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TEACH

MODULE BIOMECHANICS OF SPINE

Didactic Unit B

Biomechanical alterations of the spine

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B. Biomechanical alterations of the spine

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B. Biomechanical alterations of the spine

Part 1. Objectives

1. OBJECTIVES

The objectives of this didactic unit are:

- To learn the biomechanics behind the main cervical, thoracic and lumbosacral spine pathologies.
- To know the biomechanics related to the conservative techniques and treatment of the main spine pathologies.
- To know the biomechanics related to the surgical intervention of the main spine pathologies.

B. Biomechanical alterations of the spine

Part 2. Biomechanics of the main pathologies of the cervical spine

2.1. INTRODUCTION

There are a variety of reproducible injury patterns based on the direction and magnitude of force applied to the highest segment of the spine:

- Flexion
- Lateral-flexion
- Extension
- Compression
- Shear
- Rotation

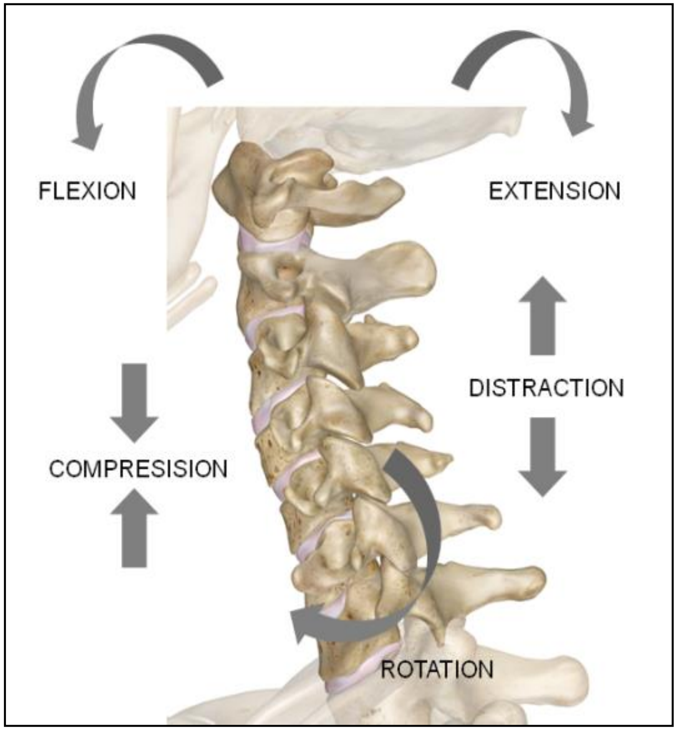


Figure 1. Injury mechanisms of the cervical spine (extracted from www.innerbody.com)

2.2. INJURIES OF THE UPPER CERVICAL SPINE

1/3 of the total of cervical injuries → 40% of this results by death

Injury level of the Cervical Spine

- Fractures of condyles of the occipital bone
- Atlantoocipital dislocation
- Fractures of the Atlas
- Atlantoaxial dislocation
- Fractures of the Axis

2.2. INJURIES OF THE UPPER CERVICAL SPINE

Main causes

- Young patients
  - High energy trauma
- Elderly patients
  - Osteoporosis

Main injury's mechanism

- ☐ Hiperflexion
- ☐ Hiperextension
- ☐ Latero-flexion
- ☐ Rotation
- ☐ Combination of all

2.2.1. FRACTURES OF CONDYLES OF THE OCCIPITAL BONE

Occipital condyle fractures (OCFs)

- Rare traumatic injury
- Associated with instability
  - Occipitoatlantoaxial joint complex
- Easily undetected under radiographs but detected with CT scan.

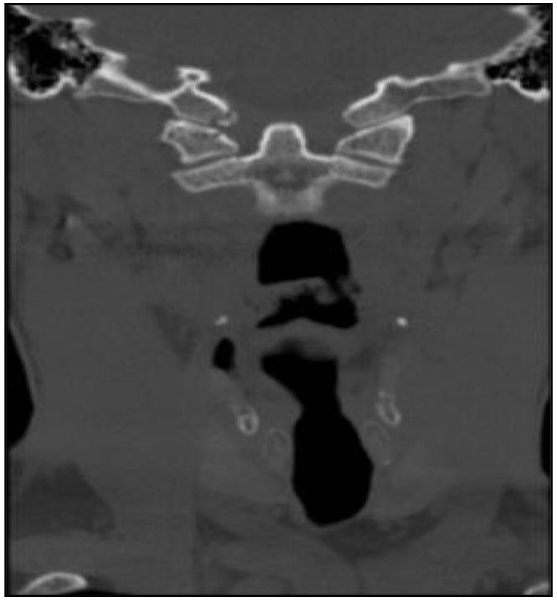


Figure 2. CT Scan of a minimally displaced fracture of the right inferior medial occipital condyle. (from Muhammad Waseem *et al*. 2014)

2.2.1. FRACTURES OF CONDYLES OF THE OCCIPITAL BONE

Table 1: Anderson and Montesano (1988) Classification of OCF

Type	Description	Biomechanics	Stability
I	Impaction	Results from axial loading; ipsilateral alar ligamente may be compromised but stability is maintened by contraleteral alar ligament and tectorial membrane	Stable fracture
II	Skull base extension	Extends from occipital bone via condyle to enter foramen magnum; stability is maintened by intact alar ligaments and tectorial membrane	Stable fracture
III	Avulsion	Mediated via alar ligament tension; associated disruption of tectorial membrane and contralateral alar ligament may cause instability	Unstable fracture

2.2.1. FRACTURES OF CONDYLES OF THE OCCIPITAL BONE

Anderson and Montesano classification		Tuli et al. classification	
	I, II	1	Nondisplaced - Stable
		2A	Displaced - Stable; no radiographic, CT, or MR imaging evidence of occipitoatlantoaxial instability or ligamentous disruption
	III	2B	Displaced - Unstable; positive radiographic, CT, or MR imaging evidence of occipitoatlantoaxial instability or ligamentous disruption

Figure 3. Tuli et al. (1997) Classification of Occipital Condyle Fractures. From Hanson J.et al. 2002

2.2.2. ATLANTOOCIPITAL DISLOCATION

Atlantooccipital dislocation (AOD) or Occipital dissociation (OCD)

- Dissociation of the occiput from cervical spine
- Produced in distraction and extensión forces applied to occiput in relation to atlas.
- Injury mechanism in rapid decelerations.
- AOD commonly in children:
  - Due to its relation head-body mass.
  - Due to its occipital condyles are smaller.
  - Due to its atlantooccipital ligaments are more lax.
  - Due to its craniovertebral junctions are more horizontal.

