Sensory Physiology, Ch 10
Outline of class lecture
After studying this chapter you should be able to:
1. Briefly describe the three layers (tunics) of the eye.
2. Describe the structures and functions of the fibrous tunic
3. Describe the structures and functions of the vascular tunic.
4. Describe the following: Accommodation, visual acuity and the way it is rated; myopia, hyperopia, and astigmatism.
5. Explain what LASIK stands for and what the procedure entails.
6. Describe the structures and functions of the nervous tunic.
7. Describe the physiology of vision
8. Explain the difference between dry and wet age-related macular degeneration (AMD)
9. Describe the structures of the lens
10. Explain the interior structures of the eye.
11. Describe the structures of the outer, middle ear and inner ear.
12. Explain the mechanism of hearing
13. Describe the structure and functions of the vestibular apparatus and its role in maintaining equilibrium.
14. Describe the following clinical conditions: strabismus, glaucoma, pterygium
15. Discuss the Clinical Applications from the study guide and be able to describe the disorders from the Applications to Health located at the end of this chapter.

Sensory Physiology: The Eye
• Ophthalmology: Study of structure, function, and diseases of the eye.

Accessory Structures of Eye
Eyelashes and Eyebrows
• Help protect the eyeballs from foreign objects, perspiration, and direct rays of the sun.

Extraocular Muscles
• Six extrinsic skeletal muscles move each eye

Disruption of Binocular Vision results in diplopia (double vision)

Strabismus
• Is a misalignment of the visual axes and loss of binocular vision.
  – Afflicts
• Due to:
  – An under acting or overacting eye muscle
  – Abnormal innervation, physical trauma, or a central processing problem
• Can result in permanent loss of vision in the “weaker” eye if not corrected during early childhood
• Initial therapy usually includes intermittent patching of the good eye before more invasive procedures such as surgery.
Structures of the Eyeball
Wall of the eye consists of three layers: 1. Fibrous tunic (outer), 2. Vascular tunic (middle), and 3. Nervous Tunic or Retina (Inner)

Fibrous Tunic (outer layer)
- **Fibrous tunic**: Consists of
- **Sclera**: The “white” of the eye
- **Cornea**: Transparent, avascular structure that forms the anterior surface of the eyeball.
  - Curved surface assists

Pterygium (tur RIDGE ium)
- A benign thickening of the conjunctiva that grows onto the cornea. Eventually is may cause vision disruption by interfering with the normal smooth surface of the cornea.
  - Most commonly caused by sun exposure.

Vascular Tunic (Middle Layer)
- Consists of three Parts:
  - **Iris**
    - The colored portion of the eye
    - Regulates the amount of light entering the eyeball by contraction/relaxation of smooth muscle that surrounds the pupil.
  - **Pupil**: The hole at the center
• **Choroid**
  - Highly vascular with dark pigment produced by **melanocytes**.
    - Blood vessels provide oxygen and nourishment to the retina
    - Black pigment functions to

![Choroid Diagram](image.png)

• **Ciliary Body**
  - Consists of
    - **Ciliary processes contain suspensory ligaments (zonular fibers)** that insert into the lens capsule, functioning to anchor it in place.
      - Secretes **aqueous humor** (plasma filtrate) that provides
        - Fluid is drained into the **scleral venous sinus (canal of Schlemm)**, which returns it to the venous blood.
        - **Glaucoma** is a condition in which there is an over production or an inadequate drainage of aqueous humor that can lead to excessive accumulation of fluid, which results in increased **intraocular pressure**. This may produce damage to the retina and loss of vision
    - **Ciliary Muscle**
      - Circular band of smooth muscle that alters the shape of the

![Ciliary Muscle Diagram](image.png)

• **Contraction**: Releases tension on the **suspensory ligaments** and thus the lens – the lens becomes more rounded, allowing the eye to focus on nearby objects.
  - Lens contains elastic fibers which causes it to become more rounded when not being pulled.
  - **Presbyopia** (old eye or vision): Inability of the eye to focus sharply on nearby objects due to loss of lens elasticity with age.

