

BIOMECHANICS OF THE HUMAN SPINE

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ABSTRACT

The paper presents biomechanics of the human spine. The vertebrae of the spine are described, including basic differentiation between vertebrae depending on their placement in the spine. The intervertebral discs are depicted. Curvatures of the spine are presented, followed by the basic biomechanics, including a movability of the spine and an influence of body posture on the spine.

KEYWORDS: human spine, vertebra, intervertebral disc, lordosis, kyphosis, biomechanics, posture

BIOMECHANIKA KRĘGOSŁUPA CZŁOWIEKA

STRESZCZENIE

Artykuł przedstawia zarys biomechaniki kręgosłupa człowieka. Opisano kręgi, uwzględniając różnice w budowie między kręgami na różnych odcinkach kręgosłupa oraz krążki międzykręgowe. Przybliżono strukturę krzywizn oraz podstawy biomechaniki kręgosłupa, uwzględniając jego zakresy ruchów i wpływ postawy ciała na kręgosłup.

SŁOWA KLUCZOWE: kręgosłup człowieka, krąg, krążek międzykręgowy, lordoza, kifoza, biomechanika, postawa

1. Introduction

A vertebral column (or a spine), in mammals, is the flexible column extending from neck to tail, made of a series of bones called the vertebrae. Its primal function is protection of the spinal cord, travelling within the spinal canal, as well as providing stiffening for the body and attachment for shoulder and pelvis girdle.

2. Anatomy of the spine

As previously mentioned, the spine consists of the vertebrae – irregular bones, which sizes and shapes vary depending on the location in the vertebral column, posture or pathologies. Other variable is the number of vertebrae in the spine – while humans have 33 to 34 vertebrae, there are animals with 60+ vertebrae, depending on the length of the tail. However, a regularity was observed, that most of the mammals have seven vertebrae in the neck part of the spine, with exception of some animals having only six (e.g. manatees) or even eight to ten vertebrae (e.g. sloths) [1].

During the process of the evolution of the human species, the spine structure altered in order to compensate different kind of loads affecting the body due to the change of movement from climbing and moving in trees to walking on legs [2]. The curves of the spine were developed, as seen in the Fig. 1.

