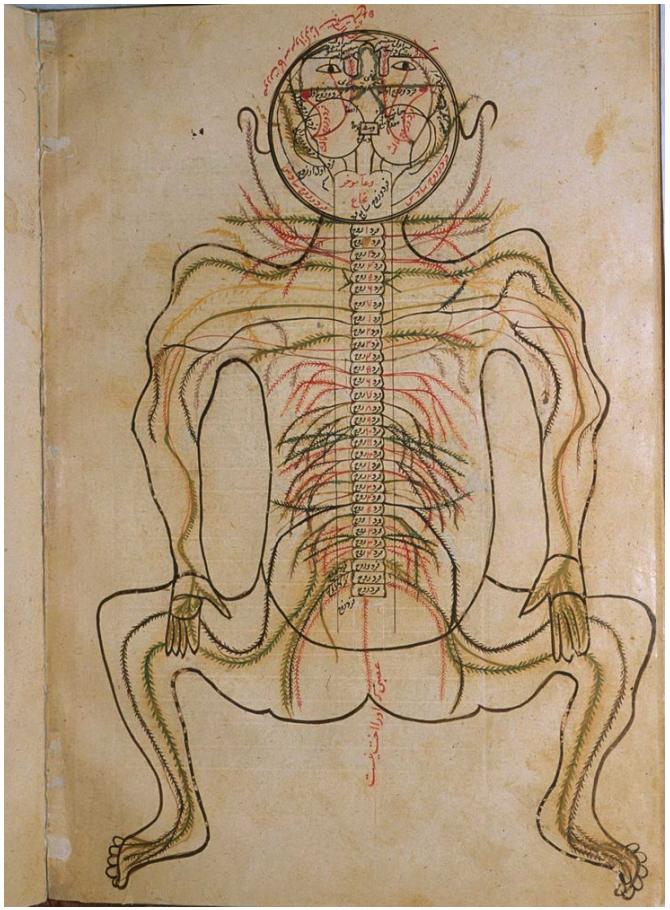
Proprioception Interoception and Exteroception



Anatomical illustration of the nervous system by Mansour Ibn-Ilyas, ca. 1400

University of Trento

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Categories of sensation

The Sensory Modalities

Sherrington (1906)

Exteroception

- Distance Senses
  - Vision
  - Audition
- Chemical Senses
  - Gustation
  - Olfaction
- Skin (Cutaneous) Senses
  - Touch (Tactile)
  - Temperature (Thermal)
  - Pain (Nociception)

Proprioception

- Kinesthesis
- Equilibrium (Vestibular)

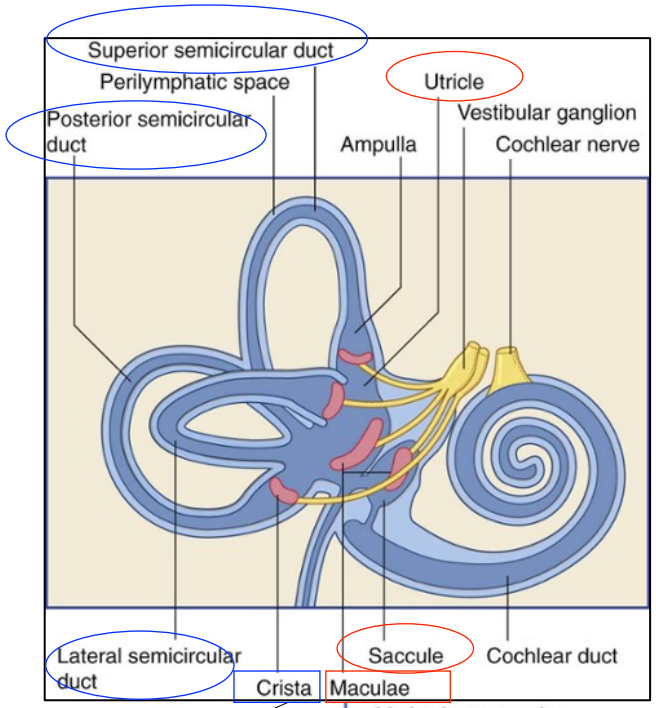
Interoception

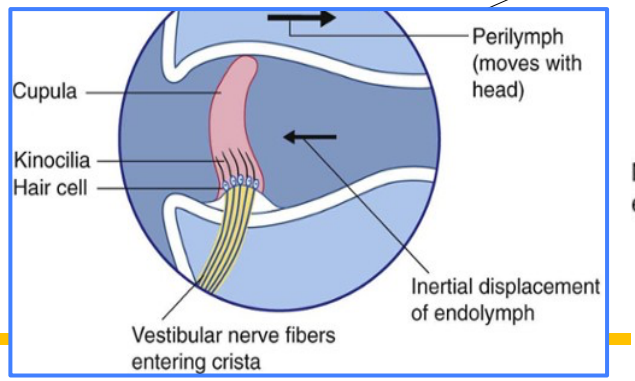
- The sense of the physiological condition of the body

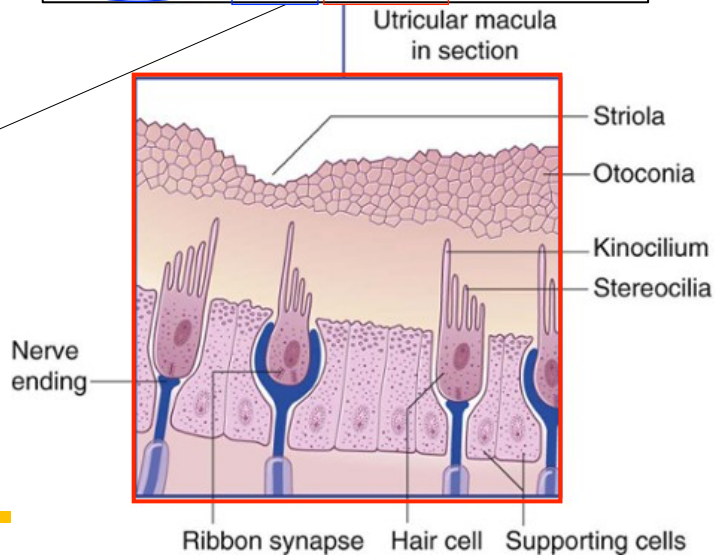
Cristae and maculae

- **Sense organs are bathed in endolimph**
- **Ampullar cristae** contain **hair cells** that sense when **long uniformly** distributed **kinocilia** penetreting in a gelatinous structure called cupula are **inertially displaced** by ampullar **endolymph**

- **Utricular and saccular maculae** contain **hair cells** that sense trough **stereocilia (~100/cell) and kinocilium (longer 1/cell**) a differential displacement exerted by otoconia (a gelatinous matrix in macula)

