Development of innovative training solutions in the field of functional evaluation aimed at updating of the

MODULE BIOMECHANICS OF SPINE

Didactic Unit B

Topic: Biomechanical alterations of the spine

Index

1. Objectives

In this didactic unit, the learner will be acquainted with the theoretical aspects of biomechanics of different segments of spine in accordance to main pathologies and possible surgical interventions and treatment procedures.

The objectives of this Didactic Unit are:

1. To learn the biomechanics behind the main cervical, thoracic and lumbar spine pathologies.

2. To know the biomechanics considerations related to the main interventions techniques of the spine injuries.

2. Biomechanics of the main injuries of the cervical spine

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 (and lateral-flexion), extension, compression, shear, and rotation (Figure 1) are the primary external forces than can be applied to the cervical spine. Due to the function of this segment itself (to position the head while maintaining stability and protecting the spinal cord), the lesions of the cervical spine can vary from lesions the minor to life-threatening.

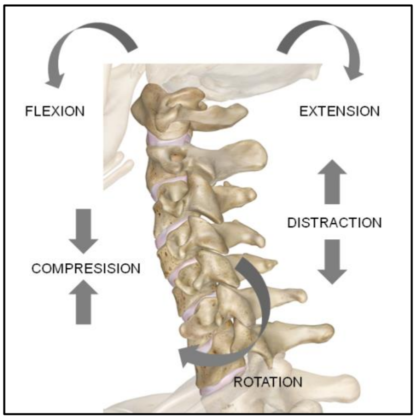

Figure 1 - Injury mechanisms of the cervical spine. (Reproduced from Cusick JF, Yoganandan N (2002) Biomechanics of the cervical spine 4: major injuries. Clin Biomech (Bristol, Avon) 17: 1–20.) Drawing extracted from www.innerbody.com.

2.1 Injuries of the upper cervical spine

This kind of injuries represent 1/3 of all cervical spine injuries and approximately 40% result by death. The level of the cervical spine that can be injured are:

- Fractures of condyles of the occipital bone
- Atlantoocipital dislocation
- Fractures of the Atlas
- Atlantoaxial dislocation
- Franctures of the axis.

Most of the cases in younger patients are caused by high-energy trauma, while by elderly people, because of the osteoporosis, is needed much less energy and even simple falls can cause the injury of the cervical spine. That is why the etiology of injuries can be different. In younger patients are caused mainly by car accidents, motorcycle and bicycle accidents and pedestrian crashes by car and in elderly populations are the main reason falls.

The mechanism of the injury is axial force, hyperflexion, hyperextension, latero-flexion, rotation and combination of all. Clinical symptoms can vary from the neck pain, restricted range of motion, antalgic position of the head, injury of the cranial nerves and different neurologic symptoms from the irritation of nerves to quadriplegia.

A dislocation is defined as “displacement of a bone from its natural position in the joint”. This is where the two bones that form a joint fully separate from each other.

A subluxation is basically defined as “a partial dislocation”. It can be no less painful than a full dislocation, but the two bones that form the joint are still partially in contact with each other.

2.1.1. Fractures of condyles of the occipital bone

Occipital condyle fractures (OCFs) are rare traumatic injuries and are important because the may be associated with instability of the occipitoatlantoaxial joint complex. The OCFs can easily go undetected due to variable presentation and the inability to diagnose them with plain radiographs, however they are detected with the Computed Tomography scan (CT scan) beeing the gold standar to identify any displacement (Figure 2) of bleending in the affected area.

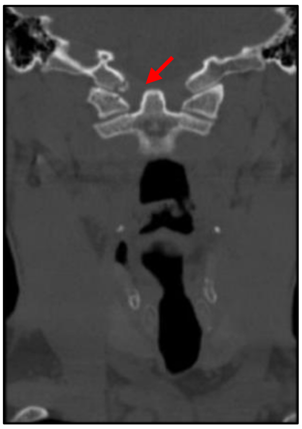

Figure 2 - Minimally displaced fracture of the right inferior medial occipital condyle. Spiral CT scan of the cervical spine was performed from the base of the skull down to the thoracic inlet at a slice thickness of 2.5 mm. Image from Muhammad Waseem *et al*. 2014.

The classification of OCFs most used is from Anderson and Montesano (1988), who considered fracture morphology, pertinent anatomy, and biomechanics (Table 1). In 1997, Tuli *et al*. proposed a new classification system considering imaging to detect injury to ligaments. This second classification regroups the different types of fractures of Anderson and Montesano (Figure 3) and proposed a new category for displaced fractures.

