

THIRTY-SEVENTH EDITION

GRAY'S ANATOMY

WILLIAMS · WARWICK
DYSON · BANNISTER

CHURCHILL LIVINGSTONE

Henry Gray

CHURCHILL LIVINGSTONE
Medical Division of Longman Group UK Limited

Distributed in the United States of America by Churchill Livingstone Inc., 1560 Broadway, New York, N.Y. 10036, and by associated companies, branches and representatives throughout the world.

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Thirty-seventh edition 1989

ISBN 0 443 02588 6

British Library Cataloguing in Publication Data

Gray, Henry, 1827-1861
Gray's anatomy. — 37th ed.
I. Man. Anatomy
I. Title II. Williams, Peter L. (Peter Llewellyn)
611

Library of Congress Cataloging in Publication Data

Gray, Henry, 1827-1861
Gray's anatomy / edited by Peter L. Williams ... [et al.]. — 37th ed.
p. cm.
Rev. ed. of: Anatomy, descriptive and surgical. 35th ed. 1973.
Includes index.
I. Anatomy, Human. I. Williams, Peter L. (Peter Llewellyn)
II. Gray, Henry, 1827-1861. Anatomy, descriptive and surgical.
III. Title. IV. Title: Anatomy.
QM23.2.G73 1989
611—dc19

88-25625

Petitioner - Avation Medical, Inc.
Ex. 1088, p. ii

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EDITED BY

PETER L. WILLIAMS

DSc MA MB BChir

ROGER WARWICK

BSc PhD MD ChB

PROFESSORS EMERITI, UNIVERSITY OF LONDON
FORMERLY PROFESSORS OF ANATOMY,
GUY'S HOSPITAL MEDICAL SCHOOL, UNIVERSITY OF LONDON

MARY DYSON

BSc PhD

LAWRENCE H. BANNISTER

BSc PhD

READERS IN ANATOMY, GUY'S HOSPITAL MEDICAL SCHOOL,
UNITED MEDICAL AND DENTAL SCHOOLS OF
GUY'S AND ST THOMAS'S HOSPITALS,
UNIVERSITY OF LONDON

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trigeminothalamic pathways exist. From the principal sensory nucleus a substantial bundle of fibres crosses the midline, a minor part remaining ipsilateral, both ascending through the upper pons, midbrain and subthalamus as the *dorsal trigeminothalamic tract* (dorsal division of the trigeminal lemniscus); in the midbrain this is dorsomedial to the red nucleus and medial lemniscus, ending in the thalamic nucleus ventralis posterior medialis (VPM) (p. 1002). Other fibres from the principal sensory and spinal

nucleus (in its whole length) mainly cross to ascend near the medial lemniscus as the *ventral trigeminothalamic tract* (ventral division of the trigeminal lemniscus); many also end in the VPM but others, mainly from neurons in the caudal part of the spinal nucleus, perhaps end in the medial geniculate body and intralaminar nuclei. Collaterals may leave these ascending tracts to terminate in the brain-stem reticular formation and other cranial nerve nuclei while some probably enter the cerebellum (p. 966).

THE SPINAL NERVES

Spinal nerves are united ventral and dorsal spinal roots, attached in series to the sides of the spinal cord. There are 31 pairs: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal. The abbreviations C, T, L, S and Co, with appropriate numerals, are commonly applied to individual nerves. These emerge through intervertebral foramina; C1 leaves the vertebral canal between the occipital bone and atlas and is hence often termed the *suboccipital nerve*; C8 issues between the seventh cervical and first thoracic vertebrae. Each nerve is continuous with the spinal cord by the ventral and dorsal roots, the latter each bearing a *spinal ganglion*.

Ventral (anterior) roots contain axons of neurons in the anterior and lateral spinal grey columns. Each emerges as a series of *rootlets* in two or three irregular rows in an area about 3 mm in horizontal width. In rats the rootlets of lumbar ventral roots are each ensheathed by a single fenestrated layer of cells. At the spinal cord surface the rootlets are separated by a labyrinth of interradicular spaces lined by this sheath. Between adjacent rootlets the interradsular spaces, which contain small blood vessels, taper distally. The interradsular spaces communicate with the endoneurial spaces of the rootlets and with the subpial space but are isolated from the subarachnoid space by the multilayered, unfenestrated sheath which surrounds the aggregations of rootlets which comprise each ventral root (Kaar & Fraher 1986).

Dorsal (posterior) roots contain centripetal processes of neurons sited in the spinal ganglia. Each consists of medial and lateral fascicles both diverging into *rootlets* entering along the posterolateral sulcus. In many mammals, including humans, the rootlets of adjacent dorsal roots are often connected by oblique filaments, especially in the lower cervical and lumbosacral regions (Pallie & Manuel 1968).

Each root is covered by the pia mater and is loosely invested by the arachnoid mater prolonged to where the roots pierce the dura mater. The dorsal and ventral roots do so separately, each receiving a dural sheath (7.204, 208); where the roots unite to form spinal nerves these sheaths fuse with the epineurium.

Spinal ganglia are large groups of neurons on the dorsal spinal roots. Each is oval and reddish, its size being related to that of its root; it is bifid medially where the dorsal root's two fascicles emerge to enter the cord. Ganglia are usually sited in the intervertebral foramina, immediately lateral to the perforation of the dura mater by the roots (7.61), but the first and second cervical ganglia are on the vertebral arches of the atlas and axis, the sacral inside the vertebral canal and the coccygeal ganglia usually within the dura mater.

The first cervical ganglia may be absent. Small *aberrant ganglia* sometimes occur on the upper cervical dorsal roots between the spinal ganglia and cord. (Heterotopic ganglionic neurons also occur in other sites, see p. 897.)

The internal structures of sensory ganglia, cranial and spinal, is similar (p. 896 and consult Van Gehuchten 1892, Marinesco 1909, Cajal 1911, De Castro 1932, Scharf 1958, Lieberman 1976). Each sensory ganglion has a laminar connective tissue capsule continuous with the epineurium of the spinal root. Endoneurial stroma permeates the ganglion, supporting its neuronal and axonal population; perineurial capsular trabeculae extend between groups of these elements. The stroma is intimately related to the satellite cells (amphicytes); it contains a few mast cells and a dense vascular network, denser around ganglion cells, into which capillary loops may be invaginated (Scharf 1958). These

capillaries are non-fenestrated in rodents (Lieberman 1968) but commonly fenestrated in primates (Olsson 1971). Ganglionic vascular permeability varies among species, amounting to a 'blood-nerve' barrier in some, largely dependent on the junctional complexes between endothelial cells; details are not available for mankind. Ganglionic neurons vary in size (15–110 µm in man, Ohta et al 1974); most are spheroidal but smaller cells appear ellipsoidal or angular in section.

Ganglionic neurons resemble other neurons but vary much in the distribution of cytoplasmic chromatin, from fine dispersal to concentration in large masses (Nissl granules); this has been the chief basis of many classifications, which remain conflicting. Melanin and lipofuchsin pigments occur in some but less than in some cranial sensory ganglia. Dense-cored vesicles are common (Lieberman 1968), despite the apparent absence of catecholamines. However, the occurrence of two extreme types is agreed: large 'light' neurons (A cells) and small 'dark' ones (B cells). In 'light' cells the granular endoplasmic reticulum is more dispersed but highly concentrated in 'dark' cells. The latter are sometimes mimicked by artefact, perhaps due to poor fixation. Both types appear in prenatal material. Functional differences remain unclarified but the axons of A cells are said to be myelinated and those of B cells non-myelinated. It has been suggested that B cells are visceral. 'Atypical' neurons have been described in dorsal root and other sensory ganglia, the most interesting being reputed to be multipolar neurons; but since synapses have not been identified in dorsal root ganglia, this is improbable and is unconfirmed. Almost all ganglionic neurons are unipolar (p. 863), many with a coiled 'stem' process close to the parent soma, forming an axonal 'glomerulus' before branching into peripheral and central parts (p. 1094). Spinal ganglionic cells have been submitted to ultrastructural studies (Duce & Keen 1977), assessment of specific intracellular substances (Hokfelt et al 1976), preferential glutamine absorption (Duce & Keen 1978) and specific reactions to neurotoxins (Jancso et al 1977). Such data, while confirming 'light' and 'dark' cells, collectively suggest a subdivision into further types, particularly of 'dark' cells. Small dark cells may occur in at least two variants, differentiated by production of either substance P or somatostatin. Different cells respond also to different neurotoxins or differ in glutamine metabolism.

Counts of cells in the dorsal root ganglia show *specific* variation, as expected; few estimates exist for human ganglia. Maximal counts are reached about three years after birth; but the subsequent supposed loss has not been confirmed. The distribution of somata and axons is variable, the former often being peripherally concentrated; but grouping of the somata between large fascicles of axons is described as more usual in human ganglia. Such grouping may indicate somatotopic organization, sometimes described in terms of somata and axons. Burton & McFarlane (1973), by injection of labelled amino acids into ganglia, associated local groups of neurons in cats' lumbar ganglia with branches of spinal nerves and also with particular spinal radicles. Horseradish peroxidase injections near peripheral receptor endings have produced more exact results in rodent sensory ganglia; no results are available for primates.

