Glossary Human Biology - Introduction

Anatomy: The science of biological structures.
Physiology: The study of the functioning body organs.
Human Body: The entire physical structure of a human being.
B. **Cavity**: A space within the body that contains various internal organs.
Homeostasis: The condition in which the body's internal environment remains relatively constant, within limits.
Systems of the Body: A group of interacting elements in the body functioning as a complex whole.

Cardiovascular S.: The constituting elements of the body (blood, heart, and blood vessels) which nourish all body tissues at (cellular level), removes metabolic waste products (in cooperation with excretory and respiratory systems) and distributes thermal energy throughout the body.
Digestive S.: The organs involved in the mechanical and chemical breakdown of food into small molecules for absorption and use.
Endocrine S.: The collection of endocrine glands of the body; in humans the
Excretory S.: The components of the body involved in the elimination of metabolic waste products from the body; in humans the liver and the kidneys.
Immune or **Lymphatic** S.: The network if cells, tissues, and organs that defends the body against microbial invaders. Made up by the lymph, lymph vessels and structures and organs containing lymphatic tissue (large numbers of white blood cells called lymphocytes).
Nervous S.: The network of nerves that integrate and coordinate the activities of all the bodily systems.

- **Parasympathetic** NS: The autonomic nervous system, having cell bodies of preganglionic neurons in nuclei in the brain stem and in the lateral gray matter of the sacral portion of the spinal cord; primarily concerned with activities that restore and conserve body energy (cranosacral division).
- **Sympathetic** NS: The autonomic nervous system, having cell bodies of preganglionic neurons in the lateral gray columns of the thoracic segment and first two or three lumbar segments of the spinal cord; primarily concerned with processes involving the expenditure of energy (thoracolumbar division).

Reproductive S.: The tissues and organs (gonads, testis and ovum) involved in the production and maturation of gametes (sperm and egg) and the supportive structures required to maintain the developing embryonic and fetal stages.
Respiratory S.: The sections of the body involved in the overall exchange of gases between the atmosphere, blood, and body cells; involves pulmonary respiration, external respiration, and internal respiration mediated by the trachea, lungs (alveolar tissue, surfactant), and muscles of the rib cage.
Skeletal S.: The *passive* and rigid body support to which muscles attach and apply force. Cartilage and osseous tissue comprise the skeletal system.

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Tissue: A group of cells of the same type performing the same function within the body. The four types are:

Bony T.: ??????????????????????????????

Connective T.: Connects and surrounds other tissues and whose cells are embedded in collagen matrix (large amount of intercellular space filled with viscous solutions):

- Types of CT: 1) Loose CT (fills space between muscles, and delicate membrane layer in underlying organs, connecting their epithelial tissues). 2) Cartilage (fibers in a gel-like matrix, provide the stiff framework of nose, ear-rims, etc). 3) Adipose CT, simply fat (stores fat droplets, acts as a mechanical buffer around kidneys, koints, etc.). 4) Fibrous CT (collagen- and elastic fibers, accounting for tendons, ligaments etc.).

Epithelial T.: (Gk. epi, on; thele, nipple) Covers the body surface and lines the body cavities, ducts, vessels, and forming glands (see glands for exo- / endocrine; see epithel for functions).
Can be squamous (flat), cuboidal (cube-shaped), columnar (column-like), or stratified (in layers).

- **Functions**: 1) Reception of environmental signals i.e. cochlea of inner ear, alfactory epithel of the nose, retina of the eye, etc. 2) Body protection, e.g. ciliated epithel in lungs and intestines; 3) Secretions of sweat, milk, wax, etc. 4) Excretion of waste, absorption of nutrients in the gut. 5) Absorption of nutrients, drugs, etc. in the gut.
- Epithelial tissue accounts for two major glands: Endo- and exocrine glands - see glands.
- **Coelomic** E.: Inner lining of the coelom.

Muscle T.: Enables animals to move by contraction (myosin- and actin filaments slide past each other);

- Giant muscle cell with many nuclei and more myofibrils; contracts when stimulated, consuming ATP; locomotion due to shortening of actin-myosin filaments; types of MT:
  Cardiac M.: Specialized muscle tissue of the heart.
  Smooth M.: Type of muscle tissue in which the actin-myosin protein fibrils are not aligned; made of spindle-shaped uninucleated cells and not striated; operating in glands, blood vessels, and internal organs such as the intestine.
  Striated M.: Type of muscle tissue in which the repeating actin-myosin protein fibrils are aligned to gives the appearance of cross striations, composed of long multinucleated cells; used for movement of skeletal apparatus.

Nervous T.: Contains neurons, cells which transmit electrochemical impulses to command, skeletal muscles or secretory glands, sense environmental changes, and process information.

Summary Human Biology - Somatic Senses, Taste and Smell

Components of Sensation: Typical event s for visual, auditory, gustatory, olfactory and somatic sensations are:

Stimulation: A change in the environment that can activate certain sensory neurons.

Transduction: A sensory receptor cell or organ that responds to the stimulus and transduces (converts) it to a generator potential.

Impulse Generation and Conduction: Upon arriving at the axon terminals, they stimulus triggers exocytosis of synaptic vesicles of neurotransmitter molecules. Once this chemical potential reaches threshold, the succeeding dendrite elicits one or more nerve impulses and propagates them along its axons.

Integration: A region of the CNS that receives and integrates the sensory nerve impulses into a sensation.

Cortex: External or surface layer of an organ; in this particular sense the outer areas of the brain associated to sensory capacities - the brain sees the picture, hears the music, feels the pain, not the receptors.

Pain: A protective mechanism for the body; it occurs whenever any tissues are being damaged, and it causes the individual to react to remove the pain stimulus. The pain receptors in the skin and other tissues are all free-nerve endings. Pain stimuli release chemicals (prostaglandins and kinins) that stimulate these free nerve endings. Pain has been classified into two major types:

- **Fast** P.: Fast pain is felt within about 0.1sec after a pain stimulus is applied; also described as sharp, pricking, acute, and electric pain.
- **Slow** P.: Slow pain begins after 1sec or more and then increases slowly over many seconds and sometimes even minutes; also described as slow burning, aching, throbbing, nauseous, and chronic pain.

P. **Suppression**: The brains capability to suppress pain stimuli by activating a special pain control system

- Analgesia System: Enkephalin-secreting neurons suppress the incoming pain signals at the vertebral cord level using ekephalins and serotinin.
- Opiate System: Morphine-like agents (a dozen opiate molecules) attach to specialized receptors of a neuron halting the ongoing firing activity of a pain receptor.

Types of Pain:

Phantom P.: The pain often experienced by patients who have had a limb amputated; they still experience sensations such as itching, pressure, tingling, or pain in the extremity as of the limb were still there.

Referred P.: A pain felt by a person in a part of his / her body that is considerably remote from the tissue causing the pain.

Visceral P.: Pain from the different viscera of the abdomen and chest; can be caused by *Ischemia* (formation of acidic metabolic end products or tissue-degradation), *Gastritis* (leakage of acidic gastric juices), Spasm of the *Hollow Viscus* (spasm of the gut, gallbladder, bile duct, ureter, or any other hollow viscus), or overdistention of the *Hollow Viscus* (extreme overfilling of the viscus).

Receptor Cell: A neuronal cell that is specialized to respond to some particular sensory stimulation generally with logarithmic characteristics - see also cell, Weber-Fechner law and range fractionation. Tasks of RCs:

- **Selective Recognition of stimuli**: A low threshold-response to physical impact from the environment.
- **Transduction**: General term for the modulation of one kind of energy into another; sense organs transduce sensory stimuli (e.g. mechanical-, photonic-, chemical energy) into nerve impulses (AP).
- **Transformation**: Conversion of the transductive AP into a digital signal (frequency encoded).

RC.-**Response**: Extero-RC response caused by a stimuli arriving from the external environment:

Range Fractionation: The pattern in which receptors within one sensory modality are tuned to receive information within relatively narrow, but not identical, intensity ranges, so the entire dynamic range of the modality is divided among different classes of receptors; i.e. certain receptors emit signals al relatively low stimuli while others start firing only at strong mechanical stimuli.

Spontaneously Active: In the absence of any stimulus, the RC or 2nd sensory fiber fires spontaneously and covers the steep part of the curve relating the stimulus intensity to the frequency of APs, so even a very small stimulus will increase or decrease the rate of firing; consequently doesn't have a threshold e.g.: hair cells.

Phasic R.: A quickly adapting RC, releasing many firing impulses but fading out as stimulus persist; common in pressure, touch, and smell perception.

Phaso-Tonic R.: A compound R with both phasic- and tonic characteristics.

Tonic R.: Fires steadily during a maintained stimulus, although the firing frequency is highest at the beginning of the stimulation; common in the perception of pain, body position, and chemicals in the blood.

RC.-**Types**:

Extero-RC: *Somatic* sensory organs that provide information about the external environment; they detect stimuli arriving at the surface of the body from a distance:

- **Chemo**-RC: A sensory receptor specifically sensitive to certain molecules (e.g. smell, taste, acidity, etc.).
- **Electromagnetic**-RC: A sensory cell that is tuned to receive light energy (e.g. eye).
- **Mechano**-RC: A sensory receptor tuned to respond to mechanical deformation, distortion or pressure (e.g. tactile senses, ear, stretching, etc.) - see tactile senses.
- **Nociceptor** RC: The type of receptors responsible for the sensation of pain (e.g. free nerve endings).
- **Thermo**-RC: A free-nerve ending sensory cell, responsive to temperature changes (e.g. in fingertips, etc.) - see thermal sensations.

Interoceptive-RC: Internal receptors provide information about the internal environment; they responding to changes w/n the body; connected to the vegetative NS.

Proprioceptor C.: Internal receptors located in muscles, tendons, joints, and internal ear; they provide information about body position (see summary hearing and equilibrium), muscle tension, and the position and activity of our joints.

Sensilla: see hair cell.

S. **Transduction**: Elongation of a stereocilium that ctivates mechano-receptive ionic K^+-channels, causing depolarization, forcing Ca^+ -channels to open triggering an AP.

Sensor: A mechanical, electrical, or biological device (receptor) that detects changes in its immediate environment.

S. **Adaptation**: Property of sensory systems to become less sensitive during prolonged or repeated stimulation.

Smell: The nose as a typical special sense chemical receptor housing the olfactory epithelium.

Olfactory Epithelium: Button sized patches in the nasal passages capable of detecting a vast amount of different smells and odors.

Olfactoric Transduction: Principle of signal amplification with a cascade receptor (D-R-G-AC-cAMP-INa); followed by an olfactoric projection in the brain; human = microsomat (10000 different odors).

Somatic Senses: The senses that includes the mechanoreceptive somatic senses (tactile and position sensations), the thermoreceptive senses (heat and cold detection), and the pain sensation.

Somato-Visceral Sensitivity: ?

Tactile-Sense: These include touch, pressure, vibration and tickle senses:

- **Itch and tickle**: Stimulation of free nerve endings by certain chemicals.
- **Pressure**: Results from the deformation of deeper tissues, (Pacinian C.).
- **Touch**: Generally results from stimulation of tactile receptors in the skin of in tissues immediately beneath the skin (hair end organs, Meissner C., Merkel D., Ruffini's end organs).
- **Vibration**: Rapidly repetitive sensory signals, (hair end organs, Meissner C.).

Classes of Receptors: At least six different types of tactile receptors are known:

Pressure:

- **Free nerve Endings** (FnE): Sensors found everywhere in the skin and in many other tissues; e.g. the only pressure sensitive receptor of the eye. According to their adaptation velocity, there are Myelinated FeE (slow adaptation, as in the case of cold temperature sensors) and Unmyelinated FeE (fast adaptation, typically the sensors responsible for tickling and itch).
- **Pacinian Corpuscle**: Quick pressure receptors found in the skin, muscle, joints, and connective tissue (adapt in 1/100 of a second); they consist of a nerve ending surrounded by a laminated capsule of connective tissue.

Touch (fast):

- **Hair-end-Organ**: A nerve sensor in which the dendrites are wrapped around a hair follicle and sensitive to any motion of these hairs (sensors of velocity which detect the change of ds/dt); e.g. wind, touch, etc.
- **Meissner Corpuscle**: An egg-shaped and encapsulated nerve ending that excites a mass of dendrites located in the dermal papillae of the skin. It has many internal branching terminal nerve filaments which are present in the non-hairy part of the skin (glabrous skin), fingertips, lips, palms, soles, eyelids, tip of tongue, nipples, clitoris, and tip of penis. MC adapt in a fraction of a second after stimulation; therefore, particularly sensitive to *movement* of very light objects.

Touch (slow):

- **Merkel's Disc** (MD): A battery of Meissner Corpuscles innerveted by a single large myelinated fiber. MD yields a steady state signal receptor that allow determination of continuos touch first by transmitting an initially strong but partially adapting signal that decreases in intensity with time. Typical sensor of the fingertips (discriminative touch).
- **Ruffini's end Organ**: Multibranched, encapsulated nerve sensors that adapt very slowly, thus signaling continuos states of deformation of the skin and deeper tissues (heavy or continuos touch), as well as in signaling joint rotation.

Taste: A special gustatory sense; that enables humans to differ between, sour, salty, bitter, and sweet.

Papilla: Small conical pumps, taste buds capable of receiving flavor molecules like sweet, salty bitter and sour.

Thermal Sensation: Free nerve ending-receptors located immediately under the skin at discrete but separated points. Different graduations of cold and heat can be perceived, progressing from freezing cold to cold to cool to indifferent to warm to hot to burning hot; these graduations are brought about by different temperature sensors.

- **Cold** Receptor: Operate within a temperature range of 10° to 40°C with a maximal firing frequency of 6 impulses/sec at 15°C. Cold receptors outnumber the warm receptors by a factor of 3 to 10 according to the location throughout the body.
- **Pain** Receptor: Both cold-pain fiber and heat-pain fiber start firing at <15°C or 45°C respectively with an increasing firing rate when these temperatures are decreased / increased.
- **Warm** Receptor: Operate within a temperature range of 30° to 50°C with a maximal firing frequency of 10 impulses/sec at 42°C.

Summary Human Biology - **Special Senses: Hearing and Equilibrium**

Abnormalities of the Ear:

Deafness: Significant or total loss of hearing caused by impairment of the cochlea, chochlear branch of the vestibulo-chochlear nerve (VIII), or by calcification of the tympanum ossicular system.
Hyperacusia: Abnormally sensitive hearing due to paralysis of the stapedius muscle in the middle ear.
Motion Sickness: Nausea and vomiting brought on by repetitive angular, linear, or vertical motion as a result of excessive stimulation of the vestibular apparatus.
Perforated Eardrum: A hole in the tympanic membrane, characterized initially by acute pain, ringing or roaring in the affected ear, hearing impairment, and sometimes dizziness. Can be caused by shockwaves of compressed air (explosions), scuba diving, trauma (ears swabs or skull fracture), or acute middle ear infections.
Tinitus: A ringing, roaring, or clicking sound in the ears.

Auditory Centers of the brain: Several sites of sound processing are known so far:

Contralateral Pathway: Signals from both ears are transmitted from the organ of Corti via the cochlear nerve through the superior olivary nucleus where nervous crossovers take place to join the contralateral side (trapezoid body, commissure of Probst, and the commissure connecting the two inferior collicoli).
Reticular Activating System: It projects diffusely upward in the brainstem, downward into the spinal cord and the cerebellum to activate the entire nervous system in response to loud noise.
Cochlear Nuclei: Certain fibers originating from the cochlea reach all the way to the brain of the auditory cortex and the inferior colliculi. Lesions in the posterior portion of the superior temporal gyrus (area of Wernicke, part of the auditory associative cortex) often make it impossible to interpret the meanings of words.

Ear: Frequency analyzing mechano-receptor, converting acoustical stimuli via a mechanical amplifier into electrical stimuli. This is done by the vibratory movement of the basilar membrane with respect to the tectorial membrane which produces shear on the stereocilia of the cochlea hair cells.
Bony Labyrinth: A series of perilymph filled cavities within the petrous portion of the temporal bone, forming the vestibule, cochlea, and semicircular canals of the inner ear.
Inner E.: Frequency analyzer; and transduction of vibratory liquid caused by a migrating sound wave;

- **Cochlea**: A tapered tube wound into a spiral like the shell of a snail, containing hair cell receptors for detecting sound; high pitch near the oval window; low pitch versus helicotrema. Elicitation is mediated via the vestibulo-chochlear nerve to the brain.
  Endocochlear Potential: Endolymph with exactly opposite ion concentration of the perilymph ($<Na^+$, $>K^+$) are exposed to an electrical potential of +80mV, with the positivity inside the *scala media* and negativity outside. It is continuously generated by the transport of K^+ into the *scala media*. Hair cells with their negative intracellular potential of -70mV generate a total of Δ150mV at the tips of the stereocilia. This voltage further lowers the minimum threshold level for sound detection.
  Scala media: The cochlear duct (*Ductus choclearis*), a membrane labyrinth containing the organ of Corti and the tectorial membrane; it is filled with endolymph, an extracellular fluid having a relatively high concentration of K^+ and low concentration of Na^+.
  Scala tympani: The lower cochlear chamber connected with the *scala vestibuli* through the helicotrema and deliminated by the round window; filled with perilymph, an extracellular fluid of high Na^+ (140mM) and low K^+ concentration (7mM).
  Scala vestibule: The upper cochlear chamber connected with the *scala tympani* through the helicotrema and deliminated by the oval window; filled with perilymph, an extracellular fluid of high Na^+ (140mM) and low K^+ concentration (7mM).
- **Helicotrema**: The apical end of the cochlea that connects the upper, perilymph filled chochlear chamber (*scala tympani*) with the lower one (*scala vestibuli*); it is the area of low frequency detection.
- **Organ of Corti** (spiral organ): The tissue within the cochlea housing the following structures:
  Basilar membrane: The delicate ribbon of tissue bearing the auditory hair cells in the cochlea. These traverse ribbons, which increase in length from the proximal to the apical end. This causes the amplitude of a travelling wave to change along the length of the membrane (mechanical resonance effect of the travelling wave passing a particular frequency-location). Maximal basilar displacement is about 1µm - anything in excess sheds off the stereocilia of the hair cells, causing loss of hearing.

Haircell or Sensilla (HC): A spontaneously firing, mechano-sensory epithelial cell bearing stereocilia (nonmotile filament-filled projections in various lengths, that lack the internal structure of motile "9+2" cilia) and in some cases one long kinocilium (a true "9+2" or "9+0" cilium). Hair cells encode both frequency (i.e. pitch) and sound intensity. Neighboring stereocilia are attached via a thin springlike link which modulates an ion-channel, allowing the free flow of ions; i.e. site of transduction of mechanical stimuli into electrochemical signals. Bending of the hair cells in one direction causes depolarization, and bending them in the opposite direction results in hyperpolarization.
The transduced signals travel via the cochlear branch of the vestibulo-cochlear nerve to the brain.
Each cell has a mechanical resonance frequency that is determined by the length of the stereocilia in the hair bundle (long cilia correspond to low frequency sound whereas short cilia to high frequencies) and an electrical resonance frequency which is determined by the balance of currents through voltage gated Ca^{2+} channels and through Ca^{2+}-sensitive K^{+} channels in the basal membrane.
Inner HC: 3 to 4 rows of external hair cells that accomplish the actual sound converting cells.
Outer HC: A single row of hair cells that contribute to the tuning effect of the inner hair cells by generating acoustic emissions (self-induced vibrations to amplify responsiveness of the inner hair cells).
HC **Transduction**: Elongation of a stereocilium that activates mechano-receptive ionic K^{+}-channels, causing depolarization, forcing Ca^{+} -channels to open triggering an AP.
Nervus acusticus (Vestibulo-chochlear VIII nerve): Under neutral conditions, the nerve fiber leading from the hair cells transmit continous impulses of 100Hz. Bent cilia modulate the frequency traffic (bending towards the kinocilium increases traffic to several hundred Hz, and vice versa). The cochlear branch of this nerve arises in the spiral organ (of Corti), pass through internal auditory meatus, the nuclei in the medulla, and ends in the thalamus. Fibers synapse with neurons that relay impulses to auditory areas in the temporal lobe of the cerebral cortex (95% of nerve fibers innervate outer HC, 5% innervate inner HC).
Afferent fibers conduct sensory signals from the transducing receptor to the processing centers of the brain, whereas the efferent fibers carry signals from the brain to certain receptors to induce signal amplification as required to tune outer hair cells; e.g. efferent control of sound-sensitivity in a loud environment, which enables selective filtering of the someone's voice.
Tectorial membrane: A fine gelatinous sheet laying on the organ of Corti in contact with the cilia of cochlear hair cells. The cilia are bent by shearing forces (i.e. a force perpendicular to the axis of the cilia) that arise when the hairs move through the gelatinous mucus that coats the tectorial membrane. Displacement of the tectorial membrane and balilar membrane occur simultaneously.

Middle E. or **Tympanum**: Impedance matching by the ossicular system; pressure conversion by 22:1. The ossicular system does not increase the movement distance of the stapes, it actually increases the force of movement by about 1.3 times; the surface area of the tympanic membrane is about $55mm^2$, that of the stapes $3.2mm^2$. This 17 fold areal difference times the 1.3 fold ration causes 22 times as much pressure to be exerted on the fluid of the cochlea.

- **Auditory Ossicle**: The bones of the middle ear (malleus, incus, and stape) encapsulated in the *Tympanic antum*, connecting the tympanic membrane and the oval window. These bones are required to avoid acoustical impedance mismatch which would otherwise occur when airborne sound (gaseous phase) should penetrate into the inner ear (liquid phase).
  Incus: The intermediate bone which articulates with the head of the stapes.
  Maleus: The handle, which is attached to the internal surface of the eardrum. Its head articulates with the body of the incus. The tensor tympani muscle attached to the shaft of the maleus, limits movement and increases tension of the eardrum to prevent damage to the inner ear from loud noise.
  Stape: The final mechano-converting bone; its footplate fits into a membrane-covered opening (oval window) in the thin bony partition between the middle and inner ear. The stapedius muscle dampens large vibrations resulting from loud noise; abnormally sensitive hearing results from paralysis of this muscle.
- **Eustachian tube** (auditory tube): The bony tube (covered with hyaline cartilage) that connects the middle ear with the nose and nasopharynx region of the throat; normally closed at its medial end, opens during swallowing and yawning.
- **Oval Window**: The connection between the inner ear and the cochlea; it is covered by the base of the stapes; approximately 0.1 x 0.05mm = $55mm^2$ (see inner ear).
- **Round Window**: A membrane-covered, separating the middle ear and the cochlea, through which pressure waves leave after travelling through the cochlea; approx. 0.5mm in diameter.

Outer E.: The external structure of the sound capturing device; average amplification x4 (frequencies in-between the 1k to 6kHz range, up to a 100 fold); it concentrates the oscillating air pressure onto a specialized surface - the eardrum.

- **Auricle** (Pinna): The outer structure of the human ear, which can be more or less leaborate and which captures and funnels sound into the ear. The rim of the pinna is the **helix**, the inferior part is termed the **lobule**.
- **Ceruminous gland**: A modified sudoriferous (sweat) gland in the external auditory meatus that secretes cerumen (ear wax).
- **Meatus**: The external 2.5cm long curved, audiotory tube, that lies in the temporal bone and leads to the eardrum.
- **Tragus**: The tab that extends from the ventral (anterior) edge of the outer ear and partially covers the opening of the ear.
- **Tympanic Membrane**: The eardrum; a thin, semitransparent partition separating the external auditory system from the middle ear.

