The Head-Neck Sensory Motor System

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Chapter 14
Development of the Vertebral Joints (C3 through T2) in Man

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The extensive literature on the primary development of the vertebral column is principally concerned with the vertebral bodies and the intervertebral disks. The earliest conclusive account of the reorganization (*Neugliederung*) of the vertebral column was given by Sensenig (1949). Töndury concerned himself mostly with the time and order of appearance of the centers of ossification in the vertebrae, and the fusion of the neural arches with the bodies (1958), but it was Verbout (1985) who finally produced a clear picture of the definitive segmentation of the elements of the vertebral column.

In contrast to this, there has been—apart from the controversial literature on the meniscoid folds—very little research on concrete morphologic findings. Regarding clinical literature, an enormous amount of work exists on the functional interpretation of the vertebral joints, which are regarded as the "guide rails of movement" (*Leitschienen der Bewegung*), and the like. Apart from my own contributions (Putz, 1981, 1989), the first more detailed descriptions of their function are those of White and Panjabi (1978) and Kummer (1981). Med (1973) and Cihak (1981) have provided merely formal descriptions of their development. The particular functional role of the spinal segment C2–3 has been elucidated by Minne and his coworkers (1970) and by Mestdagh (1976).

For a long time no analysis of the relationship of function to structure in the vertebral joints during fetal and postnatal development was attempted. This is all the more surprising since—in contrast to many other joints in the human body (the knee joint and hip joint, for instance)—the fundamental adjustment of the vertebral joints to the demands made upon them takes place during the first years of life. The investigation reported here was designed to compare and contrast the morphology of the vertebral joints in the fetus with that of the adult, and to derive the causal relationship between structure and function.

Results

In a fetus with a crown-rump (CR) length of 12 cm, the vertebral joints from C3 to T1 show little variation in the angle of inclination to the upper surface of the body (α) (Fig. 14–1). This angle is approximately 40°. Within the region under discussion, the joint surfaces of the third cervical and first thoracic vertebrae show the steepest inclination. During later stages of fetal development (CR lengths 17 and 23 cm), their angles grow even steeper, and, at the time of birth, have reached a value of 50° to 70° (Fig. 14–2A).

The vertebral joints begin to differentiate markedly during the first year of life; by the time that growth is completed, the inclination of the joint surfaces of the third cervical and first thoracic vertebrae has reached a value of 65° (±12°). The angles of the other cervical vertebrae remain significantly smaller—around 55° (±10°). The angles of the adult column are particularly clearly seen in lateral view (Fig. 14–2B).

In a similar fashion, the development of the angle between the vertebral joints (β) proceeds independently in the transverse plane. In a fetus of CR length 12 cm, no difference can be detected between the angles in the cervical and upper thoracic regions of the column. In the transverse alignment they are 180° (±5°). Figure 14–3 shows an example of a transverse section through a 17-cm fetus. Only at the end of pregnancy, the alignment of the third cervical and the first thoracic vertebral joint surfaces becomes distinguishable from that of the other cervical vertebrae. The opening angles of C3 and T1 are now somewhat smaller, while the others remain at about 180°. During the first year of life the opening angle of the third cervical vertebra narrows increasingly to 140° (±9°). The closer they lie to T1, the more the opening angles of the remaining cervical vertebrae approach this vertebra's value of about 190° (±8°). The corresponding angles of the thoracic vertebrae ordinarily reach a value (obtuse posteriorly) of over 200° (Fig. 14–4).

In this connection it must be mentioned that a similar development takes place at the level of the lumbar vertebrae. From val-

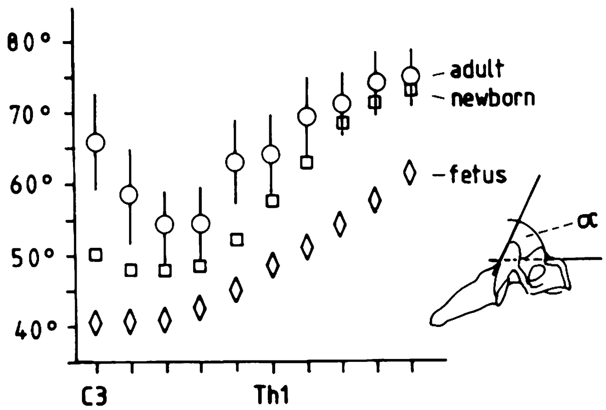

Fig. 14–1. Angle of inclination (α) of the vertebral facet joints (C3 through T2).

