Autonomic Innervation of the Viscera in Relation to Nerve Block

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IN RECENT YEARS nerve blocks have been used with increasing frequency in the diagnosis and therapy of visceral disease. Experience has demonstrated their effectiveness when properly applied. Proper application requires knowledge of the anatomy, physiology and pharmacology of the nervous system, including the segmental nerve supply of the viscera, as well as skill in the techniques of interrupting various pathways with local anesthetics. This article reviews certain aspects of this subject: (1) anatomy; (2) segmental supply of the viscera; (3) clinical application; and (4) research application. (Visceral pain is dealt with in another section of this symposium.) For a more comprehensive review, the reader is referred to the excellent texts of Kuntz,[1] Mitchell,[2] White, Smithwick and Simeone,[3] and Hovelacque.[4] Descriptions and clinical applications of nerve blocks can be found in several monographs.[5-11]

Anatomy

The autonomic nervous system (ANS) is here defined as that part of the nervous system regulating circulatory, respiratory, alimentary and genitourinary functions and other processes not under voluntary control. On the basis of anatomic, physiologic and pharmacologic differences, the ANS is separated into sympathetic and parasympathetic divisions, each with central and peripheral elements. The central elements are intrinsic parts of the central nervous system and are located in the cerebrum, cerebellum, brain stem and spinal cord, interconnected by nerve tracts. The peripheral elements consist of nerves, ganglia and plexuses, providing innervation to the heart, blood vessels, glands, viscera and smooth muscles throughout the body. The autonomic afferent fibers from these structures are concerned with the transmission of visceral sensation (including pain), with circulatory, respiratory and visceromotor reflexes, and with the integration of visceral activities. Although many writers have followed Gaskell's[12] and Langley's[13] suggestions that the term "autonomic nervous system" be restricted to efferent (motor) pathways, Mitchell,[2] among others, points out the irrationality of this concept. If its role is to regulate visceral function through reflex activity, it cannot do so without afferent (receptive) and intercalary (connector), as well as efferent neurons. The efferent autonomic pathways involve a two-neuron chain: the preganglionic (presynaptic, penultimate or primary) neuron and the postganglionic (postsynaptic, ultimate or secondary) neuron.

THE PARASYMPATHETIC OR CRANIAL–SACRAL DIVISION

The parasympathetic division (fig. 1) originates from three levels of the neuraxis: midbrain (tectal division); medulla (bulbar); and sacral portion of the spinal cord. The preganglionic neurons have their cell bodies in the nuclei of cranial nerves 3, 7, 9 and 10, located in the first two parts of the neuraxis, while their axons end in one of the cephalic ganglia or terminal ganglia located in the walls of viscera. The sacral parasympathetic preganglionic neurons have their cell bodies in the intermediolateral column of the middle three

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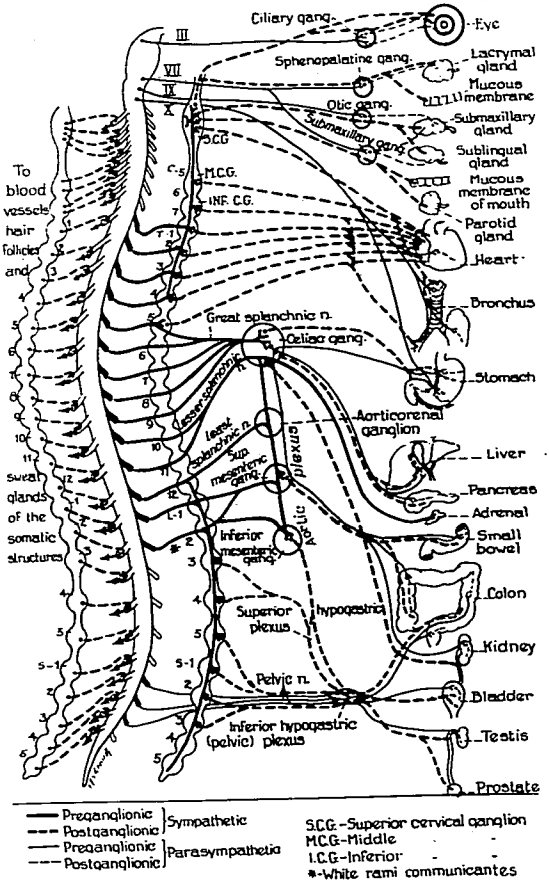

FIG. 1. Distribution of peripheral autonomic nervous system to various structures of the body. Note connections between the spinal cord and the sympathetic chain. On the right of the diagram just the white rami communicants are shown (containing preganglionic fibers). On the left the gray rami communicants (containing postganglionic fibers). (After Bonica, J. J.: *The Management of Pain*. Philadelphia, Lea & Febiger, 1953.)

sacral segments; their axons leave the cord through the anterior roots of sacral nerves 2, 3 and 4. These fibers do not join vertebral ganglia, but run directly as the pelvic splanchnic nerves (nervi erigentes) to the pelvic plexuses, through which they pass uninterrupted to their termination in the terminal ganglia on the wall of the viscera. Within these ganglia they synapse for the first time with the postganglionic neurons; each pregan-

lionic neuron of the parasympathetic synapses with one postganglionic neuron.

The Sympathetic or Thoracolumbar Division

The sympathetic division of the autonomic nervous system consists of preganglionic neurons, the paravertebral chain, prevertebral and terminal ganglia, and postganglionic neurons. The cell bodies of the preganglionic neurons are located primarily in the first thoracic to the second lumbar spinal cord segments, inclusive. Laurelle,[14, 15] among others, has shown that while most of the cells are located in the intermediolateral (lateral) column of the spinal cord, some become aggregated and form a second, less definite, column on the medial side of the pars intermedia of gray matter, which he terms the intermediomedial (medial) column. There is also evidence that some visceral cells exist in the cervical and lower lumbar regions.[14, 15, 16, 17] In some instances these cells in the cervical cord descend; those in the lower lumbar cord ascend within the spinal cord before emerging to adjacent segments; others pass through the eighth cervical or third lumbar anterior root.

The axons of these preganglionic neurons are carried in the anterior nerve roots and synapse with postganglionic neurons in the sympathetic ganglia outside the neuraxis. There are three groups of sympathetic ganglia: paravertebral, prevertebral and terminal. The paravertebral ganglia and the interganglionic fibers make up the lateral sympathetic chain to which preganglionic neurons first pass. On entering the sympathetic chain some preganglionic axons end in the first ganglion they reach; some pass cephalad or caudad for varying distances within the sympathetic trunk before they synapse; others pass through the chain without interruption to terminate and synapse within one of the prevertebral ganglia. Preganglionic fibers to the adrenal medulla synapse within chromaffin cells which are homologous to postganglionic neurons.

The preganglionic fibers from the upper five thoracic segments either terminate in the first sympathetic ganglion they reach or turn upward within the sympathetic trunk to synapse in a ganglion at a higher level, particularly the superior, middle, and the inferior cervical ganglia. Some preganglionic fibers from the fifth to tenth thoracic segments terminate in the first ganglion they reach; some ascend or descend; others pass through the paravertebral ganglia without interruption to become the greater splanchnic nerve, which terminates within the celiac ganglion. Some of the preganglionic fibers from the tenth to twelfth thoracic segments and first and second lumbar segments terminate in the first ganglion reached; some pass caudad; others pass through the ganglia uninterrupted to become the lesser and least splanchnic nerves. The lesser splanchnic nerve enters the celiac plexus and synapses in the aorticorenal ganglion, while the least splanchnic nerve passes directly to the renal ganglion, where its fibers synapse with postganglionic fibers.