Size and direction of spinal nerve roots vary. The upper four *cervical* roots are small, the lower four large. Cervical dorsal roots have a thickness ratio to the ventral roots of three to one, greater than in other regions. The first dorsal root is an exception,

being smaller than the ventral; in about 8% it is absent. The first and second cervical roots are short, running almost horizontally to their exits from the vertebral canal. From the third to the eighth cervical they slope obliquely down, obliquity and length increasing successively; the distance between spinal attachment and vertebral exit never exceeds the height of one vertebra.

Thoracic roots, except the first, are small, the dorsal only slightly exceeding the ventral in thickness. They increase successively in length and in the lower thoracic region descend in contact with the spinal cord for at least two vertebrae before emerging from the vertebral canal (but vide infra).

Kubik & Müntener (1969) consider that the cervicothoracic part of the spinal cord grows more in length than other parts and thus explain their observations which differ from the above remarks. They state that upper cervical roots *descend*, the fifth being horizontal, and that the sixth to eighth actually *ascend*, that the first two thoracic roots are horizontal, the next three ascend, the sixth is horizontal and the rest descend.

Lower *lumbar* and upper *sacral roots* are the largest and their radicles the most numerous, while the *coccygeal* roots are the smallest. Kubik & Müntener (1969) confirm that lumbar, sacral and coccygeal roots descend with increasing obliquity to their exits; since the spinal cord ends near the lower border of the first

lumbar vertebra, the lengths of successive roots rapidly increase. The consequent collection of roots is the *cauda equina* (7.60B).

The largest roots and the hence largest spinal nerves are continuous with the spinal cervical and lumbar swellings and innervate the upper and lower limbs.

Immediately distal to the spinal ganglia, ventral and dorsal roots unite to form *spinal nerves*, which emerge through intervertebral foramina and give off recurrent meningeal branches (vide infra), dividing immediately into *dorsal* and *ventral rami* (7.250). (From limited dissections Sato (1974) has described the *trifurcation* of spinal nerves at some cervical and thoracic levels, the third branch being a *ramus intermedius*.) At or distal to its origin each ventral ramus receives a *grey ramus communicans* from the corresponding sympathetic ganglion, while the thoracic and first and second lumbar ventral rami each contribute a *white ramus communicans* to the corresponding ganglia (7.236, 238). The second, third and fourth sacral nerves also supply visceral branches, unconnected with sympathetic ganglia, which carry a parasympathetic outflow direct to the pelvic plexuses (pp. 1156, 1166).

Cervical spinal nerves enlarge from the first to the sixth, the seventh and eighth cervical and first thoracic being like the sixth cervical in size. The remaining thoracic nerves are relatively small. Lumbar nerves are large, increasing in size from the first to the fifth. The first sacral is the largest spinal nerve, thereafter they decrease to the coccygeal, the smallest.

In the intervertebral foramina spinal nerves have clinically important relations. *Anterior* are the intervertebral discs and adjacent vertebral bodies. *Posterior* are the synovial zygapophysial joints. *Superior* and *inferior* are vertebral notches of the pedicles of adjoining vertebrae. Each nerve, accompanied by a spinal artery, a small venous plexus and its own meningeal branch or branches together traverse a foramen.

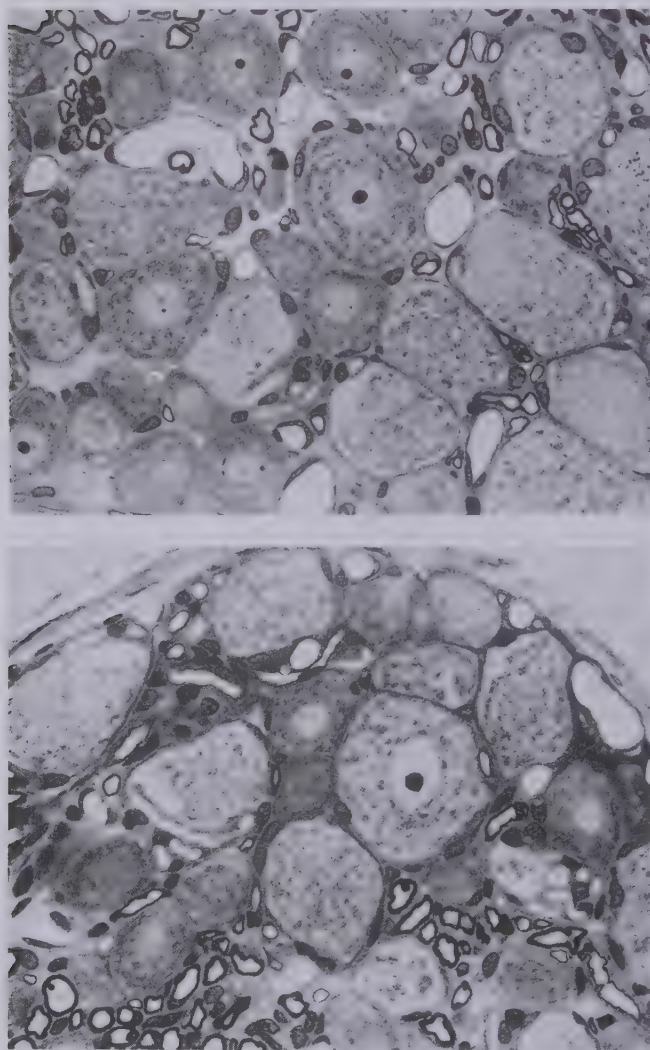
Applied Anatomy. Spinal roots may be compressed in their course between the spinal cord and their exit from intervertebral foramina. In the cervical region, vertebral disease, the degeneration of an intervertebral disc or disease of the intervertebral joints may affect the roots in their intervertebral foramen, causing pain, diminished cutaneous sensibility and muscular weakness in the field of supply. At the lumbar level, the posterior protrusion of an intervertebral disc or rupture of its annular fibres, with herniation of the nucleus pulposus, is common, particularly in the discs between the fourth and fifth lumbar and first sacral vertebrae. Disc lesions may compress one or both roots in their foramina, resulting in back pain ('lumbago'), with or without radiation of pain to one or both legs ('sciatica'), diminished cutaneous sensibility in the area of supply and weakness of the muscles innervated (e.g. tibialis anterior L. 4, extensor hallucis longus L. 5, flexor hallucis longus S. 1). Less commonly, tumours in the vertebral canal or spina bifida with meningocele may affect one or more roots in the cauda equina.

FUNCTIONAL COMPONENTS OF SPINAL NERVES

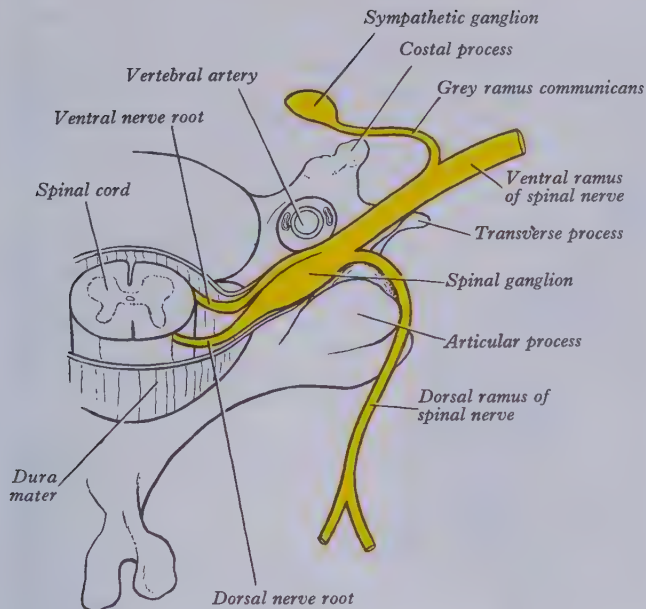
Each typical spinal nerve contains somatic and visceral fibres.

The somatic components are efferent and afferent. *Somatic efferent* fibres for the innervation of skeletal muscles are axons of α , β and γ neurons in the spinal anterior grey column. *Somatic afferent* fibres convey impulses into the central nervous system from receptors in the skin, subcutaneous tissue, muscles, fasciae, joints, etc. (pp. 909–915); they are peripheral processes of unipolar neurons in the spinal ganglia.

The visceral components, also afferent and efferent, belong to the autonomic nervous system (p. 1154). They include sympathetic or parasympathetic fibres at different spinal levels. Preganglionic *visceral efferent* sympathetic fibres are axons of neurons in the spinal lateral grey column in the thoracic and upper two or three lumbar segments; they join the sympathetic trunk along corresponding white rami communicantes to synapse with postganglionic neurons distributed to non-striated muscle or glands. The preganglionic *visceral efferent* parasympathetic fibres are axons of cells in the spinal lateral grey column of the second to fourth sacral segments; they leave the ventral rami of corresponding sacral nerves to synapse in pelvic ganglia, the



7.236 Two photographs of fields in normal rat cervical dorsal root ganglion to show contrasting features of light and dark neuronal somata. Note the capsules of satellite cells; the darkly stained multiple profiles between many of the nerve cells represent glomeruli in repeated transverse section. Interneuronal capillary profiles are also visible. Cresyl fast violet staining of semi-thin sections of material embedded in araldite. Photographs supplied by J.M. Jacobs, National Hospital for Nervous Diseases, London.