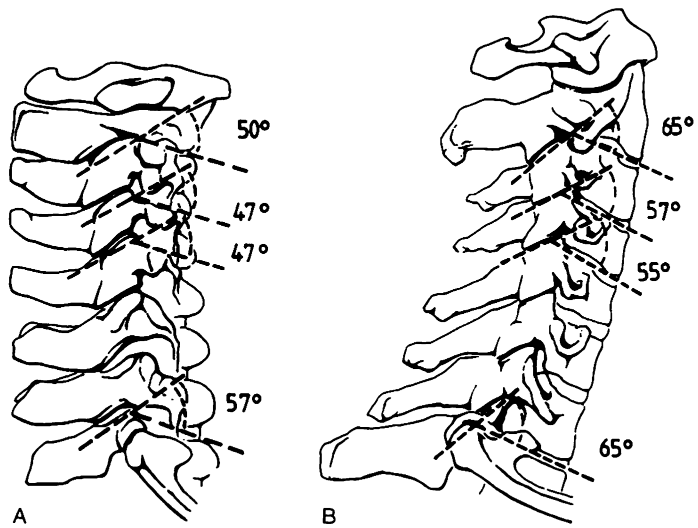

Fig. 14–2. Lateral view of the cervical vertebral column with the angles of inclination of the facet joints of (A) a newborn and (B) an adult.

Fig. 14–3. Transverse section through the facet joints of the spinal segment C2–3 of a 17-cm fetus: opening angle (β) = 180° (see also Fig. 14–4). Scale 14 : 1.

ues of 180° to 200° at birth, the angles between them change rapidly during the first year of life. The small medial components remain more or less in the frontal plane, while the lateral portions become aligned dorsally, and end up reaching values from 10° to 40°. These changes, which are remarkably extensive in this region of the vertebral column, follow the uneven distribution of cell division within the joint surface (Fig. 14–5), the rapid local growth being an expression of cell proliferation, which occurs laterally for the most part. Growth changes take place in a similar fashion in the cervical region.

Discussion

It follows from our measurements that all the vertebral joints, influenced by a unified "construction principle" show few individual differences, up to the end of pregnancy, and reach their definitive positions only during early childhood. We interpret this observation in connection with both the quantitative and qualitative development of the mechanical stresses involved.

The position of the vertebral joints during the fetal period can be shown by theoretical analysis to be an adaptation to irregular static conditions that, caused by the dynamics of flexion movements in the uterus, are limited to the duration of pregnancy. The extent of the movement and the forces that are brought about remain within bounds. Following birth, a quantitative increase in the forces acting on the column produces a qualitative change in the nature of the stresses involved; the extent of the flexion movements, and most particularly those of rotation to right and left, are markedly increased.

If one accepts Pauwels' (1980) principle of causal histogenesis (the extent of the intermittent pressure upon it is the decisive factor controlling the growth of hyaline cartilage), it is clear that the superior—but above all the lateral—edges of the cervical joints come under the influence of growth-producing stresses. This is also in accordance with the view of other authors (Lutz, 1967; Reichmann, 1970/71; Reichmann and Lewin, 1971), that, during the final stages of a movement, the forces acting on the periphery of the joint increase. On the other hand, the diagrammatic functional interpretation suggested by Penning (1978), based on a cylindric shape of the joint surface, is too greatly oversimplified.

The structure of these joints is obviously the expression of a morphologic compromise between the demands produced by the static and dynamic forces acting upon them (Figs. 14–6 and 14–7). The spinal segments nearest to the head and trunk would then have the least freedom of movement. The second and seventh cervical vertebrae are particularly under the influence of the associated massive musculature, and have developed joint surfaces that are turned toward one another to form mechanical buttresses. The atlas vertebra enjoys a special position only insofar as it, like the talus, constitutes a "bony disk."

Conclusions

Because of the arrangement of their joint surfaces and the strength of the muscles acting upon them, the spinal segments C2–3 and C7–T1 become relatively fixed points in the complex chain of the vertebral column. The postnatal changes taking place in their structure and their inclination and opening angles reflect the interplay between the functional stresses that act upon them peripherally and their power of morphologic adaptation.

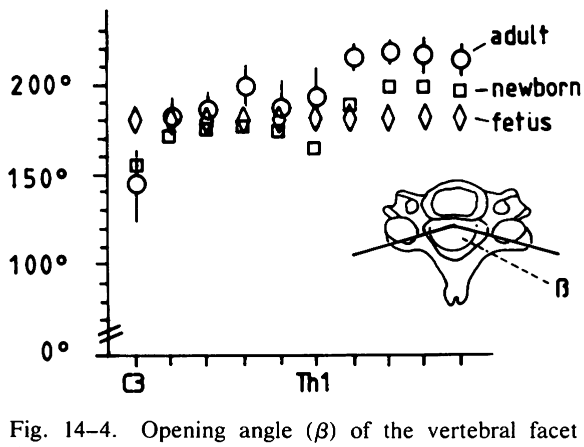

Fig. 14–4. Opening angle (β) of the vertebral facet joints (C3 through T2).