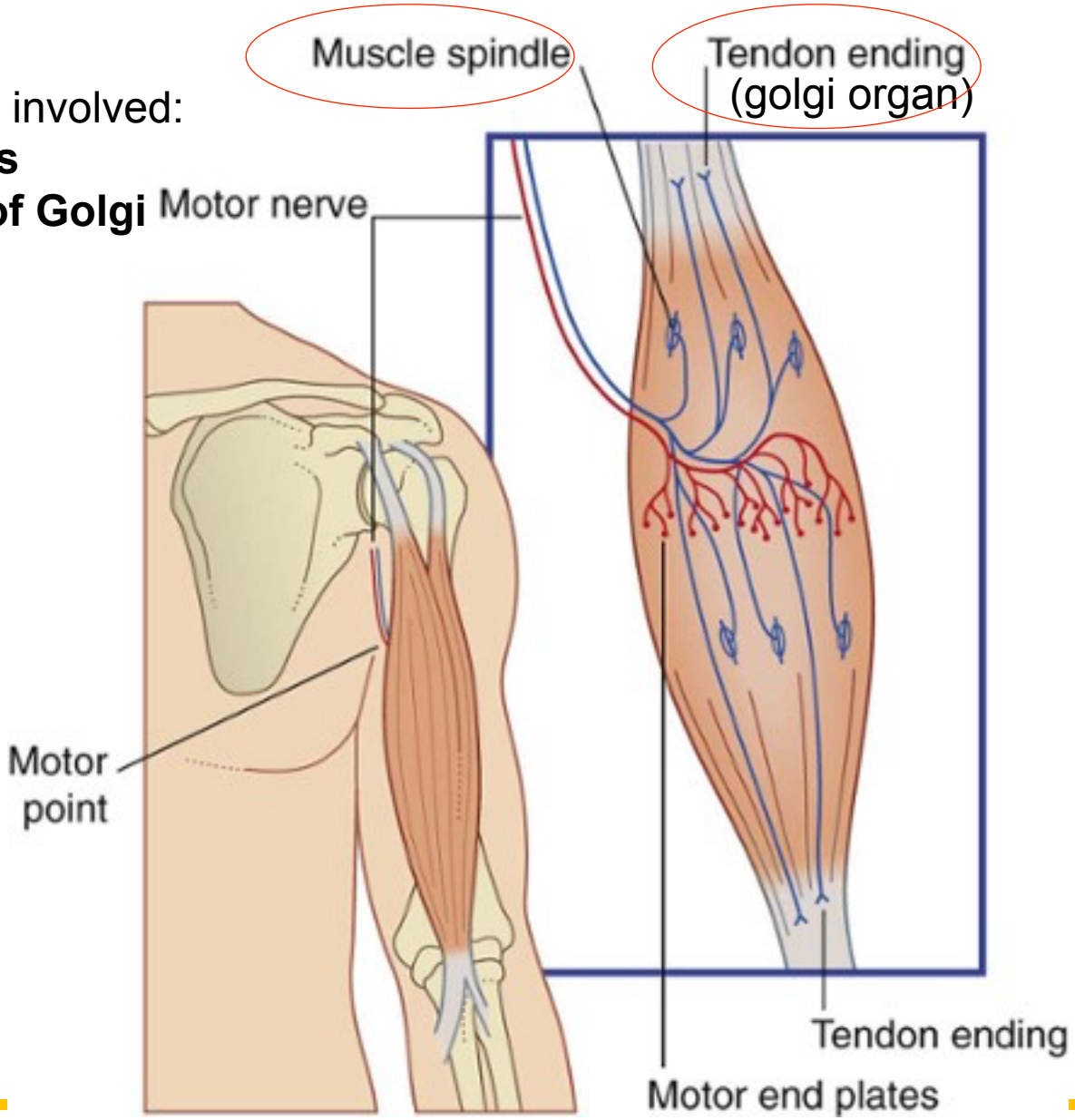






Proprioception: Kinesthesis

- Two major structures involved:
  - **Muscle spindles**
  - **Tendon organ of Golgi**



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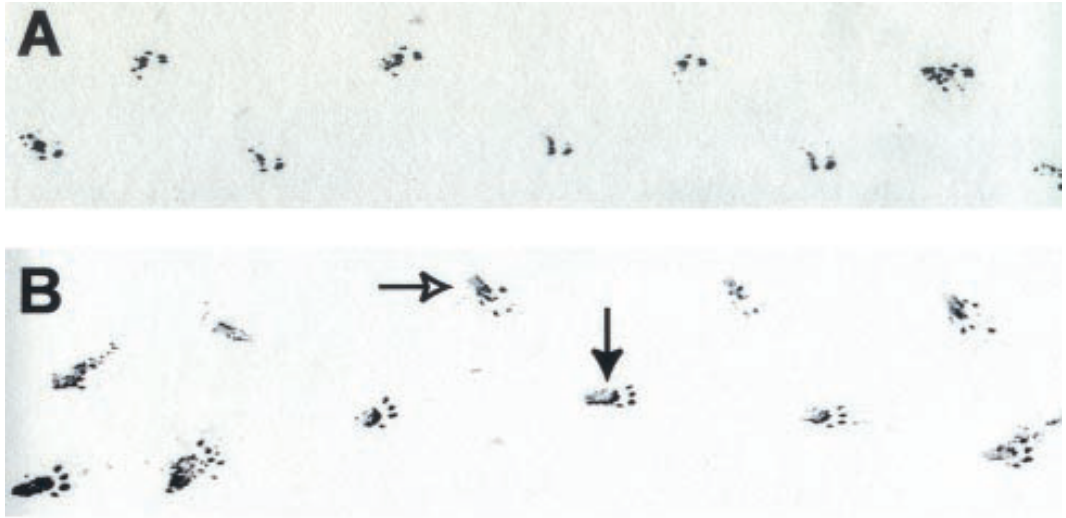
Muscle-specific ErbB2 KO mice have impaired proprioception and gait

- **Proprioception is impaired in muscle-specific ErbB2 KO m**

- This is resulting in severe **gait alterations**

WT

ErbB2 KO

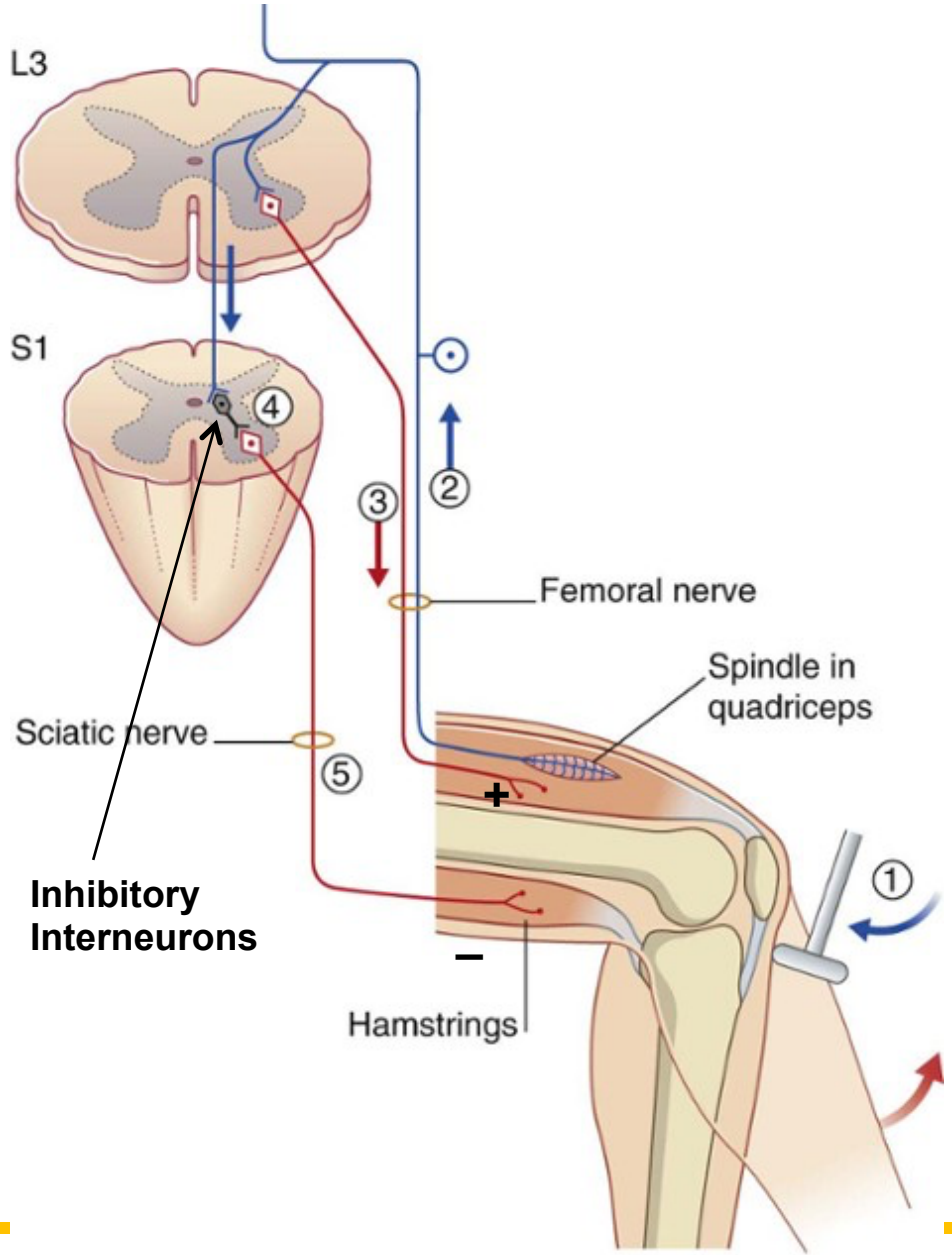


Andrechek et al. 2002

Passive stretch and spindle fibers

- **Passive stretch** of muscle spindles occurs when the **entire muscle is passively lengthen**
- **Passive stretch** may activate stretch reflexes **like the patellar reflex:**
  1. **A tap of the patellar ligament** stretch the spindles of the quadriceps
  2. **The spindle discharged excitatory impulses** to the spinal cord **(afferents)**
  3. **A monosynaptic** relay **activates motorneurons** innervating the **quadriceps (**homonymous) and inducing **extrafusal fiber contraction**
  4. Through **inhibitory spinal internurons** the activity of extensor muscle (quadriceps) is coordinated with that of **flexor muscles (→hamstring muscle is relaxed)**