7.237 Scheme showing the relations of a cervical nerve and its ganglion to a cervical vertebra.

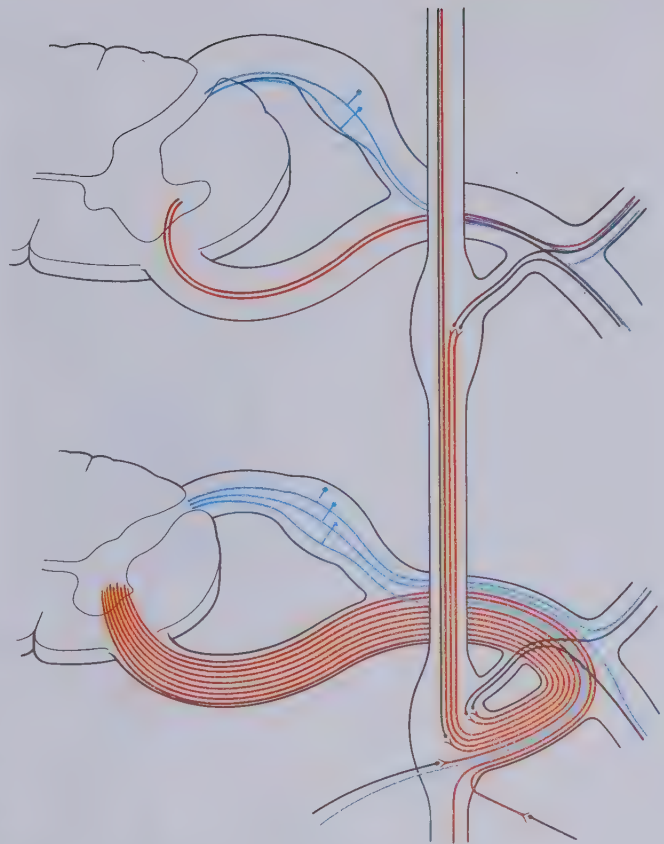
postganglionic axons being distributed mainly to muscle or glands in the walls of the pelvic viscera. *Visceral afferent* fibres are from neurons in the spinal ganglia. Their peripheral processes pass through white rami communicantes and, without synapsing, through one or more sympathetic ganglia to end in viscera. Some visceral afferent fibres may enter the spinal cord in *ventral roots*; Coggeshall et al (1973) claim that almost 30% of fibres in the feline seventh lumbar and first sacral ventral roots are non-myelinated afferents, which may project *into* the cord from neurons in the corresponding dorsal root ganglia.

Central processes of ganglionic unipolar neurons enter the spinal cord by posterior roots and connect with somatic or sympathetic efferent neurons, usually through interneurons, completing reflex paths, or they synapse with other neurons in the spinal or brain-stem grey matter which provide a variety of ascending tracts.

Little detail of the dendrites of spinal autonomic neurons is available. Schramm et al (1976) showed that sympathetic efferent neurons have largely horizontal dendritic arrays in newborn rats, re-orientated into longitudinal arrays in the next five or six post-natal weeks. No such data are available for the human spinal cord.

After emerging from its intervertebral foramen each spinal nerve supplies small *meningeal* branches and splits almost at once into *dorsal* and *ventral rami*, both receiving fibres from both roots.

The meningeal branches (*recurrent meningeal* or *sinu-vertebral nerves*), numbering two to four filaments on each side, occur at all vertebral levels (Kimmel 1961a, b). Each receives one or more rami from a nearby grey ramus communicans or from a



7.238 Scheme showing the constitution of a typical spinal nerve. In the upper part of the diagram the spinal nerve roots show the somatic components; in the lower part of the diagram the spinal roots show the visceral components. Red=somatic efferent and preganglionic sympathetic fibres, blue=somatic afferent and visceral afferent fibres, black=postganglionic sympathetic fibres.

thoracic sympathetic ganglion directly; most then pursue a recurrent (often perivascular) course into the spinal canal through the intervertebral foramen ventral to the dorsal root ganglion. Here these mixed sensory and sympathetic nerves divide into transverse, ascending and descending branches distributed to the dura mater, the walls of blood vessels, the periosteum, ligaments and intervertebral discs in the ventrolateral region of the spinal canal. Fine meningeal branches occasionally pass dorsal to the spinal ganglia to the dorsal dura, periosteum and ligaments, others passing ventrally to the posterior longitudinal ligament. Ascending branches of the upper three cervical meningeal nerves are large and distributed to the dura mater in the posterior cranial fossa (p.1088). Meningeal nerves are important in relation to the referred pain characteristic of many spinal disorders and in occipital headache.

DORSAL RAMI OF THE SPINAL NERVES

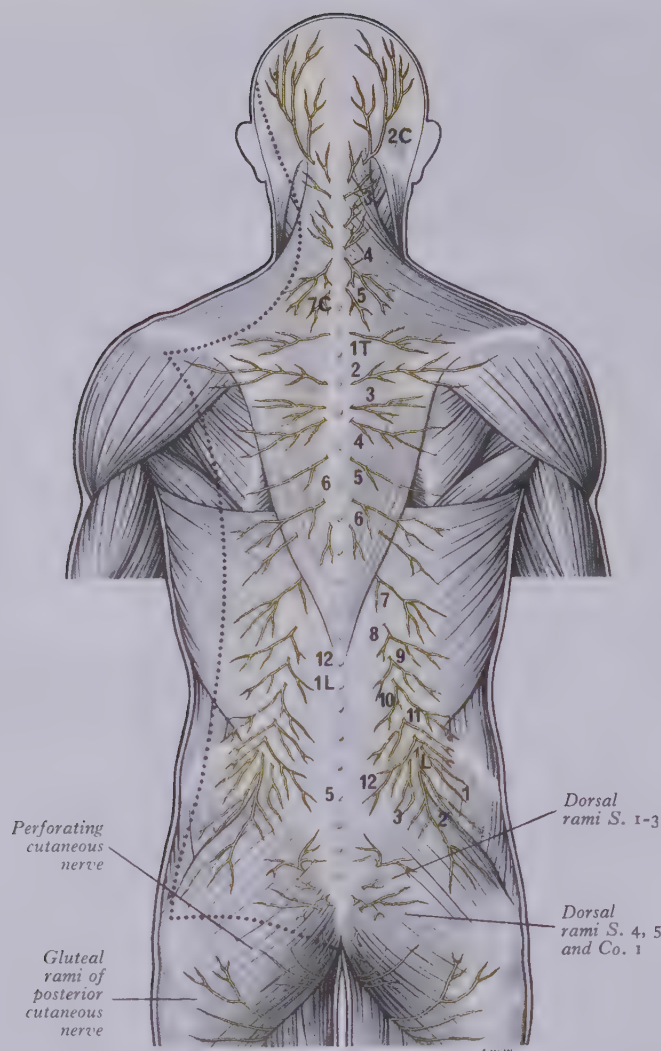
Dorsal (posterior primary) rami of spinal nerves, usually smaller than the *ventral* and directed posteriorly, divide (except for the first cervical, fourth and fifth sacral and the coccygeal) into medial and lateral branches to supply the muscles and skin (7.239) of the posterior regions of the neck and trunk.

CERVICAL DORSAL RAMI

Each cervical spinal dorsal ramus, except the first, divides into medial and lateral branches, all innervating muscles; but in general only medial branches of the second to fourth and usually

the fifth supply the skin. Except for the first and second, each dorsal ramus passes back medial to a posterior intertransverse muscle, curving round the articular process into the interval between the semispinalis capitis and semispinalis cervicis.

The first cervical dorsal ramus (suboccipital nerve) (5.40), larger than the ventral, emerges superior to the posterior atlantal arch and inferior to the vertebral artery. It enters the suboccipital triangle to supply local muscles: the rectus capitis posterior major and minor, superior and inferior oblique and the semispinalis capitis. A filament from the branch to the inferior oblique joins the second dorsal ramus (5.40). The suboccipital



7.239 The cutaneous distribution of the dorsal rami of the spinal nerves. The nerves are shown lying on the superficial muscles; on the left side the limit of the skin area supplied by these nerves is indicated by the dotted

line. The nerves are numbered on the right side and the spines of the seventh cervical, sixth and twelfth thoracic and first and fifth lumbar vertebrae are labelled on the left side.

nerve occasionally has a cutaneous branch which accompanies the occipital artery to the scalp, connecting with the greater and lesser occipital nerves.