• **Relaxation**: Increases tension on the **suspensory ligaments** and thus the lens – the lens flattens, allowing the eye to focus on far away objects
Focusing of the Eyes

- **Accommodation**: Refers to changes in the thickness of the lens to keep an image focused on the retina as the distance between the eyes and object varies.
- When viewing an object, light rays are bent (refracted) to focus the object onto the retina.
  - The bending of
  - Curvature of the cornea remains constant while the curvature of the lens can change depending on the lens's elasticity and the contraction of the ciliary muscle.

Visual Acuity

- **Visual acuity** is a rating of the ability to see objects in sharp detail (sharpness of vision).
- Person with normal (20/20) vision can read a line of letters marked “20/20” while standing 20 feet from a Snellen eye chart.
- A 20/15 rating: Person at 20 feet is able to see details that would require someone with normal vision to move up to 15 feet to see.
- A 20/50 rating: Person has move up to 20 feet to discern details that a person with normal vision can see from 50 feet away.
  - Vision is worse than average
  - Visual acuity below 20/200, with

Visual Problems due to Alterations in Refraction

- **Refraction errors** are optical imperfections that prevent the eye from properly bending (refracting) light, causing blurred vision.
  - Cause of refractive errors include: 1) the overall **length of the eye**, 2) the **curvature of the lens**, and 3) the **curvature of the cornea**.
  - The primary refractive errors are **nearsightedness**, **farsightedness** and **astigmatism**.

- **Nearsighted (myopia)**: Can see close objects but
  - Due to the **eyeball being too long** or **lens is too strong** (too steeply curved) causing the image to be focused in **front of the retina** when looking at a distant object.
  - **Corrected with diverging (concave) lenses** which spreads the light rays apart as if the object were closer and thus the image is focused further back onto the retina.

- **Farsighted (hyperopia)**: Can see distant objects but
  - Due to the **eyeball being too short** or the **lens is to weak** (too flat) causing the image to be **focused behind the retina**.
  - **Corrected with converging (convex) lenses** which provide additional focusing (converging) of light needed to bring the image forward to the retina.
• **Astigmatism:** Either the cornea or the lens has an irregular curvature resulting in blurred vision.

![Diagram of eye showing normal and astigmatic vision](image)

**LASIK**
- **LASIK** (Laser-Assisted In-Situ Keratomileusis): Surgery to correct the curvature of the cornea for conditions such as farsightedness, nearsightedness, and astigmatism.
  - **Procedure:**
    - A circular flap is
    - The underlying cornea is reshaped with a laser
    - Corneal flap is repositioned over the treated area and the flap reattaches to rest of cornea within 24 hours.

**Nervous Tunic or Retina (inner layer)**
- **Nervous tunic or retina:** Contains photoreceptors (**rods and cones**) that function to turn visual data into nerve impulses.
  - Contains two portions:

**Pigment Epithelium**
- **Pigment Epithelium**
  - Lies between the choroid and the neural portion of the retina.
  - **Functions:**
    - Synthesize
    - Phagocytosis of the shed outer segments of the photoreceptors (~10%/day).
    - Delivery of nutrients from the blood to the photoreceptors.
    - Contains enzymes to

**Photoreceptors: Rods and Cones**
- **Rods** (120 million/retina): Specialized for vision in dim light, such as moonlight
  - No color vision – see
- **Cones** (6 million/retina): Specialized for color vision and sharpness of vision – Contain 3 types of cones.
  - **Blue cones:**
  - **Green cones:** Sensitive to green light
  - **Red cones:**
  - Color vision results from various combinations of these 3 types of cones.
Structure of Rods and Cones
- Specialized neurons that consist of an outer and an inner segment.
  - **Outer segment** contains visual pigments embedded in membrane disks
  - **Inner segment** contains major organelles and synthesizes visual pigments.
    - Synapses with

