ONLINE CLINICAL WORKSHOP

"Vestibular Function and Aging & Balance"

Presented by:

Ingen Technologies, Inc.

Southeastern Neuroscience Institute

Preferred Provider Care, Inc.

Endorsed by:

The American Academy of Balance Medicine

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Important Sources Cited

- Clinical Neurophysiology of the Vestibular System Ed. 2
  - Baloh & Honrubia: F.A. Davis 1990
- The Essentials of Otolaryngology
  - Baloh: F.A. Davis 1984
- The Human Ear in Anatomical Transparencies
  - Polyak, et. al.: Sonotone: 1946
- Atlas of Speech & Hearing Anatomy
  - Folkins: Merrill 1984

Historical Perspectives

- 1700-1800's Darwin, Flourens, Purkynge & Helmholz describe vestibular & oculomotor function by observing patients
- 1873-4 Mach, Breuer & Crumb-Browne published almost simultaneous papers on theories of motion perception

Historical Perspectives

- 1915 Barany received Nobel Prize for work on vestibular pathology
  - Described labyrinthine nystagmus
  - Convection theory: developed caloric testing
  - Developed rotational testing
  - Described postural instability
    - laid groundwork for posturography and Vestibular Rehabilitation Therapy (VRT)

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Historical Perspectives

- 1929 Myers developed electro-oculography EOG to record nystagmus
- 1935 Mowrer defined the corneo-retinal potential
- 1942 Fitzgerald & Hallpike described bithermal, bilateral caloric testing, still the standard
- 1940’s Cawthorne & Cooksey published exercise protocols for dizziness

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Historical Perspectives

- 1948 Van Egmond described impulsive rotational chair testing
- 1960's & 1970's Many researchers describe exercise-improved vestibular compensation in several animal models
- 1970's & 80's Nashner, et. al. developed and began marketing dynamic posturography

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Historical Perspectives

- 1970's Norre and co-workers described "Vestibular Habituation Training" for vertigo patients and began VRT protocols in Europe
- 1970's & 80's Brandt & Daroff published exercises for BPPV patients.
- 1980's & 90's Semont, Epley & others describe single treatment approach to BPPV treatment

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Historical Perspectives

- 1985-90's Herdman, Horak, Shumway-Cook, Shepard and many others promote Vestibular Rehabilitation Therapy in the U.S.

Historical Perspectives

- 1970's to present
  - Development of customized VRT protocols
  - Infra-red oculography
  - Computer dynamic posturography
  - Ongoing research & development

Definitions

- Balance: not a definition, but a model of what we know:
  - In order for one to maintain balance under stable and unstable circumstances, information from the
    - vestibular, inner ear structures
    - visual, and proprioceptive, somatosensory, peculiar spatial orientation systems
  - Must be integrated within the central nervous system. Output to the:
    - oculomotor & postural control systems
    - continually under adaptive control to respond to alterations in head and body position maintaining orientation: relativity

Definitions

- Balance System:
  - Complex biological system that allows us to know where our body is in space and maintain the position we want.
  - Proper balance depends on information:
    - from the labyrinth of the inner ear
    - from other senses such as sight and touch
    - from muscle movement

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Definitions

- Compensation:
  - Becoming asymptomatic: Progressive *waning* of symptoms
    - Results from actions within the Central Nervous System (CNS)
    - *Not* from than from resolution of the underlying vestibular pathology
  - A well compensated patient is one whose remaining CNS processes *allow adequate control of:*
    - eye movements
    - head movements
    - body movements for
      - postural
      - gaze
      - positional functions

Definitions

- Dizziness is experienced as:
  - Disturbed sense of relationship to your surroundings
  - Feelings of lightheadedness, faintness, unsteadiness, physical instability with regard to the outside world
  - Sensation of disorientation and loss of immediate contact with surroundings

Definitions

- Disequilibrium:
  - Refers to unsteadiness, imbalance or loss of equilibrium
  - Often accompanied by spatial disorientation
    - Sensation of not knowing where one's body is in relation to vertical & horizontal planes

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Definitions

- Nystagmus:
  - Involuntary alternating fast & slow movements of eyeballs, usually with dizziness
  - Spontaneous or provoked
  - Usually horizontal
    - May involve vertical, oblique, or rotary movements
  - Observed as continual tiny jerks

Definitions

- Vertigo:
  - Sensation of rotation or movement of self
  - Sensation of rotation or movement of surroundings
  - Sensation of rotation or movement of both self and surroundings
  - Hallucination of motion often rotary

Definitions

- Vestibular disorders:
  - Diseases of the inner ear and its accompanying structures that cause dizziness or vertigo

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Vestibular System

- Transduces forces associated with with head acceleration and gravity into biological signals while allowing for balance & movement
- Located within the sensory portion of the inner ear within the petrous portion of temporal bone

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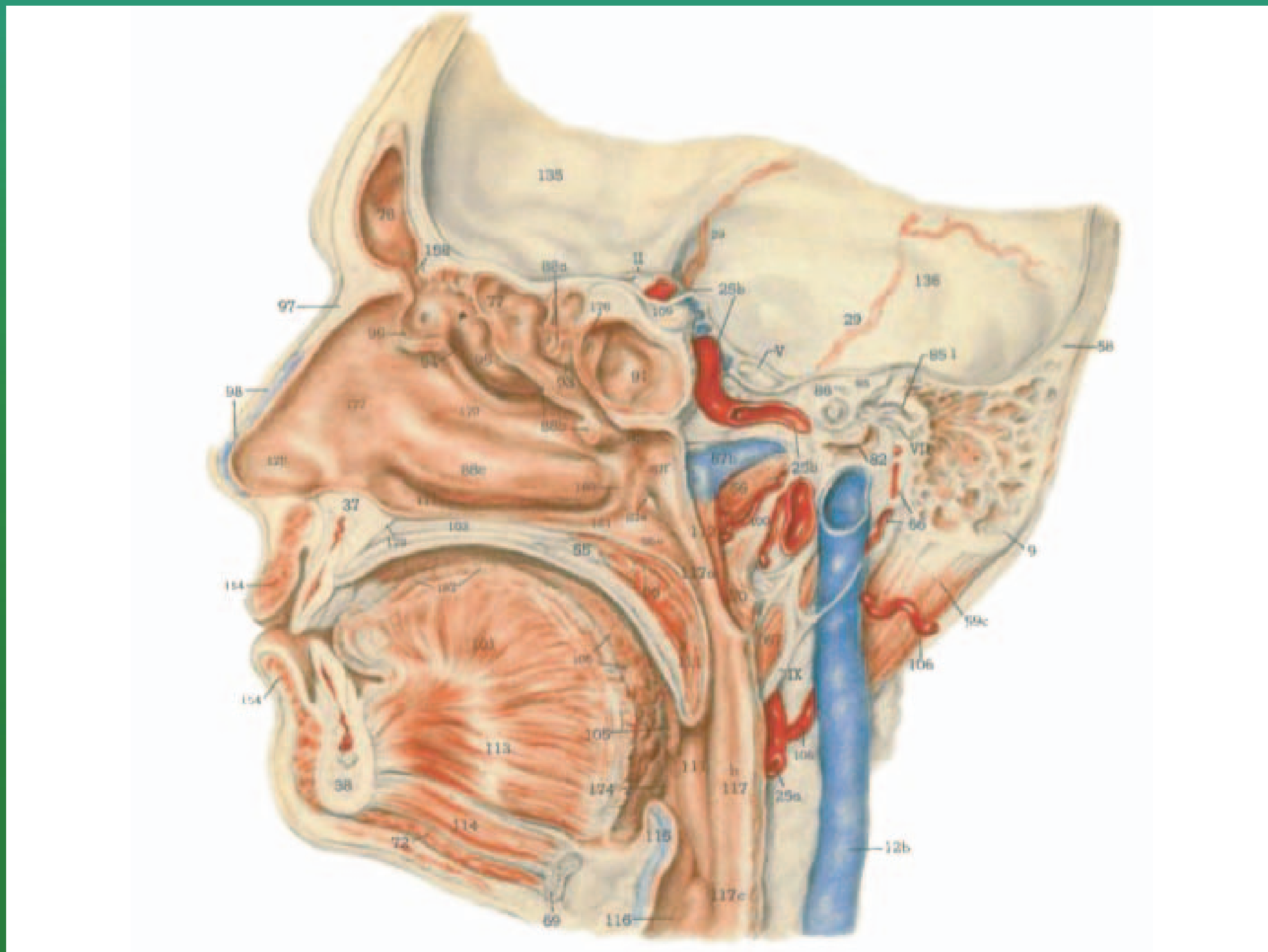

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FIGURE 16–2 Microdissection of labyrinth. (Courtesy of H. Engström and B. Engström, *The Structure and Function of the Inner Ear: Part I, The Organ of Corti.* Copenhagen: Tøpholm and Westermann I/S, 1976.)

