11.93.3 Relationship between a sympathetic trunk and spinal cord. (1-5) various courses that preganglionic sympathetic fibers (red lines) may take through the sympathetic trunk. Blue lines represent postganglionic fibers.

Rami communicantes from the chain ganglia and are distributed to the autonomic effectors in the areas supplied by these spinal nerves (Fig. 11.93.3, part 5); for example, to the smooth muscles of blood vessels, sweat glands and pilomotor muscle of hair, etc.

Important Note
Approx. 80% of the fibers in the average skeletal nerve are sympathetic fibers.

5. Some preganglionic fibers pass through the paravertebral ganglion chain (sympathetic trunk) and end on the postganglionic neurons located in the collateral ganglia (prevertebral ganglia) — the coeliac, superior and inferior mesenteric ganglia. These ganglia lie far away from the spinal cord, closer to the innervated organs.

6. In the sympathetic chain, there is a ganglion for each segment except in the neck region, where several ganglia merge to form large ganglia. For example,
inferior cervical ganglion fuse with T₁ ganglion to form stellate ganglion.

Important Note
Upon entering the sympathetic chain, the preganglionic fibers may pass directly through or else travel upwards or downwards to form synaptic contacts with ganglionic neurons in other ganglia, therefore, sympathetic activity is spread over many segments.

Exceptions
(i) Uterus is innervated by a special system of short adrenergic neurons, with cell bodies in the uterus and the preganglionic fibers to these postganglionic neurons go all the way to uterus.
(ii) Adrenal medulla, preganglionic fibers directly supply the adrenal medulla, where the postganglionic neurons have lost their axons and become specialized for secretion directly into the blood stream. It is, therefore, not really a ganglion at all, it is an ‘endocrine gland’ whose secretion is controlled by the sympathetic preganglionic nerve fibers.

S. The sympathetic ganglia can act either as:
(i) automatic relay stations with practically no change in the information they transmit to the effector organ; or
(ii) as important integrating centers capable of generating individualized responses.

The anatomical arrangements in the sympathetic nervous system to some extent tie the entire system together so it can act as a single unit, although small segments of the system can still be regulated independently.

B. PARASYMPATHETIC DIVISION OF ANS
1. The nerve fibers of this division leave the CNS from the brain and the sacral portion of the spinal cord, therefore, it is also called the Craniosacral division. Here the synapse between the pre and postganglionic neurons occur in the parasympathetic ganglia which are located within or near the effector organs (exceptions: sphenopalatine and otic ganglia).

2. Cranial outflow. It supplies the visceral structures in the head via the oculomotor (III) nerve; facial (VII) nerve and glossopharyngeal (IX) nerve; and those in the thorax and upper abdomen via vagus (X) nerve.

3. Sacral outflow. It supplies the pelvic viscera via the pelvic branches of the 2nd to 4th sacral spinal nerves.

Important Note
Approx. 75% of all parasympathetic nerve fibers in the vagus (X) nerve.

CHEMICAL TRANSMISSION AT AUTONOMIC JUNCTIONS
1. In both sympathetic and parasympathetic division, the major neurotransmitter released between pre and postganglionic fibers is A-ch (Fig. 11.93.4).
2. In the parasympathetic division, the main neurotransmitter between the postganglionic fiber and the effector cells is also A-ch.
3. In the sympathetic division, the main transmitter between the postganglionic fibers and the effectors is usually nor-epinephrine (NE).

Important Note
A-ch is released by some sympathetic postganglionic endings (page 338). Moreover, one or more substances known as cotransmitters are usually stored and released with the autonomic neurotransmitters; for example – VIP is released with A-ch; ATP and neuropeptide Y with NE (page 1086).

4. On the basis of the chemical transmitter released, the neurons in the entire nervous system are either cholinergic or adrenergic.
   (i) Cholinergic neurons i.e. neurons which secrete A-ch at their nerve endings. Examples include
   (a) all preganglionic autonomic (parasympathetic as well as sympathetic) endings
   (b) postganglionic parasympathetic endings
   (c) postganglionic sympathetic endings which innervate sweat glands, skeletal muscle blood vessels i.e. sympathetic vasodilator nerves
(d) neuromuscular junction
(e) many parts of the brain (specially cerebral cortex [page 1076], thalamus [PGO spike page 1020] and forebrain nuclei [page 1076])
(f) endings of some amacrine cells in the retina (page 1153).

(ii) Adrenergic neurons i.e. neurons which secrete NE or epinephrine at their nerve endings. Examples:
(a) postganglionic sympathetic endings other than (c) above
(b) cerebral cortex
(c) hypothalamus
(d) cerebellum
(e) brain stem
(f) spinal cord, and
(g) adrenal medulla.

Note
Initially it was believed that epinephrine (British name adrenaline) is the major sympathetic postganglionic neurotransmitter and nerve fibers that release epinephrine came to be called adrenergic fibers.

6. Many of the drugs that stimulate or inhibit various components of the ANS affect receptors for A-ch and NE. There are several types of receptors for each neurotransmitter.
(i) A-ch receptors on all autonomic (sympathetic and parasympathetic) postganglionic neuronal membranes respond to low doses of the drug nicotine and are therefore called nicotinic receptors. (Ligand-gated ion channel receptors).
(ii) The A-ch receptors on the membrane of smooth muscle, cardiac muscle, and gland cells are not stimulated by nicotine but are stimulated by the mushroom poison ‘muscarine’; they are called muscarinic receptors. (G-protein-coupled receptors). These receptors are blocked by atropine.
(For differences between two types of A-ch receptor actions, refer page 1082.)

Note
Cholinergic receptors on the neuromuscular junction of the skeletal muscle fibers, innervated by the ‘somatic’ motor neurons, are also nicotinic (page 155).