The second cervical dorsal ramus, slightly larger than the ventral and all other cervical dorsal rami, emerges between the posterior atlantal arch and the lamina of the axis, below the inferior oblique which it supplies, receiving a connection from the first cervical dorsal ramus, and divides into a large medial and smaller lateral branch. Its ganglion is extradural. The *medial* branch, termed the *greater occipital nerve* (7.239, 241), ascends between the inferior oblique and semispinalis capitis, pierces the latter and the trapezius near their occipital attachments and is joined by a filament from the medial branch of the third dorsal ramus; ascending with the occipital artery, it divides into branches which connect with the lesser occipital nerve and supply the skin of the scalp as far forward as the vertex. It supplies the semispinalis capitis and occasionally the back of the auricle. The *lateral* branch supplies the splenius, longissimus capitis and semispinalis capitis and is often joined by the corresponding third cervical branch.

The third cervical dorsal ramus, between the second and fourth in size, courses back round the third cervical articular pillar, medial to the posterior intertransverse muscle, dividing into medial and lateral branches. Its *medial* branch runs between the spinalis capitis and semispinalis cervicis, piercing the splenius and trapezius to end in the skin. Deep to the trapezius it gives rise to a branch, the *third occipital nerve*, which pierces the trapezius to end in the skin of the lower occipital region (7.239), medial to

the greater occipital nerve and connected to it. The *lateral* branch often joins that of the second cervical dorsal ramus.

The dorsal ramus of the suboccipital and medial branches of the dorsal rami of the second and third cervical nerves are sometimes joined by loops to form the *posterior cervical plexus*.

Dorsal rami of the lower five cervical nerves curve back round the vertebral articular pillars and divide into medial and lateral branches. *Medial* branches of the fourth and fifth run between the semispinalis cervicis and semispinalis capitis, reach the vertebral spines and pierce the splenius and trapezius to end in the skin (7.239). The fifth medial branch may not reach the skin. The medial branches of the lowest three cervical nerves are small and end in the semispinalis cervicis, semispinalis capitis, multifidus and interspinales. The *lateral* branches supply the iliocostalis cervicis, longissimus cervicis and longissimus capitis.

THORACIC DORSAL SPINAL RAMI

Thoracic dorsal rami pass backwards close to the vertebral zygapophysial joints to divide into medial and lateral branches. Each medial branch emerges between a joint and medial edges of the superior costotransverse ligament and intertransverse muscle, but each lateral branch runs in the interval between ligament and muscle before inclining posteriorly on the medial side of the levator costae.

Medial branches of the *upper six* thoracic dorsal rami pass between and supply the semispinalis thoracis and multifidus; they pierce the rhomboids and trapezius, reaching the skin near the

vertebral spines (7.239). *Medial branches* of the *lower six* thoracic dorsal rami chiefly supply the multifidus and longissimus thoracis and occasionally skin in the median region. *Lateral branches* increase inferiorly in size, running through or deep to the longissimus thoracis to the interval between it and the iliocostalis cervicis, supplying these muscles and the levatores costarum; the lower five or six also have cutaneous branches, piercing the serratus posterior inferior and latissimus dorsi in line with the costal angles (7.239). Some upper thoracic lateral branches also supply the skin. The twelfth thoracic lateral branch sends a filament medially along the iliac crest, then passes down to the anterior gluteal skin. Medial cutaneous branches of the thoracic dorsal rami descend close to the vertebral spines before reaching the skin; lateral branches descend as far as the level of four ribs before becoming superficial, the branch of the twelfth thoracic reaching the skin a little above the iliac crest.

LUMBAR DORSAL SPINAL RAMI

Lumbar dorsal rami pass back medial to the medial intertransverse muscles, dividing into medial and lateral branches. *Medial branches* run near the vertebral articular processes to end in the multifidus; they are related to the bone between the accessory and mamillary processes and may groove it, traversing a distinct notch or even a foramen. *Lateral branches* supply the erector spinae (sacrospinalis). In addition, the upper three give rise to cutaneous nerves which pierce the aponeurosis of the latissimus dorsi at the lateral border of the erector spinae and

cross the iliac posteriorly to reach the gluteal skin (7.239), some reaching as far as the level of the greater trochanter.

SACRAL DORSAL SPINAL RAMI

Sacral dorsal rami are small, diminishing downwards; excepting the fifth, they emerge through the dorsal sacral foramina. The *upper three* are covered at the exit by the multifidus, dividing into medial and lateral branches. Medial branches are small and end in the multifidus. *Lateral branches* join together and with lateral branches of the last lumbar and fourth sacral dorsal rami form loops dorsal to the sacrum; from these loops branches run dorsal to the sacrotuberous ligament to form a second series of loops under the gluteus maximus; from these two or three *gluteal branches* pierce the gluteus maximus (along a line from the posterior superior iliac spine to the coccygeal apex) to supply the posterior gluteal skin (7.239). The dorsal rami of the *fourth* and *fifth* sacral nerves are small and lie below the multifidus. They unite with each other and the coccygeal dorsal ramus to form loops dorsal to the sacrum; filaments from these supply the skin over the coccyx. Berthold & Carlstedt (1977) have recorded a detailed study of the feline first sacral nerve at its junction with the spinal cord.

COCCYGEAL DORSAL SPINAL RAMUS

This does not divide into medial and lateral branches. Its connections and distribution are noted above.

VENTRAL RAMI OF THE SPINAL NERVES

The ventral rami of spinal nerves supply the limbs and the anterolateral aspects of the trunk; they are mostly larger than the dorsal rami. The *thoracic* are independent and retain, like all

dorsal rami, a largely segmental distribution. The *cervical*, *lumbar* and *sacral* connect near their origins to form plexuses. Dorsal rami do not join these plexuses.

CERVICAL VENTRAL RAMI

Cervical ventral rami, except the first, appear between the anterior and posterior intertransverse muscles. The *upper four* form a *cervical plexus*; the *lower four*, with most of the first thoracic ventral ramus, form a *brachial plexus*. Each receives at least one grey ramus communicans, the upper four from the superior cervical sympathetic ganglion, the fifth and sixth from the middle ganglion and the seventh and eighth from the cervicothoracic ganglion (p. 1160). The *first cervical ventral ramus* (*suboccipital nerve*) emerges above the posterior arch of the atlas, passes forwards lateral to its lateral mass and medial to the vertebral artery. It supplies the rectus lateralis, emerges medial to it, descends anterior to the atlantal transverse process and posterior to the internal jugular vein and joins the ascending branch of the second cervical ventral ramus. The *second cervical ventral ramus* issues between the vertebral arches of the atlas and axis, ascends between their transverse processes, passes anterior to the first posterior intertransverse muscle and emerges lateral to the vertebral artery generally between the longus capitis and levator scapulae, but when scalenus medius is attached to the atlas it intervenes between the nerve and the levator scapulae. The ramus divides into an ascending branch which joins the first cervical nerve and a descending one which joins the ascending branch of the third cervical ventral ramus. The *third cervical ventral ramus* appears between the longus capitis and scalenus medius. The remaining ventral rami emerge between the scalenus anterior and scalenus medius.

The Cervical Plexus

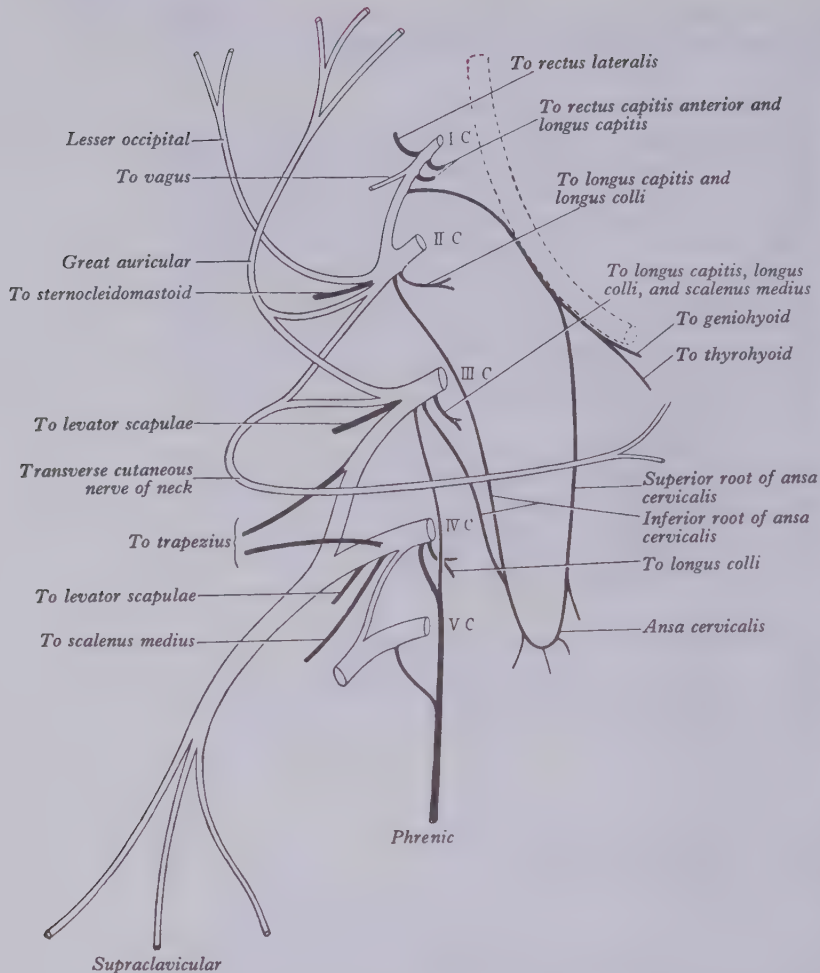
The cervical plexus (7.240), formed by the upper four cervical ventral rami, supplies some nuchal muscles, the diaphragm and areas of skin in the head, neck and chest (7.224). Level with the first four vertebrae, it is deep to the internal jugular vein and sternocleidomastoid and anterior to the scalenus medius and levator scapulae. Each ramus, except the first, divides into ascending and descending parts, which unite in communicating loops. From the first loop (C2 and 3) superficial branches supply the head and neck; from the second (C3 and 4) arise cutaneous nerves of the shoulder and chest. Muscular and communicating branches arise from the same nerves. The branches are superficial or deep; the superficial perforate the cervical fascia to supply the skin while the deep branches mostly supply muscles. The superficial form ascending and descending groups and form the deep medial and lateral series.