2.2.2. ATLANTOOCIPITAL DISLOCATION

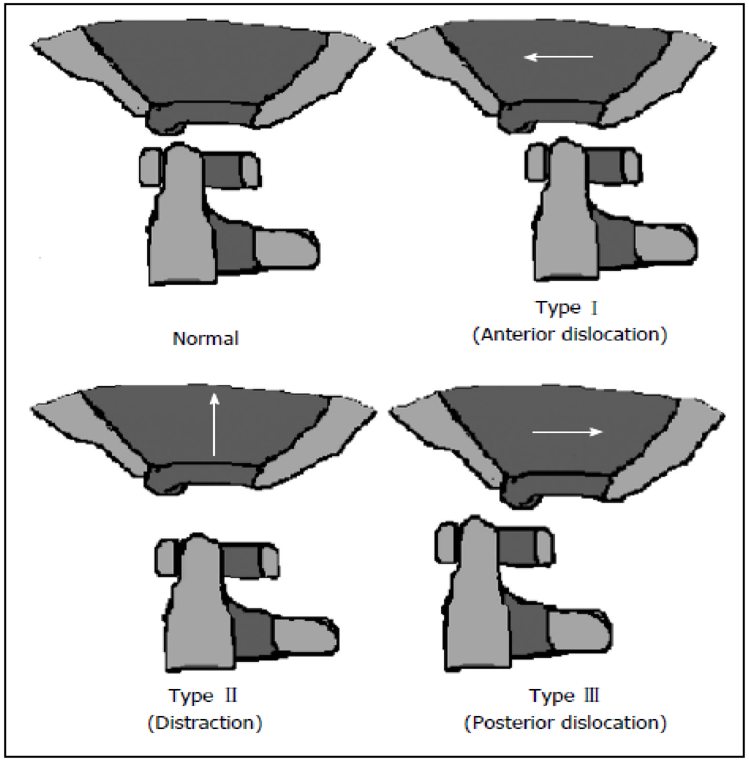


Figure 4. The Traynelis classification for Atlantoocipital dislocation (from Hall GC. et al. 2015)

2.2.3. FRACTURE OF THE ATLAS

Fractures of the Atlas

- Traumatic axial loading trough occiput
- Also produced by extensión, flexion and rotation forces.
- Depending the different combination of forces anterior or posterior arch fracture or a unilateral mass fracture can occur.

2.2.3. FRACTURE OF THE ATLAS

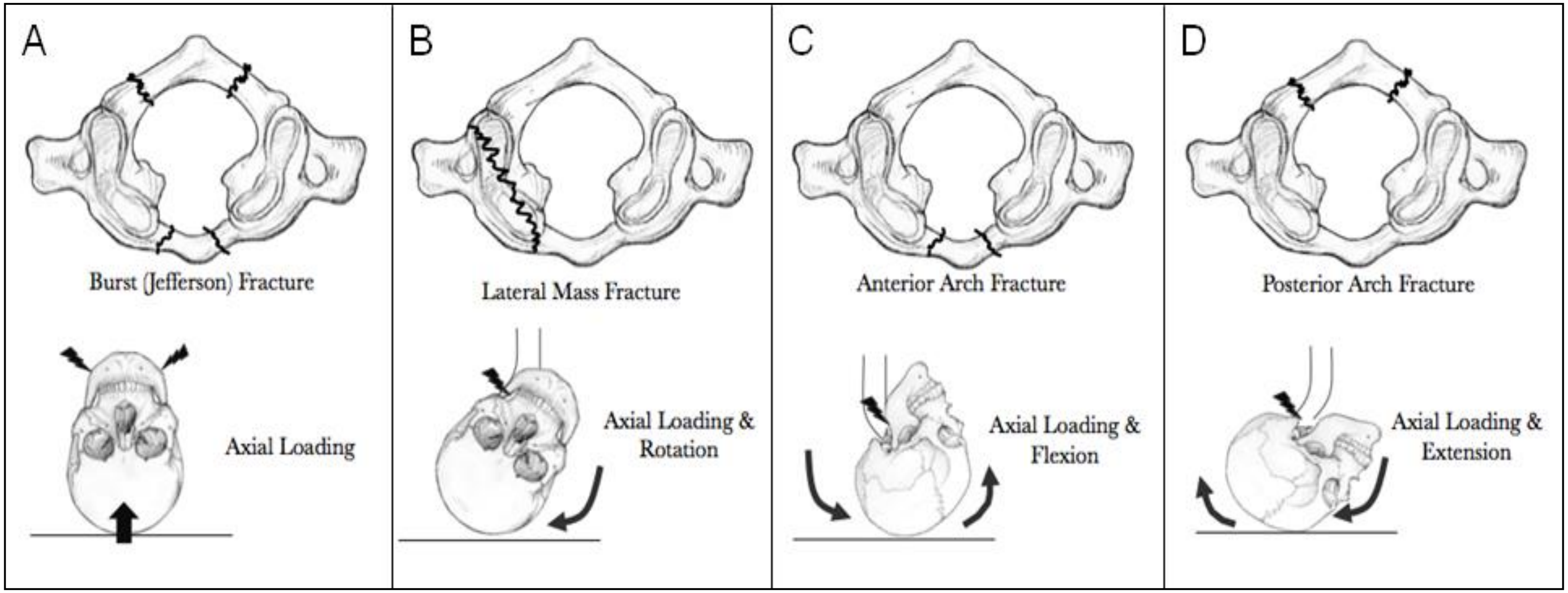


Figure 5. Atlas vertebral fractures (Image from: www.ebconsult.com)

2.2.4. ATLANTOAXIAL DISLOCATION

Atlantoaxial dislocation

- Refered to instability between atlas and axis (C1-2)
- Traumatic, inflammatory, idiopathic or congenital abnormalities can produce instability.
- Extremely rare injury by trauma if there's not a pre-existing injury .
- Disruption of the transverse ligament of the Atas.
- Also a rare injury of alar and apical ligaments due to transverse ligament injury may be produced.

2.2.4. ATLANTOAXIAL DISLOCATION

Table 2: Clinical signs of atlantoaxial dislocation (Yang et al. 2014)

Less serious signs	Moderate signs	Most severe signs
• Approximately 50% of patients present with neck pain and/or neck movement restriction • 70% of patients present with weakness and/or numbness • 90% of patients present with pyramidal signs	• Sphincter disturbances • Lower cranial nerve dysfunction • Respiratory distress	• Myelopathy • Respiratory failure • Vertebral artery dissection • Neurologic compromise • Rarely quadriplegia • Death if left untreated

2.2.4. ATLANTOAXIAL DISLOCATION

Atlantodental Interval (ADI)

- Small slitlike space between the posterior aspect of the anterior atlas ring and the anterior aspect of the odontoid process
- Measured by flexion and extensión radiograph of the neck.
- Sagittal radiograph measurement. From a line projected superiorly along the anterior border to the axis body to the anterior arch of the atlas

ADI is constant during head movements. Normaly 3mm in adults, 5mm in children.

70% of atlantoaxial clinical is due to anterior dislocation.