One preganglionic neuron makes synaptic connection with numerous (as many as 32) postganglionic neurons. In addition to the vertebral and prevertebral sympathetic ganglia, a few terminal sympathetic ganglia lie near the organs they innervate. A few intermediate ganglia are located in the white ramus or anterior spinal nerve root, and therefore not accessible to the usual sympathectomy, but these usually are involved by sympathetic blocks, thus explaining the discrepancy between the results from sympathectomy and those from the injection of a local anesthetic. Some of the postganglionic neurons rejoin the spinal nerves, while others pass distally to supply visceral structures in the head, chest or abdomen (fig. 2).

Sympathetic Trunks. The sympathetic trunks extend along the ventrolateral aspects of the vertebral column from the second cervical vertebra to the coccyx. The cervical ganglia lie ventral to the transverse processes; the thoracic, over the heads of the ribs; the lumbar, on the anterolateral surface of the vertebrae; the sacral, on the anterior surface of the sacrum medial to the anterior sacral foramina. The cephalic end of each of the two trunks is continued upward as the internal carotid nerve,

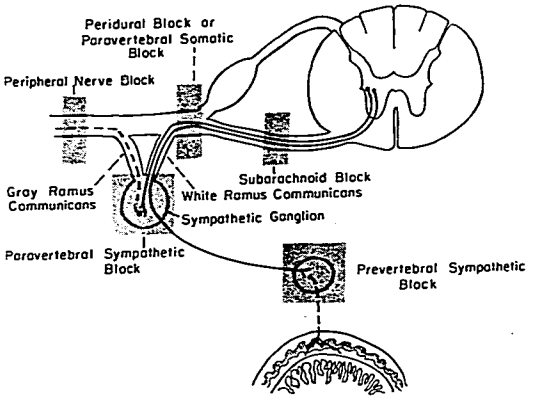

FIG. 2. The course of preganglionic and postganglionic sympathetic fibers and the techniques that may be used to interrupt them. (After Bonica, J. J.: *Clinical Applications of Diagnostic and Therapeutic Nerve Blocks*. Springfield, Illinois, Charles C Thomas, 1959.)

branches of which eventually become distributed to the head, while the caudal ends of the trunks converge and terminate in front of the coccyx as the ganglion impar. In the cervical region a condensation of the segmental ganglia has occurred, there being only four: the superior, the middle, the intermediate, and the inferior ganglia. Usually (80 per cent of subjects) the inferior cervical ganglion is fused with the first thoracic, forming a stellate ganglion. Below this level the paravertebral ganglia are arranged segmentally, there being ten to 12 thoracic, four lumbar, four or five sacral and one coccygeal.

Sympathetic trunks are connected to the spinal nerves by one or more rami communicantes. White rami communicantes consist of myelinated preganglionic neurons and visceral afferent fibers. They are limited in their distribution to the thoracic and upper two lumbar segments. Thus, 14 or 15 pairs of white rami communicantes are the only anatomic bridges between the central nervous system and the peripheral sympathetic nervous system. The gray rami communicantes consist of myelinated postganglionic sympathetic fibers which pass from the sympathetic trunks to each of the spinal nerves and are distributed as vasomotor, sudomotor, and pilomotor nerves to somatic structures.

The sympathetic trunks give off numerous branches which contribute to the formation of vascular and visceral plexuses. These include the carotid and jugular nerves which branch into the carotid plexus; the superior, middle and inferior cervical cardiac nerves, and the five thoracic cardiac nerves that contribute to the cardiac, pulmonary and esophageal plexuses; the greater, lesser and least splanchnic nerves, which end in four prevertebral ganglia—the celiac, superior mesenteric, aorticorenal and inferior mesenteric—all parts of the celiac plexus.

The peripheral sympathetic nervous system is located within fascial planes which may be considered as relatively closed spaces, or even "pouches" that facilitate spread of local anesthetics to produce extensive block. Consequently, the entire peripheral sympathetic outflow can be interrupted by placing a needle in each of three critical sites (fig. 3).

Peripheral Plexuses. The major peripheral plexuses are aggregates of ganglia and interconnecting fibers situated in front of the vertebral column, three within the thoracic cavity, and three within the abdominal cavity. These plexuses serve as redistribution or synaptic centers for autonomic fibers. They contain visceral efferent neurons of both the sympathetic and parasympathetic outflow, and, in addition,

visceral afferent fibers which mediate sensory impulses to the central nervous system via either the sympathetic or parasympathetic system.

The cardiac plexus receives sympathetic fibers from the four cervical and the upper five thoracic ganglia, parasympathetic fibers supplied by the vagus nerves and sensory fibers associated with both sets of nerves. The plexus is divided into a superficial plexus, a right deep plexus and a left deep plexus. *The pulmonary plexus* contains sympathetic fibers supplied by the upper thoracic ganglia and parasympathetic fibers supplied by the vagus and sensory fibers. An anterior and posterior pulmonary plexus surrounds the mainstem bronchus on each side. *The esophageal plexuses,* anterior and posterior, contain parasympathetic fibers supplied by the vagus nerves, sympathetic fibers supplied by the stellate and upper thoracic ganglia, and sensory fibers associated with both.

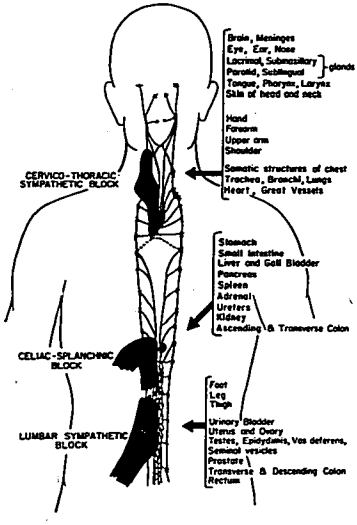

FIG. 3. The three "critical sites" which may be employed to interrupt the peripheral sympathetic nervous system. (After Bonica, J. J.: *Clinical Applications of Diagnostic and Therapeutic Nerve Blocks.* Springfield, Illinois, Charles C Thomas, 1959.)

The celiac (solar) plexus, the largest prevertebral plexus, is composed of two large aggregates of ganglion cells, the right and left celiac ganglia, a number of smaller ganglia, and a dense network of sympathetic, parasympathetic (vagus) and sensory nerves which enmesh the ganglia. The autonomic fibers include parasympathetic fibers, which reach the celiac plexus via the esophageal plexus; sympathetic fibers, contributed by the splanchnic nerves; and others which reach it directly from the sympathetic trunk. The plexus, 3 cm. long and 4 cm. wide, is situated in the epigastrium just anterior to the crura of the diaphragm and the body of the first lumbar vertebra, surrounding the celiac artery and its branches. The celiac plexus supplies autonomic fibers to all of the abdominal viscera (except the pelvic organs) through its many subsidiary plexuses, which include the gastric, hepatic, splenic, phrenic, adrenal, renal, spermatic, superior mesenteric, aortic, and inferior mesenteric plexuses. The superior hypogastric plexus is a downward continuation of the aortic plexus running in front of the promontory of the sacrum. It continues downward on each side as the hypogastric nerves, which terminate into the pelvic plexus on each side. The pelvic plexus also contains the sacral parasympathetic preganglionic fibers (nervi erigentes) and sensory fibers associated with both sympathetic and parasympathetic nerves.

Innervation of the Viscera

With this background, we now consider briefly the general course of parasympathetic, sympathetic and sensory fibers to five groups of viscera: (1) organs in the head and neck; (2) thoracic viscera; (3) abdominal viscera; (4) pelvic viscera; and (5) blood vessels, sweat glands and erector pilae muscles of the extremities. Table 1 and figures 1 to 5 complement the description. In addition to the general courses of the fibers, attention is given to the specific spinal cord segments which supply each organ.