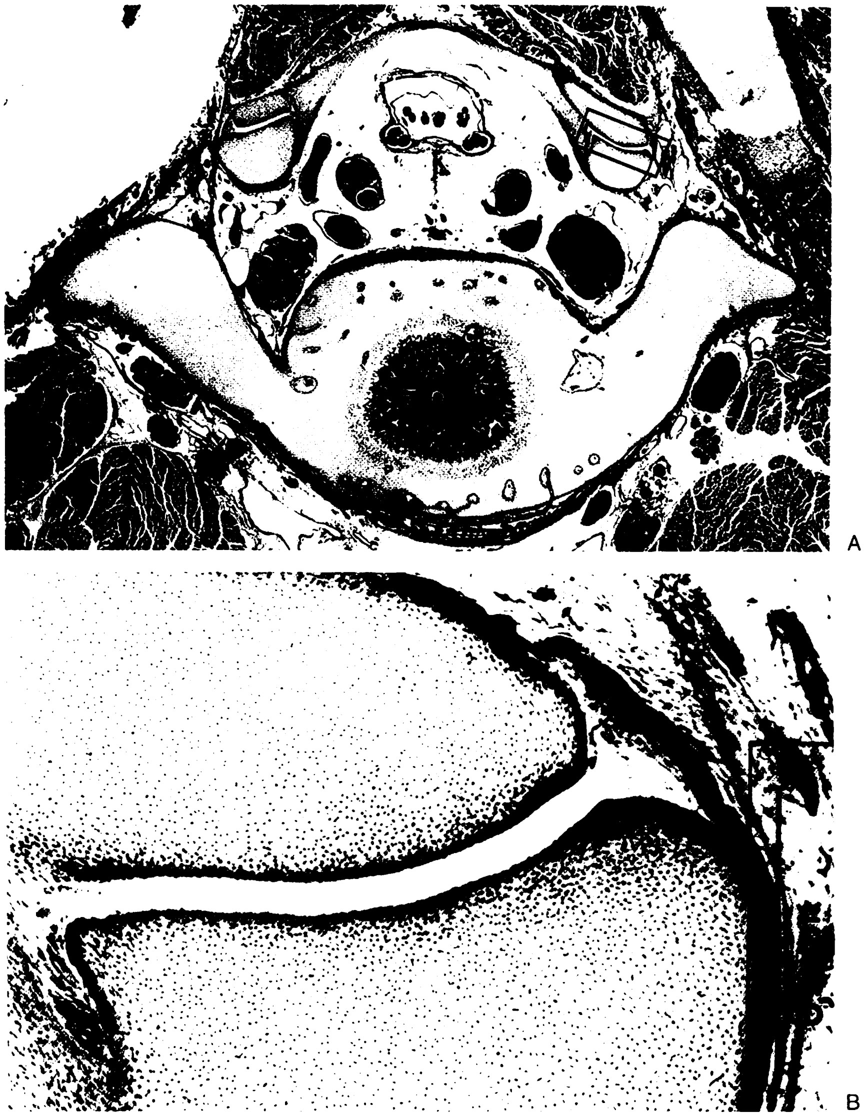

Fig. 14–5. Transverse section through a lumbar vertebra of a 40-cm fetus showing the orientation of the facet joints (β). (A) Scale 8 : 1. (B) Enlargement of boxed area in upper right of (A); scale 80 : 1.

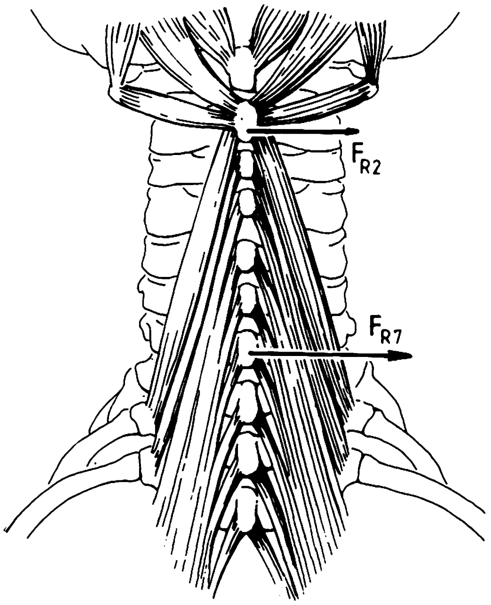

Fig. 14–6. Cervical vertebrae under muscular tension (posterior view). F_{R2}, F_{R7}, forces of rotation acting on the spinous processes of the second and seventh cervical vertebrae, respectively.

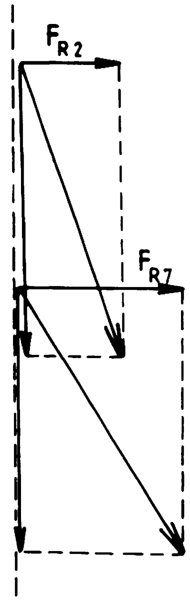

Fig. 14–7. Relative muscular stresses (of inserting muscles) acting on the cervical vertebrae C2 and C7 during rotation or unilateral extension; the rotational component (F_R) at the level of the second cervical vertebra (F_{R2}) is smaller than that at the level of the seventh (F_{R7}).