Table 1 - Anderson and Montesano (1988) Classification of Occipital Condyle Fractures

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

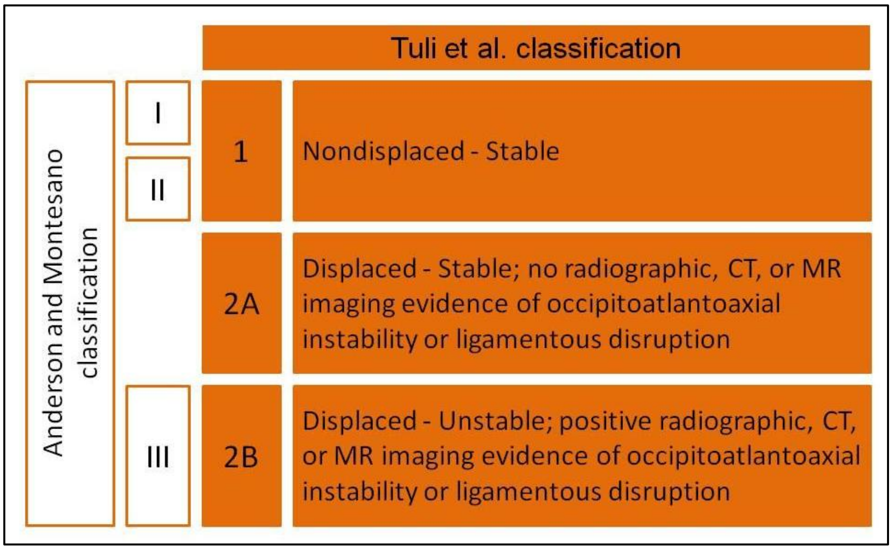

Figure 3 - Tuli et al. (1997) Classification of Occipital Condyle Fractures. From Hanson J. et al. 2002.

2.1.2 Atlantoocipital dislocation

Atlantoocipital dislocation (AOD) or occipitocervical dissociation (OCD) involves the dissociation of the occiput from the cervical spine. This occurs mainly when distraction and extension forces are applied to the occiput in relation to the atlas, although the injury can also occur due to hyperflexion, lateral flexion, or a combination of all of them. This injury mechanism can occur in rapid decelerations in motor vehicle, beeing a common cuase of death in car accidents due to the transection of the brain stem or the vertebral arteries that the AOD may cause. The ODA is more frequent in children since the different relationship between head and body in childhood enhances the traumatic inertia necessary to produce this type of injury. Children's occipital condyles are smaller, their heads are larger relative to their bodies, the atlantooccipital ligaments are more lax, and the articulating planes of the craniovertebral

junctions are more horizontal as compared to adults, which is summarized in that the craniovertebral junction are less stable in children than those of adults.
The AOD was classified by Traynelis et al. in 1986 in three types of injuries (Figure 4). Type I is an anterior displacement of the occiput relative to the atlas, Type II is a distraction of the occiput from the atlas, and Type III is a posterior displacement of the occiput relative to the atlas.

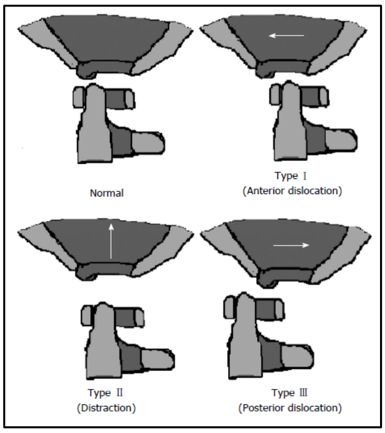

Figure 4 - The Traynelis classification for Atlantoocipital dislocation. Image from Hall GC. et al. 2015.

2.1.3. Fractures of the Atlas

Atlas fractures account for 3-13% of all cervical spine injuries and are associated with traumatic axial loading of the head through the occiput on to the lateral masses of C1. However, other forces can cause fracture of the atlas, including extension, flexion, and rotation forces. While these fractures are frequently described as Jefferson fractures, the Jefferson fracture properly refers to a particular four part fracture of the atlas, that its with bilateral fractures of the anterior and posterior arches of the atlas (Figure 5.A). Depending on the different combinations of forces applied concomitantly with axial compression, an isolated anterior (Figure 5.C) or posterior arch fracture (Figure 5.D) or a unilateral lateral mass fracture (Figure 5.B) can occur. Associated with the fracture of Atlas, transverse ligament injury can occur, allowing excessive C1–C2 mobility.

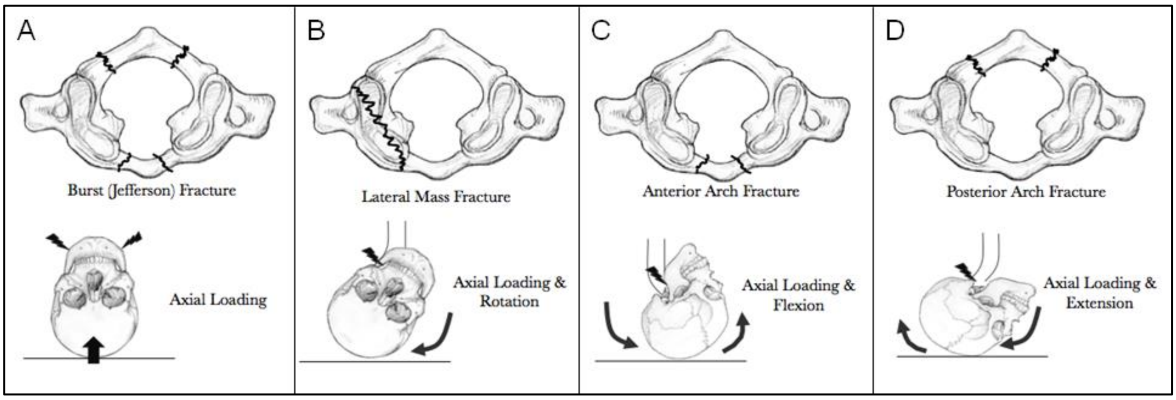

Figure 5 - Atlas vertebral fractures. A: Jefferson fracture produced by axial force. B:Lateral mass fracture produced by axial loading and rotation. C: Anterior arch fracture produced by axial and flexion