(iii) There are two major classes of adrenergic receptors, also distinguished largely by the specific drugs that stimulate or block them, α and β-adrenergic receptors:
(a) activation of α-adrenergic receptors results in excitatory effects on smooth muscles of most of the tissues; and inhibitory on many neural and metabolic functions. These effects are mediated by the opening of specific ion channels in the plasma membrane;

![Diagram](image-url)

Fig. 11.03.4 Transmitter used in various components of the peripheral nervous system (Ep: Epinephrine, NE: Nor-epinephrine)
Summary: Adrenergic and Cholinergic receptors in the ANS

### Adrenergic Receptors

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Location</th>
<th>Response</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_1$</td>
<td>Widespread, found in most tissues; not in the heart.</td>
<td>Excitation, stimulation of metabolism.</td>
<td>Activation of enzymes, release of intracellular Ca$^{2+}$.</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>Sympathetic and parasympathetic neuroeffector junctions.</td>
<td>Inhibition of neurotransmitter release.</td>
<td>Reduction in cAMP concentrations.</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>Heart, kidneys, liver, adipose tissues.</td>
<td>Stimulation, increased energy consumption.</td>
<td>Enzyme activation.</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>Smooth muscles in vessels of heart and skeletal muscle, intestinal muscles, lungs and bronchi.</td>
<td>Inhibition, relaxation.</td>
<td>Enzyme activation.</td>
</tr>
</tbody>
</table>

### Cholinergic Receptors

<table>
<thead>
<tr>
<th>Type</th>
<th>Summary</th>
<th>Response</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicotinic</td>
<td>All autonomic (sympathetic and parasympathetic) synapses between pre and postganglionic neurons; neuro muscular junctions.</td>
<td>Stimulation, excitation.</td>
<td>Opening of chemically regulated Na$^+$ channels</td>
</tr>
<tr>
<td>Muscarinic</td>
<td>All parasympathetic neuro-effector junctions, cholinergic sympathetic neuroeffector junctions.</td>
<td>Variable.</td>
<td>Enzyme activation via G-protein causing changes in membrane permeability to K$^+$.</td>
</tr>
</tbody>
</table>

(b) **activation of $\beta$-adrenergic receptors** results in excitatory effects on heart, neural and metabolic functions; and inhibitory effects on some smooth muscles. These functions are mediated by the generation of second messenger (cAMP).

(iv) Both nicotinic and $\alpha$- and $\beta$-adrenergic receptors are further subdivided into $\mathrm{N}_1$, $\mathrm{N}_2$, $\alpha_1$, $\alpha_2$ and $\beta_1$, $\beta_2$ respectively; again according to the drug that influences them (for details, refer to page 764).

Two divisions of ANS act in a complementary (opposite) manner. Some of the organs like the heart and many glands and smooth muscles in walls of the hollow viscera are innervated by both sympathetic and parasympathetic fibers, that is, they receive **dual innervation**. Whatever effect one division has on the effector cells, the other division frequently has just the opposite effect. Dual innervation by nerve fibers that cause opposite responses provides a very fine degree of control over the effector organ.

3. **Two divisions of ANS act in a synergistic (cooperative) manner**: In the case of **sphincter muscles**, both adrenergic and cholinergic innervation are excitatory, but one supplies the constrictor component of the sphincter and other the dilator. **Example**: Iris muscles in the eyes, sexual function (Table II.93.2)

4. (i) There is usually no A-ch in the circulating blood, and the effects of localized cholinergic discharge are generally discrete and of short duration because of the high concentration of acetyl cholinesterase at cholinergic nerve endings.

**Note**

The responses produced in postganglionic neurons by stimulation of their preganglionic neuron include not only a fast EPSP that generate action potential but also a slow EPSP and IPSP (page 887). These slow response modulate and regulate transmission in autonomic ganglia.

**RESPONSES OF EFFECTOR ORGANS TO AUTONOMIC NERVE IMPULSE**

**General Principles**

(Also refer to page 764)

1. Some of the organs are innervated by one division of ANS only, such as:

   - (i) uterus, adrenal medulla, pilomotor muscle in the skin, sweat gland and most arterioles from the sympathetic division only; while
   - (ii) the lacrimal glands, ciliary muscle of eyes, glands of stomach and pancreas from the parasympathetic division only.
NE spreads farther and has a more prolonged action than A-ch. It diffuses into the bloodstream from adrenergic nerve endings; while epinephrine and dopamine come from the adrenal medulla.

It acts mainly on α-receptors; it also acts on receptors but has no action on β-receptors. Unlike epinephrine, it acts equally on both α and β receptors, it has a special property of stimulating β-receptors.

Epinephrine and epinephrine are equally potent with respect to their action on α1, α2 and β1 receptors at β2 receptors are relatively selectively activated by epinephrine, i.e., they are more sensitive to epinephrine than NE. Therefore, both NE and epinephrine are equally strong as vasoconstrictors in many tissues (skin, viscera) but they differ with reference to effects on large vessels, lungs, heart, etc., play a significant role in respiratory and circulatory reflexes.

1. Afferents from the visceral organs
   (i) most of these fibers transmit pain impulses, other serve as afferent links eliciting reflexes e.g. emptying of urinary bladder, colon, rectum, etc.
   (ii) Baroreceptors and chemoreceptors: afferents from large vessels, lungs, heart etc. play a significant role in respiratory and circulatory reflexes.