Equilibrium: Positioning in space is achieved by a static detector (utricle and saccule) and a dynamic detector (semicircular canals with their ampullae).

Bony Labyrinth: A series of perilymph filled cavities within the petrous portion of the temporal bone, forming the cochlea, semicircular ducts, and vestibule of the inner ear.

Semicircular duct: The membranous semicircular canals filled with endolymph and floating in the perilymph of the bony semicircular canals. They contain cristae that are concerned with dynamic equilibrium (maintenance of head position in response to sudden movements such as rotation, acceleration, and deceleration).

- **Ampulla**: A saclike dilution of one the semicircular canal housing cristae (the hair cells with its apical tuft and cupula). The flow of endolymph through the appropriate duct of the ampulla excites the sensory cells.
- **Semicircular canals**: Three bony channels(anterior, lateral, and posterior), filled with perilymph, in which lie the membranous semicircular canals filled with endolymph. They contain receptors for *dynamic* equilibrium.
- **Statoconia** (Otolith): A particle of calcium carbonate ($CaCO_3$) embedded in the otolithic membrane that functions in maintaining static equilibrium.
- **Statoconic** (Otolithic) **Membrane**: A thick, gelatinous, glycoprotein layer located directly over the hair cells of the macula (thickened region on the wall of the utricle and saccula); the hair cell protruding into the membrane layer are deflected according to gravitational pull by the weight of the statoconia, causing electrochemical stimuli - similar as in the hair cells of the cochlea.
- **Vestibular Apparatus**: Collective term for the organs of equilibrium, which includes the saccule, utricle, semicircular ducts, and the vestibular branch of the *Nervous acousticus* (see cochlea).
  The vestibule is a small space or cavity at the beginning of the inner ear canal, containing the saccule, utricle and the interface to the middle ear (oval window); both saccule and utricle contain the *otolithic membrane*.
  Maculae (Gk. spot): The static sensory organ of the utricle and the saccule (containing hair cells, gelatinous layer, and statoconia) for detecting orientation of the head with respect to gravity; each of the two macculae is oriented in different directions so that at least some of the hair cells are stimulated when the head bends forward, on the side, backwards, etc.
  Oval Window: A small, membrane-covered opening between the middle ear and inner ear into which the footplate of the stapes fit;
  Saccule: The inferior and smaller of the two chambers in the membranous labyrinth inside the vestibule of the inner war containing the receptor organ for static equilibrium (maintenance of the position of the head).
  Utricle: The larger of the two divisions of the membranous labyrinth located inside the vestibule of the inner ear, containing a receptor organ for static equilibrium.
- **Vestibular Nerve**: The vestibular branch arises in the semicircular canals, saccule, and utricle and forms vestibular ganglion that join the cochlear branch to form the vestibular-cochlear (II) nerve; fibers end in pons and cerebellum.

Physical Background of Sound: Sound is an adiabatic pressure wave; the pressure differences between compression and rarefaction of a sound of a wave (constituting the wavelength) can not equalize each other.

Diffraction: The deviation of sound from rectilinear propagation. The bending of sound around an obstacle or through a narrow slit occurs in such a way that low frequencies experience a larger degree of diffraction than higher frequencies; important for frequency discrimination in the cochlea.

Fourier Analysis: A mathematical method that will resolve any periodic wave form into a series of simple sine waves; i.e. superposition of fundamentals and their multiple harmonics.

Loudness: The physiological sensation directly related to sound intensity or volume. Sound is an amplitude modulated wave (information contained within the amplitude of the signal);

relative loudness or sound level: Intensity level I_S, sound intensity [W/m^2]

$I_{SL} = 10 \cdot \log(I_S/I_0)$ [decibel, dB] I_0, threshold intensity [W/m^2]

Source of sound	Sound Level [dB]	Effect on hearing (ratio of I_S/I_0)
Needle falling on glass plate (1m)	0	Threshold of hearing (1:1)
Rustle of leaves	10	(10:1)
Whisper	20	(100:1)
quiet radio in home	40	($10 \cdot E^3$:1)
Conversation in home	65	($3.16 \cdot E^6$:1)
busy street traffic	70	($10 \cdot E^6$:1)
Car engine (≈6000rpm) at a distance of 1m	85	Ear damage begins ($316 \cdot E^6$:1)
Riveter	95	($3.16 \cdot E^9$:1)
Disco music, amplified	115	($316 \cdot E^9$:1)
Air-raid siren, nearby	125	($x \cdot E^{12}$:1)
Jet airplane 30m away	140	($100 \cdot E^{12}$:1)

Sound-Spectrum: A longitudinal wave phenomenon that consists of successive compression and refraction of an elastic medium through which the wave travels (requires a compressible and expandable medium). This medium can be solid, liquid, or gaseous.

- **Infrasonic** S.: A sound of a frequency too low to be heard by the normal human ear - below 20 [Hz].
- **Sound** S.: The audible frequency range between 20 and 20k[Hz].
- **Ultrasonic** S.: A sound of a frequency too high to be heard by the normal human ear - above 20[kHz].

f - **Frequency**: For a body undergoing simple harmonic motion (SHM), the number of vibrations it makes per unit time (vibrations per second)

$f = 1/T$ [1/s] = hertz, [Hz] T, period [s]

Speed of S.: In a medium such as air sound is highly dependent upon temperature: 330 [m/s] at 0°C; 340[m/s] at 20°C, since hotter air has more KE, therefore molecules vibrate more vigorous, therefore conduct sound better; sound channeling occurs in layers of hot and cold air.

λ- **Wavelength**: The distance between successive crests, throughs, or identical parts of a wave [m].

Physiology of equilibrium:

Dynamic equilibrium: Maintenance of the body position, mainly the head, on response to sudden movements such as rotation, acceleration, and deceleration, detected by the semicircular ducts.

Static Equilibrium: Maintenance of posture in response to changes in the orientation of the body, mainly the head, relative to the ground, detected by the two maculae.

Physiology of hearing:

Frequency Determination: Sound is captured as both a standing wave (outer ear) and a migrating wave pattern (inner ear). The brain picks up the location of the stimulated hair cells not the frequency of the migrating wave! (hearing is a process of detecting locations rather than frequencies); every hair cell possesses a distinct mechanical resonance frequency in accordance with its frequency detecting location to increase stimulus response. Due to the cochlea's curved nature, low frequency perturbations move as a travelling wave along the whole length of the basilar membrane, whereas high frequencies displace only the initial parts of the membrane (this geometric form ensures frequency discrimination - low frequencies refract better than higher frequencies (see diffraction - physical background).

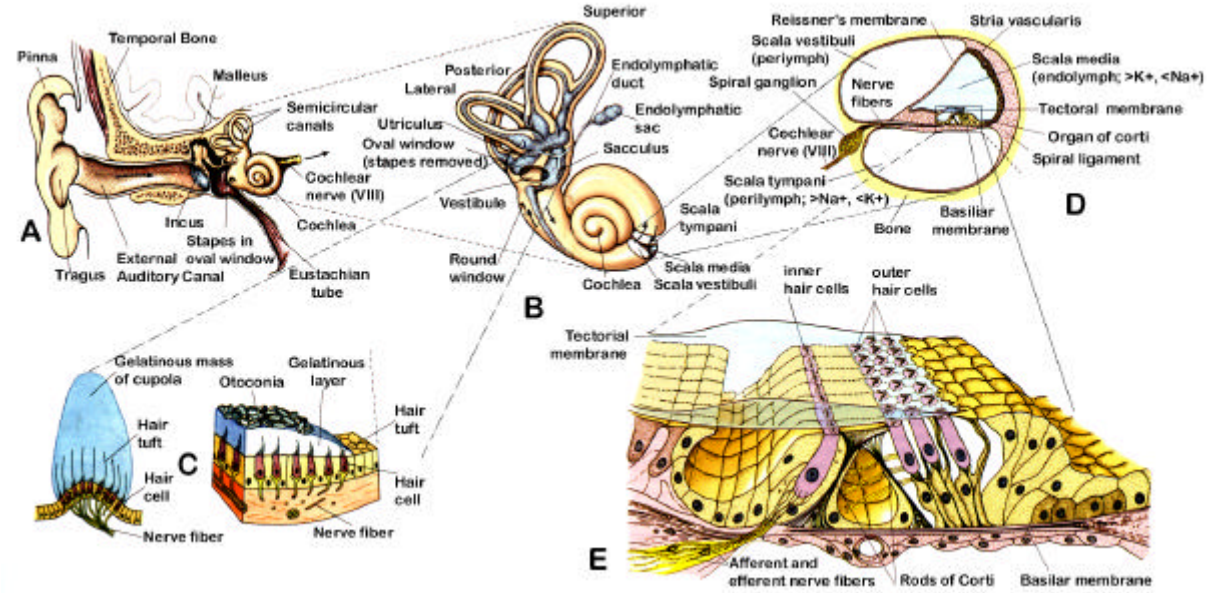
- Frequencies <200Hz: The distal end of the basilar membrane (at the helicotrema) encodes frequencies of 200Hz; frequencies lower than that are discriminated by the volley principle; i.e. volleys jumping along the entire length of the basilar membrane.

Loudness Determination: Can occur in at least three ways:

- Increased basilar membrane deflection: Louder sounds generate an increased vibrational amplitude;
- Spatial summation: Increased loudness enlarges the resonating area at the outer edges of the basilar membrane by increasing the fringes of the resonating portion;
- Outer hair cell stimulation: Higher sound intensities gradually incorporate the outer hair cells into sound detection.

Time Lag mechanism (determination of origin of sound): Horizontal time (binaural) differences between signal perception of the ears and further signal processing in a parallel array of neurons allow the exact allocation of the sound source in space. Discrimination of emanating frequencies above or below ones head (vertical plane) is mainly achieved by the pinnae of the two ears. It changes the quality of the sound entering the ear.

Threshold of Hearing (for the non-aged ear): Detection of frequencies of <20Hz requires sound intensities of up to +65dB; sensitivity gradually increases to 0dB (at 35Hz) all the way down to -70dB for frequencies in the 2kHz band where the trend reverses to reach levels of -20dB for frequencies around the 20kHz range.



The human auditory organs and organs of equilibrium are located in the ear.

A. The major parts of the ear.
B. The semicircular canals and cochlea. The stapes has been removed to reveal the oval window. The pathway taken by the auditory signals is shown. At the far right, a section has been removed from the cochlea to reveal the inner structure.
C. Detailed structure of two parts of the organs of equilibrium. The cilia of receptors in a semicircular canal are embedded in the gelatinous cupula. When fluid moves the canal, the cupula bends the cilia (left). Particles called otoconia rest on the cilia of receptors in the sacculus (one of the maculae). Changes in the position of the head cause the otoconia to shift position, changing how much the cilia are bent.
D. Sound stimuli are trancduced by hair cells in the cochlea; a cross section through the cochlear canal shows the outer chamber (*scala vestibuli* and *s. tympani*) and the organ of Corti attached to the basilar membrane in the central canal.
E. Enlargement of the organ of Corti; the cilia of the hair cells are embedded in the gelatinous layer of the tectorial membrane, whereas their cell bodies are fixed with respect to the basilar membrane.

Summary Human Biology - Special Senses: Vision

Abnormalities of the Eye:

Achromatopsy: ???????????????? mismatched interpretation of red and green due to a defective expression of the genome (X-chromosomes encode red and green; Y chromosome encodes blue)

Astigmatism: An irregularity of the curvature of the lens or cornea of the eye causing the image to be partly out of focus and producing faulty vision.

Cataract: Loss of transparency of the lens of the eye or its capsule or both.

Color Blindness: Absence of a single group of color-receptive cones from the retina leads to color blindness of that particular color and the wavelengths in-between involving that particular hue.

- **Deuteranopy**: Colorblindness of green; although green is missing the visual spectrum is not shortened.
- **Protanopy**: Colorblindness of red with a shorthened visual spectrum at the long wavelength end; effects more males (8%) than females (1.4%).
- **Tritanopy**: Complete colorblindness for any of the three ground-colors (RGB); very rare.

Conjunctivitis: Inflammation of the conjunctiva, the delicate membrane covering the eyeball and lining the eyelids; usually of microbial origin.

Glaucoma: Eye disorder in which there is increases pressure due to an excess of fluid within the eye; i.e. excess liquids from both humors can not flow off via the trabeculae further through the canal of Schlemm into the extracellular veins. As the pressure rises, the axons of the optic nerve (at the site of the optic disc, where it leaves the eye) are compressed, distorting or even blocking the flow of nutrients of the axons, which eventually causes death of the involved neurons of the retina.

Hyper(metr)**opia** (farsightedness): A condition in which visual images are focused behind the retina with resulting defective vision of near objects; can occur if the eyeball is too short or occasionally, to a lens system that is too weak.

Myopia (near-sightedness): An eyeball that is too long or the refractive power of the lens too strong, causing the focal point to center in front of the retina; defect in vision so that objects can be seen distinctly only when very close to the eyes.

Night Blindness: A nutritional deficiency of vitamin A_1 decreases the amount of available photopsin (cones) or rhodopsin (rods). The result is reduced photosensitivity of the eyes. Since bright light requires less (all trans-retinol) vitamin A, it is stored in the cytoplasm of the rods and cones; to increase the photosensitivity at low light, the stored vitamin A is reconverted to photopsin / rhodopsin; night blindness results out of an insufficient supply of vitamin A from the cytoplasm to generate the extra photopsin / rhodopsin molecules.

Presbynopia: The tendency for a human eye to become less able to focus to close objects with age due to denaturation of lens proteins; occurs as the lens becomes less compliant.

Strabismus (squint, cross-eyedness): The lack of fusion of the eyes in one or more of the coordinates (horizontal, vertical, torsional strabismus) due to either malfunctioning extraocular muscles or improper muscular control by the oculomotoric centers of the brain.

Eye: Organ of visual (photo-) reception that includes optical processing of light;

Anatomical Structures of the E.:

Blind Spot: see optic disc.

Cavity: The large fluid filled interior cavity of the eyeball divided into two smaller ones by the lens.
The fluid, originating from the choroid plexus of the posterior chamber, passes forward between the iris and the lens, through the pupil, into the anterior chamber.

- **Anterior** C.: The section anterior (in front) of the lens filled with the aqueous humor; further divided into:
  Anterior Chamber: The chamber behind the cornea and in front of the iris.
  Posterior Chamber: The chamber behind the iris and in front of the suspensory ligaments and lens.
- **Posterior** C.: The larger cavity behind the lens, filled with the vitreous humor.

Fovea (area centralis): The area with the highest visual resolution due to small divergence and convergence in the pathway linking photoreceptors to ganglia cells; area centralis is dominated by cones; with an average diameter of 0.3mm it covers an area of approx. $1mm^2$.

Horizontal Cell: A nerve cell whose fibers extends horizontally in the outer plexiform layer of the vertebrate retina; interconnecting adjacent photoreceptors, lowering resolution.

Humor: The intracellular fluid system which maintains sufficient pressure to keep the eye distended. This *intraocular pressure*, is produced mainly by the aqueous and to a lesser extent by the vitreous humor.

- **Aqueous** H.: The watery fluid that fills the anterior cavity between the cornea and the lens of the eye. It is formed by the ciliary processes of the ciliary body at a rate of 2-3µL/minute. This fluid is mainly composed of Na^+, Cl^-, CO_3^{2-}, water and several nutrients such as amino acids, ascorbic acid and glucose.
  Intraocular Pressure (IOP): The pressure that maintains the shape of the eyeball and keeps the retina smoothly applied to the choroid so the retina will form clear pictures. It averages 15mmHg (2kPa) and is counterbalanced by the resistance of the outflow of aqueous humor through the anterior iridocorneal angle via a meshwork of trabeculae and the canal of Schlemm and its production by the ciliary processes.
  The trabecular meshwork houses phagocyting cells which clean the fluid to prevent infection and blockage of the outflowing canals.
- **Vitreous** H. (vitreous body): A soft, jelly-like substance that fills the posterior cavity of the eyeball, lying between the lens and the retina. It is composed primarily of greatly elongated proteoglycan molecules.

Lens: Transparent organ lying posterior to the pupil and iris of the eyeball and anterior to the vitreous humor.

- **Suspensory Ligament**: Densely arranged connective tissue that attaches the lens to the ciliary body.

Pupil: Opening of center of iris of eyeball for light transmission.

Optic Disc (blind spot): A small area of the retina with no light receptor cells; it represents the openings through which the fibers of the ganglion neurons emerge as the optic nerve.

Optic Nerve (II): Nerve fibers and their associated connective tissue coursing together outside the central nervous system, connecting the retina with the visual centers of the brain - see also visual pathway.

Ora Serrata: The irregular margin of the retina lying internal and slightly posterior to the junction of the choroid and ciliary body; i.e. the fringing edges of the retina.

Scleral Venous Sinus (Canal of Schlemm): A circular venous sinus located at the junction of the sclera and the cornea through which aqueous humor drains from the anterior chamber of the eyeball into the veins.

Tunic: The tree anatomical divisions of the eyeball;

- **Fibrous Tunic**: The outer coat of the eyeball, made up of the posterior sclera and the anterior cornea.
  Cornea: The clear surface of the eye through which light passes as it enters the eye and is equipped with the corneal lens, which focuses light entering the ommatidium (the functional unit of the compound eye, consisting of the lens, a focusing cone, and photoreceptor cells).
  Sclera: The white coat of fibrous tissue that forms the outer protective covering of the eyeball except in the area of the anterior cornea.
- **Nervous Tunic**: The innermost coat; i.e. the retina, which lies in the posterior portion of the eye.
  Retina: The photosensitive inner surface of the eye. The entire structure is supplied with blood by retinal arteries and veins.
  <u>Layers of the Retina</u> (in order of incident light, according to the everse structure of the human eye): Inner limiting membrane, layer of optic nerve fibers, ganglionic layer (ganglion cells), inner plexiform layer (amacrine cells), outer plexiform layer (fiber of Müller), outer nuclear layer cell body of rods and cones), outer limiting membrane, photosensitive layer (rods, and cones), pigment layer (black melanin layer to prevent light reflection -absent in albinos) - see visual pathway and also scan at the end.
  <u>Plexiform Layer</u>: Layer of nerve cells that mediate lateral interactions with the retina (preprocessing of signals originating from the retinal receptors).
  - **Horizontal Cells**: A nerve cell whose fibers extend horizontally in the outer plexiform layer of the human retina and interconnects adjacent photoreceptors; these cells accomplish the task of lateral inhibition.
  - **Bipolar Cells**: A neuron with two axons emerging from opposite sides of the soma; they transmit signals from the photoreceptor cells to the retinal ganglion cells.
  - **Signal Convergence**: A pattern in which inputs from many different neurons impinge upon a single neuron. The retinal periphery groups 15-45 rods to 1 bipolar cell (increased sensitivity), whereas the fovea groups 1-20 cones to 1 bipolar cell (high resolution).
  - **Amacrine Cells**: Neurons without axons, found in the inner plexiform layer and interconnect adjacent bipolar cells, and mediate stimuli down to the ganglion cells by a slope triggered firing pattern; i.e. fire only at changes of signal states when objects move cross the retina, change of illumination, etc.
  - **Ganglion Cells**: The afferent neurons of the optic nerve, that carry visual information from the inner plexiform layer to the higher centers of the brain. About every cone in the fovea is connected to a ganglion cell, whereas several rods are routed down to one ganglion cell in the peripheral area - this accounts for the greater sensitivity of the peripheral retina to weak light and moving objects.

Cone: The *bright-light* visual receptor cell that has a tapered outer segment in which the lamellar photosynthetic membranes (of free floating disks) remain continuos with the surface membrane; cones responds to one out of three particular colors (red sensitive pigments = 445nm, green sensitive pigments = 535nm, and blue sensitive pigments = 570nm); hue is calculated by differences of the RGB-values (short 440nm-blue; medium 540nm-green; long 567nm-red) overall max. sensitivity in the yellowish-greenish spectrum, corresponds to approx. 555nm.
Rod: The *dim-light* visual receptor cells many times more sensitive to light than cones (membrane lamellae in the form of pigmented, free floating disks held in place by an outer segment - 4 times the length of cones). Based on cellular physiology and on high degree of convergence onto second order cells; not sensitive to a particular frequency, rather to the full visible spectrum (illuminance detector - max. sensitivity at 505nm, which corresponds to the bluish-greenish spectrum).

- **Vascular Tunic**: The middle layer of the eyeball, composed of three portions:
  Choroid: The distal coat of the tunic, to which the outermost pigmented layer of the retina is attached. It is a highly vascular tissue, which provides nutrients to the cones and rods (via diffusion).
  Ciliary Body: The lateral portions of the vascular tunic that includes the ciliary muscle and the ciliary processes; it is also the production site of the aqueous humor.
  Iris: The pigmented circular diaphragm located behind the cornea of the vertebrate eye.

External Accessory Structures of the E.:

Commissure: The angular junction of the eyelids at either corner of the eye.

- **Lateral** C.: Further from the midline of the body, in this case outer junction of the eyelid.
- **Medial** C.: Nearer to the midline of the body, in this case inner junction of the eyelid.

Conjunctiva: The delicate membrane covering the eyeball and lining the eyes.
Eyebrow: The hairy ridge above the eye, keeping sweat from dripping into the eye.
Eyelash: Hairy fence-like structure at outer rim of the palpebra; keeps dust particles away.
Lacrimal Canal: A duct, one on each eyelid, commencing at the punctum at the medial margin of an eyelid and conveying the tears medially into the nasolacrimal sac.
Lacrimal Caruncle: Fleshy, yellowish projection of medial commissure containing modified sweat and sebaceous glands.
Lacrimal Gland: Secretory cells located at the superior lateral portion of each orbit that secrete tears into the excretory lacrimal ducts that open onto the surface of the conjunctiva.
Lacrimal Sac: The superior expanded portion of the nasolacrimal duct that receives tears fr/ a lacrimal canal.
Muscles of the eyes: Six extrinsic muscles enable eye movements.

- **Superior Rectus**: Superior and central part of eyeball; rolls eyeball upward.
- **Inferior Rectus**: Inferior and central part of eyeball; rolls eyeball downward.
- **Lateral Rectus**: Lateral side of eyeball; rolls it laterally.
- **Medial Rectus**: Medial side of eyeball; rolls it medially.
- **Superior Oblique**: Insertion between superior and lateral recti of eyeball; rotates it on its axis, directing cornea downward and laterally. Muscle deviated by *trochlea* (fibro-cartilaginous pulley).
- **Inferior Oblique**: Insertion b/w inferior and lateral recti of eyeball; rotates on its axis; directs cornea upward and downward.

Palpebra (eyelid): Folds of skin and muscle lined by the conjunctiva. Aids in lubrication of cornea.