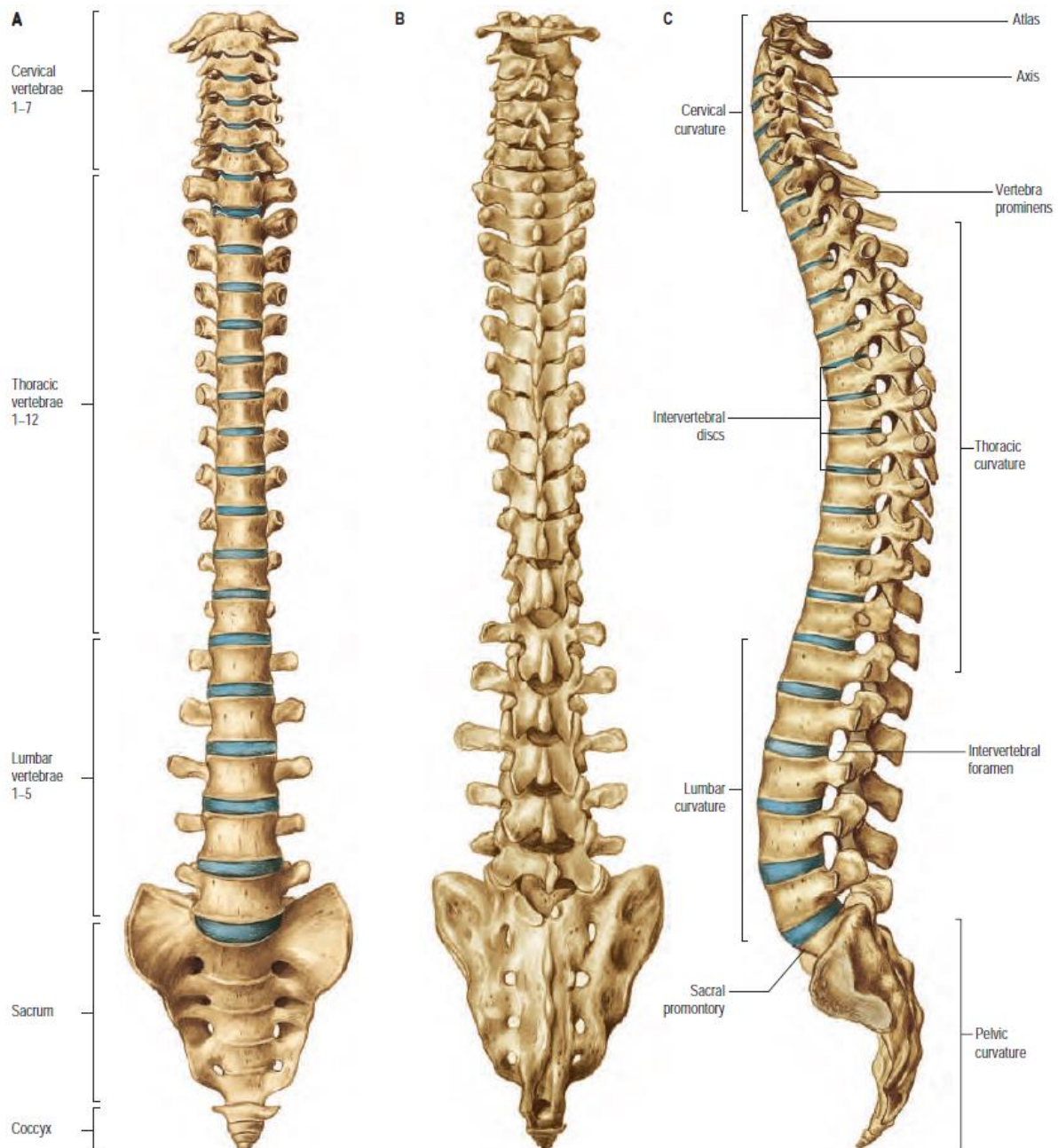


Fig. 1. The vertebral column. A, Anterior aspect. B, Posterior aspect. C, Lateral aspect [3]

Human spine consists of vertebrae and discs surrounded by a group of supporting ligaments. The spine connects a base of a skull with a lower part of the torso, and forms a rib cage along with ribs and a sternum. The vertebral column can be divided in five parts: the cervix, thoracic and lumbar spine as well as the sacrum and the coccyx.

2.1. The vertebrae

Each vertebra is an irregular bone. The size of vertebrae varies according to the placement in the spine. A typical vertebra consists of a body and a vertebral arch with a vertebral foramen between them and processes (articular, transverse, and spinous) for articular and muscular attachments (Fig. 2).

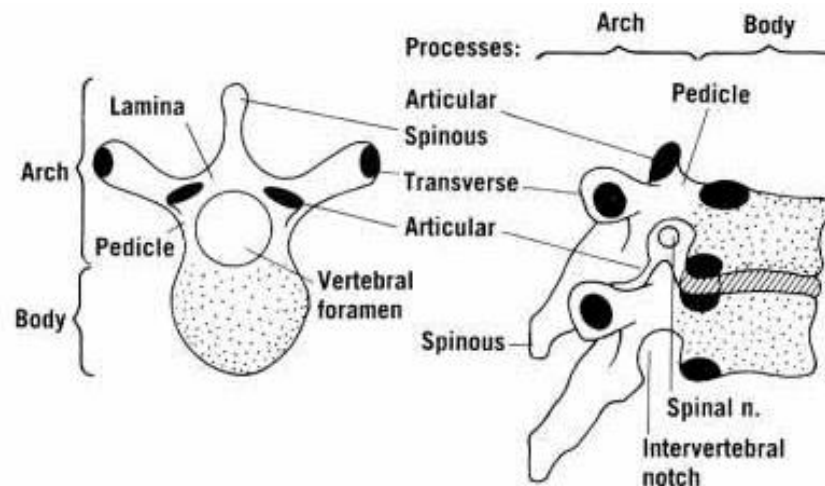


Fig. 2. The parts of a vertebra [4]

The cervical spine carries and allows the movement of the head, hence the atypical structure of some of its vertebrae. The first vertebra (atlas) has neither body nor spinous process and consists of two lateral masses connected by a short anterior and a longer posterior arch. The second (axis) is connected with the atlas via dens (odontoid process), projecting upwards from the body and articulating with the anterior arch of the atlas. The remaining vertebrae are typical, with small and oval bodies. The seventh cervical vertebra (vertebra prominens) has significantly longer spinous process, which is easily felt from the skin surface. In some cases, the vertebra prominence is associated with cervical ribs, which may develop separately from costal processes [4, 5].