2. Somatic afferent fibers. These fibers come mainly from the skin, mucous membrane, muscles and tendons.

3. Afferents from the taste, olfactory tract and vestibular organ can also modify the activity of ANS.

### Important Notes

1. In humans, β-adrenergic mechanism predominates.

### Table 11.93.2: Major effects of ANS activity

<table>
<thead>
<tr>
<th>Effector organ</th>
<th>Sympathetic effect</th>
<th>Parasympathetic effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iris muscle</td>
<td>Constricts radial muscle (dilates pupil) via α1</td>
<td>Contracts sphincter muscle (constricts pupil)</td>
</tr>
<tr>
<td>Ciliary muscle</td>
<td>Relaxes (flattens lens for far vision) via β2</td>
<td>Contracts (makes lens to become more convex for near vision)</td>
</tr>
<tr>
<td>Heart</td>
<td>s heart rate via β1, β2</td>
<td>s heart rate</td>
</tr>
<tr>
<td>SA node</td>
<td>s contractility and conduction velocity via β1, β2</td>
<td>s contractility and conduction velocity</td>
</tr>
<tr>
<td>Atria</td>
<td>s conduction velocity via β1, β2</td>
<td>s conduction velocity</td>
</tr>
<tr>
<td>AV node and conduction system</td>
<td>s contractility and conduction velocity via β1, β2</td>
<td>s contractility slightly (indirectly)</td>
</tr>
<tr>
<td>Ventricles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterioles</td>
<td>Constricts (via α1, α2) or dilates (via β2)</td>
<td>Dilates</td>
</tr>
<tr>
<td>Coronary</td>
<td>Constricts (via α1, α2)</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>Constricts (via α1, α2)</td>
<td></td>
</tr>
<tr>
<td>Skeletal muscle</td>
<td>Constricts (via α1) or dilates (via β2)</td>
<td></td>
</tr>
<tr>
<td>Abdominal viscera and kidneys</td>
<td>Constricts (via α1, α2) or dilates (via β2)</td>
<td></td>
</tr>
<tr>
<td>Penis or clitoris</td>
<td>Constricts</td>
<td></td>
</tr>
<tr>
<td>Veins</td>
<td>Constricts (via α1, α2) or dilates (via β2)</td>
<td>Dilates (produces erection)</td>
</tr>
</tbody>
</table>

A reference list of the ANS effects are given in Tables 11.93.2 and 11.93.3.
### Table 11.93.2: Major effects of ANS activity

<table>
<thead>
<tr>
<th>Effector organ</th>
<th>Sympathetic effect</th>
<th>Parasympathetic effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lungs</strong></td>
<td>Relaxes (via $\beta_2$)</td>
<td>Constricts</td>
</tr>
<tr>
<td>Bronchial muscles</td>
<td>Inhibits secretion (via $\alpha_1$) or stimulates (via $\beta_2$)</td>
<td>Stimulates secretion</td>
</tr>
<tr>
<td>Bronchial glands</td>
<td></td>
<td>Stimulates secretions (watery secretions)</td>
</tr>
<tr>
<td><strong>Salivary glands</strong></td>
<td>Stimulates secretion (thick secretions) (via $\alpha_1$)</td>
<td>$\uparrow$ $s$</td>
</tr>
<tr>
<td><strong>Stomach and Intestine</strong></td>
<td>$\downarrow$ $s$ (via $\alpha_1$, $\alpha_2$, $\beta_2$)</td>
<td>Relaxes</td>
</tr>
<tr>
<td>Motility, tone</td>
<td>Constricts (via $\alpha_1$)</td>
<td>Stimulates, specially enzymes</td>
</tr>
<tr>
<td>Sphincters</td>
<td>Inhibits (via $\alpha_2$)</td>
<td>Contracts</td>
</tr>
<tr>
<td>Secretion</td>
<td></td>
<td>Glycogen synthesis</td>
</tr>
<tr>
<td><strong>Gall bladder</strong></td>
<td>Relaxes (via $\beta_2$)</td>
<td>Stimulates secretion (via $\alpha_1$)</td>
</tr>
<tr>
<td>Liver</td>
<td>Glycogenolysis (via $\alpha_1$, $\beta_2$, gluconeogenesis)</td>
<td>$\uparrow$ $s$ insulin and glucagon secretion</td>
</tr>
<tr>
<td><strong>Pancreas</strong></td>
<td>Inhibits secretion (via $\alpha_1$)</td>
<td></td>
</tr>
<tr>
<td>Exocrine glands</td>
<td>Inhibits insulin and glucagon secretion (via $\alpha_1$)</td>
<td></td>
</tr>
<tr>
<td>Endocrine glands</td>
<td>and stimulates insulin and glucagon secretion (via $\beta_2$)</td>
<td></td>
</tr>
<tr>
<td><strong>Fat cells</strong></td>
<td>Increases fat breakdown, causes release of FFA (via $\alpha_2$, $\beta_2$)</td>
<td></td>
</tr>
<tr>
<td><strong>Urinary bladder</strong></td>
<td>Relaxes (via $\beta_2$)</td>
<td>Contracts</td>
</tr>
<tr>
<td>Detrusor muscle</td>
<td>Constricts (via $\alpha_1$)</td>
<td>Relaxes</td>
</tr>
<tr>
<td>Sphincter</td>
<td></td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Uterus</strong></td>
<td>Pregnant: contracts (via $\alpha_1$)</td>
<td>Erection</td>
</tr>
<tr>
<td>Pregnant and Non-pregnant: relases (via $\beta_2$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Male reproductive tract</strong></td>
<td>Ejaculation (via $\alpha_1$)</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>Contracts (erection of hairs) (via $\alpha_2$)</td>
<td>Generalized (cholinergic) sweating secretion</td>
</tr>
<tr>
<td>Pilomotor muscle</td>
<td>Localized (adrenergic) sweating (via $\alpha_1$)</td>
<td></td>
</tr>
<tr>
<td>Sweat gland</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lacrimal gland</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\uparrow$ $s$: Increases; $\downarrow$ $s$: Decreases; (*): these cells are not innervated by this branch of the ANS.

### Note

Sympathetic and parasympathetic nerves produce antagonistic effects on the organs which they both supply; however, normally the two systems act synergistically to meet the specific demands of any given situation.