**Visual Pigments (photopigments):**
- Consists of two components: 1) **Opsin**, an integral protein in the disc plasma membrane that is bound to retinal and 2) **retinal**, the light absorbing part, which is synthesized from vitamin A.
- **Rods and cones contain the same retinal pigment but differ in their types of opsin.**
  - Rods contain rhodopsin and cones contain derivatives of rhodopsin called **color pigments** or **photo opsins**
  - Type of opsin present determines the wavelength of light that can be absorbed by retinal.
    - Their stimulation in various
    - New disks containing visual pigments are continuously assembled at the base of the outer segment.
    - After ~10 days, the disks are shed at the outer segment tip and phagocytosed by the pigment cells.
Photoreception
• In darkness, Na+ channels in the outer segment membrane are kept open allowing Na+ to flow in.
  – Although Na+ is continuously pumped back out, the transmembrane potential is about -40 mV, rather than the -70 mV of a typical resting neuron.
  – At -40 mV the photoreceptor is continuously releasing inhibitory neurotransmitters onto the associated bipolar cell.
    • The bipolar cell does not send a nerve impulse to the brain under these conditions.
    • The movement of Na+ into and out of the

• When a photon of light is absorbed by the retinal portion of opsin the retinal changes shape from its inactive 11-cis form to its active 11-trans form.
  – The 11-trans form detaches from the opsin which starts a chain of reaction that ultimately closes Na+ channels and prevents its entry into the cell while active transport continues to remove Na+ from the cell causing the cell become hyperpolarized.
    • The arrival of a photon thus reduces the dark current.
    • The detachment of retinal from opsin is

• The rate of neurotransmitter release declines as

• The decreased inhibitory neurotransmitter release indicates to the adjacent bipolar cell that the associated photoreceptor has absorbed a photon and sends a neural impulse to the brain.
Recovery After Stimulation
• Once activated by a photon the 11-trans form of retinal must be enzymatically converted to the 11-cis form and recombined with opsin.
  – 11-trans form is transported from the photoreceptors to the pigment epithelial cells where it is converted back to the 11-cis form and then transported back to the photoreceptors.
  – Bleaching contributes to the lingering visual impression you have after you see a flashbulb go off and see “ghost” images
  – Bleaching is not noticeable under normal circumstances because the eyes are continually making small involuntary changes in position that move the image across the retina’s surface.

Clinical Application: Night Blindness
• Deficiency in vitamin A can result in a decline in retinal pigment and a corresponding decrease in vision.
• At first daylight vision is not affected because of the increased amount of photon stimulation activates remaining visual pigments.
• Problem first becomes apparent at night, which dim light proves insufficient to activate the rods.
  – This condition is known as

Dark Adaptation
• In the light, bleaching reaction results in an increased amount of activated visual pigments in the rods and cones.
• activated visual pigments in the rods and cones.
  – Dark adaptation occurs due to an increased amounts of inactivated visual pigments that become highly sensitive to even the lowest amount of light stimulation.

Fovea Centralis
• Fovea centralis is a small depression within the macula lutea and contains the densest concentration of cones.
  – Area of highest visual
  – Foveal cones have long slender bodies; the blood vessels and other retinal cells are all displaced to the side rather than resting directly on top of the cones. This allows light to pass unimpeded to the cones.

Other Retinal Neurons
• Bipolar cell layer
  – Transmits signal form
  
• Ganglion cell layer
  – Ganglion cell axons extend posteriorly to the optic disc (blind spot) and exit the eyeball as the optic nerve.
  – Transmit signals of vision to the midbrain and thalamus and then to the visual cortex.
Optic Disk
• **Optic disk (blind spot):** Region where the axons of ganglion neurons exit the eyeball as the optic nerve.
  – Area contains no rods or cones; thus we cannot see an image that strikes this region and hence the name.