Physical Properties affecting vision:

Brightness: Emission or reflection of light; synonymous for intensity of light.
Depth of focus: The distance through which objects are in focus when a lens is in one fixed shape; it increases when light is prevented from passing through the perimeter of the lens (site of increased optical aberrations). Best possible depth of focus is obtained with extremely small pupils, i.e. at bright light.
Diopters (power of a lens): The focal length (f) in meters of a convex lens given as 1/f [D], the shorter the focal length the greater the power. A healthy human lens can cover a range of approx. +14 D. The refractive power of the entire visual apparatus is about +59D. Concave lenses which have diverging properties but have the same focal length as convex lenses, are assigned as "-"D.
Hue: The property of color that is perceived and measured (wavelength in [nm]) on a scale ranging from red through yellow, green and blue to violet; and in particular a graduation of color, tint, shade.

Lens Equation: The lens of the eye is an optical instrument which focus or disperse incoming light waves and has converging properties; i.e. a convex lens, which is thicker in the middle than at the edges, causing parallel rays passing through it to converge to the focal point:

L. **Equation**: $1/d + 1/d' = 1/f$	d, distance of object	[m]
L. **Magnification**: $M_L = -d'/d$	d', distance of image	[m]
	f, distance of focus	[m]

L. **Rays**: Three principle rays characterize a lens' behavior:

- The 1st incoming ray parallel to the lens' axis will be deflected to pass the focal point past the lens.
- The 2nd, center-seeking ray will straight pass through the center without a deflection.
- The 3rd incoming ray striking the focal point will be deflected to a parallel beam past the lens.

L. **Distortions**:

- **Astigmatism**: A defect caused when the radius of curvature is not uniformly the same throughout the lens; i.e.: the inability to focus simultaneously light-trays arriving in different planes.
- **Chromatic Aberration**: Chromatic distortion of an image produces by a lens or lens-system (red refracts more than blue light).
- **Spherical Aberration**: Parallel incoming rays at the edge of a lens do not meet at the focal point as do rays which are closer to the axis of lens.

Parallax: An apparent change in the direction of an object, caused by a change in the viewer's position.

Quantum: Radiation of light is emitted in discrete bundles of energy; just as matter is quantified as a whole number of atoms, or electric charge is a whole number multiple of a single charge. Cones are able to detect a single photon of light; the energy contained in a quantum of radiation is equal to Planck's constant divided by the wavelength; since there are only few cones in the fovea, but many in the outer areas of the retina, peripheral minimal perception threshold exceeds that of the fovea, With a simultaneous decrease in pint resolution (fewer cells/mm^2):

	h, planks c. = $6.6 \cdot E^{-34}$	[J·s]
	c, speed of light = $3 \cdot E^8$	[m]
$E = h \cdot c / \lambda$	λ, wavelength	[m]

Refraction: The bending of an oblique ray of light when it passes from one transparent medium of one density to another with a different density, caused by a difference in the speed of light in those media. At the air-water interface, light entering the eye bends towards the perpendicular air-water line and vice versa.

R. **Index**: The refractive power of a medium compared with that of air, designated as $n_{diamond} = 2.4$; $n_{water} = 1.3$:

	n, index of refraction	[-]
$n = c_{vacuum}/v_{of\ light\ in\ medium}$	c, v, speed of light	[m/s]
$n_1 \cdot \sin\theta_1 = n_2 \cdot \sin\theta_2$	θ_x, angle ($\perp$ to surface)	[degree]

Resolution: Decides whether two remote sources can be clearly distinguished by the eye (also known as **Rayleigh**'s criterion):

	λ, wavelength	[m]
	2·r, diameter of object	[m]
$360° = 2 \cdot \pi$ [rad] $1' = 2.909 \cdot 10^{-4}$ [rad] $1'' = 4.848 \cdot 10^{-6}$ [rad]	θ, angle of resolution	[rad]
• **Point** R.: $\theta_R = 1.22 \cdot \lambda / 2 \cdot r$ [rad]	λ, wavelength	[m]

- **Spatial** R.: Integration by a post-synaptic neuron of simultaneous synaptic currents that arise from the terminals of different pre-synaptic neurons;

Saturation: Gradual blending of base colors; i.e. RGB (pink = reddish white ; brown = grayish yellow); with this graduation, the eye can differentiate between $100E^3$ to $1E^6$ different colors.

Physiology of the eye:

Adaptation (sensory): Decrease in sensitivity during sustained presentation of stimuli.

- **Dark** A.: At dark conditions, large amount of rhodopsin are required to produce a photochemical response in the form of a membrane potential. The retinal and opsin molecules in rods and cones are converted to light sensitive pigments. Vitamin A is reconverted to retinal to provide extra light sensitive pigments. Dark adaptation after bright light exposure can take up to 45mins, in which the cones are activated in the first 10mins, followed by the activation of rods; in total, dark adaptation boosts sensitivity by a $25E^3$ fold.
- **Light** A.: At bright light, only very little photopsin / rhodopsin is required to trigger photochemical response. Large portions of photochemicals in both rods and cones are reduced to retinal and subsequently to vitamin A which is stored in the cytoplasm of the cones and rods.
- **Neuronal** A.: The visual centers of the brain further modify vision - see visual pathway.
- **Pupilary Reflex**: A neuronal reflex, that originates in the retina and controls the aperture of the iris. When circular smooth muscle fibers of the iris contract, they decrease the proportion of incident light that is allowed to enter the eye; contraction of the radially oriented muscle fibers reverse this process.

Accommodation: Increase in curvature of the lens in order to bend the light-rays toward the central fovea (adjustment of focal length). The fibers of the zonula (ciliary processes) exert outwardly directed tension around the perimeter of the lens; radially arranged ciliary muscle (suspensory ligaments) adjust the amount of tension exerted on the lens. When the ciliary muscles relax, the lens flattens by elastic tension exerted by the muscle of the ciliary processes, which pull the perimeter of the lens outward - objects far from the eye appear sharp. Objects close to the eye are brought into focus when the ciliary muscles contract. Accommodation is directly controlled by the parasympathetic nerves.
Binocular Convergence: A neuronal mechanism which positions the eyes so that the images formed fall on analogous portions of the 2 retinas, avoiding double vision. When an object is close, each of the 2 eyes must rotate toward the middle of the nose; when on object is far away, the 2 eyes rotate outward from the midline.
Color Vision: Spectral sensitivities based on the on the degree of stimulation of each class of RGB cones; equal stimulation of all the red, green, and blue cones gives on the sensation of seeing white. Color vision predominantly takes place in the fovea.
Determination of Distance: Depth reception can occur in 3 different ways:

- **Moving Parallax**: Moving objects close to the eye pass rapidly across the retina while the images of distant objects remain almost completely stationary.
- **Retinal Size**: An object of known size, according to its distance, projects a proportionally small image onto the retina.
- **Stereopsis**: Objects focused at close range result in a less parallel arranged optical axis than objects viewed at infinity and produce images that are projected on different sites of the retina.

Eye Movements: Movements of the eyes is controlled by a cerebral system which includes:

- Muscular Control: Three pairs of muscle (controlled by nerve III, IV, and VI of the medial longitudinal fasciculus) allow horizontal and vertical orientation of the eyeball.
- Neuronal Pathways: Both voluntary and involuntary fixation areas in the brain control the oculomotoric centers of the brain stem.

Flicker Fusion-Frequency: The frequency at which images are projected onto the retina to observe harmonic motion of single images; around 16-18 frames per second.
Lateral Inhibition: Excitation and inhibition of a retinal area is brought about by the horizontal cells to increase the contrasting capabilities of visual processing - see visual pathway.
Light Intensity: Discrimination of light intensity requires a proportional electrical signal output from cones and rods. This electrotonic conduction (rather than an "all-or-non" response as in the case with action potentials) is essential for the interpretation of light intensities by the visual centers of the brain.
Photoreception: Electromagnetic receptors that detects light on the retina of the eye (in order of signal processing); cones function best in bright light and provide high resolution (color receptors dominate the *Area centralis* = fovea), whereas rods function best in dim light.

- **Photopsin**: A colored (red, green or blue), light-sensitive photopigment molecule in cones - see rhodopsin for signal transduction and resynthesization of the bleached molecule.
- **Rhodopsin**: A purplish red, light-sensitive photopigment molecule of rods; a chromoprotein (combination of scotopsin and retinal proteins) with 11-*cis* retinal as its prostethic group; found in the rods and cones of the retina. The *cis*-form is the activated light sensitive photopigment.
  Dark Current: A steady sodium current that leaks into the upper segment of the visual receptor cell (in both rods and cones), while a sodium pumps at the base of each receptor cell complete this circle by actively exporting these ions. The dark current is reduced by photo-excitation which hyperpolarizes the membrane potential from -30mV to -55mV.
  Retinal: The carotenoid pigment portion of the photopigment rhodopsin. In the dark, the bonds of C-11 are arranged in the *cis* configuration.
  Rhodopsin Isomerization: Rhodopsin changes its steric conformation into the straight, all-*trans* configuration when it absorbs a photon - with still the same chemical but different physical structure. The *trans* form decomposes quickly (bleaching happens in msecs) to batho-rhodopsin, then to lumino-rhodopsin, and finally to meta-rhodopsin I+II. The later, via an enzymatic amplificating cascade, changes the electrical resistance of the membrane, causing hyperpolarization.
  Rhodopsin Regeneration: Rhodopsin is reconstituted out of retinal and opsin via an isomerase-activity out of retinal and scotopsin, by returning the retinal to the 11-*cis* configuration; this can take several minutes and is one reason for prolonged visionary images.

- **Enzymatic Cascade**: When light hits the photopigment, the enzymatic cascade is triggered and amplifies the signal by a $10E^3$ fold. The resulting hyperpolarized membrane potential is caused by increased negativity due to decreased membrane conductance of Na^+-ions (see dark current). This electrical depolarization (electrotonic conduction - see light intensity) is proportional to the logarithm of the light intensity. It is then pre-processed in *horizontal* and *amacrine* cells before it is conveyed down the optic nerve to the visual centers of the brain.
  Transduction of light: A photon hitting a rod excites rhodopsin; the so activated retinal increases the activity of a G-protein on the discs - signal amplifying cascade - by a 250 fold, which then activates many PDE- (phosphodiesterase) molecules reducing the intracellular concentration of cCMP (amplification of a further 400 fold). A low concentration of cGMP causes the Na^+ channels to close (dark current); the membrane-resting potential (MRP) becomes hyperpolarized (from -30mV to -55mV) which triggers an action potential, that promotes the release of glutamate as the main neurotransmitter of cones and rods.

Range Fractionation: The pattern in which receptors within one sensory modality are tuned to receive information within relatively narrow, but not identical, intensity ranges, so the entire dynamic range of the modality is divided among different classes of receptors. For example, the rods respond to dim light but are saturated in bright light; cones are less sensitive to dim light but remain responsive in bright light.
Receptive Field: Tat area of the retina, that when stimulated influences the activity of a given neuron is the receptive field of that neuron; the area of the retina by which stimulation by light causes a ganglia cell to activate or block; concentric on-off centers; fovea: 2.5µm; peripheral retina: 2mm.

Visual Pathway and **Information Processing**: The nerve impulses leaving the retina from the nasal halves via the optic nerves, cross to the opposite side where they join the fibers from the opposite temporal retinas to form the optic tracts (see scan below). The fibers of each optic tract synapse in the dorsal lateral geniculate. From there, the fibers pass by way of the optic radiation to the primary visual cortex of the occipital lobe.

Structures in order of signal processing:

Hemiretina: The retinal halves of the eye that are superimposed in the visual processing centers of the brain.

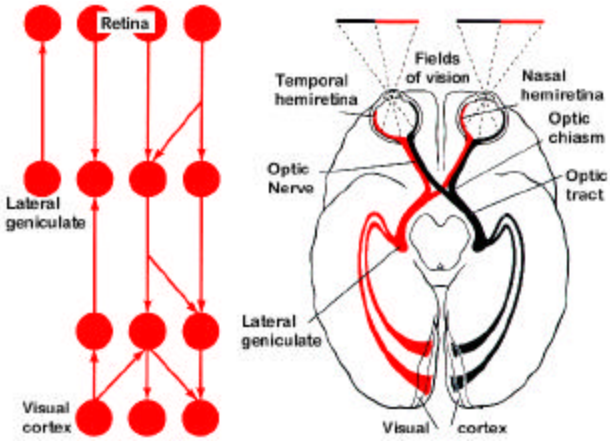
- **Nasal** H.: The field of vision of the left hand side connected to the right brain hemisphere.
- **Temporal** H.: The field of vision of the right hand side connected to the left brain hemisphere.

Optic Nerve (II): Chordlike bundle of nerve fibers and their associated connective tissue coursing together outside the central nervous system, connecting the retina with the visual centers of the brain.
Optic Chiasma: A swelling under the hypothalamus of the human brain where the two optic nerves meet; some axons cross the midline here and project to the contra-lateral side of the brain.
Optic Tract: A bundle of axons that transmits nerve impulses from the retina of the eye between the optic chiasm and the thalamus.
Lateral Geniculate: A region of the brain (thalamus) that processes visual information:

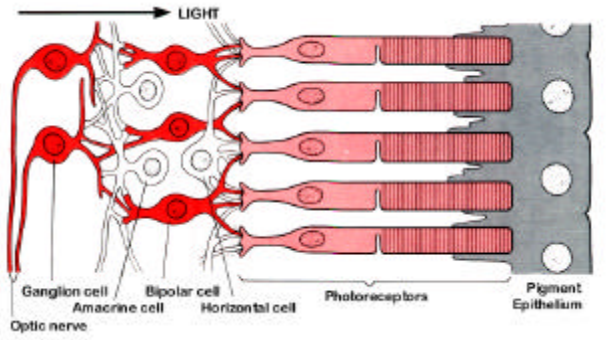
- it relays visual information from the optical tract to the visual cortex by way of the optic radiation; crossover in the optic chiasm allow the respective hemiretinal areas of the two eyes to connect with neurons that are approximately superimposed over one another;
- it gates the transmission of signals to the visual cortex; i.e. it is assumed that both gating circuits help to control the visual information that is allowed to pass.

Optic Radiation: Axons of neuronal fibers synapting with the lateral geniculate, and project into the primary visual areas in the occipital lobes of the cerebral cortex.
Visual Cortex (VC): The cerebral cortex in the occipital region of the cerebrum; devoted to processing visual info.

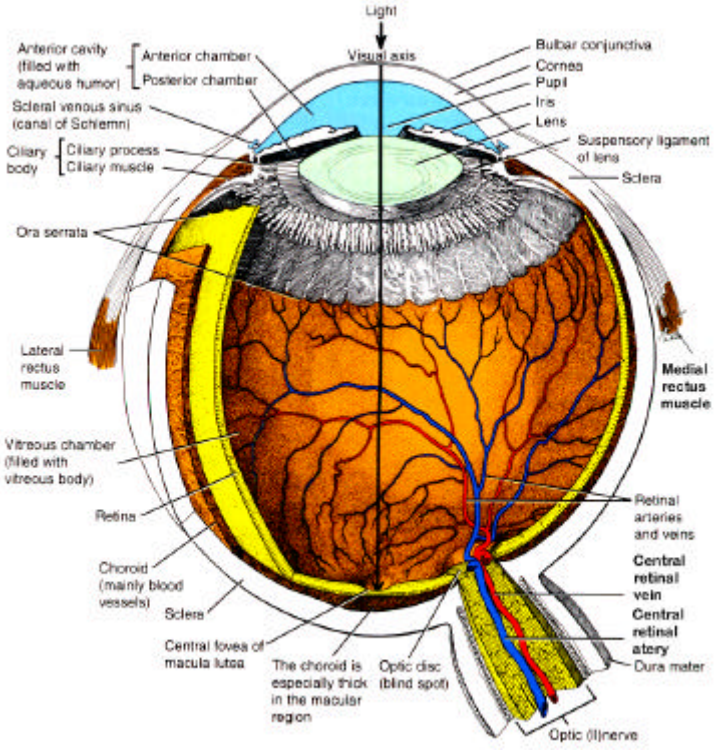
- Primary VC: The terminus of direct visual signals from the fovea positioned at the outermost occipital pole of the medial aspect of each occipetal cortex. Based on the retinal area, the fovea has several hundred times as much representation in the primary VC as do the peripheral portions of the retina.
- Secondary VC: These are the centers of the visual association areas and surround the primary VC. Secondary signals are transmitted to these areas for analysis of visual meanings; i.e. color interpretation, motion, position in space, 3-D rendering, which stay in close connection with both the somatic and motoric cortex of the brain.
  Signal Summation: Spatial and temporal summation of incoming retinal signals in the visual centers of the brain to give a visual estimate of distance and velocity.



Visual information is transmitted from the retina to the brain through layers of cells. The left and right sides of the *optic tectum* each receive projections from the entire field of view of the contralateral eye. (Left) Each side of the visual field is projected to the opposite side of the visual cortex (the temporal half of the left retina and nasal half of the right retina project to the left visual cortex). (Right) The neurons that initially process visual information are organized in layers. The retina contains the first three layers, and the remainder are in the brain, in the lateral geniculate nuclei and in the cortex. Information converges and diverges between the layers, and it flows in both directions between the layers



The function of the retina is based on 5 major types of neurons. Photoreceptors receive light stimuli and transduce them into neuronal signals. Bipolar cells carry signals from photoreceptors to the ganglion cells, which send their axons into the central nervous system through the optic nerves. Horizontal and amacrine cells, which are located in the outer and inner plexiform layers, respectively, carry signals laterally (inhibitiory).



Superior view of the transverse section of the left eyeball

Summary Human Biology 2 - Nervous Tissue

Motor Neuron (also efferent neuron): A neuron that conducts nerve impulses from the brain and spinal cord to effectors that may be either muscles (or glands). Innervation of the face exceeds with its complex variations (5 α-MN/muscle fiber) is far more elaborated than other parts of the skeletal structure (1 α-MN/muscle fiber).

- **a-MN**: Innervating, efferent (carries information from higher brain centers toward structures in the periphery) neuron stimulating the extrafusal muscle fiber. In the flexion reflex, a α-MN located in the ventral spinal cord, is triggered by noxious stimuli applied to the skin, causes excitation (contraction) of a motor neuron that controls a flexor muscle.
- **g-MN**: Innervating, efferent (carries information from higher brain centers toward structures in the periphery) neuron stimulating the intrafusal muscle fiber.

Sensory Neuron: The central area of an intrafusal fiber cannot contract because it lacks actin and myosin, but it contains two detecting sensory fibers (Ia, II). Tendons, with their connective tissue capsule are penetrated by one or more sensory fibers of type Ib. All these 3 types have in common the innervating, afferent (carries information from the periphery to the higher brain centers) principle.

- **Type Ia** SN (Golgi Tendon Organ): Stretch receptor with rapidly conducting sensory fibers with large diameter; the dendrites of such a fiber wrap in a spiral manner around the central area of each intrafusal fiber.
- **Type Ib** SN: Stretch receptors which entwine among and around the collagen fibers of tendon capsule; serve as protective receptors to avoid over-stretching and excessive tension.
- **Type II** SN: Second class of stretch receptors which are locked on either side of some intrafusal fibers.

Motor Unit: The unit of motor activity consisting of a motor neuron and the muscle fiber it innervates. Under normal conditions 80% of the fibers are stimulated in a well trained person; the remaining 20% are kept in reserve and become only available via epinephrine stimulation (fight or flight response); damage can be done to muscles in extreme sports by activating that reserve potential via anabolica.

Neuromuscular Junction (NMJ): The synapse that connects a motor neuron with a skeletal muscle fiber. When a nerve impulse (AP) reaches the synaptic end bulbs, it trigger exocytosis of synaptic vesicles. These vesicles fuse w/ the plasma membrane and liberate ACh, which diffuses into the cleft. As ACh binds to a receptor, it triggers the inflow of Na^+ ions. The inrush of Na^+ changes the resting membrane potential of the postsynaptic membrane and triggers a muscle action potential that travels that travels from the center to the edges of the muscle cells and initiates the events leading to muscle contraction.

- **Acetyl-Choline** (ACh): An acetic acid ester of choline; important synaptic excitatory transmitter.
- **ACh-Esterase** (AChE): An enzyme that hydrolizes ACh to acetyl and choline; it resides on the postsynaptic membrane surface to halt electro-chemical triggering once signal transmission is complete.
- **End Plate**: The neuromuscular synapse, where the motor axon forms many fine terminal branches that end over a specialized system of folds in the postsynaptic membrane of the muscle cell.
- **Neurotransmitter**: A chemical mediator (ACh) released by a presynaptic nerve ending that interacts with receptor molecules in the postsynaptic membrane. This process generally induces a permeability increase to an ion or ions and thereby influences the electrical activity of the postsynaptic cell.
- **Receptor**: Membrane bound molecules that interact specifically with messenger molecules.
- **Synaptic Cleft**: The space separating the cells at a synapse.
- **Synaptic Vesicles**: Membrane-bound vesicles located w/n axon terminals containing neurotransmitter molecules.

Nerve Fibers: General term for any process (axon or dentrite) projecting from the cell body of a neuron.

Afferent NF: Afferent fibers conduct sensory signals from the transducing receptor to the processing centers of the brain.

Efferent NF: Centrifugal; a neuron that carries information from higher brain centers toward structures in the periphery.

Nervous System: The collection of all neurons in an animals body. It manages:

- Control of mental and physical response reactions.
- Information uptake, -processing, and -memorization.
- Regulation of vital body functions.
- Signal processing: stimulus - reception - integration and neuronal response - motoric response

Autonomic or Vegetative NS: The efferent nerves that controls involuntary visceral functions; beyond conscious control of the brain; it regulates the vital functions like heart beat, respiration etc.:

- **Parasympatethic** NS: The craniosacral part of the autonomic NS; in general, increased activity of these neurons support vegetative functions such as digestion, relaxation, recovery, etc.
- **Sympatethic** NS: Thorocolumnar part of the autonomic NS; increased activity in the sympathetic neurons typically provides metabolic support for vigorous physical activity, fight or flight, stress-response, increased rate of heartbeat etc.

Central NS (CNS): A group of neurons and parts of neurons that are contained within the brain and spinal cord in vertebrates; or within the brain, ventral nerve cord, and major ganglia of invertebrates.
Intrinsic NS: Network of neurons in gastro-intestinal tract and -ducts responsible for digestive tasks.
Peripheral NS (PNS): The set of neurons and parts of neurons that lie outside of the CNS.

Nervous Tissue of Muscles: Each individual muscle cell is equipped with a single motor neuron; entire complex (skeletal muscle fiber + neuronal plate) also called a **motor unit**.
Hilus: An area, depression, or pit where blood vessels of nerves enter or leave and organ.

Potential: The potential above zero to the peak of the action potential.

Action P. (AP): Transient all-or-none reversal of a membrane potential produced by a regenerative inward current in excitable membranes originating from the hillock area; i.e.: nerve impulse, or spike; a typical AP starts with a depolarization, followed by an overshoot, and a final phase of repolarisation (depends greatly upon Na^+/K^+ availability and the proper function of Na^+- and K^+-channels) and does not require ATP, instead used the PE generated by the membrane pumps. AP's are considered to be sent like a frequency modulated-signal i.e.: the more intense the stimulus, the denser the spikes are packed (FM-modulated)-AP's can't be added up.

- **All-Or-None Response** of AP: Pertaining to the independence of response magnitude from the strength of the stimulus; response is "all" if the stimulus achieves threshold and "none" if the stimulus fails to achieve threshold; (depolarization, overshooting, repolarization - see polarization and Hodgkin cycle).