The twelve thoracic vertebrae are part of the thorax (or chest) along with the ribs, which articulate with vertebrae. The rotational movement may occur between thoracic vertebrae, but it is limited due to the connection with the rib cage. In the upper part of thoracic spine, the body of a vertebra is oval-shaped in transverse dimension. Downwards, the antero-posterior dimension changes, making the body more heart-shaped, and in the lower part – kidney-shaped.

The five lumbar vertebrae, located between the rib cage and the pelvis, are large and kidney-shaped with short and thick pedicles and laminae. The fifth lumbar vertebra is significant because of its body being much thicker in front than behind, due to the articulation between this vertebra and sacrum.

The sacrum consists of five sacral vertebrae merged together into a large bone. The bone is roughly triangular-shaped, with the basis directed upward and the apex pointing down and frontward. The sacrum articulates above with L5, laterally with the hip bones, and inferiorly with the coccyx.

The coccyx is the final segment of the vertebral column. It comprises of three to five coccygeal vertebrae usually fused in adults, with the shape similar to the sacrum [4, 6].

2.2. The intervertebral discs

An intervertebral disc is located between adjacent vertebrae in the spine. It consists of an outer fibrous ring (the annulus fibrosus) surrounding the nucleus pulposus in the centre. The annulus fibrosus consists of fibrocartilage containing concentric layers of dense, regular connective tissue – collagen. The nucleus pulposus is composed of a gel-like material that consists of mainly water, as well as a loose network of collagen fibers. Due to its content, the nucleus can withstand and distribute significant pressure across the disc.

2.3. The curvature of the spine

The cervical spine curves slightly inward, in a shape called a lordosis. It extends from the atlas to the second thoracic vertebra, with its apex between the fourth and fifth cervical vertebrae. The thoracic spine arcs backward, creating a kyphosis. It extends between the second and the eleventh and twelfth thoracic vertebrae, and its apex lies between the sixth and ninth thoracic vertebrae. This

curvature is caused by the increased posterior height of the thoracic vertebral bodies. The lumbar spine is similar in shape to the cervical spine and extends from the twelfth thoracic vertebra to the lumbosacral angle. There is an increased convexity of the last three segments as a result of the greater anterior height of the intervertebral discs and some posterior wedging of the vertebral bodies. Its apex is located at the level of the third lumbar vertebra. The pelvic curve is concave anteroinferiorly and involves the sacrum and coccygeal vertebrae. It extends from the lumbosacral junction to the apex of the coccyx [5]. Curvatures increase with age of a patient, hence the humpbacked posture and decrease of height.

3. Biomechanics of the spine

The smallest motion unit of the spine is a motion segment consisting of two adjacent vertebrae with the intervertebral disc between them. The connection is based on the articular triad, composed of two symmetrically located zygapophysial (or facet) joints and the intervertebral disc. The possibility of movement within the unit depends on parameters of the triad, ligaments and the shape of articular processes [7, 8].

The movability of the spine as a whole is a sum of movements within each motion segment. There are three planes of movement in the spine: a sagittal plane (flexion and extension in a range of approximately 90°), frontal plane (lateral flexion in the maximum range of approx. 60°) and horizontal plane (turning around vertical axis – approx. 90° in each way) [8].

Curvatures of the spine in a sagittal plane are crucial for a distribution of stress in the vertebral column, which entails durability of spinal structures and suppression of dynamic loads. Charriere et al. [9] determined the correlation between curvatures and durability of the spine – according to the authors, the durability of the spine is proportional to the square of curvature amount “+1”. Thereby, human spine consisting of four physiological curvatures is seventeen times more resistant to stress than the straight spine [7, 8].

The spine is a complicated mechanism, differentiated in terms of materials. In one kinematic chain there are stiff bone elements cooperating with discs, supported by ligaments. The vertebrae, similarly to other bones, are composed of outer cortical bone and inner cancellous bone. The cortical bone is more durable and dense, while the cancellous one is less durable, but able to distribute stress better, thanks to its trabecular structure. Mechanical properties of vertebrae form under pressure resulting from performing everyday activities. It should be noted, that either lack of load or overloading can negatively affect the structure of these tissues.

