Sit up straight! It's good physics

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Abstract

A simplified model has been developed that shows forces and torques involved in maintaining static posture in the cervical spine. The model provides a biomechanical basis to estimate loadings on the cervical discs under various postures. Thus it makes a biological context for teaching statics.

Risk factors for the development of injuries and pains in the neck region include postures with prolonged flexion of the cervical spine and lack of restitution, because the forward head posture is associated with increased activity of the back neck muscles and increased compressive loading on the spine.

The concepts of force and torque and their relationship to the establishment of static equilibrium are fundamental to an understanding of cervical posture. We discuss the forces and torques acting in a simplified neck model so that students who do not have a mathematics and physics background may learn or consolidate the involved concepts of mechanics and may prevent or minimize neck pain by taking simple precautions.

Cervical spine

The cervical spine consists of seven vertebrae. The topmost vertebra C1 supports the skull; the last C7 is above the thoracic vertebra T1. The vertebrae are separated by intervertebral discs (figure 1). The discs are tough lozenges of fibrous cartilage with a nucleus N in the centre of thick fluid. The primary functions of the discs are to provide several degrees of freedom to the spine, to sustain loads transmitted from segments above, to act as shock absorbers, to distribute forces and to eliminate bone-to-bone contact.

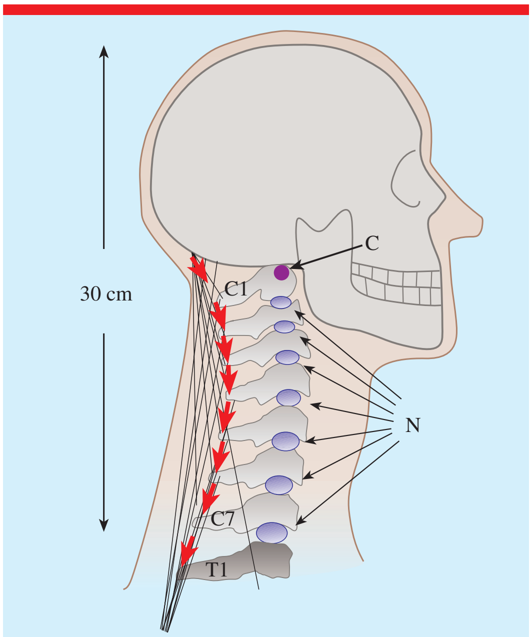

Figure 1. Model of head and cervical spine. The posterior neck muscles are represented by cables attached to the vertebrae. The arrows show only the supposed global force directions.

The sagittal (from ahead to behind) plane of the cervical spine has an anteriorly convex

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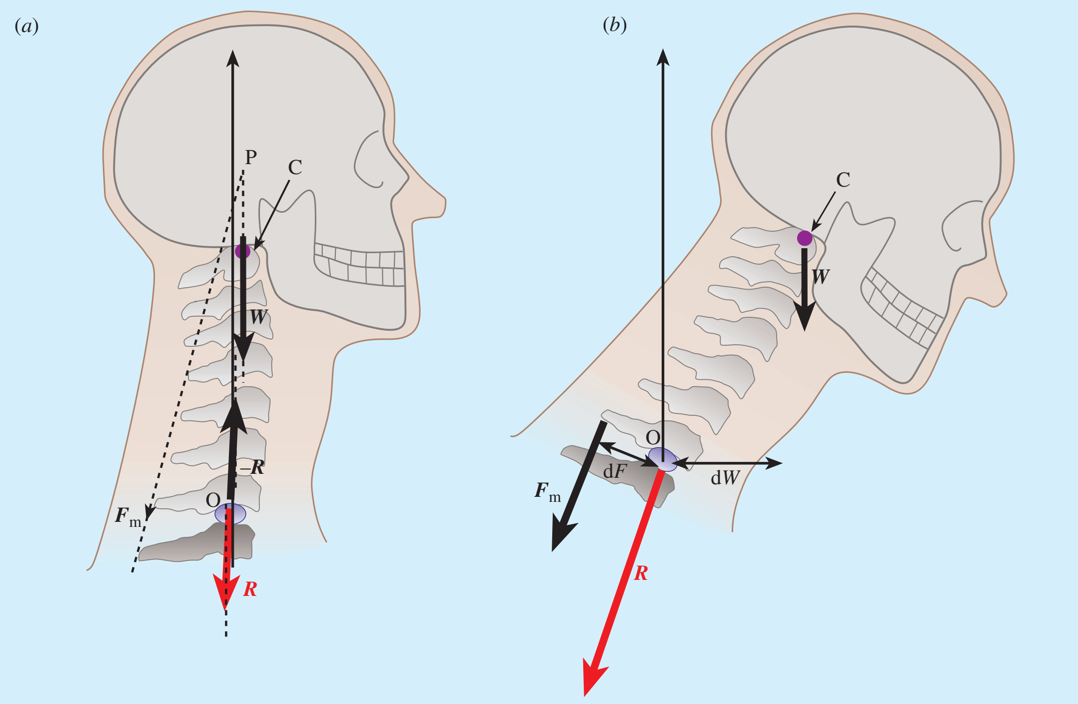