  This control is called **RECIPROCAL INHIBITION**



Interoception and the control of respiration

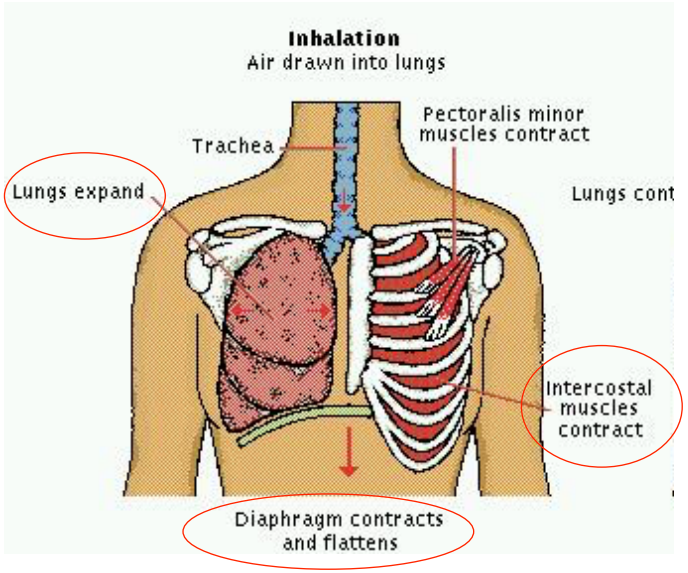
Afferent pathway:

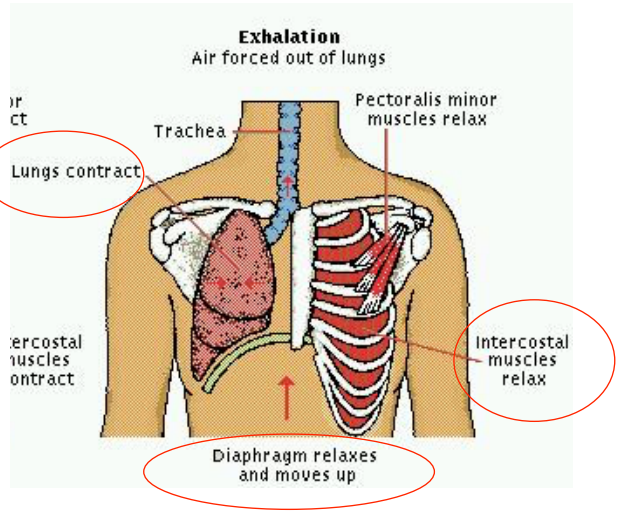
- Respiratory center receive afferent impulses from different parts of the body according to movements of thoracic cage and lungs.
- From peripheral chemoreceptor and baroreceptor impulses are carried by glossopharyngeal and vagus nerves to respiratory center.

Efferent pathway:

- Nerve fiber from respiratory center leaves the brain and descend in anterior part of lateral column of spinal cord.
- These nerve fibers terminate in the motor neurons in the anterior horn cells of the cervical and thoracic segments of spinal cord.
- From motor neurons two sets of nerve fiber arise which supplies particular muscle:

1. Phrenic nerve fibers: supplies diaphragm
2. The intercostal nerve fibers: supplies intercostal muscles.

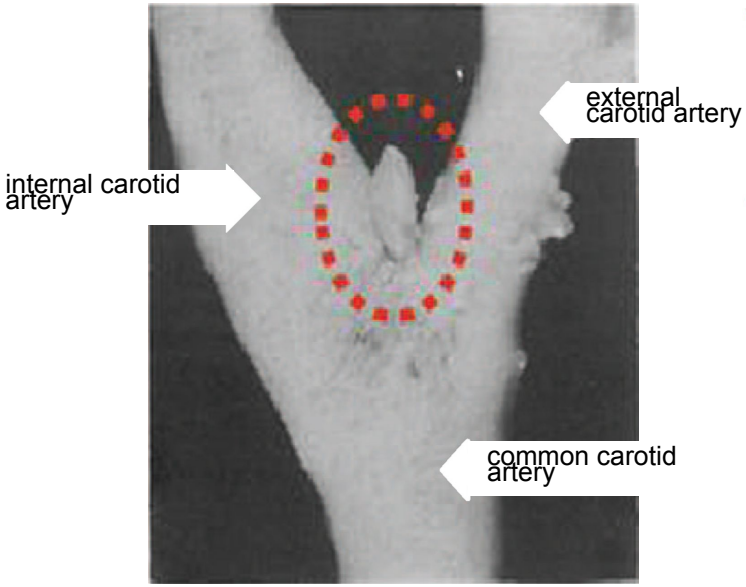


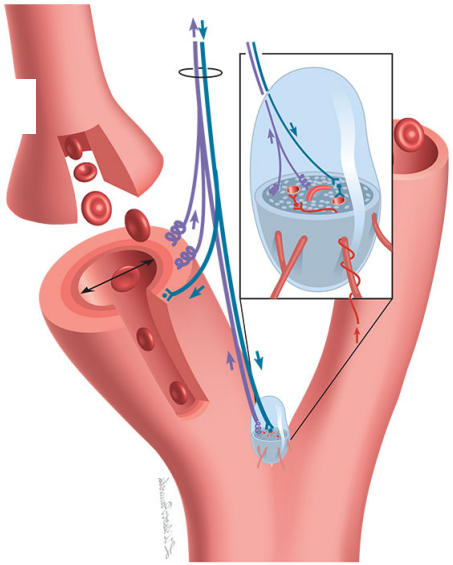


Interoception: carotid body

Chemoreceptors important for the control of respiration are located in

- **Internal Carotids (carotid body)**
- Aortic Arches
- **CNS**





- **Carotid bodies (CB)** respond to:
  - **Blood CO_2 levels/ protons (H+)**
  - **Blood levels of O_2**
  - **Hypoglycemia**
  - **Hypoperfusion**

- **CB** are the **most perfused organ**/ gram weight in the body (2000ml/min per 100mg tissue)

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Exteroception

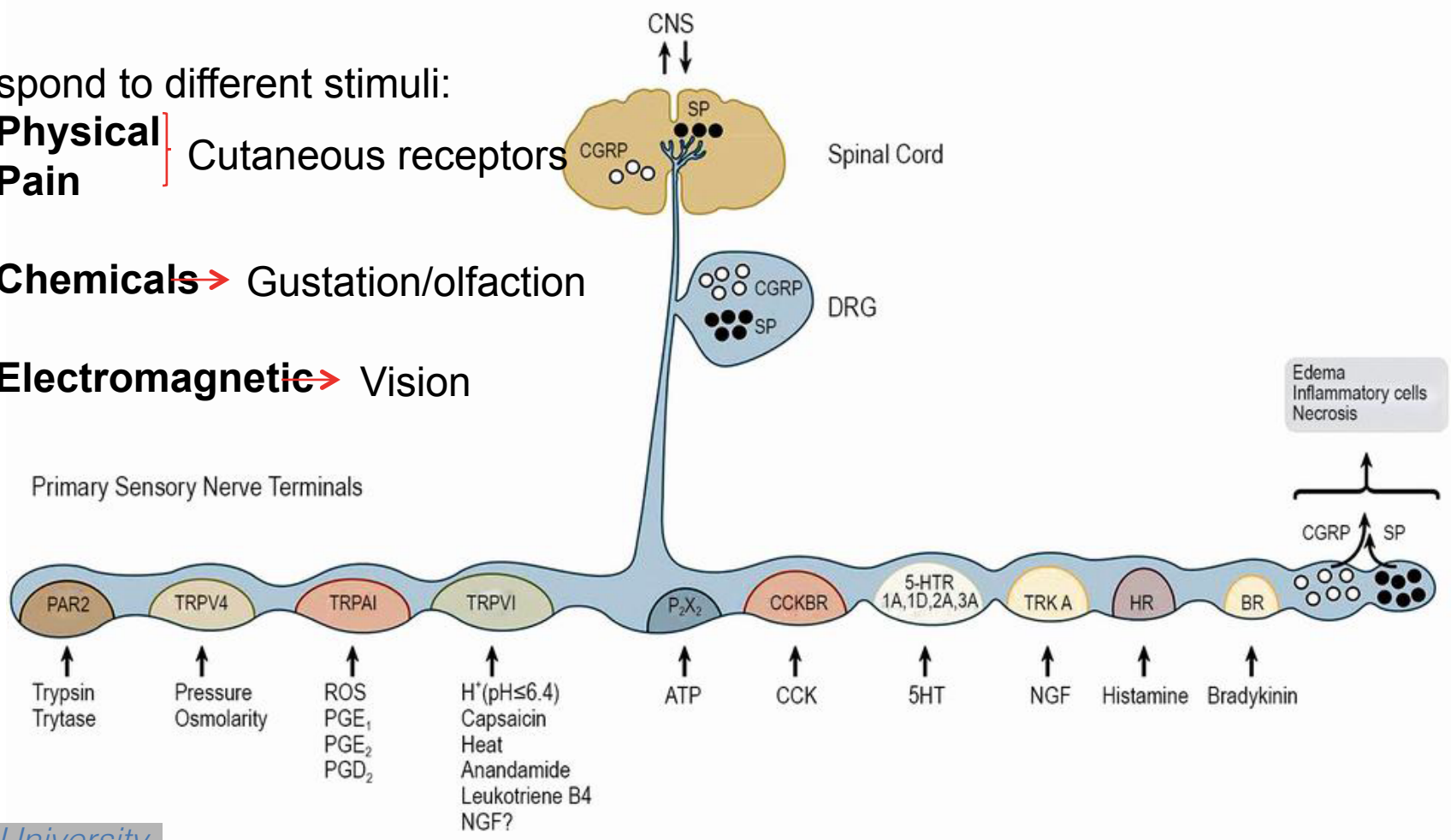
Exteroception: perception of the outside world

