

The Head-Neck Sensory Motor System

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Contents

Part I The Head-Neck System from an Anthropologic Viewpoint

1. The Upright Head in Hominid Evolution, 5
Phillip V. Tobias

Part II Evolution of the Head-Neck Movement System

2. Why Develop a Neck? 17
Carl Gans
3. Evolution of the Dorsal Muscles of the Spine in Light of Their Adaptation to Gravity Effects, 22
Françoise K. Jouffroy
4. Modeling of the Craniofacial Architecture during Ontogenesis and Phylogenesis, 36
Anne Dambricourt-Malassé and Marie-Josèphe Deshayes

Part III Comparative Aspects of the Head-Neck Movement System

A. Invertebrates

5. Stabilizing Head/Eye Movements in the Blowfly *Calliphora erythrocephala*, 49
Roland Hengstenberg
6. The Head-Neck System of the Blowfly *Calliphora*: 1. Anatomic Organization of Neck Muscles, Motoneurons, and Multimodal and Visual Inputs, 56
Nicholas J. Strausfeld
7. The Head-Neck System of the Blowfly *Calliphora*: 2. Functional Organization and Comparisons with the Sphinx Moth *Manduca sexta*, 64
Jürgen J. Milde, Wulfilä Gronenberg, and Nicholas J. Strausfeld
8. The Absence of a True Head-Neck in Decapod Crustaceans: Consequences for Orientation and Equilibration, 71
Michelle Bévengut and Douglas M. Neil

B. Vertebrates

9. Neural Processes between Visual Sign Stimuli and Head Movements in Toads, 79
Jörg-Peter Ewert, Evelyn Schürg-Pfeiffer, and Wolfgang Willi Schwippert
10. Control of Gaze in Salamanders, 85
Gerhard Manteuffel
11. Reflex Contributions to the Control of Head Movement in the Lizard, 91
Dave H. B. Wang and John H. Anderson

12. Optocollic Reflexes and Neck Flexion–Related Activity of Flight Control Muscles in the Airflow-Stimulated Pigeon, 96
Dietrich Bilo
13. Comparison of Head Movement Strategies among Mammals, 101
James H. Fuller

Part IV Embryology and Ontogeny of the Head-Neck Movement System

14. Development of the Vertebral Joints (C3 through T2) in Man, 115
Reinhard Putz
15. Head Position and Posture in Newborn Infants, 118
François Jouen
16. Head-Trunk Coordination and Locomotor Equilibrium in 3- to 8-Year-Old Children, 121
Christine Assaiante and Bernard Amblard

Part V Architecture of the Head-Neck Movement System

A. Bones and Muscles

17. Skeletal Geometry in Vertebrates and Its Relation to the Vestibular End Organs, 129
Werner Graf, Catherine de Waele, and Pierre Paul Vidal
18. The Cervical Spine, from Anatomy and Physiology to Clinical Care, 135
John H. Bland and Dallas R. Boushey
19. Heterogeneous Structure and Function among Intervertebral Muscles, 141
Frances J. R. Richmond, David C. Gordon, and Gerald E. Loeb
20. Relationship between Force and Cross-Sectional Area of Postcervical Muscles in Man: Influence of Variations in the Morphology of the Neck, 148
Marie-Anne Mayoux-Benhamou, Marc Wybier, Jacques Patrick Barbet, Sylvain Labbé, and Michel Revel

B. Models and Theories

21. Biomechanical Models of the Head-Neck System, 150
Johannes Dimnet
22. Muscle Behavior May Solve Motor Coordination Problems, 153
Neville Hogan and Ferdinando A. Mussa-Ivaldi
23. Multidimensional Geometry Intrinsic to Head Movements around Distributed Centers of Rotation: A Neurocomputer Paradigm, 158
András J. Pellionisz, Bertrand Le Goff, and Jozsef Laczkó

