ASPECTS CONCERNING THE FUNCTIONAL IMPORTANCE OF THE VERTEBRAL COLUMN

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ABSTRACT (online version)

The vertebral column, the sustaining axis of the body, is characterized by resistance and elasticity. Composed of specific structures, an overlapping of bone pieces with cartilaginous discs interposed, the vertebral column is permanently submitted to a static and dynamic strain, each of its segments having its specific involvement in the maintaining of the body position and in the realization of movements. This article presents some aspects of the functional importance of the spine, materialized especially in the types of movements that can be realized by the segments of the vertebral column and in their participation at sustaining the weight of the body.

KEY WORDS: vertebrae, intervertebral discs, disco-corporeal complex, vertebral segment, types of movement.

The vertebral column, a genuine support pillar of the human body, fulfils two mechanical imperatives: resistance and elasticity. A role in the resistance of the vertebral column is played by the architecture of the vertebral bone structures, their mineralization, the presence of the three curvatures, namely the cervical lordosis, the thoracic cifosis, the lumbar lordosis, which alternate in the sagittal plane, contributing to the body stability and the equilibrium in orthostatism. An important role in the elasticity of the vertebral column is played by its segmental structure, because it is formed by a sequence of bony components, the vertebrae, between which the intervertebral discs are interposed. Thus structured, the vertebral column represents a whole, resistant but at the same time flexible, elastic and mobile. It fulfils an important role in the organism that is concretized in the sustaining of the superior part of the body, in its mobility and in the protection conferred to the spinal cord. In this article we will refer to the mobility and the sustaining function of the vertebral column.

THE MOBILITY OF THE VERTEBRAL COLUMN

Junghans (1950) introduced the term “the movement segment”, in referring to the mobility spaces between the vertebrae. In the movement segment are included the intervertebral discs, the cartilaginous plates, the anterior longitudinal ligament, the posterior longitudinal ligament, the
zygapophyseal joints, the ligamentum flavum, as well as the corresponding elements of the vertebral canal, of the intervertebral foramen, the space between the spinous and transverse processes. The elements of the movement segment influence one another, the intervertebral disc being its most voluminous component, which conditions, to a great extent, the functionality of the movement segment. Within the notion of movement segment, Schenk (1964) includes the muscles and the nerves corresponding to the vertebrae. Roaf (1960) talks about the primary vertebral unity, which consists of two successive vertebrae and the disco-ligamentar complex between them. Diaconescu et al. (1977) think that the motosegment is the morfofunctional unity of the rachis, within which they include both the elements taken into consideration by Schenk, and the vertebral bodies as Roaf does.

Castaing and Santini (1983) consider that the rachidian functional unity is the articular segment, consisting of three components: the disco-corporeal complex, the zygapophyseal joints and the intervertebral ligaments. The articular segment allows for multidirectional movements: flexion, extension, right or left lateral flexion, right or left rotation.

The disco-corporeal complex forms an anatomo-physiological ensemble which allows for all these movements, but the movements should not surpass the resistance capacity of the anatomical structures, there intervening its other two elements, the zygapophyseal joints and the intervertebral ligaments, with a role in guiding and, respectively, in limitation (Fig. 1).