Respond to different stimuli:

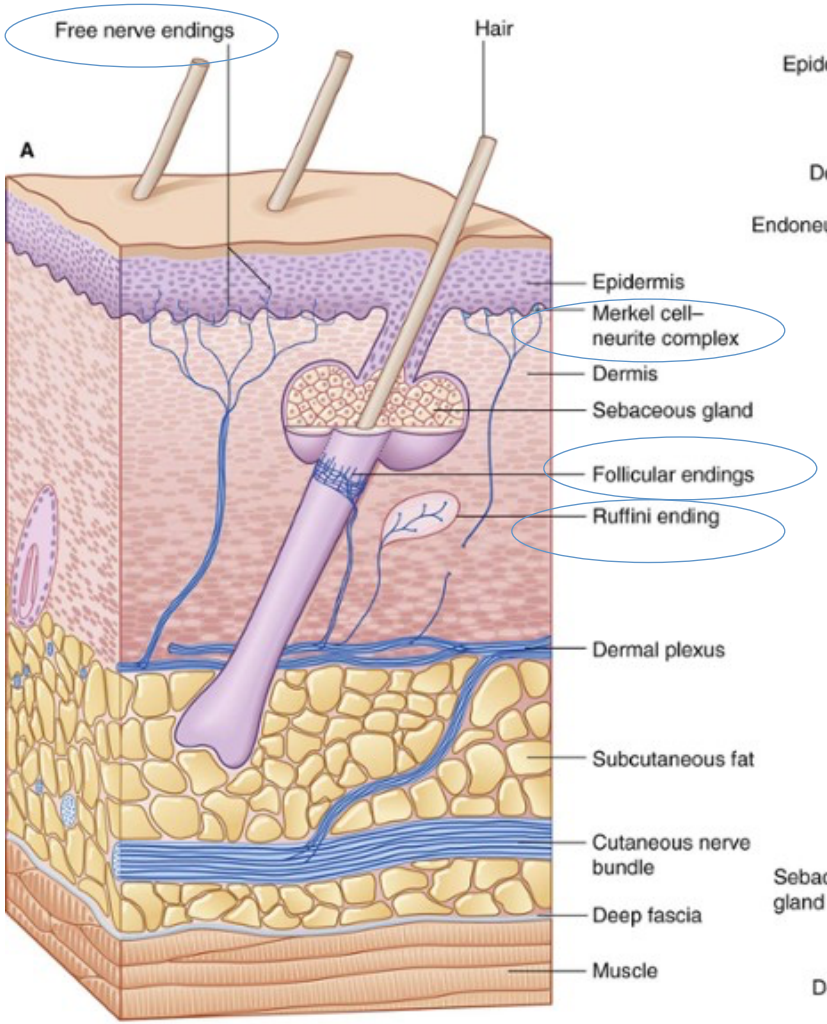
- **Physical**
- **Pain**

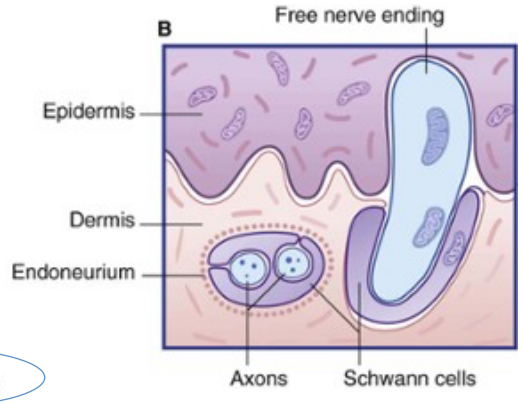
Cutaneous receptors

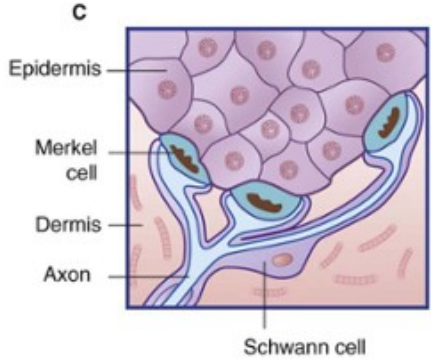
- **Chemicals** → Gustation/olfaction
- **Electromagnetic** → Vision

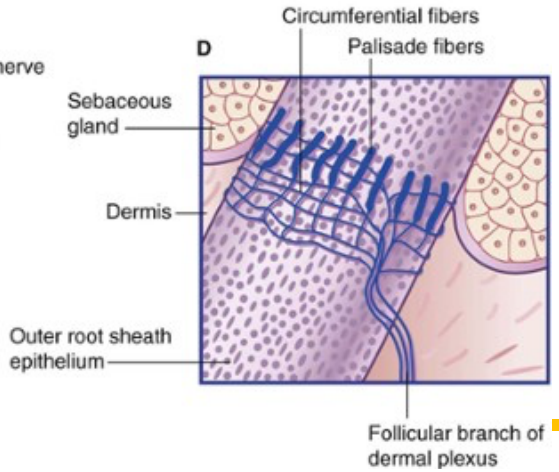


Non-glabrous skin









Free nerve endings (also glabrous)

- **Epidermal** nerve endings
- **Dermal** nerve endings
- Different stimuli:
- **Thermoreceptors**
- **Nociceptors**

Merkel cells (also in glabrous)

- **Cells are forming a complex with the neurite**
- **Sense pressure** for example from edges of objects
- Slowly adapting

Follicular nerve endings

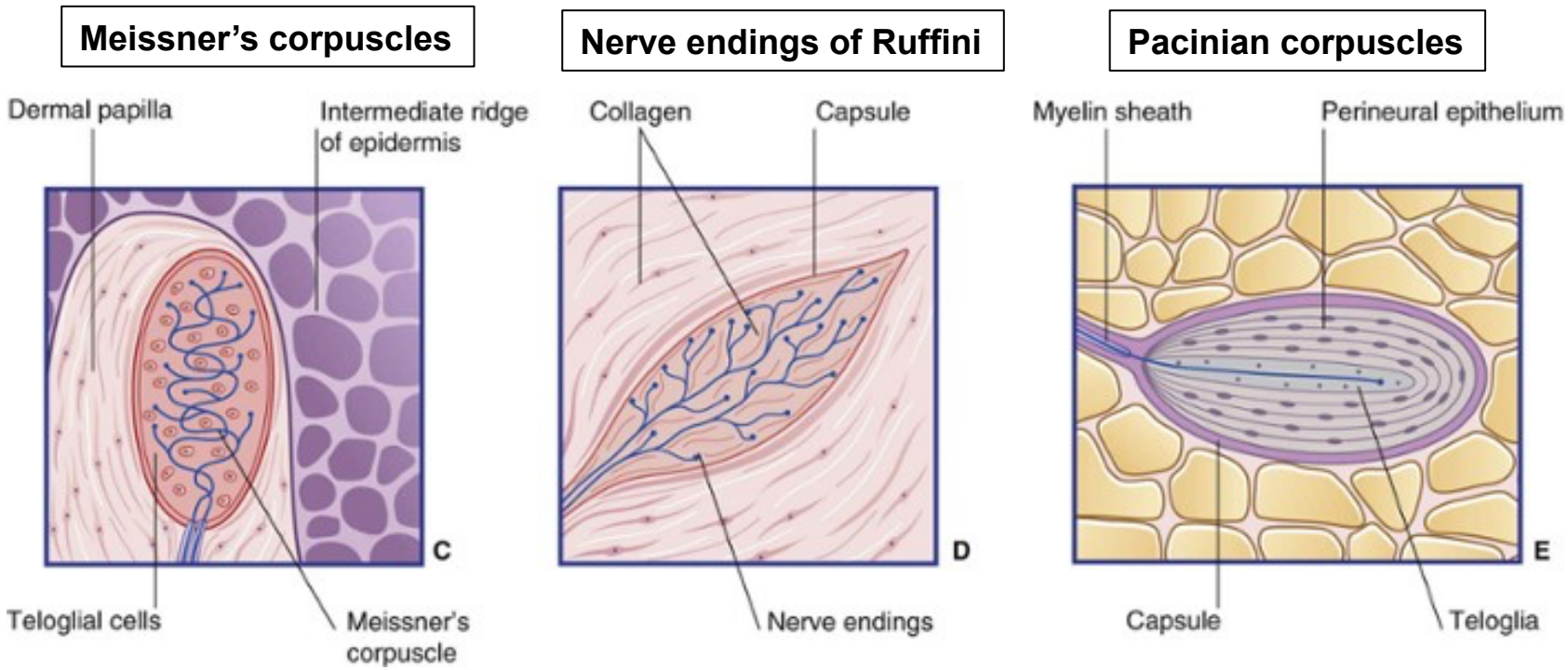
- **Palisade (lanceolate) of naked** nerve endings
- **Circumferential** terminals
- Each follicular unit **innervate multiple follicles**
- Rapidly adapting