Propagation of AP: Ca^{2+}-ions influx into a nerve cell will trigger an AP once threshold has been reached. At the site of AP, the membrane resting potential (-60mV) becomes more positive (+40mV) due to the opening of Na^+-channels. Depolarization spreads passively in both directions along the axon but the Na^+ channels proximal to the nerve cell are still inactivated (refractory period) and cannot be reopened again. Instead Na^+ channels distal to the AP site of the nerve cell have not yet experienced voltage change, hence *depolarization* will take place once the threshold-level is exceeded opening those Na^+-channels. The influx of Na^+-ions causes the axon-potential to *overshoot* until the repolarisation-level is reached (+40mv). In this moment Na^+-channels close while K^+-channels open to allow K^+-ions to rush into the axon gradually *repolarizing* the potential until hyper-polarization is reached (-70mV). There K^+-channels close again to permit the potential to rise slightly to the resting potential (-60mV). Continuously operating Na^+/K^+-pumps transport Na^+-ions into the extracellular fluid, and K^+-ions into the axonal cytosol.

- **Active** P.: The membrane sustained propagation from one end to the other of the nerve of an AP which reached the threshold of response due to the stored potential energy built up by the membrane pumps.
- **Saltatory** P.: A series of discontinued AP's along myelin sheaths (passive conductance) and at each node of Ranvier (active conduction), enhancing transmission rapidly over internodial distances despite thin axons, and saving energy as well (see nodes of Ranvier, cell - Schwann).
- **Passive** P.: An AP not reaching the threshold will propagate as far as determined by the length constant of a particular nerve (determined by isolation and cross-section - see there).
- **Transmission of AP**: Transmission of AP from on to the other nerve is accomplished by either chemical or electrical synapses (see synapse-types of).

Membrane P. (MP): The electric potential measured from within the cell relative to the potential of the extracellular fluid, which is by convention at 0 potential i.e.: potential difference between opposite sides of the membrane; its a dynamic equilibrium of in- and outflowing ions;(see also MRP).
Receptor P.: A change in MP elicited in sensory receptor cells by sensory simulation, which changes the flow of ionic current across the cell membrane.
Resting P.: (MRP) The normal unstimulated membrane potential of a cell at rest; can be up to -100mV (average membrane potential at rest: -60mV for K^+-ions) resulting from an unbalanced Na^+/K^+ ratio, where fore e2 K^+- taken up 3 Na^+-ions are transported out i.e.: dynamic balance of in/out-ward flowing ions (see Na/K pump).

Reversal P.: The MP at which no current flows through the membrane ion channels, even though the channels are open; it is equal to the EP for ions that are conducted through open channels - compare EPSP and IPSP.

Reflex: An action that is generated without the participation of the highest neuronal centers and is thus non voluntary; an involuntary motor response mediated by a neuronal arc in response to sensory input. It permits the body to make exceedingly rapid adjustments to homeostatic imbalances. Reflexes occur in the gray matter; these are fast, predictable, automatic responses to changes in the environment (faster than processing information via the cranial pathways of the brain); there are somatic reflexes (contraction of skeletal muscles) and autonomic reflexes (unconsciouls perceived reflexes of the viscera).

Relfex Arc (RA): A neuronal pathway that connects sensory input and motor output; consists of afferent input to an integrated nerve center (CNS) that produces activity in efferent nerves to an effector organ:

- **Receptor**: The distal end of a sensory neuron (dendrite); it responds to a specific stimulus by producing a graded generator potential that leads to a nerve impulse once threshold level is reached.
- **Sensory neuron**: The nerve impulse propagates into the sensory neuron in the gray matter of the spinal cord (afferent pathway).
- **Integrating center**: The region of the CNS within the gray matter that consists of one or more associated neurons, which may rely the impulse to other association neurons.
  Monosynaptic RA: A reflex pathway in which the sensory neuron and the motor neuron pass via a single synapse.
  Polysynaptic RA: A reflex pathway in which the sensory neuron synapses its information to other associated neurons as well as to the motor neuron; e.g. neurons that mediate info to the centers of the brain.
- **Motor neuron**: Impulses triggered by the integrating center propagate out of the CNS along a motor neuron to the part of the body that will respond (efferent pathway).
- **Effector**: The responding part of the body such as a muscle or gland; its action is a reflex (somatic if the effector is a smooth-, cardiac muscle, or gland; or autonomic if it is a visceral reflex).

Relfex Types:

- **Crossed Extensor** R.: A reflex in which extension of the joints in one limb occurs in conjunction with contraction of the flexor muscles of the opposite limb.
- **Flexor** R. (withdrawal R.): A polysynaptic, protective reflex in which the flexor muscles are stimulated while extensor muscles are inhibited.
- **Stretch** R. (tendon jerk or myotatic R.): A monosynaptic reflex triggered by sudden stretching of muscle spindle within a muscle that elicits contraction of the same muscle.
- **Tendon** R.: A polysynaptic, ipsilateral reflex that is designed to protect tendons and their associated muscles from damage that might be brought about by excessive tension. The receptors involved are called tendon organs (Golgi tendon organs).

Summary Human Biology 2 - Muscle Tissue

Abnormalities:

Gangrene: Death of a soft tissue, such as muscle, that results from interrupted blood supply.
Muscular Dystrophy: An inherited muscle destroying disease; it affects only the skeletal (voluntary controlled) muscles and is caused by the absence of a sarcolemal protein, named dyshopin.
Muscle Fatigue: Overstimulated groups of skeletal muscle, that have become progressively weaker while they no longer respond; occurs when muscles can't produce enough ATP to meet their needs, due to insufficient oxygen supply, depletion of glycogen, buildup of lactic acid, failure of action potentials in the motor neuron to release ACh, and unexpected fatigue mechanisms in the central nervous system.
Myoma: A tumor consisting of muscle tissue.
Myostenia gravis: ????????????
Necrosis: A pathological type of cell death that results from disease, injury, or lack of blood supply in which many adjacent cells swell, burst, and spill their contents into the interstitial fluid, triggering and inflammatory response.
Paralysis: Loss or impairment of motor (muscular) function resulting from a lesion of nervous or muscular origin.
Tenosynovitis: Inflammation of the tendons, sheaths, and synovial membranes surrounding certain joints; affected sheaths often become swolen. Condition frequently follows trauma, strain, or excessive exercise.

Developmental Stages and phenotypical Expression of Muscles:

Myogenesis: Birth of muscle fibers; 6 weeks after conception, the formation of myoblasts is followed by the development of myotubes (fusion of myoblasts to a chainlike aggregation) and finalized in the 9^{th} week by myo-satellic cells. Further volumetric increase of muscle tissue (hypotrophy in the embryonic stage) induced by growth hormones and achieved by cell division.

- **Myoblast**: Embryonic precursor for skeletal muscle fibers.
- **Myogenic Regulatory Function** (MRF):
- **Pregnancy**: After the 7^{th} week in pregnancy, muscle fibers actively adapt to changed physiological requirements by actively communicating between each other via neuronal stimuli and gap junctions between muscle cells. This enables growth (triggering RNA-cascade to induce protein synthesis of actin and myosin fibers) and degeneration during and after pregnancy.
- **Regeneration process** of an injured muscle fiber: An injury triggers a cascade of reactions; cellular infiltration and inflammation of the injured fiber (by inflammatory cells and myonuclei) induce digestion of damaged components (degenerative phase); this is followed by the proliferation and migration of satellite cells (in skeletal muscle fiber) or pericytes (in smooth muscle fiber) which fuse into a chainlike formation giving rise to myotubes (proliferation and fusionizing phase); finally, these myotubes form new myofibrils and mediated by myofibrillar proteins synthesize to new fiber filling completely the injured site (myogenetic phase). Cardiac muscle tissue is not able to undergo regenerative processes and forms scars instead.

Synaptogenesis: The birth of the neuromuscular junction; prior to innervation ACh receptors are distributed across the muscle fiber surface. As the nerve contacts the muscle fiber and electric activity ensues, receptors aggregate in the region of the neuromuscular junction. As maturation progresses, extra-junctional receptors decrease significantly while junctional receptors increase in number and density.
Termination: The finishing touches of synapse formation; approx. 50% of all synapses formed during synaptogenesis are faulty, hence are eliminated by a feedback loop via endogenic lysosomes or exogenic protease activity (sort of macrophages):
Stable ACh-receptors experience a positive feedback which promotes finalization whereas an unstable ACh-receptor experiences a negative feedback by an excess of Ca^{2+} ions (toxic) which leads to their elimination. Regeneration is incomplete if satellite cells are eliminated by a widespread destruction of the basal lamina and the sarcolemma of the muscle fiber $\rightarrow$ transplantation.

Motion: Skeletal muscles produce movements by exerting force on tendons, which, in turn, pull on bones or other structures such as skin. Bones serve as levers, and joints as fulcrum of the levers;

Lever System: A rigid rod that moves about on some fixed hinge point (F, fulcrum), an effector muscle (E), and a resisting moment (R):

- **1st class Lever**: Fulcrum is centered b/w an effort (effector muscle) and resistance (gravitanional pull as the angular moment); e.g. neck muscle (E), cervical curve (F), and weight of head (R).
- **2nd class Lever**: Fulcrum at one end, the effort at the opposite end, and the resistance in-between them; e.g. *Gastrocnemius muscle* (E), toe tips (F), tarsales (R).
- **3rd class Lever**: Fulcrum at one end, the effort at the opposite end, and the resistance in-between; e.g. *Biceps brachii* (E), ellbow (F), gravitational pull of hands (R).

Group Action: Movements that require several muscles acting together:

- **Agonist** (Gk. agogos, leader) The prime mover, as in the case of the arm, the *Biceps brachii*.
- **Antagonist** (Gk. antiagonistes, opposite) As the mover contracts, the antagonist relaxes; in the case of the arm, the *Triceps brachii* muscle.
- **Synergist** (Gk. syn, together; ergon, work): Steadying or stabilizing movement, to avoid unwanted movements, and to increase the agonists efficiency.

Muscle: A "tasty" organ composed of one of the three types of muscle tissue (approx. 700 skeletal, 1 cardiac, and several visceral), specialized for *active* contraction to produce voluntary or involuntary movement of parts of the body. In combination with the other three main body tissues, provide a useful tool for locomotion and other vital body functions. Its modular structure, low energetic requirements at stand-by, and the availability of oxygen as fuel resulted in its global distribution.

Chemical Constituents of muscles:

- **Inorganic C**.: Up to 57% of a muscle cell consists of water; the remaining 25% are made of the following minerals K^+, Na^+, Cl^-, Mg^{2+}, Ca^{2+}, phosphate
- **Organic C**.: Energy providing constituents are lipids, glucose, kreatin-phosphate, ATP, arginine-phosphate, enzymes and proteins as the responsible contractile unit.

Muscles participate in:

- **Body Stabilization**: Muscle contraction maintain the body in stable positions, such as standing or sitting. Postural muscles display sustained contraction when a person is awake (e.g. neck muscles to hold the head upright); sustained contraction of the sphincter (smooth muscles) may prevent outflow of the contents of hollow organs.
- **Motion**: Walking, running, localized motion such a s grasping rely on the integrated functioning of bones, joints, and skeletal muscle.
- **Movement w/n the body**: Cardiac muscle contraction pump blood to all body tissues and help to regulate blood pressure. Peristalsis of smooth muscle contraction aid food and chyme locomotion, sperm ejaculation, urine excretion into the bladder and drainage of lymph and venous blood back to the heart.
- **Thermogenesis**: A contracting muscle generates metabolic heat as a by-product. Much of the heat is used to maintain normal body temperature (85% of all body heat). Involuntary muscle contraction (shivering) can increase thermogenesis by several hundred percent.

Muscle Anatomy: Structural organization of muscle from a macroscopic to microscopic level (see scan below):

Macroscopic elements of a Muscle: Connective tissue surrounds and protects underlying muscle tissue.

- **Fascia**: A fibrous membrane of connective tissue that covers, supports, and separates muscles; a fascia is held together by the epimysium, and itself encloses several fascicles.

  Deep F.: The inner sheath wrapped around a muscle (around the epi-, peri-, endomysium) to keep it in place. Each of the mysial layers houses a dense network of blood capillaries for the transport of O_2, CO_2, lipids and nutrients as well as capillaries of the lymphatic system to allow drainage of excess (interstitial) liquid; all 3 may extend beyond the muscle fibers as a tendon:

  Endomysium: Invagination of the perimysium separating each individual muscle fiber (cell); it houses the basic muscle fibers (cells) with its electro-chemical devices.

  Epimysium: A fibrous connective tissue around muscles, below the *deep fascia* enclosing *perimysial* fibers (enclosing a bundle of muscle fibers).

  Perimysium: Invagination of the epimysium that divides muscles into bundles (fascicle); each bundle encloses some muscle cells, which themselves are separated by the endomysium.

  Superficial F.: The subcutaneous, continuos outer sheath between the dermis of the skin and the deep fascia of the muscle. It represents the framework for nerves and blood vessels; composed of areolar connective and adipose tissue, and stores water, fat, insulates, and cushions (mechanical protection);

- **Fascicle**: A small bundle or cluster bound by perimysium, enclosing several muscle fibers.
  Muscle Fiber (or myofibers, MF): A giant skeletal muscle cell, with many nuclei. It consists of myofibrils, sarcomeres, and their myofilaments (see microscopic elements - myofibril).
  Extrafusal MF: Contractile muscle fiber that make up the bulk of skeletal muscle.
  Intrafusal MF: The muscle fibers within a muscle spindle organ.
- **Tendon**: A band of tough fibrous connective tissue (continuation of endo-, epi-, and peri-mysium), that anchors skeletal muscle to bones.
  Insertion: Attachment of the other tendon form the muscle to the moveable bone.
  Origin: Attachment of a muscle tendon to the stationary bone.

Microscopic elements of a Muscle fiber: Several myofibril are bound together by following structures:

- **Myofibril**: The contractile element of a skeletal muscle; a longitudinal unit of muscle fiber made up of sarcomeres and surrounded by the sarcoplasmic reticulum, containing actin- and myosin-filaments. It encapsulates the sarcoplasm and the myofibril with its sarcomeres.
  Elastic Filament (Titin): The 3rd most plentiful protein in skeletal muscle (after actin and myosin); it anchors myosin to the Z-discs and thereby helps to stabilize the position of the thick filaments.
  Intermediate Filament (in smooth muscles only): An irregular network of protein filaments, that provide structural reinforcement, hold organelles in place, and give shape to the cell.
  Thin Filament (Actin): (Gk. actos, a ray) A ubiquitous protein, connected to the. G-actin is the globular monomer that polymerizes to form F-actin, the backbone of the thin filaments; other actin proteins of the thin filament are tropomyosin and troponin complex.
  Thick Filament (Myosin): The 200 proteins that cross bridges in muscle fibers; it is also found in many other cell types and is associated with cellular motility. Each myosin molecule consists of a globular double head attached to a α-helical neck (heavy meromysin; 57nm long) and a long thin tail (light meromyosin; 93nm long).
- **Sarcolemma** (Gk. sarcos, flesh): The surface (plasma) membrane of a muscle fiber; it also serves as the electro-chemical interface of the moto-neural stimulation.
  Basement membrane (*Basal lamina*): Thin, extracellular fibrous membrane surrounding the sarcolemma of a myofibril. It houses satellite cells that are essential in the repair of injured muscles.
  Mitochondrion: A microbody that provides cells with energy in form of ATP-molecules by aerobically (using O_2) breaking down glucose molecules into H_2O and CO_2.
- **Sarcomere**: (Gk. meros, part of) The contractile unit of myofibrils bounded by transverse tubules; it extends form one Z-disc to the next:
  A-Band: The dark area of actin with the overlapping myosin segment.
  I Band: The less dense area with the remaining myosin segments that do not overlap with actin.
  H zone: The central non-overlapping myosin segment.
  M Line: The dividing protein line that halves the H zone.
  Z Disc: Narrow plate-shaped regions of dense material, that separate sarcomeres from each other.
  Dense Body (in smooth muscles only): The site of attachment of intermediate filaments (similar to Z discs) that are irregularly distributed throughout the cell.
- **Triad**: A complex of 3 units in a muscle fiber composed of the following structures:
  Sarcoplasmatic Reticulum (SR): A dense smooth membrane-limited network surrounding each myofibril (a fluid filled system of cisterns, equivalent of endoplasmatic reticulum in cells). Functions to reabsorb calcium ions during relaxation and to release them to cause contraction.
  Terminal Cistern: The closed spaces that make up part of the sarcoplasmic reticulum on both sides of the Z line, making close contact with transverse tubules.
  Transverse Tubules: Small, cylindrical invaginations of the sarcolemma of striated muscle fibers (cells) that conduct muscle action potentials toward the center of the myofibrils.

Muscle Characteristics: Five principal characteristics enable a muscle to carry out its functions and thus contribute to homeostasis:
Conductivity: The ability to conduct action potentials along the plasma membrane.
Contractility: The ability of muscle tissue to shorten (thicken), thus generating force to do work.
Elasticity: Muscle tissue tends to return to its original shape after contraction or extension.
Excitability: The ability to respond to certain stimuli by producing electrical action potentials triggered by neurotransmitters (ACh), or hormones.
Extensibility: Muscles can be extended (stretched) without damage to the tissue.

Muscle Contraction and Relaxation: A muscle fiber develops its greatest tension (maximum efficiency) when there is optimal overlap of the thick and thin filaments; efficiency decreases with decreasing or increasing width past the mid-average of the H-zone (see scan below).

Contraction: Upon stimulation of the neuro-muscular junction, free Ca^{2+} rushes out into the myoplasm (via appropriate release channels) and initiates the sliding filament mechanism.

- **Actomyosin Complex**: The bound complex of cross-bridged actin and myosin filaments.
- **Adenosine-TriPhosphate** (ATP): ATP is required to split the actomyosin complex into its constituting partners; binding of ATP to the myosin head causes the myosin heads to detach from the actin filament, while ATP cleaves itself into ADP+P.
- **Ca-binding proteins**: Ca-ions mediating muscle contraction can react with the following proteins:
  Caldesmon: A Ca-binding regulatory protein in smooth muscle, which plays a role in the latch mechanism of some smooth muscles.
  Calmodulin: A troponin-like calcium-binding regulatory protein found in essentially all tissues.
  Calsequestrin: A Ca-binding protein that contributes to the regulation in muscle relaxation.
  Parvalbumin: Calcium-binding protein found in vertebrate muscle; it binds Ca^{2+} in the cytoplasm, thus accelerating muscle relaxation.
  Troponin: A complex of globular calcium-binding proteins associated with actin and tropomyosin in the thin filaments of skeletal muscle. When troponin binds Ca^{2+}, it undergoes a conformational change, allowing tropomyosin to reveal myosin binding sites on the actin filaments.
- **Sliding Filament Mechanism**: Decrease of sarcomere length by which actin and myosin slide past each other. Free Ca^{2+} entering the myoplasm binds to special mediator proteins that allow myosin cross-bridges to bind to actin filaments. This results in a twisting of the myosin head which causes the sarcomere to shorten (the power stroke is characterized by the swiveling of the myosin heads towards the center of the sarcomere). Further excitation causes the myosin head to detach (the recovery stroke is initiated by the splitting ATP into ADP+P); the released energy is used to reshape the myosin head thus allowing reaction with the next actin, itself conformationally changed by other Ca-ion;
  Skeletal MC: The sliding filament mechanism of skeletal muscles fibers is mediated via external or autonomous signals. An ACh receptor initiates the process by releasing Ca^{2+} via the transverse tubules into the myoplasm (= sarcoplasm); the ions attach to *troponin* (part of the actin protein) causing a conformational change of the tropomyosin molecule, allowing myosin cross-bridges to bind to actin filaments and initiate contraction; filaments pass each like an oar of a boat. Contraction continues if ATP is available and Ca^{2+} level in the sarcoplasm remains high.
  Smooth MC: Since these fibers lack a troponin; Ca^{2+} enters the myoplasm to bind with calmodulin forming a Ca^{2+}/calmodulin complex that traps caldesmon. Caldesmon fixed in this reaction does not interfere with the actin-myosin reaction, thus muscle contraction can occur. In yet another contraction mechanism, the Ca^{2+}/calmodulim complex activates the myosin-light-chain kinase that uses ATP to phosphorylate myosin heads, enabling the formation of the actomyosin complex.
  Smooth muscles fibers lack transverse tubules (Ca^{2+} takes more time to diffuse to and from the tissue) thus increasing both contraction and relaxation latent periods. Hormones (e.g. epinephrine which have a relaxing effect), temperature, CO_2, pH-changes, and ion concentrations also affect contraction.

Relaxation: Turning off the sliding filament mechanism is brought about by reabsorbtion of Ca-ions from the myoplasm back (Ca-pumps are powered by ATP) and storage in the sarcoplasmic reticulum (Calsequestrin traps Ca^{2+} in the SR). It is initiated once AChE breaks down ACh in the synaptic cleft, causing closure of the Ca^{2+} channels while Ca-pumps actively withdraw the ions into the SR; attachment of ATP to myosin triggers detachment from actin filaments and reorientates the myosin heads; the missing Ca-ions cause a steric hindrance of the tropomyosin-troponin complex (in skeletal muscle) and caldesmon binding to the actin-myosin complex, restricting muscle contraction (in smooth muscle). Since myosin heads can't dock with actin, the thin filaments slip back to their relaxed state.

Muscle Contraction and Tension: To enable gradual contraction patterns rather than the an *all-or-none* reaction (typical contraction of a single muscle fiber). Sarcomeres are aligned in registers; the more motor-neurons stimulate the muscle, the stronger is the contraction; several patterns are distinguished:
Frequency Stimulation: Increase in strength of contraction by a second stimulus applied after the refracting period and before relaxation of a muscle.

- **Staircase Effect** (Treppe): The gradual increase in the force of contraction of a muscle caused by repetitive stimuli of the same strength.
- **Tetanus**: An uninterrupted muscular contraction caused by high frequency motor impulses.

Twitch MC: A brief contraction of all the muscle fibers in response to a single action potential in its motor neuron; a myogram (record of muscle contraction) distinguishes 3 distinct states of a twitch MC:

- **Contraction Period**: Upward tracing of contracting force brought about by shortening of the sarcomere; typically 10 to 100ms.
- **Latent Period**: The brief period between application of the stimulus and the beginning of contraction, in which Ca^{2+} is being released from the sarcoplasmic reticulum; typically 2ms.
  Relaxation Period: Downward tracing of contracting force due to the active withdrawal of Ca^{2+} back into the sarcoplasmic reticulum, resulting in relaxation; typically 10-100ms long.

Muscle Metabolism: Muscle contraction requires energy in the form of ATP; relaxed muscle tissue requires about 20%, whereas contracting tissue can require as much as 200% more energy.

Primary Energy Compound: ATP as the immediate energy resource accounts only for a few seconds of muscle activity; anything in excess requires an other recruitment mechanisms.

- **Phosphagen System**: Phospho-creatine and phospho-arginine is 3 to 5 times more plentiful than ATP and represents a high energy phosphate group that can be convert to ATP by giving of creatine or arginine respectively; it provides extra energy for further 15secs.

Secondary Energy Compounds: Stored proteins, carbohydrates, and fats are converted during the active state to provide the tissue with pyruvate, glucose, amino acids, or fatty acids; a series of reactions generates acetyl-coenzyme (an energy-rich molecules) that fuels the Krebs cycle in the assemblage ATP from ADP (see HB- or Biochem.-Metabolism).