force. D: Posterior arch fracture produce by axial and extension force. Image from: www.ebconsult.com.

2.1.4. Atlantoaxial dislocation

Atlantoaxial dislocation refers to a loss of stability between the atlas and axis (C1–C2), resulting in loss of normal articulation. The atlantoaxial joints can lose stable articulation from traumatic, inflammatory, idiopathic, or congenital abnormalities. Caused by a traumatic event without pre-existing injury is an extremely rare pathologic entity. It arises from a flexion/shear force that causes disruption of the transverse ligament of the atlas. Rarely, injury of the transverse ligament can also involve simultaneous disruption of the alar and apical ligaments. In these ligamentous dislocations, the atlas will lose articulation with the dens, and the anterior atlantal arch may translate completely superiorly and posteriorly with significant damage to the ligaments.

The presentation of atlantoaxial dislocation may range from minor axial neck pain to death. Table 2 shows the clinical signs derived from this lesion.

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

This lesion can be defined with radiographic measurements of atlantoaxial joint articulation using the atlantodental interval (ADI). The ADI is a small slitlike space (horizontal distance) between the anterior arch of the atlas and the dens of the axis. Flexion and extension radiographs of the neck allow for the measurement of the ADI and to determine whether the atlantoaxial joint reduces itself in these positions. The ADI is measured froma line projected superiorly along the anterior border to the axis body to the anterior arch of the atlas (Figure 6).

The ADI is normally constant in distance during movement of the head and generally does not exceed 3 mm for adults and 5 mm for children. The majority (70%) of clinical atlantoaxial dislocation presentations are due to anterior dislocations. Anterior dislocation increases the ADI, decreasing the space available for the spinal cord, which is measured from the posterior aspect of the dens to the anterior aspect of the posterior atlantal ring.41 A decrease in the space available for the spinal cord increases the risk of spinal cord compression as well as neurologic sequelae. Of note, the space available for the spinal cord of less than 14 mm predicts the development of paralysis, and has been shown to correlatewith severity of paralysis.

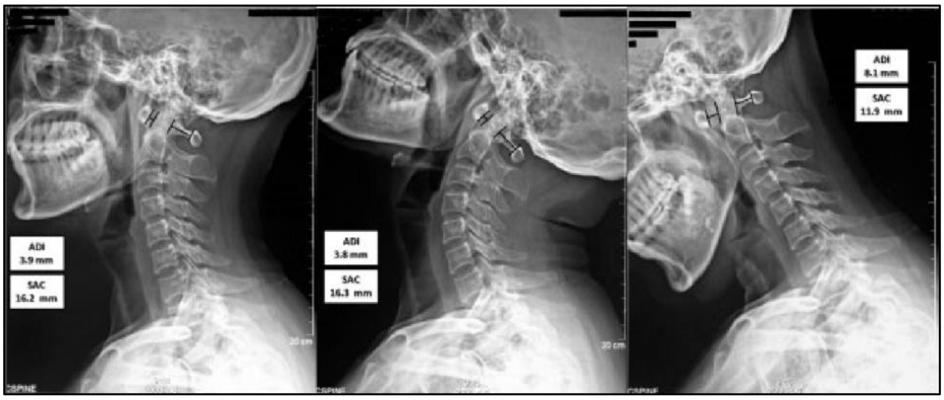

Figure 6 - Neutral (left), extension (center), and flexion (right) lateral X-rays showing the atlantodental interval (ADI) anterior to the odontoid process and the space available for spinal cord posteriorly. The ADI is above the average for adults of 3 mmand is slightly reduced in extension, but severely increased in flexion. This patient's space available for spinal cord (SAC) reducing to below 14 mm indicates risk of paralysis. Image from Yang *et al*. 2014.

2.1.5. Fractures of the axis

Odontoid fractures are among the most common fractures of the cervical spine, accounting for about 10% of all cervical spine injuries. These injuries tend to be more silent clinically unless they cause spinal cord compression, which is rare due to the relatively large SAC at this level in the cervical spine. Odontoid fractures can be caused by both extension and flexion forces. When a flexion/shear force is the cause of an odontoid fracture, there is anterior displacement of C1 on C2, although this may also be seen as sequelae of an extension injury. Odontoid fractures are classified by the Anderson and D′Alonzo classification:

- Type 1 fractures occur at the tip of the odontoid and are typically treated nonoperatively.
- Type 2 fractures are through the waist of the odontoid process. These fractures have a high rate of nonunion due to a poor vascular supply. Type 2 fractures are usually treated surgically (halo versus C1–C2 posterior fusion), unless they occur in an elderly patient with comorbidities that prevent surgery.
- Type 3 fractures extend into the C2 body, and can typically be treated nonsurgically.

