

## Anatomical bases of the study of the constraints to which the cervical spine is subject in the sagittal plane

### A study of the center of gravity of the head

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**Summary.** The authors have determined the position of the center of gravity of six isolated formolized heads by the suspension method, based on the work of the Bordeaux anthropologist, Beauvieux; in his opinion, the nasion-opisthion line (root of nose to posterior edge of the foramen magnum) characterizes the horizontality of the head, irrespective of species. The center of gravity is situated at the middle of the nasion-inion line (root of nose to external occipital protuberance), behind the sella turcica, above and slightly in front of the external auditory meatus. In profile, the axis of gravity falls on leaving the center of gravity and passes in front of the cervical spine, which remains in balance thanks to a fulcrum lever whose two arms are equal when the gaze is directed 30° downwards in relation to the horizontal. This is the true reference position for the cervical spine in the sagittal plane.

#### Etude du centre de gravité de la tête.

#### Application à l'appréciation des contraintes subies par le rachis cervical dans le plan sagittal

**Résumé.** Les auteurs ont déterminé la situation du centre de gravité de 6 têtes formolées isolées par méthode de suspension en se référant aux travaux de l'anthropologue bordelais Beauvieux qui considère que la ligne nasion-opisthion (racine du nez-bord postérieur du trou occipital) caractérise l'horizontalité de la tête quelle que soit l'espèce considérée. Ce centre de gravité se situe au milieu de la ligne nasion-inion (racine du

nez-protubérance occipitale externe) en arrière de la selle turcique, au-dessus et légèrement en avant du conduit auditif externe (CAE). De profil, l'axe de gravité abaissé à partir de ce centre passe en avant du rachis cervical qui s'équilibre grâce à un levier inter appui dont les deux bras de levier sont égaux quand le regard est dirigé à 30° vers le bas par rapport à l'horizontale, véritable position de référence du rachis cervical dans le plan sagittal.

**Key words :** Cervical spine – Head

The position of the center of gravity of the head is much debated. Without doubt, confusion has arisen because the equilibrium of the cervical spine in the sagittal plane has been studied most frequently with the subject's head in the position of attention, the axis of gravity being drawn vertically from the point of contact with the ground. In the present study, the cervico-cephalic segment was studied in isolation. Based on the work of Beauvieux [2], who defined the reference plane for horizontality of the head, we used a suspension method to determine the center of gravity of 6 formolized heads. Thus, the balance of the head could be specified in the sagittal plane, in relation to different positions of the head.

Studies of the center of gravity of the isolated head have been performed by volumetry (Dempster [4]) or by a suspension method. In two cadavers, Braune and Fischer [3] located the center of gravity behind the sella turcica.