The annulus fibrosus, situated at the periphery of the intervertebral disc, consists of a succession of concentric fibrous lamellae, which, in their turn, consist of conjunctive fibres arranged obliquely. Their obliqueness is oriented in contrary directions in the neighbouring lamellae. This obliqueness decreases constantly towards the periphery, until, in the external lamellae, it becomes vertical. On the other hand, towards the central portion of the annulus, the orientation of the fibres comes near, more and more, to the horizontal. At the periphery of the annulus fibrosus, these conjunctive fibrous lamellae fix themselves on the compact bone region. The nucleus pulposus, the central part of the intervertebral disc, is limited, at its superior and inferior parts, by the two neighbouring vertebral bodies and, circumferentially, by the fibrous texture of the peripheral ring. In this space the nucleus pulposus is maintained under pressure. It consists of a gelatin-looking mass, with hydrophilic qualities, very rich in water. The thickness of the discs varies at the different vertebral levels. Their thickness reaches the maximum value at the lumbar level, while the minimum value can be found at the cervical level. But, from a functional point of view, more important than the thickness is the proportion between the thickness of the disc and the height of the vertebral body. This proportion is responsible for the mobility of the respective vertebral region, the bigger it is, the more important the mobility is. The cervical region, which has a disco-corporeal proportion of 2/5, presents the biggest mobility, the lumbar region, with a proportion of 1/3, is less mobile than the cervical one, and the thoracic region, with a proportion of 1/5 is the least mobile of all. A reason for this reduced mobility of the thoracic segment is also its relation with the ribs and, through them, with the sternum.

When the vertebrae and, implicitly, the intervertebral discs, are submitted to a mechanical strain, there occurs an increase in the internal pressure of the nucleus and in the tension of the fibres of the annulus fibrosus, in a different way, according to the type of strain, with the propensity of re-bringing the system in the initial state, through the autostability mechanism of the vertebral column. At the young adults, the discs have a very resistant structure, so that, after a violent straining, the first affected are the bones. A healthy disc can be damaged only in a forced flexion. The situation changes in the last decade of life (Williams, 1989). Adams et al.’s research (1996) show that degenerative modifications of the disc, related to age, have led to a reduction of approximately 50% of the diameter of the central region, the nucleus, and the pressure in this region.
decreased with 30%, while the annulus extension increased with 80%, and the tensional maxims at its level increased with 160%. The degenerative modifications led to a transfer of the tensions from the nucleus towards the peripheric region, especially its posterior part, which can have as a result new splittings. Changes to the tissue properties of the disc, including dehydration and reorganization of the nucleus and stiffening of the annulus fibrosus, alter the mechanics of load transfer in the spine. There is no direct correlation between degenerative changes to the disc and to the adjacent vertebral bodies (Ferguson et al, 2003) Concerning the age related modifications of the vertebrae, structural analyses (Mosekilde, 1989) revealed a marked increase in the distance between the horizontal trabeculae. In individuals older than 75 years this increase was significantly higher for females. The biomechanical compression tests showed a significant age related decrease in stress values in the vertical direction both for males and females. It has been demonstrated that age by itself is the major determinant of vertebral bone strength, mass and microarchitecture. Loading plays an important role in the maintenance of trabecular connectivity and it affects bone mass, microarchitecture and size throughout life (Mosekilde, 2000). The mobility deficiency between two vertebrae is not usually reflected in a considerable reduction of the mobility of the vertebral column. If, on the other hand, the intervertebral articulation acquires an exaggerated mobility and becomes unstable, the rigidity of the entire vertebral column can be reduced.

The second element of the disco-corpooreal complex, the zygapophyseal joints, has the role of guiding the movements. The morphology and the specific orientation of the articular processes on the various levels of the vertebral column are adapted to their functional necessities.

The intervertebral ligaments play a role in limiting the movements. The interspinous ligaments, strengthened by the supraspinous ligament, are very resistant and are strong obstacles for the flexion. The ligamenta flava prevent slightly the flexion, the lateral flexion and the rotation. They also have a protective role, completing posterior the walls of the rachidian canal. The intertransversar ligaments limit the movements of lateral flexion and of rotation. The posterior vertebral longitudinal ligament impedes the flexion. The anterior vertebral longitudinal ligament is the only ligamentar obstacle for the extension.
The analysis of movements can be done for the vertebral column as a whole, for its regions (cervical, thoracic and lumbar) or for each intervertebral articulation in turn.

The cervical region is the most mobile. In order to ensure the neck’s suppleness, the movements at this level are very complex and need appropriate guiding. At this level there have been described the uncovertebral articulations between the unciform apophyses of the superior vertebral surface, to which correspond the infero-lateral portions of the above vertebra. The cervical region as a whole consists of two anatomically and functionally distinct parts: the superior cervical segment or the suboccipital rachis, represented by atlas and axis, tied together and also tied to the occipital bone in a complex articular concatenation and the inferior cervical segment, from the level of the inferior articular surface of the axis to the superior plateau of the first thoracic vertebra.