Additionally, the odontoid process accounts for about 37% of the stiffness of the C1–C2 complex; the surrounding ligaments (alar ligament, transverse ligament, anterior and posterior longitudinal ligament) account for the remaining stiffness. If an injury to these ligaments is seen on magnetic resonance imaging (MRI) in addition to odontoid fracture, it could indicate an unstable C1–C2 complex; this situation may necessitate surgery.

Another class of C2 injury is the traumatic spondylolisthesis of the axis, describes a fracture of the elongared pars interarticulares of the posterior arch of the second cervical vertebra. It has been historically attributed to hyperextension and distraction (tension and rearward rotation of the head), which can result from blows to the face and chin or from judicial hanging. To the traumatic spondylolisthesis of the axis is colled Hangman's Fracture. Rupture of the C2-C3 intervertebral disc accompanies the pars fracture and creates dramatic instability in the more serious forms of the injury. Automobile crashes have replaced hangings as the most common cause of these often fatal injuries.

When the upper cervical spine is destabilized and sagittal balance is compromised, the lower cervical spine compensates, which may lead to subaxial pathology and deformities. When atlantoaxial dislocation causes diminished lordosis at the C0–C2 segment, the subaxial cervical region compensates with increased lordosis to maintain balance. Some patients with end-stage changes can develop kyphosis at the occipitoaxial segment together with extreme hyperlordosis subaxially, resulting in swan neck deformity.

2.2 Injuries of the lower cervical spine

Subaxial cervical spine or lower cervical spine injuries represent a broad array of injury patterns and degrees of instability between C3 and T1 levels. This section describes the most referenced lesions in the literature and the biomechanics behind each lesion.

2.2.1 Burst fractures

Axial loading of the cervical spine with the neck in neutral position will cause a compression fracture or a burst fracture of the vertebral body and can occurs in the lower cervical vertebrae from C3 to T1 levels. There is no flexion force applied, and thus the posterior ligamentous complex should be intact. As the axial compression is transmitted through the vertebral body, an anterior wedge deformity of the vertebral body occurs. If this force continues, the posterior portion of the vertebral body will be retropulsed into the canal, potentially causing a spinal cord injury.

2.2.2 Teardrop fracture

Teardrop fractures occur when a combination of flexion and axial compression forces acts on the spinal column simultaneously. Most commonly, this injury can occur when a person dives head first into a shallow pool. The anterior column of the cervical spine fails in compression and the posterior portion of the vertebral body is retropulsed into the canal. In the subaxial cervical spine there is decreased room available for the spinal cord, often leading to cord compression and spinal cord injury. The most severe pattern results in posterior subluxation of the posterior vertebral body into the canal; acute kyphosis; and disruption of the anterior and posterior longitudinal ligament, due to this, the teardrop are severe injuries associated with a high incidence of quadriplegia.

2.2.3 Midsagittal cleavage fracture

One variation of burst fractures is a midsagittal cleavage fracture. The most common sites of these fractures in the lower cervical spine are C4, C5, and C6. Because the vertebrae are a closed bony ring, complete fracture through the anterior and posture cortex of the vertebral body is often accompanied by fractures to the lamina, and disruption of the facet joints. They are grossly unstable injuries and bony fragments, often trapezoidal in shape, are displaced posteriorly and impinge on the spinal cord.

2.2.4 Disruption of the facet joints

Facet dislocation occurs when a flexion/distraction force combined with rotatory forces are applied to the cervical spine. It usually affects the C4–C5 or C5–C6 levels. The inferior articular facet of the higher cervical level moves over the superior articular facet of the lower cervical level. This can occur unilaterally or bilaterally, and may also involve a fracture of one or both facets and/or lateral masses:

- In unilateral facet dislocations, the forces acting on the cervical spine are mostly flexion and rotatory in nature. The presenting symptom is often a monoradiculopathy of the exitins nerve root.
- In bilateral facet dislocations there is less of a rotatary force and more of a pire flexion/distraction force acting on the cervical spine. This allows for the inferior articular facet of the upper cervical level to dislocate anteriorly over the superior articular facet of the lower cervical level bilaterally.

2.2.5 Spinous apophysis fracture

It consists of the rupture of one or more spinous processes in the lower cervical area. it is usually referred to as excavator fracture since it occurs in people who perform this activity. The injury mechanism consists of a high magnitude force transmitted from the shoulder girdle to the spinous apophysis through the muscles. It can also occur due to muscle fatigue. The resulting vector of the force transmitted to the spinous apophysis is horizontal, which initially acts to attach the shoulder girdle to the spine and to the thoracic cage.

