patients with TL **burst fractures**:

- **Level 1-2 evidence** (Bailey et al. 2014, Shamji et al. 2014 - studies did not include burst fractures of the upper and midthoracic and lower lumbar spine) - nonoperative management with or without an external brace produces **equivalent improvement in outcomes** (radiological and clinical [pain and disability]) - decision to use an external brace is at the discretion of the treating physician.
- bracing is **not associated with increased adverse events** compared to not bracing.
- **no brace** leads to **shorter duration of stay**.

Unstable, canal impingement see indications for surgery under compression fractures >>

→ **surgery** via **anterior*** or **posterior approach: DECOMPRESSION** + STABILIZATION** with restoration of normal vertebral body height (long-term stabilization is provided by interbody arthrodesis using bone graft).

***posterior approach (laminectomy)** increases instability and is ineffective to relieve anterior impingement

****DECOMPRESSION** is not always needed; should not be attempted until adequate **EXTERNAL STABILIZATION** (halo-vest) or **POSTERIOR STABILIZATION** has been performed

DECOMPRESSION

- full laminectomy.
- if at the cord level, remove pedicle, drill the cavity behind the fragment, and push the retracted fragment back into cavity – **ligamentotaxy**.
- for fragment tamping back into place, may do discectomy above the fracture to create the room for it.
- may use **US** to check if ventral decompression is complete.

STABILIZATION:

- traditional **open** approach → fusion with pedicle screws
- percutaneous** approach → stabilization with pedicle screws (it is not fusion!!!!; hardware needs to come out later)

N.B. do not use **polyaxial** screws for TRAUMA (one of AO principles!)

N.B. include at least 2 levels above and 2 levels below fracture; short segment fusions (1 above, 1 below) are rarely acceptable!

CNS Evidence-Based Guidelines for Thoracolumbar Spine Trauma (2019)**Burst fractures in neurologically intact patient**

Conflicting evidence to recommend for or against the use of **surgical intervention** to improve **clinical outcomes** - discretion of the treating provider.

- main emphasis – integrity of posterior ligamentous complex (PLC)

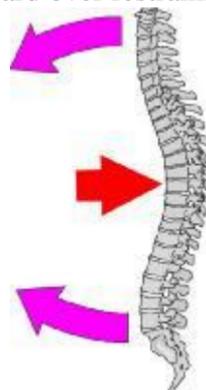
Nonburst fractures

- **Insufficient evidence** to recommend for or against the use of **surgical intervention** - discretion of the treating physician.

FLEXION-DISTRACTION injury, s. CHANCE ("SEAT BELT") fracture

- **failure of MIDDLE and POSTERIOR column** (injury to ligamentous components, bony components, or both) with **varying degrees on ANTERIOR column collapse**.

- **history** - George Quentin Chance, a Manchester-based British radiologist described the eponymous fracture in 1948.
- **mechanism** - often due to **lap belts** in motor vehicle accidents - individual is subjected to sudden deceleration and torso is flexed forward over restraining belt.

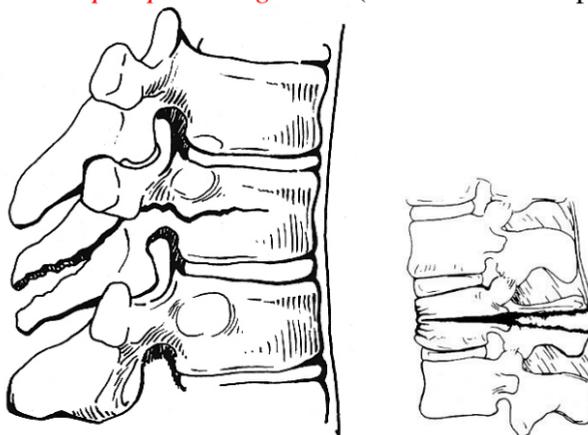


- no rotation or lateral displacement of fracture fragments.
- typical location - **thoracolumbar region** (T10-L2); in children may be located in the mid lumbar area.
- only about 15% of Chance fractures lead to **neurological deficits**.
- up to 50% of patients with Chance fractures will have associated **intra-abdominal injuries** (esp. bowel perforations and mesenteric lacerations) – look for **“seat belt sign”** on physical exam + CT (stranding in the subcutaneous fat of the anterior abdominal wall).