TABLE 1. Sympathetic Innervation of Body Structures

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Efferent Pathways: Location of Cell Body in Spinal Cord and Course of Preganglionic Neurons‡	Efferent Pathways: Site of Pre-postganglionic Synapse	Efferent Pathways: Course of Postganglionic Fibers	Efferent Pathways: Main Functions
Head and neck Eye*	None associated with sympathetics (see parasympathetics)	T1, 2, (3), (4) — To and through cervical sympathetic chain	Superior cervical ganglion or ganglia in internal carotid plexuses	Internal carotid plexuses → ciliary ganglia or nasociliary nerves → ciliary nerves, or along vessels	Dilatation of pupil; vasoconstriction; accommodation for far vision; elevation of lid
Lacrimal gland*	None associated with sympathetics (see parasympathetics)	T1, 2 — To and through cervical sympathetic chain	Superior cervical ganglion	Internal carotid plexuses → vidian nerve → sphenopalatine ganglion → maxillary nerve → zygomatic nerve	Vasoconstriction; secretion?
Parotid salivary gland*	None associated with sympathetics (see parasympathetics)	T1, 2 — To and through cervical sympathetic chain	Superior cervical ganglia	External carotid plexuses → internal maxillary and middle meningeal plexuses → otic ganglia → communication to auriculotemporal nerves and their parotid branches	Vasoconstriction; secretion?
Submandibular and sublingual glands*	None associated with sympathetics (see parasympathetics)	T1, 2 — To and through cervical sympathetic chain	All cervical ganglia	External carotid plexuses → facial plexuses → submandibular ganglia → direct glandular filaments or via lingual nerves, or carried directly to glands along vessels	Vasoconstriction; secretion?
Thyroid gland	Follow sympathetics → T1, 2 — Reflex function (receives pain fibers from cervical spinal nerves)	T1, 2 — To and through cervical sympathetic chain	Superior and middle cervical ganglia	Perivascular plexus accompanying superior and inferior thyroid arteries	Vasoconstriction
Blood vessels (face, scalp, bones and meninges)	None (Sensory nerves to vessels contributed by cranial nerves 5, 7, 9 and 10 and upper cervical nerves)	T1, 2, (3), (4) — To and through cervical sympathetic chain	All cervical, internal carotid, and vertebral ganglia	In perivascular plexuses accompanying various branches of carotid and vertebral arteries	Vasoconstriction
*Upper Extremities**	Branches of brachial plexus → C5 to T1 — Perivascular nerves → follow sympathetic fibers	T2 to 8, (9) — To upper thoracic and lower cervical sympathetic chain	Middle and stellate ganglia; T2 and 3 ganglia	Rami communicantes to roots of brachial plexuses → branches of plexuses	Vasoconstrictor, sudomotor, and pilomotor function

‡ Each preganglionic fiber passes peripherally via the homologous anterior root and white ramus communicans to the symphathetic trunk.
* These viscera have unilateral innervation.
( ) These segments inconstant.

TABLE 1.—(*Continued*)

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Efferent Pathways			
		Location of Cell Body in Spinal Cord and Course of Preganglionic Neurons‡	Site of Pre-postganglionic Synapse	Course of Postganglionic Fibers	Main Functions
Thoracic Viscera					
Heart	Follow sympathetics (none in superior cervical nerve) → T1 to 4, (5) — Mediate pain	T1 to 4, (5) To upper thoracic and the cervical sympathetic chain	All cervical and the upper four (5) thoracic ganglia	Superior and middle and inferior cervical and thoracic cardiac sympathetic nerves → cardiac plexuses	Increase cardiac rate and stroke volume → increased cardiac output
Larynx, Trachea, Bronchi and Lungs	Follow inferior cervical and thoracic sympathetic nerves → T2 to 7 — Convey reflex impulses	T2 to 7 To upper thoracic sympathetic chain	Stellate and upper five thoracic ganglia	Pulmonary branches from sympathetic trunk → pulmonary plexuses	Bronchial dilatation and vasoconstriction (vasodilatation under certain conditions)
Esophagus Upper	Follow esophageal sympathetic nerves → T2 to 7, (8) — Mediate pain	T2, 3, 4 → Thoracic sympathetic chain	Stellate ganglion and T2, 3, 4 ganglia	Esophageal branches from sympathetic trunk → esophageal plexuses	Decreased motility and contraction of sphincters
Lower		T5, 6, 7 → Thoracic sympathetic chain	T(4), 5, 6, 7, (8) ganglia		
Thoracic aorta	Follow upper five thoracic sympathetic nerves → T1 to 5 — Mediate pain	T1 to 5 Thoracic sympathetic chain	Upper five thoracic ganglia	Branches from cardiac sympathetic nerves; direct thoracic nerves	Vasomotor function
Abdominal viscera					
Stomach	Follow sympathetic nerves → T6, 7, 8, 9	T6 to 9(10) Greater splanchnic nerves and celiac plexus	Celiac ganglia	Right and left gastric and gastroepiploic plexuses	Diminution of peristalsis and secretion; contraction of pylorus; vasoconstriction
Gallbladder and bile ducts	Follow sympathetic nerves → T5 to 9 — Mediate pain	T5 to 9, (10) Greater splanchnic nerves and celiac plexus	Celiac ganglia	Hepatic and gastroduodenal plexuses	Diminution of peristalsis; conduction of pain
Liver	Follow sympathetic nerves → T5 to 9 — Mediate pain	T6 to 9, (10) Greater splanchnic nerves and celiac plexus	Celiac ganglia	Hepatic plexus	Vasoconstriction; conduction of afferents from visceral peritoneum and ligaments?

TABLE 1.—(*Continued*)

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Different Pathways: Location of Cell Body in Spinal Cord and Course of Preganglionic Neurone†	Different Pathways: Site of Pre-postganglionic Synapse	Different Pathways: Course of Postganglionic Fibers	Main Functions
Pancreas	Follow sympathetic nerves → T5 to 10	T5 to 10	Celiac ganglia	Direct branches from celiac plexus and off-shoots from splenic, gastroduodenal and pancreaticoduodenal plexuses	Vasoconstriction and slight secretion?
	Mediate pain	Greater splanchnic nerves and celiac plexus			
Small intestines	Follow sympathetic nerves T6, 7, 8, (10) (duodenum)	T6 to 11	Celiac and superior mesenteric ganglia	Superior mesenteric plexus → nerves alongside jejunal and ileal arteries	Motility decreased; sphincters relaxed; secretion inhibited
	T9, 10, 11 (jejunum and ileum) —	Greater and lesser splanchnic nerves to celiac plexus			
	Mediate pain				
Cecum and appendix*	Follow sympathetics → T10 to 12	T10 to 12	Celiac and superior mesenteric ganglia	Nerves alongside ileocolic artery	Diminution of peristalsis and secretion
	Mediate pain —	Greater and lesser splanchnic nerves → celiac and superior mesenteric plexuses			
Colon to splenic flexure*	Follow sympathetics → T12 and L1 —	T12 (11) to L1	Superior and inferior mesenteric ganglia	Mesenteric plexuses → nerves alongside right, middle, and superior left colic arteries	Diminution of peristalsis and secretion
	Mediate pain	Lesser, least and lumbar splanchnic nerves			
Splenic flexure to rectum*	Follow sympathetics → L1, 2 —	L1, 2	Ganglia in inferior mesenteric and superior and inferior hypogastric plexuses	Nerves alongside inferior left colic and rectal arteries	Diminution of peristalsis and secretion; contraction of sphincter ani internus
	Mediate pain (pain fibers also follow sacral parasympathetic)	Lumbar and sacral branches of sympathetic trunks → inferior mesenteric and hypogastric plexuses			
Adrenal glands*	Follow sympathetics —	T5 to 12	Chromaffin cells of adrenal medulla	Some direct branches and others through celiac plexus and superior renal nerves	Secretion of catecholamines
	Reflex?	Greater, lesser and least splanchnic nerves and first lumbar splanchnic nerve			

TABLE 1.—(*Continued*)