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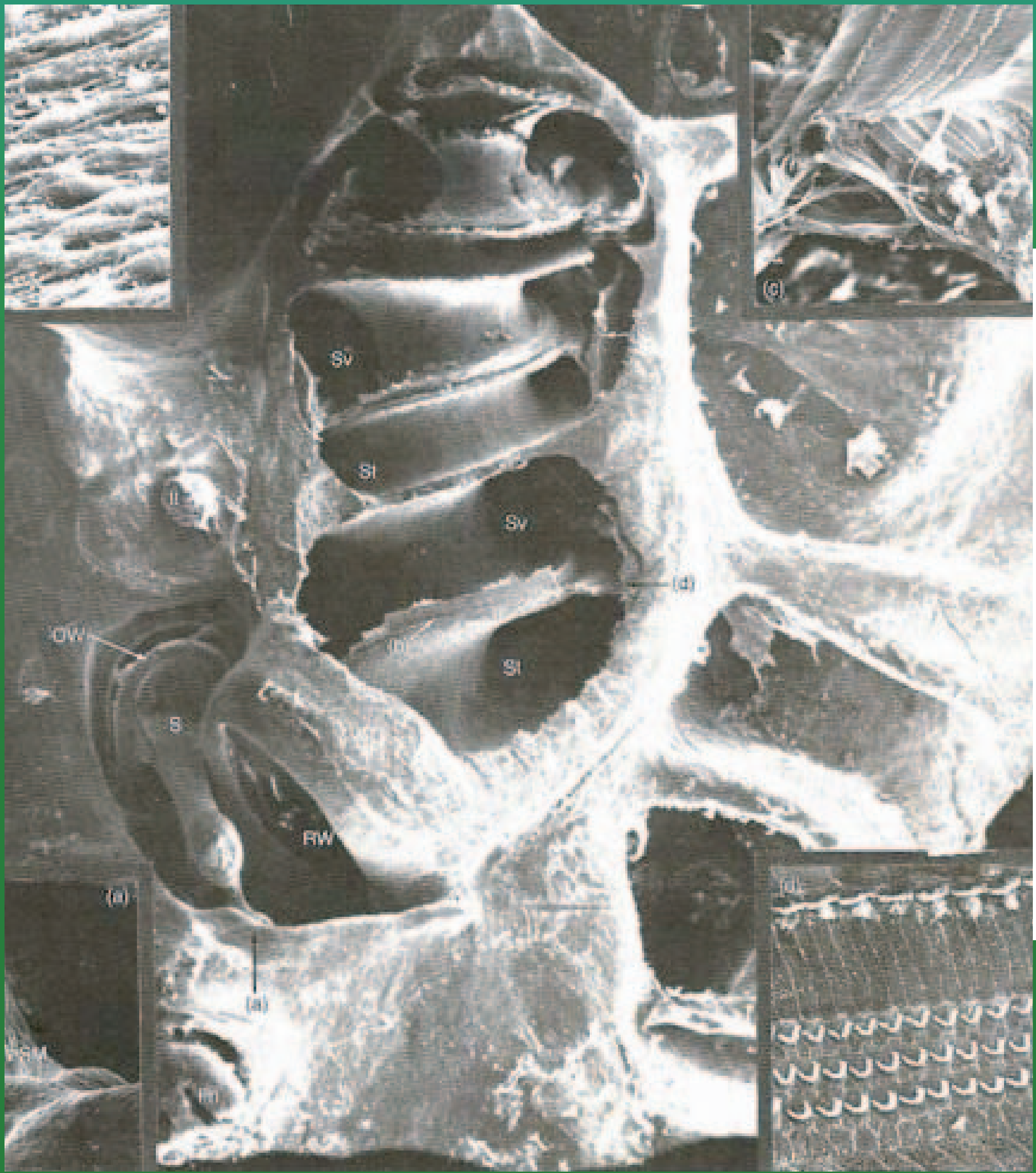

FIGURE 16–3 Scanning electron micrograph showing the coiling of the chincilla cochlea ($3\frac{3}{4}$ turns): (S) stapes, (OW) oval window, (RW) round window. The inserts show details at the points indicated on the central photograph. In (a), (SM) stapedial muscle. (b) tympanic layer below the basilar membrane. (c) cross section of the organ of Corti. (d) hairs of the inner and outer hair cells: (Sv) scala vestibuli, (St) scala tympani, (tt) attachment of tensor tympani, (Fn) facial nerve. (Courtesy of Ivan Hunter-Duvar, as shown in William A. Yost and Donald W. Nielsen, *Fundamentals of Hearing: An Introduction*. New York: CBS College Publishing, 1977.)

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Scope of the Problem

- Incidence
  - Falls are most common cause for death and disability in the elderly
  - 50% of people over age 75 who fall with a hip fracture will expire within the next 12 months
  - Dizziness and loss of balance are the most common reason for elderly hospital admissions and physician visits.
  - Falls are #1 reason for Nursing Home admissions
  - 80 million population in US over age 65 by 2050

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Scope of the Problem

- One of the top 10 reasons for individuals to visit a physician — higher in elderly
  - 5 million patients per year or 5–10% of total visits
- 30 – 40% of population will have an episode in their lifetime — increases with age
- 60% of closed head trauma victims report dizziness
- 20% of normal population with unilateral vestibular loss

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Scope of the Problem

- 50–60% of all adults will experience dizziness symptoms at least once in their lifetime
- 2/3 of hearing impaired children are seen to have vestibular abnormalities and balance problems

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Scope of the Problem

- Meniere's Disease
    - 15.3 cases/100,000 population in U.S.
- Benign Paroxysmal Positional Vertigo (BPPV)
    - Most common vestibular disorder
    - 600+ cases/100,000 population in U.S.
- 1997 estimate for spending on medical care for dizziness and balance =
- $3-4 billion

Aging & Presbystasis

- By 2010, 40 million Americans over age 65
  - 40% of these over age 75
  - 70's & 80's most rapidly increasing population
- Individual over age 65—most common reason to visit physician
- Community Dwelling
  - Over age 65 25–35% fall each year
  - Over age 75 32–42% fall each year
  - 50% who fall experience multiple falls per year

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Aging & Presbystasis

- During the 20th century the # of persons under age 65 increased three–fold
- # of persons over age 65 increased 11 times
- Elderly population will double between now and 2050 to 80 million
    - Most growth between 2010–2030 with baby boomers

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Falls

- Over 2 million people in the U.S. fall and sustain serious injury annually
  - >50% over age 65 fall once per year
  - >50% of fallers fall more than once
  - Leading cause of fatal and non-fatal injuries for population over age 65
  - If over age 75 and fall with fracture, chances 50% patient will expire within 12 months

Falls

- Women fall more than men
- JAMA study: Older people falling more often and getting hurt at an increasing rate
  - Number of elderly rising
  - Increase in use of meds which cause balance loss

Falls

- In U.S. alone, over $20 billion spent annually on falls
  - Not including hidden costs
    - pain,disability, lawsuits, impact on family,
    - deterioration of general well being
  - Majority of $ on hip fracture treatment >$40,000 each
  - Nursing homes report an average of 6 falls per bed per year

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Aging & Balance

- Half of patients receive no diagnosis
- 70% receive Meclizine Rx
- Vestibular suppressants are often counterproductive to the compensation process.

Aging & Balance

- Symptoms
  - falling
  - dizziness
  - vertigo
  - Disequilibrium
  - postural instability
  - loss of balance
  - “faintness” or shortness of breath

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Neuropathology of Aging Vestibular System

- Degenerative changes in peripheral input
  - vestibular organs
    - otoconia, macula, hair cells, Scarpa's ganglion cells
  - somatosensory and proprioception
    - decrease in peripheral nerve velocity; proprioception of joints; and vibratory sensation in lower limbs
  - vision
    - blurred vision, decreased tracking skills, oscillopsia, cataracts, double vision

Neuropathology of Aging Vestibular System

- Changes in the CNS
  - vestibular nuclei = central integrators from peripheral vestibular system
  - neuromuscular responses slower
  - decreased circulation due to ischemic disease
  - decrease in number of nerve cells
  - demyelination of nerve cells

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Neuropathology of Aging Vestibular System

- Changes in sensory organization
  - postural instability
  - can't process conflicting sensory inputs as well
  - increased postural sway
  - can't use ankle and hip strategies for mild perturbations of movement
  - difficulty in judging limits of stability (LOS) when center of gravity(COG) moves over the base of support(BOS)

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Improvement of Balance and Equilibrium in the Elderly

- Rehabilitation therapy
  - balance retraining
  - substitution strategies
  - use of lower body movement strategies
  - improvement of gait (assistive devices PRN)
  - motor and postural control
  - CNS sensory integration
  - vertigo habituation and/or elimination of BPPV

Balance Disorders/Fall Prevention Clinics

- A "team" approach
  - Physician (usually ENT/Otologist/ Neurotologist or Neurologist)
  - Nurses
  - Audiologist and/or Vestibular Technician
  - Physical Therapist
  - Occupational Therapist

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Inner Ear: Bony Labyrinth

- Series of hollow channels in the petrous portion of the temporal bone
- Auditory & vestibular organs
- Anterior = cochlea
- Posterior = vestibular end organs
- Central = vestibule bordered by recesses of otolith organs. Diameter = 4mm.

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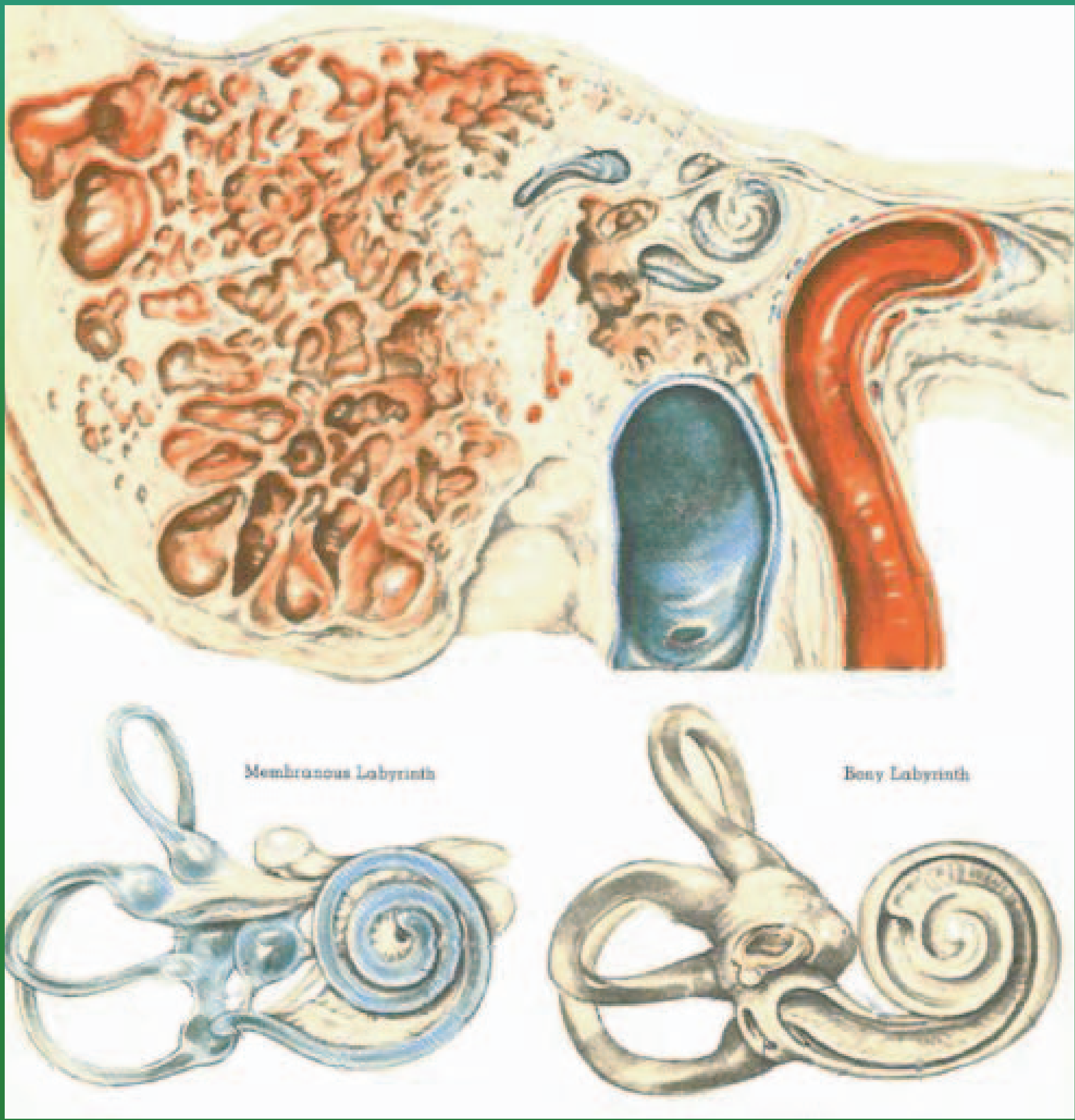