At the level of the occipitoatlantoidian articulation, which relates the superior articular surfaces of the lateral masses of the atlas with the articular surfaces of the occipital condyles, movements of flexion, extension, lateral flexion, rotation are possible, according to some authors (Kapandji, 1982), and, according to others (Diaconescu et al, 1977), only movements of flexion and extension. Between the atlas and the axis, movements of rotation are possible, realized at the level of the atlantoaxoidiene articulations. Simultaneously with the movement of rotation, there also occurs an anterior, respectively posterior, sliding, as well as a vertical one (2-3 mm) of the lateral masses of the atlas, which gives the movement a helicoidal aspect.

While movements which are independent of the rest of the vertebral column can occur at the level C1-C2, from the C2 vertebra downwards there cannot be any independent vertebral movement. The inferior cervical segment performs movements of flexion, extension as well as a combined movement of lateral flexion – rotation, to which an extension component is added. This combined movement is determined by the way the facets of the articular processes are oriented, which permits neither a movement of pure rotation, nor a movement of pure lateral flexion. Although at the level of the inferior cervical segment this univocal movement of lateral flexion – rotation is produced, the superior cervical segment eliminates, with the help of the small occipital muscles, the unwanted components of the movement (Kapandji, 1984).
The thoracic region is more rigid. Its mobility is more reduced than that of the lumbar region, fact that is influenced by the mechanical resistance of the thorax which determines a considerable limitation of the movements at this level, by the architectonic characteristics of the vertebrae and by the reduced height of the intervertebral discs of this region. Flexion, extension, lateral flexion and rotation are produced at this level. The elementary rotation of one vertebra towards another one at the thoracic level is ampler than the one that occurs at the lumbar level, and a role in this is played by the different orientation of the articular processes on the two vertebral levels. The articular facets of the articular processes of the thoracic vertebrae are similar to segments of a cylinder, whose center is very close to that of the vertebra which performs the rotation. Consequently, the rotation will be done around a common axis, and the respective intervertebral disc will be submitted to torsion; in this situation, the amplitude reached can be bigger than in the case of the lumbar segment, where, in a similar situation, appears shearing (Kapandji, 1984).

The mobility of the lumbar region is at the middle, between that of the cervical region and that of the thoracic region. Arseni and Stanciu (cited by Diaconescu et al, 1977)) think that it is likely that this region, out of all parts of the human skeleton, should suffer the most important functional abuses, due to an appreciable permanent loading, to a large degree of mobility and to an uneconomical mechanism of sustaining the body weight (the gravitation line is anterior to the lumbar region). In the lumbar region, movements of flexion, extension, lateral flexion and rotation are possible. The axial rotation of the lumbar vertebrae is very reduced, for the same reason: the arrangement of the articular facets of the articular processes, this time as segments of a cylinder with sagittal orientation. Because the centre of these cylinders is different than the one of the vertebral bodies around which the rotation is done, the rotation of the vertebra is associated with its sliding, and the respective intervertebral disc will be strained to shearing. The functionality of the L4 and L5 vertebrae is influenced by the iliolumbar ligaments which tie the vertebrae to the iliac bone.

The lumbosacral articulation is the pivot around which all the movements of the vertebral column on the pelvis are realized. Movements of flexion, extension, lateral flexion and rotation are possible. It is a weak point of the rachidian edifice, because here the body weight is transmitted to the sacrum and also here the movement of the trunk on the pelvis occurs.
THE SUSTAINING FUNCTION OF THE VERTEBRAL COLUMN

The vertebral column supports the head, the trunk and the upper limbs, transmitting then the weight to the pelvis and to the lower limbs.