Age-related Macular Degeneration
• Age-related Macular degeneration (AMD), is the leading cause of blindness in people aged 60 and older.
• There are two major types of AMD, "dry" and "wet" macular degeneration.
• **Dry (non-neovascular) AMD:** Most common type, accounts for
  – Accumulation of drusen (waste products from photoreceptors) accumulates between the retina and the choroid.
  – Usually progresses slowly and rarely progresses to legal blindness.
• **Wet (neovascular) AMD:** Least common, accounts for
  – Accumulation of drusen and abnormal blood vessel growth (neovascularization) occurs **underneath the retina** in the choroid layer.
    • As the name implies, the appearance is wet: blood and serum leak out of the new frail blood vessels, and may lift the macula causing visual distortions and permanent tissue damage.
  – Retinal detachment and scarring may occur, causing significant loss of vision and many times, legal blindness.
Lens
  • **Lens**: Lies posterior to the iris and pupil and helps focus images on the retina for clear vision.
    – Held in position by **zonular fibers (suspensory ligaments)** that are attached to lens capsule.
  • **Lens consists of** transparent elastic proteins called

Interior of the Eye
  • The lens divides the interior of eye into two cavities – the **Anterior Cavity** and **Posterior Cavity** (vitreous chamber)
  • **Anterior Cavity** – anterior to the lens
    • **Aqueous humor**:
      • Continually secreted by **ciliary processes**, flows through anterior cavity and is drained by the **scleral venous sinus (Canal of Schlemm)**
      • Helps maintain eye shape and
  • **Posterior Cavity (Vitreous Chamber)** – Between the lens and retina.
    • **Vitreous body (humor)**
      • Jelly-like substance that looks like raw egg white.
      • Formed during embryonic development and is not replaced thereafter.
    • Function: Contributes to **intraocular pressure**, helps to prevent the eyeball from collapsing, and holds the retina flush against the internal portions of the eyeball.

• **Eye Floaters**
  • As you age, the gel-like vitreous humor composed of millions of fine collagen fibers shrink and tend to clump together. These bits of debris cast tiny shadows onto your retina, and you perceive these shadows as **eye floaters**. Floaters move as your eyes move. They appear to zoom away when you try to look directly at them, and drift slowly when your eyes stop moving.
  • Floaters can happen at any age. They most often occur between ages 50 and 75.
Special Senses: The Ear
Regions of the Ear

- Ear is divided into 3 Regions:
  1.
  2.
  3.

External Ear consist of:

- **Auricle (pinna)**
  - Flap of elastic cartilage covered by skin that collects and channels sound into the external auditory canal

- **External auditory canal (meatus)**
  - Tube (1") that lies in the temporal bone and runs from the auricle to the eardrum
  - Line by skin containing course hairs and specialized sebaceous glands called **ceruminous glands** that produce earwax (**cerumen**)
    - Hairs and **cerumen** help prevent dust and foreign objects from entering the ear and slows the growth of microorganisms.

- **Tympanic Membrane (ear drum)**
  - Thin, semitransparent partition between the external and middle ear
    - **Perforated eardrum** describes
      - Transmits sound vibrations that enter the ear to the **auditory ossicles** in the middle ear.
Middle Ear consists of:

- **Tympanic Cavity**
  - Small air filled cavity hollowed out of the temporal bone that houses the **auditory ossicles**
  - Connected to the nasaopharynx via the **auditory tube** (Eustachian tube or pharyngotympanic tube)
    - Functions to equalize air pressure within the tympanic cavity with that of

- **Auditory Ossicles**
  - Bones that are named for their shape:
    - **Malleus** = hammer; attached to internal surface of eardrum
    - **Incus** = anvil; intermediate bone
    - **Stapes** = stirrup;
  - Vibrations of **tympanum** convert arriving sound waves into mechanical movements that are transmitted via the **auditory ossicles** to the **oval window**.
    - Because tympanum is 22 times larger and heavier than the oval window, a 1 µm movement of the tympanum produces a 22 µm deflection of the oval window
    - Amplification allows us to
  - **Articulations** of ossicles are by way of **synovial joints** as the bones are attached to the surrounding temporal bone by ligaments.
    - **Tensor tympani muscle** (attached to malleus) and **stapedium muscle** (attached to stapes) are skeletal muscles that protect the inner ear against prolonged loud noise, but not brief ones such as a gunshot.
  - **Oval** and **round window**.
    - **Oval window**: Membrane-covered opening between the middle and inner ear.
    - **Round window**: Opening directly below the oval window
Inner Ear

- **Inner ear** provides the senses of **hearing** and **equilibrium** and consists of a number of chambers and canals in the temporal bone that can be divided into two main divisions: the **bony** and **membranous labyrinth**.