Figure 2. Force balance and load $\boldsymbol{R}$ in (*a*) physiological and (*b*) 30° flexed posture.

curvature (lordosis). In normal (physiological) standing posture, the average lordosis is a circular arc of about 34° with C1 vertically aligned with T1 [1]. The mechanical stability of the cervical spine comes from the intervertebral discs and ligaments (20%) and from the neck muscles (80%) [2]. The neck muscles, more than 20 pairs acting with apparent redundancy in various directions, take care of the static and dynamic control of the head and neck. Muscles that have similar functions operate with differences in moment arm on different ranges of motion to ensure functional optimization. In addiction to the active force, muscles develop a passive force when stretched above their resting length [3, 4].

The cervical muscle system is characterized by complex anatomy. However, for our didactical aim, we can suppose that, for a man of height 1.78 m and body mass 80 kg, the extensor muscle forces follow anatomically the back of the vertebrae with a distance from the centre of the discs of about 4 cm [5]; the mass of the head and neck is about 6 kg (8% of body mass); the length of neck and head is about 30 cm with centre of mass C located 14 cm (47%) from the top of the head and 16 cm (53%) from C7.

Load on the lower cervical vertebra

The primary forces acting on the cervical spine are the weight of the head and neck, the tensions in the muscles, the tensions in the ligaments and the reaction forces. Under static conditions both the net summation of all force components and the torque of all forces must equate to zero ($\Sigma_i \boldsymbol{F}_i = 0$ and $\Sigma_i \boldsymbol{F}_i \times \boldsymbol{d}_i = 0$). Also, the torque created at each intervertebral joint from the weight of the head and the upper portions of the neck must be balanced by internal torques generated by tensions in muscles and ligaments.

In order to estimate the load on the lower cervical disc C7–T1, students can draw the force vectors that come into play (figure 2) based on a cervical x-ray photograph. The nucleus of the disc is considered as the fulcrum and joint for balancing forces. Muscles that originate from the head or cervical spine and connect above the C7 vertebra are not considered, because they are responsible for maintaining equilibrium only in segments above C7. The global muscle action (all extensor muscles) that transfers the force below the C7 vertebra is represented by the force vector $\boldsymbol{F}_m$. Because muscles operate so as to counterbalance