Part VI Sensors of the Head-Neck Movement System

24. Somatosensory Pathways from the Neck, 171
David J. Tracey and Philip S. Bolton
25. Physiologic Properties and Central Actions of Neck Muscle Spindles, 175
Victor J. Wilson
26. Excitatory and Inhibitory Mechanisms Involved in the Dynamic Control of Posture during the Cervicospinal Reflexes, 179
Ottavio Pompeiano
27. Suppression of Cervical Afferents Impairs Visual Cortical Cell Development, 188
Pierre Buisseret

28. Eye and Neck Proprioceptive Messages Contribute to the Specification of Gaze Direction in Visually Oriented Activities, 193
Régine Roll, Jean Louis Velay, and Jean-Pierre Roll
29. Influence of Neck Receptor Stimulation on Eye Rotation and on the Subjective Vertical: Experiments on the Tilt Table, under Water, and in Weightlessness, 197
Joachim Wetzig and Rudolf J. von Baumgarten
30. Cervico-ocular Reflexes with and without Simultaneous Vestibular Stimulation in Rabbits, 201
Neal H. Barmack, Pierangelo Errico, Aldo Ferraresi, and Vito E. Pettorossi
31. Vestibular and Optokinetic Asymmetries in the Ocular and Cervical Reflexes, 208
Vito E. Pettorossi, Pierangelo Errico, Aldo Ferraresi, Francesco Draicchio, Rosa Maria Santarelli, and Rosa Bruni
32. Cervicovestibular Interactions in Coriolis-Like Effects, 213
Willem Bles and Jelte E. Bos
33. Gravitational, Inertial, and Coriolis Force Influences on Nystagmus, Motion Sickness, and Perceived Head Trajectory, 216
James R. Lackner and Paul DiZio
34. Head Position versus Head Motion in the Inhibition of Horizontal Postrotary Nystagmus, 223
Eberhard Koenig, Wilhelm Dengler, Michael Fetter, Asta Hann, and Johannes Dichgans

Part VII Neuronal Mechanisms of the Sensory-Motor Transformations in the Head-Neck Movement System

A. Spinal Mechanisms

35. Intrinsic Properties of Neck Motoneurons, 231
P. Kenneth Rose
36. Organization of the Motor Nuclei Innervating Epaxial Muscles in the Neck and Back, 235
Yuriko Sugiuchi and Yoshikazu Shinoda

B. Vestibular Neurons

37. Eye and Head Movements as Specialized Functions of Vestibular Circuits, 241
Kurt-Peter Schaefer and Dietrich Lothar Meyer
38. Electrophysiology and Pharmacology of Two Types of Neurons in the Medial Vestibular Nucleus and Nucleus Gigantocellularis of the Guinea Pig In Vitro, 244
Mauro Serafin, Asaid Khateb, Catherine de Waele, Pierre Paul Vidal, and Michel Mühlethaler
39. Examination of the Descending Projections of the Vestibular Nuclei Using Anterograde Transport of *Phaseolus vulgaris* Leukoagglutinin, 251
Anne Y. H. Donevan, Monica Neuber-Hess, and P. Kenneth Rose
40. Vestibular Nerve Inputs to Vestibulospinal and Vestibulo-ocular Neurons of the Squirrel Monkey, 255
Richard Boyle, Jay M. Goldberg, and Stephen M. Highstein