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Efferent Pathways			
		Location of Cell Body in Spinal Cord and Course of Preganglionic Neurons†	Site of Pre-postganglionic Synapse	Course of Postganglionic Fibers	Main Functions
Kidneys*	Follow sympathetics → T11, 12, L1 — Mediate pain	T(10), 11, 12, L1, (2) Lesser and least splanchnic nerves and first lumbar splanchnic nerves → celiac and renal plexuses	Celiac and aorticorenal ganglia	Along renal plexus	Vasoconstriction; influence on secretion?
Ureters*	Follow sympathetic nerves → T11, 12, L1, 2 — Mediate pain	T11, 12, L1, 2 Lesser and least splanchnic nerves	Superior and inferior mesenteric ganglia	Superior and inferior mesenteric plexuses → superior, middle and inferior ureteric nerves	Diminution of peristalsis
Pelvic viscera Bladder	Follow sympathetic nerves → T11 to L1 — Pain from fundus	T11, 12, L1, 2 Lesser and least splanchnic and lumbar splanchnic nerves → superior and inferior hypogastric plexuses	Prevertebral ganglia	Perivascular plexuses	Relaxation of wall and contraction of internal sphincter; vasoconstriction
Uterus	Follow sympathetic nerves → T10, 11, 12, (L1) — Mediate pain from entire organ including cervix	T6 to L1 inclusive Splanchnic nerves → aortic and superior hypogastric plexus	Various paravertebral ganglia	Lumbar and sacral splanchnic nerves; superior and inferior hypogastric plexuses	Vasoconstriction; excitation or inhibition of uterine contraction depending on existing conditions
Testes, ductus deferens, epididymis, seminal vesicles, prostate	Follow sympathetic nerves → T10 to L1 — Mediate pain	T6 to L1 inclusive Splanchnic nerves → aortic and superior hypogastric plexus	Prevertebral ganglia	Vascular plexuses	Contraction of ductus deferens; ejaculation of semen; secretion of prostate; vasoconstriction
*Lower limbs**	Branches of lumbar and sacrococcygeal plexuses → L2 to S3 — Perivascular nerves →follow sympathetic	T10 to 12, L1, 2 Sympathetic chain	L1 to 5, S1 to 3 Paravertebral ganglia	Gray rami communicantes → to lumbar and sacral plexuses; direct branches to perivascular plexuses	Vasoconstriction, sudomotor, and pilomotor function

TABLE 2. Parasympathetic Innervation of Body Structures

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Efferent Pathways: Location of Cell Body of Preganglionic Neuron	Efferent Pathways: Course of Preganglionic Fibers	Efferent Pathways: Site of Synapse with Postganglionic Neuron*	Efferent Pathways: Main Functions
Head and neck Eye	Ciliary nerves → nasociliary and ophthalmic nerves → trigeminal nerves — Pain reflexes	Oculomotor nucleus	Ciliary nerve	Ciliary ganglion	Contraction of sphincter pupillae and ciliaris muscle; accommodation to near vision
Lacrimal gland	Follow parasympathetic efferent nerves	Superior salivatory nucleus	Glossopalatine nerve → geniculate ganglion → superficial petrosal nerve → vidian nerve → sphenopalatine ganglion → zygomatic nerve	Sphenopalatine ganglion	Tear secretion; vasodilatation
Parotid salivary gland	Through auriculotemporal nerves to trigeminal nerves and through lesser superficial petrosal nerves to glossopharyngeal nerves	Inferior salivatory nucleus	Glossopharyngeal nerve and the tympanic branches → tympanic plexus → lesser superficial petrosal nerve → otic ganglion → auriculotemporal nerve and its parotid branches	Otic ganglia	Secretion of saliva; vasodilatation
Submandibular and sublingual salivary glands	Lingual nerve → chorda tympani nerve → sensory roots of facial nerve	Superior salivatory nucleus	Facial nerve → chorda tympani nerve → lingual nerve → submandibular ganglion → direct filaments to submandibular glands and via lingual nerve to sublingual glands	Submandibular ganglion	Vasodilatation; secretion of saliva
Thyroid gland	Superior laryngeal (vagal) nerve	Dorsal nucleus of vagus	Superior laryngeal branch of vagus nerve	Terminal ganglia	Unknown
Blood vessels of head	None	In or near facial and vagal nuclei	Follow branches of trigeminal, facial and vagus nerves	Ciliary, otic and sphenopalatine ganglia	Vasodilatation
Upper extremities	No definite proof of a parasympathetic supply. The dorsal root efferents (if they exist) are said to be parasympathetic.				
Thoracic viscera Heart	Vagus nerve — Reflex (not pain)	Groups of cells near nuclei ambigui and dorsal vagal nuclei	Vagus nerves and cranial roots of accessory nerves which join them	Intrinsic cardiac ganglia; ganglia in cardiac plexus	Slowing of heart: constriction of coronary arteries
Larynx, trachea, bronchi and lungs	Vagus nerves — Pain and reflexes	Dorsal vagal nuclei	Vagus nerves through pulmonary plexuses	Pulmonary plexuses and ganglia alongside or in bronchi	Bronchial constriction; bronchial secretion; vasodilatation?
Esophagus	Vagus nerves	Dorsal vagal nuclei	Vagus nerves—directly and through esophageal plexus	Enteric plexuses	Increase peristalsis; secretomotor; relaxation of sphincter

* The course of the short postganglionic fibers is usually within the wall of the structure supplied.

TABLE 2.—*(Continued)*

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Efferent Pathways			
		Location of Cell Body of Preganglionic Neuron	Course of Preganglionic Fibers	Site of Synapse with Postganglionic Neuron*	Main Functions
Abdominal viscera Stomach	Vagus nerves — Conduction of impulses concerned with nausea and hunger (not pain)	Dorsal vagal nuclei	Vagus nerves and their gastric and pyloric branches	Enteric plexuses	Increase peristalsis and secretion; relax pylorus
Gallbladder and bile ducts	Vagus nerves — Reflexes (not pain)	Dorsal vagal nuclei	Vagus nerves, through celiac and hepatic plexuses	Ganglia in or near structures	Increases peristalsis and secretion?
Liver	Vagus nerves — Reflex function (not pain)	Dorsal vagal nuclei	Vagus nerves, directly and through celiac and hepatic plexuses	Terminal ganglia in or near viscus	Increase secretion? vasodilatation?
Pancreas	Vagus nerves — Reflex function (not pain)	Dorsal vagal nuclei	Vagus nerves, through celiac plexus and its splenic and gastroduodenal offshoots	Terminal ganglia in or near viscus	Increase secretion? vasodilatation?
Small intestines	Vagus nerves — Reflex function (not pain)	Dorsal vagal nuclei	Vagus nerves through celiac and superior mesenteric plexuses → jejunal and ileal nerves	Enteric plexuses	Increase peristalsis and secretion relaxation of sphincter
Cecum and appendix	Vagus nerves — Reflex function (not pain)	Dorsal vagal nuclei	Vagus nerves through celiac and superior mesenteric plexuses → ileocolic nerves	Enteric plexuses	Increase peristalsis and secretion relaxation of sphincter
Colon to splenic flexure	Vagus nerves — Reflex function (not pain)	Dorsal vagal nuclei	Vagus nerves through celiac and superior mesenteric plexuses nerves alongside right and middle colic arteries	Enteric plexuses	Increase peristalsis and secretion; relaxation of sphincter
Splenic flexure to rectum	Nerves to distal colon and rectum → hypogastric plexuses → pelvic splanchnic nerves — Mediate pain	Cells in dorsolateral parts of ventral horns in midsacral cord segments	Pelvic (erigentes) nerves → hypogastric plexuses → nerves to distal colon and rectum	Enteric plexuses	Increase peristalsis and secretion; relaxation of internal sphincter
Adrenal glands	Vagus nerves?	?	Vagus nerves, through celiac plexus and adrenal nerves	?	?
Kidneys	Vagus nerves	Dorsal vagal nuclei	Vagus nerves through celiac and renal plexuses and occasionally directly	Renal ganglia close to kidney	Vasodilatation, contraction of pelvis, and other unknown functions?
Ureters	Except for lower ends (pelvic splanchnics) afferents probably are carried in symphathetic nerves	Cells in dorsolateral parts of ventral columns in midsacral cord segments	Pelvic nerves → through inferior and superior hypogastric plexuses and ureteric nerves	Small ganglia on ureteric nerves; inferior hypogastric plexuses?	Increase peristalsis?