Inner Ear Fluids

- Perilymph:
  - Mixture of cerebrospinal fluid CSF & blood
  - CSF comes from cochlear aqueduct
  - Blood comes from inner ear blood vessels within the perilymphatic space
- Endolymph:
  - Thought to arise from
    - Secretory cells in stria—vascularis of cochlea
    - Dark cells of vestibular labyrinth

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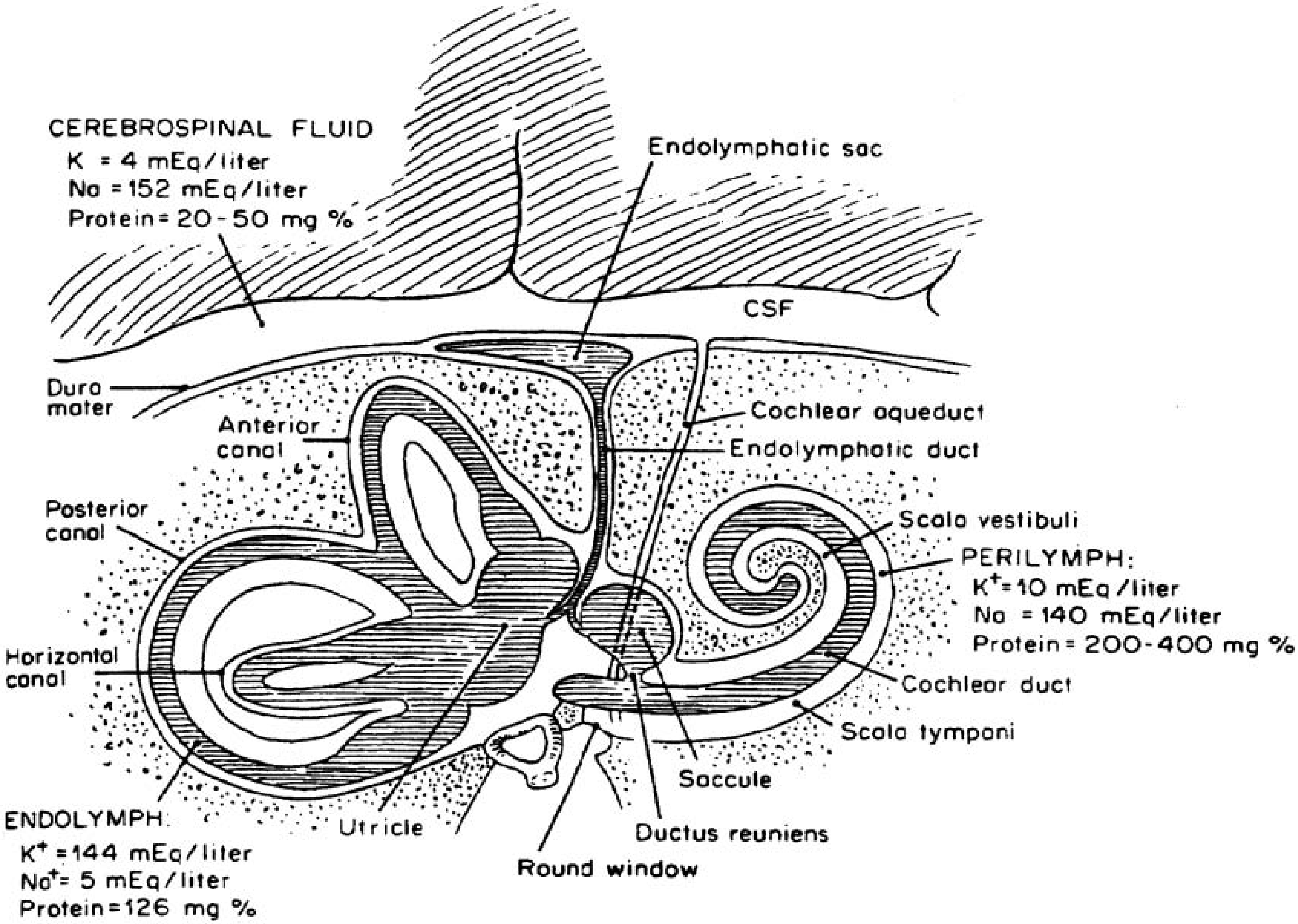

Figure 2—5. Cross section of the inner ear.

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Internal Auditory Canal

- Narrow channel
  - CN VII facial
  - CN VIII statoacoustic
  - internal auditory artery
- Other landmarks
  - Vestibular aqueduct: endolymphatic sac
  - Cochlear aqueduct: connects subarachnoid and perilymphatic spaces

Membraneous Labyrinth

- Enclosed within channels of bony labyrinth
- Surrounded by
  - Perilymphatic fluid
  - Supportive network of connective tissue
  - Blood vessels
- All lie between and around the membraneous labyrinth and the interior periosteum of the bony labyrinth

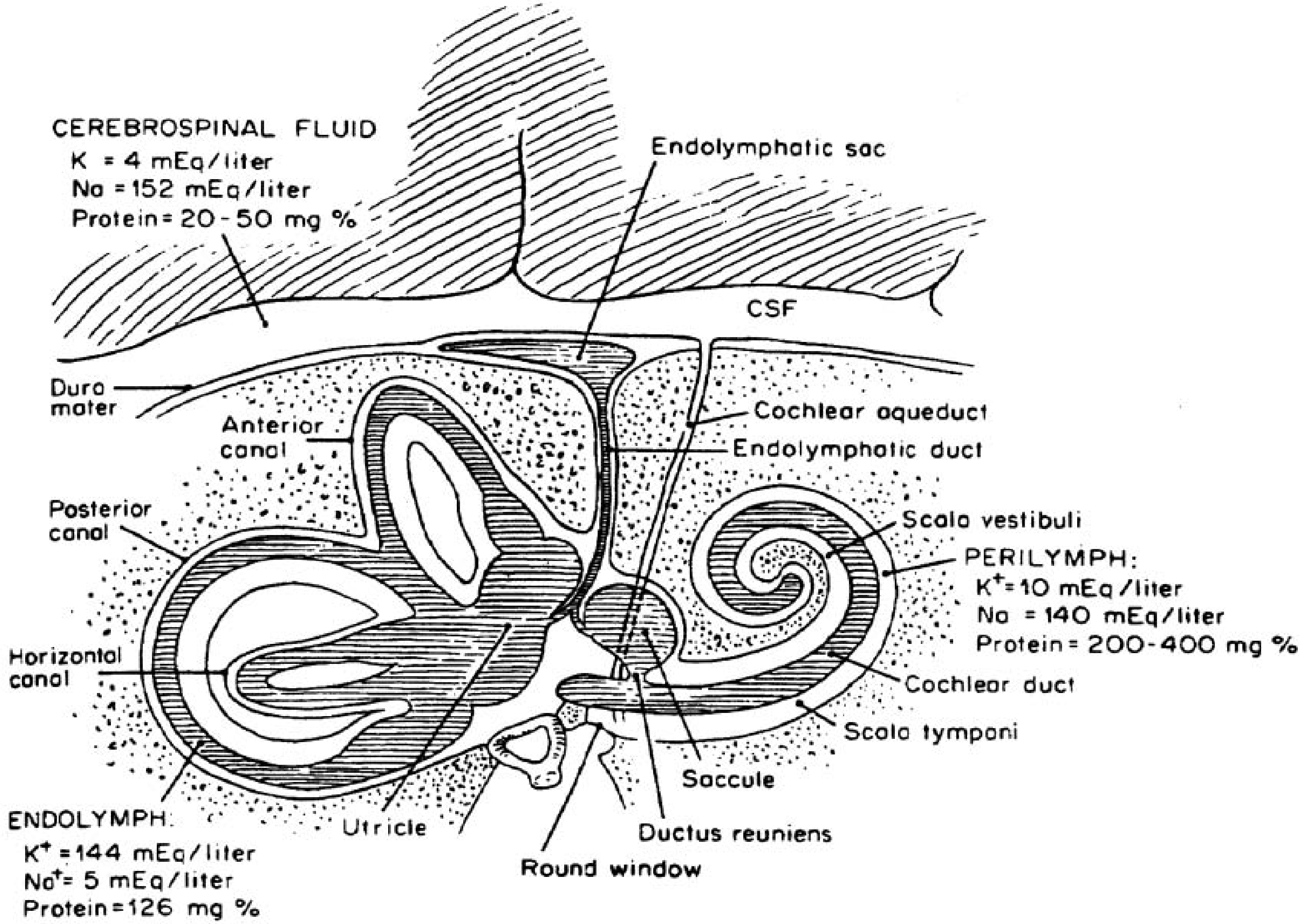

Figure 2—5. Cross section of the inner ear.