### Table 11.93.3: Main differences between two major divisions of the ANS compared

<table>
<thead>
<tr>
<th>Sympathetic component</th>
<th>Parasympathetic component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. It is also called <a href="#">thoracolumbar division</a> of the ANS ($T_1$ to $L_2$).</td>
<td>It is also called <a href="#">craniosacral division</a> of the ANS (i) cranial outflow is via III, VII, IX and X cranial nerves (ii) sacral outflow is via pelvic branches of $S_2, 3, 4$ spinal nerves.</td>
</tr>
<tr>
<td>2. Preganglionic fibers are short, myelinated and end either in paravertebral sympathetic ganglionic chain or prevertebral ganglion.</td>
<td>2. Preganglionic fibers are long, myelinated and end on short postganglionic neurons located on or near the visceral structure.</td>
</tr>
<tr>
<td>3. Postganglionic nerves are long and nonmyelinated: (i) to the head originate in superior, middle and inferior cervical ganglia and travel to the effector organs with blood vessels; (ii) to viscera originate in coeliac and lower abdominal and pelvic ganglia.</td>
<td>3. Postganglionic nerves are short and nonmyelinated.</td>
</tr>
</tbody>
</table>
### Table 11.93.3: Main differences between two major divisions of the ANS compared

<table>
<thead>
<tr>
<th>Sympathetic component</th>
<th>Parasympathetic component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upon entering the sympathetic chain, preganglionic fibers travel upwards or downwards to form sympathetic contacts with ganglionic neurons in other ganglia, therefore, sympathetic activity is spread over many segments.</td>
<td>Very few connections link the preganglionic neuron. Moreover, parasympathetic post-ganglionic neurons are located within the organ to be controlled. Therefore, parasympathetic effect is localized i.e. target is usually a single organ or system.</td>
</tr>
<tr>
<td>It prepares the individual to cope with the emergency i.e. prepare for either flight or fight reactions (as described by Walter Cannon). For example, its stimulation: (i) relaxes accommodation and dilates the pupil (letting more light into the eyes); (ii) increases heart rate and blood pressure (providing better perfusion of the vital organs and muscles); (iii) constricts skin blood vessels (limits bleeding from wounds); (iv) decreases threshold in the reticular formation (reinforcing the alert and arousal states); (v) increases blood glucose and FFA levels (supplying more energy). Because of these actions, therefore, this division of ANS is sometimes known as Catabolic Nervous System. The major transmitter released between pre and postganglionic fibers is A-ch whereas at postganglionic endings is nor-epinephrine.</td>
<td>It is concerned with vegetative aspect of day-to-day living. For example, (i) its action favours digestion and absorption of food by: (a) increasing activity of intestinal musculature; and (b) increasing gastric secretion and relaxing pyloric sphincter. (ii) dilates sexual erectile tissues; (iii) shows down body activities by decreasing heart rate and force of contraction; (iv) ensures storage of absorbed nutrients by increasing glycogen synthesis and insulin secretion. Therefore, sometimes, this division is referred as Anabolic Nervous System.</td>
</tr>
</tbody>
</table>

### Study Questions

1. Explain why different terms are assigned to the ANS.
2. List main differences between:
   - (i) Somatic and autonomic nervous system.
   - (iii) Cholinergic and adrenergic neurons.
3. How is sympathetic activity spread over many segments of the spinal cord? Explain how it acts as a single unit.
4. Enumerate the exceptions in the organization of two divisions of the ANS.
5. Justify the following statements:
   - (i) Autonomic output is diffuse.
   - (ii) Two divisions of the ANS act synergistically in any given situation.
   - (iii) Sympathetic nervous system is sometimes referred as catabolic nervous system whereas parasympathetic as anabolic
6. Which component of the ANS prepares the individual to cope with the emergency situation? List the body responses which are associated with it.

### MCQs

1. Autonomic ganglia are:
   - (a) Cholinergic
   - (b) Adrenergic
   - (c) Noradrenergic
   - (d) Dopaminergic
2. Sympathetic nerves in spinal cord originate between:
   - (a) C₁ - C₆
   - (b) C₇ - T₁
   - (c) T₁ - L₂
   - (d) T₁₂ - L₅
3. The maximum parasympathetic fibers are contained in the:
   - (a) III nerve
   - (b) VII nerve
   - (c) IX nerve
   - (d) X nerve
4. Atropine blocks A-ch receptors in all areas except:
   - (a) Iris
   - (b) Auerbach plexus
   - (c) A-V node
   - (d) Neuromuscular junction
5. \(\alpha_1\)-adrenergic receptors do not exist in:
(a) Iris muscle
(b) Heart
(c) Lungs
(d) Liver

6. \(\beta\)-blockade leads to all except:
(a) Hypotension
(b) Bradycardia
(c) Bronchodilatation
(d) Loss of libido

7. Head ganglion of autonomic nervous system is:
(a) Thalamus
(b) Superior cervical ganglion
(c) Hypothalamus
(d) Stellate ganglion

8. Vagal stimulation cause the following except:
(a) Increase in intestinal secretion
(b) Constriction of intestinal musculature
(c) Relaxation of bronchial musculature
(d) Fall in blood pressure

9. Fight or flight response include all except:
(a) Pupillary dilatation
(b) Generalised vasodilatation
(c) Decreased threshold in reticular formation
(d) Increased blood glucose

10. ANS regulates the activity of all of the following except:
(a) Glands of GIT
(b) Gland of skin
(c) Heart
(d) Skeletal muscle

11. Internuncial neurons are:
(a) Essential part of stretch reflex
(b) Essential part of all polysynaptic reflexes
(c) Always excitatory
(d) Always inhibitory

12. ANS is also called:
(a) Vegetative nervous system
(b) Efferent visceral nervous system
(c) Involuntary nervous system
(d) All of the above

13. What percentage of fibers in an average skeletal nerve are sympathetic:
(a) 20
(b) 40
(c) 60
(d) 80

14. Stimulation of postganglionic sympathetic neurons does not cause:
(a) Dilatation of pupil
(b) Secretion of saliva
(c) Release of epinephrine from adrenal medulla
(d) Sweating