Ruffini endings (also glabrous)

Encapsulated nerve endings

Three types of cutaneous **mechanoreceptor** nerve endings are encapsulated by **capsules formed by 3 layers:**

- **Outer coat** of **connective tissue**
- **Middle coat** of **perineural epithelium**
- **Inner coat** of modified **Schwann cells (teleoglia)**



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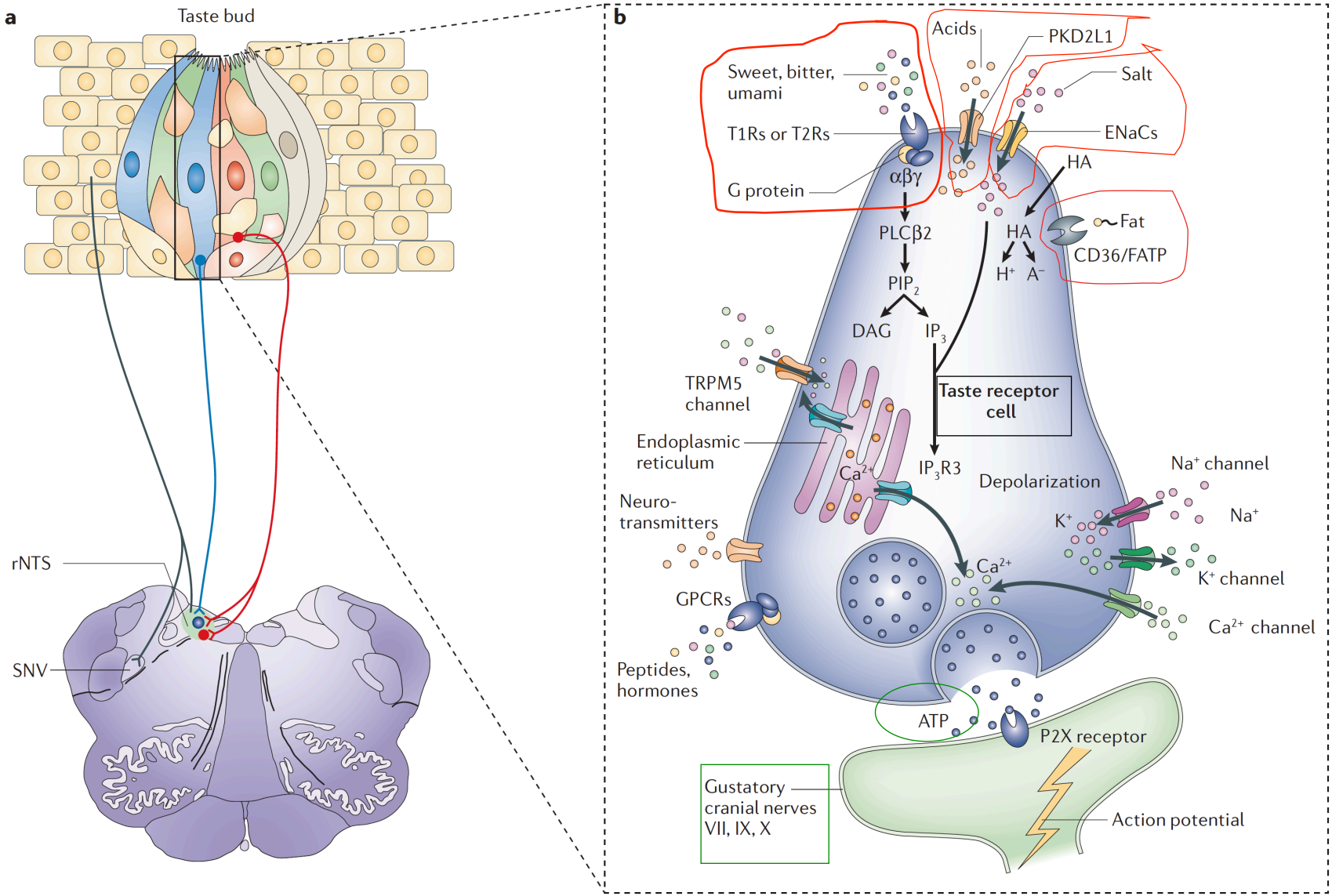
Sensory receptor cells



Taste receptor cells

Transduction of mechanical vibrations

- Sound waves enter the **outer ear** and **Tympanic membrane** vibrates back and forth

- **Ossicles** transfer vibration to **oval window,** causing it to vibrate against the cochlea →sends **pressure waves** through **perilymph**

- **Waves travel** from **vestibular canal** to **tympanic canal** and dissipate against **round window:**
  - ➢ Low frequency sounds – complete route
  - ➢ Higher frequency sounds – pass through cochlear duct
- Cause vibration of **basilar membrane**