The durability of bones (i.e. vertebrae) changes with age. Since birth bone tissue rebuilds itself internally under pressure, strengthening its structure. The best mechanical properties of the bone are observed in people between 25 and 35 years old. With progressing age the properties weaken, hence the growing susceptibility to injuries [7].

Swedish scientist Alf Nachemson conducted the analysis of pressure changes in lumbar spine both *in vivo* and *in vitro*, depending on gender, age, posture, performed activities and degeneration of vertebra's tissue. Results of the research were presented as a correlation between the changes of pressure affecting lumbar intervertebral discs and human posture, with standing position as the reference (100% of pressure), as shown in the Fig. 3 [9].

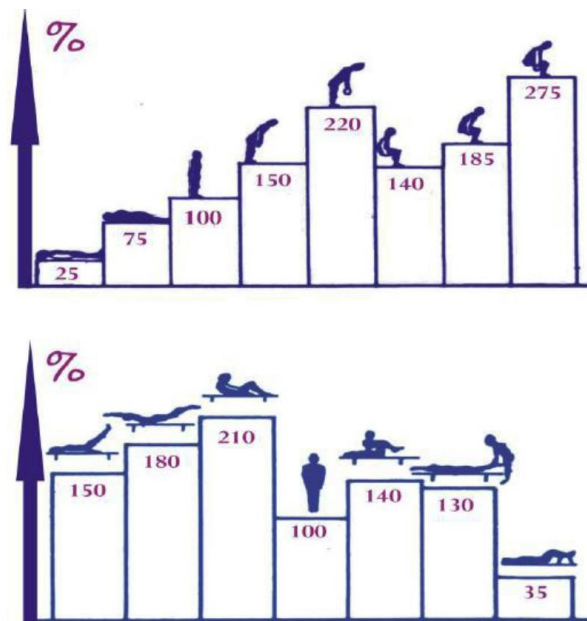


Fig. 3. The pressure affecting L3-L4 intervertebral discs depending on the body posture [9]

4. Conclusions

Human spine is the complex mechanism consisting of multiple vertebrae, discs and ligaments. Its curved structure, developed during the course of evolution, gave the human kind an ability to walk straight. While performing various daily activities the vertebrae withstand changing amount of pressure, which can effect in degeneration of spine's tissues, leading to injuries. Modern technology gives an opportunity to study these changes for better understanding of biomechanics of the human spine.

5. References

- [1] BioMed Central. "Sticking their necks out for evolution: Why sloths and manatees have unusually long (or short) necks". [Online]. Available: <https://www.sciencedaily.com>. [Accessed: 06-May-2011].
- [2] A. Gibbons. "Human Evolution: Gain Came With Pain". [Online]. Available: <http://www.sciencemag.org>. [Accessed: 16-February-2013].
- [3] R. Putz and R. Pabst, Eds., *Sobotta. "Atlas of Human Anatomy"*, vol. 2, 14th ed. Munich, Germany: Elsevier GmbH, 2006.
- [4] R. O'Rahilly et al., *Anatomy: A Regional Study of Human Structure*, 5th ed. Philadelphia, PA: W.B. Saunders, 1986.
- [5] S. Standring, Ed., *Gray's Anatomy: The Anatomical Basis of Clinical Practice*, 41st ed. London, UK: Elsevier, 2016.
- [6] W. Woźniak, Ed., *Anatomia człowieka*, 2nd ed. Wrocław, Poland: Elsevier Urban & Partner, 2003.
- [7] M. Gzik et al., Eds., *Biomechanika i inżynieria rehabilitacyjna*. Warsaw, Poland: Akademicka Oficyna Wydawnicza EXIT, 2015.
- [8] R. Będziński et al., Eds., *Biomechanika i inżynieria rehabilitacyjna*. Warsaw, Poland: Akademicka Oficyna Wydawnicza EXIT, 2004.
- [9] M. Mańko et al., „Zastosowanie metod inżynierii odwrotnej do projektowania sztucznego krążka międzykręgowego,” in *Innowacje w fizjoterapii*, vol. 2. Lublin, Poland: Fundacja TYGIEL, pp. 171-197, 2015.