TABLE 2.—(*Continued*)

Structures	Main Visceral Afferent Pathways — Entrance into Neuraxis and Primary Function	Efferent Pathways: Location of Cell Body of Preganglionic Neuron	Efferent Pathways: Course of Preganglionic Fibers	Efferent Pathways: Site of Synapse with Postganglionic Neuron*	Efferent Pathways: Main Functions
Pelvic viscera Bladder	Pelvic nerves (afferents from base of bladder)	Cells in dorsolateral parts of ventral columns in mid-sacral cord segments	Pelvic nerves → inferior hypogastric plexuses → vesical nerves	Vesical plexuses	Contraction of walls and relaxation of internal sphincter; vasodilatation?
Uterus	None	Cells in dorsolateral parts of ventral columns in mid-sacral cord segments	Pelvic nerves → inferior hypogastric plexuses → uterine and tubouterine nerves	Paracervical ganglia of inferior hypogastric plexuses and ganglia along vessels	Vasodilatation; generate uterine contractions
Testes, ductus deferens, epididymis, seminal vesicles, prostate	None ?	Cells in dorsolateral parts of ventral columns in mid-sacral cord segments	Pelvic nerves → inferior hypogastric plexuses → spermatic, testicular and prostatic plexuses	Paracervical ganglia of inferior hypogastric plexuses and ganglia along vessels	Vasodilatation erection
Lower limbs	No definite proof of a parasympathetic supply. The dorsal root efferents (if they exist) are said to be parasympathetic.				

HEAD AND NECK (fig. 4)

Sympathetic Nerves. Preganglionic neurons that originate in the first and second thoracic spinal segments pass to the thoracic chain via the *white rami communicantes,* proceeding cephalad to end in the cervical ganglia. Nerves concerned with the eye, lacrimal gland and parotid gland end in the superior cervical ganglion or terminal ganglia in the carotid plexus, where they synapse. The postganglionic fibers proceed cephalad as the carotid nerve and plexus, which surrounds the internal carotid artery. Those preganglionic fibers concerned with submandibular and sublingual glands synapse in all of the cervical ganglia with postganglionic fibers that form the external carotid plexus. Preganglionic neurons, which control vasomotor, pilomotor and sudomotor functions to the head and neck, originate in the upper four thoracic spinal segments and pass via the upper four *white rami communicantes* to the sympathetic chain, proceeding cephalad to synapse in all cervical ganglia with postganglionic fibers. The latter, in turn, contribute to the plexuses which surround the arteries of the head and neck.

Parasympathetic Nerves. The head is supplied by preganglionic fibers that run in the third, seventh and ninth cranial nerves. The preganglionic fibers associated with the oculomotor nerve arise from cells located in the oculomotor nucleus and terminate in the ciliary ganglion, where they synapse with postganglionic fibers. The preganglionic fibers associated with the facial nerve arise from cells located in the superior salivatory nucleus and terminate in the sphenopalatine ganglion or the submaxillary ganglion, to synapse with postganglionic fibers. From the sphenopalatine ganglion, postganglionic fibers pass through the zygomatic branch of the maxillary nerve to the lacrimal gland, while those arising from the submaxillary ganglion supply the submaxillary and sublingual glands. The parasympathetic preganglionic fibers associated with the glossopharyngeal nerve arise from cells in the inferior salivatory nucleus and pass via the petrous ganglion and tympanic branch of the nerve, and then the small superficial petrosal nerve, to the otic ganglion. Postganglionic fibers arise from the latter and reach the parotid gland via the auriculotemporal branch of the mandibular nerve. The *thyroid gland* receives parasympathetic fibers from the vagus by way of the superior and inferior laryngeal nerves, which accompany the superior thyroid artery to the gland.

Sensory Nerves. All of these structures possess sensory fibers which are components of the appropriate cranial nerves. It is likely that the blood vessels also possess sensory fibers, which accompany the sympathetic nerves.

Clinical Applications. The sympathetic nerves to the head can be interrupted by blocking a portion of the cervical sympathetic chain. Although block of the superior cervical ganglion interrupts most of these fibers, it does not include those which reach the head via the vertebral plexus. For this reason, stellate ganglion block is the procedure of choice.[5] The anterior paratracheal technique is the most commonly used.[6, 7] Disorders of the head for which sympathetic block has been advocated are numerous. The older French literature contains glowing reports of the efficacy of stellate-ganglion block in treatment of ophthalmalogic disorders, including obstruction of the central retinal artery due to embolism or thrombosis; acute optic neuritis; toxemic and hypertensive retinitis of pregnancy; chronic optic atrophy; retinitis pigmentosa and glaucoma.[8, 10, 11, 18, 19, 20] Dramatic results have also been reported in treating vertigo, tinnitus, deafness, atrophic rhinitis and other disorders of the ear and nose.[8, 19, 20] Facial disorders treated with this technique in the past include atypical facial neuralgia, so-called Sluder's neuralgia, facial palsy and migraine.[8, 18] In our experience, this procedure is of no value

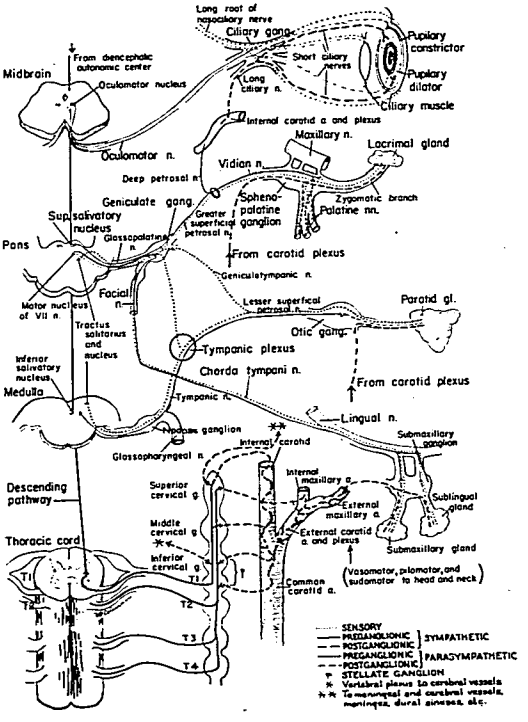

FIG. 4. The autonomic nerve supply to the head and neck. (After Bonica, J. J.: *The Management of Pain.* Philadelphia, Lea & Febiger, 1953.)

in any of these conditions except certain types of facial palsy. For the latter condition we [5] and others [8] have noted a speed-up in return of facial nerve function following cervicothoracic sympathetic block.

The efficacy of sympathetic block in treating cerebrovascular spasm, thrombosis or embolism has been the subject of intense controversy. Numerous reports of dramatic successes and disappointing failures have been published. In our series, 10 per cent of the patients experienced dramatic improvement and another 15 per cent moderate improvement during the ensuing 24 hours. In view of the normal vagaries of cerebrovascular accidents and the tendency to spontaneous recovery, these results are not very significant. This is not surprising, because sympathetic nerves have little or no control over normal cerebral circulation. On the other hand, the advocates of this treatment emphasize that this may not be the case in patients with cerebrovascular disease, and, because the block is a simple procedure, it should be tried, provided intracranial hemorrhage is first ruled out and before anticoagulant therapy is initiated.

Sympathetic block and sympathectomy have been advocated as an adjunct in the management of patients with residual effects of cerebrovascular accidents and for the treatment of epilepsy and spastic paralysis.[8] Unfortunately, the results have been disappointing. Sympathetic block of the adrenal gland by means of subarachnoid block or celiac plexus block has been advocated in patients with severe hyperthyroidism requiring thyroidectomy,[21] but medical therapy rarely makes this technic necessary.

