VERTEBRAL COLUMN JOINTS AND THEIR RANGE OF MOTION: ANATOMICAL AND CLINICAL ASPECTS

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Abstract

The vertebral column is a central biomechanical structure of the human musculoskeletal system that contributes to body stability, distributes mechanical loads, and permits movement in multiple directions. These functions depend on the coordinated actions of the intervertebral discs, zygapophyseal (facet) joints, ligaments, and craniovertebral joints. This article examines the anatomical features of the joints of the vertebral column, their orientation in different segments, and their influence on spinal movement. The characteristics of flexion, extension, lateral flexion, and rotation in the cervical, thoracic, and lumbar regions are considered in relation to anatomical and biomechanical factors. The article also discusses the roles of the atlanto-occipital and atlanto-axial joints in head movement, the mechanical function of the intervertebral discs, and the effects of age-related and degenerative changes on spinal mobility. Because range-of-motion values vary according to measurement method, age, sex, and study protocol, standardized normative data should be used when interpreting clinical findings.

Keywords: Vertebral column, zygapophyseal joint, facet joint, intervertebral disc, spinal mobility, range of motion, craniovertebral junction, degenerative changes.

1. Introduction

The vertebral column (columna vertebralis) is a complex anatomical structure that provides support, protects the spinal cord, and permits movement. One of its main functions is to protect the spinal cord; it also transmits body weight to the pelvis and distributes mechanical loads generated during movement.

A key functional feature of the vertebral column is its ability to maintain a balance between stability and mobility. This balance is maintained not by the structure of individual vertebrae alone, but by the combined activity of the intervertebral discs, facet joints, ligaments, and paravertebral muscles. Together with the discs, the facet joints are important structural components of the spinal motion segment, participating in guiding movement and limiting excessive displacement.

The mobility of the vertebral column varies among its regions. The cervical region has a high degree of mobility, allowing it to control the position of the head in space. The thoracic region is relatively limited because it is anatomically connected to the rib cage. In the lumbar region, flexion and extension movements occupy an important place alongside the function of load-bearing.

The aim of this article is to describe the anatomical structure of the joints of the vertebral column, their functional role in movement, and the clinical significance of these features.

2. General structure of the vertebral column

The vertebral column typically consists of 33–34 vertebrae. It includes 7 cervical, 12 thoracic, 5 lumbar, 5 fused sacral vertebrae, and usually 4–5 coccygeal vertebrae.

Adjacent vertebrae are connected by several types of anatomical structures. Intervertebral discs are located between the vertebral bodies and form fibrocartilaginous connections. The articular processes of adjacent vertebral arches form the synovial zygapophyseal joints.

In addition, the upper part of the vertebral column contains the atlanto-occipital and atlanto-axial joints, which provide the connection with the skull. These joints are of particular importance for head movements and for the mechanical stability of the craniovertebral region.

3. Intervertebral discs

The intervertebral disc (discus intervertebralis) is located between adjacent vertebral bodies. Its main structural components — the outer annulus fibrosus, the central nucleus pulposus, and the cartilaginous endplates — are functionally interconnected structures [5].

The adult vertebral column typically contains 23 intervertebral discs. The discs participate in maintaining the flexibility of the vertebral column, distributing axial loads, and preventing direct bone-to-bone contact between adjacent vertebral bodies.

The discs should not be regarded merely as passive “shock absorbers”; they contribute actively to the biomechanics of the vertebral column. Their interaction with the facet joints is important for the normal function of the spinal motion segment [4,5].

4. Zygapophyseal joints

The zygapophyseal, or facet, joints are synovial joints formed between the superior and inferior articular processes of adjacent vertebrae. They consist of articular surfaces, articular cartilage, a capsule, and synovial structures [1,3].

The facet joints do not simply permit spinal movement. Their orientation influences the direction and extent of movement at each vertebral segment. At the same time, they participate in limiting excessive displacement and in transmitting mechanical loads [1,4].

In the cervical region, the facet joints have an anatomical orientation that allows head and neck movements to occur over a wide range. In the thoracic region, the position of the facets allows a certain degree of rotational movement, although this movement is limited by the rib cage. In the lumbar region, the relatively sagittal orientation of the facets supports flexion-extension while limiting axial rotation [2,3].

5. Ligaments of the vertebral column

The ligaments play an important mechanical role in maintaining vertebral column stability.

The anterior longitudinal ligament (ligamentum longitudinale anterius) runs along the anterior surface of the vertebral bodies and participates in limiting excessive movement, particularly during extension.

The posterior longitudinal ligament (ligamentum longitudinale posterius) runs along the posterior surface of the vertebral bodies and is one of the structures that limits flexion movement.

The ligamenta flava connect adjacent vertebral arches. Their structure, rich in elastic fibers, is important for the movement of the vertebral column and for its mechanical recoil properties.

The interspinous ligaments (ligamenta interspinalia) and the supraspinous ligament (ligamentum supraspinale) are located between the spinous processes and participate in limiting excessive flexion. The intertransverse ligaments (ligamenta intertransversaria), located between the transverse processes, help limit lateral flexion movement.

6. Craniovertebral joints

The craniovertebral region comprises the occipital bone, atlas, and axis and their associated articulations and supporting structures. The anatomy of this region is complex, with the bones, ligaments, and neurovascular structures situated in close proximity to one another [12].