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Anatomy of the Otolith Organs

- 1. Utricle & Saccule
  - Linear forces and static tilt (gravity)
- 2. Contained in the vestibule of the labyrinth—at right angles to each other
- 3. Sensory hair cells contained w/in macula, covered by otolithic membrane.
  - Otoconia embedded on surface of membrane

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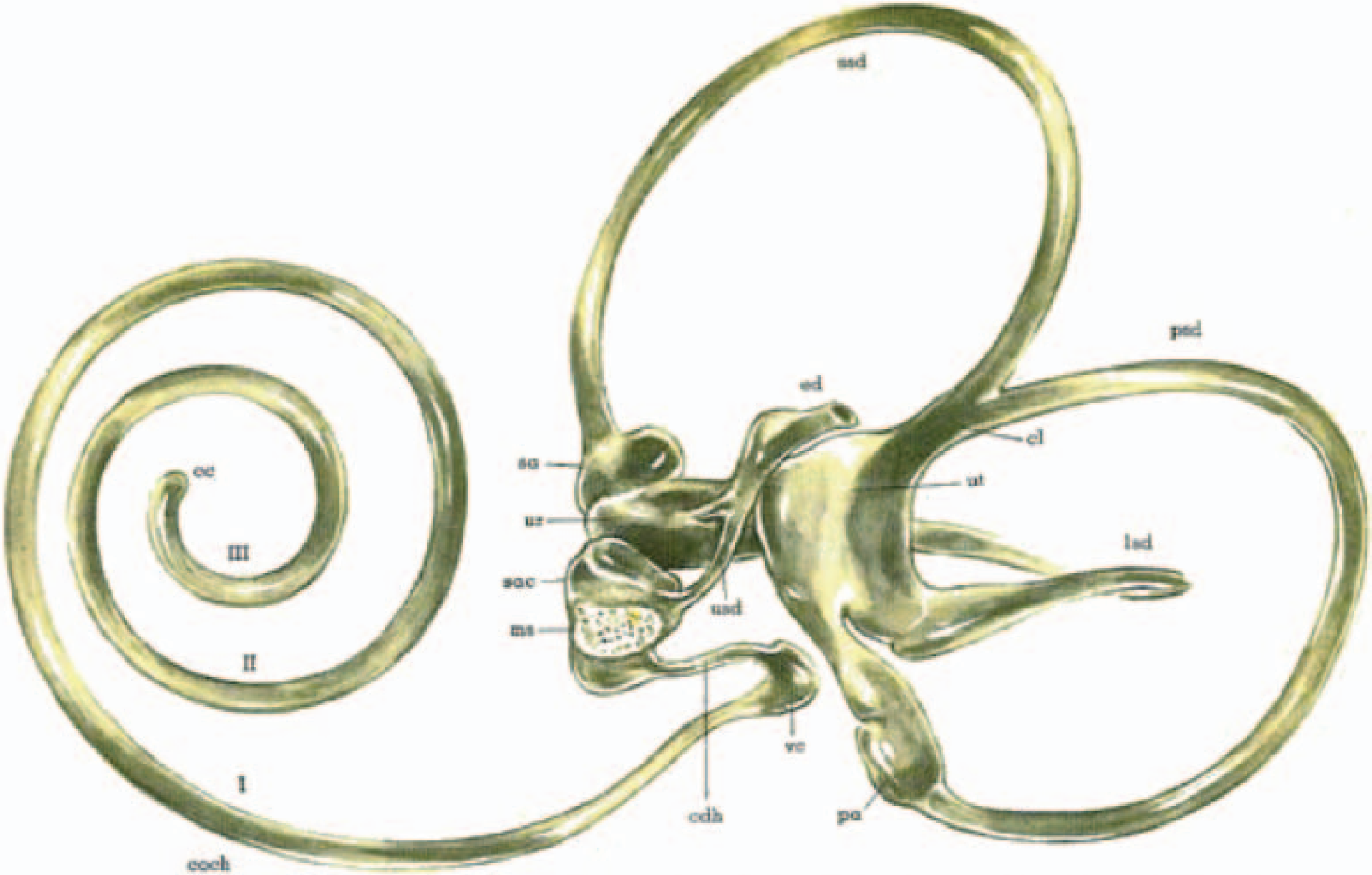

Fig. 61.—Right side of the human membranous labyrinth, moderately magnified and viewed from the posterior aspect.

cc cupular caecum, or blind end of cochlear duct; **cdh** canalis reuniens, or Hensen's duct connecting saccule and cochlear duct; **cl** common limb of superior and posterior semicircular ducts; **coch** cochlear duct (scala intermedia); **ed** endolymphatic duct (cut off and without endolymphatic sack); **lsd** lateral semicircular duct; **ms** macula of saccule; **pa** posterior ampulla; **psd** posterior semicircular duct; **sa** superior ampulla; **sac** saccule; **ssd** superior semicircular duct; **ur** utricular recess; **usd** utriculo-saccular duct; **ut** utricle; **vc** vestibular caecum, or blind end of cochlear duct; **I, II, III** basal, middle, and apical coils of cochlear duct. Lateral ampulla is not visible in this view. Adapted from Siebenmann, *Zeits. f. Ohrenheilk.*, v. 82, y. 1922.

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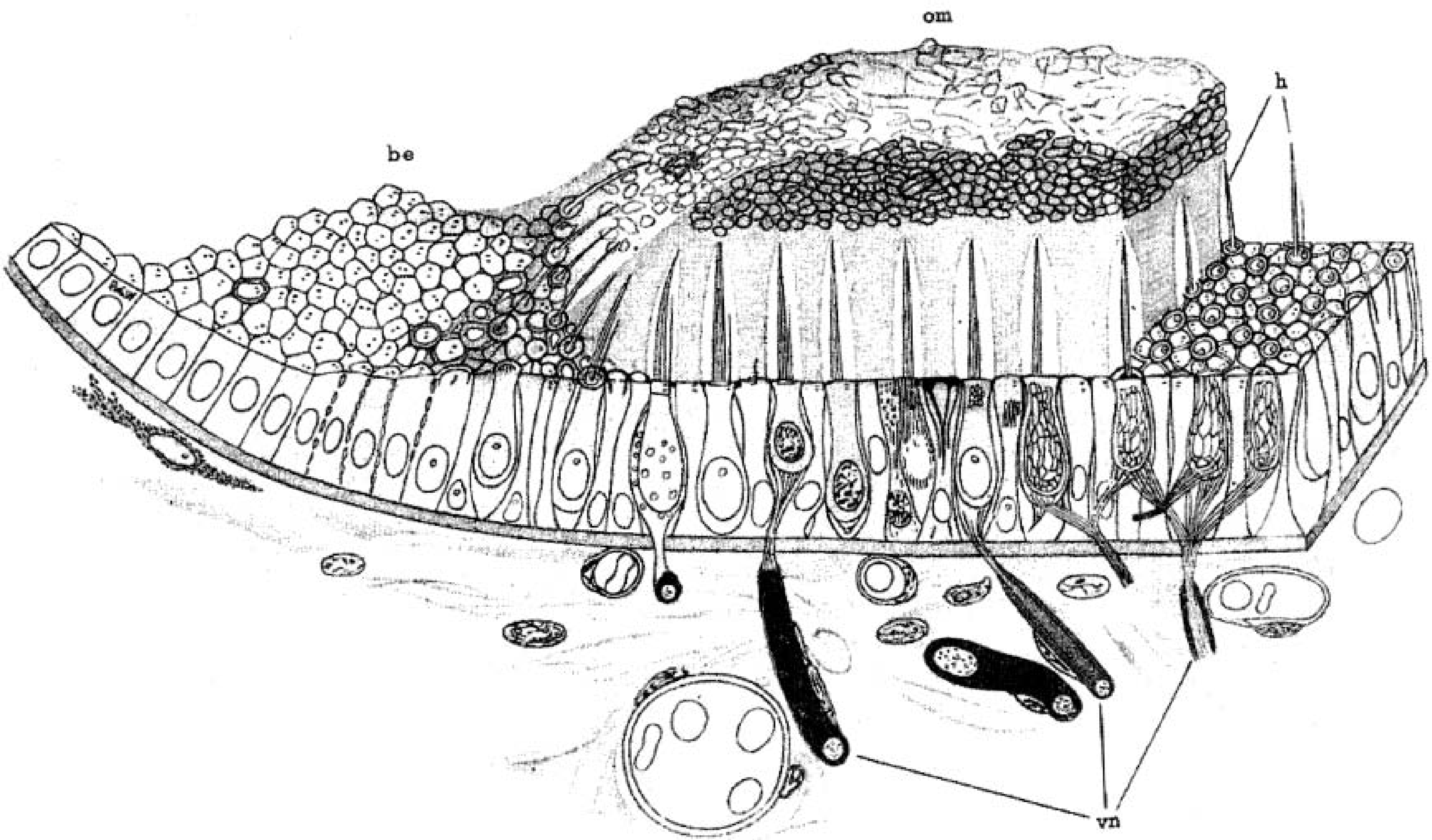

Fig. 66.—Schematical three-dimensional diagram of the structural make-up of a macula of the vestibule along its edge.

be undifferentiated epithelium surrounding macula; **h** hairs of hair cells protruding above epithelium into the covering jelly-like substance; **om** otolithic membrane with imbedded otoconia, or crystals of mineral, above the tops of hairs; **v** blood vessel; **vn** fibers of vestibular nerve terminating around the sensory hair cells of macula. From W. Kolmer, in Alexander and Marburg, *Handb. d. Neurol. d. Ohr.*, v. 1, y. 1924.