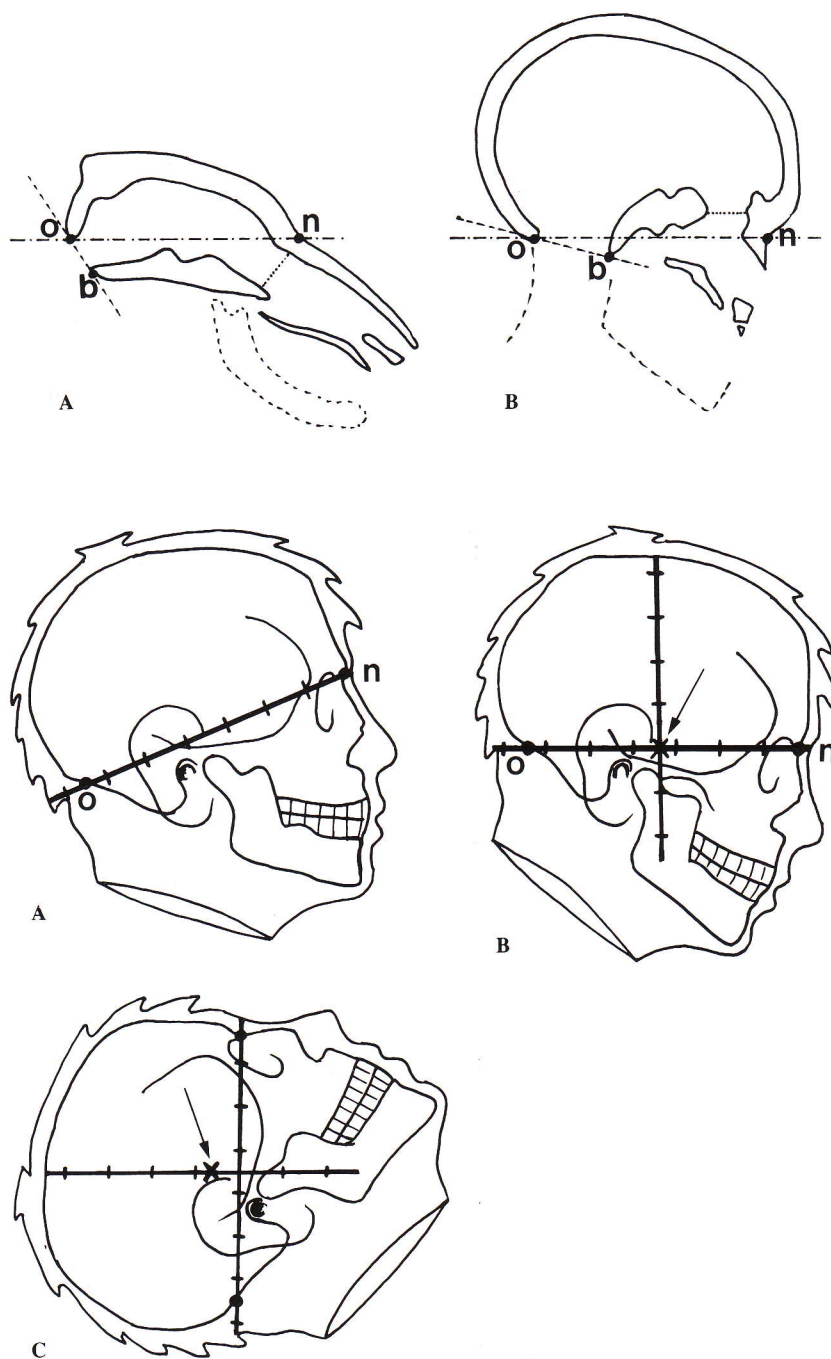
In reality, an axis of gravity for the spine in profile, passing through the external auditory meatus, the 6th cervical vertebra, the 9th thoracic vertebra, and the 3rd sacral segment has often been described (Asmussen [1]). More recently, Marnay [5] has suggested that, in a spine which is in equilibrium in profile, a vertical ABC traced from the external auditory meatus must necessarily pass between the femoral head and the second sacral segment.

Our study was intended to specify the center of

gravity of isolated formolized heads using a suspension method, so the heads had to be stabilized in a profile reference position.

In this respect, the work of Beauvieux seemed of interest; he showed that the nasion-opisthion line is parallel to the lateral (or horizontal) semicircular canal of the labyrinth, irrespective of species.

Beauvieux suggested that evolution from quadrupeds to bipeds was accompanied by closing-off of the angle formed by the nasion-opisthion line and the foramen



**Fig. 1**

The nasion-opisthion reference plane of Beauvieux parallel to the plane of the lateral or horizontal semicircular labyrinthine canal. This is horizontal, irrespective of species **A** (quadruped) or **B** (biped). Evolution occurs with closing-off of the angle bon (horizontalization of the foramen magnum)

Plan de référence nasion-opisthion de Beauvieux parallèle au plan du canal semi-circulaire externe ou horizontal du labyrinthe. Il est horizontal quelle que soit l'espèce **A** (quadrupède) ou **B** (bipède). L'évolution se fait dans le sens de la fermeture de l'angle bon (horizontalisation du trou occipital)

**Fig. 2**

Methodology **A** Nasion-opisthion reference line **B** Suspension horizontalizes this line **C** The center of gravity is at the point of application of the suspension which horizontalizes the perpendicular to the point previously obtained

Méthodologie **A** Ligne nasion-opisthion de référence **B** Par suspension on conduit cette ligne à l'horizontale **C** Le centre de gravité est au point d'application de la suspension qui horizontalise la perpendiculaire au point précédemment obtenu

magnum, rather as if the vertical foramen magnum of quadrupeds became horizontal and parallel with the reference line of Beauvieux, the nasion-opisthion (Fig. 1).

Method (Fig. 2)

Six formolized heads (3 male, 3 female) were isolated. They were weighed, and the cranial index was calculated to establish cranial type, whether dolicho or brachycephalic.

To determine the position of the center of gravity, the first step was to suspend the heads in a Gardner head holder, which was so applied as to horizontalize the nasion-opisthion line.

A perpendicular to this line was dropped from this point of support. The contact point with the heads enabling this perpendicular line to become horizontal was considered to represent the center of gravity.