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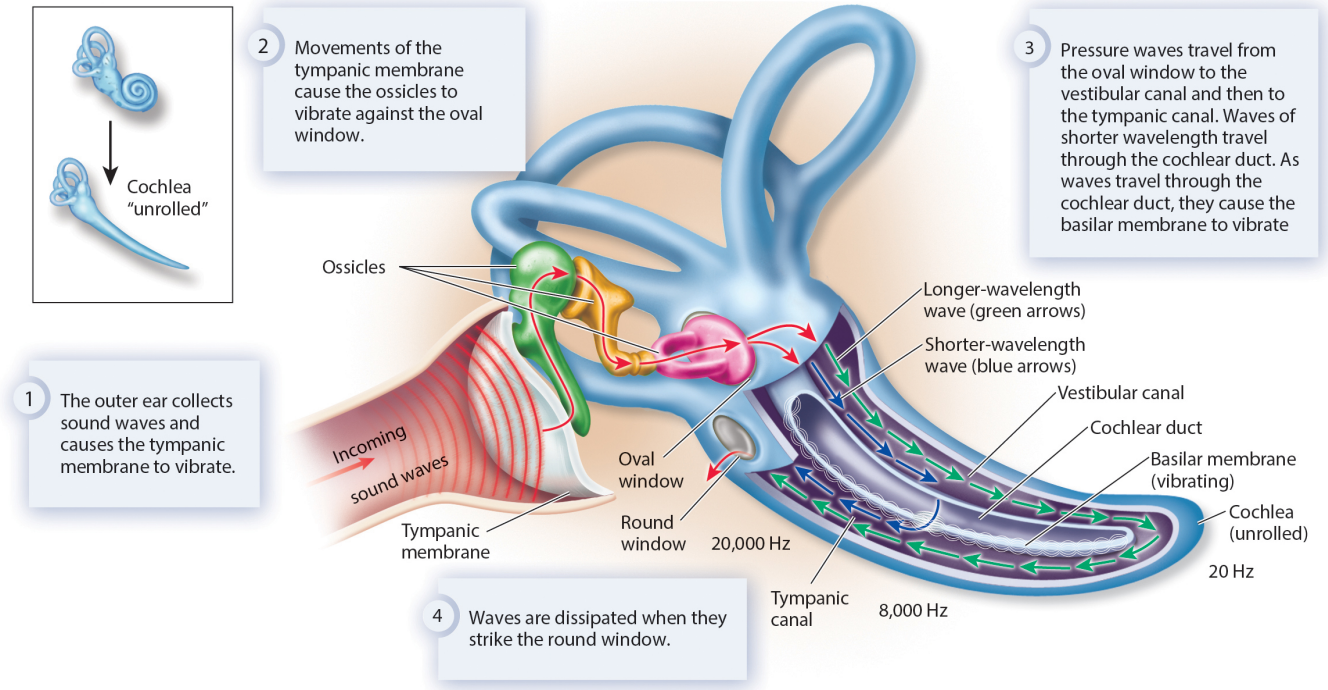
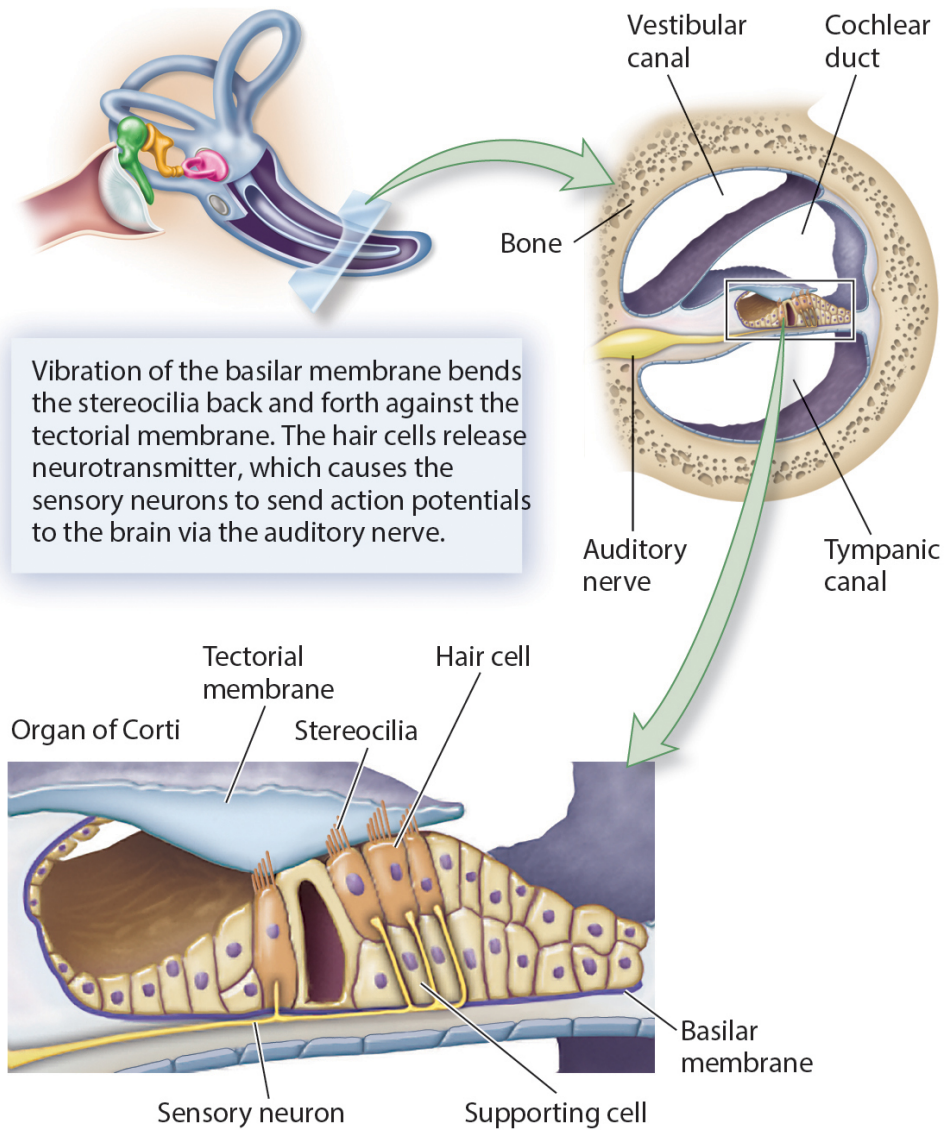


Generation of electrical signals

- Mechanical vibrations are transduced into electrical signals within the **organ o Corti** of the cochlea
- Hairs bending in one direction sends an **action potential**
- Frequency of action potentials is determined by the **vibration of the basilar membrane**



The basilar membrane is aligned with fibers:

- Fibers short and rigid at the **base of the cochlea: →High frequency waves** vibrate them
- Longer fibers are **near the end: → Low frequency waves** vibrate them

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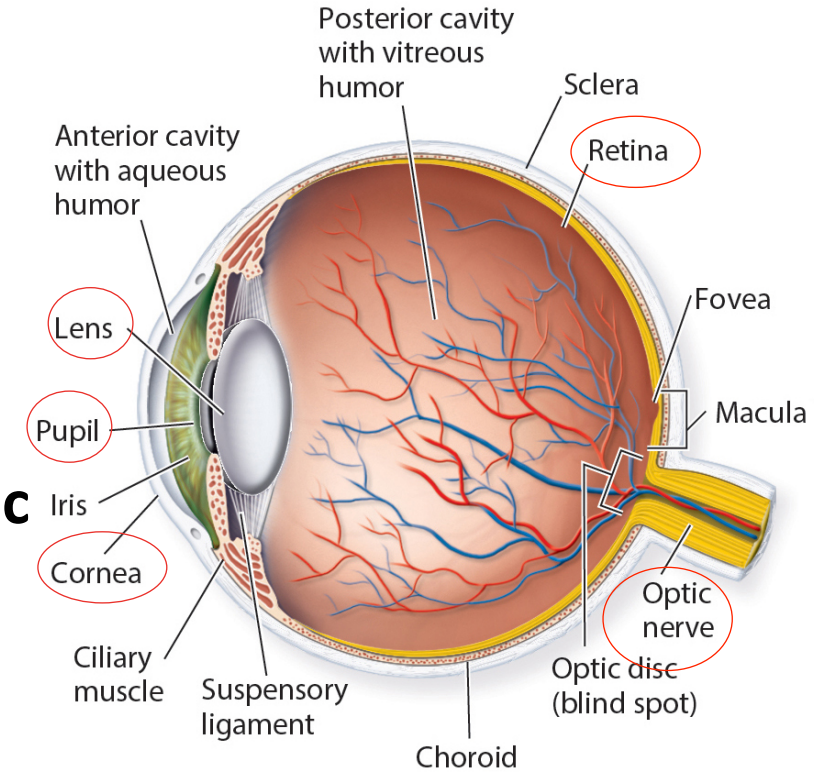
The single-lens eye

Light transmitted **through cornea**, **pupil**, **lens**, to **layer of photoreceptors** (the **retina**) at the back of the eye

- Visual image is formed on the retina

Photoreceptors trigger **electrical changes in neurons**

- Pass out of the eye through the **optic nerves** to brain



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Rods and cones

Rods

- Sensitive **to low-intensity light (up to a single photon)**
- Used mostly **at night**
- Do **not detect colors**
- Generate a **black-and-white** image
- Nocturnal animals rely primarily on rod vision

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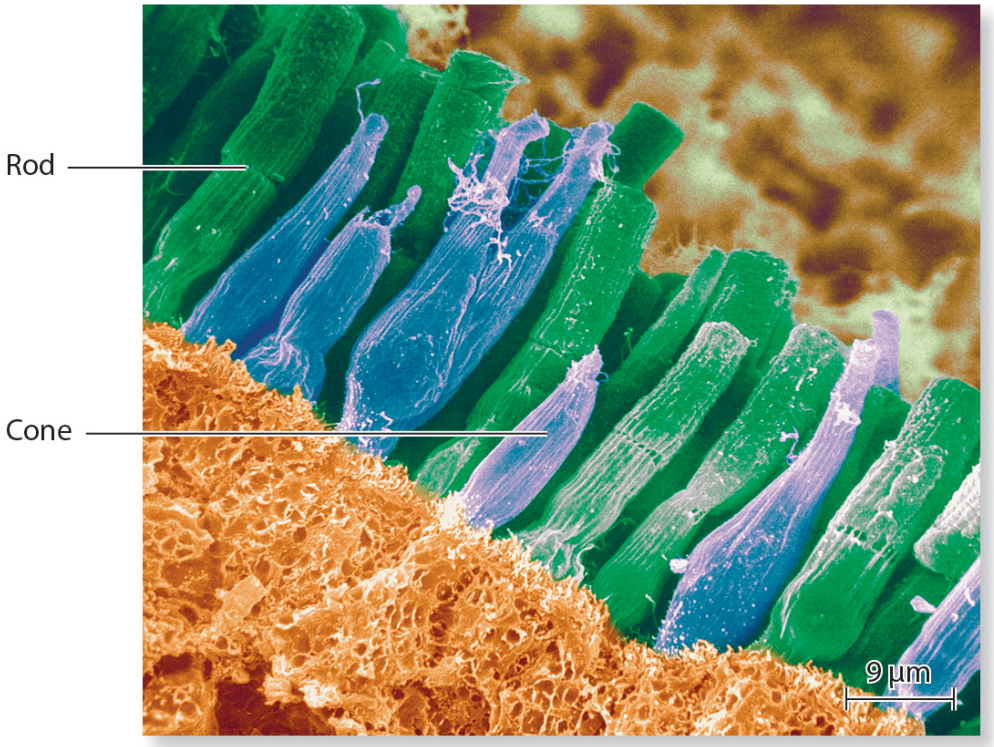