SUBTYPES (dependent on *axis of flexion*):

CLASSIC CHANCE SUBTYPE, s. osseous Chance (although 2 columns disrupted, but classically stable!!!) - axis of flexion anterior to anterior longitudinal ligament:

- 1) horizontal fracture through **posterior and middle column bony elements** (spinous process, pedicles, transverse processes)
- 2) disruption of **supraspinous ligament** (increase in interspinous distance)



FLEXION-DISTRACTION SUBTYPE (unstable*) - axis of flexion posterior to anterior longitudinal ligament: Classic Chance fracture + **anterior wedge fracture**.



*all 3 columns are involved

- diagnosis of posterior element failure requires **CT**.
- if **pars interarticularis** is disrupted (in either type of fracture), then instability is increased → significant subluxation → **neurologic sequelae**.

SUBTYPES (by element injury):

- a) **osseous** Chance injury - fractures of the spinous process, pedicles, and the vertebral body.
- b) **ligamentous** Chance injury - rupture of the interspinous ligament, posterior longitudinal ligament, ligamentum flavum, facet joint capsule, and intervertebral disc.
- c) **osteoligamentous** Chance injury – combination of osseous and ligamentous injuries.

18 year-old female with lap belt caused **fracture dislocation at L4-5 with spinal cord transection**:



Source of picture: Viktoras Palys, MD >>

TREATMENT

- A) purely osseous injury (Magerl type B2) + no neurological deficits → **TLSO** (thoracolumbosacral orthosis) for 8-12 weeks
- chance fracture is usually reduced on a Risser table by applying hyperextension to the injured thoracolumbar area; custom-designed plaster or fiberglass is then applied.
 - biggest drawback is patient compliance because the orthotic device is uncomfortable.
 - union rates are high with conservative management.
 - extensive rehabilitation program is necessary to regain muscle strength and mobility.

- B) **ligamentous injury (Magerl type B1), neurological deficits, kyphosis > 15 degrees, obese and large individuals** → **surgery**: long-segment posterior fixation using pedicle screws, +/- interbody fusion, +/- decompression.

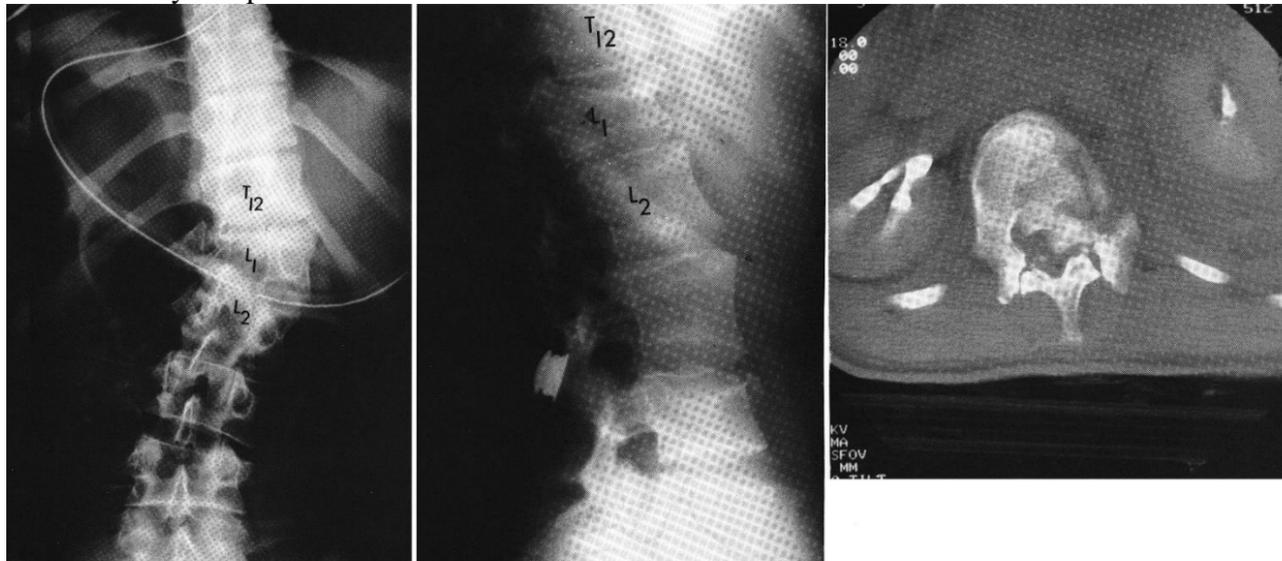
- ligamentous injuries need longer instrumentations than purely osseous injuries.
- if no need for decompression, may consider **percutaneous techniques** of screw insertion without arthrodesis (common in burst fractures but reports of good outcomes in Chance fractures also exist)