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Otolith Orientation

- Utricle & saccule both communicate with endolymphatic duct for nourishment but by seperate and different openings
- Endolymph in superior utricular portion of labyrinth thus seperated from endolymph of saccule & cochlea.
- May be relevant to Menier's pathophysiology

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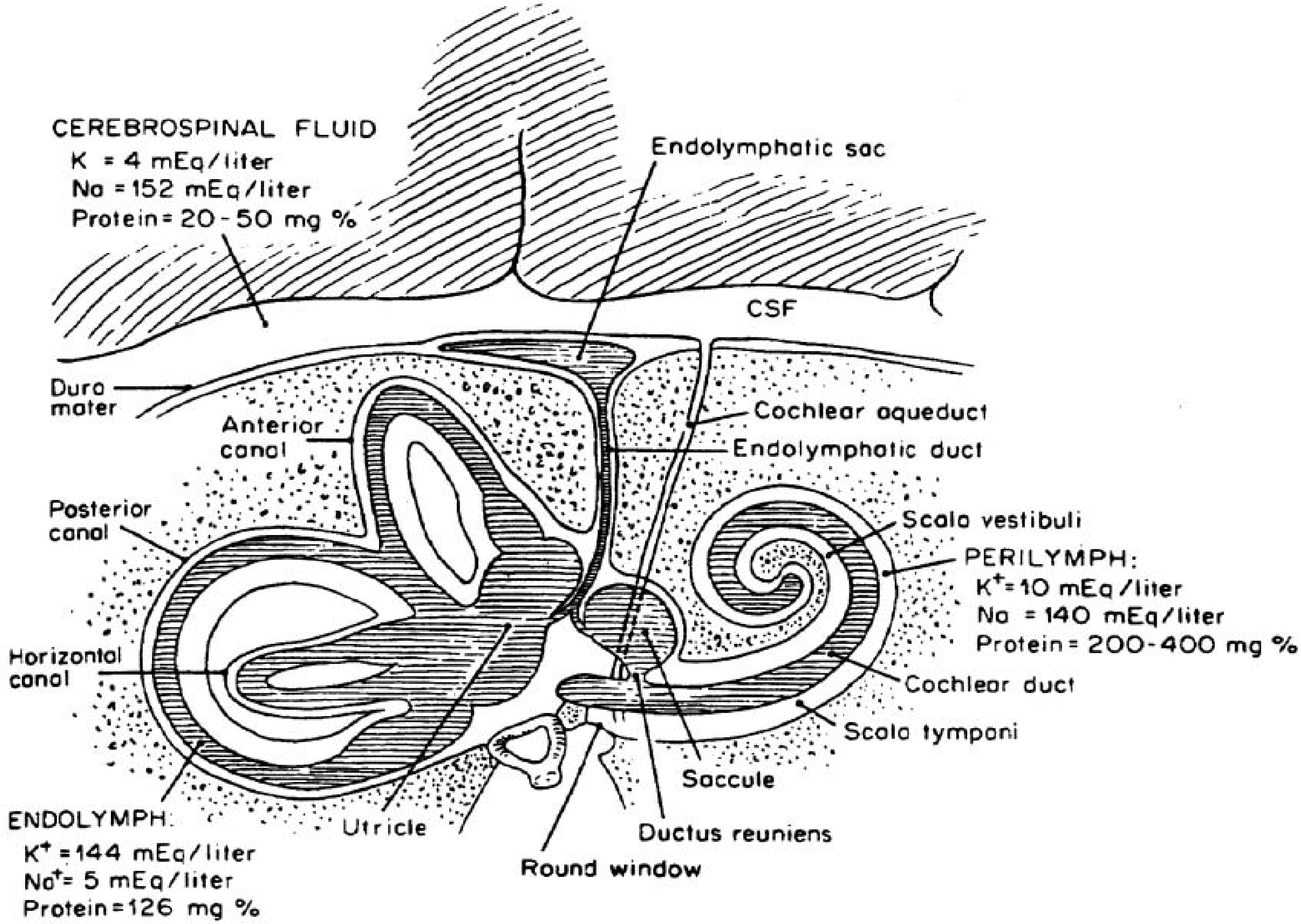

Figure 2—5. Cross section of the inner ear.

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Otolith Orientation

- Striola is a distinct curved zone running through the center of each macula
- Displacement of macula's otolithic membrane in one direction has an opposite physiologic influence on the set of hair cells on each side of striola

Otolith Orientation

- Hair cells on either side of striola oriented so kinocilia point in opposite directions
- 4,000 hair cells
- Utricle
  - Kinicilia face striola
- Saccule
  - Kinicilia face away from striola

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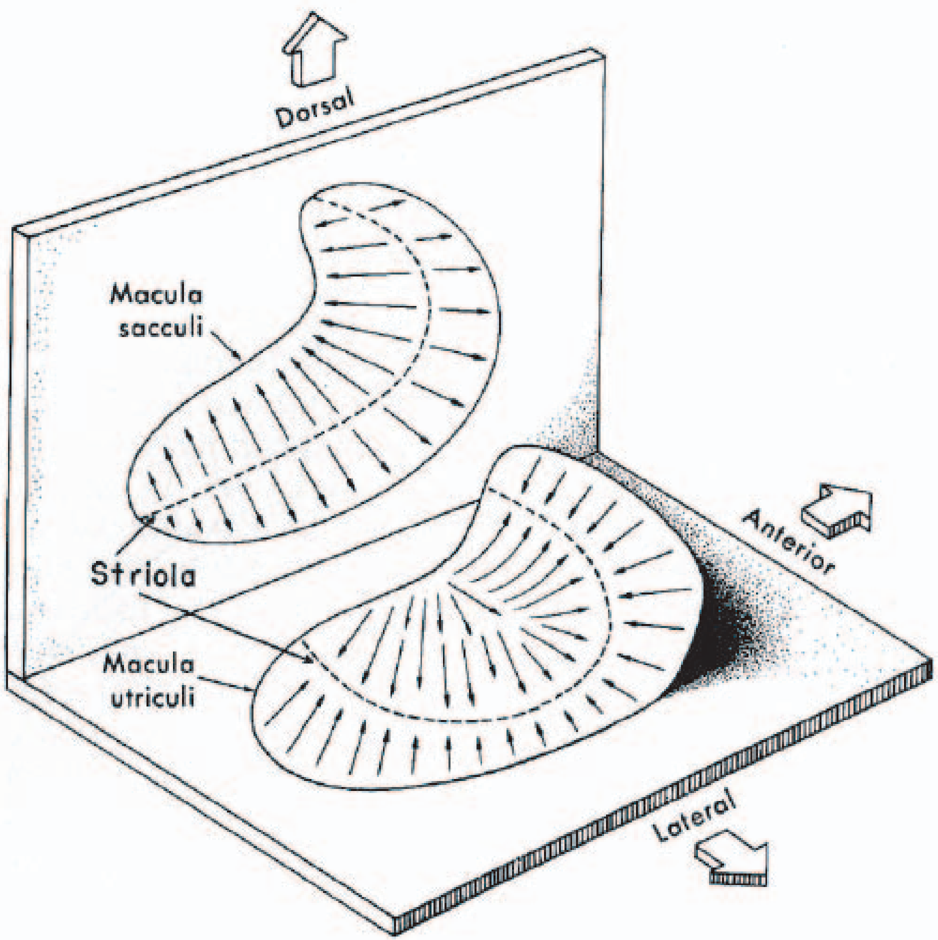

Position of the saccula and utricular maculae. Arrows indicate the direction of hair cell polarization on each side of the striola. (From Barbara HO and Stockwell, CW: Manual of electronystagmography. CV Mosby, St. Louis, 1976, with permission.)

Hair Cell Action

- Force must act parallel to the top of hair to stimulate—shearing action
  - Maximum stimulus when force directed along axis that bisects stereocilia bundle and passes through the kinocilium.
  - Deflection toward kinocilum = depolarization
  - Deflection away from kinocilium = hyperpolarization
- Perpendicular force—compression—causes no stimulation

Semicircular Canals

- 3 membraneous tubes
- 2 sets: 1 per ear
- Diameter .4mm
- Length: 6.5 mm
- Aligned to form a coordinate system
- Horizontal Semicircular Canal (HSC), makes 30 degree plane with horizon
- Anterior Semicircular Canal (ASC) and Posterior Semicircular Canal (PSC)
- ASC aligned medially
- PSC aligned front to back

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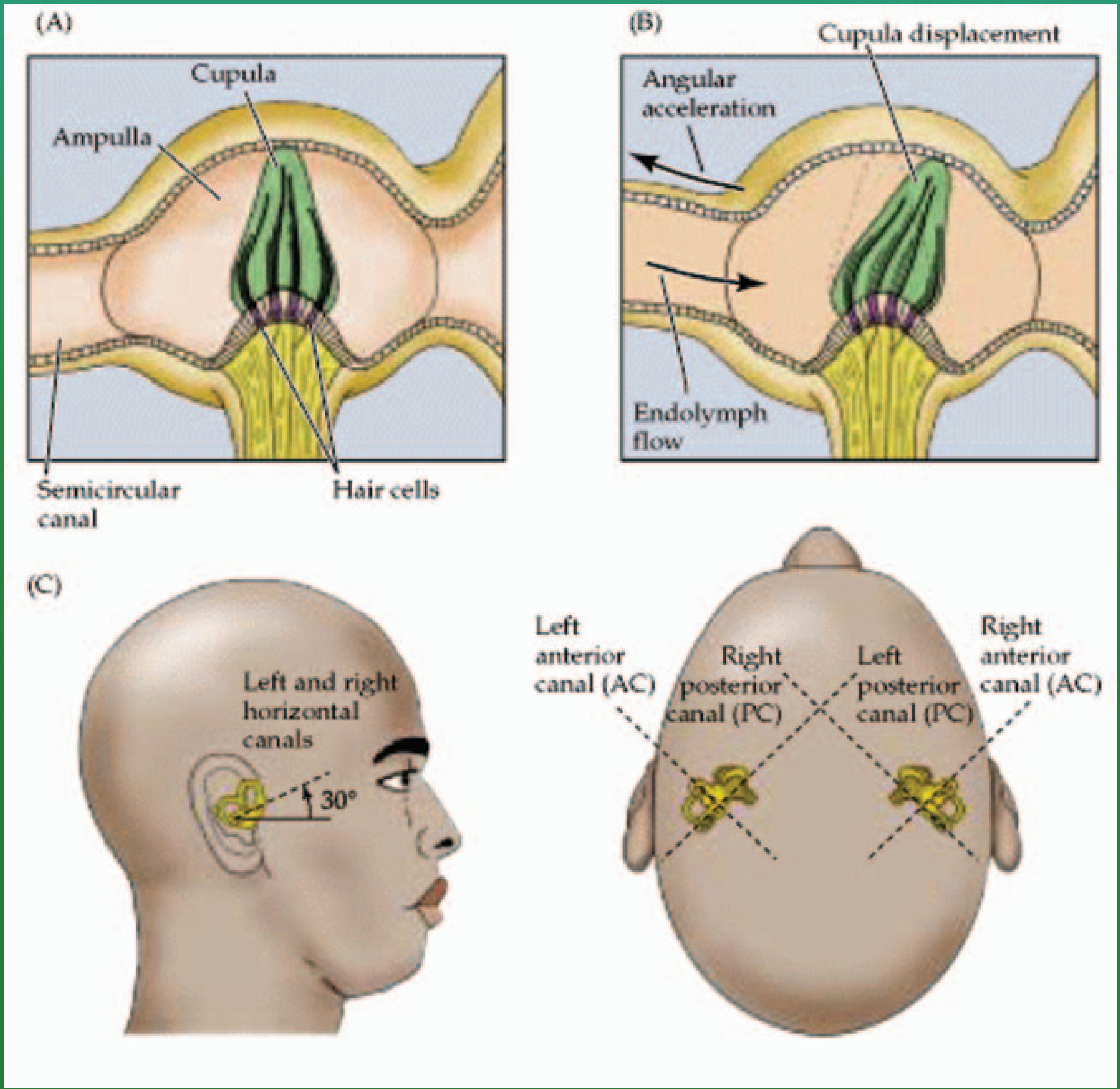

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Semicircular Canals

- All angular movements stimulate at least 2 canals and often all 3
  - Alignment not perfectly orthogonal
- Each canal forms about 2/3 of a circle
- Ampulla common crus & vestibule complete circle
- Ampulla arranged perpendicular to longitudinal axis of canal
- 23,000 hair cells total of three ampulla

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A right eardrum membrane, auditory ossicles and chorda tympani above; Below, a model of the bony labyrinth of the inner ear partly opened in order to show the membr anous labyrinth (in blue) within.