15. Post-ganglionic sympathetic neurons stimulation causes all except:
(a) Secretion of saliva
(b) Dilatation of pupils
(c) Hepatic glycogenolysis
(d) Release of epinephrine from adrenal medulla

16. The ratio of afferent to efferent nerve fibers in vagus is:
(a) 1 : 1
(b) 2 : 1
(c) 3 : 1
(d) 4 : 1

17. Sympathetic cholinergic innervation is seen in:
(a) Apocrine sweat glands
(b) Eccrine sweat glands
(c) Iris
(d) Pancreas

18. Acetylcholine through nicotinic receptors provides:
(a) Contraction of skeletal muscle
(b) Decrease of heart rate
(c) Secretion of saliva
(d) Contraction of pupils

19. The most important response to the stimulation of \(\beta\)-adrenergic receptors is:
(a) Cerebral vasodilation
(b) Splanchnic vasoconstriction
(c) Decreased blood sugar
(d) Increased cardiac activity

20. Which of the following arterioles is least sensitive to epinephrine?
(a) Skeletal muscle
(b) Cerebral
(c) Cutaneous
(d) Renal afferent

21. Parasympathetic stimulation would decrease the following except:
(a) SA node rhythmicity
(b) Heart rate
(c) A-V conduction time
(d) Atrial contractil

22. Widespread discharge of the sympathetic nervous system will not cause:
(a) Dilatation of the pupils of the eyes
(b) Increased heart rate
(c) Decreased blood glucose concentration
(d) Increased myocardial contractility

23. Vagal stimulation following intake of food does not affect secretion of:
(a) Stomach
(b) Pancreas
(c) Parotid
(d) Gall bladder

Answers:
1. (a) 2. (c) 3. (d) 4. (d) 5. (b) 6. (c) 7. (b) 8. (c) 9. (b)
11. (b) 12. (d) 13. (d) 14. (c) 15. (d) 16. (d) 17. (b) 18. (a) 19. (d)
Clinical Anatomy of Lateral Ventricle

Hydrocephalus

- Lateral Ventricle Size

- Schizophrenia
  - Bipolar
  - Alzheimer's
  - However, not clear that it's cause or result

= Ventriculitis

= Meningitis

= Ventriculostomy - Endoscopy
Venous drainage of cerebellum
1. Superior cerebellar veins, drain into the great cerebral vein.
2. Inferior cerebellar veins, drain into adjacent venous sinuses.

Venous drainage of Brainstem
Midbrain: It is drained by basal and great cerebral veins.
Pons: These veins terminate into basal, transverse, and petrosal sinuses.
Medulla: These veins drain into basilar plexus of veins and inferior petrosal sinus.
Third Ventricle

Third ventricle is a midline cavity of diencephalon. It is a median cleft between two thalami. Anteriorly, it communicates with lateral ventricle through the interventricular foramen (foramen of Monro). Posteriorly, it communicates with fourth ventricle through cerebral aqueduct (Duct of Sylvius). There are four extensions (recesses) of third ventricle: (a) Suprapineal recess, (b) Pinea1 recess, (c) Infundibular recess, and (d) Optic recess.

Boundaries of third ventricle are:

1. **Anterior wall**: Lamina terminalis, anterior commissure, anterior columns of fornix.
2. **Posterior wall**: Pineal body, posterior commissure, cerebral aqueduct.
3. **Roof**: Ependyma lining of under surface of tela choroidea of 3rd ventricle. The choroid plexus of third ventricle projects downwards from roof.
4. **Floor**: Optic chiasma, tuber cinereum, infundibulum (pituitary stalk), mammillary body, perforated substance and tegmentum of midbrain. Optic recess is seen at the junction of floor with anterior wall.
5. **Lateral wall**: Medial surface of thalamus, hypothalamus and hypothalamic nuclei. Interventricular foramen (Monro) is seen at the junction of roof with anterior and lateral wall.

- Interthalamic adhesion connects medial surface of two thalami. Thalamus forms the lateral wall of 3rd ventricle. The interthalamic adhesion connects lateral walls of 3rd ventricle.
- Habenular stria lies at the junction of roof and lateral wall. Two striae join posteriorly at habenular commissure.
- Anterior columns of fornix run backward from anterior wall and sink into lateral wall to reach mammillary body.
FOURTH VENTRICLE

It is the cavity of hindbrain (rhombencephalon) lying between cerebellum (posteriorly), and pons and medulla (anteriorly). Superiorly it communicates with 3rd ventricle through cerebral aqueduct (aqueduct of Sylvius). Inferiorly it communicates with central canal through a median (magenic) and two lateral (Luschka) foramina. It has lateral boundaries, floor, roof and a cavity.

Lateral boundaries

- Superior laterally: It is formed by superior cerebellar peduncle. Inferior laterally: it is formed by gracile and cuneate tubercles, and inferior cerebellar peduncles (Media and Inferior).

Roof

- Upper part is formed by convergence of superior cerebellar peduncles and superior medullary velum. Lower part is formed by transverse lamina of 4th ventricle and piamater of tela choordae of 4th ventricle, and inferior medullary velum. Roof possesses a pair of choroid plexus.

Floor (Rhomboid fossa)

- It is diamond or rhomboidal shaped and is formed by posterior surface of pons (upper triangular part or pontine part) and dorsal surface of medulla (lower triangular part or medullary part) junction of pons and medulla forms intermediate part. Features of 4th ventricle are:
  • Median sulcus (midline groove) divides the floor into two symmetrical halves.
  • Lateral sulcus is present on each side of median sulcus, it presents facial colliculus formed by genu (recurring fibers) of facial nerve looping around abducent nucleus. Facial colliculus lies in pons (i.e., in pontine part of floor).
  • Hypoglossal triangle overlying hypoglossal nucleus and vagal triangle overlying dorsal nucleus of vagus. Both of these triangles lie in the medulla (medullary part of floor).
  • Vestibular area overlies vestibular nuclei, partly in pons and partly in medulla.
  • Sulcus coeruleus, a bluish area due to presence of pigmented neurons containing substantia ferruginea.
  • Superior and inferior fovea.

