Spinal biomechanics – biomechanical considerations of spinal stability in the context of spinal injury

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Abstract

The concepts of spinal stability are central to the decision-making processes following spinal trauma. In order to completely understand spinal stability knowledge of the local anatomy and basic biomechanics of the spine is required. This article aims to revise these concepts and discuss their impact on stability of the spine. Mechanisms of injury in the cervical, thoracic and lumbar spine are discussed alongside the biomechanics of structural failure at each level. The basic concepts of clinical spinal stability are explored with comment on the biomechanical considerations for specific fracture patterns.

Keywords spinal biomechanics; spinal fracture; spinal injury; spinal stability

Introduction

Spinal injuries represent a small proportion of patients seen in most trauma units but the impact of injuries on a patient's life can be devastating, with high levels of morbidity and a significant impact on social function. Injury to the spinal column can occur as a result of high-energy trauma affecting healthy tissues or lower energy trauma affecting poor quality tissues, such as insufficiency fractures in osteoporotic vertebrae. Estimates suggest that there are 120 000 osteoporosis-related vertebral fractures in the UK each year.[1] Worldwide there may be up to 1.4 million clinical vertebral fractures each year with the majority occurring in Europe and the USA.[2] High-energy injuries are less common but are more likely to result in mechanical instability and traumatic spinal cord injury. Approximately, 1000 patients sustain a traumatic spinal cord injury each year in the UK.[3] Following an injury to the spinal column functional outcome is poor and leads to some of the lowest rates of return to work following injury of all major organ system trauma.[3]

The concept of spinal stability is at the centre of clinical decision making in the injured spine. Good understanding of the normal anatomy and function of the spine allows clinicians to appreciate potential mechanisms of injury and evaluate the need for medical intervention when stability is compromised. This article will outline the relevant anatomical and biomechanical knowledge required to help guide clinical decision-making following spinal injury, providing a background to the concepts involved in the management of region specific injuries discussed elsewhere in this symposium.

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Anatomy of the vertebral column

The vertebral column is a complex series of mobile vertebrae and intervertebral discs that connects the head to the pelvis. It is responsible for the transmission of load from the upper body to the lower limbs and is maintained in an upright posture by the ligaments and muscles that attach to it. There are 24 mobile segments (seven cervical, 12 thoracic and five lumbar vertebrae), 4–5 fused sacral vertebrae and four fused coccygeal vertebrae. These segments are connected in the anterior column by the intervertebral disc and in the posterior column by paired synovial facet joints. The anatomical variation seen throughout the spine allows an upright posture to be maintained and facilitates bipedal gait. The craniocervical junction transmits the weight of the head through the vertebrae alone and includes a more complex series of articulations. This allows greater range of movement in the cervical spine and a smaller footprint for muscular attachment at the base of the skull. The size of vertebral bodies increases from cranial to caudal levels, reflecting the increasing compressive forces placed upon them. The fused sacral vertebrae are larger still and facilitate load transfer to the pelvis and lower limbs.

At birth there is a global kyphosis (C-shape) to the spine and the normal sagittal profile develops as a child gains control of head movement and begins to walk. An anterior convexity (lordosis) develops in the cervical and lumbar regions and this is balanced by a posterior convexity (kyphosis) in the thoracic and sacral regions. In the coronal plane the spine should remain straight throughout growth. The development of sagittal profile continues until skeletal maturity. Normal thoracic kyphosis (measured between T5 and T12) is reported to be 10–40°, while normal lumbar lordosis (measured between T12 and S1) is considered normal between 40 and 60°. The functions of the vertebral column include:

- Protection of the spinal cord
- Providing a balance of stability and mobility during the maintenance of upright posture and during movement/ambulation
- Transmittance of movement to the upper and lower extremities

Cervical spine

There is considerable variation in the bony anatomy of the cervical spine and this allows a greater range of movement in this

Please cite this article in press as: Loughenbury PR, et al., Spinal biomechanics – biomechanical considerations of spinal stability in the context of spinal injury, Orthopaedics and Trauma (2016), http://dx.doi.org/10.1016/j.mporth.2016.07.010

region when compared to the rest of the vertebral column. From C3 to C7 (the subaxial cervical spine) there is a uniform morphology with a triangular vertebral foramen (surrounding the cord) and bilateral foramina transversaria through which the vertebral artery and vein pass. The foramen transversarium at C7 contains the vertebral vein but the artery lies outside of the foramen at this level. The spinous processes of C3–C6 have a distinctive bifid appearance. The articulation between cervical vertebrae (excluding between C1 and C2) consists of two posterior intervertebral facet joints, between the inferior and superior articulating facets, and the intervertebral disc. The facet joints (apophyseal or zygapophyseal joints) are synovial plane joints and are orientated in the coronal plane. This orientation allows for an increased range of flexion/extension, lateral bending and rotational movement. In the cervical spine the uncovertebral joints, an additional articulation between the uncinate processes located on the superior and inferior anterolateral aspects of the vertebral bodies, help to facilitate a greater range of rotation whilst limiting lateral flexion.