Most of these fractures are located in C6 and C7 levels due to these are the vertebrea with the greatest length spinous processes and therefore, are not able to withstand high flector moments generated by the horizontal forces, producing a fracture of spinous processes close to the vertebral body.

2.2.6 Whiplash-associated dirsorder

The term “whiplash-associated disorder” is used to describe the clinical manifestations of whiplash injury. Whiplash is an acceleration-deceleration mechanism of energy transfer to the neck. It may result from rear end or side-impact motor vehicle collisions, but can also occur during diving or other mishaps.

Luan F. et al (2000), Established the kinematic sequence that occurs in the head and neck after an impact is as follows (Figure 7):

1) In the first stage (0-100 ms after the onset of impact), flexural deformation of the neck is observed along with a loss of cervical lordosis. The initial lordotic neck at 20 ms becomes straight. After 50 ms, both upper and lower cervical spines are subjected to a flexion moment. The shear force is transmitted initially through the lower levels and eventually through the upper levels but does not reach the superior end of the cervical spine. The axial force then changes from compressive to tensile at about the 60 ms.
2) In the second stage (100-130 ms), the cervical spine assumes an S-shaped curve as the lower vertebrae begin to extend and gradually causes the upper vertebrae to extend. Eventually, the straightened neck once again becomes lordotic. An extension moment occurs at the lower vertebrae, while a flexion moment acts at the upper levels. Shear forces are acting at all levels along with a tensile axial force.
3) During the final stage (after 130 ms), the entire neck is in extension due to extension moments at both ends. Shear forces and tensile axial forces continue to act at all levels. The shear forces throughout the loading phase may subject the lower FJCs to excessive stretch while initial cervical spine compression may cause facet joint capsules to locally compress and slide along the joint. The posterior-most regions of the joint compress more than the anterior-most regions, exhibiting a "pinching" mechanism. Excessive joint compression/sliding may also induce pain if these joints contain pain-sensitive structures.

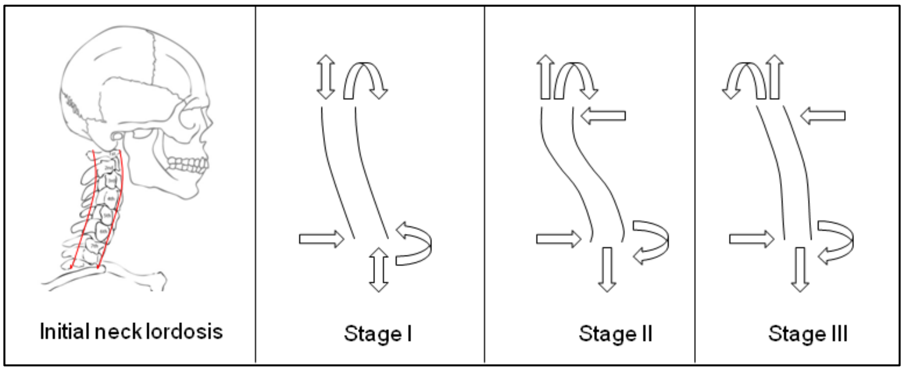

Figure 7 - Models of neck deformation, and force and moment diagrams at three stages of a rear-end impact. Image reproduced from Luan F. et al. 2009.

In a similar way, Kaneoka K. et al. (2002) tested to voluntary subjects seated on a sled to simulate car rear impact acceleration (Fig.3). Impact speed of 8km/h was used to study the head-neck-torso kinematics and cervical spine responses. The authors divided the responses into four phases: 1) Sled motion (0-40 ms): cervical motion has not occurred, 2) Neck axial force (40-100 ms): .

Table 3 - Phases and kinematics events of the neck, cervical spine and torso 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		

3. Biomechanics of the main injuries of the thoracic and lumbar spine

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.

3.1 Endplate fractures

Endplate fractures are produced by compressive forces and are located mainly in the thoracic and upper lumbar spine. They are caused by axial compression forces but can also occur due to a flexion force or a combination of them. There are three types of fractures that involve the endplates:

- Fractures located only in the central part of the endplate.
- Fractures located in the peripheral area, involves the external of cortical bone that lines the vertebral bodies.
- Transverse fractures that cross the endplate from part to part.

Endplate failure plays a primary role in the development of burst fractures, allowing the nucleus to breach the cranial endplate, increasing intervertebral pressure, and leading to an outward-directed displacement of the cortical shell with fragmentation.

3.2 Burst fractures

The forces responsible for vertebral burst (Figure 8) is a compression force of high magnitude, which are most commonly associated with falls and traffic accidents. The result of burst fracture are anterior and posterior body failure, body height loss and retropulsion of the posterior aspect of the vertebral body into the spinal canal. The thoracolumbar area is especially prone to this type of fractures, that is, from T11 to L2. In fact, it is considered biomechanically the weakest point in the spine due to this region represents the transition zone from a rigid segment to a mobile segment, lordotic posture and more sagitally oriented facet joints. Stability in this zone depends on the integrity of the ligaments and bony components.