41. Spatial Innervation Patterns of Single Vestibulospinal Axons in Neck Motor Nuclei, 259
Yoshikazu Shinoda, Tohru Ohgaki, Yuriko Sugiuchi, and Takahiro Futami
 42. Properties of Vestibulo-ocular and/or Vestibulocollic Neurons in the Cat, 266
Yoshio Uchino and Naoki Isu
 43. Eye Movement–Related Activity in the Vestibulo-ocular and Vestibulocollic Pathways in the Cat, 273
Yoshiki Iwamoto, Toshihiro Kitama, and Kaoru Yoshida
 44. Single Vestibular Unit Recordings in the Alert Cat during Active and Passive Head Movements, 279
James H. Fuller
- C. Collicular and Reticular Neurons**
45. The Superior Colliculus and Head Movements in the Cat, 289
Vivian C. Abrahams, E. Dawne Downey, and Adriana A. Kori
 46. Properties of Eye and Head Movements Evoked by Electrical Stimulation of the Monkey Superior Colliculus, 292
Mark A. Segraves and Michael E. Goldberg
 47. Role of the Tectoreticulospinal System in the Coordination of Eye-Head Orienting Movements, 296
Douglas P. Munoz, Daniel Guitton, and Denis Pélisson
 48. Retrograde Axonal Transport of Fluorescent Tracers from Medullary Reticular Structures to the “Neck” and “Forelimb” Segments of the Cervical Spinal Cord, 306
Noemi Corvaja Ciriani, Alessandra Gennari, Paola d’Ascanio, and Ottavio Pompeiano
 49. Reticulospinal Control of Head Movements in the Cat, 311
Shigeto Sasaki
 50. Contribution of Reticulospinal Neurons to the Dynamic Control of Head Movements: Presumed Neck Bursters, 318
Alexey Grantyn, Alain Berthoz, Olivier Hardy, and Antoine Gourdon
- D. Interstitial Nucleus of Cajal and Beyond**
51. Involvement of the Interstitial Nucleus of Cajal in the Midbrain Reticular Formation in the Position-Related, Tonic Component of Vertical Eye Movement and Head Posture, 330
Kikuro Fukushima and Junko Fukushima
 52. Control of Vertical Head Movement via Forel’s Field H, 345
Tadashi Isa, Toru Itouji, and Shigeto Sasaki
 53. Role of the Lateral Mesencephalic Reticular Formation in the Control of Head Movements, 351
Olivier Hardy and Jacques Mirenowicz
 54. Brain Stem Control of Coordinated Eye-Head Gaze Shifts, 356
R. David Tomlinson and Manohar Bance
 55. Electromyographic Activity of Neck Muscles in Relation to the Initiation of Head Turning Induced by Stimulation of the Caudate Nucleus in the Cat, 362
Tadao Ohno and Hiroshi Tsubokawa

Part VIII Synergies and Strategies of Head Movements and Gaze Control**A. Head Movement Control**

56. From Interdependent to Independent Control of Head and Trunk, 369
Horst Mittelstaedt and Marie-Luise Mittelstaedt
57. Multidimensional Analysis of Head Stabilization—Progress and Prospects, 374
Barry W. Peterson, James F. Baker, and Emily A. Keshner
58. Multiple Control Mechanisms Contribute to Functional Behaviors of the Head and Neck, 381
Emily A. Keshner and Barry W. Peterson
59. Listing's Law for Gaze-Directing Head Movements, 387
Douglas Tweed and Tutis Vilis
60. Sensitivity Analysis of a Human Head Movement Model, 392
Andreas C. Arlt, Wolfgang H. Zangemeister, and Jürgen Dee
61. Nonlinear Dynamics of Involuntary Head Movements, 400
Jefim Goldberg

B. Orienting and Stabilizing Eye and Head Movements

62. Active Head Movement Analysis of Vestibulo-ocular Reflex Dynamics, 404
Dennis P. O'Leary and Linda L. Davis
63. Eye-Head Main Sequence in Midsagittal Vertical Plane in Humans, 408
Claudie André-Deshays and Samuel Ron
64. Effect of Freeing the Head on Eye Movement Characteristics during Three-Dimensional Shifts of Gaze and Tracking, 412
Han Collewyn, Robert M. Steinman, Casper J. Erkelens, Zygmunt Pizlo, and Johannes van der Steen
65. Coordination of Head and Eyes during the Performance of Natural (and Unnatural) Visual Tasks, 419
Eileen Kowler, Zygmunt Pizlo, Guo-Liang Zhu, Casper J. Erkelens, Robert M. Steinman, and Han Collewyn
66. Gaze Saccades to Visual Targets: Does Head Movement Change the Metrics? 427
Wolfgang Becker and Reinhard Jürgens
67. Eye-Head Coordination during Active and Passive Head Rotations in the Dark, 434
Roberto Schmid and Daniela Zambarbieri
68. Identification of Peripheral Visual Images in a Laterally Restricted Gaze Field, 439
John L. Semmlow, Gabriel M. Gauthier, and Jean-Louis Vercher
69. Visual and Vestibular Contributions to Head-Eye Coordination during Head-Free Pursuit, 443
Graham R. Barnes and Jane F. Lawson
70. Mathematical Modeling of Visual and Nonvisual Mechanisms of Head-Eye Coordination, 449
Graham R. Barnes