ASCENDING SUPERFICIAL BRANCHES

These branches of the cervical plexus (7.240-242) include:

- Lesser occipital C2
- Greater auricular C2, 3
- Transverse (anterior) cutaneous C2, 3

The *lesser occipital nerve* (7.240, 241), from the second cervical ventral ramus and sometimes also from the third, curves



7.240 A plan of the cervical plexus. The hypoglossal nerve is shown by interrupted lines and the muscular branches by solid black lines. The roman numerals and letters I C to V C indicate the *ventral rami* of these cervical spinal nerves.

around the accessory nerve and ascends along the posterior border of the sternocleidomastoid. Near the cranium it perforates the deep fascia and ascends the scalp behind the auricle, supplying the skin and connecting with the great auricular and greater occipital nerves and the posterior auricular branch of the facial. It varies in size and is sometimes double. Its *auricular branch* supplies the skin on the upper third of the medial auricular aspect and connects with the posterior branch of the great auricular nerve. The auricular branch is occasionally derived from the greater occipital nerve.

The great auricular nerve (7.240, 241), is the largest ascending branch. It arises from the second and third cervical rami, encircles the posterior border of the sternocleidomastoid, perforates the deep fascia and ascends on the muscle beneath the platysma with the external jugular vein. It passes to the parotid gland, dividing into anterior and posterior branches. The *anterior branch* is distributed to the facial skin over the parotid gland, connecting in the gland with the facial nerve. The *posterior branch* supplies the skin over the mastoid process and on the back of the auricle (except its upper part); a filament pierces the auricle to reach its lateral surface where it is distributed to the lobule and concha. The posterior branch communicates with the lesser occipital, the auricular branch of the vagus and the posterior auricular branch of the facial nerve.

The transverse (anterior) cutaneous nerve of the neck (7.240, 241) arises from the second and third cervical rami, curves round the posterior border of the sternocleidomastoid near its midpoint and runs obliquely forwards, deep to the external jugular vein, to the muscle's anterior border. It perforates the

deep cervical fascia, dividing under the platysma into ascending and descending branches distributed to the anterolateral areas of the neck. The *ascending branches* ascend to the submandibular region, forming a plexus with the facial nerve's cervical branch beneath the platysma; others pierce the platysma and are distributed to the skin of the upper anterior areas of the neck. The *descending branches* pierce the platysma and are distributed anterolaterally to the skin of the neck, as low as the sternum.

DESCENDING SUPERFICIAL BRANCHES

These are: supraclavicular (C3, 4): medial, intermediate and lateral.

The supraclavicular nerves (7.240, 241) arise by a common trunk from the third and fourth cervical ventral rami and emerge from the posterior border of the sternocleidomastoid, to descend under the platysma and the deep cervical fascia; they divide into medial, intermediate and lateral (posterior) branches, which diverge to pierce the deep fascia a little above the clavicle.

The *medial supraclavicular nerves* run inferomedially across the external jugular vein and the clavicular and sternal heads of the sternocleidomastoid to supply the skin as far as the midline and as low as the second rib. They supply the sternoclavicular joint. The *intermediate supraclavicular nerves* cross the clavicle to supply the skin over the pectoralis major and deltoid down to the level of the second rib, next to the area of supply of the second thoracic nerve (7.254). Overlap between these nerves is minimal. The *lateral (posterior) supraclavicular nerves* descend superficially across the trapezius and acromion, supplying the skin of the upper and posterior parts of the shoulder.

DEEP BRANCHES—MEDIAL SERIES

These include the following communicating and muscular branches:

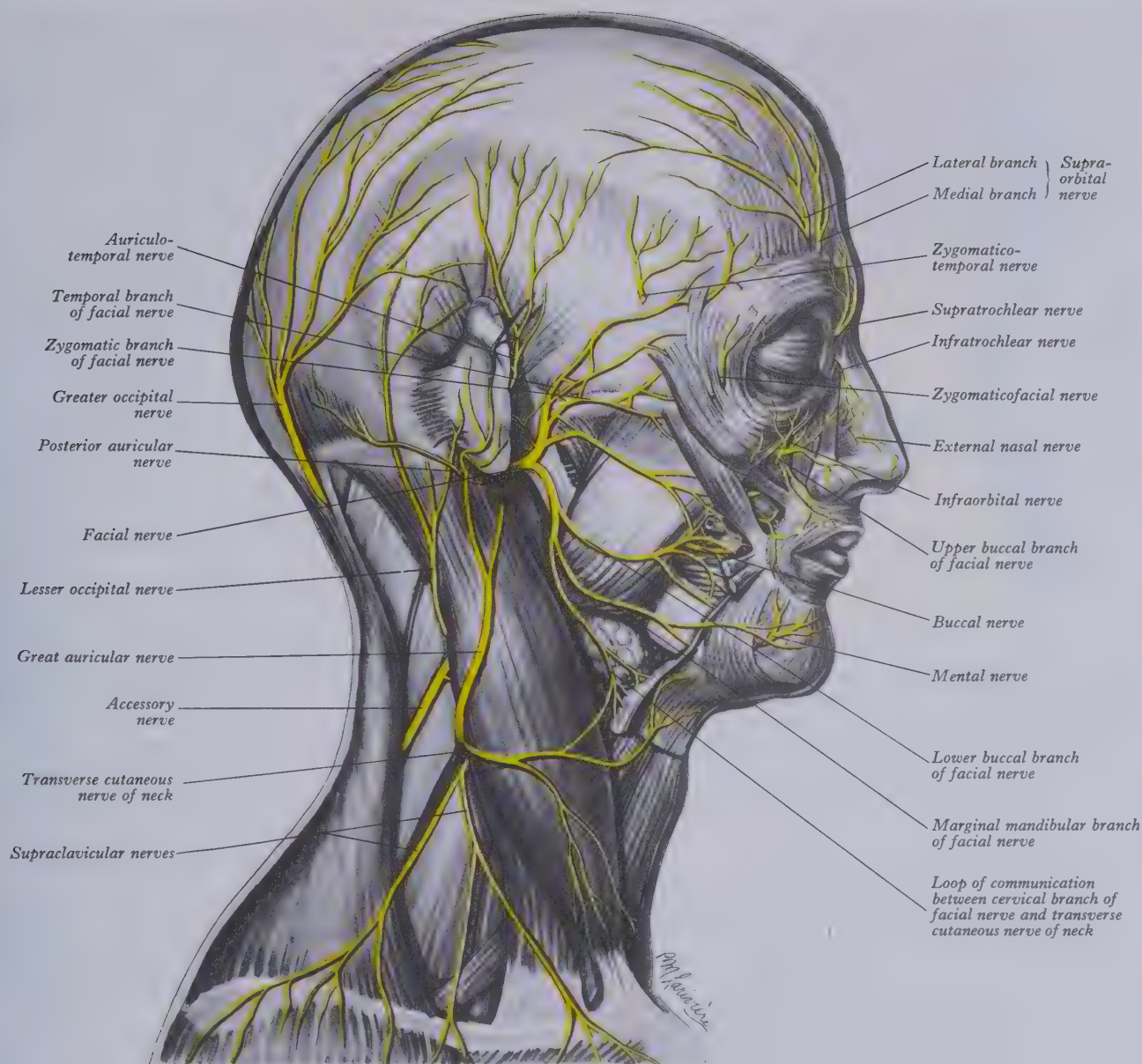
Communicating branches with	Hypoglossal	C1, 2
	Vagus	C1, 2
	Sympathetic	C1-4
Muscular branches to	Rectus capitis lateralis	C1
	Rectus capitis anterior	C1, 2
	Longus capitis	C1-3
	Longus colli	C2-4
	Inferior root of ansa cervicalis	C2, 3
	Phrenic nerve	C3-5

Communicating branches pass from the loop between the first and second cervical rami to the vagus, hypoglossal nerve and sympathetic. The hypoglossal branch later leaves it as a series of branches, viz. the meningeal, *superior root of ansa cervicalis*, nerves to the thyrohyoid and probably to the geniohyoid (p. 585). A branch also connects the fourth and fifth cervical rami; the first four cervical ventral rami each receive a grey ramus communicans from the superior cervical sympathetic ganglion.