Jason K Chu et al. Percutaneous Instrumentation Without Arthrodesis for Thoracolumbar Flexion-Distract Injuries: A Review of the Literature. Neurosurgery . 2017 Feb 1;80(2):171-179. doi: 10.1093/neuros/nyw056. PMID: 28173564
- **number of levels to instrument:**
 - no comparative study of long *versus* short segment fusion of FDI exists.
 - literature predominantly supports long segment posterior fixation with pedicle screws - out of a concern for the increased long term stability (vs. unnecessary motion segment loss → adjacent level disc disease).
 - Finkelstein et al. achieved adequate results with **single segment** stabilization

J.A. Finkelstein, E.K. Wai, S.S. Jackson, et al. Single-level fixation of flexion distraction injuries J Spinal Disord Tech, 16 (2003), pp. 236-242
 - while **posterior tension band wiring** replicates the function of the posterior ligamentous structures, rigid arthrodesis by pedicle screw placement obviates the need for additional fixation.

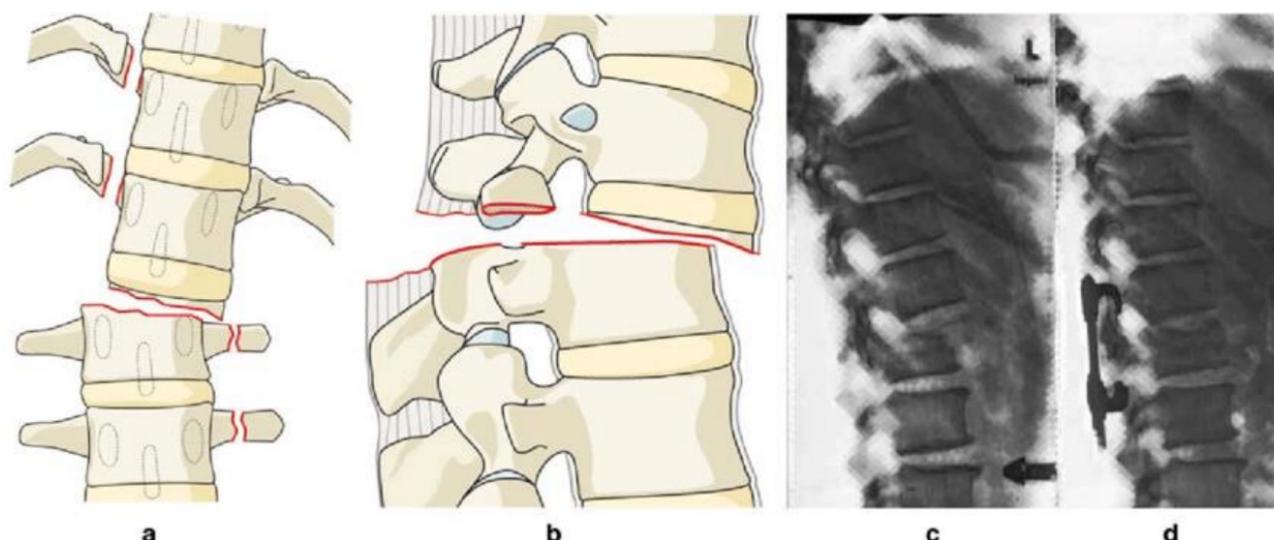
LATERAL FLEXION FRACTURE

Lateral flexion injury at L1-2 junction - acute scoliosis in frontal view; compression of anterior elements with posterior displacement of middle element in lateral view; fracture of lateral part of vertebral body and pedicle in CT:

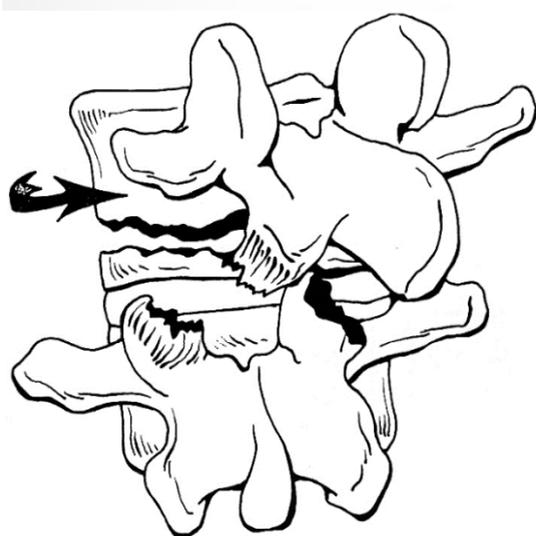
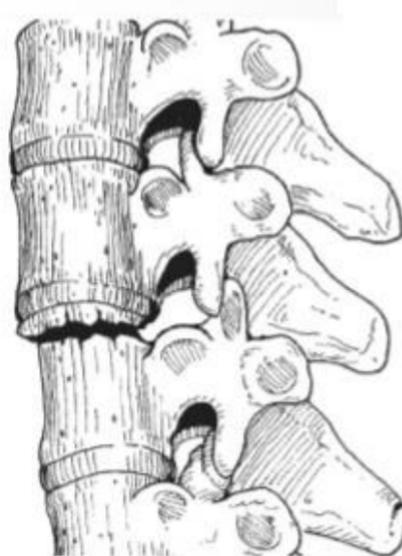


“SLICE” FRACTURE-DISLOCATION, S. TORSIONAL / ROTATIONAL INJURY, HOLDSWORTH SLICE FRACTURE

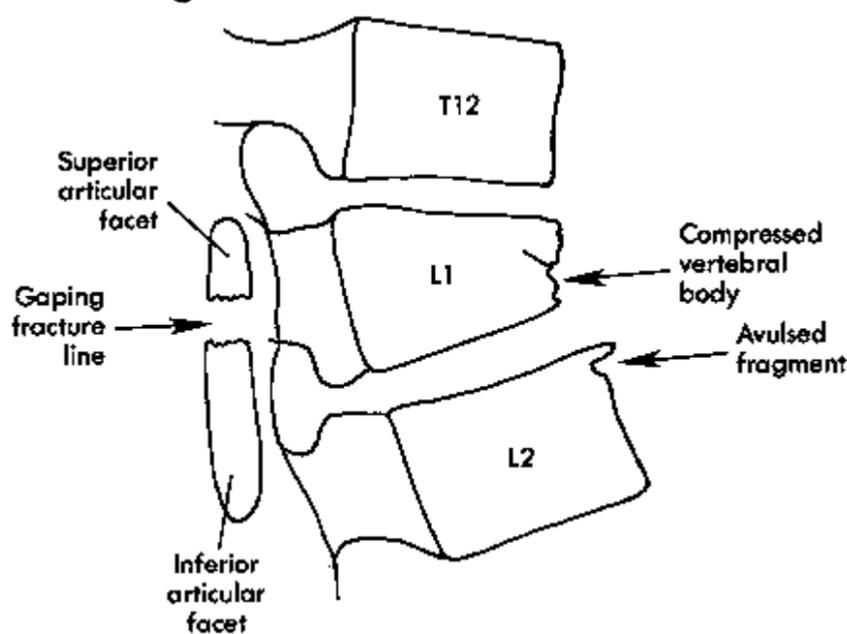
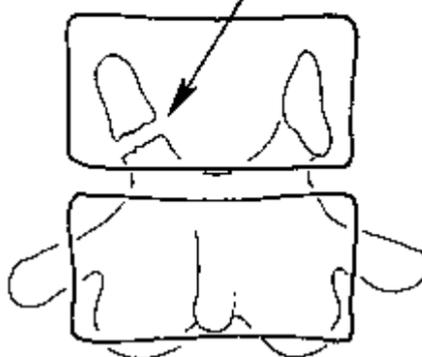
(unstable)
 - occurs in **(thoraco)lumbar region** (articular processes are large, curved, and nearly vertical – unilateral facet dislocation cannot occur) - **one or both articular processes fracture** → upper vertebra swings anteriorly on lower:



- An unstable fracture dislocation of the thoraco lumbar junction of the spine.
- The injury comprises a fracture through a vertebral body, rupture of the posterior spinal ligaments and fractures of the facet joints.