2.2.4. ATLANTOAXIAL DISLOCATION

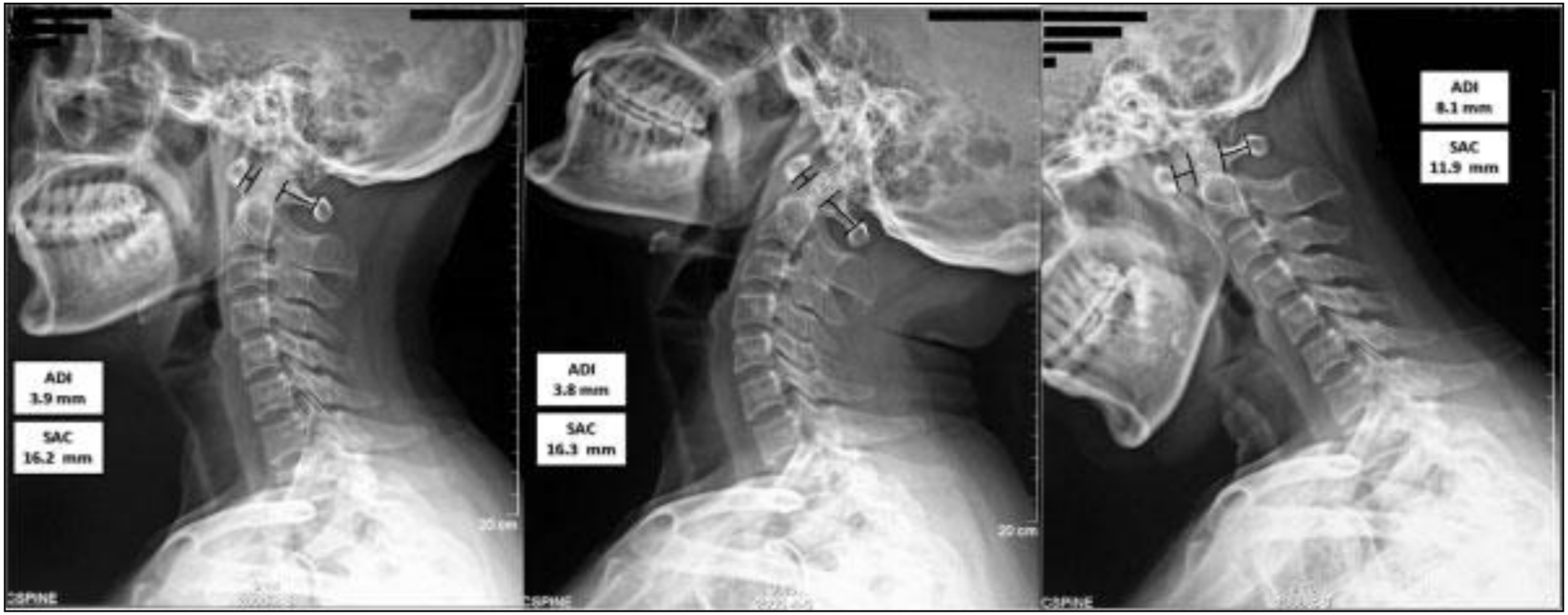


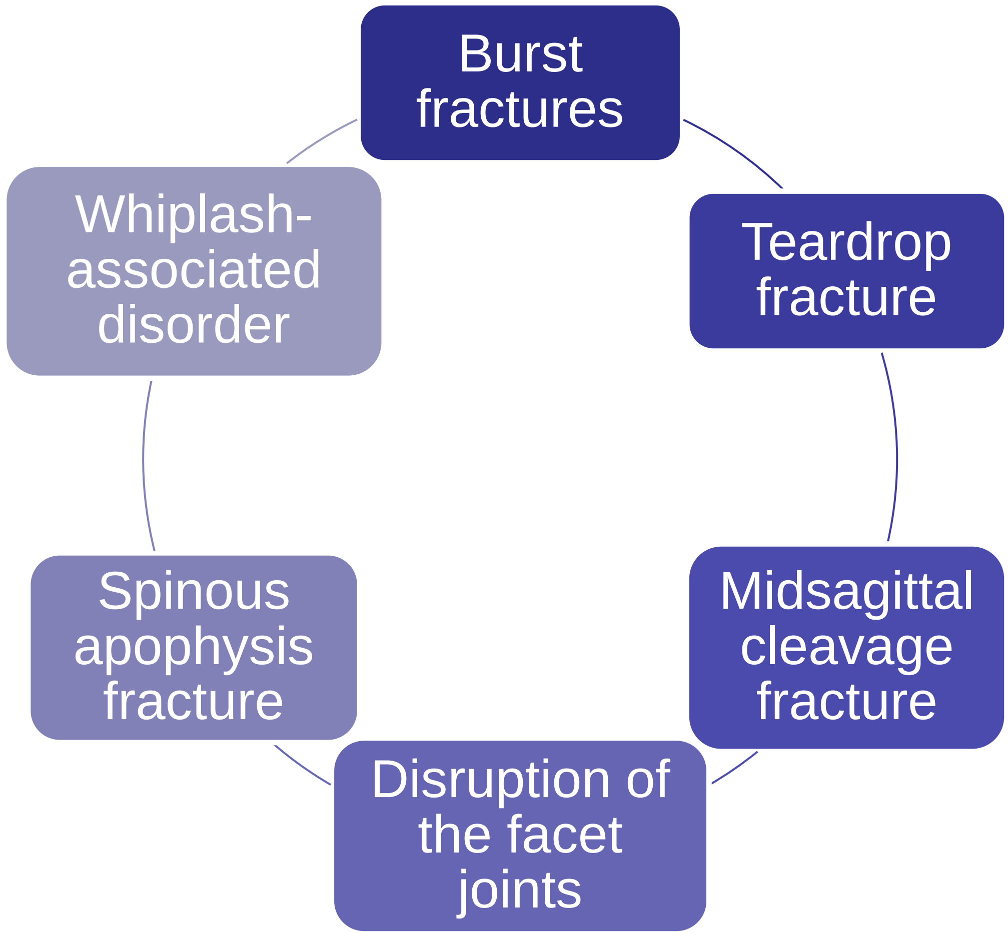
Figure 6. ADI during flexo-extensión cervical spine's movement (from Yang et al. 2014)

2.2.5. FRACTURE OF THE AXIS

Fracture of axis

- The most common fracture of the spinal spine (10% of all spine injuries).
- Clinically silent unless they cause spinal cord compression.
- Odontoid fracture can be caused by both extensión and flexion forces.
- The injury of alar, transverse, anterior and posterior longitudinal ligaments may produce unstable C1-2 complex.
- The traumatic spondylolsthesis of the Axis creates dramatic instability.
- The lower cervical compensates the altered sagital balance of upper cervical spine.

2.3. INJURIES OF THE LOWER CERVICAL SPINE



2.3.1. BRUST FRACTURES

Axial loading force in cervical spine

Neck position in neutral. No flexion force applied.