Cones

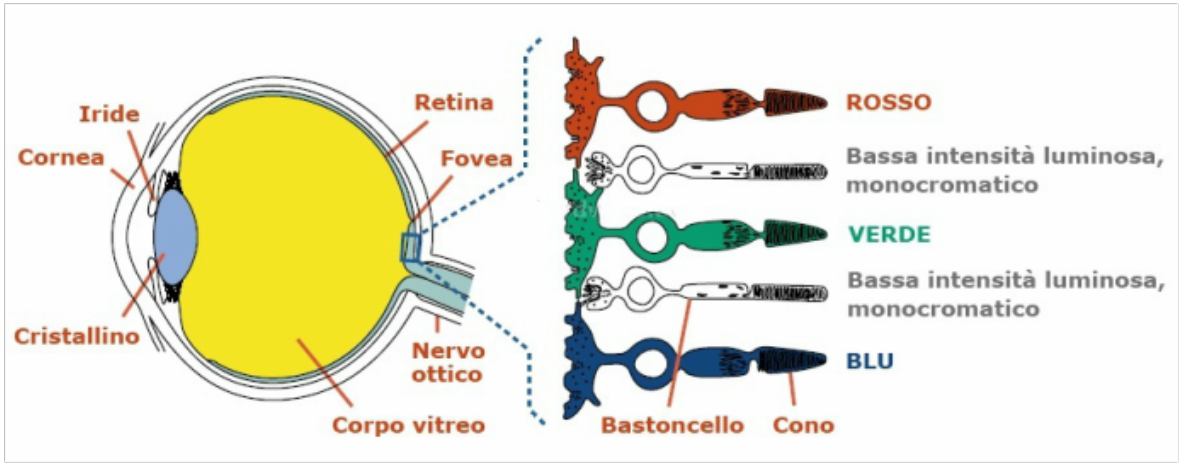
- Require **more light**
- Used in daylight by most **diurnal** vertebrates and some insects
- **Detect color**
- **Fewer cones than rods** in human retina

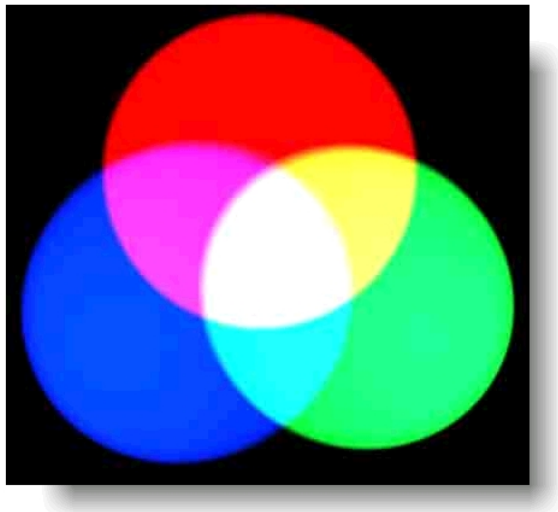
Human cone pigments

Composed of **retinal** (derivative of vitamin A)plus **1 of 3 possible opsin proteins (g protein coupled receptors)**

- Each **type of opsin** determines **wavelength absorbed**
- Responds best to either **red, green, or blue light**

- Each cone cell makes only one type





- **Brain uses information** about proportion of each type of cone stimulated **to generate all other colors**

- **Humans have 3 types of color-sensitive photoreceptors**,

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Digestive tract

Animal Nutrition

- Animals require:
  - 5 categories of **organic nutrients**
    - Carbohydrates →glucose →.carbon + energy
    - Proteins →amino acids → protein synthesis or energy
    - Lipids → membrane components, thermic insulation or energy
    - Nucleic acids → synthesis of DNA, RNA and ATP
    - Vitamins → coenzymes

Tabella 41.1 Principali nutrienti degli animali, risorse alimentari, alcune loro funzioni e sintomi dovuti alla loro carenza nei vertebrati

Classe di nutrienti	Risorse alimentari	Funzioni nei vertebrati	Sintomi dovuti alla carenza
Carboidrati	Tutte le risorse alimentari, specialmente piante ricche di amido	Fonti di energia; componenti di alcune proteine; fonti di carbonio	Indebolimento muscolare; perdita di peso; formazione di chetoni (diminuzione del valore di pH nel sangue)
Proteine	Tutte le risorse alimentari, specialmente carne, legumi, cereali e radici	Forniscono gli amminoacidi per la sintesi di nuove proteine; alcuni amminoacidi sono utilizzati come fonte di energia	Perdita di peso; atrofia muscolare; debolezza; depressione del sistema immunitario; maggiore suscettibilità alle infezioni
Lipidi	Tutte le risorse alimentari, specialmente carni grasse, latticini e piante oleose	Principali componenti delle membrane; fonti di energia; isolanti termici; costituiscono i componenti di alcuni ormoni	Perdita dei capelli; perdita di peso; disturbi ormonali e riproduttivi
Acidi nucleici	Tutte le risorse alimentari	Forniscono gli zuccheri, le basi azotate e i fosfati utilizzati per la sintesi di DNA, RNA e ATP	Nessuno; i componenti degli acidi nucleici possono essere sintetizzati dalle cellule partendo da amminoacidi e zuccheri

  - **Inorganic nutrients**
    - Water
    - Minerals

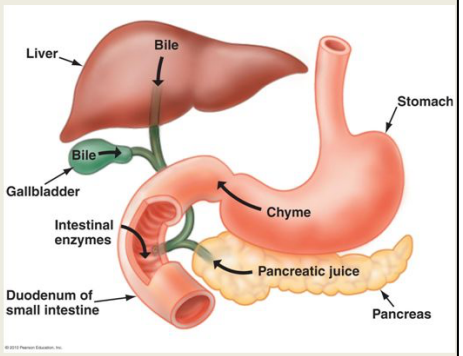
  - 4 groups of **essential nutrients** (cannot be synthesized from precursor molecules)
    - Essential amino acids
    - Essential fatty acids
    - Vitamins
    - Minerals

Small intestine and Accessory organs

ORGAN	MAJOR FUNCTIONS*	COMMENTS/ADDITIONAL FUNCTIONS
Mouth and associated accessory organs	Ingestion: food is voluntarily placed into oral cavity Propulsion: voluntary (buccal) phase of deglutition (swallowing) initiated by tongue; propels food into pharynx Mechanical breakdown: mastication (chewing) by teeth and mixing movements by tongue Digestion: salivary amylase in saliva, produced by salivary glands, begins chemical breakdown of starch	Mouth serves as a receptacle; most functions performed by associated accessory organs. Mucus in saliva helps dissolve foods so they can be tasted and moistens food so that tongue can compact it into a bolus that can be swallowed. Saliva cleanses and lubricates oral cavity and teeth.
Pharynx and esophagus	Propulsion: peristaltic waves move food bolus to stomach, thus accomplishing involuntary (pharyngeal-esophageal) phase of deglutition	Primarily food chutes; mucus produced helps to lubricate food passageways.
Stomach	Mechanical breakdown and propulsion: peristaltic waves mix food with gastric juice and propel it into the duodenum Digestion: pepsin begins the digestion of proteins Absorption: absorbs a few fat-soluble substances (aspirin, alcohol, some drugs)	Also stores food until it can be moved into the duodenum. Hydrochloric acid produced is a bacteriostatic agent and activates protein-digesting enzymes. Mucus produced helps lubricate and protect stomach from self-digestion. Intrinsic factor produced is required for intestinal absorption of vitamin B_{12}.
Small intestine and associated accessory organs (liver, gallbladder, pancreas)	Mechanical breakdown and propulsion: segmentation by smooth muscle of the small intestine continually mixes contents with digestive juices and, along with short-distance peristaltic waves, moves food along tract, allowing sufficient time for digestion and absorption Digestion: digestive enzymes delivered from pancreas and brush border enzymes attached to microvilli membranes complete digestion of all classes of foods Absorption: breakdown products of carbohydrate, protein, fat, and nucleic acid digestion, plus vitamins, electrolytes, and water, are absorbed by active and passive mechanisms	Small intestine is highly modified for digestion and absorption (circular folds, villi, and microvilli). Alkaline mucus produced by intestinal glands and bicarbonate-rich juice ducted in from pancreas help neutralize acidic chyme and provide proper environment for enzymatic activity. Bile produced by liver emulsifies fats and enhances (1) fat digestion and (2) absorption of fatty acids, monoglycerides, cholesterol, phospholipids, and fat-soluble vitamins. Gallbladder stores and concentrates bile, releasing it to small intestine in response to hormonal signals.
Large intestine (cecum, colon, rectum)	Digestion: some remaining food residues are digested by enteric bacteria (which also produce vitamin K and some B vitamins) Absorption: absorbs most remaining water, electrolytes (largely NaCl), and vitamins produced by bacteria Propulsion: propels feces toward rectum by haustral churning and mass movements Defecation: reflex triggered by rectal distension; eliminates feces from body	Temporarily stores and concentrates residues until defecation can occur. Copious mucus produced by goblet cells eases passage of feces through colon.