- **Aerobic System**: Release of energy by cellular respiration in mitochondria (O_2-mediated breakdown of fuel molecules) reduces pyruvic acid to water and CO_2, with a total yield of 36 ATP from each cleaved glucose molecule. Since this is a time-consuming process, activities lasting more than 30secs swap to the anaerobic system.
  Myoglobin: Once oxygen supply via the blood stream is insufficient, extra amounts of free oxygen can be recruited from the myoglobin storage sites from within the muscle fibers of type I and IIa.
- **Anaerobic System** (Glycogen-Lactic Acid): Conditions where oxygen levels are low or absent. Glucose is split into 2 molecules of pyruvic acid which yields 1 ATP each with the concomitant production of L-lactate (lactic acid). Given off to the bloodstream, the kidneys, heart, and liver can metabolize lactic acid to generate ATP (liver cells are capable of converting this acid back to glucose). This system provides an extra 30 to 40secs of muscular activity.

Muscle Nomenclature: Arrangement of muscular fascicles (a small bundle or cluster of muscle fiber / cells) in skeletal muscle tissue is correlated with the power of a muscle and its range of motion;

Naming skeletal muscles	Example
Direction: relative to the midline: • Rectus: Fiber runs parallel to the midline of the body; • Transverse: Fiber runs perpendicular to midline; • Oblique: Fiber runs diagonally to the midline;	 *Rectus abdominis*; *Transversus abdominis*; *External oblique*;
Location: Structure near which a muscle is found: • A muscle near the frontal lobe; • A muscle near the tibia;	 *Frontalis*; *Tibialis anterior*;
Size: Relative size of the muscle: • Maximus: means largest; • Minimus: means smallest; • Longus: means longest; • Brevis: means short;	 *Gluteus maximus*; *Gluteus minimus*; *Adductor longus*; *Peroneus brevis*;
Number of origins: Number of tendons of origin: • Biceps: means two origins • Triceps: means three origins; • Quadriceps: means four origins;	 *Biceps brachii*; *Triceps brachii*; *Quadriceps formis*;
Shape: Relative shape of the muscle: • Deltoid: having a triangular shape; • Trapezius: ;having a trapezoid shape; • Serratus: ;having a saw-toothed shape; • Rhomboideus: ;having a rhomboid (diamond) shape;	 *Deltoid*; *Trapezius*; *Serratus anterior*; *Rhomboideus major*;
Action: Principal action of the muscle: • Abductor: moves a bone away from the midline; • Adductor: ;moves a bone closer to the midline; • Depressor: ;produces a downward movement; • Extensor: increases the angle at a joint; • Flexor: decreases the angle at a joint; • Levator: ; produces an upward movement; • Pronator: turns the palm downward or posteriorly; • Rotator: moves a bone around its longitudinal axis; • Sphincter: decreases the size of an opening; • Supinator: turns the palm upward or anteriorly; • Tensor: makes a body part more rigid;	 *Abductor pollicis longus*; *Adductor longus*; *Depressor labii inferioris*; *Extensor carpi ulnaris*; *Flexor carpi radialis*; *Levator scapulae*; *Pronator teres*; *Rotatores*; *External anal sphincter*; *Supinator*; *Tensor fasciae latae*;

Fascicle: A small bundle or cluster of muscle fibers (cell); the length of muscles fibers can vary considerably and according to their task can extend even beyond three joints (multi-articular muscles i.e. *Extensor digitorum longus*) or septed (*Rectus adbominalis*).

Arrangement and description of fascicles	Example
Circular: Fascicles are arranged in a concentric circular pattern to form sphincter muscles that enclose an orifice (opening)	*Orbicularis oculi*
Fusiform: Fascicles are nearly parallel with longitudinal axis of muscle and terminate at either end in flat tendons, but muscle tapers toward tendons where the diameter is less than that of the belly	*Digastric muscle*
Parallel: Fascicles are parallel with longitudinal axis of muscle and terminate at either end in flat tendons	*Stylohhoid muscle*
Pennate: Fascicle are short in relation to muscle length and the tendons extend nearly the entire length of the muscle • Unipennate: Fascicles are arranged on only one side of the tendon • Bipennate: Fascicles are arranged on both sides of a centrally positioned tendon; Biceps means two origins; • Multipennate: Fascicles attach obliquely from many directions to several tendons; Triceps means 3 origins, and Quadriceps 4 origins;	*Digitorum longus, Brachialis; Rectus femoris, Biceps brachii;* *Deltoid muscle, Triceps brachii, Quadriceps femoris;*

Muscle Spindle: An encapsulated proprioceptor in a skeletal muscle, consisting of specialized intrafusal muscle fibers and nerves endings; stimulated by changes in length or tension of muscle fibers. The ends of the spindles are anchored to endomysium and perimysium.

Extrafusal MF: Regular muscle fibers that surround the muscle spindle; are innervated by large α-motor neurons.

Intrafusal MF: 3 to 10 specialized muscle fibers (cells), partially enclosed in a spindle-shaped connective tissue capsule; these fibers make up a muscle spindle. Contract when stimulated by the γ-motor neurons.

Muscle Tonus: Small contractions that give firmness to a relaxed skeletal muscle.

Concentric Contraction: Contraction that shortens the muscle.

Eccentric C: Gradual extension of a muscle while working against a force.

Isometric C: Contraction during which a muscle does not shorten significantly.

Isotonic C: Contraction in which the force generated remains constant while the muscle shortens.

Tonic C: A steady, slow contraction achieved w/o an action potential; e.g. muscles of the eyeball.

Muscle Types:

Apart from a cardiac muscle cell, all other types can be repaired if damaged.

Characteristic	**Skeletal M.**	**Cardiac M.**	**Smooth M.**
Cell appearance, diameter and length	Long cylindrical fiber w/ many peripherally located nuclei; striated; unbranched; 10-100µm; 0.1-300mm long.	Branched cylinder usually w/ one centrally located nucleus; striated; intercalated discs join neighboring fibers; 14µm; 50-100µm lg	Spindle-shaped fiber w/ one, centrally positioned nucleus; no striations; 3-8µm in diameter; 30-200µm long
Location	Attached to bones	Heart	Walls of hollow viscera; airways, blood vessels, iris and ciliary body of eye, urethra, viscera, arrector of hair follicle.
Connect. tissue components	Epi-, peri-, and endomysium	Endomysium	Endomysium
Transverse tubules	Aligned w/ each A-I band junction	Aligned w/ each Z-disc	-
Gap junctions	-	Yes, via intercalated discs	Yes, in visceral
Ca^{2+} source	Sarcoplasmic reticulum	Sarcoplasmic reticulum and extracellular fluid	Sarcoplasmic reticulum and extracellular fluid
Reg.-Proteins for contraction	Troponin and tropomyosin	Troponin and tropomyosin	Calmodulin and myosin light chain kinase
Contraction, mediated by	Fast; Acetylcholine released by motor neuron	Moderate; Acetylcholine, norepinephrine, hormones	Slow; Acetylcholine, norepinephrine, hormones, pH, pO_2, stretching
Relaxation mediated by	AChE & calsequestrin, parvalbumin;	? similar to skeletal muscle relaxation;	Caldesmon
Nervous control	Voluntary (somatic NS)	Involuntary (autonom.NS)	Involuntary (autinom. NS)
Regeneration	Limited, via satellite cells that induce hypertrophy	None - scar formation	Considerable by pericytes inducing hyperplasia

Cardiac M.: A self-contracting (involuntary - not under conscious control) striated muscle where the intrinsic contracting waves (self-generated action potentials) propagate along the entire tissue; starting from the sinoatrial node = pacemaker region, via the bundle of HIS and Purkinjie fibers, down to the apex. CM-cells are typically Y-shaped, allowing interconnections among each other; intercellular propagation is mediated by gap junctions of intercalated discs; the CNS implies a modulating task only (propagation of approx. 0.8m/s);

- **Sympaticus stimulation**: Managed by the sympatethic NS, resulting in an increased heartbeat.
- **Vagus stimulation**: Managed by the parasympatethic NS, resulting in a lowered heartbeat.

Being the only blood propelling organ, CM-cells are rich in mitochondria; therefore, require huge amounts of glycogen, gluconitrates, lipids, and O_2 (aerobic production of ATP). Healing of damaged CM cells (heart attack) by scar formation only; i.e. hypertrophy (an excessive enlargement or overgrowth of tissue w/o cell division).

- **Autorhytmic cells**: Specialized intrinsic cells, capable of stimulating CM fibers; these cells can also be moduoated by neuronal and hormonal influences, causing an in/decrease of the heart beat.
- **Intercalated discs**: Ends of nerve fibers interconnect neighboring cells by irregular transverse thick endings, which contain desmosomes that hold the fibers together. Gap junctions embedded in these discs allow muscle action potentials to spread from one muscle fiber to the next and thus allow contraction of entire bundles as a functional unit.

Smooth M. (SM): A muscle of mesenchymatic origin without sarcomeres (contraction is slower, but lasts longer) and hence without striations. These non-striated tissue of involuntary control is subject to hormonal and neuronal influence - in some even autorhythmic. Each fiber has a ratio of 10-15 : 1 of thick to thin filaments. Shortening of SM produces a bubblelike expansion of the sarcolemma, in which fibers twist like a helix. Myofilaments are non-uniformly distributed within small, mononucleated, spindle-shaped cells. Damaged SM are replaced by enlarging pericytes of adjacent muscle cells or via "*satellite*" cells (dormant stem cells); e.g. postnatal period of a woman.

- Multi-unit SM: Individual fibers, each dotted with its own neuron terminal and gap junctions to neighboring cells allow single muscle cell stimulation; multi-unit SM are found in arteries, airways, arrector pilli muscles that attach to hair follicles, radiar and circular muscle of the iris and cilliary body that adjust the refractive power of the lens.
- Single-unit SM (visceral SM): The type of muscle found in the intestinal tract, because of their extended rate of response. SM-cells communicate electrically through gap junctions, desmosomes and tend to contract in sequential waves. Besides the intestine, they are also found in the other hollow viscera (stomach, uterus, and urinary bladder) and wrapped around arterioles, and veins.

Striated M. (skeletal): Muscle fibers with a high myoglobin an mitochondria content appear red (*red muscle fiber*) whereas those with a lower content appear white (*white muscle fiber*); a fibers ability to slow-twitch or fast-twitch depends how rapidly it splits ATP. Based on these structural and functional characteristics, skeletal muscle fibers are classified into three types (type I, IIa, IIb):

Structural Feature	*Slow oxidative (Type I)*	*Fast oxidative (Type IIa)*	*Fast glycolytic (Type IIb)*
Diameter of fiber	Smallest	Intermediate	Largest
Myoglobin cont.	Large	Large	Small
Mitochondria	Many	Many	Few
Capillaries	Many	Many	Few
Color	**Red**	**Red** to **pink**	**White** (pale)
Functional Features			
ATP production	Aerobic process	Aerobic process	Glycolytic process
ATP hydrolysis	Slow	Fast	Fast
Velocity of contract.	**Slow**	**Fast**	**Fast**
Fatigue resistance	High	Intermediate	Low
Glycogen storage	Low	Intermediate	High
Order of recruitment	First	Third	Second
Activities	Maintaining posture, **endurance** activities; fatigue resistant; the stronger the stimulus, the stronger muscle contraction	Walking, running, sprinting; **Fatigue resistant**; can arise from endurance type exercise out of type IIb;	**Rapid**, intense movements of short duration; fatigue easily; react in "all or nothing" pattern; rise in with weight lifting activities;

Endurance-type exercises, such as running or swimming, cause a gradual transformation of some fast glycolytic (type IIb) fibers into fast oxidative (type IIa) fibers.

Narcosis: Muscle relaxation by inhibition of electromotoric transmission; i.e. blockage of ACh receptor sites.

Oxygen Demand of Muscle Tissue: Oxygen is required in the final metabolic steps in the conversion of fuel packages fed into the Krebs cycle and the successively attached electron transport chain. Any depletion of oxygen deviates the energy rich harvest via the aerobic in favor of the anaerobic pathway, with the concomitant production of lactate. To avoid excess production of lactate, oxygen is stored in the following tissues: myoglobin of muscles, hemoglobin, increased influx of air into the lungs, dissolved in various body tissues.

Regeneration of Muscle Tissue: Skeletal muscle fibers have little potential to divide; growth of skeletal muscle is due to enlargement of existing cells (hypertrophy), rather than an increase in the number of fibers (hyperplasia); regeneration of damaged tissue is mediated by:

Satellite Cells: Dormant stem cells that fuse with each other to form new skeletal muscle fibers; they undergo fibrosis in that a scar forms (fibrous connective tissue); this especially applies for damaged cardiac muscle tissue.

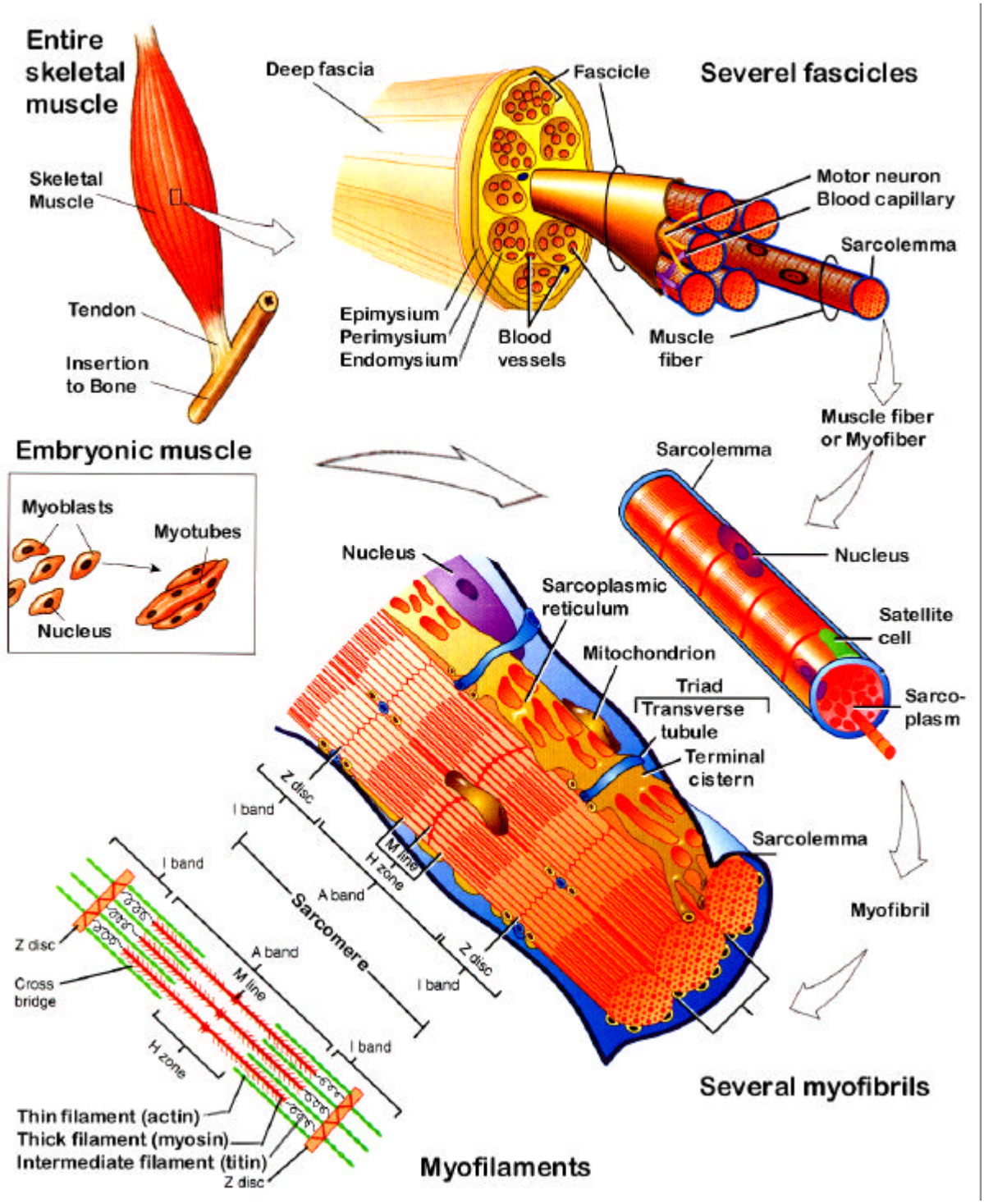
Pericytes: Stem cells w/n the endothelium of blood capillaries and veins, which accounts for the high power of regeneration in smooth muscle fibers; e.g. hyperplasmia in the uterus lining.

Rigor Mortis: Rigidity that develops in a dying muscle as Ca^{2+} leaks out of the sarcoplasmic reticulum and binds with troponin; quickly, ATP becomes depleted and cross bridges remain attached (myosin heads detach only once ATP binds to myosin); the cell dies in absence of O_2 and ATP. It disappears again once tissue decomposition initiates.

Tendon: see Muscle fiber - connective tissue.

Thermogenesis: Muscular contraction of skeletal muscle tissue to generate heat; partly used to maintain body temperature. Shivering induces involuntary thermogenesis.

Tonus: Sustained resting contraction of muscle, produced by basal neuromotor activity; see muscle tonus.



Histology of skeletal muscle tissue (adapted from Lodish et al.)

All skeletal muscles are organized in a stereotyped hierarchy. The organ called a muscle consists of parallel multinucleate fibers, each of which contains many myofibrils. Muscles are attached to bones or other anchor points through tough connective tissue bands called tendons. Each muscle fiber is derived embryonically from a group of myoblasts that fuse to form myotubes. A myotube then synthesizes the proteins characteristic of muscle fibers and differentiates into its adult form. The myofibrils are made up of sarcomeres, arranged end-to-end. Each sarcomere contains thin filaments of actin and thick filaments of myosin, which interdigitate in a precise geometric relationship. The thin and intermediate filaments are anchored in regions called Z disks.

Summary Human Biology - Bones and Skeleton

Abnormalities of the Bones and Skeleton:

Abnormal Curvature of the Vertebral column: Various conditions may exaggerate the normal curvature:

- **Kyphtosis** (hunchback): An exaggerated thoracic curve, due to degeneration of the invertebral discs.
- **Lordosis** (swayback): Is an exaggeration of the lumbar curve, due to increased weight of the abdomen resulting out of pregnancy, extreme obesity, etc.).
- **Scolosis**: Is a lateral bending of the vertebral column in the thoracic region due to a poor posture or one leg being shorter than the other.

Atrophic Bone: Decrease in size due to certain failures, abnormality of nutrition, or lack of use.

Arthritis: A form of rheumatism in which the joints have become inflamed. Osteoarthritis: It apparently results from a combination of aging, irritation of the joints, and wear and abrasion; a degenerative disease far more common than rheumatoid arthritis and usually less damaging.

Bursitis: Inflammation of the bursa.

Fracture: A break, rupture, or crack in bones when exceeding the maximal permissible load.

Herniated (slipped) **disc**: A rupture of an intervertebral disc; the *nucleus polposus* protrudes posteriorly into the vertebral cavity toward the spinal cord and nerves causing considerable pain.

Osteoporosis: Age-related disorder characterized by decreased bone mass and increased susceptibility to fractures; can also be induced via lactose intolerance, pregnancy, diabetes, or inheritance; effects backbone (humpback), femur, hip-bones; most common in Caucasians.

Spina Bifida: A congenital defect of the vertebral column, in which the lamina fail to unite at the midline; can cause paralysis of certain inner organs.

Paget's Disease: A disorder characterized by greatly accelerated remodeling process in which osteoclastic resorption is massive and new bone formation by osteoblasts id extensive. As a result, there is an irregular thickening and softening of the bones.

Rheumatism: A painful state of the supporting body structures; bones, ligaments, joints, tendons, or muscles.

Rickets: Characterized by an inability of the body to transport Ca^{2+} and P from the digestive tract into the blood for utilization by bones. Epiphyseal cartilage becomes wider than normal, and bones stay soft. Usually caused by a deficiency of vitamin D, Ca^{2+} , and P.

Articulation: see joint.

Bone (Osteon): The main supporting tissue of humans, composed if a matrix of collagen hardened by calcium-phosphate, and consists of approx. 25% water, 25% proteins, and 50% mineral salts.

Bone Anatomy: Structural parts of the skeletal systems are bone tissues, cartilage, red and yellow bone marrow, and periosteum. An adult bone (e.g. tibia) which shape is genetically determined, is made up of the following anatomical structures:

- **Articular Cartilage**: A thin layer of hyaline cartilage covering the epiphysis where the bone forms a joint with another bone. It reduces friction and absorbs shock waves.
- **Diaphysis** (Gk. dia, through; physis, growth): The shaft or long, main portion of the bone.
- **Endosteum** (Gk. endo, within): A layer of osteoblasts that lines the medullary cavity and contains scattered osteoclasts (cells that may assume a role in the removal of the bone - see bone formation).
- **Epiphysis** (Gk. epi, above): The extremities or ends of the bone.
- **Methaphysis** (Gk. meta, after): The region in a mature bone where diaphysis joins the epiphysis.
- **Marrow Cavity** (Medullary, Gk. central part): The space within the diaphysis that contains the fatty *yellow marrow* in adults. *Yellow marrow* consists primarily of fat cells and a few scattered blood cells (see bone tissue - spongy bone).
- **Periosteum**: (Gk. peri, around; osteo, bone) A dense, white fibrous membrane around the surface of the dense bone. It consists of two layers:
  Fibrous Layer: Outer layer composed of connective tissue containing blood vessels, lymphatic vessels, and nerves that pass into the bone.
  Osteogenic Layer: The inner layer that contains elastic fibers, blood vessels, and osteoprogenitor cells capable of developing into osteoblasts - cells responsible for forming new bone during growth and repair (see bone formation).

Bone Formation and **Growth**: Process by which bone forms in the body, called ossification or osteogenesis. Many other tissues in the body need Ca^{2+} in order to perform their functions (e.g. nerve cells, muscle cells, blood cells); bones are therefore used as a reservoir for metabolic requirements. A delicate homeostasis in removing and depositing Ca is maintained. Hormones (e.g. growth hormone, estrogen), vitamin (e.g. D), mineral imbalance (e.g. Ca, P), and mechanical (e.g. sports) factors induce mineralization resulting in a net increase of the substantia compacta (dense or compact bone).

- **Osteoclast**: (Gk. clast, to break) A large, multinuclear cell that destroys or resorbs bone tissue; these cells are important in the development, growth, maintenance, and repair of bony tissue.
- **Osteoprogenitor** (Gk. pro, precursor; gen, to produce): An unspecialized stem cell of mesenchymal origin, that can undergo mitosis and further differentiate into an osteoblast; they are found in the inner part of the periosteum, endosteum, and in the canals of bones.
  Osteoblast (Gk. osteo, bone; blast, bud): A bone-forming, collagen secreting cell, w/ no mitotic potentials. Osteoblasts are usually found on the surface of bones; as they become trapped by the surrounding bony matrix, they become trapped in their secretions and mutate to osteocytes.
  Osteocyte (Gk. cyte, cell): A mature bone cell derived from osteoblast that has lost its ability to produce new bone tissue, but maintain their daily cellular activity (exchange of nutrients and metabolic waste prosucts via the blood).