Compresion fracture

Vertebrae body from C3 to T1 may be injured

Posterior ligamentous complex remain intact

Maintained force may retropulse the vertebral body causing spinal cord injury.

Figure 7. Sagittal CT showing C5-6 burst fracture with compromised canal of the spinal cord (from Neupsykey.com)

2.3.2. TEARDROP FRACTURE

- Produced in mixed axial compression and flexion forces
- Posterior portion of the vertebral body retropulsed into the canal.
- Posterior subluxation of the vertebral body
- Acute kyphosis
- Disruption of the anterior and posterior longitudinal ligament
- High incidence of quadriplegia.

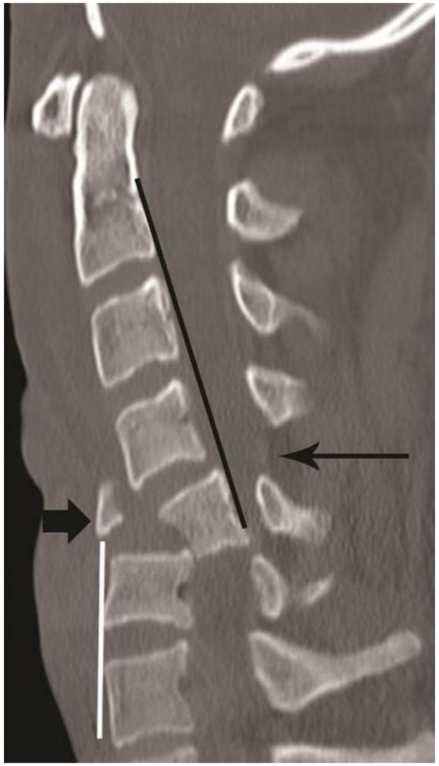


Figure 8. Sagittal CT teardrop fracture in Young patient (from ResearchGate.com)

2.3.3. MIDSAGITTAL CLEAVAGE FRACTURE

- Variation of Burst fracture.
- Usually seen in lower cervical spine (C4-5-6)
- The C4-5-6 closed bony ring shape determine this fracture.
- Fracture in lamina and facet joint disruption due to vertebral body fracture.
- Highly and glossly unstable injury.
- Body bony parts often impinge spinal cord.

2.3.4. DISRUPTION OF THE FACET JOINTS

Flexion/extensión forces mixed with rotatory forces may produce facet dislocation.

C4-5 or C5-6 levels usually affected.

Inferior facets of the higher vertebra slide over the lower vertebra

May involve a fracture in one or both vertebral facet.

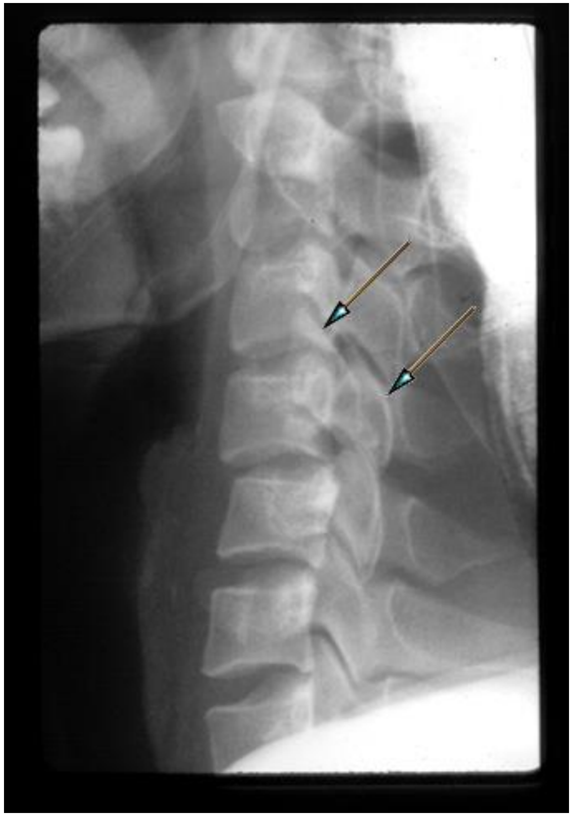
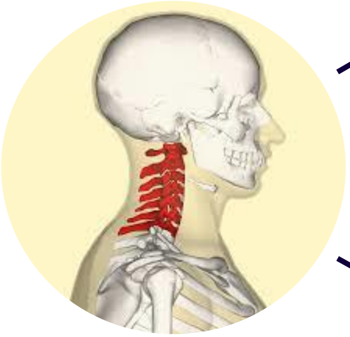


Figure 9. Bilateral facet dislocation (from Orthobullets.com)

2.3.4. DISRUPTION OF THE FACET JOINTS



Unilateral facet dislocation

- Forces acting are mostly flexion and rotatory.
- Often monoradiculopathy symptom

Bilateral facet dislocation

- Forces acting are mostly flexion/distraction.
- Less rotatory forces than in unilateral dislocation.
- The forces acting allows upper cervical dislocate anteriorly over lower cervical.

2.3.5. SPINOUS APOPHYSIS FRACTURE

Rupture of one or more cervical spinous processes.

Usually refered as “excavator fracture”

High magnitude force transmitted from shoulder girdle to spinous apophysis

Fracture usually located in C6-7 due to its longer spinous processes

Spinous processes ar not able to whitstand high flexor moment

Fracture close to vertebral body

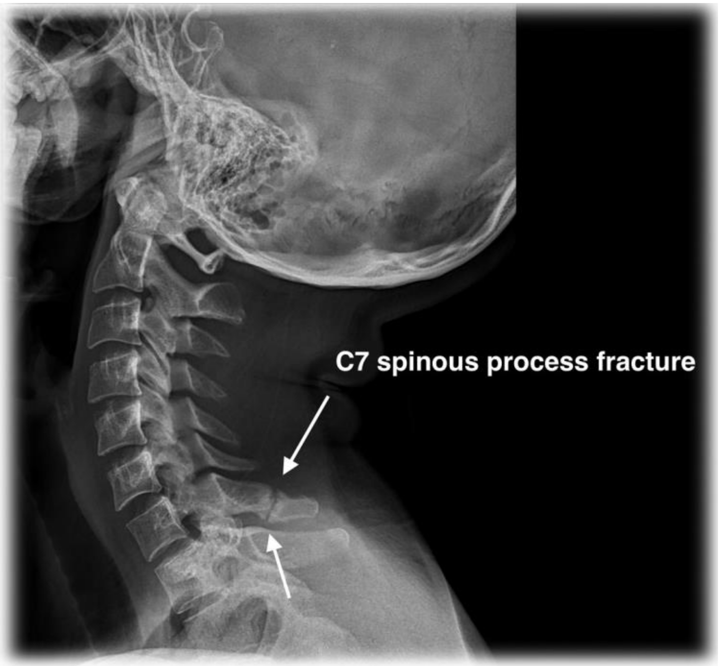


Figure 10. Fracture of the C7 spinous process (from earthlab.com)

2.3.6. WHIPLASH-ASSOCIATED DISORDER

Term to describe clinical manifestations of whiplash injury

Mechanism of acceleration-deceleration of energy transfer to the neck

Produced from rear end or side-impact motor vehicle collisions

Also produced during diving activities.