Muscular branches supply the rectus capitis lateralis, rectus capitis anterior, longus capitis and longus colli.

The inferior root of the ansa cervicalis (nervus descendens cervicalis) (7.240) is formed by the union of a branch from the second with another from the third cervical ramus. It descends on the lateral side of the internal jugular vein, crosses it a little below the middle of the neck, and continues forwards to join the superior root anterior to the common carotid artery, forming the *ansa cervicalis* (*ansa hypoglossi*) (6.69), from which all infrahyoid muscles are supplied, except the thyrohyoid. In 160 dissections, the inferior root was from the second and third cervical ventral rami in 74%, from the second to fourth in 14%, from the third alone in 5%, from the second alone in 4% and from the first to third in 2% (Porirae & Chernikov 1965).

The phrenic nerve, sole motor supply to the diaphragm, also contains widespread sensory fibres. It arises chiefly from the fourth cervical ramus but also has contributions from the third and fifth (7.240). Formed at the upper part of the lateral border of the scalenus anterior, it descends almost vertically across it *behind the prevertebral fascia* on its anterior surface. It descends posterior



7.241 The nerves of the right side of the scalp, face and side of the neck.

to the sternocleidomastoid, the inferior belly of omohyoid (near its intermediate tendon), the internal jugular vein, transverse cervical and suprascapular arteries (6.68) and, on the left, the thoracic duct. It then runs anterior to the subclavian artery, posterior to the subclavian vein and enters the thorax by crossing medially in front of the internal thoracic artery (6.90), after which it descends anterior to the pulmonary hilum, between the fibrous pericardium and mediastinal pleura, to the diaphragm, accompanied by the pericardiophrenic vessels. The right and left phrenic nerves differ in their intrathoracic relations.

The *right phrenic nerve*, shorter and more vertical, is separated at the root of the neck from the second part of the right subclavian artery by the scalenus anterior. It is then lateral to the right brachiocephalic vein, the superior vena cava and the fibrous pericardium covering the right surface of the right atrium and inferior vena cava.

The *left phrenic nerve*, at the root of the neck, is commonly stated to leave the medial edge of the scalenus anterior to pass anterior to the first part of the left subclavian artery and behind the thoracic duct. However, Quist (1977) claims that both right and left nerves are *symmetrical* in their cervical course and that at the thoracic inlet the left crosses anterior to the second part of the

left subclavian artery, separated by the scalenus anterior. Thereafter the left phrenic crosses anterior to the left internal thoracic artery, descending across the medial aspect of the left lung's apex and its pleura to the first part of the subclavian artery, which it crosses obliquely to reach a groove between the left common carotid and subclavian arteries. It passes anteromedially superficial to the left vagus nerve just above the aortic arch and behind the left brachiocephalic vein. It then passes superficial to the aortic arch and the left superior intercostal vein, anterior to the left pulmonary hilum, to lie between the fibrous pericardium covering left surface of the left ventricle and the mediastinal pleura (p. 750).

In the neck each nerve receives variable filaments from the cervical sympathetic ganglia or their branches and may also connect with internal thoracic sympathetic plexuses (Pearson & Sauter 1971); these connections may represent a devious course of sympathetic fibres to these plexuses (p. 1161). In its thoracic course each nerve supplies sensory branches to the mediastinal pleura, fibrous pericardium and parietal serous pericardium.

Diaphragmatic relations (Merendino et al 1956, Perera & Edwards 1957). The right phrenic nerve traverses the diaphragm's central tendon, either by the caval orifice or just lateral to it. The



2.442. A diagram showing the cutaneous nerve supply of the face, scalp and neck. Legend: = trigeminal nerve, = facial nerve, = vagus nerve. Blue = cervical dorsal root.

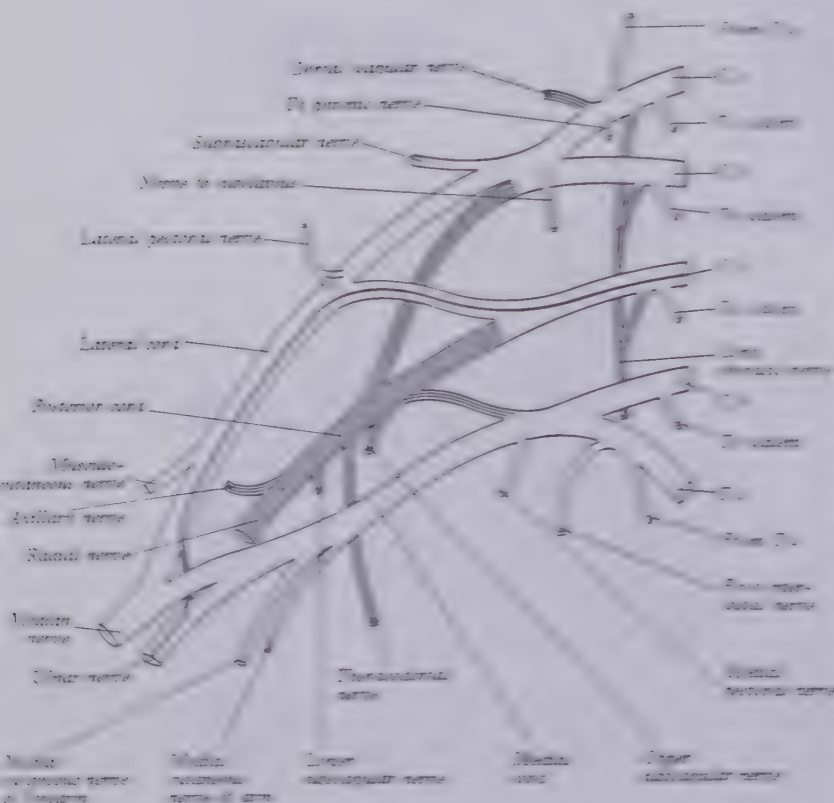


Fig. 3. A plan of the brachial plexus. The posterior division of the trunk and their derivatives are shaded and the fibres from C₅ which enter the ulnar nerve are shown as a heavy black line. Letters and numbers C₄-C₈ and T₁-T₄ indicate the neural roots of these cervical and thoracic spinal nerves.

[illegible][illegible]

However, previous work. Focusing on the primary power-law fit with an α value around unity, other papers have focused on the primary fit with $\alpha = 1$, the secondary power-law curve. This is consistent with many terms and frequency processes, or sometimes associated with the sub-sonic wind. I would argue the primary curve fits best to the data and is a useful tool for the preliminary identification of several. An alternative physical term may be derived from the frequency of ionospheric waves or from the wave frequency ω itself.

General Answer: Division is the physical term in the set-completion paradigm, the corresponding half of the disjunctive which dominates. It is an abstract physical term, often written as $\div$, meaning if the main term is $\div$ then the relative structure of the product dominates further.

Table 1. *Continued*

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Communicating—Person	11.10.2	
Medium	Metaphor—Language	11.10.2
	Empirical	11.10.2
	Literary language	11.10.2
	External medium	11.10.2

Communicating branches. These are branches that are not directly connected to the main branch, but are connected to it through a communication channel. They are used to transfer data between the main branch and other branches.

Muscular branches are distributed to the following structures:

The Brack and Flows

The cranial nerve roots of the first three spinal nerves contain the greater part of the first dorsal root ganglion (Fig. 1). The fourth nerve usually gives a branch to the first and the first dorsal ganglion contains the roots of the second. Distribution of the nerves from C1 and T1 vary when the branch from C6 is large, that from T1 is frequently absent and the nerve from T1 is reduced, forming a typical type of pattern. If the branch from C6 is small or absent, the distribution of C1 is

reduced but that of T₁ is larger and one from T₂ is always absent. The arrangement sometimes is a plexiform type of plexus. When united roots are the roots of the plexus, almost equal roots are variable in their mode of union. The commonest arrangement is as follows: the fifth and sixth roots unite at the lower border of the scalenus medius as the *upper trunk*; the eighth cervical and first thoracic roots run behind the scalenus anterior as the *lower trunk*; the seventh cervical becomes the *middle trunk*. These three trunks unite laterally, first above or behind the clavicle and inferomedially run *anterior* and *posterior* divisions: the anterior divisions of the upper and middle trunks form a *lateral cord*, lateral to the axillary artery. The anterior division of the lower trunk descends at first behind, then medial to the axillary artery, forming the *medial cord* which often receives a branch from the seventh cervical ramus. Posterior divisions of all three form the *posterior cord*, at first above and then behind the axillary artery. The lower trunk's posterior division is much smaller than the others, containing few, if any, fibres from the first thoracic ramus. It is frequently derived from the eighth cervical before the trunk is formed.