Calcification (mineralization, ossification): Deposition of mineral salts in the framework formed by collagen fibers of the matrix induces crystallization and subsequent hardening of the tissue. Without collagen fibers that serve as reinforcement rods, bones would be very brittle. Two alternative ways to form dense bony tissue are known and involve the replacement of preexisting connective tissue:

- **Endochondral Ossification** (Gk. endo, within; chondro, cartilage): Also called intra-cartilaginous ossification, in which hyaline cartilage is replaced by bone from within. Once blood vessels penetrate the perichondrium, they stimulate the cells of the internal layer to enlarge and become osteoblasts; these cells begin to form a collar of compact bone (stage of periosteum). Further activity of these cells elevate the pH (alkaline) causing precipitation of Ca^{2+} (calcification) in the intercellular substance. Consequently, cartilaginous tissue dies due to hindered diffusion of nutrients, giving rise to dense bone tissue. Most bones of the body, including the skull, are formed in this way.
- **Intramembranous Ossification** (L. intra, within; membrana, membrane): Formation of bone directly on or within the loose fibrous membrane without first going through a cartilage stage. Osteoblasts from mesenchymal origin secrete intercellular material, generating collagenous fibers that forms the trabecular matrix. This spongy bones filled with vascularized connective tissue which differentiates into red bone marrow, mesenchyme tissue at the outside condenses, and incorporates calcium salts to form dense bone tissue. Almost all flat bones of the skull (incl. clavicle) are formed this way.

Bone Function: The skeletal system performs several basic functions:

Blood Cell Production: Red marrow in certain bones is capable of producing blood cells, a process called *hematopoiesis* or *hemopoiesis*. Red marrow consists of blood cells in immature stages, fat cells, and macrophages. Red marrow produces red blood cells, some white blood cells, and platelets.

Mineral Homeostasis: Bones store several minerals that can be distributed to other parts of the body upon demand (bones release Ca^{2+} for muscle contraction and nerve activity). The principal stored minerals are calcium carbonate ($CaCO_3$), hydroxy apatate ($Ca_3(PO_4)_2 \cdot (OH_2)$, and small amounts of MgOH, F, SO_4^{2-}; see also calcium homeostasis.

Movement: Bones serve as levers to which muscles are attached. When the muscles contract, the bones acting as levers produce movement.

Protection: Many internal organs are protected from injury by the skeleton, e.g. the brain is protected by the cranial bones, the spinal cord by the vertebrate, the heart and lungs by the rib cage, and internal reproductive organs by the pelvic bones.

Storage of Energy: Lipids stored in cells of the yellow bone marrow (adipose cells) are an important chemical energy reserve.

Support: The skeleton provides a framework for the body an, as such, it supports soft tissues and provides a point of attachment for many muscles.

Bone Tissue: Depending on the size and distribution of the spaces, the refions of a bone may be categorized as:

Compact B. (Dense B. or *Substantia compacta*): The dense bony tissue with no apparent spaces in which the layers of lamellae are fitted tightly together. Compact bones are found immediately deep the periosteum and external to spongy bone; histological structures of compact bones are:

- **Interstitial Lamella**: The areas in-between osteons consisting of osteocytes and caniculi; they are thought to be fragments of older osteons that have been partially destroyed by osteoclasts during rebuilding or growth.
- **Osteon** (Harvesian System): Any cylindrical unit within the compact bones consisting of the central (Harvesian) canal and its concentrically arranged structures (caniculi, lacunae, lamella, and osteocytes - see bone formation).
  Canaliculus: A microscopic radiating channel that connects neighboring lacunae; it ensures sufficient nutrient supply to adjacent osteocytes and is filled with extracellular fluid.
  Concentric Lamella: Concentric rings of dense bone that houses osteocytes and surround the central canal.
  Lacuna: A small, hollow space in which osteocytes are embedded.
  Haversian (central) **Canal**: A circular channel running longitudinally in the center of an osteon (Haversian system) of mature compact bone, containing blood and lymph vessels and nerves.
  Volkmann's (perforating) **Canal**: A minute passageway, perpendicularly orientated, by means of which blood vessels and nerves from the periosteum penetrate into compact bone.

Spongy B. (Cancellous B. or *Substantia spnogiosa*): An irregular latticework of thin plates of bone called *trabeculae*. Fibrous cord of connective tissue serving as supporting fiber by forming a septum extending into an organ from its wall capsule. It does not contain true osteons.

- **Marrow**: A soft, spongelike material in the cavities of bone.
  Red marrow produces blood cells;
  Yellow marrow consisting mainly of fatty tissue, and has no blood-producing function; upon metabolic requirements, metamorphosis into red marrow is possible.
- **Trabeculae** (Gk. little beam): The irregular latticework of thin plates of bone forming spaces that enclose red bone marrow; the site of hemopoiesis (red blood cell production).

Bone Types: Almost all the bones of the body may be classified into four principal types:

Flat B.: Generally thin bones composed of two nearly flat plates of compact bone tissue; e.g. cranial bones, scapulae, sternum, and ribs.

Irregular B.: Complex shaped bones showing a wide range of spongy and compact bone tissue; e.g. certain cranial bones and the vertebrae.

- **Sesamoid** B.: Small pressure resistant bones of the tendons; e.g. kneecap, thumb, and toes.
- **Sutural** B.: Bones located in the joints of certain cranial plates; they vary in number from person to person.

Long B.: Have greater length than width and are slightly curved for strength; they consist mostly of compact bone tissue; e.g. femur, fibula, humerus, phalanges, radius, tibia, and ulna.

Short B.: Somewhat cube shaped, spongy bones as those of the carpals and tarsals.

Calcium Homeostasis: Bone is the major reservoir of Ca^{2+} in the body. Hormones like PTH or calcitonin mediate between the blood Ca-level (buffering system) and the bones; bony Ca^{2+} is released by osteoclasts when blood Ca-levels are low (risk of respiratory arrest) and reabsorbed by osteoblasts when Ca-levels are too high 8risk of cardiac arrest).

Calcitonin (CT): A hormone excreted from the thyroid gland that inhibits osteoclast activity and speeds up Ca^{2+} uptake by the bones from the bloodstream, thus lowering blood Ca-levels.

Para-Thyroid Hormone (PTH): Besides promoting the recovery of Ca^{2+} from primary urine, it significantly increases the number and activity of osteoblasts, thus elevating blood Ca-levels.

Cartilage: A type of connective tissue consisting of chondrocytes in lacunae embedded in a dense network of collagen and elastic fibers, firmly embedded in chondriotin sulfate (jelly-like substance). The elastic cartilaginous tissue protects the underlying bony tissue from abrasive mechanical influences.

Types of C.:

- **Elastic** C.: Chondrocytes are located in a threadlike network of elastic fibers. It provides strength and maintains the shape of organs, i.e. epiglottis of the larynx, the external part of the ear (pinna), and the auditory (eustachian) tube.
- **Fibro-**C.: Rigid cartilage that provides strength; chondrocytes are scattered through many bundles of visible collagenous fibers; found at the symphisis pubis (point where the hip bones fuse anteriorly at the midline), in the intervertrebal discs between vertebrae and the menisci of the knee.
- **Hyaline** C.: Also called gristle, appears as a bluish-white, glossy, homogenous mass that provides flexibility and support; the most abundant kind of cartilage in the body; it is found at joints over the ends of the long bones (known as articular cartilage) and forms the *costal* cartilages at the ventral ends of the ribs. It also forms the nose, larynx, trachea, bronchi, and bronchial tubes. Most of the embryonic skeleton is made up of this type of cartilage.

Cartilage **Formation** and **Growth**: Process by which cartilage forms in the body. Unlike other connective tissues, cartilage has no blood vessels or nerves (avascular, nutrition of chondrocytes occurs via diffusion only); hence, cartilage is a slow growing, metabolically inactive tissue in which quick regeneration of damaged cartilage is possible only via injective means.

Chondroblast: (Gk. chondro, cartilage; blast, cell) A cartilage-forming cell, that matures into a chondrocyte.

- **Chondrocyte**: Cell of mature cartilage.

Chondroclast: (Gk. clast, to break) A cell that destroys or resorbs cartilaginous tissue.

Joint or articulation: A point of connection or articulation between more or less movable bodily parts.

Functional Classification of J.: Takes into account the degree of movement these joints permit.

- **Amphiatrosis** Gk. amphi, on both sides; athros, joint): Slightly moveable joints.
- **Diarthrosis** (Gk. diathros, movable): Articulating, freely moving, opposing bones; see synovial joint.
- **Synarthrosis** (Gk. syn, together): An immovable joint ; e.g. gomphosis, suture, and synchondrosis.

Structural Classification of J.: Based on the presence or absence of a joint cavity (space b/w articulating bones) and the kind of connective tissue that binds the bones together:

- **Cartilaginous** J.: A joint without a joint cavity where the articulating bones are held tightly together by hyaline cartilage, allowing little or no movement.
  Synchondrosis (Gk. syn, together; chondros, cartilage): A cartilaginous, hyaline joint found in the epiphyseal plates of the diaphysis; e.g. passage between dense bone and the zone of resting cartilage.
  Symphisis (Gk. growing together): A hyaline, cartilaginous joint of fibrous tissue in the shape of a broad, flat disc; e.g. pubic symphysis holding together the 2 pubic bones; joints b/w the first rib and the sternum.
- **Fibrous** J.: A joint that allows little or no movement, where the articulating bones are held together by fibrous (collagenous) connective tissue:
  Gomphosis (Gk. bolt together): A fibrous joint in which a cone-shaped peg fits into a socket; e.g. articulations of the roots of the teeth with the alveoli (sockets) of the maxillae and mandible.
  Suture (L. sutura, seam): A fibrous joint, especially in the skull, where bone surfaces are closely united.
  Synostosis: A joint in which the dense fibrous connective tissue that unites bones at a suture has been replaced by bone, resulting in a complete fusion across the suture line.
  Syndesmosis (Gk. syndesmo, band): A fibrous band or ligament of dense connective tissue; e.g. holdfast between the tibia and the fibula or the radius and the ulna.
- **Synovial** J.: A fully movable or diarthrotic joint in which a synovial cavity is present between the two articulating bones (covered with articular cartilage) and separated by the articular capsule (synovial membrane and fibrous capsule); e.g. articulation of femur and tibia.
  Articular Capsule: The surrounding unit that encloses the synovial fluid and unites the articulating bones; it is composed of two layers:
  Fibrous caps.: The outer layer of dense connective tissue, attached to the periosteum of articulating bones.
  Synovial Membrane: The inner of the two layers of the articular capsule of a synovial joint, composed of loose connective tissue covered with epithelium that secretes synovial fluid into the joint cavity.
  Bursa: A sac or pouch of synovial fluid located at friction points, especially articulating joints.
  Meniscus or articular disc: Fibrocartilage pad between articular surfaces of bones of some synovial joints (e.g. knee) that subdivides the synovial cavity into two separate spaces, allowing the two bones of different shapes to fit tightly together.
  Synovial Fluid: Secretion of synovial membranes that lubricates joints and nourishes articular cartilage.

Movements of Synovial Joints (diarthrosis) of the human body; maximal degree of movement in a healthy adult individual is obstructed by bone- (e.g. elbow), tendon- (elasticity), and muscular (e.g. wrist) limitations.

- **Angular**: There is an increase or decrease at the angle b/w bones.
  Abduction: Movement of a bone from the midline.
  Adduction: Movement of a bone toward the midline.
  Extension: Usually involves an increase in the angle b/w the anterior surfaces of articulating bones.
  Flexion: Usually involves a decrease in the angle b/w the anterior surfaces of articulating bones.
  Hyperextension: Continuation of extension beyond the anatomical position.
- **Circumduction**: A movement in which the distal end of a bone moves in a circle while the proximal end remains stable.
- **Gliding**: One surface moves back and forth and from side to side over another surface without angular or rotary motion.
- **Rotation**: Movement of a bone around its longitudinal axis; may be medial or lateral.
- **Special movements** of the Synovial Joint (diathrosis):
  Depression: Movement of a part of the body downward.
  Dorsiflexion: Flexion of the foot at the ankle joint.
  Elevation: Movement of a part of the body upward.
  Eversion: Movement of the sole of the foot outward at the ankle joint.
  Inversion: Movement of the sole of the foot inward at the ankle joint.
  Plantar flexion: Extension of the foot at the ankle joint.
  Protraction: Movement of the mandible or clavicle forward on a plane parallel to the ground.
  Retraction: Movement of a protracted part backward on a plane parallel to the ground.
  Supination: Movement of the forearm in which the palm is turned anterior and superior.
  Pronation: Movement of the flexed forearm in which the palm id turned anterior or superior.

Types of Synovial Joints (diarthrosis) of the human body:

- Gliding SJ.: Articulating surfaces usually flat, allowing nonaxial movements; e.g. intercarparl and intertarsal joints.
- Hinge SJ.: Spoonlike surfaces fits into a concave surface allowing flexion and extension; e.g. elbow, ankle, and interphalangeal joints.
- Pivot SJ.: Rounded, pointed, or concave surface fits into a ring formed partly by bone and partly by a ligament, allowing rotational movements; e.g. atlantoaxial and radioulnar joints.
- Ellipsoidal SJ.: Oval-shaped condyle fits into an elliptical cavity, allowing flexion and extension, abduction-adduction; e.g. radiocarpal joint.
- Saddle SJ.: Articular surfaces concave in one direction and convex in opposite direction, allowing flexion and extension, abduction-adduction; e.g. carpo-metacarpal joint of thumb.
- Ball-and Socket SJ.: Ball-like surface fits into a cuplike depression, allowing flexion and extension, abduction-adduction, rotation; e.g. shoulder and hip joints.

Ossification (Gk. osteon, bone; L. facere, to make): See Bone Formation.

Skeleton (Gk. skeletos, dried up): The *passive* and rigid body support to which muscles attach and apply force. In an adult usually consists of approx. 206 bones (number of bones of the rip cage may fluctuate) grouped in two principal divisions:

Appendicular S.: Contains the 126 bones of the free appendages, which are the upper and lower extremities, plus the bones at the shoulder and hip girdles, which connect the free appendages to the axial skeleton these are: pectoral girdles (clavicle, scapula), upper extremities (humerus, ulna, radius, 8 carpals, 5 metacarpals, 5 sets of distal-, middle- and proximal-phalanges except of the thumb where the middle segment is absent), pelvic girdle or hip (a paired set of ilium, ischium, and pubis which attach to the sacrum of the vertebral column), lower extremities (femur, tibia, patella, fibula, 7 tarsals: calcaneus, talus, cuboid, navicular and 1^{st} ,2^{nd} ,3^{rd} cuneiforms; 5 metatarsals, 5 sets of distal-, middle-, and proximal-phalanges except of the big toe where the middle segment is absent as well).

Axial S.: The 80 bones of the longitudinal axis, or center, of the human body forming a straight line and runs vertically along the body's center of gravity; these bones are: skull (cranium, face), hyoid (Gk. u-shaped; the only bone that does not articulate with any other bone but where muscles of the tongue, neck, and pharynx attach), auditory ossicles, vertebrate column, and thorax (sternum, ribs).

Skull: The skeleton of the head consisting of the 8 cranial and 14 facial bones.
Cranial Bones: ethmoid b., frontal b., occipetal b., 2 parietal b., sphenoid b., 2 temporal b.
Facial bones: paired lacrimal b., mandible (lower jaw), paired maxillae (upper jaw), inferior nasal conchae, paired nasal b., 2 palatine b., paranasal sinus, vomer (plowshare), 2 zygomatic (cheek-)bones.

Tendons: A white fibrous cord of dense, regularly arranged connective tissue that attaches muscle to bone; see HB-Muscle.

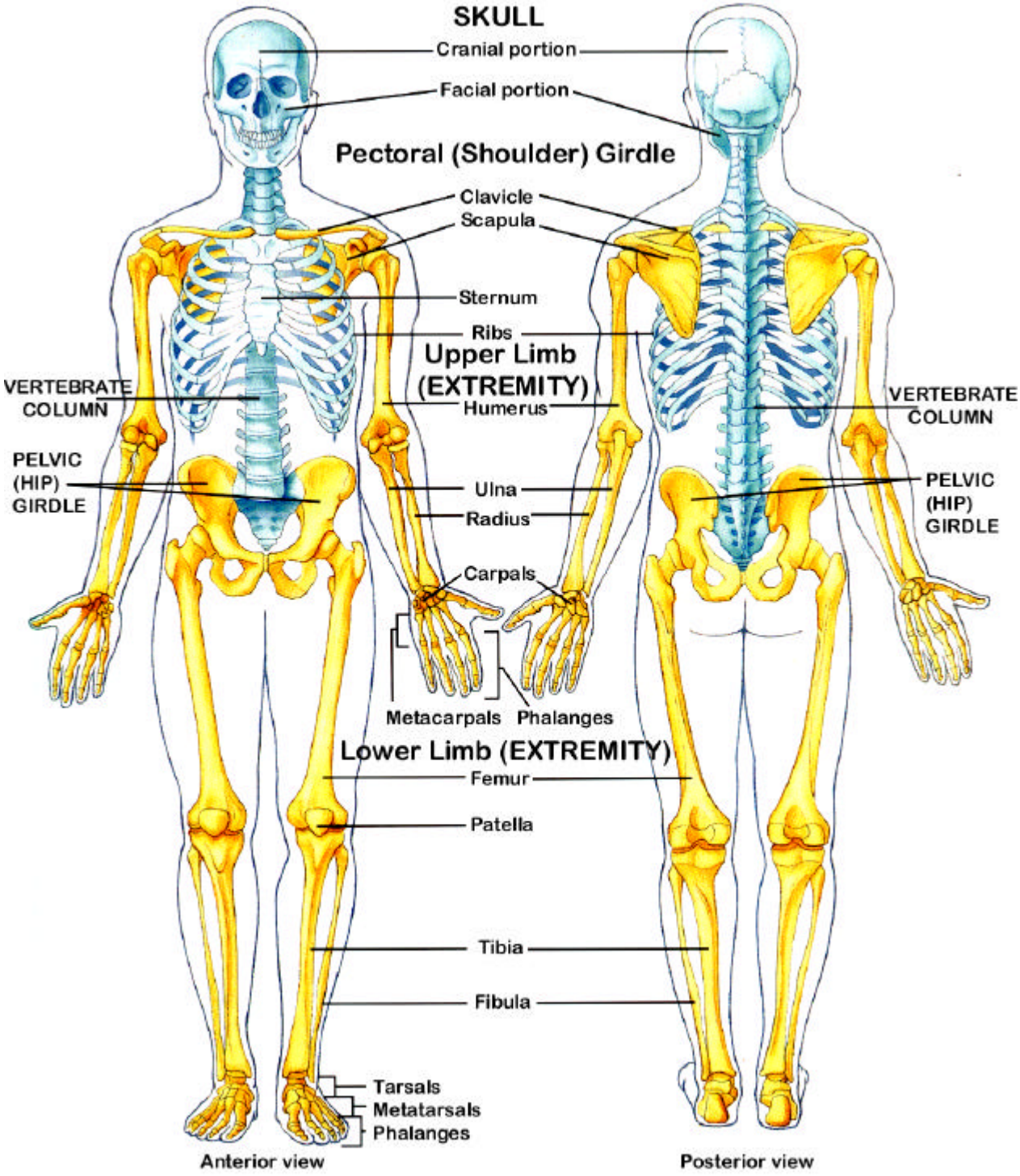
Thorax: The chest; the skeletal portion of the thorax formed by the sternum, costal cartilage, ribs, and the bodies of the thoracic vertebra. It protect vital organs such as the lungs, heart, spleen, liver, kidneys, and is off essential importance in the ventilation of the lungs.
Ribs: 12 pairs of rips make up the thoracic cavity. The 1st through 7th pairs of ribs have direct anterior attachment to the sternum by a strip of hyaline cartilage (true ribs); the remaining 5 pairs indirectly are attached to the sternum via the 7th rib-pair (false ribs). The 11th and 12th rib pairs are floating ribs since their anterior ends to not attach to the sternum.
Sternum: The breastbone; a flat narrow bone in the middle of the thoracic wall. It is structured in 3 segments: the manubrium (the superior portion of the sternum), body (the middle part), and xiphoid process (the sword-like inferior process).

Vertebral Column (backbone, spine, spinal column): The 26 vertebrae of an adult and 33 vertebrate of a child; encloses and protects the spinal cord and serves as a point of attachment for the ribs and back muscles; most of the vertebrate have an anterior body (weight bearing part), 3 posterior processes (spinous, and 2 transverse), a centrally located foramen (hollow region enabling the passage of blood vessels and nerves), and 2 lateral intervertebral foramen (radiation of the spinal nerve root ganglia). Superior facets (and lateral demifacets) form the articulating hinge points for the succeeding vertebrate (and additional facets for the ribs in the thoracic segments of T1-T12). The S-curved appearance of the vertebrate column provides increased strength, help to maintain balance in an upright position, absorb shock waves, and protect against fracture.

- **Cervical Vertebrate**: The upper 7 (C1-C7) constricted neck vertebrates of the vertebrate; and includes:
  Atlas: The 1st cervical vertebra (C1) in the shape of a ring and no body which supports the head; its circular shape allows head rotation in the vertical direction.
  Axis: The 2nd cervical vertebra (C2) with a peglike process (dens) pivots the atlas, enabling head horizontal head rotation.
- **Thoracic Vertebrate**: The 12 (T1-T12) vertebrates in the chest region of the spine. Articulating surfaces on each side of the transverse processing tips represent the hinge points of the ribs.
- **Lumbar Vertebrate**: The lower 5 (L1-L5) vertebrates of the backbone between the ribs and pelvis. These are the largest and strongest of the vertebral column to which back muscles attach and a large portion of body weight is supported.
- **Sacrum**: The penultimate section of the sine (lacking intervertebral discs), forming a triangular bone with the merged 5 sacral vertebrates.
- **Coccyx**: The final spinal appendix of 4 fused coccygeal vertebrates at the inferior end of the vertebral column.

Intervertebral Disc: A pad located between the bodies of two vertebrates, with an outer fibrous ring of fibro-cartilage and an inner soft, pulpy, highly elastic structure (*nucleus polposus*). The disc form strong joints, permit movement and absorb vertically propagating shock waves.
Intervertebral Foramen: A paired set of openings in each vertebrate through which the nerves pass that connect the spinal cord to various regions of the body.

Overview of the human skeleton



Axial skeleton: blue
Appendicular skeleton: yellow
Hyoid bone not shown

Glossary Human Biology 1 **Digestive Tract**

Cholesterol: A natural sterol, a precursor to the steroid hormones produced in the liver; cholesterol is transported by carrier molecules (surrounded by a proteinous coating) like:
HDL-high density lipoprotein: A protein with a few packed cholesterol molecules only.
LDL-low density lipoprotein: A protein heavily loaded with cholesterol, which makes it less transportable and hence more likely to become deposited on arterial walls; smoking, lack of physical exercise, heavy drinking, and a carbohydrate-rich diet facilitate the formation of LDL.
VLDL-very low density lipoprotein: A protein heavily overloaded with cholesterol.