Block of Parasympathetic Nerves. Blocking of parasympathetic fibers is indicated in disorders characterized by parasympathetic hyperactivity. Because all of these fibers are contained in cranial nerves, selective block cannot be limited to them.

Block of the sphenopalatine ganglion, as it lies in the pterygopalatine fossa, is used as a diagnostic–prognostic procedure to interrupt parasympathetic pathways in the management of *Heidenhain's phenomenon,*[3, 6] a pseudomotor response characterized by retraction of the upper lip when the maxillary nerve is stimulated. It has been suggested that this and other pseudomotor responses to injury of single cranial nerves are produced by proprioceptive stimuli arising from movements of muscles of the face, jaw, and tongue with stimulation of the mesencephalic nucleus of the fifth nerve or the reticular formation close to the intramedullary portion of the facial nerve. This sets off an autonomic (parasympathetic) discharge and liberates acetylcholine, which produces a slow tonic contraction of the muscles of the upper lip. Since block in the pterygopalatine fossa interrupts parasympathetic, sympathetic, and somatic afferent fibers, it should interrupt the reflex arc, thus preventing the response. Sphenopalatine ganglion block is also useful in the management of "crocodile tears." This condition, occurring after partial injury to the central portion of the facial nerve, is characterized by excessive tear secretion on mastication of bitter, sour, or salty foods. Interruption of the parasympathetic pathways in the sphenopalatine ganglion prevents the phenomenon, and, if the severity of the condition warrants a prolonged interruption, it may be advisable to give the patient a trial with alcohol block.

Block of the mandibular nerve as it emerges through the foramen ovale is useful in managing the *Marcus Gunn phenomenon,*[3, 6] which follows injury of the oculomotor nerve and is characterized by abnormal upward retraction of the upper eyelid during mastication. It has been suggested that movement of the muscles of mastication initiates afferent stimuli, which are propagated over the proprioceptive fibers of the mandibular nerve to the mesencephalic nucleus. Here, they initiate efferent discharges which pass via parasympathetic fibers associated with the oculomotor nerve and effect release of acetylcholine, resulting in marked contraction of the eyelids. Block of the mandibular nerve with a local anesthetic drug followed by alcohol can stop the associated movements. This technique is also useful in diagnosis and prognosis of the *auriculotemporal syndrome,* which follows injury to branches of the auriculotemporal nerve produced by inflammatory reaction or trauma during surgery of the parotid gland. It is characterized by pain in the gland with reflex vasodilatation and sweat-

ing in the region of the temple and cheek during mastication.

Block of the carotid sinus nerve is useful as a diagnostic–prognostic procedure in the management of carotid sinus syndromes. This condition is characterized by recurrent attacks of syncope and is due to an abnormally sensitive carotid sinus reflex. Block of the carotid sinus plexus is valuable in distinguishing among the causes of syncope as well as in predicting the effects of surgical denervation for treatment. Block prior to manipulation of the head and neck may also be indicated with a sensitive carotid sinus.

Thoracic Viscera

Sympathetic Nerves. The thoracic viscera are supplied by sympathetic preganglionic nerves, which have their cells in the upper five thoracic spinal cord segments. Their axons pass via the upper five *white rami communicantes* and, upon entering the sympathetic chain, synapse at the same level or pass cephalad to synapse in higher thoracic or in the cervical ganglia. Postganglionic neurons arise from all of these cervical and the upper five thoracic sympathetic ganglia, passing distally to contribute to the cardiac, pulmonary and esophageal plexuses and thence to the viscera.

Parasympathetic Nerves. Preganglionic parasympathetic fibers originate in cells in the dorsal nucleus of the vagus. Axons course through the vagus and its branches to end in the cardiac, pulmonary and esophageal plexuses, where they synapse with short postganglionic neurons that pass to the muscles of these organs.

Sensory Nerves. Sensory nerves of the thoracic viscera accompany both the vagus and sympathetic nerves. Those associated with the vagus are involved in circulatory and respiratory reflex activity, mediating pain from the bronchial tree and the esophagus. Pain from the heart is conveyed by sensory fibers that accompany the sympathetic nerves and enter the spinal cord via the dorsal roots of the upper five thoracic nerves. Apparently no sensory nerves accompany the superior cervical sympathetic cardiac nerve.

Clinical Applications. Blocks of the autonomic nerves to the thoracic viscera can be employed as diagnostic, prognostic and therapeutic measures for a variety of disorders. These include: angina pectoris; severe pain of acute myocardial infarction; pain from the aorta or tracheobronchial tree; tachycardia and severe pulmonary disorders. Vagal efferents and afferents are usually blocked at the base of the skull just below the jugular foramen and in the lower part of the neck. Sympathetic efferent fibers and sensory fibers can be interrupted by: (1) cervicothoracic (stellate) sympathetic block; (2) paravertebral block of the upper thoracic sympathetic chain (T1 to T5); (3) segmental epidural block (T1 to T5); (4) segmental subarachnoid block (T1 to T5); (5) direct injection of the cardiac plexuses. The last two methods are not often used.

Stellate ganglion block, using the anterior paratracheal technique, is the simplest and safest method of interrupting the sympathetic nerves to the thoracic viscera (as well as to the head, neck and upper extremity). Ten ml of local anesthetic injected in front of the transverse process of the seventh cervical vertebra diffuses as far cephalad as the fourth cervical vertebra and as far caudad as the fourth thoracic vertebra (fig. 3). This involves the chain from the middle cervical ganglion above to the fourth or fifth thoracic ganglion below; therefore, the procedure is really a cervicothoracic sympathetic block rather than a stellate block. This technique is effective in treating severe intractable pain of acute myocardial infarcation, and is a diagnostic–prognostic procedure in angina pectoris as well as in severe pain of aortic origin. Numerous investigators have reported it to be an effective therapeutic measure in intractable paroxysmal tachycardia.[3, 5, 8, 9] After Leriche [11] suggested the use of stellate block for pulmonary disease, numerous reports appeared in the literature extolling its efficacy in treating embolism, intractable asthma, acute edema, tuberculosis, pneumonia and other infections.[8, 10, 20] In most of these conditions we have found it useless, except for its placebo effect. In patients with nonfatal pulmonary embolism, we, and others,[8] have noted prompt relief of pain, dyspnea, orthopnea and cyanosis. The benefit has been attributed to inter-

ruption of reflex spasm in pulmonary vessels. In order to interrupt the sympathetic nerve supply to the thoracic viscera, it is essential to extend the block as far caudad as the fifth thoracic ganglion. Therefore, it is best to inject the solution slowly, with the patient sitting up, to facilitate caudad spread of the solution.

Paravertebral segmental block of the sympathetic chain is employed when a small amount of a local anesthetic or neurolytic agent is to be used or when the block is to be limited to certain segments. If the point of the needle is properly placed in front of the costotransverse ligament, 3 ml of solution diffuses sufficiently to include the ganglion and at least one segment of the interganglionic chain. Paravertebral alcohol block for the symptomatic treatment of angina pectoris constitutes one of the most brilliant chapters in the history of nerve block therapy.[3, 5] During the past four decades, this technique has played an important role in the management of patients with severe intractable angina pectoris unrelievable by medical means. Of the hundreds of patients who have been treated with this technique, more than three-quarters have received satisfactory pain relief, with a mortality rate of less than 5 per cent.[5, 8, 22, 23] The same procedure has been used effectively in treating severe intractable pain of aortic aneurysm.[3, 8, 23]

Segmental epidural block, limited to the upper five thoracic dermatones, interrupts the sympathetic outflow to the thoracic viscera as well as the sensory input from these structures. By producing bilateral interruption with one puncture and by introducing a catheter, the block can be extended for many hours, even days. For optimal results, the puncture is made at T4 and the catheter advanced until its tip is at the level of the third thoracic vertebra. Usually, 4 to 5 ml. of solution is sufficient to interrupt all of these pathways. Recently, Bauman and Fletcher [24] employed this technique to decrease vasoconstriction and bronchoconstriction in newborn infants with the respiratory distress syndrome.