OTHER IMPORTANT PARTS OF BRAIN

- Basal ganglia: The basal ganglia, like the cerebellum, constitute another accessory motor system that function not by itself but in close association with the cerebral cortex and corticospinal motor control system. Infact, the basal ganglia receive

![Diagram of Brain](image-url)
v) *Limbic lobe* which includes septal area, cingulate gyrus, parahippocampal gyrus.
vi) Hypothalamus, anterior nucleus of thalamus, habenular nucleus, interpeduncular nucleus, mid brain tegment nuclear, stria medullaris thalami, fasciculus retroflexus, medial forebrain bundle.

**Anterior perforated substance**
- It is an irregularly quadrilateral area perforated by numerous small blood vessels penetrating lateral leptomening arteries arising from 1st part of middle cerebral arteries and lying in front of optic tract and behind olfactory tri
- It is a part of basal forebrain, is a region of gray matter in limbic system immediately posterior to gyrus rectus. It

mattered is confluent above with corpus striatum. It is bounded:-

A) **Medially**: Medial relations are:-
   i) *Anteromedial*: Medial olfactory striae.
   ii) *Immediate medial*: Optic tract and chiasma.
   iii) *Posteromedial*: Optic tract.

B) **Laterally**: Lateral relations are:-
   i) *Anterolateral*: Lateral olfactory stria.
   ii) *Immediate lateral*: Linen insulae (gyrus ambiens)
   iii) *Posterolateral*: Uncus.

***
eyeball. Increased CSF pressure compresses the wall of retinal vein leading to forward bulging of optic disc with oedema of the disc. Oedema of the optic disc is known as papilloedema. It can be viewed by an ophthalmoscope.
- **Lumbar puncture:** The epidural space is the space between vertebral canal and dura mater. The epidural space is deeper in the midline. The procedure is same as lumbar puncture, the needle should reach only in the epidural space and not deep to it in the dura mater. Epidural space is utilized for giving anaesthesia or analgesia (see Fig. 11.5).
- **Inflammation of pia mater and arachnoid mater is known as meningitis.** This is commonly tuberculous or pyogenic. It is characterised by fever, marked headache, neck rigidity, and a changed biochemistry of CSF.

### CEREBROSPINAL FLUID (CSF)

The cerebrospinal fluid is a modified tissue fluid. It is contained in the ventricular system of the brain and in the subarachnoid space around the brain and spinal cord. CSF replaces lymph in the CNS (Fig. 22.5).

#### FORMATION

1. The bulk of the CSF is formed by the choroid plexuses of the lateral ventricles and lesser amounts by the choroid plexuses of the third and fourth ventricles.
2. Possibly, it is also formed by the capillaries on the surface of the brain and spinal cord.

#### ABSORPTION

1. CSF is absorbed chiefly through the arachnoid villi and granulations, and is thus drained into the cranial venous sinuses.
2. It is also absorbed partly by the perineural lymphatics around the first, second, and eighth cranial nerves.
3. It is also absorbed by veins related to spinal nerves.

#### FUNCTIONS OF CSF

1. CSF decreases the sudden pressure or forces on delicate nervous tissue.
2. CSF nourishes nervous tissue. Only CSF comes in contact with neurons. Even blood cannot directly come in contact with neurons. It provides nourishment and returns products of metabolism to the venous sinuses.

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![Diagram of the brain and cerebrospinal fluid](image)

**Fig. 22.5:** Formation, circulation and absorption of CSF

- The total quantity of CSF is about 150 ml. It is formed at the rate of about 200 ml per hour or 5000 ml per day.
- The normal pressure of CSF is 60 to 100 mm of water.
Neurons cannot live without glucose and oxygen for more than 3-5 minutes. These are constantly provided by CSF.

Neural gland secretions reach pituitary gland via CSF. A major function of CSF is to cushion the brain within its solid vault. The brain and CSF have approximately the same specific gravity, so that the brain simply floats in the fluid.

There is no CSF brain barrier, so drugs can reach the neurons through CSF. There is blood CSF barrier. There are no antibodies in CNS, making infections of brain very serious entity.

**CLINICAL ANATOMY**

Drainage of CSF at regular intervals is of therapeutic value in meningitis. Certain intractable headaches of unknown aetiology are also known to have been cured by a mere lumbar puncture with drainage of CSF.

Obstruction in the vertebral canal produces **Froin's syndrome or loculation syndrome**. This is characterized by yellowish discolouration of CSF (xanthochromia) below the level of obstruction, and its spontaneous coagulation after withdrawal due to a high protein content. Biochemical examination of such fluid reveals that the protein content is raised, but the cell content is normal. This is known as **albumino-cytologic dissociation**.

**Hydrocephalus:** It is the dilatation of ventricular system and occurs due to obstruction of CSF circulation. It may be of the following types:

- **Communicating:** If the obstruction is outside the ventricular system, usually in the subarachnoid space or arachnoid granulations, it is termed as communicating. This occurs due to fibrosis following meningitis. It is also called external hydrocephalus.

  Clinical features are:
  - Head size is rather large.
  - Tense anterior fontanelle.
  - Dilated veins over thin scalp.

- **Non-communicating:** If the obstruction is within the ventricular system. It is called non-communicating or internal hydrocephalus. This is usually caused by a tumour or inflammation (Figs 22.6a and b). A shunt procedure is employed to divert the CSF from the ventricular system into the peritoneal cavity.

Figs 22.6a and b: (a) Ventricles in normal case, and (b) ventricles in hydrocephalus case

**Mnemonics**

**PAD**

- P = Pia mater
- A = Arachnoid mater
- D = Dura mater
MENINGES OF THE BRAIN AND CEREBROSPINAL FLUID

CLINICOANATOMICAL PROBLEM
An infant of 3 months was brought to a neurologist for abnormal large size of her head with, differently looking eyes. On examination, she showed large and tense fontanelles

- What is the condition called?