6.1. Atlanto-occipital joint

The atlanto-occipital joint (articulatio atlantooccipitalis) is formed between the occipital condyles (condyli occipitales) and the superior articular surfaces of the atlas [12].

This paired joint is primarily involved in flexion-extension movements of the head. Lateral flexion is also present, although its amplitude is limited compared to flexion-extension.

6.2. Atlanto-axial joints

The atlanto-axial joints (articulationes atlantoaxiales) consist of one median and two lateral joints. In the median atlanto-axial joint, the dens of the axis (dens axis), together with the anterior arch of the atlas and the transverse ligament, forms a functional complex that serves as the center of rotational movement.

The lateral atlanto-axial joints are formed between the superior articular surfaces of the atlas and the axis. This complex of joints plays an important role in the axial rotation of the head.

7. Range of motion of the vertebral column

The range of motion (ROM) of the vertebral column is determined by the combined effects of several anatomical and biomechanical factors. These include the orientation of the facet joints, the mechanical properties of the discs, the elasticity of the ligaments, the activity of the muscles, and the influence of adjacent anatomical structures.

There is no single universal range-of-motion (ROM) value. In different studies, the measurement method, instruments, body position, age, and other methodological factors can influence the results. In particular, systematic reviews on cervical ROM have shown considerable heterogeneity between studies [6].

7.1. Cervical region

The cervical spine is one of the segments with the highest mobility. Flexion, extension, lateral flexion, and rotation movements all occur in this region.

Cervical movement is not determined by the C3–C7 segments alone. The atlanto-occipital and atlanto-axial joints also form an important part of head movement. For this reason, it is important to take the craniovertebral region into separate account when assessing clinical ROM.

Because normative values for cervical ROM can differ considerably between studies, it is necessary to indicate the measurement method and source when reporting particular angles as “normal” [6].

7.2. Thoracic region

The thoracic vertebral column is anatomically and mechanically connected to the ribs. For this reason, movement in this segment is closely linked to the configuration of the rib cage.

Flexion, extension, lateral flexion, and rotation occur in the thoracic region, but their amplitudes vary according to the measurement method and individual anatomical characteristics.

7.3. Lumbar region

The lumbar vertebral column plays an important role in bearing body weight and transmitting mechanical loads to the pelvis. The anatomical structure of the lumbar segments allows flexion and extension movements while relatively limiting axial rotation.

Normative data indicate that lumbar ROM in healthy populations can vary depending on factors such as age and sex [7]. Therefore, it is not correct to adopt a particular angle as a universal norm for all individuals when assessing lumbar ROM.

8. Lumbosacral junction

The lumbosacral joint (articulatio lumbosacralis) is a functionally important junction between the L5 vertebra and the upper part of the sacrum. This region participates in transmitting body weight and the mechanical loads that arise during movement.

The anatomical configuration of the lumbosacral region contributes to the sagittal profile of the vertebral column and lumbar lordosis. At the same time, the mechanical properties of this segment should be assessed together with the function of the entire spinal motion segment.

9. Age-related and degenerative changes

With aging, various structural changes occur in the intervertebral discs and facet joints. These can include a decrease in water content within the intervertebral disc, changes in matrix composition, a reduction in disc height, and other degenerative processes [8,9].

Disc degeneration is not simply a process of "wear." It is a complex process related to the interaction of biological aging, mechanical loading, cellular changes, and other factors [10].

Degenerative processes can also affect the facet joints. Because of the mechanical interrelationship between the disc and the facet joints, a change in one structure can influence the loading of the other [11].

As a result of degeneration, the mechanical properties of the spinal segment can change, and in some cases the stiffness of the vertebral column may increase. However, this process does not proceed in the same way in all patients.

10. Clinical significance

Understanding the anatomy and biomechanics of the joints of the vertebral column is important for clinical practice. The discs, facet joints, and ligaments function as an interconnected system. For this reason, a pathological change in one anatomical structure can affect the mechanical loading of the other structures.

Degenerative changes in the facet joints may be associated with pain syndromes in the lumbar, cervical, and thoracic regions [1,11].

Intervertebral disc degeneration, in turn, may be associated with disc herniation, spinal stenosis, degenerative spondylolisthesis, and other pathological conditions [5,10].

From this perspective, knowledge of the normal anatomy and movement mechanisms of the joints of the vertebral column is of fundamental importance for neurology, traumatology and orthopedics, rehabilitation, and musculoskeletal medicine.

11. Conclusion

The joints of the vertebral column, together with the intervertebral discs, facet joints, and ligaments, function as a single functional biomechanical system. Their interrelationship allows the vertebral column to simultaneously maintain stability and carry out movement.

The movement characteristics of different regions of the vertebral column are influenced by facet joint orientation, the mechanical properties of the discs, ligamentous and muscular factors, and adjacent anatomical structures. The craniovertebral region plays a special role in the complex movements of the head, while the thoracic region, together with the rib cage, plays a special role in body mechanics. The lumbar segments, in turn, ensure the balance between load-bearing and movement functions.

Instead of using a single universal number to assess ROM values, it is necessary to take into account age, sex, measurement method, and study protocol. Differences in the methodology used to assess spinal mobility can substantially influence the reported results.

Age-related degenerative changes affect the structural and mechanical properties of the discs and facet joints. For this reason, an in-depth study of the normal anatomy and biomechanics of the joints of the vertebral column provides an important scientific basis for understanding its pathological conditions.

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