- **Bony Labyrinth**
  - Series of cavities within the temporal bone that is lined with periosteum and contains a fluid called **perilymph** (similar to cerebrospinal fluid) that surrounds the **membranous labyrinth** which contains a fluid called **endolymph**.

- **Membranous Labyrinth**
  - Lies within the

- **The Bony and Membranous Labyrinth** are divided into 3 areas: **Semicircular canals**, **vestibule**, and **cochlea**
  - Combined, the **semicircular canals and vestibule** are referred to as the **Vestibular apparatus**: Function in the detection of head position and head movement (equilibrium).
  - **Cochlea**:

Types of Equilibrium

- **Equilibrium** is the ability of the body to maintain appropriate posture and balance. **There are two types of equilibrium**: **Static and Dynamic**
  - **Static equilibrium**: Refers to maintenance of the position of the body (mainly the head) relative to the force of gravity.
    - The **vestibule (utricle and saccule)**:
      - Provides
      - Provides information about linear acceleration associated with changes in velocity when traveling horizontally or vertically. Examples: riding in a car, elevator, or when skipping rope
  - **Dynamic equilibrium**: Refers to maintenance of body positions (mainly the head) in response to sudden movements such as rotation.
    - The **semicircular canals**: Provide a sense of
      - Helps a person maintain balance when turning the head, spinning, or tumbling.
Structures and Functions of the Vestibule: Saccule and Utricle

- The vestibule consists of two saclike otolithic organs – the saccule and the utricle.
  - **Function**: Provides information about *linear acceleration* and *head position*.
  - In the wall of each utricle and saccule is a sensory structure called a **macula**.

- **Each macula** consists of **hair cells, an otolithic membrane, and otoliths**.
  - **Hair cells**: Neuroepithelial cells innervated by the vestibular branch of the *vestibulochchlear nerve* (VIII).
  - Have numerous (70 or more) **sterocilia** (microvilli) and one **kinocilium** (normal cilium), that extends beyond the stereocilia.
  - **Supporting cells**: Support the hair cells
    - Secret
  - **Otolithic membrane**: *Gelatinous glycoprotein layer* that surrounds and floats directly over the hair cells.
    - Contains small protein/ **calcium carbonate** crystals called **otoliths** (ear stones) that increase the mass of the membrane.
    - Results in a

How the Vestibule Works to Maintain Equilibrium

- Changes in head position due to gravity, linear acceleration, or linear deceleration pulls the otolithic membrane resulting in bending of the stereocilia of the hair cells.
• If you tilt your head in any direction, the **otolithic membrane** is pulled by gravity in the direction of the tilt and slides over the hair cells and bends the hairs, which stimulates them.
• Similarly, if you are sitting upright in a car that suddenly accelerates forward, the **otolithic membrane**, due to its inertia, slides backward and stimulates the hair cells by bending them.
• The bending of the stereocilia of the hair cells leads to the generation of nerve impulses that are transmitted to the brain (medulla and cerebellum) via the vestibular branch of the **vestibulocochlear (VIII) nerve**.
• The **cerebellum** is the primary site for equilibrium processing.
• Sensory information will then go from the medulla/cerebellum to the **thalamus** and up to the cortex.