C. Timing and Prediction

71. Timing of Coordinated Head and Eye Movements during Changes in the Direction of Gaze, 455
Johannes van der Steen
72. Gaze Movements: Patterns Linking Latency and Vestibulo-ocular Reflex Gain, 461
Wolfgang H. Zangemeister and Lawrence Stark
73. Eye-Head Coordination: Direction-Specific Differences of Horizontal Saccades Executed Toward or Opposite in Direction to Concurrent Head Motion, 467
Siegbert Krafczyk, Walter Paulus, and Thomas Brandt

D. Linear Movement Analysis

74. Decoding of Optic Flow by the Primate Optokinetic System, 471
Frederick A. Miles, Urs Schwarz, and Claudio Busettoni
75. Eye Movements and Visual-Vestibular Interactions during Linear Head Motion, 479
Gary D. Paige and David L. Tomko

E. Perception

76. Perception of Liminal and Supraliminal Whole-Body Angular Motion, 483
Alan J. Benson and Sally F. Brown
77. Perception of the Orientation of the Head on the Body in Man, 488
Janet L. Taylor
78. Perception of Horizontal Head and Trunk Rotation in Space: Role of Vestibular and Neck Afferents, 491
Thomas Mergner, Christoph Siebold, Georg Schweigart, and Wolfgang Becker
79. Cortical Representation of Head-in-Space Movement and Some Psychophysical Experiments on Head Movement, 497
Otto-Joachim Grüsser, Wolfgang Guldin, Lawrence Harris, Johann-Christoph Lefèbre, and Max Pause

F. Eye-Head Coordination and Reflex Behavior

80. Kinematic Characteristics of the Head Trajectory during Horizontal Head Movements in Monkeys, 510
Bertrand Le Goff, Pierre Madic, Philippe Liverneaux, and Francis L. Lestienne
81. Mechanisms of Gaze Control and Eye-Head Coupling in the Cat Whose Head is Unrestrained, 516
Daniel Guitton, Douglas P. Munoz, and Henrietta L. Galiana
82. Modeling Head-Free Gaze Control in the Cat, 520
Henrietta L. Galiana, Daniel Guitton, and Douglas P. Munoz
83. Eye-Head Coordination in Oblique Gaze Shifts in Cats, 526
André Roucoux, Marc Crommelinck, and Liliane Borel
84. Vestibulo-Ocular Reflex Inhibition Mechanism during Goal-Directed Saccades in Man, 531
Denis Pélisson and Claude Prablanc
85. Mechanism for Voluntary Cancellation of the Vestibulo-ocular Reflex in Squirrel Monkeys That Is Not Related to Smooth Pursuit, 536
Robert A. McCrea and Kathleen E. Cullen