During the embryonic or foetal stage, in upper and lower limbs, the human brachial plexus reflects the original four-nerve organization of a primitive fin. The posterior cord is the posterior supply, the medial and lateral cords the flexor supply. Moreover, if a limb is modified this pattern, e.g. a scapula and the anterior part of the dorsal are reduced; the anterior part of the posterior nerve. For comparative morphology of the plexus outside Homo, see p. 10.

Relations of the Brachial Plexus

In the neck, the plexus is in the posterior triangle, in the angle between the clavicle and lower posterior border of the sternocleidomastoid, covered by platysma, deep fascia and skin, through which it is palpable. It is crossed by the supraclavicular nerves, the nerve to the subclavius, the inferior belly of the omohyoid, the external jugular vein and the superficial ramus of the transverse cervical artery (6.17). It emerges between the scaleni anterior and medius; its proximal part is superior to the first part of the subclavian artery; the lower trunk posterior to the point where posterior to the medial two-thirds of the clavicle, the subclavius and the supraclavicular vessels and lies in the first part of the axillary artery and the subscapularis. In the axilla the arterial and posterior cords are lateral to the first part of the axillary artery, the medial cord being behind it. The cords surround the second part of the artery, named according to their names. In the lower axilla the cords divide into nerves for the upper limb. Except for the median nerve's medial root, these nerves are related to the artery's third part as their cords are in the second, i.e. branches of the lateral cord are lateral to the medial cord and of the posterior cord posterior to the artery.

Close to their exit from the intervertebral foramina, the fifth and sixth cervical ventral rami receive grey rami communicantes from the middle cervical sympathetic ganglion, the seventh and eighth from the cervicothoracic ganglion (p. 116). The first thoracic ventral ramus also receives a grey ramus from and contributes a white ramus to the cervicothoracic ganglion.

Branches of the brachial plexus may be described as *suprascapular* and *infraclavicular*.

SUPRACLAVICULAR BRANCHES

There arise 1) from roots or 2) from trunks.

From roots	1) Nerves to scaleni and omohyoid	C ₅ , 6, 7, 8
	2) Branch to parotid nerve	C ₅
	3) Dorsal scapular nerve	C ₅
	4) Long thoracic nerve	C ₅ , 6, 7
From trunks	5) Nerve to subclavius	C ₅ , 6
	6) Suprascapular nerve	C ₅ , 6

Branches to the latissimus and longus colli arise from the lower cervical ventral rami near their exit from the intervertebral foramina. Anterior to the scalenus anterior the parotid nerve is joined by a branch from the fifth cervical ramus.

The dorsal scapular nerve, from the fifth cervical ventral ramus, pierces the scalenus medius, passes behind the levator scapulae, which it occasionally supplies, and runs with the deep branch of the dorsal scapular artery in the rhomboid, which it supplies.

The long thoracic nerve, which is usually formed by roots from the fifth to the seventh cervical rami, the last may be absent. Its division is demonstrated all three roots in one of the following ways. The upper two roots pierce the scalenus medius obliquely, uniting in or lateral to it; the nerve descends dorsal to the brachial plexus and the first part of the axillary artery. Crossing the superior border of serratus anterior to reach its lateral surface, it may be joined by the root from C₇, which emerges between the scaleni anterior and medius and descends on the latter's lateral surface. The nerve continues downwards to the lower border of the serratus anterior, supplying branches to each of its digastric.

The nerve to the subclavius, small and arising near the junction of the first and second cervical ventral rami, passes anterior to the plexus and the third part of the subclavian artery and is usually connected to the plexus nerve. It passes above the subclavian vein to supply the subclavius.

The suprascapular nerve (6.18) is a large branch of the upper trunk, runs laterally deep to the trapezius and omohyoid, enters the supraspinatus fossa through the suprascapular notch inferior to the superior transverse scapular ligament, runs deep to the supraspinatus and curves round the lateral border of the scapular spine with the suprascapular artery to reach the infraspinatus fossa, where it gives two branches to the supraspinatus and acromioclavicular rami in the shoulder and acromioclavicular joints. The suprascapular nerve was found to have a numerous branch in six upper limbs out of 61 Japanese cadavers. Hirayashi (1960). When present, it pierces the deltoid muscle close to the tip of the acromion; in the one case where its peripheral distribution was examined, it was found to supply the skin of the proximal third of the arm within the territory of the axillary plexus.

INFRACLAVICULAR BRANCHES

These result from the cords and their fibres may be traced back to the spinal nerves. They are as follows:

Lateral cord	Lateral pectoral	C ₅ , 6, 7
	Musculocoracius	C ₅ , 6, 7
	Lateral root of median	C ₅ , 6, 7
	Medial pectoral	C ₆ , T ₁
Medial cord	Medial pectoral	C ₆ , T ₁
	Medial cutaneous of forearm	C ₆ , T ₁
	Medial cutaneous of arm	C ₆ , T ₁
	Ulnar	C ₇ , 8, T ₁
Posterior cord	Medial root of median	C ₆ , T ₁
	Upper subscapular	C ₅ , 6
	Thoracodorsal	C ₅ , 6, 7
	Lower subscapular	C ₅ , 6
	Axillary	C ₅ , 6
	Radial	C ₅ , 6, 7, 8, T ₁

The lateral pectoral nerve, which is larger than the medial, may arise from the anterior divisions of the upper and middle trunks or by a single root from the lateral cord; its fibres are from the fifth to seventh cervical rami. It crosses anterior to the axillary artery and vein, pierces the deep fascial fascia and supplies the deep surface of the pectoralis major. It sends a ramus to the medial pectoral nerve forming a loop in front of the first part of the axillary artery (6.19), to supply some fibres to the pectoralis minor.

The medial pectoral nerve, derived from eighth cervical and first thoracic ventral rami, branches from the medial cord while this is posterior to the axillary artery. It curves forwards between the axillary artery and vein, anterior to the artery it joins a ramus of the lateral pectoral nerve, entering the deep surface of the pectoralis minor to supply it. Two or three branches pierce the pectoralis minor and others may pass round its inferior border to end in the pectoralis major.

The **superior subscapular nerve**, smaller than the inferior, arises from the posterior cord (C5 and 6), enters the subscapularis at a high level and is frequently double.

The **inferior subscapular nerve**, also from the posterior cord (C5 and 6), supplies the lower part of the subscapularis, ending in the teres major, which is sometimes supplied by a separate branch.

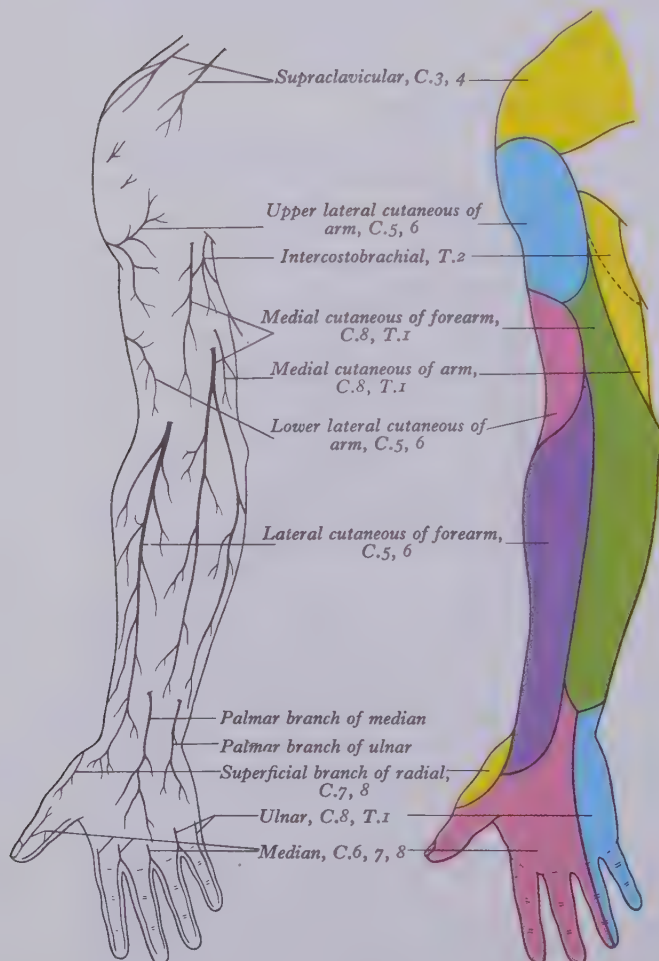
The **thoracodorsal nerve**, from the posterior cord, derives its fibres from the sixth to eighth cervical ventral rami, arises between the subscapular nerves and accompanies the subscapular artery along the posterior axillary wall to supply the latissimus dorsi, reaching its distal border.