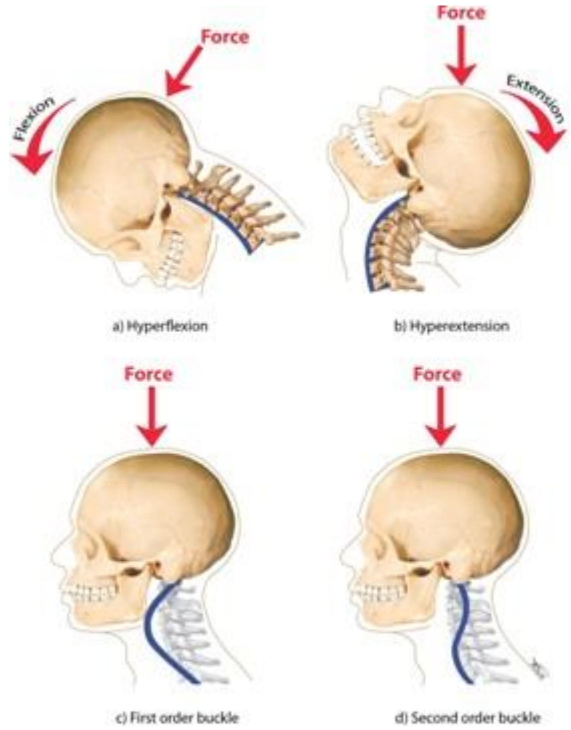


Figure 11. Whiplash mechanism and vector force applied (from activephysioterapy.com)

2.3.6. WHIPLASH-ASSOCIATED DISORDER

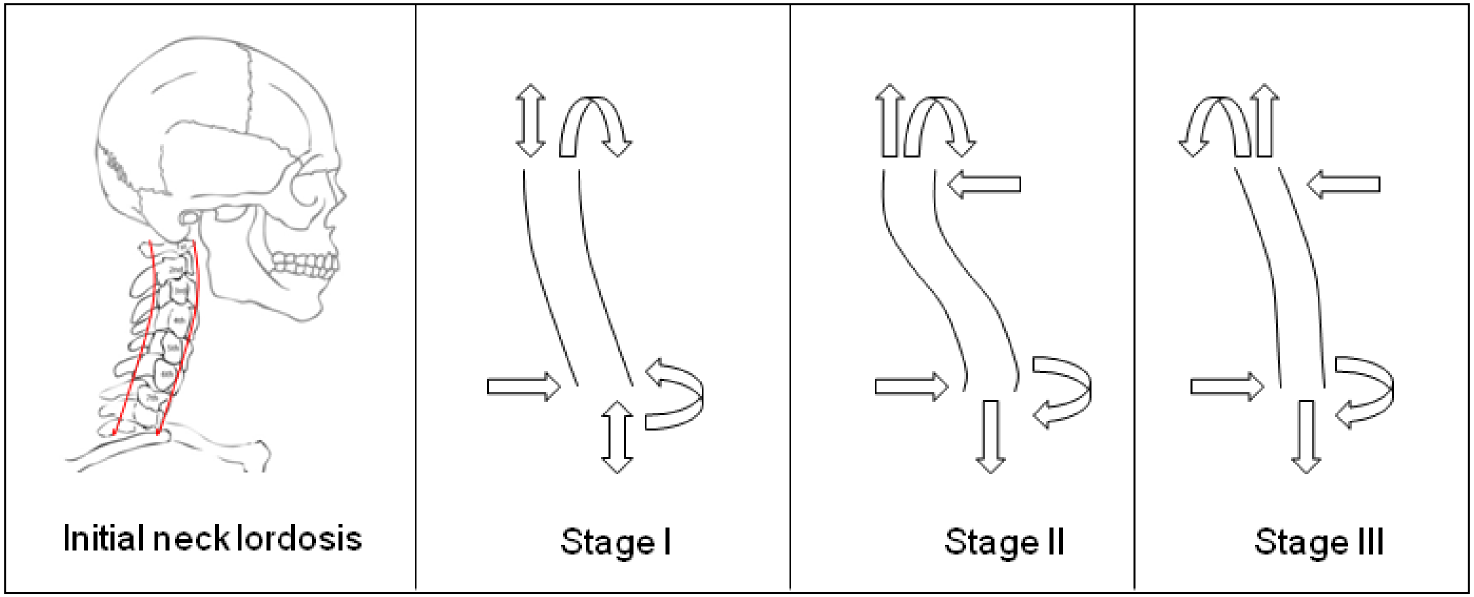


Figure 12. Models of neck deformation, and force and momento diagrams at three stages of a rear-end impact (from Luan F. et al. 2009)

2.3.6. WHIPLASH-ASSOCIATED DISORDER

Table 3: Phases and kinematics events during a rear impact (Kaneoka K. et al 2002)

Phase 1: Slede motion	Phase 2: Neck axial force	Phase 3: Axial and shear force	Phase 4: Full extension
0-40 ms	40-100 ms	100-160 ms	150-220 ms
a. The seat begins to press the back of the volunteer	a. The torso moves forward–pushed by the seatback	a.The sled slows the torso rebounds and moves forward with some backward rotation	a. The torso moves forward and downward
b. The spine begins to straighten	b. The torso moves upward–parallel to the seat inclination,causing axial compression of the cervical spine due to the inertia of the head, which reaches a maximum	b. The axial force on the neck decreases while the shear force on the neck reaches a peak at about 120 ms	b. The head and neck rotation reaches full extension
c. Cervical motion has not occurred	c.The head remains stationary due to inertia, with a slight initial flexion	c. The head begins to rotate into extension	c. Shear and axial forces in the neck decrease
d. No muscular response in the neck	d. C6 rotates earlier into extension than the upper vertebral segments (C3, C4 and C5)	d. The cervical spine moves into alignment in extension	d. The muscular discharge finishes by around 220 ms
	e. The vertebrae of the neck assumes an “S” shape with the upper region in flexion and the lower region in extension	e. The EMG of the sternocleidomastoid discharges from about 115 ms	
	f. No muscular response in the neck		

B. Biomechanical alterations of the spine

Part 3. Biomechanical alteration of the thoracic and lumbar spine

3.1. ENDPLATE FRACTURES

Located mainly in thoracic and upper lumbar spine

Produced by axial compressive, flexion forces or a mix of both

Fractures located in the central area, peripheral área or transverse the endplate