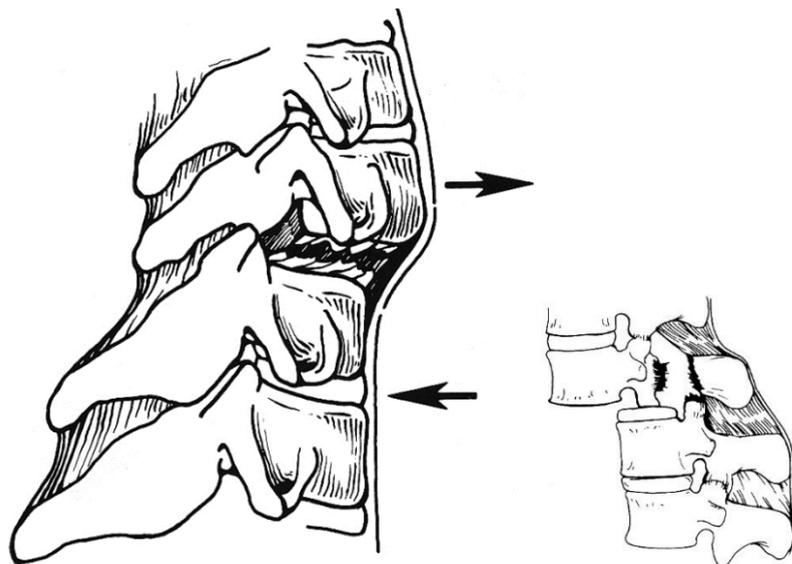
Fracture of superior articular facet



- Sir Frank Wild Holdsworth (1904-1969), a renowned British orthopedic surgeon who laid a solid foundation for rehabilitation of spinal injuries under the aegis of the Miners' Welfare Commission, described in detail the management of thoraco-lumbar junctional rotational fracture.

FACET FRACTURE-DISLOCATION

- direct blow → displacing vertebra off adjacent one with fracture and dislocation of articular processes and rupture of ligaments & disk.
- failure of all three columns - grossly unstable (although stability may be maintained by rib cage).
- frequent severe injury to neural elements.
- imaging represents recoiled position of some greater displacement at time of injury.



Treatment - reduction and fusion

N.B. *percutaneous internal stabilization is contraindicated* as ligamentous complex and disc are disrupted!

- open reduction of locked facets – bilateral Smith-Peterson osteotomies to remove medial facets (reduction happens spontaneously) → posterolateral fusion.
- may place ropivacaine infusion pump for postop pain management.

FRACTURE OF PARS INTERARTICULARIS (SPONDYLOLYSIS)

- see p. Spin17 >>

FRACTURE OF TRANSVERSE PROCESS

(stable)

- associated with severe injury to **paravertebral muscles** (e.g. psoas with retroperitoneal hemorrhage)
- correlation exists between L₁ transverse process fracture and same-side **renal injury**.

PATHOLOGIC FRACTURES

- caused by **trivial injury** predisposed by **disorders with considerable loss of bone substance**:

- 1) **osteoporosis** (vertebral fracture increases risk of death 9 times!)
 - 50% of all osteoporotic fractures are vertebral (1/3 are lumbar, 1/3 are thoracolumbar, and 1/3 are thoracic).
 - 2) chronic **steroid** use
 - 3) vertebral **malignancies** (metastases, multiple myeloma)
 - 4) vertebral **osteomyelitis** (incl. tuberculous).
 - 5) hyperparathyroidism
 - 6) prolonged immobilization
- most often - **thoracolumbar compression (wedge) fractures**. *see above >>*
 - N.B. compression fracture → seek for treatable risk factors!
 - most common fractures of thoracolumbar spine! (most frequently T₁₂-L₁ level).
 - stable in **thoracic** spine - thoracic cage provides support.
 - compression fractures **above midthoracic** region are suggestive of malignancy.

CLINICAL FEATURES

- many remain undiagnosed - present with **progressive painless kyphosis or scoliosis**.
 - others present with **back pain*** and **tenderness**.
 - may result in **compression** of cord or cauda equina.
 - *axial, nonradiating, aching, stabbing, may be disabling
- N.B. presence of **kyphosis** (esp. > 15°) decreases risk of SCI!

DIAGNOSIS

- **occult** compression fractures may be detected with Tc^{99m}-hydroxydimethylpyrimidine **bone scans**.
- **differentiation MALIGNANT vs. BENIGN fractures** (not always possible by imaging):
 - Benign compression fractures** - plate-like increased T2 signal beneath fracture, with sparing of remaining vertebral body and pedicles.
 - Metastatic disease** - frequently globular, involving more than half of vertebral marrow and often extending into pedicles.

AP and lateral views of L₁ **osteoporotic** wedge compression fracture:



TREATMENT

- as COMPRESSION FRACTURES *see above >>*
- **kyphoplasty** is ideal for pain due to pathologic fractures due to metastases!!!

BIBLIOGRAPHY for ch. "Spinal Trauma" → follow this [LINK >>](#)