The bony anatomy of the atlanto-axial spine is highly specialized to allow movement of the head (Figure 1). The C1 vertebra (atlas) has no vertebral body and instead has an anterior arch and flattened posterior arch with a midline tubercle. The C2 vertebra (axis) does have a vertebral body and includes the odontoid peg, a superior extension of the body that sits behind the anterior arch of C1. This relationship is supported by a number of ligaments that provide stability to the articulation. The cruciate ligament includes a strong transverse portion that runs between the C1 lateral masses and passes behind the odontoid peg. This prevents C1/2 subluxation. There is also a smaller vertical portion that connects C2 to the base of the skull. The tip of the odontoid peg is connected to the base of the skull by the alar ligaments (attaching to the side of the odontoid peg) and by the weak apical ligament (attaching to the tip of the odontoid peg). These ligaments provide stability in lateral flexion and rotation. The articular processes between C1 and C2 are medially orientated and permit both flexion/extension and rotation movements.

Thoracolumbar spine

In the thoracolumbar spine, the intervertebral disc and paired posterior facet joints connect adjacent spinal levels. The thoracic vertebrae have a uniform morphology (Figure 2) including a circular vertebral foramen, which is smallest at T7. There is an increase in size of the vertebral bodies moving from cranial to caudal. They have long spinous processes that are inferiorly angulated and vertically orientated facet joints. They also have articulations with the ribcage through the costovertebral joints, articulations between facets on the vertebral bodies and the corresponding ribs. There are additional articulations (costal facets) between the ribs and the transverse processes of T1–T10. This series of articulations and the close relationship with the ribcage provide significant stability in the thoracic spine and resist movement in all directions. The lumbar vertebrae also experience a uniform morphology with stout, kidney shaped vertebral bodies and a triangular vertebral foramen. Facet joints are orientated in the sagittal plane and this allows flexion/extension movements and lateral flexion but provides resistance to rotational movements. A more coronal orientation is seen at the lumbosacral junction (L5/S1) and this provides resistance to anterior subluxation, a mechanism that counteracts the shear forces produced by the orientation of the disc space at this level.

Intervertebral discs

The intervertebral discs lie between adjacent vertebrae in the vertebral column. They act to transmit load and confer stability to the column. The disc consists of a central nucleus pulposus

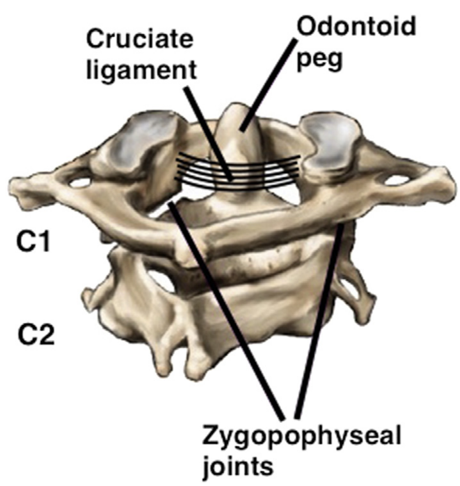

Figure 1 C1/C2 articulation.

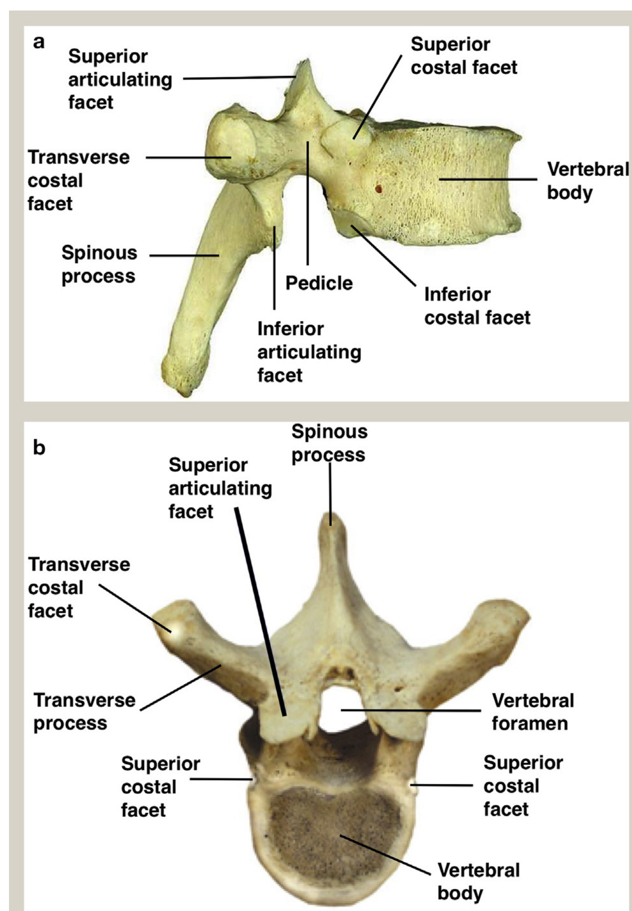

Figure 2 Vertebral anatomy of a typical thoracic vertebra (**a**) lateral view (**b**) superior view.

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