Blood Supply

- Labyrinthine artery
  - Originates from anteroinferior cerebellar artery
  - Sometimes from basilar artery or its branches
  - Irrigates
    - Ganglion cells
    - Dura membranes
    - Arachnoidal membranes
    - All within the internal auditory meatus

Blood Supply

- Labyrinthine artery
  - 2 main branches once enters inner ear
    - Common cochlear artery
    - Anterior vestibular artery
- Because arteries course independently within canal it's possible for only one area to be affected by pathology

Blood Supply

- Common cochlear artery : 2 branches
  - Posterior vestibular artery
    - Irrigates inferior sacculus
    - Irrigates ampulla of PSC
  - Main cochlear artery
    - Irrigates spiral ganglion
    - Irrigates basilar membrane structures
    - Irrigates stria vascularis

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Blood Supply

- Anterior vestibular artery
  - Irrigates utriculus
  - Irrigates ampulla of ASC & HSC
  - Irrigates small portion of sacculus

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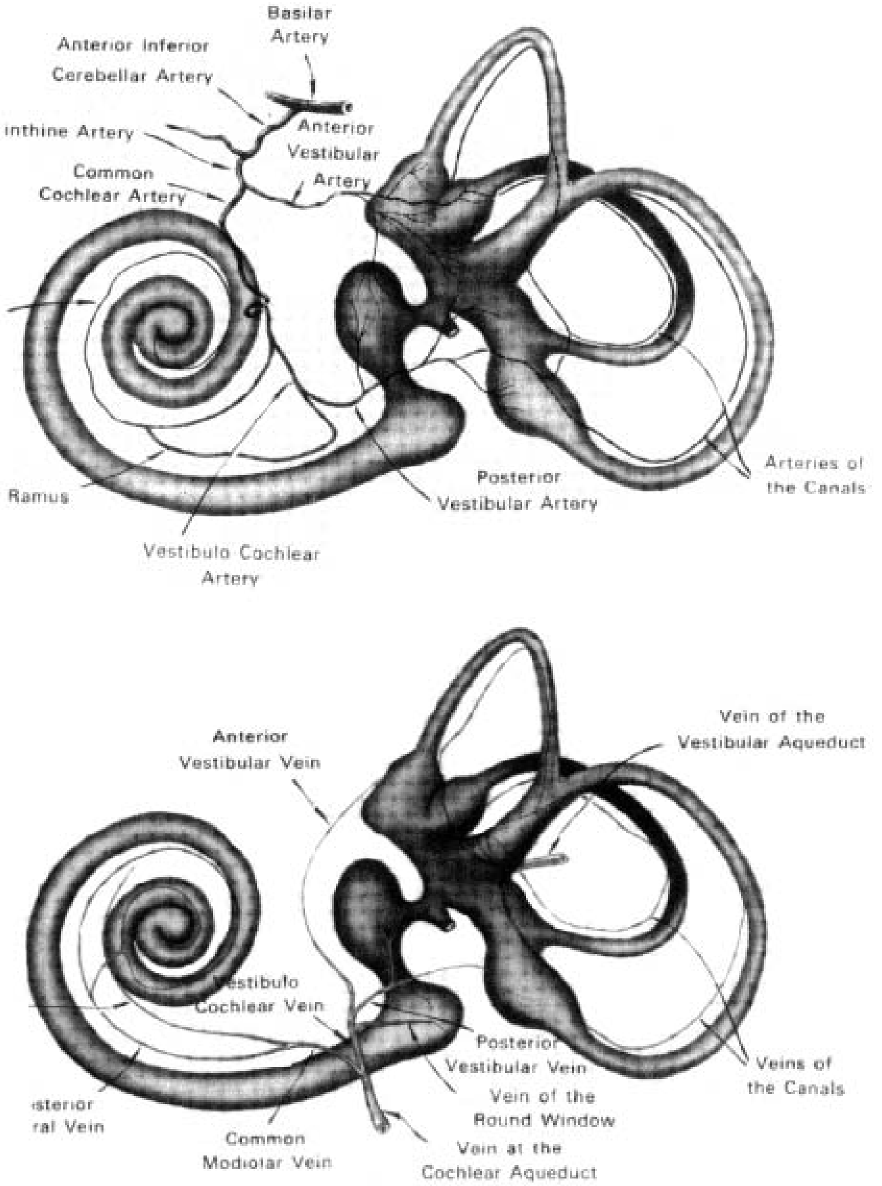

terial (*A*) and venous (*B*) labyrinthine circulation. (From Schuknecht, HF: Pathology of the Ear. ity Press, Cambridge, 1974, with permission.)

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Blood Supply

- Anterior vestibular vein
  - Drains utriculus
  - Drains ampulla of ASC & HSC
- Posterior vestibular vein
  - Drains sacculus
  - Drains ampulla of PSC
  - Drains basal end of cochlea
- Vestibulocochlear vein
  - Joining of AVV + PVV + round window vein
- Common modiolar vein
  - Drains cochlea
  - Joins vestibulocochlear vein

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Blood Supply

- Crucial
- Limited
- Within 15 seconds of interruption nerve fibers become unexcitable
- If prolonged then irreversible
- Loss of function leads to new bone growth filling cavity

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Vascular Innervation

- Different sources of blood supply lead to independent pathologic vestibular changes in cases of vascular abnormalities

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Vestibular Nerves

- Primary afferents: approx 1.4 hair cells per afferent fiber
  - innervate each crista and macula of labyrinth
  - Drains ampulla of ASC & HSC
- Superior
  - horizontal and superior semicircular canals, saccule and utricle
- Inferior
  - posterior semicircular canal and saccule