**Ans:** The condition is called hydrocephalus. It is due to blockage of flow of CSF. If excessive CSF collects within ventricular system, it is called internal hydrocephalus.

If excessive fluid collects in the subarachnoid space, it is called external hydrocephalus.

The treatment is surgery.

MULTIPLE CHOICE QUESTIONS

1. Which sequence lists cranial meninges in order from superficial to deep?
   a. Pia, arachnoid, dura
   b. Dura, pia, arachnoid
   c. Dura, arachnoid, pia
   d. Arachnoid, dura, pia

2. In region where two layers of dura mater separate, the gap between them contains:
   a. Dural venous sinus
   b. Epidural veins
   c. Subdural fluid
   d. Subarachnoid fluid

3. Regions of cranial dural partition is:
   a. Fossa turcica
   b. Falx cerebri
   c. Tentorium cerebelli
   d. Falx cerebelli

4. Dura and arachnoid extend up to the lower border of which vertebra?
   a. 2nd lumbar
   b. 3rd lumbar
   c. 2nd sacral
   d. 5th sacral

5. CSF perform which of following functions?
   a. Provide buoyancy for brain
   b. Cushion neural structure from sudden jerks
   c. Deliver nutrition and chemical messengers
   d. All of above

6. Which structure produces CSF in each ventricle?
   a. Choroid plexus
   b. Arachnoid villus
   c. Arachnoid granulation
   d. Diaphragma sellae

7. From subarachnoid space, CSF flows into dural venous sinus through:
   a. Lateral apertures
   b. Median aperture
   c. Arachnoid villi
   d. Arachnoid trabeculae

8. Blood brain barrier of CNS is missing or markedly reduced in which of following locations?
   a. Spinal cord and cerebellum
   b. Pituitary gland and thalamus
   c. Choroid plexus, pons and medulla oblongata
   d. Choroid plexus, hypothalamus and pineal gland

9. How much is the total volume of CSF in ml?
   a. 50
   b. 100
   c. 150
   d. 275

**ANSWERS**

1. c 2. a 3. b 4. c 5. d 6. a 7. c 8. d 9. c
**INTRODUCTION**

The spinal cord is the long cylindrical lower part of central nervous system. It occupies upper two-thirds of vertebral canal and is enclosed in the three meninges. It gives rise to 31 pairs of spinal nerves and retains the basic structural pattern.

**DISSECTION**

Study the spinal cord after it was removed from vertebral canal (see Chapter 11) and separated from the dura mater and arachnoid mater. Identify the dorsal root to the presence of dorsal root ganglion or spinal ganglion. Note the position of cervical enlargement in the upper part and lumbo-sacral enlargement in the lower part. See the numerous nerve roots surrounding the filum terminale, forming the cauda equina (Figs 23.2 and 23.3).

Cut transverse sections of spinal cord at cervical, thoracic, lumbar, and sacral regions to note the shape and size of the horns in relation to white matter (Table 23.2).

**Features**

The spinal cord is 18 inches or 45 cm in an adult male and 42 cm in adult female. It is surrounded by the three meninges (Fig. 23.1).

It extends from upper border of atlas vertebra to the lower border of first lumbar vertebra in an adult. In children it extends up to L3 vertebra. Superiorly, it is continuous with the medulla oblongata, inferiorly it terminates as conus medullaris (Fig. 23.2).

As the spinal cord is much shorter than the length of the vertebral column, the spinal segments do not lie opposite the corresponding vertebrae. In estimating the position of a spinal segment in relation to the surface of the body, it is important to remember that a vertebral spine is always lower than the corresponding spinal

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**Figure 23.1:** Spinal cord with its meninges

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**Table 23.1:** Level of vertebral levels and spinal segments

<table>
<thead>
<tr>
<th>Vertebral levels</th>
<th>Spinal segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-C7</td>
<td>C1-C8</td>
</tr>
<tr>
<td>T1-T6</td>
<td>T1-T8</td>
</tr>
<tr>
<td>T7-T9</td>
<td>T9-T12</td>
</tr>
<tr>
<td>T10-T11</td>
<td>L1-L5</td>
</tr>
<tr>
<td>T12-L1</td>
<td>S1-S5 and Cal</td>
</tr>
</tbody>
</table>

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*Note: This table shows the correspondence between vertebral levels and spinal segments.*
Mid brain = Weber = III + Cortico spinal
  
  perinaud
  Beneal = III + Medial Lemini
  ARP

Pons = < Routine Haemor
  milled Gobbles = VI + VII

Medial med. sy = XII + C / L
  Hemipleg

Lateral med. syn.
  IX, X, XII N. Palsy
  + Lateral Spinothalamic Trace
Tracts in spinal cord

Ascending tracts

<table>
<thead>
<tr>
<th>Tract</th>
<th>Termination</th>
<th>Crossing over</th>
<th>Sensations carried</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anterior spinothalamic tract</td>
<td>Joins with <em>medial lemniscus</em> in pons and ends in the <em>ventroposterolateral nucleus of the thalamus</em></td>
<td>Ascends 2 to 3 spinal segments and then Crosses to the opposite side</td>
<td>Non-discriminative touch</td>
</tr>
<tr>
<td></td>
<td>Forms the spinal lemniscus in the pons and ends in the <em>ventro-posterolateral</em> (VPL) nucleus and intra laminar nuclei of thalamus</td>
<td>Crosses to opposite side in the same spinal segment</td>
<td>Pressure (<em>st</em>)</td>
</tr>
<tr>
<td>2. Lateral spinothalamic tract</td>
<td></td>
<td>It crosses twice</td>
<td>Pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) First it crosses to opposite side in the same spinal segment</td>
<td>Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Crosses back to same side at the level of midbrain through the superior cerebellar peduncle</td>
<td></td>
</tr>
<tr>
<td>3. Anterior/ventral spinocerebellar tract</td>
<td>Ipsilateral anterior cerebellar vermis via superior cerebellar peduncle (<em>st</em> 60, PG1 93)</td>
<td>The fibers ascend ipsilaterally. They do not cross to opposite side</td>
<td>Unconscious proprioception and exteroceptive information from the lower part of the body and lower limbs</td>
</tr>
<tr>
<td></td>
<td>The fibers pass via the ipsilateral inferior cerebellar peduncle to the cerebellum (<em>st</em> 60, PG1 93)</td>
<td></td>
<td>Responsible for maintaining posture and gross movement of entire lower limb</td>
</tr>
<tr>
<td>4. Posterior/dorsal spinocerebellar tract</td>
<td></td>
<td>The fibers ascend to the <em>Nucleus gracilis</em> in lower medulla</td>
<td>Unconscious proprioception and touch, and pressure from lower half of the body and lower extremity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Responsible for the fine coordination between movements of various muscles of lower limb</td>
</tr>
</tbody>
</table>