- Part IX Head Movement during Posture, Locomotion, and Complex Movements**
86. What about the So-Called Neck Reflexes in Humans? 543
Victor S. Gurfinkel, Michael A. Lebedev, and Yuri S. Levick
 87. Do Head Position and Active Head Movements Influence Postural Stability? 548
Andreas Straube, Walter Paulus, and Thomas Brandt
 88. Significance of Muscle Proprioceptive and Vestibulospinal Reflexes in the Control of Human Posture, 552
Michael Trippel, Gerhard A. Horstmann, and Volker Dietz
 89. Influence of Tactile Cues on Visually Induced Postural Reactions, 555
Lawrence R. Young and Gail Standish
 90. Differential Influence of Vertical Head Posture during Walking, 560
Wolfgang H. Zangemeister, Maria V. Bulgheroni, and Antonio Pedotti
 91. Control of Head Stability and Gaze during Locomotion in Normal Subjects and Patients with Deficient Vestibular Function, 568
Osric S. King, Scott H. Seidman, and R. John Leigh
 92. Head-Trunk Coordination in Man: Is Trunk Angular Velocity Elicited by a Support Surface Movement the Only Factor Influencing Head Stabilization? 571
John H. J. Allum, Flurin Honegger, and Emily A. Keshner
 93. Visual, Vestibular, and Somatosensory Control of Compensatory Gaze Nystagmus during Circular Locomotion, 576
David Solomon and Bernard Cohen
 94. Different Patterns in Aiming Accuracy for Head-Movers and Non-Head Movers, 582
Chantal Bard, Michelle Fleury, and Jacques Paillard
 95. Head Kinematics during Complex Movements, 587
Thierry Pozzo, Alain Berthoz, and Loïc Lefort
 96. Head-Forelimb Movement Coordination and Its Rearrangement in the Course of Training in the Dog: Role of the Motor Cortex, 591
Olga G. Pavlova and Alexey V. Alexandrov
 97. Preferential Activation of the Sternocleidomastoid Muscles by the Ipsilateral Motor Cortex during Voluntary Rapid Head Rotations in Humans, 597
Letizia Mazzini and Marco Schieppati
- Part X Disorders of the Head-Neck System**
- A. Vestibular Disorders**
98. Head-Shaking Nystagmus—A Tool to Detect Vestibular Asymmetries in Patients, 603
Eberhard Koenig, Michael Fetter, Sachiko Takahashi, and Johannes Dichgans
 99. Effect of Peripheral Vestibular Disorders on Head-Trunk Coordination during Postural Sway in Humans, 607
Charlotte L. Shupert, Fay Bahling Horak, and F. Owen Black
 100. Eye-Head Coordination in Normal and Hemilabyrinthectomized Cats, 611
Liliane Borel and Michel Lacour

101. Vestibular Compensation: Sensitive Period and Role of Sensory-Motor Activity in Substitution Processes, 617
Yoh'i Zennou-Azogui and Christian Xerri
 102. Response Characteristics of Central Vestibular Neurons and Compensatory Mechanisms following Hemilabyrinthectomy, 620
Ying-Sing Chan and Joseph C. Hwang
 103. Vestibular *N*-Methyl-D-Aspartate Receptors in Normal and Compensated Guinea Pigs, 625
Catherine de Waele, Nicholas Vibert, Alain Berthoz, and Pierre Paul Vidal
 104. Effects of *N*-Methyl-D-Aspartate Receptor Antagonists on Vestibular Compensation in the Guinea Pig: In Vivo and In Vitro Studies, 631
Paul F. Smith and Cynthia L. Darlington
 - B. Neurologic Disorders**
 105. Control of Head-Eye Posture in the Roll Plane: Comparative Neurology of the Ocular Tilt Reaction, 636
G. Michael Halmagyi and Ian S. Curthoys
 106. Subjective Visual Vertical and Eye-Head Coordination (Roll) with Brain Stem Lesions, 640
Marianne Dieterich and Thomas Brandt
 107. Cervical Contribution to Balance: Cervical Vertigo, 644
Jeffrey J. Brown
 108. Clinical and Experimental Investigations of Visually Guided Eye and Head Movement: Role of Neck Afferents, 648
Minoru Maeda
 109. Experimental Torticollis in Cats and Monkeys: Effect of Lesions and Drugs, 654
Francine Malouin and Paul J. Bédard
 110. Spasmodic Torticollis: Its Electromyographic Recording and Treatment by Alcoholization, 659
Osamu Hasegawa
 111. Functional Outcome after Segmental Arthrodesis of the Cervical Spine, 663
Henri Mestdagh and Hervé Lecllet
 112. Fixed Gaze and Eye-Head Coordination in Basal Ganglia Diseases (Parkinson's Disease, Huntington's Chorea, and Pallidum Necrosis), 668
Didier Bazalgette, Maurice Zattara, Nguyen Bathien, and Pierre Rondot
 113. Neuroleptic Treatment-Induced Abnormal Neck Posture, 674
Yoshihiro Kaneko
 114. Abnormal Timing of Antagonist Splenius Burst in Head Movements of Patients with Cerebellar Disorders: Clinical and Modeling Results, 678
Wolfgang H. Zangemeister, Jürgen Dee, and Andreas C. Arlt
 115. Strategies of the Eye-Head Orientation in Human Infants Related to Cognitive Development, 684
Marguerite Roucoux and Christine Culée
- References, 689
- Index, 739