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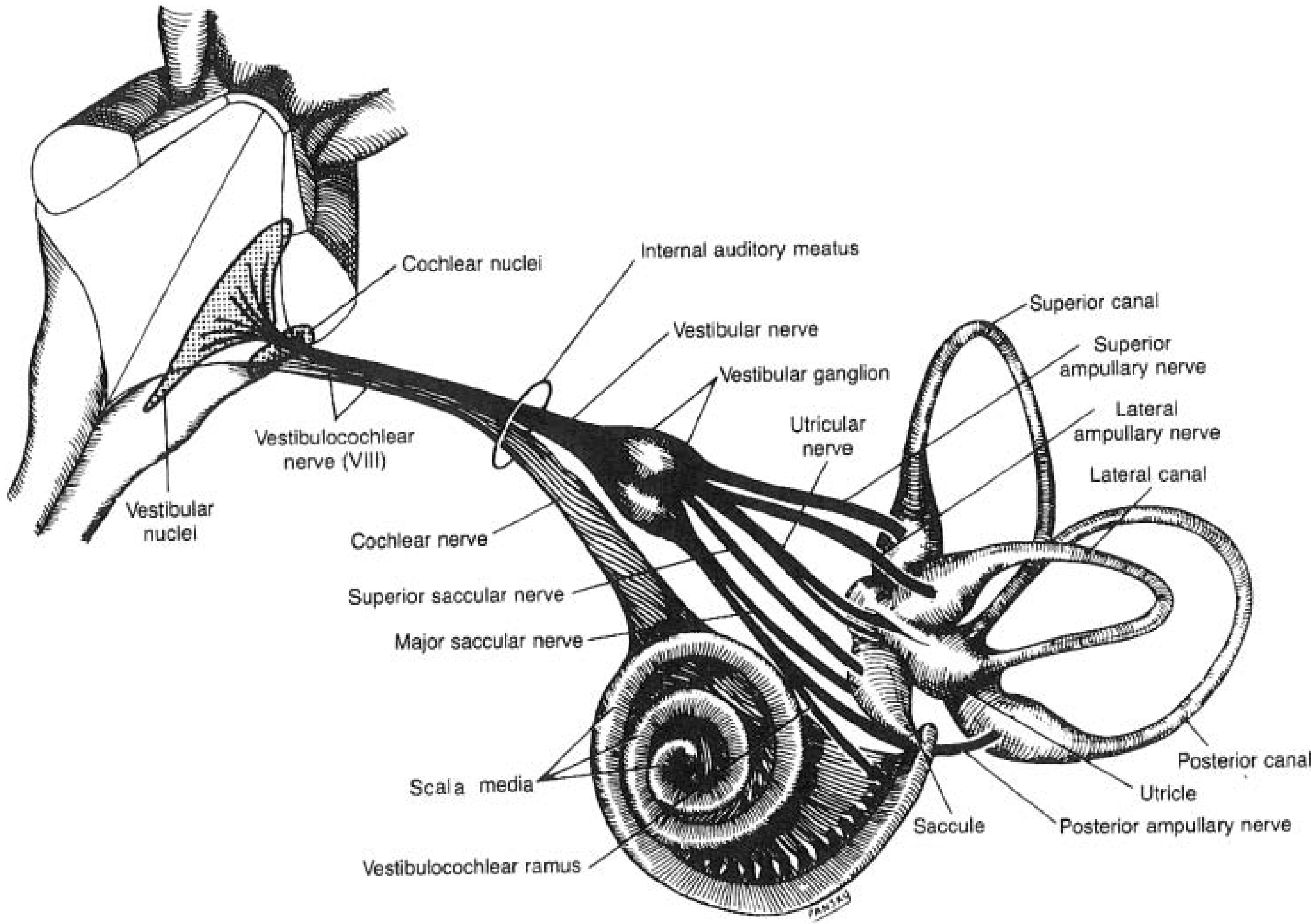
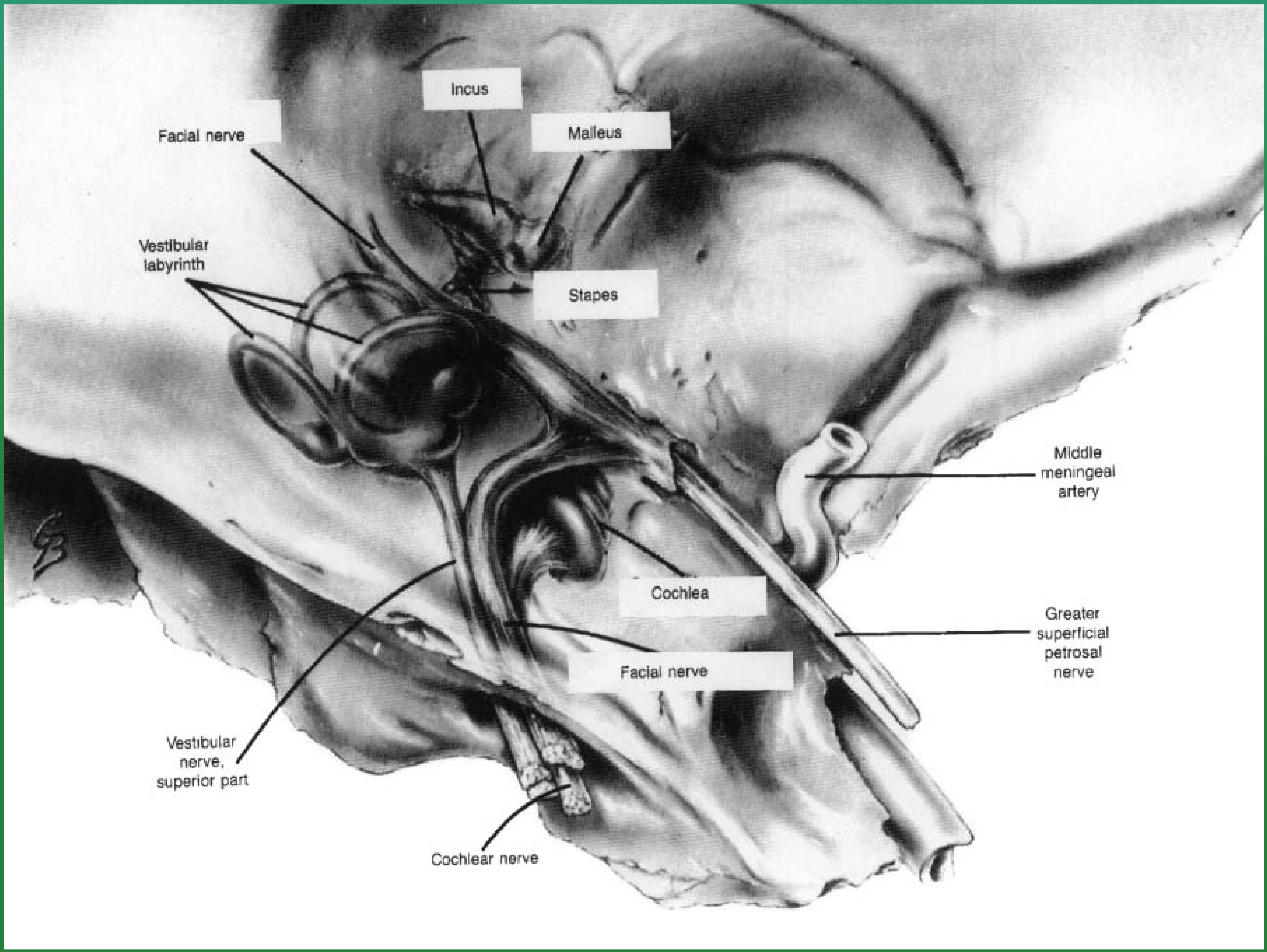


FIGURE 21–11 Schematic showing the course and distribution of the vestibulocochlear (VIII) nerve. (From E. House and B. Pansky, *A Functional Approach to Neuroanatomy*. New York: McGraw-Hill Book Company, 1960. Used with permission.)


Incus
Malleus
Facial nerve
Vestibular labyrinth
Stapes
Middle meningeal artery
Cochlea
Greater superficial petrosal nerve
Facial nerve
Vestibular nerve, superior part
Cochlear nerve

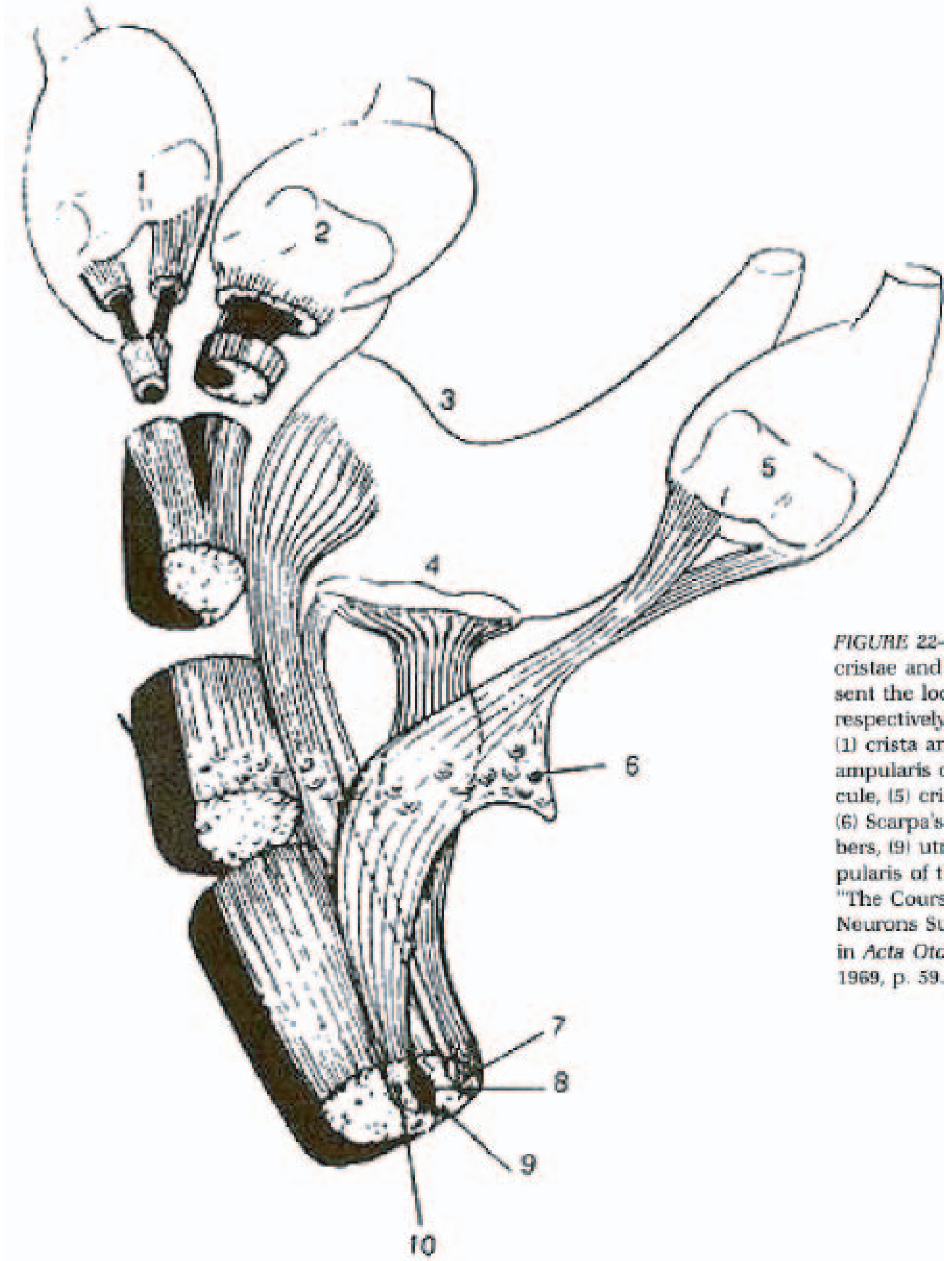


FIGURE 22–6 Schematic of the innvervation of the cristae and macculae. The dark and light areas represent the location of large and small diameter neurons, respectively, to the superior and horizontal cristae. (1) crista ampularis of the superior canal, (2) crista ampularis of the horizontal canal, (3) utricle, (4) saccule, (5) crista ampularis of the posterior canal, (6) Scarpa's ganglion, (7) saccular nerve, (8) efferent fibers, (9) utricular nerve, (10) nerve from crista ampularis of the posterior canal. (Courtesy of B.R. Gacek, "The Course and Central Termination of First Order Neurons Supplying Vestibular Endorgans in the Cat." in *Acta Otolaryngologica*, Supplementum 254, 1969, p. 59.)