Segmental subarachnoid block is used to treat severe intractable pain from thoracic visceral diseases, including cancer. For this purpose, phenol or alcohol is injected in small amounts.

Abdominal Viscera

Sympathetic Nerves. Preganglionic sympathetic fibers, which control the function of abdominal viscera, have their cell bodies in spinal cord segments T5 to L2. Their axons pass via the *white rami communicantes* and through the sympathetic trunk without interruption to become the splanchnic nerves, which end in prevertebral ganglia, where they synapse with postganglionic neurons. The postganglionic fibers leave the celiac and related ganglia, and together with vagal and sensory fibers, run along the various arteries to reach the organs. In the peculiar case of the adrenal gland the preganglionic fibers pass without interruption to end around the chromaffin cells of the adrenal medulla, which presumably act as postganglionic fibers. Each organ is supplied by sympathetic nerves, which originate in specific spinal cord segments. The reputed site of origin of these fibers is shown in Table 1.

Parasympathetic Nerves. The upper abdominal viscera are supplied with parasympathetic fibers from cell bodies in the dorsal motor nucleus of the vagus, which pass via the vagi and the prevertebral visceral plexuses to end in terminal ganglia in the walls of the viscera. Here they synapse with short postganglionic fibers. In the intestine, it is probable that fibers terminate in Auerbach's myenteric plexus and Meissner's submucous plexus.

Sensory Nerves. Sensory nerves supplying the abdominal viscera accompany both the vagus and sympathetic nerves. The vagal sensory fibers subserve reflex regulation of visceral activity, including vomiting, and transmit sensations of distention, fullness and nausea. Most of the evidence suggests that these parasympathetic nerves do *not* transmit pain sensation. Sensory fibers which are components of the splanchnic nerves enter the spinal cord via the posterior roots of the T5 to L2 nerves. They are the primary pathways of pain from the abdominal viscera and subserve reflex mechanisms.

Clinical Applications. Block of the nerve supply to the abdominal viscera can be used

in various painful and nonpainful disorders. The sympathetic sensory and efferent nerve supply can be interrupted by: (1) paravertebral block of the lower thoracic (T5 to T12) and upper lumbar sympathetic chain; (2) paravertebral block of the splanchnic nerves; (3) segmental epidural block (T5 to L2); and (4) subarachnoid block extending to T5. The vagus nerves can be blocked specifically in the lower part of the neck. Both the sympathetic and parasympathetic nerves can be interrupted by bilateral celiac plexus block: injection of 15 ml. of solution in the proper fascial plane interrupts as far caudad as the superior hypogastric plexus which innervates all of the abdominal viscera except the pelvis (fig. 3).

Segmental paravertebral sympathetic block is a valuable diagnostic and prognostic procedure when selective sympathetic interruption is indicated. From 1920 to 1935 it was used extensively by European clinicians, especially Lawen,[25] Kappis,[26] and Mandl,[9] in the differential diagnosis of intra-abdominal visceral disease. It was believed that blocking specific segments afforded a means of delineating pain pathways and interrupted visceromotor reflexes. While it is of value in some cases, paravertebral block has certain limitations imposed by the significant overlap of the segmental innervation of the abdominal viscera. For example, the nerve supply to the stomach is derived from the sixth to the ninth segment, while the gallbladder receives nerves from the fifth to the ninth thoracic segments. Even if the segments do not overlap closely, as for example the stomach (T6 to T9) and the appendix (T10 to T12), care must be exercised in evaluating the results. Unless very small amounts of solution (2 to 3 ml. or less) are used in the paravertebral region, there is sufficient spread of solution to produce anesthesia of adjacent segments. On the other hand, it may be useful when the nerve supplies of two viscera are widely separated. Thus, it can be used in unusual cases to determine whether epigastric pain is the result of disease of viscera in the chest or in the abdomen—to differentiate myocardial infarction from acute pancreatitis, pulmonary embolism from a ruptured ulcer, or pneumonia from appendicitis. It may also help in differentiating pain due to disease of the viscus with bilateral innervation from that caused by disease of a viscus with a unilateral nerve supply. For example, right-lower-quadrant pain can be eliminated by a right-sided block if it is due to renal disease, but it cannot be relieved completely if it is due to acute appendicitis. Paravertebral sympathetic block also is useful in ascertaining whether the pain arises from the viscera or the abdominal wall, and whether reflex visceral disturbances involve sympathetic or parasympathetic pathways. Several prognostic blocks of the thoracic sympathetic chain should be used prior to sympathectomy or neurolytic block.

Celiac plexus block or splanchnic nerve block is frequently used for the management of severe intractable visceral pain due to cancer, chronic pancreatitis, post-cholecystectomy syndrome, and visceral pain of unknown origin. White and his associates[3, 23] and others[27] reported good results with sympathectomy for abdominal pain of unknown origin after all other forms of medical therapy and numerous ill-advised abdominal operations have failed. For optimal results, proper selection of cases, including the use of at least three prognostic blocks, is mandatory. The procedure is also effective in controlling severe acute pain from ureteral colic, acute pancreatitis, and other acute visceral disease in which the pain is so severe that it cannot be controlled with usual doses of narcotics.[5, 6, 28, 29, 30, 31] Fine[32] has used celiac plexus block to release splanchnic vasoconstriction for the treatment of endotoxic shock in animals. He noted a reduction in the mortality rate from 80 per cent to 20 per cent or less. Celiac plexus block or splanchnic block has been used as a diagnostic–prognostic procedure in cardiospasm, achalasia, megacolon, and hypertension in patients in whom sympathectomy is contemplated. It is hardly necessary to stress that sympathectomy is now rarely used for these procedures.

Alcohol splanchnic or celiac-plexus block has been advocated by European physicians for the treatment of chronic peptic ulcer and diabetes mellitus, but this method cannot be considered seriously in view of recent devel-

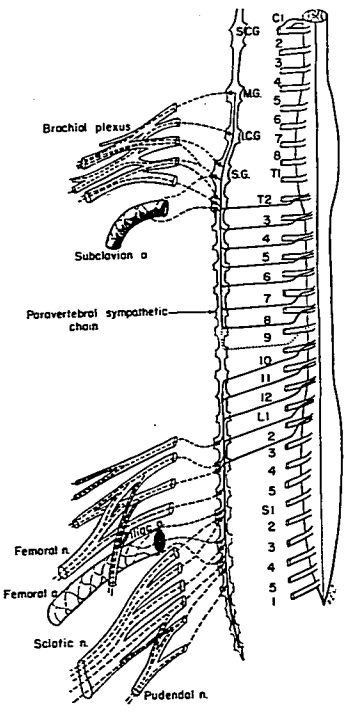

FIG. 5. Course of the sympathetic pathway for the upper and lower extremities. (After Bonica, J. J.: *Clinical Applications of Diagnostic and Therapeutic Nerve Blocks*. Springfield, Illinois, Charles C Thomas, 1959.)

opments of these diseases.[28, 29] Ochsner and his associates[30] have successfully treated a number of patients with fibrocystic disease of the pancreas by splanchnic block and/or splanchnicectomy. Luzuy[19] reported treatment of pylorospasm in infants with repeated sympathetic block with "excellent" results. Mandl[9] reported success with this method in controlling pain of tabetic crises, but our experience has been disappointing.

Segmental epidural block is often preferable in treating many of the conditions mentioned above because it requires only one puncture and can be continued for hours. It can also be used for surgical anesthesia if operation is indicated. It is especially useful in the treatment of severe intractable pain due to acute pancreatitis, ureteral colic and other acute visceral diseases.