Neurological deficit is lowest in thoracolumbar junction fractures when compared with the cervical spine, where de neurological damage is highest in patients with burst fractures independent of accident mechanism. The burst fracture can be stable or unstable, in part, depending on the indemnity of the posterior longitudinal ligament. Denis F. (1983) proposed that injury to the middle column *i.e.* the posterior portion of the vertebral body, posterior longitudinal ligament and posterior disc was sufficient to create instability. It is widely accepted that the posterior ligaments have probably failed if there is greater than 30° of kyphosis and/or 50% of vertebral body height loss on plain radiographs (Heary RF. et al. 2007). Denis F. (1983) also classified unstable fractures into three types: mechanical (1st degree), neurological (2nd degree) or combined mechanical/neurological (3rd degree).

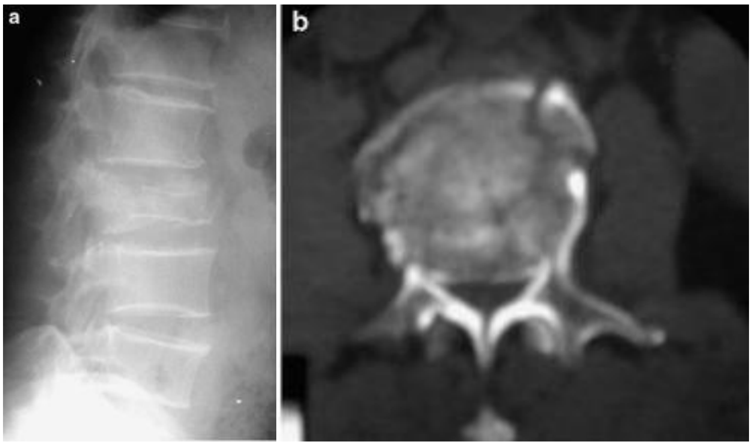

Figure 8 - a) Lateral radiograph shows an L2 burst fracture in a 59-year-old man. b) Axial CT image demonstrates 70% canal compromise. Image from Altay M. et al. 2007.

3.3 Wedge fractures

Wedged fractures of the vertebral bodies are an injury that is produced by an axial compression force applied to the vertebral body combined with a moment of flexion that causes the mechanical failure of the anterior region of the vertebral body. They are also called compression fractures. For this type of fracture to occur, the line of action of the compressive force must be placed anterior to the center of the vertebral body. Often, this type of fractures can be accompanied by the damage of the posterior ligaments that must also contain the flexor moments produced by the axial force that impacts the anterior area of the vertebra.

Figure 9 - Compression wedge fracture from sagittal multiplanar reconstruction. The injurie no involvement in the posterior elements. Image from González-Montané J.L. 2014.

This type of lesions is common in people with osteoporosis. In this type of patient, spinal fractures occur more often at the mid-thoracic (T7-T8) and thoracolumbar (T11-L1) regions than elsewhere in the spine. The reasons underlying this bimodal distribution are probably due to the variations in the curvature of the spine where the maximum thoracic kyphosis occurs around T7-T8, this may result in greater anterior bending moments and increase risk of anterior wedge fractures in this region. At the thoracolumbar junction, the higher incidence of fracture at T12-L1 is due to increased load-bearing by the vertebral bodies, as the ribcage no longer helps support superincumbent loads at these spinal levels.

3.4 Seat-belt injuries

Seat-belt injury are typical lesions of the thoracolumbar junction as a result of a hyperflexion centered in said area that at the same time causes a distraction force from the most posterior area of the vertebra. The injury mechanism is a rapid deceleration of a person traveling in a vehicle whose previous movement is retained by the seatbelt. The consequences of this injury can vary from damage of ligament structures, to fracture of bone elements or the fracture-dislocation combination.

Denis (1985) classified seat belt fractures into four types (Figure 10). The first type is a pure ligamentous disruption with facet dislocation; the second type is the classical Chance fracture with horizontal splitting of bone; the third type is a twolevel injury through the posterior ligamentous complex, pedicle and disc and the fourth type is a two-level injury through the posterior ligamentous complex, pedicle, body and disc. Whereas there is general agreement that pure ligamentous injury with a facet dislocation type of seat belt fracture is unstable, there is less agreement regarding the stability of the other types of seat belt injuries.

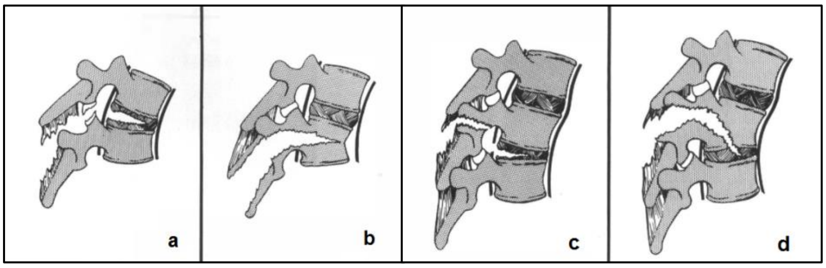

Figure 10 - Seat-belt fracture classification. a: pure ligamentous disruption with facet dislocation. b: Chance fracture with horizontal splitting of bone. c: Injury of posterior ligamentous complex, pedicle and disc. d: Injury of posterior ligamentous complex, pedicle, body and disc injury. a and b are injuries at one level. c and d are injuries in two levels. Image from Yu WY. et al. 1986.