Digestion: The process whereby large food molecules are broken down by hydrolytic enzymes into smaller units that can be absorbed. Digestion can be split into several digestive phases:
- Cephale P.: Activation of gastric activity via the *Vagus* nerve (vagal motor is parasymphatetically activated), mental coordination of smell (nose), taste (mouth), and thought (mind).
- Gastric P.: Gastric activity initiated by mechanical stimuli (chewing, swallowing), formation of chyme; initiation of chemical breakdown.
- Intestinal P.: Completion of chemical breakdown, absorptive part of digestion.

D. **Enzymes**: Enzymes secreted by alimentary canal to aid in chemical digestion.
D. **Epithelium**: Epithelium lining the small intestine.

Energy Harvest: The final digestive steps in which an aerobic pathway breaks down glucose to CO_2 and H_2O, (O_2 as the final electron acceptor); produces a total of 36 ATP per molecule of glucose (see HB-metabolism).
Glycolysis: (Gk. glyk, sweet; lysis, dissolution) A series of reactions in the cytoplasms of a cell, that converts glucose to pyruvate w/ the concomitant production of a small amount of ATP (highly exergonic). The series of reactions does not require the presence of oxygen to occur - essential for the brain to function.
$C_6H_{12}O_6 + 2ADP + 2P_i + 2NAD^+ \rightarrow 2C_3H_4O_3 + 2ATP + 2NADH + 2\ H^+ + 2H_2O$
Krebs Cycle: A series of eight major reactions following glycolysis, in which acetate residues within mitochondria are degraded to CO_2 and NADH. Under aerobic conditions, the generation of energy (ATP, NADH, $FADH_2$) from glucose is the oxidative decarboxylation of pyruvate (oxalacetate on both sides of EQ):
$acetylCoA + 3NAD^+ + FAD + GDP + P_i + 2H_2O \rightarrow 2CO_2 + 3NADH + FADH_2 + GTP + 2H^+ + CoA$
Electron Transport Chain: The energy bucket brigade - the voltage gradient across the mitochondrial wall, drives electrons along with H^+ ions to O_2 to generate water: $1/2O_2 + NADH + H^+ \rightarrow H2O + NAD^+$

Process	Raw material	ATP used	ATP produced	End product
Glycolysis	glucose ($C_6H_{12}O_6$), NAD^+	2	4	pyruvate, NADH
Krebs Cycle	pyruvate ($C_3H_4O_3$), NAD^+, FAD	0	2	CO_2, NADH, $FADH_2$
e-transport chain	NADH, $FADH_2$, O_2	0	32	H_2O, NAD^+, FAD

Epiglotis: A flap of tissue just above the larynx (windpipe or trachea) that closes during swallowing and prevents food from entering the lungs.

Esophagus: The region of the mouth that transports a food bolus from the mouth through the pharynx into the stomach. This is achieved by a traveling wave of circular muscle constriction (peristalsis) in tubular tissue. Anatomically structured in: Epithelium (mucosa), mucus tissue (*Lamina propria mucosa*), muscle layer (*Lamina muscolaris*), innervated connective tissue (*Submucosa*).

Hunger: Eating habits are controlled nervously in the hypothalamus;
Abnormalities: *Anorexia nervosa* (severe restriction of food intake) and *Bulimia nervosa* (secret bingeing of huge amounts of food followed by forcefully induced vomiting).
Hyper*phagia* excess food intake, *aphagia* aversion towards foods.
Control of H.: Feeding center thought to be centered and controlled by the Hypothalamus;
- Glycolytic hypothesis: Glucose receptors of the hypothalamus detect and control feeding patterns.
- Thermostatic hypothesis: Increased input of food boosts metabolism, resulting in a caloric effect, i.e.: thermo-receptors of the hypothalamus detect the increased temperature and suppress further food intake.
- Lipostatic hypothesis: Energy needed in body metabolism is brought in by switching to the fatty acid mobilization, once glucose reserves of the body are used up.

Saturation of H.: Excess energy related molecules are stored in the Adipose Tissue.
- Resorptive S.: Dilatation of stomach signals a stop in food-intake.
- Peptide Factors: CCK (**c**hole**c**ysto**k**inin) once given off by the duodenum signals satiation.

Intestine: The long, tube-like section of the digestive tract b/w the stomach and anus; protected by a mucus lining; most food digestion and absorption takes place via villi, themselves covered with microvilli.

Small Intestine: Site of attack in which different types of food are split by different types of enzymes.

- **Duodenum**: 6m long anterior section of the small intestine; with the help of excretions from the pancreas and the liver cleave the greasy components of food (peptidase cleaves proteins, sucrase cleaves sugars, amylase cleaves starch and glycogen, lipase cleaves lipids, nuclease cleaves nucleic acids).
  D. **Epithelium**: Tightly packed cellular tissue with little intercellular space (Crypts of Lieberkuehn) which increase the allover surface area of the duodenum to approx. 2000m^2.
  Crypts of Lieberkuehn: Continuously mitotically dividing cells that in the bottom of the crypts that migrate outward toward the top of the villi and are finally sloughed off during intestinal motion. During their slow migration, morph into the mucus producing goblet cells and other epithelial cells.
  Mucosa: Mucus-secreting cells of the intestine (epithelial cells of villi dotted w/ microvilli) supplied with a network of arterioles, venules, and lymphatic vessels.
- **Jejunum**: Short stretch between duodenum and ileum; further digestive secretion and digestion.
- **Ileum**: 2m long posterior section of the small intestine, which absorbs the fatty acid components.

Large Intestine: Most of the chyme's utilizable matter has been already absorbed; the remaining substance is largely fat-free. The large intestine mainly dehydrates the remaining substrate.

- **Cecum** (*Appendix*): The blind pouch; no known digestive function; contains lymphatic tissue, i.e.: cells of immune system.
- **Colon**: The last portion of the large intestine, the wide part of the alimentary canal that leads to the rectum; absorbs water, ions and vitamin from the chyme, stores and solidifying feces.
- **Rectum**: The expandable portion of the intestine between colon and anus which serves as a storage compartment; expels solid wastes by defecation, usually once a day. Feces contains about 10% epithelial cells, enzymes, and bile pigments.
- **Anus**: The opening of the alimentary canal; waste elimination.

Intestinal Absorption: Absorption of the digestible substances of the chyme is achieved approx. 2 hours after food intake – the period of eating to absorption can be considered as the absorption phase, in which the flow of blood into the intestinal tissue is increased (concomitant production of metabolic heat – caloric effect).

Intestinal Disturbances: *Coelicaly*: Difficulties to absorb certain proteins.
Constipation: Slow movement of feces through the large intestine, associated with dry, and hard feces.
Flatulencies: Degassing of intestinal tract. The fermenting activity of microorganisms with the concomitant production of acetic acid, lactic acid, and alcohol counteract gas formation. Production of gas due to an incomplete hydrolization of proteinous food which results in H_2S, and other gaseous S-components.
Hemorrhoids: Venous cushioning of terminal anal muscle which normally triggers defecation, can rupture when intentional pressure is exerted during a forceful defecation.
Gluten enteropythy: Incapacity to absorb glutamic acid and proline in any form with the concomitant effect of reducing the overall intestinal surface by destroying (micro-)villi.

Intestinal Movement: Transport of chyme or feces is brought about:
Intestinal **Oscillation**: Oscillating movements of the intestine which help peristalsis.
Peristalsis: A traveling wave of constriction in tubular tissue produced by contraction of circular muscle, brought about by an arrangement of circular and longitudinal layers of muscles.

Intestinal secretions: for pancreatic and bile secretions, see there.
CCK (**c**hole**c**ysto**k**enin): Hydrolyzation can only take place once the chyme is neutralized (gastric chyme is too acidic); therefore, stimulates contraction of the gallbladder, liberating fat-emulsifying bile into the small intestine, and triggers release of pancreatic protein-digesting hormones; CCK is released in response to the presence of amino and fatty acids in the duodenum.
CCK also works on regulatory centers in the brain and produces the sensation of being full.
GIP (**G**astric **I**nhibitory **P**eptide) liberated from the small intestine in response of high levels of fatty acids, suppresses gastric secretion of HCl and pepsin.
Lactase: A lactose (milk sugar) digesting enzyme produced in babies; production stops at a later age.
Secretin: Stimulates pancreatic secretion, but inhibits gastric activity by lowering release of gastric gastrin, which slows down the production of pepsin and H^+ secretion in the stomach.

Larynx: The cartilaginous structure located at the entrance of the trachea and houses the vocal chords.

Liver: A large, lobed exocrine gland that (1) destroys aging and defect blood cells, (2) stores glucose in the form of glycogen (induced by pancreatic insulin) or disperses glucose to the bloodstream (induced by pancreatic glucagon), (3) stores vitamins and iron, (4) detoxifies poisons including conversion of NH_3 to urea, (5) fat metabolism, i.e. produces bile, (6) involved in the synthesis of non-essential amino acids, deamination.

Overview of the most important metabolic functions of the liver (see also biochemistry - metabolism):		
Carbohydrates	Glycogen	homeostasis of BGL via hormonal regulation (glycogenolysis)
	Glucose	homeostasis of BGL via hormonal regulation (gluconeogenesis)
	Galactose	utilization of galactose from lactose (biosynthesis of galactose)
	Fructose	utilization of fructose from saccharose
Lipids	Lipoprotein	biosynthesis, assemblage, and decomposition of HDL,LDL
	Fatty Acid (FA)	biosynthesis of ketone-bodies during β-oxidation of FA
	Cholesterol	biosynthesis of cholesterol according to fat intake
N-containing Compounds	Amino Acids (AA)	synthesis of non-essential AA; degradation, decarboxylation of AA to amines
	Urea	biosynthesis of urea in uric acid cycle
	Kreatin	Biosynthesis
Proteins	Albumin	biosynthesis and secretion (plasmatic blood-protein)
	Coagulat. enzymes	biosynthesis and secretion

The liver is supplied with blood by both an artery and a vein (*Vena portae*). The lymphatic system is directly connected to the liver (hepatic cells) as well.

- **Urea Cycle**: Deamination of AA's leads to ammonia (NH_3) and keto acids. This ammonia molecule, enriched with an extra H^+ becomes the ammonium ion (NH_4^+), which is highly soluble in water. It takes 4ATP to generate 1 urea molecule and about 500mL of water to carry off 1g of ammonia:
  $2NH_3 + CO_2 \rightarrow H_2N\text{-}(C{=}O)\text{-}NH_2 + H_2O$

Liver Tissues: The basic functional unit of the liver is the liver lobule, a cylindrical structure several mm in length and up to 2mm in diameter. The human liver contains about $50E^3$ to $100E^3$ individual lobules.

- **Connective Tissue**: Fibrous tissue guarantees that hepatic cells keep their hexagonal shape.
- **Hepatic Cell**: The functional tissue (heptone, liver parenchyma) within the hepatitic plates, that execute the bile generating tasks. These cells also provide the cholesterol needed for the body, in which large quantities of carbohydrates are converted to fat. Liver cells are replaced by new ones after 3-4 weeks.
  Fat → glycerol + **f**atty **a**cid; FA → (oxidized) → acetyl-CoA.
  Gluconeogenesis: Synthesis of carbohydrates (CH) from non-CH sources, such as fatty or amino acids.
  Glycogenesis: Synthesis of glycogen (glucose-6-phosphate) out of glucose; required to maintain a constant **b**lood **g**lucose **l**evel (BGL).
  Glycogenolysis: Breakdown of glucose-6-phosphate (glycogen) to glucose.
  Hepatic Cellular Plate: An approx. 2-cell layer thick triangular structure that houses several liver cells, encircled by sinusoidal venules that radiate centrifugally from the central vein like spokes of a wheel (several plates fit into one lobule). Embedded in the liver cells lie the small *bile canaliculi* that empty bile into bile ducts. Small *Portal venules* originating from the gastrointestinal tract supply the sinusoids with glucose-rich blood. The *Hepatic artery* adds extra O_2-rich blood to the septal tissue.
  Littoral (Kupffer) **Cells**: These line the sinusoidal walls surrounding the hepatic plates, and are capable of phagocytizing bacteria and are the detoxifying elements of the liver tissue.

Bile: A viscous yellow or greenish alkaline fluid with lipid digesting properties, produced by the liver from modified cholesterol molecules and stored in the gallbladder. Contains bile salts, bile pigments (such as bilirubin and billiverdin, from the breakdown of red blood cells), certain lipids, and glycine. It emulsifies, and splits fat globules into micelles, hence acting like a detergent. Bile also determines color of feces.

Bile Salts: Bile acid such as cholic acid conjugated with glycine or taurine, promoting emulsification and solubilization of intestinal fats; other ionic compounds found within: Na^+, K^+, Ca^{2+}, Cl^-, HCO_3^-.

Gallbladder (*Vesica fellea*): A sac lined with smooth muscle cells, that concentrates (withdrawal of water), regulates ionic concentration, and stores bile for eventual discharge into the intestine. Discharge of bile is stimulated by CCK (cholecystokinin).

Liver Abnormalities: *Hepatitis*: Inflammation of the liver parenchyma caused by certain viruses;
Hepatitis A: Mild form of *H.* caused by improperly washed foods (salads, contaminated ice-creams, etc.) via aerosol transfer; virus spreads from intestine via the bloodstream to the liver and usually results in *jaundice* (yellowing of skin and eyes and browning of urine); usually does not show chronic or severe patterns.
Hepatitis B (serum hepatitis): Caused by intravenous blood transfer, saliva, or via sexual intercourse; after an incubating period of about 40-160 days, a typical yellowish skin color appears along with swelling of the liver and shows a chronic pattern; not treated will develop into liver cirrhosis and ultimately to liver cancer.
Hepatitis C (unrelated to type A, B): The most widespread of all types of hepatitis and is mediated by blood transfusion and possibly by sexual intercourse; it is not as severe as type A and B, but can cause chronic ailments such as *cirrhosis*.
Hepatitis D and E: Poorly understood strains that await further investigation.

Lymph: Plasma-like fluid collected from the intestinal fluid and returned to the bloodstream via the thoracic duct; contains white, but not red, blood cells; see circulatory system.

Mouth: The most anterior section of the gut.

Muscles of the M.: They give both lateral and vertical freedom to the mandible (lower jar).
Musculus masseter: Inner Flügelmuskel, *Musculus temporalis*: Schläfenmuskel;
Occlusio: Closing muscle joining maxilla and mandible.

Teeth: Humans first develop a set of deciduous teeth (milk T.); 2 incisors, one canine, and two premolars on each side of each jaw; followed by permanent teeth, with an additional set of 3 molars on each side.

- **Anatomy** of a Tooth:
  Crown: The enamel constituting the (hard protective cover, consisting of Ca-crystals - protects the dentin layer underneath) projects above the gum, and often bears two or more hillocks (cups);
  Neck: is surrounded by the gum; often, the dentin layer (similar in compositions to bone) is visible;
  Root: One or more roots are embedded in the jaws (maxilla/mandible); a bone-like cement made of collagen fibers, covers much of the root and holds the tooth firmly in the jaw. Finally, desmodont with alveolar out-pockets is the most external layer connected to the alveolar bony tissue of the jaw.
  Root-canal with the tooth's pulp consists of connective tissue, blood supply vessels and nerves.
- **Abnormalities**:
  Caries: Decay of dental substance (enamel, dentin) by the bacterium *Streptococcus mutans.*
  Parodonthosis: Withdrawal of the gums due to lack of nutrients or poor hygiene.
  Prognathie: Enlarged upper jaw; maxilla does not rest slightly in front of the Mandible's incisors;
  Progenia: Enlarged lower jar; mandible exceeds maxilla;

Saliva: A water-like fluid secretes in the upper alimentary canal (headgut); aids in mechanical and chemical digestion. α-amylase is contained in the saliva to facilitate digestion of carbohydrates, mainly starch (pH ≈ 6.5 required for amylase to work). Saliva also serves to lubricate the food bolus and to squirt it through the pharynx into the stomach. Up to 1.5L of saliva/day is produced by the three salivary glands alone.
Major constituents of S.: H_2O, α-amylase, K^+, I, $Ca(HCO_3)_2$ acting as a bicarbonate buffer (source of tartar) and mucin (= muco-polysaccharide) as the lubricant.

Salivary Gland: Three exocrine glands, required during the initial phase of food digestion:

- Parotid G.: Situated just below the opening of the auditory tube; lubricates the upper pharynx.
- Mandibular G.: Located next to the vocal cords, lubricate the lower part of the pharynx with saliva.
- Sublingual G.: Supplies anterior bucal region with saliva.

Tongue: In most organisms, serves as an organ to manipulate food and transport if toward the pharynx, where it is swallowed. It is supported by a pair of longitudinal, as well as vertical muscles. The underside of it is made of a rather loose mucus membrane, whereas the upper side is dotted with terminal nerves, mechano- and chemo-receptors.

- Papillae: Small conical bumps, which house the taste buds. Each bud consist of a pore leading to a secondary nerve cell arranged in an overlapping pattern – like an artichoke; Although the sensitivity amongst buds towards various taste is overlapping according to their locating at the tongue, they can distinguish 4 different tastes (sweet, salty, bitter, and sour). The *Facial* (VII), and *Glossopharengeal* (IX) nerves connect these receptors to the central nervous system.

Nose: A typical chemical receptor housing the olfactory epithelium, which covers about $6cm^2$ (other $20cm^2$ is covered by the nasal mucus membrane).

Olfactory Epithelium: Button sized patches in the nasal passages capable of detecting a vast amount of different smells and odors (up to 10000 different odors). Embedded between supporting cells, the apex of the dendrite is dotted with up to 10 cilia on which receptor molecules are located.

Properties of smell triggering molecules: volatile, polar, water soluble to a certain extent,

Nutrients: Organic compounds used in the synthesis of new bio-molecules and as fuel (cellular energy).

Carbohydrates: Source of metabolic energy; mono-saccharides (glucose), disaccharide (sucrose), polysaccharides (starch, amylose, amylopectin). If deprived of carbohydrates, body will break down first its fat stores, then its own muscle tissue, and convert the subunits to glucose, thus providing the sensitive nervous system cells with the glucose they need to stay fully active.

- Macro-polysaccharides: Glyco-protein, proto-glycane.

Lipids: Energy storage nutrients like fatty acids: Lipids provide twice as much energy than glucose does and does not mix with water – every glucose molecule binds about 2g of H_2O.

- Polyunsaturated fatty acids: Arachidonic acid, linolic acid, linolenic acid.

Minerals: *Inorganic* chemical elements, i.e.: Ca, Fe, I, K, Mg, Na, P, S, etc. - see table below.

Proteins: Source of amino acids. Too much protein intake can lead to kidney damage since nitrogenous molecules cannot be stored in the body – those organs must work overtime in the excretion of large quantities of nitrogenous waste.

- **Essential Amino Acids** (not synthesizeable by the body itself): leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.

Vitamins: Simple *organic* compounds not manufactured by the body i.e.: A, E, D, K etc. - see table below.

Pharynx: Anterior region of the gut, generally muscular and adapted for ingestion. It is bounded anteriorly by the mouth and nasal cavities and posteriorly by the esophagus and larynx.

Pancreas: An exo-, and endocrine gland located behind the stomach; the main supplier of digestive enzymes and neutralizing salts for the small intestine (some pancreatic excretions are triggered by secretin, an enzyme of the small intestine).

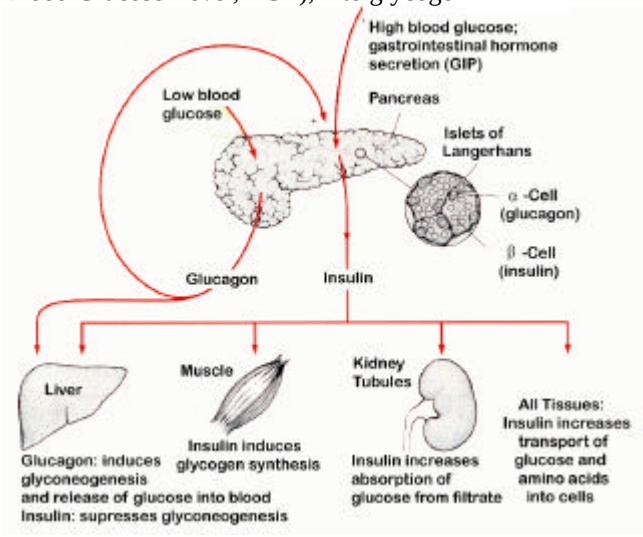
Pancreatic **Endocrine Secretions**:

- **Glucagon** an *endocrine excretion* into the blood produced by the alpha cells, signaling the release of sugars (glycogenolysis), thereby regulating blood glucose levels.
- **Insulin**, a protein hormone synthesized and secreted by the beta cells of the pancreatic islets; controls cellular uptake of carbohydrate and influences lipid and amino acid metabolism.
- **Somatostatin**: Growth-hormone-inhibiting hormone, which inhibits growth hormone release from the pituitary, and is produced by the δ-cells of the islets of Langerhans.

Pancreatic **Exocrine Secretions**:

- **Amylase**, a carbohydrase that hydrolyzes (cleaves) all but the terminal glycosidic bonds within starch and glycogen, producing disaccharides and oligo-saccharides.
- **Bicarbonate**: Either in the form of sodium-hydrogen carbonate or HCO_3^- alone (from dissociation of H_2CO_3) neutralizes and buffers the acid chyme in the duodenum:
  $4NaHCO_3 \rightarrow 4Na^+ + 4HCO_3^- \rightarrow 4Na^+ + 2H_2O + 4CO_2 + 2O_2$
- **Chymotrypsin**, a protoelytic enzyme that specifically attacks peptide bonds containing the carboxyl groups of tyrosine, phenylalanine, tryptophan, leucine, and methionine; activated by trypsin.
- **Lipase**, enzymes that specially cleave lipids.
- **Nucleases** cleave nucleic acids.
- **Trypsin**, an enzyme that specifically attacks peptide bonds in which the carboxyl group is provided by arginine or lysine once activated by enterokinase (occurring in the intestine).

Blood Glucose Metabolism: The liver is the main glucose-binding organ which polymerizes glucose from the sugar-rich blood of intestinal origin (400mg/0.1L **B**lood **G**lucose **L**evel, BGL), into glycogen
This lowers the BGL to approx. 100mg/0.1L, hence reducing the osmotic properties of blood.
Glucose + 1ATP + glucokinase →
→ glucose-6-phosphate (glycogen)
An otherwise elevated BGL would have damaging effects to peripheral tissue and other organs.
The pancreatic hormones insulin and glucagon play a major role in regulating blood glucose levels. High levels of blood glucose and glucagon and/or gastrointestinal hormones signaling food ingestion (e.g. gastrointestinal inhibitory peptide, GTP) stimulate the pancreatic β-cells to secrete insulin, which stimulates glucose uptake in all tissues.
Glucagon, secreted by pancreatic α-cells, exerts an action that is antagonistic to that of insulin in the liver, where it stimulates glyco-neogenesis and glucose release.