Chapter 14

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

Reinhard Putz

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

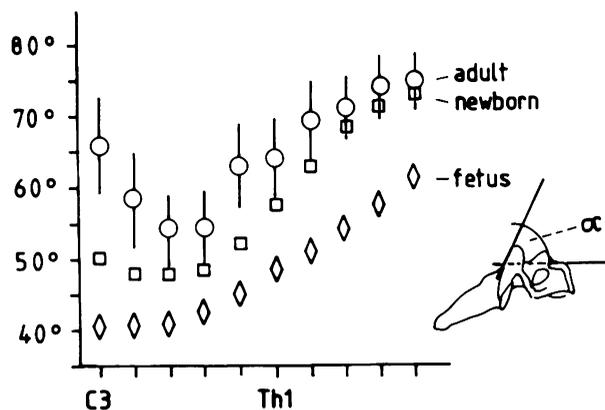


Fig. 14-1. Angle of inclination (α) of the vertebral facet joints (C3 through T2).

tion 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 $65^\circ (\pm 12^\circ)$. The angles of the other cervical vertebrae remain significantly smaller—around $55^\circ (\pm 10^\circ)$. 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 $180^\circ (\pm 5^\circ)$. 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 $140^\circ (\pm 9^\circ)$. The closer they lie to T1, the more the opening angles of the remaining cervical vertebrae approach this vertebra's value of about $190^\circ (\pm 8^\circ)$. 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-

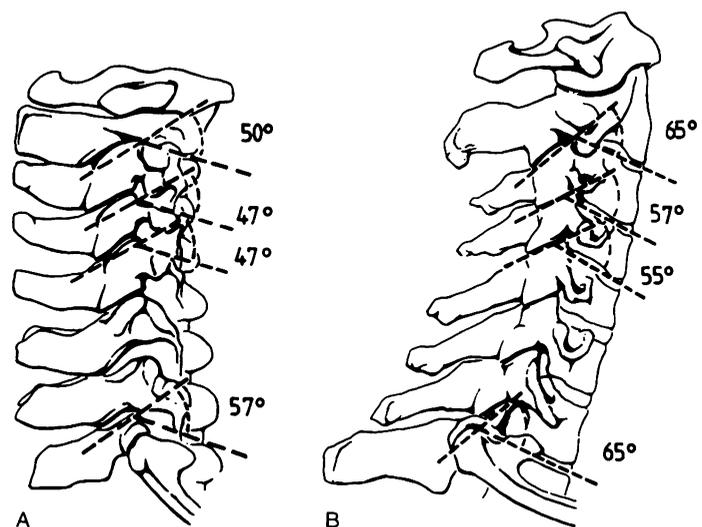


Fig. 14-2. Lateral view of the cervical vertebral column with the angles of inclination of the facet joints of (A) a newborn and (B) an adult.



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 cylindrical 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.

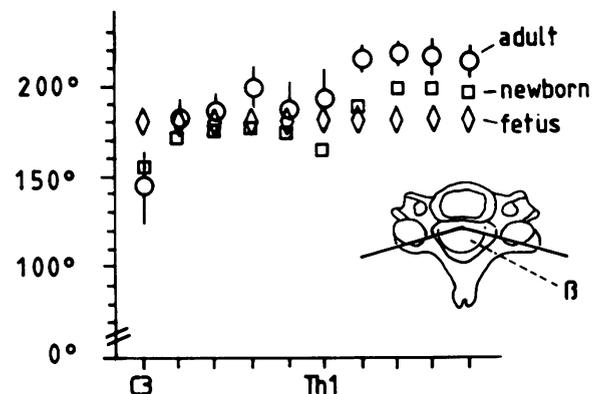


Fig. 14-4. Opening angle (β) of the vertebral facet joints (C3 through T2).