PELVIC VISCERA

Sympathetic Nerves. The bladder, genital organs, distal part of the colon and rectum are supplied by sympathetic preganglionic neurons arising in T5 to L2 spinal segments. Some of these synapse in the celiac ganglion; some in the aorticorenal ganglion; some in the lumbar sympathetic chain; others end in ganglia located in the pelvic plexus. They reach the pelvis via the lumbar and sacral splanchnic nerves and aortic plexus and the superior, middle and inferior hypogastric (pelvic) plexuses.

Parasympathetic Nerves. Preganglionic neurons supplying these structures have their cell bodies in spinal segments S2, 3, and 4. Their axons make up the *nervi ergentes* that contribute to the pelvic plexus. A few of the fibers synapse with the short postganglionic fibers within the plexus, but most of them synapse in the wall of the viscera.

Sensory Nerves. Sensory nerves accompany both the sympathetic and parasympathetic nerves and some components of the pudendal (somatic) nerves. The sensory nerves that convey pain from the cervix are associated with sympathetic fibers and enter the spinal cord at T11 to L1, and not via the sacral segments as generally believed.[33, 34]

Clinical Applications. The sympathetic nerve supply to the pelvic viscera can be interrupted by injecting 10 to 15 ml. of a local anesthetic on the anterolateral surface of the fourth or fifth lumbar vertebra. This volume, injected in the proper fascial plane, diffuses cephalad as far as the second lumbar vertebra and caudad to the superior hypogastric plexus. Interruption of the sacral parasympathetic fibers can be achieved by injection into the transsacral foramina. These procedures are particularly useful as diagnostic–prognostic tools in predicting the effect of alcohol block or transsacral rhizoteomy in patients with urinary retention due to paraplegia.[3, 5]

Extremities

The blood vessels, sweat glands and erector pili muscles in the extremities (and trunk) have only sympathetic and sensory nerves. Most of the evidence suggests that they are not supplied with parasympathetic fibers (fig. 5).

Preganglionic Sympathetic Nerves. Preganglionic sympathetic nerves to the upper extremity have cell bodies in spinal cord segments T2 to T8 inclusive, while those in the lower extremity are in T10 to L2 inclusive. These preganglionic fibers synapse in the sympathetic chain with the unmyelinated postganglionic fibers which join the spinal somatic nerves as the *gray rami communicantes.* Most of these postganglionic fibers follow the nerves and are distributed to the blood vessels, sweat glands and hair follicles at irregular intervals.

Some of the postganglionic sympathetic fibers destined for the proximal portion of the upper extremity pass directly to the subclavian artery without passing through the brachial plexus. Similarly, some fibers to the proximal portion of the thigh pass directly to the femoral artery. The vasomotor fibers in the extremities have the same distribution as the somatic nerves, which convey them peripher-ward. In the forearm, for example, the distribution is sharply demarcated into the ulnar, median and radial zones.[2, 8] Moreover, the more distal vessels of the extremity have a greater number of sympathetic fibers than the more proximal ones.

Sensory Nerves. Some of the senory nerves supplying the blood vessels, sweat glands and hair follicles are components of mixed spinal nerves, carried directly to those dorsal spinal roots, whereas others accompany the sympathetic nerves and pursue more tortuous routes.

Clinical Applications. Interruption of the sympathetic nerves to an extremity is frequently used in the management of peripheral vascular disease and is especially useful in diagnosis and therapy of acute vasospastic disease, as a prognostic method in Raynaud's disease or phenomenon, and acrocyanosis.[5] The technique is of equivocal value in chronic obstructive vascular disorders. Sympathetic block is the primary form of treatment of causalgia and other reflex sympathetic dystrophies, a group of disorders characterized by burning pain, hyperalgesia, vasoconstriction, increased sudomotor activity and trophic changes.[5] In such cases, blocks are repeated daily, and if necessary a prolonged block is effected with a neurolytic agent. Sympathetic block may also prove effective in certain types of phantom limb sensations and is useful in hyperhidrosis before a consideration of sympathectomy. This procedure may be indicated in special cases of acute bursitis, tendonitis or tenosynovitis accompanied by severe reflex vasospasms and hyperhidrosis, but it is useless in managing chronic arthritis, Charcot joint, delayed or non-union of fractures, poliomyelitis and other chronic disorders suggested by some investigators.[9, 11]

Autonomic Nerve Block as a Research Tool

Most information about autonomic pathways was obtained long ago in animals, using histologic, physiologic and pharmacologic techniques. Information obtained from studies in man is still meager. Regional block of autonomic pathways, skillfully carried out, can and should be used as a research tool to study man. The extensive use of paravertebral block in delineating pain pathways from the abdominal viscera has been mentioned. The use of paravertebral block by Cleland [35] to delineate the pain pathways from the uterus was a milestone in the understanding of the pain of labor. By combining the use of paravertebral thoracic somatic block, segmental epidural block and lumbar sympathetic block, I [33, 34] extended Cleland's work and demonstrated that the cervix (as well as the body of the uterus) is supplied by pain-conducting sensory fibers that are associated with the sympathetics and enter the spinal cord at T11, T12 and L1, not by sensory fibers associated with the sacral parasympathetic as is generally believed.[1, 2, 3] Subsequently, this was confirmed in gynecologic patients by Routledge and Elliott.[36] More recently, bilateral block of the glossopharyngeal and vagus nerves has been used by Widdicombe and his associates [37, 38, 39] in studying reflex control of breathing. Otton, Wilson and their associates [40, 41] have used upper seg-

mental epidural blocks to study circulatory control. Greater use of nerve blocks would provide additional information about neurogenic control of circulation in man. For example, the action on the heart of each of the upper five thoracic sympathetic segments could be studied with paravertebral block, using small volumes and radiographic control. Identification of the influence of unilateral and bilateral vagal block alone, then superimposed on sympathetic block, on cardiac rate, stroke volume, cardiac output, peripheral resistance and other parameters of circulatory function would enhance our knowledge of circulatory control in man greatly.

There is also a need to restudy the sensory spinal cord segments that convey painful impulses from the abdominal viscera. As previously mentioned, our knowledge of these segments is based primarily on the studies of Lawen, Kappis, and Mandl. These workers used large amounts of agents that undoubtedly spilled into adjacent segments. They did not use radiographic controls to determine the exact level of an injection. Therefore, it would seem desirable to restudy this problem with improved regional anesthetic techniques, using very small volumes and advanced radiographic techniques. Pain from the gastrointestinal tract could be provoked by distension of small segments with a balloon.[42, 43]

Another area where nerve blocks could be used to great advantage is the study of the neurophysiology of uterine contraction and cervical resistance. The vast literature on the influence of the nervous system on uterine contraction is replete with conflicting data.[1, 34] Results of some of these studies indicate that the sympathetic nervous system is inhibitory and the parasympathetic system is stimulating. Others suggest the opposite effect, and still others suggest that there is no effect. One factor responsible for this confusing state of affairs is the differences in experimental techniques used in laboratory animals. To date, no systematic studies have been carried out in humans. Recent technologic advances, which permit the study of uterine contractions in women in labor without risk to the mother or infant, could be combined with a skillful application of systematic sympathetic block, epidural block, transsacral block, and paracervical block to delineate the influence of each on contractions.

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Drugs

NARCOTICS Alphaprodine ("Nisentil") has been used extensively in obstetrics. The respiratory-depressing property of this drug was compared with that of morphine in six male volunteers. Respiratory depression was defined in terms of the displacement of the CO_2 respiratory response curve from the control curve, one of the more sensitive indices of respiratory depression. Alphaprodine caused significant respiratory depression. At the peak of activity, 19 mg. of alphaprodine is equivalent to 10 mg. of morphine. If alphaprodine continues to be of clinical value, its analgesic and respiratory-depressing effects on the mother, and the respiratory impact on the fetus, should be determined more closely by carefully designed and controlled clinical trials. (*Forrest, W. H., and Bellville, J. W.: Respiratory Effects of Alphaprodine in Man, Obstet. Gynec. 31: 61 (Jan.) 1968.*)