**Semicircular Canals**
• **Semicircular canals**: Contain receptors that function in detection of movement (dynamic equilibrium).
  - Canals project in three different planes at nearly right angles to each other.
  - **Ampulla**: Enlargement at
    - The **crista ampularis** is the receptor for movement (dynamic equilibrium) and made up of a **crista** and a **cupula**
      - **Crista**:
      - **Cupula**: Gelatinous glycoprotein mass that covers the hair cells of the crista.
        - The **cupula** has a higher density than that of the surrounding endolymph and essentially rests above the receptor surface.
How the Semicircular Canals Work to Maintain Equilibrium

- When the head moves, the attached semicircular canals and hair cells move with it. The endolymph, however, is not attached and lags behind due to its inertia. As the moving hair cells drag along the stationary fluid, the hairs bend.
- Bending of the stereocilia is transduced into nerve impulses that are transmitted to the brain via the vestibular branch of the vestibulocochlear nerve.
  - When the endolymph stops moving, the elastic nature of the cupula allows it to return to its normal position.
  - If rotation continues, the moving endolymph finally catches up. If the head rotation stops suddenly, the fluid has built up momentum and cannot stop immediately. The fluid continues to rotate in the direction of the head rotation, leaving the person with a turning sensation.

Vertigo
- Vertigo:
  - Result of a disturbance in the vestibular system (i.e., structures of the inner ear, the vestibular nerve, brainstem, and cerebellum) causing a conflict between the signals sent to the brain.
    - Example: Visual input vs. the inner ear signals
  - Can result from:
    - Head injuries
    - Tumor
    - Infections of the inner ear
    - Alcohol
    - Migraine headaches

Nystagmus
- Nystagmus:
- Causes:
  - Brain's control of eye movements is poor, resulting in an inability to look steadily at an object.
  - Vision problems (myopia or hyperopia)
  - Optic nerve damage

Structures of the Cochlea
- Is subdivided into three channels that spiral around a central bony core.
- The partitions that separate the 3 channels are shaped like the letter “Y”
  - Cochlear duct (Scala media): Lies between the wings of the Y and is composed of the membranous labyrinth
    - Contains endolymph and organ of Corti (Spiral organ)
  - Scala vestibuli: Channel above the cochlear duct which begins at the oval window and contain perilymph.
  - Scala tympani: Channel below the cochlear duct that ends as the round window and contains perilymph.
    - The scala tympani and scala vestibuli
Organ of Corti (Spiral Organ)

- **Organ of Corti**: The organ of hearing and lies on the basilar membrane
  - Hair cells function to convert a mechanical vibration (stimulus) into an electrical signal (nerve impulse).
  - At their basilar ends, hair cells synapse with the cochlear branch of the vestibulocochlear or auditory nerve (VIII).

Mechanism of Hearing

1. The auricle directs sound waves into the external auditory canal

2. Sound waves strike the tympanic membrane and cause it to vibrate at the same frequency as the incoming sound waves.
   - Eardrum vibrates slowly in response to low-frequency (low-pitched) sounds and rapidly in response to high-frequency (high-pitched) sounds.
3. The central area of the eardrum connects to the malleus. The eardrum’s vibrations are transmitted from the malleus to the incus and then to the stapes.
5. Movement of the oval window sets up fluid pressure waves in the **perilymph** of the **cochlea**. 
   - As the oval window bulges inward, it pushes on the **perilymph** of the **scala vestibuli**; 
     these pressure waves are transmitted to the **scala tympani** and eventually to the round 
     window, causing it to bulge outward into the middle ear.

6. The pressure waves cause the vestibular membrane to vibrate which in turn initiates fluid 
   pressure waves in the **endolymph** of the **cochlear duct**.

7. The pressure waves in the endolymph cause the **basilar membrane** to vibrate and as a result, 
   the hair cells or the **organ of Corti** move against the **tectorial membrane**. 
   - Bending of the **hairs** is transduced into electrical impulses that travel via the cochlear 
     nerve to that areas of the brain involved with interpretation of sound.

8. The hair cells of the **organ of Corti** are arranged in rows; a very soft sound may stimulate only 
   a few hair cells in a portion of one row. 
   - As the volume of a sound increases, additional hair cells are stimulated as the 
     vibrations of the basilar membrane increase.

9. Areas of the basilar membrane vibrate at different frequencies. 
   - Sound waves of **high frequency** are detected closer to the oval window whereas **low 
     frequency** sounds have optimal vibration (resonance) further away from the oval 
     window.