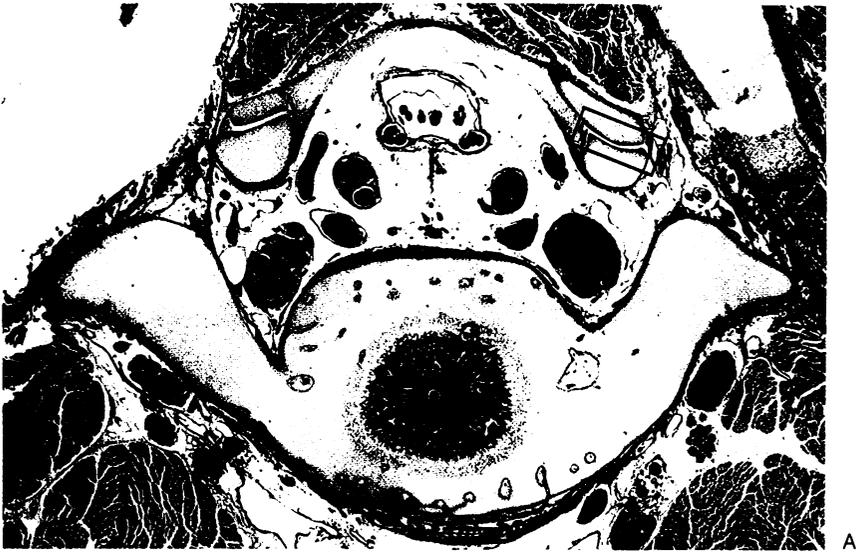


Fig. 14-5. Transverse section through a lumbar vertebra of a 40-cm fetus showing the orientation of the facet joints (β). (A) Scale 8:1. (B) Enlargement of boxed area in upper right of (A); scale 80:1.

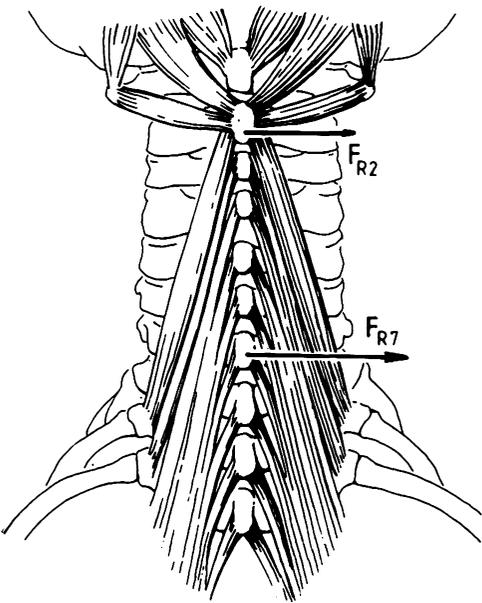


Fig. 14-6. Cervical vertebrae under muscular tension (posterior view). F_{R2} , F_{R7} , forces of rotation acting on the spinous processes of the second and seventh cervical vertebrae, respectively.

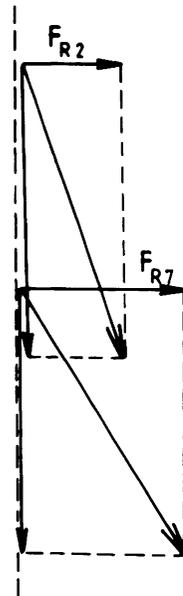


Fig. 14-7. Relative muscular stresses (of inserting muscles) acting on the cervical vertebrae C2 and C7 during rotation or unilateral extension; the rotational component (F_R) at the level of the second cervical vertebra (F_{R2}) is smaller than that at the level of the seventh (F_{R7}).