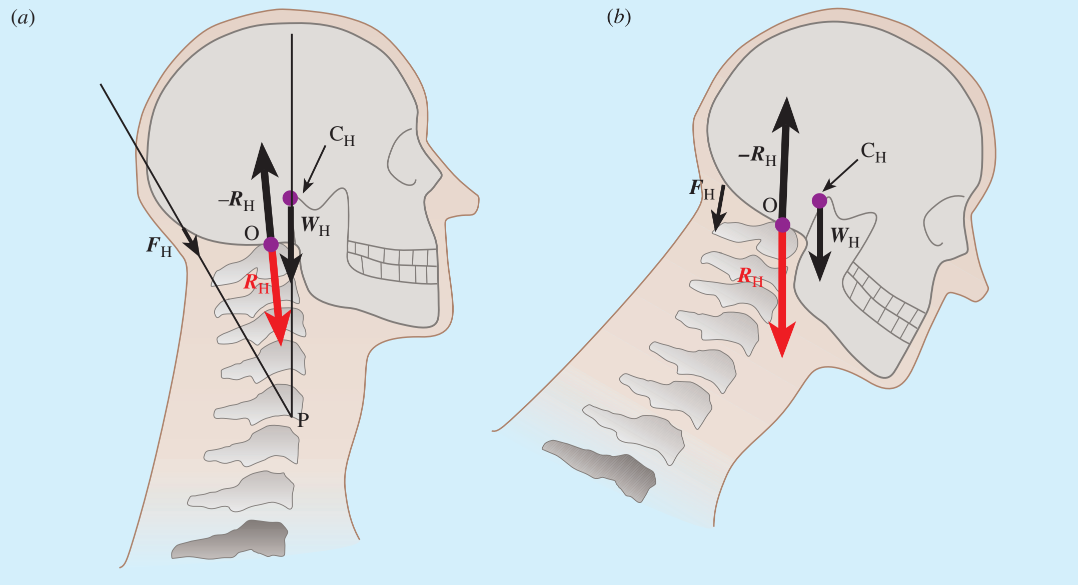


Figure 3. Forces and load $\boldsymbol{R}_H$ by head balance in (*a*) physiological and (*b*) flexed posture.

the shearing effects acting on the vertebrae [6], the possible part of the counteracting torque caused by passive structure (ligaments) is ignored (it is significant only in an extremely flexed posture).

In an upright physiological posture (figure 2(*a*)), the weight of the head and neck $\boldsymbol{W}$ acts at their centre of mass C, which is located close to the vertical axis at the joint origin.

Considering that for equilibrium the force lines of $\boldsymbol{W}$, $\boldsymbol{F}_m$ and the reaction force $-\boldsymbol{R}$ must meet at a point P, it is relatively easy for students to determine first the force $\boldsymbol{F}_m$ and then by graphical construction the resultant (load) $\boldsymbol{R}$. The uncertainty caused by putting the direction of $\boldsymbol{F}_m$ on the back of the vertebrae is covered by the enormous variance in the range exhibited by normal cervical spines, and in any case would not modify the balance requirements that imposed a little value on the force F_m so as to maintain static equilibrium. Therefore the resulting load $\boldsymbol{R}$, the addition of $\boldsymbol{W}$ and $\boldsymbol{F}_m$, applied on the supportive disc C7–T1 is in practice just the weight of the head and neck (60 N).

Increased flexion of the cervical spine increases the horizontal distance dW of the centre of mass C of the head and neck from the joint origin and consequently increases the torque required from the muscular force F_m to maintain static equilibrium (figure 2(*b*)). With the values W = 60 N, dF = 4 cm and dW = 8 cm, a force F_m = 120 N is needed for equilibrium. The resulting load $\boldsymbol{R} = W + F_m$ has a value of about 170 N. According to the literature, forward flexion increases the compressive load by many times the weight of the head and neck in physiological posture [5].

Load on the upper vertebra

The model with global muscle action can help to estimate the load at each vertebra, if only the upper mass of it is considered. For example, we consider now the load on the joint origin at the vertebra C1 (figure 3).

The mass of the head is about 5 kg (6% of body mass) with a centre of mass C_H located at the posterior–inferior sella turcica [5]. In physiological posture the direction of the muscle force $\boldsymbol{F}_H$ acting at the back of the skull is sloping forward (figure 3(*a*)). Considering the horizontal distances of $\boldsymbol{W}_H$ and $\boldsymbol{F}_H$ from the joint origin, the torque balance requires the force F_H to have a value estimated to be about 15 N. The resultant load $\boldsymbol{R}_H$ at the joint O, determined by graphical addition of the head weight $\boldsymbol{W}_H$ and the force $\boldsymbol{F}_H$, is about 70 N. P is the point at which all acting forces, included the reaction force $-\boldsymbol{R}_H$, meet to keep the system in equilibrium.

(*a*) (*b*)