It plays a primary role in burst fracture

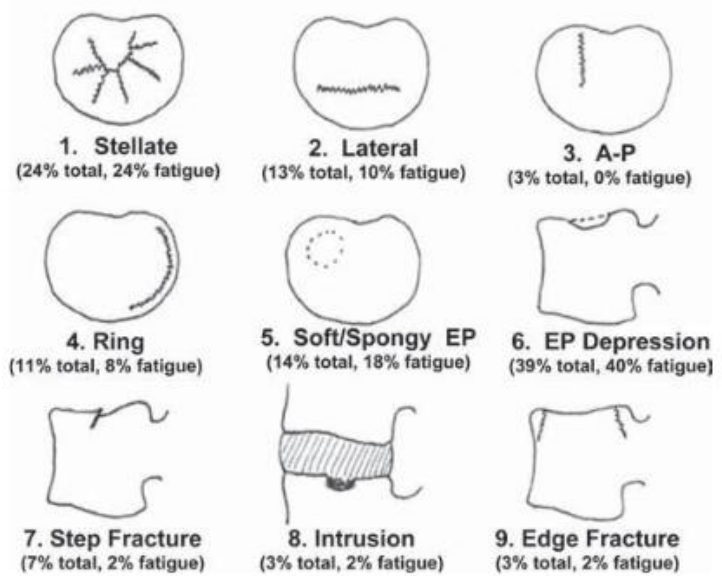


Figure 12. Vertebral endplate fracture classification system (from Gallagher S. et al. 2005)

3.2. BURST FRACTURES

Produced by compression forces of high magnitude.

Anterior and posterior vertebral body failure, body height loss and retropulsión.

T11 to L2 is biomechanically the weakest segment against this fracture

Lower neurological signs than in cervical spine burst fracture

Can be stabilized by the posterior longitudinal ligament

Classified as mechanical, neurological or combined

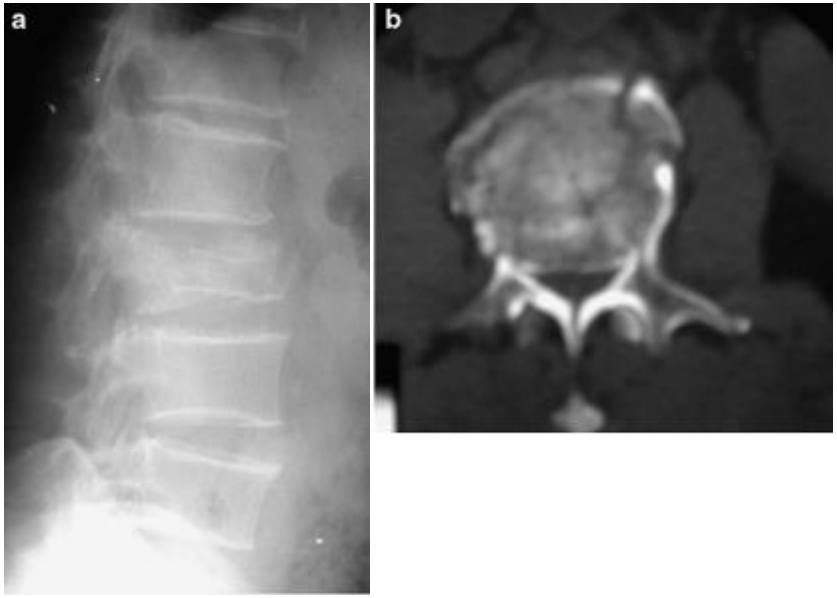


Figure 13. a) Lateral radiograph shows an L2 burst fracture in a 59-year-old man. b) Axial CT image demonstrates 70% canal compromise. Image from Altay M. et al. 2007.

3.3. WEDGE FRACTURES

Produced by an axial compression force combined with a momento of flexion

Mechanical failure in the anterior region of the vertebral body

The line of action of the compresive force is placed anterior to the vertebral body

Usually damage of posterior ligaments

Common fracture in osteoporosis patients

T12-L1 has the highest fracture incidence due to increased load-bearing

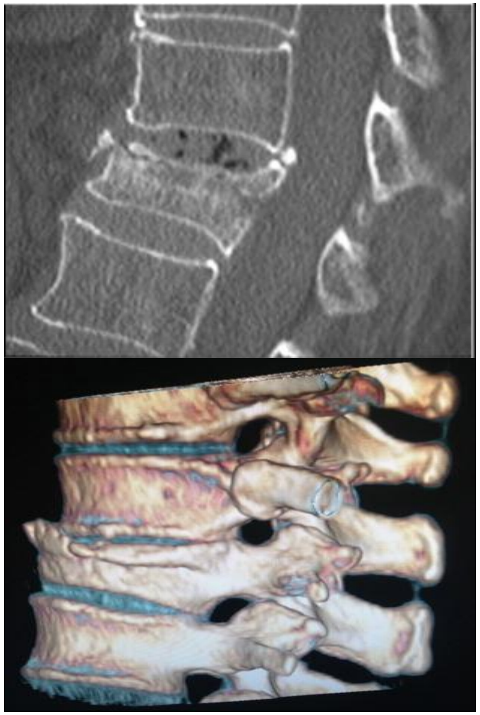


Figure 14. Compression wedge fracture from sagittal multiplanar reconstruction. The injurie no involvement in the posterior elements. Image from González-Montané J.L. 2014.

3.4. SEAT-BELT INJURIES

Common lesión of thoracolumbar junction area

Fracture result of a hyperflexion mixed with a distraction force

Consequences as ligament damage, bone fracture or fracture-dislocation bone

Ligamental disruption with facet dislocation is unstable

3.4. SEAT-BELT INJURIES

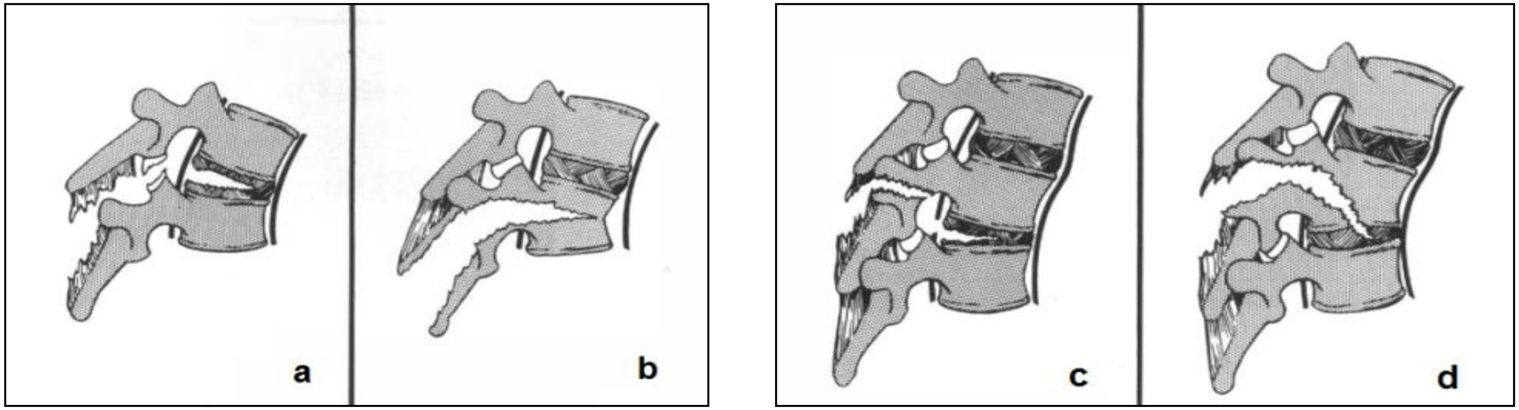


Figure 15. Seat-belt fracture classification. a: pure ligamentous disruption with facet dislocation. b: Chance fracture with horizontal splitting of bone. c: Injury of posterior ligamentous complex, pedicle and disc. d: Injury of posterior ligamentous complex, pedicle, body and disc injury. a and b are injuries at one level. c and d are injuries in two levels. Image from Yu WY. et al. 1986