4. Biomechanical considerations related to spine interventions

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. In this chapter we will review the possible biomechanical consequences of the most severe interventions in the spinal segments most susceptible to injury.

4.1 Upper cervical intervention

The occiput–C1–C2 complex is the most mobile portion of the cervical spine. The occiput–C1 motion segment makes the largest contribution to flexion (21°) and extension (3.5°), while the primary movement of the C1–C2 motion segment is axial rotation (23.3–38.8° per side). The main indication for occipitocervical fusion is instability of the craniocervical junction. Many disorders can cause instability of this complex such as trauma (Atlanto-occipital dislocation, occipital condyle fracture, atlas and axis fractures), malignancy, rheumatoid arthritis, congenital anomalies, or infectious diseases. The posterior internal stabilization prevents compression of the neural structures, enables correction of cervical deformity and reduces pain. Currently, screw-based constructs are the most popular option (Figure 11).

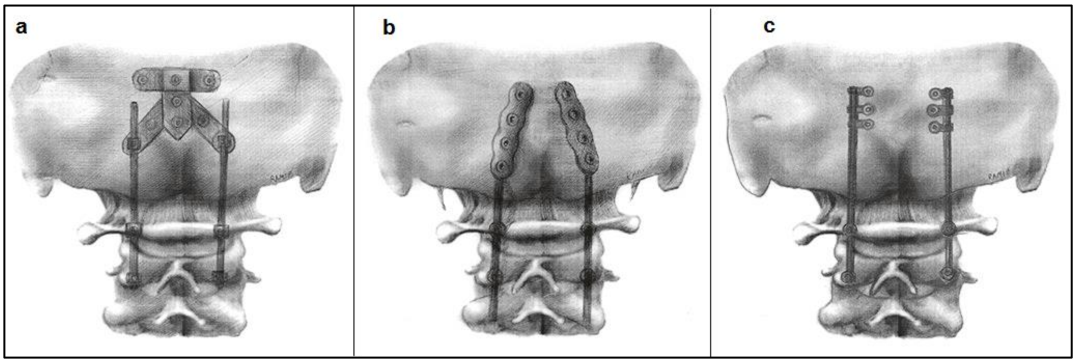

Figure 11 - The most common screw-based constructs. (a) Occipital plate. (b) Hinged rods with an integrated occipital plate end. (c) Eyelet connectors directed medially. Image from Ashafai NS. et al. 2019.

The kinematics complications from the occipitocervical fusion are that technique can restrict cervical mobility until 40% of total cervical flexion–extension, 60% of total cervical rotation and 10% of total cervical lateral bending, if the occiput-C1 and C2 are involved. Also, the excessive flexion results in the patient having an impaired line of sight and swallowing difficulties. Postoperative dyspnea and/or dysphagia after occipitocervical fusion are rare but pose an obstacle to activities of daily living and are occasionally lifethreatening. Although cervical flexed alignment has been thought to be a major factor for dyspnea and/or dysphagia, the mechanical stenosis of the oropharyngeal space also contribute to this problem after surgery of occipitocervical fusion. A decrease in the O-C2 angle of 10º cause a reduction of the oropharyngeal airway space in the neutral position of approximately 37%.

Recently, a study compared the procedures of posterior fixation of the Atlantoaxial versus occipitocervical joint. The atlantoaxial is the more demanding procedure compared to the occipitocervical fusion but provides greater range of motion by preserving the C0/C1 motion segment. Occipitocervical fusion leads to further and considerable limitation of movement compared to atlantoaxial fusion alone. After occipitocervical fusion, there is virtually no extension, flexion, and rotation in the upper cervical spine.

4.2 Lower cervical intervention

In the lower cervical spine, there are different considerations to take into account. Immobilization or joint replacement can affect adjacent levels due to biomechanical changes that occur after the intervention. Nabhan A. et al (2011) analyze the possible effects at the levels adjacent to the joint disc replacement versus anterior cervical discectomy and fusion (Figure 12) in people with symptomatic degenerative cervical disc disease. In this study, at a mean follow-up of 12 months, therewas no change in the average segmental motion immediately cranial to the disc prosthesis, whereas there was an increase in average segmental motion immediately cranial to the fusion but without a significant difference.

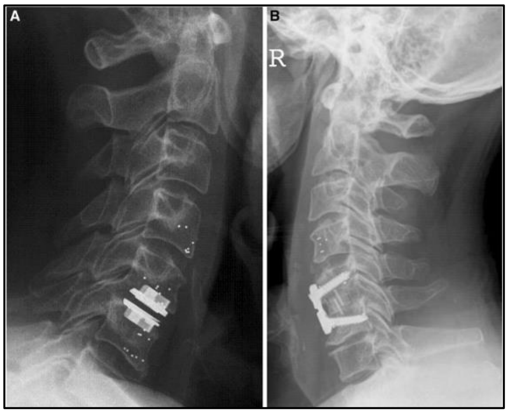

Figure 12 - Lateral X-ray of acervical spine showing thetantalum markers of thevertebral body C4, C5 and C6. a - Incorporated tantalum markers after disc replacement. b - The same with titanium plate fixation. Image from the study of Nabhan A. et al (2011).