Results (Fig. 3)

In Table 1, it may be seen that irrespective of sex, head weight and dolicho- or brachycephalic type, the center of gravity so determined is most frequently located at

Table 1. Global results

Specimen number	Sex	Head weight (kg)	Cranial index	Type	Nasion-Inion line	Relationship to sella turcica
1	F	3.671	85	Brachy	Middle	Behind
2	F	3.730	76	Dolicho	Middle	Behind
3	F	4.026	72	Dolicho	Middle	Behind
4	H	4.326	80	Brachy	2 cm in front of the middle	Under
5	H	5.213	83	Brachy	1 cm behind the middle	Behind
6	H	4.816	73	Dolicho	Middle	Behind

the middle of the nasion-inion line. Radiologically, this center lies behind the sella turcica, above and slightly in front of the external auditory meatus. The six centers of gravity were projected clinically over an area of 1 cm<sup>2</sup> centered on the antero-superior implantation of the helix.

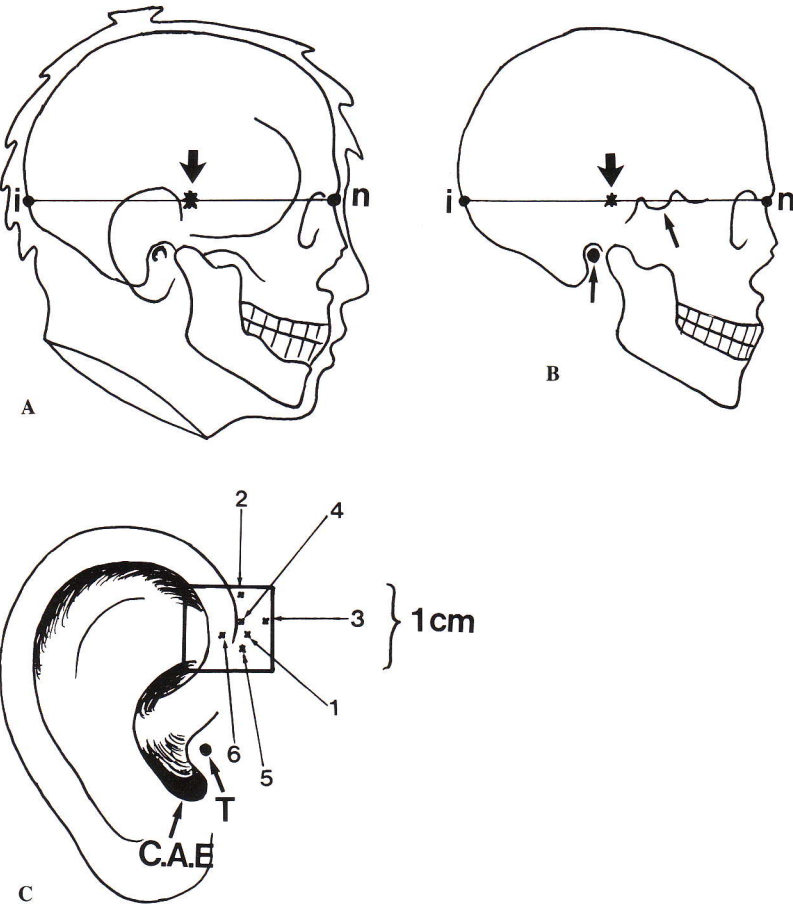
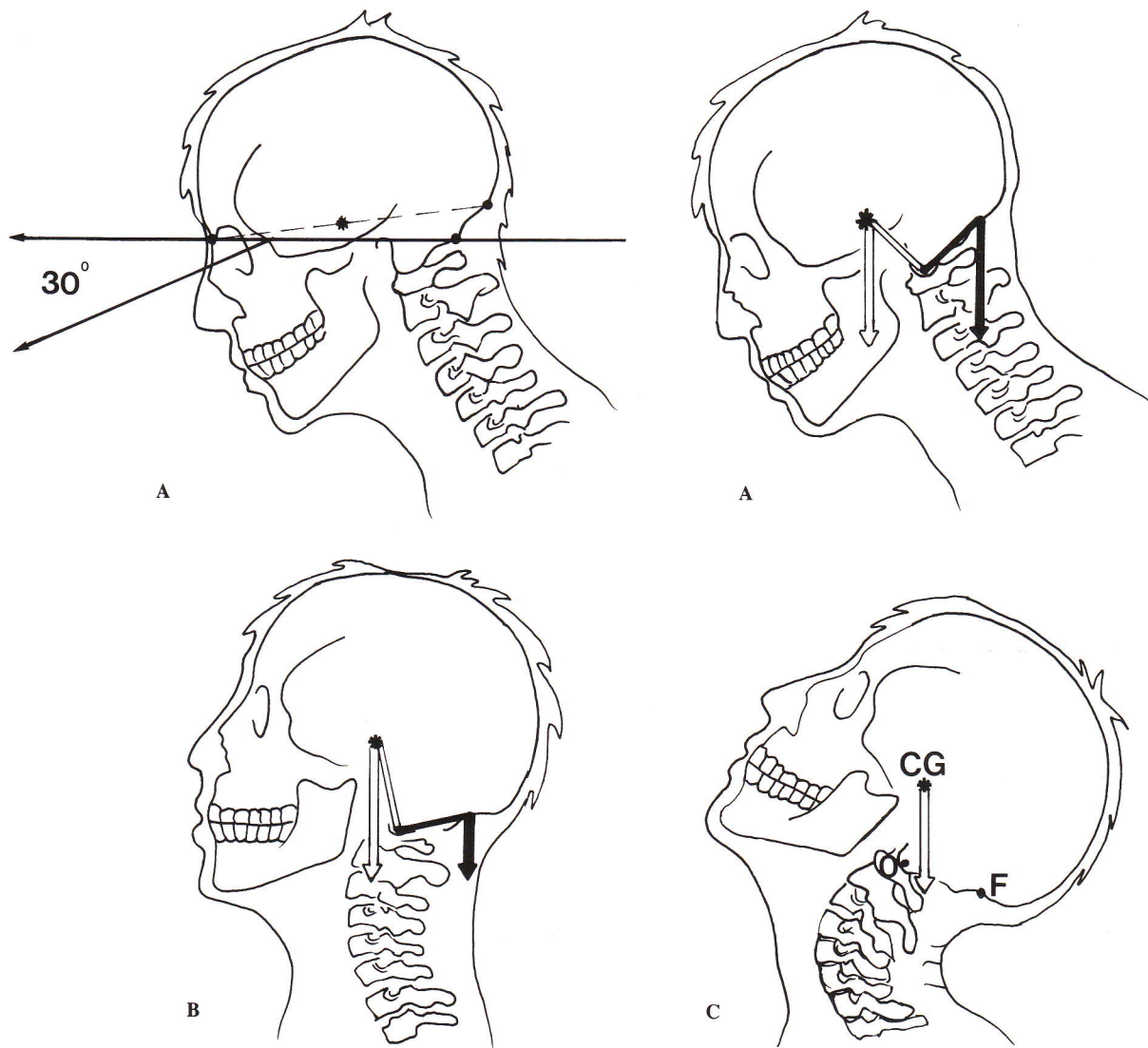