B. Biomechanical alterations of the spine

Part 4. Biomechanical considerations after spine intervention

4.1. UPPER CERVICAL INTERVENTION

Occiput-C1-C2 complex

- The most mobile portion of the cervical spine
- It makes the largest contribution to flexion-extension

C1-C2 complex

- Axial rotation as its main movement contribution

4.1. UPPER CERVICAL INTERVENTION

Occipitocervical fusion

- Main indication for this procedure: instability of the craniocervical junction.
- Disorders as trauma, malignancy, rheumatoid arthritis, congenital anoalies, of ifectious diseases.

Prevents

- Compression of the neural structures.
- Cervical deformities.
- Reduction of pain.

Complications

- Cervical mobility restriction.
- Dysnea or dysphagia.

4.1. UPPER CERVICAL INTERVENTION

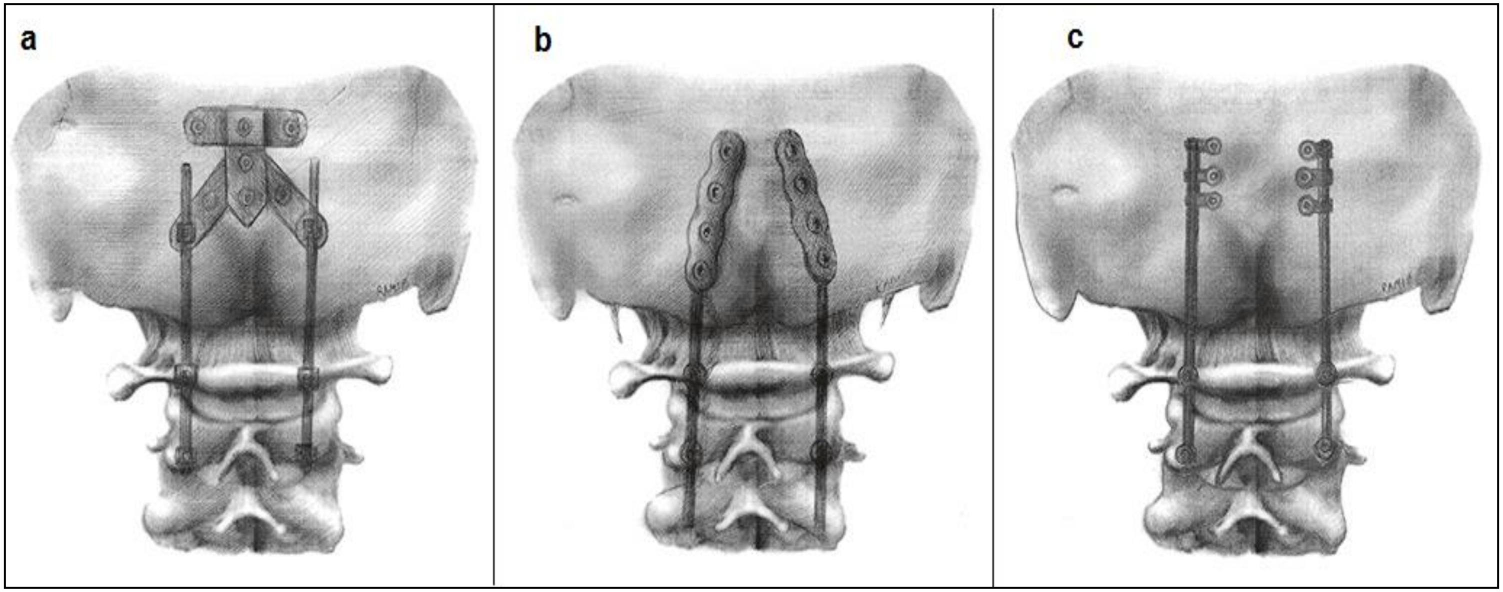


Figure 16. The most common screw-based constructs. (a) Occipital plate. (b) Hinged rods with an integrated occipital plate end. (c) Eyelet connectors directed medially. Image from Ashafai NS. et al. 2019.

4.2. LOWER CERVICAL INTERVENTION

Immobilization or joint replacement

- Can affect adjacent levels due to biomechanical changes.

Research experiences

- No average segmental motion difference was observed between interventions (Nabhan A. et al)
- 25.6% patients with anterior cervical fusión would develop new syntomatic disease in adjacent segments within 10 years.