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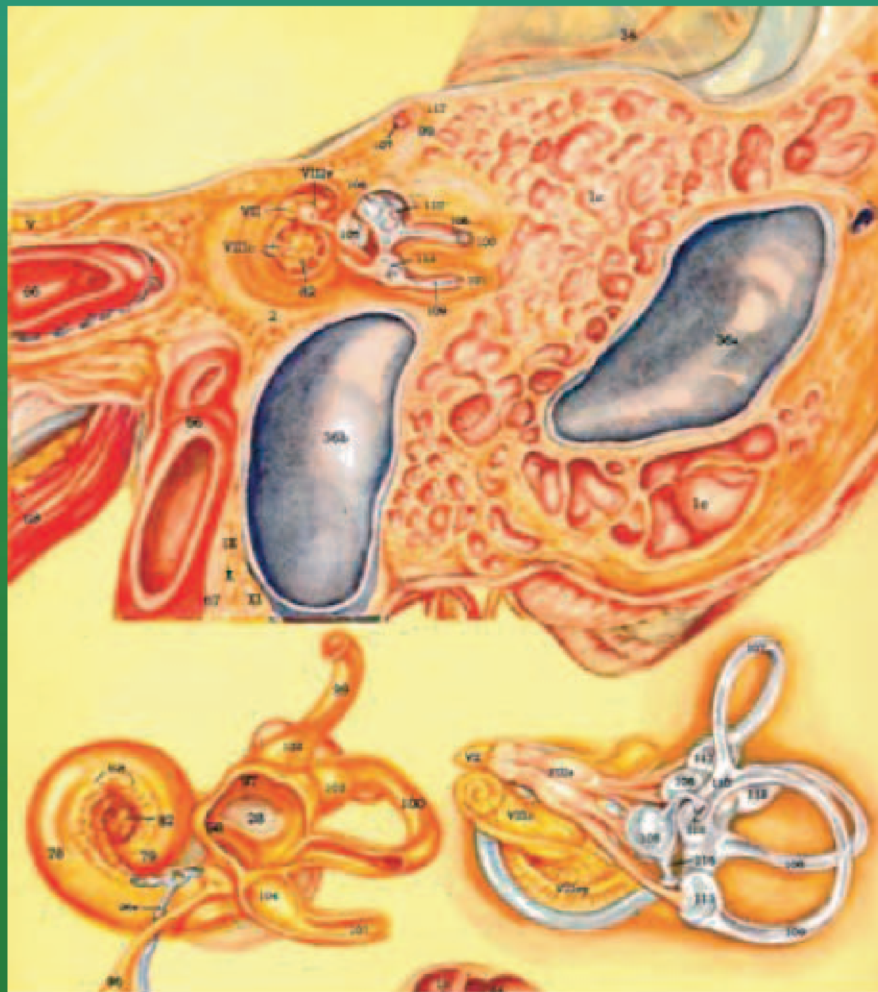

FIG. 48 TOPOGRAPHY OF THE MEMBRANOUS VESTIBULE AND INTERNAL AUDITORY MEATUS (ABOVE); BONY AND MEMBRANOUS LABYRINTHS IN BACK VIEW (BELOW)

Section through the posterior portion of petrous bone (2) showing most of the membranous vestibule: the saccule (105), the utricle (106), the three semicircular ducts (107, 108, 109, 110), and the posterior ampulla (113), all incased in the bony labyrinth. Of the cochlea only the base of the modiolus (82) containing the cochlear nerve (VIIIc) remains. The facial (VII) and vestibular (VIIIv) nerves are lodged in the upper compartment of the internal auditory meatus. The left lower insert gives the inside view of the vestibule (97, 98) including the oval window (28); the right lower insert the posterior view of the membranous labyrinth (blue) and its nerves: cochlear (VIIIc, yellow), and vestibular (VIIIv, pink).

Cerebellum

- Major recipient from vestibular nuclei
- Provides "fine tuning for vestibular reflexes"

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Vestibulo–Cerebellum

- AKA flocculonodular lobe
  - receives input from vestibular nerves & nuclei
- Mediates gain of VOR
  - momentary and long—term
- Modulates smooth pursuit
  - cerebellar atrophy results in impaired smooth pursuit
- Relay station for otolithic input

Human brain viewed from below. Numerals identify the cranial nerves. (From Carlton G. Smith, *Serial Dissections of the Human Brain*. Baltimore: Urban & Schwarzenberg, 1981.)

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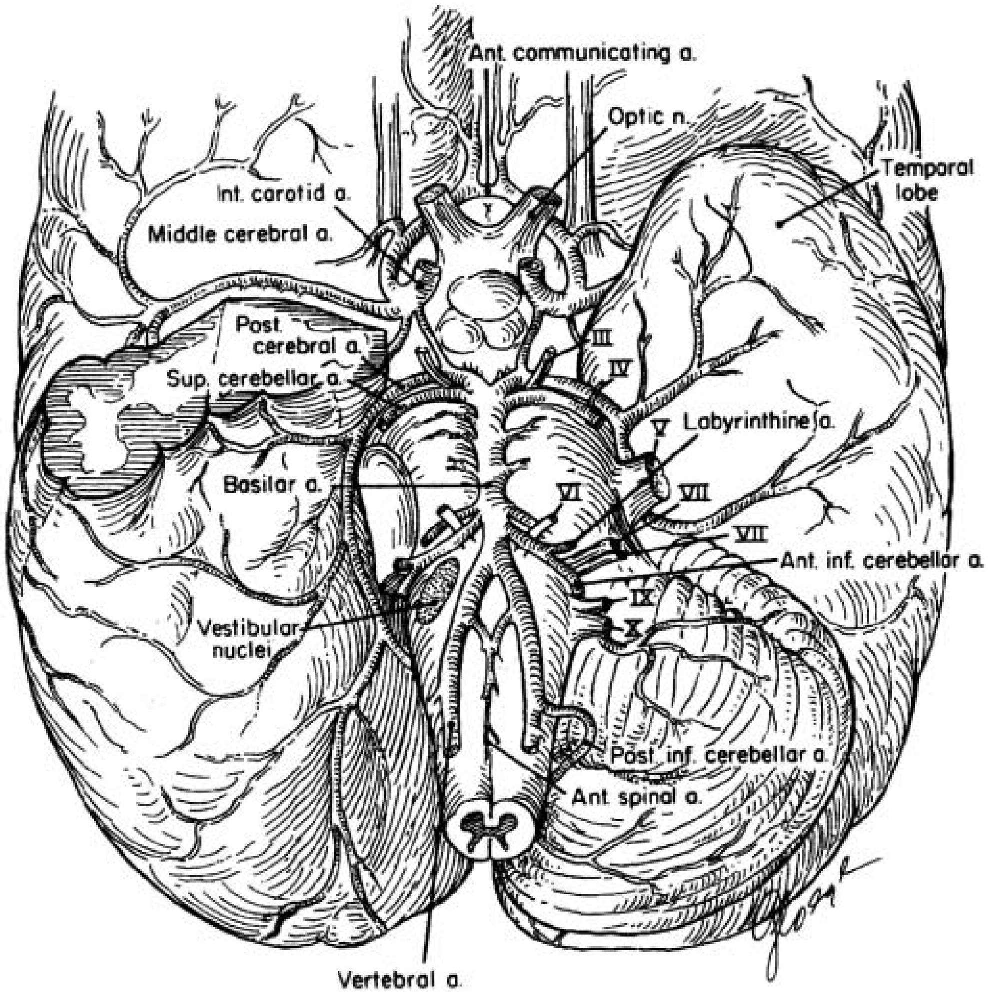

FIGURE 53. Vertebrobasilar circulation. Stippled area denotes location of the vestibular nuclei. In addition to the brainstem, labyrinths, and cerebellum, the vertebrobasilar circulation supplies the inferomedial part of the temporal lobes (including the hypocampus) and the occipital lobes via the posterior cerebral arteries. The latter accounts for the frequent occurrence of visual symptoms with vertebrobasilar insufficiency.

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Spino – Cerebellum

- Input from lower extremities
- Mediates Vestibulo Spinal Reflex (VSR - postural control)
  - Lesions result in gait ataxia and trunkal instability

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Vestibular Reflex Systems

- Vestibulo–Ocular Reflex (VOR)
  - Necessary for functional vision during static and dynamic conditions
  - ALL head movements result in loss of visual acuity due to retinal slip
    - VOR stabilizes image on retina by reflexive movement of eyes equal and opposite to head
    - Eye Movement = Head Movement -- GAIN = 1.0
    - Gain modulated by frequency and velocity of head movement, lighting, mental activity & visual suppression

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Vestibular Reflex Systems

- Major Functional Roles
  - Maintain posture
    - Induces muscle contractions that produce negative geotropic forces to compensate for steady changes in the direction of the force of gravity
      - If gravity were unopposed body would collapse
  - Maintain equilibrium & ocular stability during movement
    - Reflexes arise from Semicircular Canal (SC) & otolith organs
  - Maintain muscular tone
    - Reflex also arises from SC's & otolith organs

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Semicircular Canal–Ocular Reflexes

- Originally obtained by recording eye muscle response following physiologic or electrical stimulation of each receptor

- Excitatory & Inhibitory natures of connections established

    - Excitatory run through contralateral Medial Longitudinal Fasciculus (MLF),
    - Inhibitory run through ipsilateral MLF

- Stimulation of canal nerves results in eye movement in approximately the plane of that canal

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Semicircular Canal–Ocular Reflexes

Semicircular Canal	Excitation	Inhibition
Horizontal	Ipsilateral: Medial Rectus Contralateral: Lateral Rectus	Contralateral: Medial Rectus Ipsilateral: Lateral Rectus
Posterior	Ipsilateral: Superior Oblique Contralateral: Inferior Oblique	Ipsilateral: Inferior Oblique Contralateral: Superior Rectus
Anterior	Ipsilateral: Superior Rectus Contralateral: Inferior Oblique	Ipsilateral: Inferior Rectus Contralateral: Superior Oblique

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Vestibulo–Ocular Reflex

- End organs connect to group of motoneurons producing eye movement to compensate for a specific head movement with the objective of maintaining gaze stability

- No blind spots in receptive fields of inner ear organs
  - Sensors react to individual components of linear and angular acceleration in any direction of 3D space
  - Organs in each ear form a complementary set of acceleration sensors

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Vestibulo–Ocular Reflex

- Each receptor organ simultaneously activates an excitatory and inhibitory pathway to agonist and antagonist muscles
  - Results in a push—pull system of control
- Most natural head movements activate several receptors simultaneously
  - Inputs from multiple receptors converge on secondary neurons
- Alternate interneuron pathways form complementary reverberating circuits
  - Fine tunes end—organ reflexes

Vestibulo–Ocular Reflex

- Strength and even specificity of some connections can be modified by multi—sensory interactions
- Complete reversal of VOR after subjects wore left—right environment reversal goggles for 2 weeks
  - Occurred gradually over days
  - Returned to normal more quickly than original adaptation

2. Cervical–Ocular Reflex (COR)

- Similar to VOR
- Stretch receptors in cervical muscles—output to oculomotor nuclei
- Normally minor role—may increase if patient has bilateral vestibular deficit and/or VOR not fully functional

3. Otolith–Ocular Reflex

- Input from otoliths
- Output to oculomotor nuclei controlling vertical eye movement
- Also vertical—rotatory movements
- Appears each vertical eye muscle connected to specific areas of maculae so groups of hairs oriented in opposite directions excite agonist & antagonist muscles

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4. Vestibulo–Spinal Reflex (VSR)

- Stabilizes head and controls erect stance
- Input from canals and otoliths
- Output to anti–gravity muscles
  - extensors of neck, trunk & extremities
  - Tonic, lengthening & resistance changes
- System adaptive
  - varies with body position, balance strategy and viewing condition