Accessory organs

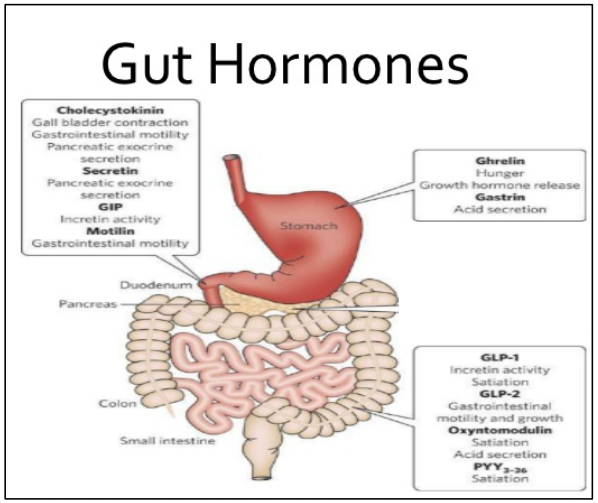
- Role of liver
  - Produces bile to assist in fat digestion
- Role of gall bladder
  - Stores bile from liver
- Role of pancreas
  - Produces bicarbonate
  - Produces digestive enzymes



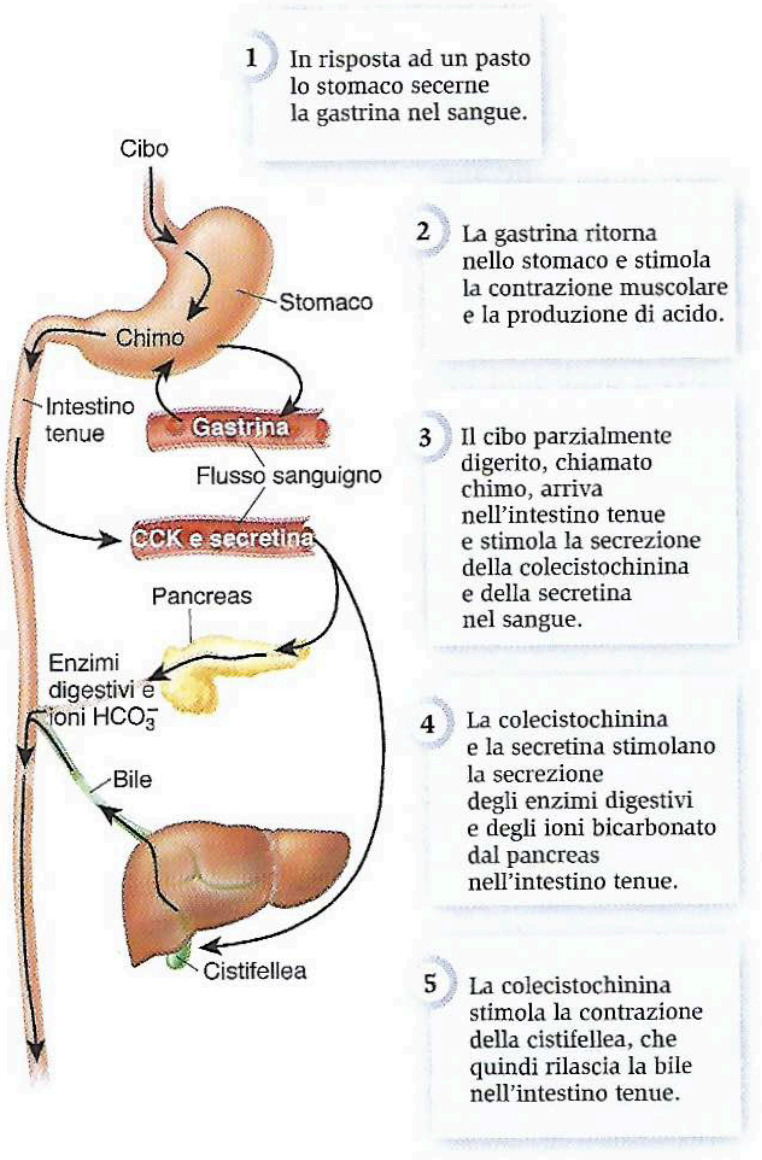
Pancreatic Juice *(from pancreas)*			Bile *(from liver)*
Proteases *(digests proteins)* **Trypsin** **Chymotrypsin** → Proteins → Peptides	**Carboxypeptidase** → Peptides → Amino acids	**Amylase** *(digests carbohydrates)* → Starch → Maltose	**Lipase** *(digests fats)* → Dietary fat Triglycerides → Monoglycerides Fatty acids **Bile Salts** *(digests fats)* → Monoglycerides Fatty acids

Control of GI tract: hormones

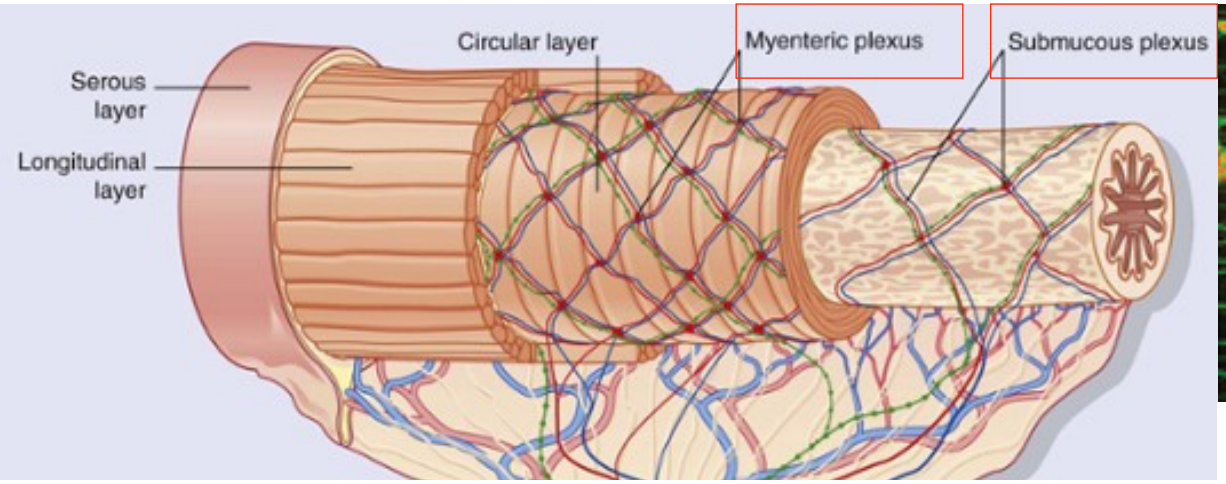
- Secreted by cells (**Enteric Endocrine Cells)** scattered mainly throughout stomach and small intestine

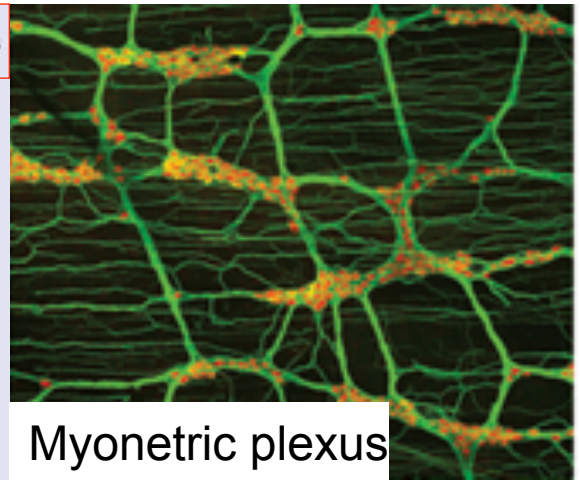


- Hormone's **targets are:**
- **Stomach** (gastrin)
- **gallbladder and pancreas**(secretin and CCK)



Intrinsic innervation (ENS)





The **enteric nervous system** is formed by:

- **thousands of small ganglia**
- **~200-600 million neurons** in human (> than total sympathetic; ~ all spinal cord neurons)

Myenetric plexus is extending from the **upper esophagus to anal sphincter→ major role in controlling motility**
Submucosal plexus is absent in the esophagus and and scarce in the stomach→ mainly associated with district with large fluid fluxes→ play their **major role in controlling secretion of water and electrolytes**

Submucosal plexus may be formed of 1, 2, or 3 **distinct layers→** in **human are two (outer/inner)**

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