4.2. LOWER CERVICAL INTERVENTION

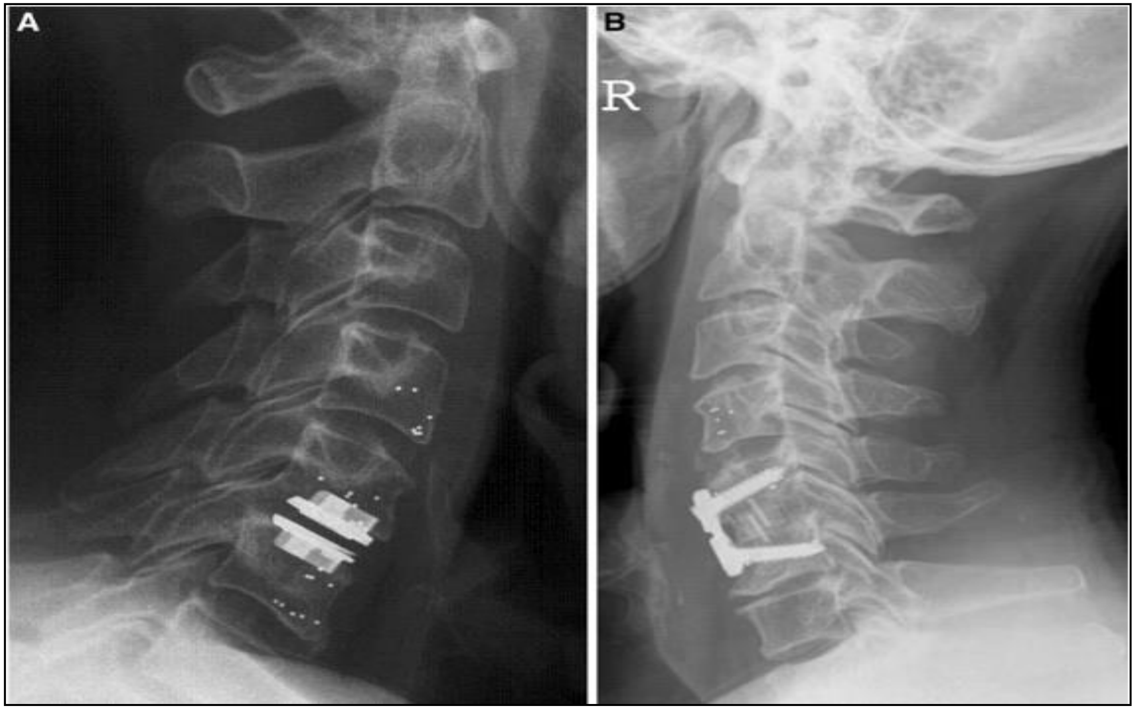


Figure 17. Lateral X-ray of acervical spine showing thetantalum markers of thevertebral body C4, C5 and C6. a - Incorporated tantalum markers after disc replacement. b - The same with titanium plate fixation. Image from the study of Nabhan A. et al (2011).

4.3. THORACIC AND LUMBAR INTERVENTION

Spinal fusion

- T12-L1 level is the most usual intervention zone.
- Satisfactory short termed technique.
- Long term difficulties in adjacent levels.
- Syntomatic degeneration is one of the most frequent reason for further surgery.

Spino-pelvic aligment

- Affects spinal loading.
- Its relation with disc degeneration and adjacent segment degeneration are highly discussed.
- Lumbar hypolordosis is an independent risk factor for disc degeneration progression.

4.3. THORACIC AND LUMBAR INTERVENTION

Research experiences

- Se Jin Choi et al. (2018) study suggest that L4-5 and L5-S1 contribute to spinal extensión and lateral flexion ROM but not a significat role in spinal flexion movements.
- Obid P. et al (2017) study determines the loss of mobility segment by segment in three systems of instrumentation for lumbar spine fusión from T11 to L5.
- Is not proved that hybrid constructs limit the ROM more than rigid instrumentation.

4.3. THORACIC AND LUMBAR INTERVENTION

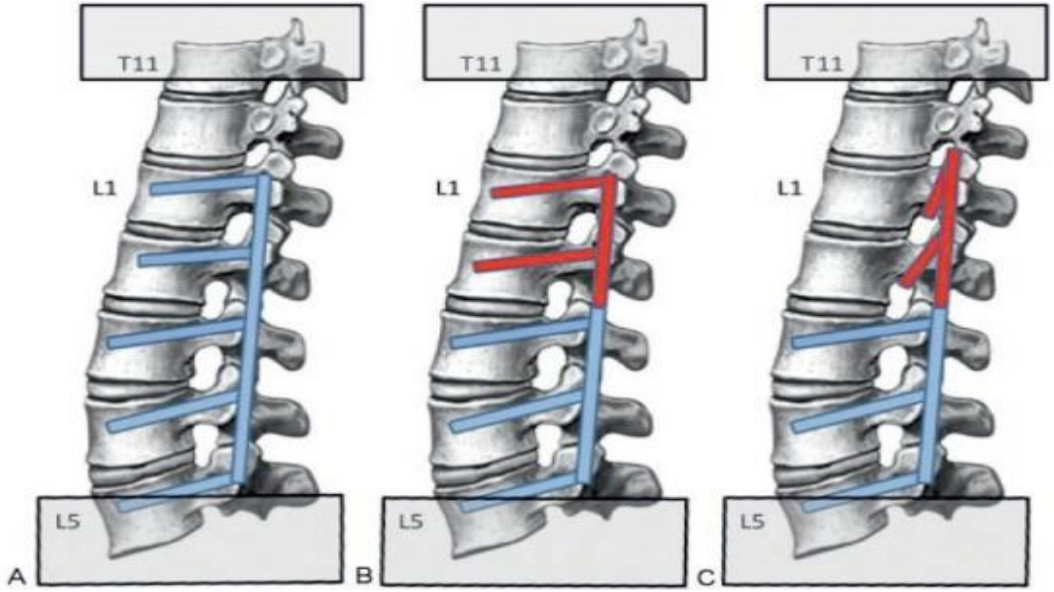


Figure 18. Schematic overview showing the setup of the three test groups from study of Obid P. et al. (2017). (A) Group R: four-level rigid instrumentation; (B) group D: two-level rigid instrumentation (L3–L5) combined with the Elaspine system (Spinelab AG, Winterthur, Switzerland) (L1–L3); and (C) group H: two-level rigid instrumentation (L3–L5) combined with laminar hooks (L1–L3).

5. KEY IDEAS

•There are different types of injures on the cervical spine depending on the direction and magnitude of the force that is applied on the spine: flexion, extension, compresion, distraction, rotation.

•The upper cervcal spine injuries commonly result in death (about 40%) and because the type of injury can damage important areas of the central nervous system. The most referenced injuries in the literature are: Fractures of condyles of the occipital bone, Atlantoocipital dislocation, Fractures of the Atlas, Atlantoaxial dislocation, and Franctures of the axis.

•Lower cervical spine injuries represent a broad array of injury patterns and degrees of instability, being the most common: the Burst fractures, the Teardrop fractures, the Midsagittal cleavage fracture, the Disruption of the facet joints, the Spinous apophysis fracture, and the Whiplash-associated disorder.

5. KEY IDEAS

•The great difference between the cervical spine and the thoracic and lumbar areas that the latter has a stiffness that the cervical spine does not have, so the mechanisms of injury are very different between them.

•In the thoracic and lumbar regions the most common injuries are usually: the Endplate fractures, the Burst fractures, the Wedge fractures, and the Seat-belt injuries typical in the thoracolumbar junction.

•Medical treatments applied to spinal injuries can usually be conservative or surgical, depending on the severity of the injury and the stability of the damaged vertebral segment. Different medical decisions can have an important impact on functionality, since it will produce biomechanical changes in vertebral function in order to repair or stabilize the lesion.

5. KEY IDEAS

•In the upper cervical spine, immobilization techniques can reach restrict cervical mobility until 40% of total cervical flexion-extension, and if occiput-C1 and C2 are involved, the limitation can reach 60% of total cervical rotation and 10% of total lateral bending.

•In the lower cervical spine, more severe interventions such as fusion bring with them the adjacent segment disease, inducing stress, load, and intradiscal pressure at levels adjacent to the fusion site.

•In the thoracic and lumbar spine, more severe interventions also limit mobility, being critical fusion sites for loss of function T11-L5, L4-L5, and L5-S1.

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