Fig. 3 Results. Location of center of gravity **A** At the middle of the nasion-inion line **B** Radiographic projection of this center behind the sella turcica, above and slightly in front of the external auditory meatus **C** Projection over an area of 1 cm<sup>2</sup> centered on the antero-superior attachment of the helix

Résultats. Situation du centre de gravité **A** Au milieu de la ligne nasion-inion **B** Projection radiographique de ce centre derrière la selle turcique, dessus et légèrement en avant du CAE **C** Projection sur une aire de 1 cm<sup>2</sup> centrée sur l'insertion antéro-supérieure de l'hélix

**Fig. 4**

Equilibrium of cervical spine **A** In the reference position, with the gaze directed  $30^\circ$  downwards, the 2 lever-arms are equal **B** With the gaze horizontal **C** In hyperextension the lever tends to become inter-resistant

Equilibre du rachis-cervical **A** En position de référence, le regard à  $30^\circ$  vers le bas, les 2 bras de levier sont égaux **B** Le regard à l'horizontale **C** En hyper-extension, le levier a tendance à devenir inter-résistant

## Discussion

A precise knowledge of the position of the center of gravity of the head is important in deciding the constraints suffered by the cervical spine in the sagittal plane.

The weight of the head (representing an average of 7% total body-weight) applied from the center of gravity determined in this manner passes in front of the cervical spine; in order to maintain equilibrium there must be a contraction of the posterior muscles, whose average

insertion is at about the middle of the opisthion-inion line.

In fact, this equilibrium depends on the position of the head (Fig. 4), three positions of which were studied in radiographs of volunteers. Three fundamental points had to be established : the center of rotation (O) at the occipito-atloid articulation, the application point of the force (F) at the middle of the nasion-opisthion line, and the application point of the resistance corresponding to the center of gravity of the head.

Cervico-cephalic equilibrium in the sagittal plane is

obtained by fulcrum leverage. This is almost perfect when the head is slightly inclined forwards, with the gaze directed 30° downwards.

In this position the lever arms of resistance and force are equal; there is a position of equilibrium where the nasion-opisthion line is horizontal. It is interesting to note that this position with a 30° downward gaze is recommended by ergonomists as a good working position; moreover, it occurs more frequently than any other in our everyday life, particularly in conversation.

When the eyes are horizontal in the position of attention, the lever is still of the fulcrum type, but the axis of gravity is directed backwards over the upper cervical vertebrae.

Finally, as the head moves into a position of hyperextension, the center of gravity is projected

between the center of rotation (O) and the application point of the force (F), with the lever becoming inter-resistant.

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