- **BGL Abnormalities**: *Diabetes mellitus*: A metabolic malady, probably caused by a virus, in which there is a partial or complete loss of activity in the pancreatic islets; the concomitant insulin insufficiency leads to inadequate uptake of glucose into cell and loss of blood glucose in the urine; if uncured leads to *Athereo sclerosis*, severe coronary heart disease, multiple microcirculatory lesions, diabetic retinopathy, cataracts, hypertension, and chronic renal disease.
  Coma diabeticum: Shift from carbohydrate to fat metabolism to generate energy boosting the level of keto acids, acetoacetic acids, and hydroxy-buttric acid, resulting in acidosis; with a very low level of Na^+ which is excreted along with the keto acids (<pH). Na^+ is replaced by H^+, rendering the overall body-pH even more acidic.
  Hypoglycemia: The CNS derives essential energy from glucose metabolism. If insulin causes BGL to fall too low, the metabolism of the CNS becomes depressed leading to an insulin shock with the typical symptoms, like trembling, and severe sweat outbreaks.

Saliva: See mouth.

Stomach: In humans, a monogastric, expandable, elastic-walled sac that receives food from the esophagus via the cardiac sphincter. It stores and churns food, initiates protein digestion, and forms chyme; the stomach is the major site of hydrolyzation for pepsin (cleaves proteins). The stomach is fastened by a dorsal and a ventral mesenterium; its muscular activity is brought about by a set of longitudinal and circular muscles.

Chyme: The mixture of partially digested food and digestive juices found in the stomach and intestine; about 2.5L/day is secreted by gastric glands.

Sphincter: A ring of muscle surrounding the gastric openings that controls the size of the opening. C*cardiac sphincter*, opens to the esophagus, *pyloric sphincter* opens to the duodenum.

Major gastric secretions:

HCl (hydrochloric acid): H^+ is excreted by ***parietal*** cells located in the midsection of the gastric gland; HCl is secreted when the vagal motor discharges, Its pH ≈ 1.5, is caused by the hydrochloric secretions causing amylase to denaturize, its also serves as a bacterio- and fungicide.

H^+ ions produced by the breakdown of water, are actively transported out of the cell, consuming one ATP each (powering against the huge concentration gradient across the gastric lining); this reaction is catalyzed by carbonic anhydrase: $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$ ≈ 55kJ of energy is required to generate 1mol H^+.

A Cl^-/HCO_3^- exchange pump resides on the basolateral membrane importing the Cl^- and exporting to the extracellular fluid the HCO_3^- ions. The Cl^- then channels passively through the parietal cell into the gastric lumen on the apical membrane.

Gastrin, a gastric hormone (deriving from polyric cells of the lower stomach), triggers formation of HCl and pepsin. Secretion is enhanced with foods such as caffeine, alcohol, and active ingredients in spices; but stops when gastric pH falls below 2.

- Negative Feedback Loop: Gastrin is secreted in response to intragastric protein, stomach distension, and input from the vagus nerve. Gastric inhibitory peptide (GIP), liberated from the small intestine in response to high levels of fatty acids, inhibits these activites.

Mucin: Special mucus secreting (***goblet***) cells located in-between chief- and parietal cells as well as in the upper gastric gland (gastric pit), protect the gastric lining from self-digestion.

Pepsinogen / Pepsin: A proteolytic enzyme in the form of pepsinogen, that converts under low pH to pepsin; Pepsinogen is excreted by ***chief*** cells of the lower portion of the gastric gland. Pepsin is an edopeptidase which selectively cleaves inner peptide bonds (next to carboxylic side groups) of large protein molecules.

Important Minerals

Macrominerals and their functions	
Calcium (Ca)	Component of bones and teeth, muscle contraction, blood clotting, hormone secretion
Phosphorus (P)	Component of bones and teeth, energy metabolism; component of nucleic acid and lipids
Chlorine (Cl)	Principal extracellular negative ion; water balance; acid-base balance; formation of gastric HCl
Sulfur (S)	Component of many proteins
Potassium (K)	Main intracellular positive ion; transmission of impulses in nerve and muscle (effects membrane permeability); acid-base balance; protein synthesis
Sodium (Na)	Main intracellular positive ion; transmission of impulses in nerve and muscle; acid-base balance; water balance
Magnesium (Mg)	Appropriate balance between Mg and Ca needed for nerve and muscle function; lack of Mg leads to cramps; activates enzymes
Microminerals and their functions	
Chromium (Cr)	Required in the glucose metabolism; lack of Cr reduces glucose uptake
Cobalt (Co)	Component of cobalamin (vitamin B_{12}); synthesis of red blood cells
Copper (Cu)	Enzyme activation (thyrosinase); synthesis of hemoglobin; lack of Cu interferes with pigmentation and *anemia*;
Iodine (I)	Component of thyroid hormone, boosts metabolism; lack of I leads to goiter in adults and cretinism in infants; *anemia* due to inhibited synthesis of B_{12}
Flour (F)	Incorporated into the enamel of teeth; excess F stains teeth grayish
Iron (Fe)	Component of hemoglobin, myoglobin, and cytochromes; deficiency first leads to *Regads* (torn angles of the mouth), tiredness, and in severe cases to *anemia* (deficiency in red blood cells)
Manganese (Mn)	Enzyme activation (pyruvat-decarboxylase); lack of Mn leads to sterility and *Chondro-dystrophy* (malformations of the bones);
Molybdenum (Mo)	Enzyme activation (aldehyd-oxidase)
Selenium (Se)	Enzyme activation (glutation-peroxidase); antioxidant; lack of Se could lead to *muscular atrophy*; liver-, muscle-, and heart disturbances; depression of the immune system; decreased pathogenic resistance;
Zinc (Zn)	Enzyme activation (carbohydrase, alcohol- and lactat-dehydrogenase); lack of Zn can be a cause of *Anorexia*, altered sense of taste (gustin relies upon Zn), loss of hair, *Alopecia*, retarded wound healing

Common Vitamins

Vitamin	Common Sources	Function	Symptoms of Deficiency
Water soluble (hardly any overdose possible)			
B_1,Thiamine	Yeast, meat, whole grains, eggs, milk, green veggies	B_1 pyrophosphate coenzyme in decarboxylation reactions during carbohydrate meta-bolism (enzyme activator – decarboxlase); heat sensitive; alcoholics have an increased demand of B_1	*Beriberi*: spasms or rigidity of legs, nerve & muscle degeneration; deficiency of heart activity, depression, forgetfulness;
B_2,Riboflavin	same as B_1; colon bacteria	Flavin mononucleotide and flavin dinucleotide (FMN, FAD) are coenzymes for dehydro-genase reactions - electron transport in mitochondria and certain oxidations in the ER(endoplasmc reticulum)	Similar to PP deficiency, cracking finger nails and lips; *Rhagaden*, depression, malforma-tion of the unborn
B_6,Pyridoxine	same as B_1	Pyridoxol-phosphate is a coenzyme for many reactions involving amino acid metabolism: transamination, decarboxylation, etc.; essential for brain-, heart-,and liver activities	Dermatitis, gastro-intestinal disturbances, *Anemia*, skin disorders, depressions, cramps
B_{12}, Cobalamin	Synthesized by intestinal bacteria, in animal foods only	Intrinsic factor; Co-containing coenzymes involved in amino acid conversion and for DNA synthesis; cell division; synthesis inhibited in alcoholics;	Decreased RNA activity resulting in *Anemia*; inflam-mation of nervous tissue
C, Ascorbic Acid	Citrus fruits and fresh veggies	Maintenance of intercellular substances: collagen fibers of connective tissue, capillary walls, helps in the absorption of Fe; involved in the buildup of teeth, bones, and the formation of blood and stress hormones	*Scurvy*: bleeding gums, loosening of teeth (*Gingivitis* – smoking), slow wound healing;
H, Biotin	Bacteria, Plants (readily available) and animals, yeast (bound to proteins)	Involved in skin formation; decomposition of carbohydrates and as a building factor of certain proteins; has anti-oxidative properties	Inflamed and scaly skin, pallid tongue, *conjunctivitis* sensitive eyes
PP, Niacin, Nicotinic acid	same as B_1	**P**ellagra **P**reventive (*pelle agra*); Nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP)are coenzymes for many dehydrogenase reactions in cellular oxidation	*Pellagra*: cracked, scaly skin, dark-red tongue & mouth irritated mucous membr. (*diarrhea*), nervous disorders (*shaker*), insanity
Folic Acid	same as B_1	Coenzyme tetrahydrofolic acid converts glycine to serine; required in DNA synthesis; cell division	Similar to B_{12} deficiency, *Anemia*, disturbed growth of hair and bone; inflamma-tions of mucus membrane
Pantothene, Pantothenic acid	coenzyme A in every living cell, as in yeast, whole grain, liver, kidney, egg, veggies	part of coenzyme A and essential in the bodies metabolism; hair, tissue and mucus membrane formation require panthotene as well as synthesis of antibodies	Likelihood of infections in the gastrointestinal tract, growth retarding, *Burning feet* syndrome
Fat soluble			
A, Retinol	Butter, eggs, fish liver oils, plants; carotene in plants can be con-verted to vitamin A	Component of the light-sensitive pigment, visual purple, in the retina; maintenance and growth of epithelial cells (skin); functioning sexual organs;	Night blindness, inflammation of eyes, dry and scaly skin, increased susceptibility to infection
D_2, Ergo- D_3, Chole- -calciferol	Butter, eggs, fish oils, liver; formed in skin w/ UV light	Absorption and utilization of Ca and P; required in muscle activity and blood clothing, signal transmission of nerves, cell permeability	*Rickets*: weak bones and defective teeth, *osteoporosis*,
E, α-Tocopherol	Veggie-+-oil, , egg yolk, milk fat, liver, widely distributed	Not completely known, antioxidant (protects cell membranes – lipids), maintains muscle	Ruptured red blood cells, anemia, sterility, neg. effects on muscle and nervous tissue
K, Phyto-menadion	Green veggies, colon bacteria	Quinone compounds - generated by intestinal bacteria for the synthesis of blood-clotting proteins in the liver	Bleeding, especially in newborns, who lack bacteria

Summary of functions and secretions* of the digestive tube and accessory organs

Digestive tube			Accessory organ		
Organ	Function	Secretion	Organ	Function	Secretion
Mouth	Teeth breaks up food particles		**Salivary Glands**	• Moisten food	• Saliva lubricates • Amylase cleaves starch • Bicarbonate neutralizes
Pharynx	Swallowing				
Esophagus	Transports foods				
Stomach	• Stores and churns food • Initiates protein digestion • Limited absorption	• Pepsin cleaves protein • HCL activates enzymes, breaks up food, kills germs • Mucus protects stomach • Gastrin stimulates HCl and pepsin-ogen secretion	**Liver**	• Breaks down and builds up many bio-molecules • Stores vitamins and iron • Destroys old blood cells • Detoxifies poisons	• Bile aids in lipid digestion
Small Intestine	• Completes digestion • Absorbs nutrients	• Mucus protects gut wall • Peptidase cleaves proteins • Sucrase cleaves sugars • Amylase cleaves starch + glycogen • Lipase cleaves lipids • Nuclease cleaves nucleic acids • Secretin stimulates secretion of pancreatic juices, and inhibits gastrin production • CCK triggers the release of pancreatic juices and bile from the gallbladder	**Gall Bladder**	Stores bile	
			Pancreas	• Adds digestive enzymes • Neutralizes stomach acid • Regulates blood glucose levels	• Bicarbonate neutralizes stomach acid • Trypsin and chymotrypsin cleave proteins • Carboxy-peptidase cleave peptides • Amylase cleaves starch and glycogen • Lipase cleaves lipids • Nucleases cleave nucleic acids • Insulin causes body cells to take up glucose • Glucagon causes cells to release glucose
Large Intestine	• Reabsorbs water, ions, vitamins • Stores wastes				
Appendix	• No known digestive function • Contains cells of the immune system (Lymphatic system)				
Rectum	Expels wastes				
Anus	Opening for waste elimination				

(*) excluding mucus and water, which make up some 95% of the actual secretions

Glossary Human Biology 2 **Metabolism**

Cytosol: The unstructured aqueous phase of the cytoplasm between the structured organells.
Metabolic Pathway: A sequence of enzymatic reactions involved in the alteration of one substance into another.
Metabolism: The totality of physical and chemical processes involved in anabolism, catabolism, and cell energetics.

Mitochondrion (pl. Mitochondria): A microbody that provides cells with energy in form of ATP-molecules by breaking down certain C-containing molecules (glucose) into water and CO_2 (needs O_2). They are defined by two limiting membranes. Sizes and shapes of M vary considerably within one cell, mitochondria move, change shape, divide and fuse; Mitochondria do have their own genome. This DNA encodes the cytochrome (e-transport chain), rRNA, tRNA. By far the most mitochondria are found in smooth muscle tissue of the heart.

- **Matrix**: It contains several copies of the circular mitocondrial DNA molecules, many mitochondrial ribosomes, and hundreds of enzyme molecules, including those that carry out the reaction of the Krebs cycle. Due to the continues deprotonizing activity of the electron transport chain, the matrix predominantly is alkaline (high pH).
- **Membrane**: A two-layered phospholipid sheet perforated with heaps of proteins, sugar lipids, glycoproteins, and anchoring sites of cytoskeletal fibers.
  Intermembrane space: The space between the inner and outer layer in which the electron transport chain discharges protons (H^+) during the final steps of aerobic respiration, rendering this space very acidic.
  Inner M.: The site of the final steps of the aerobic pathway, housing the electron transport chain and ATP-synthesizing enzymes, which can only perform properly with a steep pH gradient.
  Cristae: The part of the inner membrane that forms folds or invaginations (increases surface area to extend the energetic output and to prevent the electrons of the electron transport chain to reconvert into the energetically lower state), which project into the interior of the organelle. Cristae may be shelflike or tubular.
  Outer M.: The outer layer houses large membrane-bound proteins that perforate the membrane to allow the passage (active or passively) of small molecules required in aerobic phosphorylation; **in**: pyruvate, ADP+P_i, O_2, NAD^+, FAD **out**: ATP, NADH, $FADH_2$, CO_2, H_2O and others (malate, fatty acids, steroids, amino acids, heme-pigments, etc.)

Metabolic ATP-Synthesis: The final digestive steps in which an aerobic pathway breaks down glucose (oxidative pathway of glucose) or fatty acids (oxidative pathway of FA) to CO_2 and H_2O, consumes O_2 as a final electron acceptor, and produces a total of 36 ATP per molecule of glucose.

- **Preliminary Steps**: Two major although different pathways are utilized by cells to obtain the starting components which fuel the Krebs cycle and the successive energy bucket brigade:
  b-**Oxidation of Fatty Acids**: A series of reactions occurring in the matrix of mitochondria, that degrades fatty acids (at the β-carbon) to AcetylCoA consuming 1 ATP. The series of reactions does not require the presence of oxygen to occur - essential for the brain to function.
  $C_6H_{12}O_6 + 2ADP + 2P_i + 2NAD^+ \rightarrow 2C_3H_4O_3 + 2ATP + 2NADH + 2\ H^+ + 2H_2O$
  Glycolysis of Glucose: (Gk. glyk, sweet; lysis, dissolution) A series of *anaerobic* reactions in the cytoplasms of a cell, that converts glucose to pyruvate w/ the concomitant production of a small amount of ATP (highly exergonic). Glucose is essential for grain function.
  $C_6H_{12}O_6 + 2ADP + 2P_i + 2NAD^+ \rightarrow 2C_3H_4O_3 + 2ATP + 2NADH + 2\ H^+ + 2H_2O$
- **Krebs Cycle**: A series of 8 major reactions w/n mitochondria, following glycolysis, in which acetate residues are degraded to CO_2 and NADH. Under aerobic conditions, the generation of energy (ATP, NADH, $FADH_2$) from glucose is the oxidative decarboxylation of pyruvate (oxalacetate on both sides of EQ):
  acetylCoA + $3NAD^+$ + FAD + GDP + P_i + $2H_2O \rightarrow 2CO_2$ + 3NADH + $FADH_2$ + GTP + $2H^+$ + CoA
- **Electron Transport Chain**: The energy bucket brigade - the voltage gradient across the mitochondrial wall, drives electrons along with H^+ ions to O_2 to generate water: $1/2O_2 + NADH + H^+ \rightarrow H2O + NAD^+$

Aerobic Metabolism: Foodstuff molecules are oxidized completely to CO_2, and H_2O by molecular O_2.
Energy harvest of the glycolytic pathway: Total production = 36 ATP molecules
Energy harvest of the fatty acid pathway: Total production = 106 ATP molecules
Regarding oxygen-consumption, phosphorylation and complete oxidation of glycerol yields 6.5mol ATP, glucose 6.34mol ATP, and free fatty acids 5.61mol ATP.

Process	Raw Material	O_2 required	ATP's used	ATP's produced	End products
• β-Oxidation	FA, FAD, NAD^+,	No	1	0*	NADH, $FADH_2$
• Glycolysis	Glucose, NAD^+	No	2	4	Pyruvate, NADH
Krebs cycle	Pyruvate, NAD^+, FAD	No	0 (2*)	2 (28*)	CO_2, NADH, $FADH_2$
Electron TC.	NADH, $FADH_2$	Yes	0	32 (80*)	H_2O, NAD^+, FAD

(*) Oxydation of palmytol-CoA yields 10.5ATP from 7$FADH_2$, 17.5ATP from 7NADH, and 80ATP from the 8 moleculesof acetyl-CoA; 2ATP are consumed in the activation of palmitate.

- **Oxidative phosphorylation**: The substrates needed are pyruvate, fatty acids, ADP, and P_i. They are transported to the matrix from the Cytosol by transports; O_2 diffuses into the matrix. A shuttle system provides free electrons from cytosolic NADH to generate mitochondrial NADH. Fatty acids, and Pyruvate are needed to keep the Krebs-cycle running which provides the mediators for the electron transport chain. ATP is transported to the Cytosol in exchange for ADP and P_i, CO_2 diffuses out from the mitochondrial matrix into the Cytosol across the mitochondrial membranes:

  $$NADH + H^+ + 3ADP + 3P_i + ½O_2 \rightarrow NAD^+ + 4H_2O + 3ATP$$

- **Synthesis of ATP-**: (the F_0F_1 ATPase complex) The F_0 portion is an integral membrane protein; the F_1 portion forms the head and is bound to the F_0 subunits. The synthesis of ATP from ADP and P_i occurs spontaneously at a catalytic site of F_1, due to tight binding of ATP to this site. Proton movement through F_0, driven by the proton-motive force, promotes the catalytic synthesis of ATP by causing the bound ATP to be released; this frees up the site for the binding of ADP and P_i, which, in turn, spontaneously combine to form another tightly bound ATP; the entire process is osmotically coupled.

Anaerobic M.: Foodstuff ,molecules are oxidized incompletely to lactic acid (CH_3-CHOH-COOH).
Lactic acid formation represents not only energetic escape route but also helps to gain time when oxygen is not readily available. Being an acid, lactate lowers the pH considerably; therefore lactic acid can be transported via the blood stream to the liver, where it is resynthesized to glucose (gluconeogenesis) or reconverted at the site of origin into pyruvate via the enzyme lactate-dehydrogenase.
To avoid excess production of lactate, oxygen is stored in the following tissues: myoglobin of muscles, hemoglobin, residual air of the lungs, dissolved in various body tissues.
Energy harvest of the glycolytic pathway: Total production = 2 ATP molecules
Energy harvest of the fatty acid pathway: Total production = 0 ATP molecules

Process	Raw Material	O_2 required	ATP's used	ATP's produced	End products
• β-Oxidation	FA, FAD, NAD^+,	No	1	0	NADH, $FADH_2$
• Glycolysis	Glucose, NAD^+	No	2	4	Pyruvate, NADH
Fermentation	Pyruvate, NADH	No	0	0	NAD^+, ethanol or lactate and H_2O

Other means of anaerobic ATP-snythesis: A deficiency of ATP can be overcome by lifting a fraction of metabolites back to an energy-richer level:

- ADP + ADP → ATP + AMP ??????????????????????
- Creatine-P + ADP → ATP + Creatine ??????????????

Nutrients: Organic compounds used in the synthesis of new bio-molecules and as fuel (see HB-digestion and scan below).

Carbohydrates: Source of metabolic energy; mono-saccharides (glucose), disaccharide (sucrose), polysaccharides (starch, amylose, amylopectin); all together feed the glycylatic pathway of cellular respiration via glucose, pyruvate, and Acetyl-CoA.

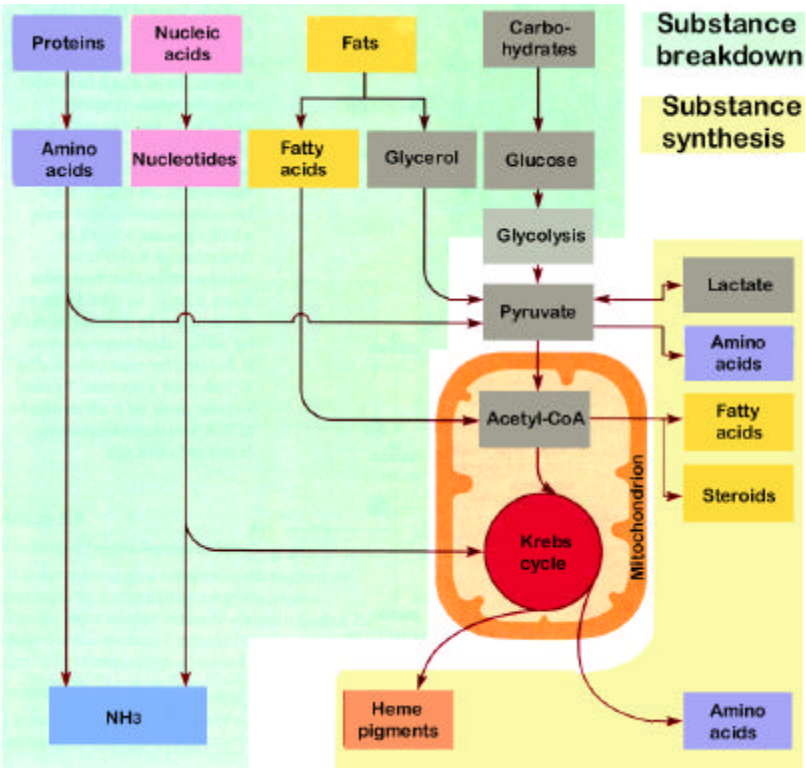
Lipids: Energy storage nutrients like fatty acids: Lipids provide twice as much energy than glucose does and does not mix with water – every glucose molecule binds about 2g of H_2O; lipid intermediates in the form of fatty acids (Acetyl-CoA) and glycerol (pyruvate) feed the aerobic pathway.

Minerals: *Inorganic* chemical elements, i.e.: Ca, Fe, I, K, Mg, Na, P, S, etc.

Proteins: Source of amino acids. Only a certain extent is stored in the body, large quantities are excreted as nitrogenous waste; intermediates feed the preliminary step of the Krebs cycle in the form of Acetyl-CoA.

- **Essential Amino Acids** (not synthesizeable by the body itself): leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.

Vitamins: Simple *organic* compounds not manufactured by the body i.e.: A, E, D, K etc.



The Metabolic Clearinghouse:
While only certain molecules can feed directly into the Krebs cycle, biological polymers - proteins, nucleic acids, fats and polymers - can themselves be broken down into constituent parts, and these can be modified into intermediates that feed into the cycle. In this way, an organism can harvest energy not just from glucose but from any of the biological polymers. In addition, Krebs cycle intermediates can be removed from the cycle and modified into new materials for the cell, including amino acids, fatty acids, steroids, and iron-containing heme pigments.