It is supposed that the presence of fusion could increase load and segmental range of motion at adjacent levels and cause localized trauma with subsequent accelerated disc degeneration. There are many potentially important factors associated with the development of adjacent segment disease beside to the increased segmental motion: stress, load, and intradiscal pressure at levels adjacent to the fusion site. Hilibrand et al. (1999) predicted that in 25.6% of the patients who underwent anterior cervical fusion, new symptomatic disease would occur at an adjacent segment within 10 years of the operation.

Similar to the study by Nabhan A. et al. (2011), the authors Ghobrial GM. et al (2019) compare the consequences at the levels underlying both techniques but in a 10-year prospective study. They funded that compared with anterior cervical discectomy and fusion, fewer patients with cervical disc arthoplasty required surgery for symptomatic adjacent level degeneration, but this did not achieve statistical significance. However, when data from 2 prospective, randomized studies with similar inclusion and exclusion criteria were combined to increase the power of the assessment, a significant difference in symptomatic adjacent level diseaserequiring surgery was observed at 7-yr follow-up.

4.3 Thoracic and lumbar intervention

The main cause of low back pain is due to the degeneration process. At the same time, one of the main surgical techniques used in this pathology is spinal fusion. Although in the short term the result of this technique is satisfactory, in the long term there are adverse events at the levels adjacent to the surgery. Among patients who require further surgery in subsequent medical examinations, symptomatic degeneration of the adjacent segment is one of the most frequent reasons.

Spino-pelvic alignment is known to affect spinal loading and has been increasingly discussed as being related to disc degeneration and adjacent segment degeneration in particular. Aberrant changes in mechanical loading are believed to adversely affect intervertebral cell and tissue biology and could subject adjacent discs to structural disruptions that initiate or contribute to disc degeneration. A recent clinical long term follow-up study furthermore identified lumbar hypolordosis as an independent risk factor for accelerated progression of disc degeneration, even without fusion.

On the other hand, depending on the level of the fusion, there may be a limitation of movement. This information is shown in the study by Se Jin Choi et al. (2018). In this work they determined that the ROM of lumbar extension was statistically affected by fusion at the L4/5 or L5/S1 level, like the ROM of lumbar lateral flexion. The ROM of lumbar lateral rotation was not affected by fusion at the L4/5 or L5/S1 level. The results suggest that the lower lumbar segments (L4/5 and especially L5/S1) contribute to spinal ROM (extension and lateral flexion), but these segments alone do not play significant roles in spinal flexion movements.

Similar to the work of Jin Choi et al. (2018), the study of Obid P. et al. (2017) determines the loss of mobility segment by segment in three systems of instrumentation for lumbar spine fusion from T11 to L5. The groups of this study were (Figure 13): (A) Rigid group: four-level rigid instrumentation; (B) Dynamic group: two-level rigid instrumentation (L3–L5) combined with the Elaspine system (Spinelab AG, Winterthur, Switzerland) (L1–L3); and (C) Hook group: two-level rigid instrumentation (L3–L5) combined with laminar hooks (L1–L3).

The hypothesis that hybrid constructs limit the ROM in the dynamic instrumented levels but allow more motion than the rigid instrumentation could not be proven. Both the Elaspine system and laminar hooks reduced the ROM in the instrumented levels close to that of the rigid instrumentation, resulting in similar increasing mobility in the segments adjacent to the instrumentation. Thus a dynamic system would not prevent the injuries of the adjacent levels that are observed in the fusions with rigid systems.

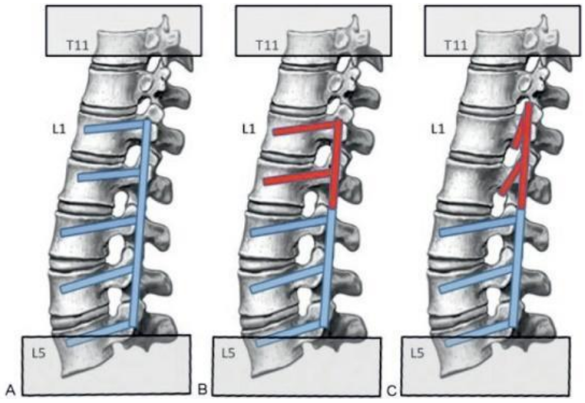

Figure 13 - Schematic overview showing the setup of the three test groups from study of Obid P. et al. (2017). (A) Group R: four-level rigid instrumentation; (B) group D: two-level rigid instrumentation (L3–L5) combined with the Elaspine system (Spinelab AG, Winterthur, Switzerland) (L1–L3); and (C) 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.
- 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.
- 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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