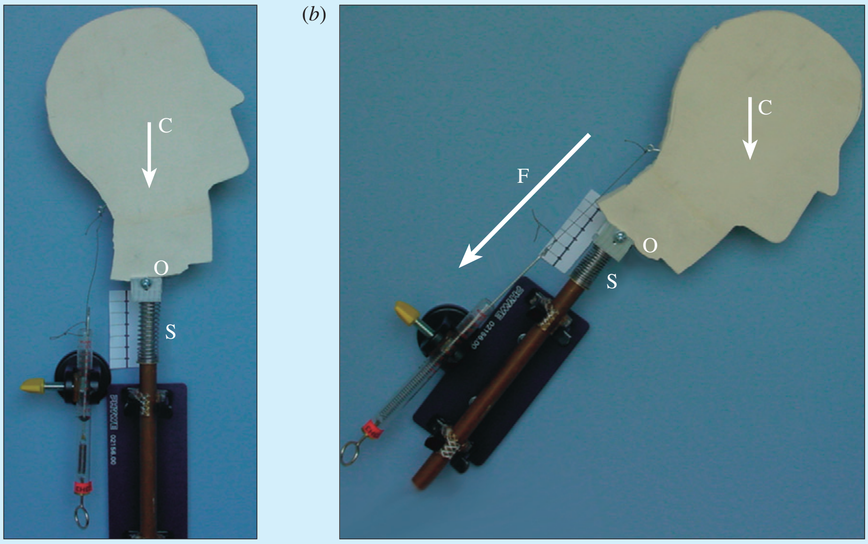


Figure 4. Equilibrium shown by a wooden model in (*a*) upright and (*b*) flexed position.

A 30° increase in flexed posture increases (in fact doubles) the distance of the weight $\boldsymbol{W}_{\mathrm{H}}$ from the joint origin (figure 3(*b*)). The required force F_{H} to maintain static equilibrium would be about 30 N and the resultant load R_{H} about 80 N.

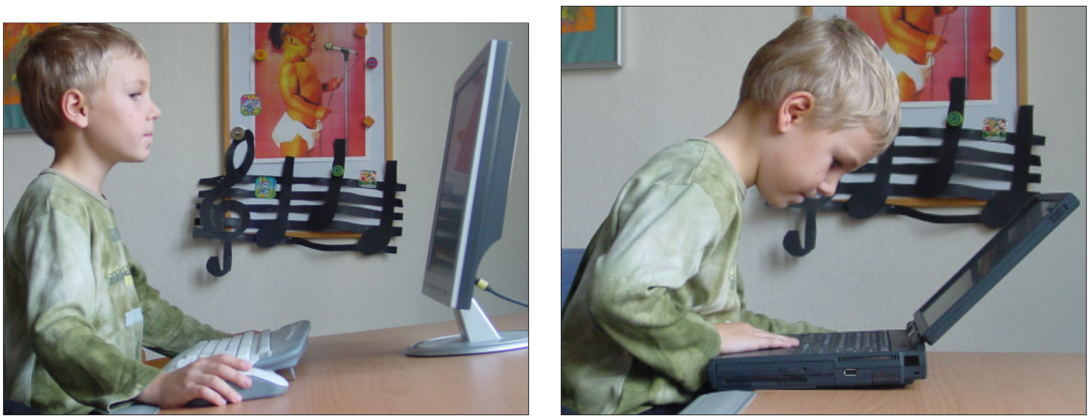
Mechanical model

In order to show that the compressive load on the lower cervical spine increased by forward flexion, one can use a two-dimensional model of the head and neck that is cut from a wooden board (figure 4). At its base the model has a fulcrum O about which it can rotate. The model is supported on a spring S.

The model in the upright position (*a*), with the centre of mass C close to the vertical line through the fulcrum, needs no force for equilibrium. Therefore, only the weight $\boldsymbol{W}$ compresses the spring S. In the flexed position (*b*), the force $\boldsymbol{F}$ must be provided to balance the moment of the weight $\boldsymbol{W}$. The resultant force $\boldsymbol{F} + \boldsymbol{W}$ on the fulcrum is seen to compress the spring much more.

Sitting posture

Many people spend much time in a sitting position. Sitting in the flexed posture that is commonly adopted, for example in looking at a display unit,



(*a*) (*b*)

Figure 5. (*a*) Correct posture and (*b*) poor posture with head forward.

may increase lower cervical flexion and is an important risk factor for neck pain [7–9]. What is more, such a prolonged static posture adopted by children and adolescents during growth can lead to the development and progression of spinal deformities. Figure 5(*a*) shows the correct posture with head and neck approaching the physiological position, while figure 5(*b*) shows a poor posture with head forward which has a larger bending moment.

If prolonged postures with the cervical spine in the physiological position should be preferred, the screen should be positioned in such a way that the axis of vision is horizontal or inclined slightly downward [10], providing that other factors in the workspace do not detract from this choice. Of course, an upright head position is desirable, but does not override the notion that movement is preferable to stasis and that the work activities should provide opportunities for head movements. Also managers and teachers should think more about feasible structural and organizational means of decreasing the load on the spine or varying the posture more.

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