The weight of the head has the permanent tendency to determine its fall ahead, this being counterbalanced by the permanent tonus of the muscles of the nape. The head as a whole realizes a first-order lever. The support point is at the level of the occipital condyles, the resistance force is realized by the weight of the head and the active force is due to the muscles of the nape, which oppose the fall of the head.

The suboccipital cervical segment has a great functional importance. It represents the most strained point, from a mechanical perspective, of the cervical region, and, at the same time, the most mobile, the most important bone element for stability being the odontoid process. The atlas and the axis distributes the weight of the head to three columns which continue along the entire vertebral column, namely a main column, anterior, at the level of the vertebral bodies, and two lateral columns, at the level of the articular processes.

The curvatures of the vertebral column increase its resistance (an elastic column with curvatures is more resistant to vertical pressures than a perfectly rectilinear column). The obliqueness of vertebral bodies diminishes, as well, the compression efforts they are submitted to. Only the perfectly horizontal vertebral bodies and the perfectly horizontal discs support all the vertical pressures. At the level of the oblique discs the vertical forces decompose in a perpendicular force on the vertebral plateau and a force in the plane of the discs. The forces act not only upon the vertebrae, but also upon the intervertebral discs. The tension in the centre of the nucleus of the intervertebral disc is never zero. This phenomenon is due to its water-binding capacity, which determines the swelling of the nucleus in its inextensible box, in this space the nucleus pulposus being maintained under pressure. The phenomenon has been compared with the stage of precompression in the technology of concrete, according to which the precompression is a tension stage created in advance in a beam which has to endure a certain weight. Once someone gets older, this state of precompression diminishes, which explains the decrease in the elasticity of the vertebral column of the older people.

The equilibrium of an articular segment is similar to the equilibrium of a balance (Castaing et al, 1983). Because the weight of the body is
transmitted anterior compared with the articular segment, it has the tendency of flexing the vertebral column. The counterbalance of this tendency is realized especially by the extensor muscles of the vertebral column. These forces of flexion and extension are transmitted through a lever with uneven arms at the level of the fulcrum (Fig. 2).

In order for the equilibrium to be maintained, the size of the forces must be inversely proportional with the length of the arms of the lever. The lengthening of the arm of the lever on which the weight is applied needs a corresponding increase of the resistance force that is of the extensor muscles force.

The lumbosacral junction represents a weak point of the rachidian edifice. The superior surface of the first sacral vertebra is inclined anterior and downwards and the body of the last lumbar vertebra has the tendency of sliding in the direction of this inclination. The sliding force strains the articular processes which oppose it. The transmission of these forces at this level is realized through the posterior portion of the vertebral arch situated between the superior articular processes and the inferior articular processes. Through its participation at the forming of the pelvic girdle, the sacrum realizes a bond between the vertebral column and the limbs. Thus, the
weight endured by the last lumbar vertebra and transmitted to the sacrum is
distributed in two equal parts through the sacrum alae and it is oriented
towards the acetabulum. The reaction force of the earth is transmitted
through the femoral head and neck. A part of this orients itself towards the
pubic symphysis, getting into equilibrium with the one opposing it, and
another part orients itself upwards. This reaction force of the earth
transmitted through the coxofemoral articulation forms, together with the
weight transmitted through the vertebral column to the sacrum, a couple of
rotation which has the tendency of moving the sacrum backwards; this
phenomenon is counterbalanced by the presence of the very strong
ligaments.

Important is, as well, the protection conferred by the vertebral column
to the spinal cord due to its localization in the vertebral canal. Some authors
take also in consideration the formogenetic function (Diaconescu et al 1977)
which refers to the shaping role of the vertebral column. They consider that
the dynamics of the thoracic vertebral region is implicated in forming the
pulmonary lobes. They also sustain the role of the dynamics of the thoraco-
lumbar region in determining the external form of the liver.

Through all these aspects concerning its functionality, the vertebral
column is an important element for the physical activities of daily life and
the maintenance of the integrity of its specific structures has a profound
influence on the quality of life.

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