5. Dorsal column
   a) *Fasciculus gracilis*
   b) *Fasciculus cuneatus*

*Nucleus gracilis* in lower medulla

*Nucleus cuneatus* in lower medulla

Fibers arising from *nucleus gracilis* and *cuneatus* decussate in the medulla to form the *medial lemniscus*

Conscious kinetic and static proprioception, vibration sense, discriminatory touch, and pressure from lower limb and lower half the body is carried by fasciculus gracilis and from upper limb and upper half of the body by fasciculus cuneatus (*st* 60, PG1 93)
Joints between vertebral bodies
- From axis to the sacrum, bodies of adjacent vertebrae are united by following ligaments:
  - Anterior longitudinal ligament: Attached to anterior margins of vertebral bodies. Anterior atlanto-occipital ligament is considered as continuation of anterior longitudinal ligament (LPH99).
  - Posterior longitudinal ligament: Lies in vertebral canal and attached to posterior margins of vertebral bodies. Membrana tectoria is a continuation of posterior longitudinal ligament (SPG98).
  - Intervertebral disc: It is a thick plate of fibrocartilage which has two parts: (i) central nucleus pulposus, remnant of notochord (ALMS99), and (ii) peripheral annulus fibrosus develops from sclerotome (ventral). Disc is an avascular structure (ALMS99). Prolapse of intervertebral disc is most common at lumbosacral region (L5, S1) followed by L4, L5 levels.

Curvatures of vertebral column
- During fetal life and at birth the vertebral column shows a continuous curvature with the concavity direct forwards. In fully developed spine, thoracic and sacral curvatures are 'concave forwards' and hence are called primary curvatures. Cervical (AL87) and lumbar curves are convex forwards (or concavity backwards) and are termed as 'secondary curvatures' (AL87) because they develop after birth. Cervical curvature develops 3-4 months after birth and lumbar curvature develops 12-15 months after birth.

SPINAL CORD
- The spinal cord is an elongated cylindrical lower part of CNS occupying upper two thirds of vertebral canal. It is enveloped by three meningeal layers - dura, arachnoid and pia mater. Spinal cord gives origin to 31 pairs of spinal nerves (WB90, Kerala 92, TN91) (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal). The spinal cord begins as a continuation of medulla oblongata at the level of upper border of atlas (C1 vertebra) and ends at lower border of L1 in adults (AL78, AL80, AL96, HG, PG108). In newborn its termination is at L1 level (AL78, AL80, PG108). Spinal cord is as long as vertebral canal till 3rd month of intrauterine life (PG108) and therefore vertebral column grows more rapidly so that at birth the level of termination lies at L1 level (AL80). Inferiorly spinal cord terminates as conus medullaris. It is 18 inches (45 cm) long in adult male and 42 cm long in adult female. It is not uniformly cylindrical (PG108) but shows two enlargements: cervical (C3-T3) and lumbar (L4-S3).

Spinal meninges
- Spinal meninges are continuous above with cerebral meninges. Outermost is dura mater, middle one is arachnoid mater, and innermost is pia mater. The space between dura and arachnoid matters is called subdural space. The space between arachnoid and pia matters is called subarachnoid space. Space outside the dura is called extradural (epidural) space.
- The spinal cord extends in the lower part of L1 as conus medullaris. Below the level of conus medullaris only pia mater is continued as a thin fibrous cord, the filum terminale extending to first segment of coccyx. Below lower border of L1, this collection of nerve roots is called as cauda equina (PG108). Cauda equina is formed by lower four pairs of lumbar, five pairs of sacral and one pair of coccygeal spinal nerves (PG108). Both arachnoid mater and subarachnoid space end at S3 levels (AL80). Subdural space also ends at S2 level.

Spinal nerves
- There are 31 pairs of spinal nerves (WB90, TN91, Kerala90) (8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal). Spinal nerves are mixed nerves containing both sensory and motor fibres. Each nerve is attached to spinal cord by means of a dorsal and a ventral roots. Dorsal and ventral roots join to form a spinal nerve. Thus, at each spinal segment. There are two spinal nerves (right and left) and 4 roots (right and left ventral; right and left dorsal).
- Ventral root is motor and dorsal root is sensory (NNEP). Dorsal root is characterized by the presence of a sensory ganglion, dorsal root ganglion containing pseudounipolar neuron (NNEP).
- Cervical spinal nerves emerge from the vertebral canal through intervertebral foramina above the level of their numerically corresponding vertebrae, i.e., C1 nerve emerges above atlas (C1 vertebra) through the gap between atlas and occipital bone; C2 nerve emerges through the foramen between C1 and T1 vertebrae. Thoracic, lumbar and sacral spinal nerves emerge from the vertebral canal through intervertebral foramina below the level of their numerically corresponding vertebrae, i.e., T1 nerve emerges through the foramen between T1 and T2 vertebrae and L1 emerges between L1 and L2 vertebrae.