The **axillary (circumflex humeral) nerve** (7.248) arises from the posterior cord, its fibres being derived from the fifth and sixth cervical ventral rami. It is at first lateral to the radial nerve, posterior to the axillary artery and anterior to the subscapularis, at whose lower border it curves back inferior to the humeroscapular articular capsule and, with the posterior circumflex humeral vessels, traverses a quadrangular space bounded *above* by the subscapularis (anterior) and teres minor (posterior), *below* by teres major, *medially* by the long head of triceps and *laterally* by the humeral surgical neck. The nerve finally divides into anterior and posterior branches. The *anterior branch*, with the posterior circumflex humeral vessels, curves round the humeral neck, deep to the deltoid, to its anterior border, supplying it and giving a few small cutaneous branches which pierce the muscle to ramify in the skin over its lower part. The *posterior branch* supplies the teres minor and the posterior part of the deltoid; on the branch to teres minor an enlargement or pseudoganglion usually exists. The posterior branch pierces the deep fascia low on the posterior border of the deltoid, continuing as the *upper lateral cutaneous nerve of the*

arm and supplying the skin over the lower part of the deltoid and the upper part of the long head of triceps (7.244). The axillary trunk supplies a branch to the shoulder joint below the subscapularis.

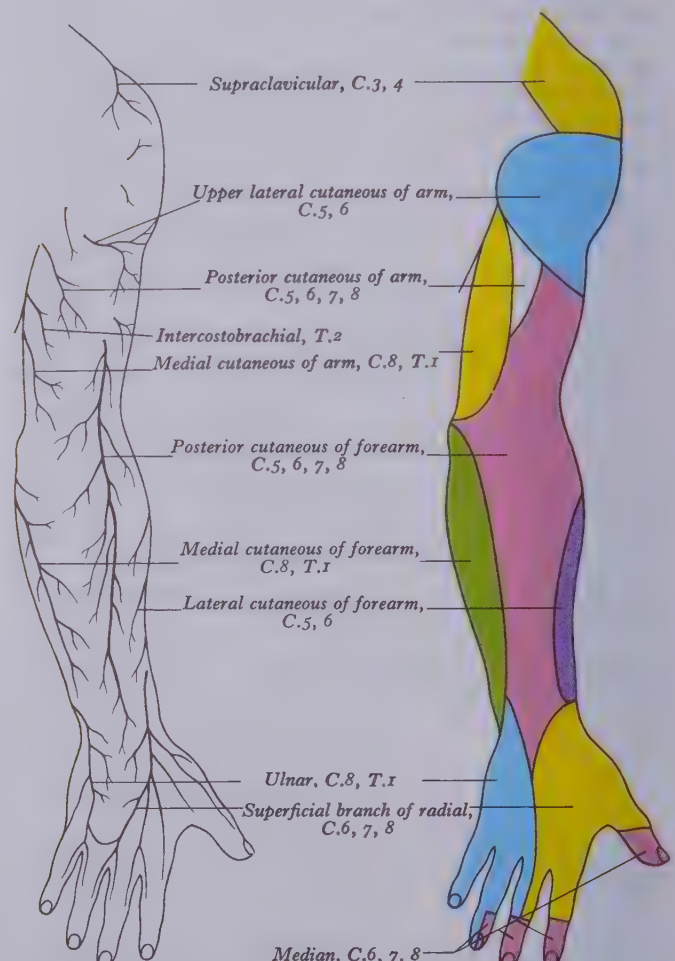
The **musculocutaneous nerve** (7.247), from the lateral cord opposite the lower border of the pectoralis minor and derived from the fifth to the seventh cervical ventral rami, pierces the coracobrachialis and descends laterally between the biceps and brachialis to the lateral side of the arm; just below the elbow it pierces the deep fascia lateral to the tendon of biceps, continuing as the *lateral cutaneous nerve of the forearm*. A line drawn from the lateral side of the third part of the axillary artery across the coracobrachialis and biceps to the lateral side of the biceps tendon is a surface projection for the nerve, but this is varied by its point of entry into the coracobrachialis (Latarjet et al 1967). It supplies the coracobrachialis, both heads of biceps and most of the brachialis. The branch to the coracobrachialis leaves the musculocutaneous before it enters the muscle; its fibres are from the seventh cervical ramus and may branch directly from the lateral cord. Branches to the biceps and brachialis leave after the musculocutaneous pierces the coracobrachialis; the branch to the brachialis supplies the elbow joint. The nerve also supplies a small branch to the humerus, entering with the nutrient artery.

The **lateral cutaneous nerve of the forearm** (7.244) passes deep to the cephalic vein, descending along the radial border of the forearm to the wrist, supplying the skin of the forearm's anterolateral surface and connecting by branches around its radial border with the posterior cutaneous nerve of the forearm and the terminal branch of the radial nerve. Its trunk gives rise to a slender recurrent branch which extends along the cephalic vein as far as the middle third of the upper arm, distributing filaments to the



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7.244 The cutaneous nerves of the right upper limb, their areas of distribution and segmental origins, viewed from the anterior aspect.



7.245 The cutaneous nerves of the upper right limb, their areas of distribution and segmental origins, viewed from the posterior aspect.

skin over the distal third of the anterolateral surface of the upper arm close to the vein (Horiguchi 1981). Although observed in the nineteenth century (Arnold 1851, Bolk 1898), this recurrent branch has more recently been omitted from most descriptions of the nerve supply of the upper limb. At the wrist joint the lateral cutaneous nerve of the forearm is anterior to the radial artery and some filaments, piercing the deep fascia and accompanying this to the dorsum of the carpus. The nerve then passes to the base of the thenar eminence, ending in cutaneous rami. It connects with the terminal branch of the radial nerve and the palmar cutaneous branch of the median nerve.

The *musculocutaneous* nerve has frequent variations. It may run behind the coracobrachialis or adhere for some distance to the median nerve and pass behind the biceps. Some fibres of the median nerve may run in the musculocutaneous nerve, leaving it to join their proper trunk; less frequently the reverse occurs, the median nerve sending a branch to the musculocutaneous. Occasionally it supplies the pronator teres and may replace radial branches to the dorsal surface of the thumb.

The medial cutaneous nerve of the forearm (7.247), from the medial cord, is derived from the eighth cervical and first thoracic ventral rami. At first it is between the axillary artery and vein and supplies a ramus piercing the deep fascia to supply the skin over the biceps, almost to the elbow. The nerve descends medial to the brachial artery, pierces the deep fascia with the basilic vein midway in the arm and divides into anterior and posterior branches. The larger, *anterior branch* usually passes in front of, occasionally behind, the median cubital vein, descending anteromedial in the forearm to supply the skin as far as the wrist and connecting with the palmar cutaneous branch of the ulnar nerve (7.244). The *posterior branch* descends obliquely medial to the basilic vein, anterior to the medial epicondyle, and curves round to the back of the forearm, descending on its medial border to the wrist, supplying the skin. It connects with the medial cutaneous nerve of the arm, the posterior cutaneous nerve of the forearm and the dorsal branch of the ulnar (7.245).

The medial cutaneous nerve of the arm, supplying the skin in that area (7.244) and the smallest branch of the plexus, arises from the medial cord and contains fibres from the eighth cervical and first thoracic ventral rami. It traverses the axilla, crossing anterior or posterior to the axillary vein, to which it is then medial, and communicating with the intercostobrachial nerve; it descends medial to the brachial artery and basilic vein (7.247) to a point midway in the upper arm, where it pierces the deep fascia to supply a medial area in the arm's distal third, extending on to its anterior and posterior aspects. Some rami reach the skin anterior to the medial epicondyle, others over the olecranon. It connects with the posterior branch of the medial cutaneous nerve of the forearm. Sometimes the medial cutaneous nerve of the arm and the intercostobrachial nerve are connected in a plexiform manner in the axilla. Sometimes the intercostobrachial nerve is large and reinforced by part of the lateral cutaneous branch of the third intercostal nerve, replacing the arm's medial cutaneous nerve and receiving from the brachial plexus a connection representing the latter; occasionally this connection is absent.

THE MEDIAN NERVE

The median nerve (7.247) has two roots from the lateral (C₅,6,7) and medial (C₈, T₁) cords, which embrace the third part of the axillary artery, uniting anterior or lateral to it. Some fibres from C₇ often leave the lateral root in the lower part of the axilla passing distomedially posterior to the medial root, usually anterior to axillary artery, to join the ulnar nerve (7.263); they may branch from the seventh cervical ventral ramus. Clinically they are believed to be mainly motor to the flexor carpi ulnaris. If the lateral root is small, the musculocutaneous nerve (C₅,6,7) connects with the median nerve in the arm.

The median nerve enters the arm at first lateral to the brachial artery; near the insertion of the coracobrachialis it crosses in front of (rarely behind) the artery, descending medial to it to the cubital fossa where it is posterior to the bicipital aponeurosis and anterior to the brachialis, separated by the latter from the elbow joint. It

usually enters the forearm between the heads of the pronator teres, crossing to the lateral side of the ulnar artery and separated from it by the deep head of pronator teres. It proceeds behind a tendinous bridge between the humero-ulnar and radial heads of the flexor digitorum superficialis, descending posterior and adherent to the flexor digitorum superficialis and anterior to the flexor digitorum profundus. About 5 cm proximal to the flexor retinaculum it emerges from behind the lateral edge of the flexor digitorum superficialis, becoming superficial just proximal to the wrist between the tendons of the flexors digitorum superficialis and carpi radialis, projecting laterally from behind the tendon of the palmaris longus. It then passes deep to the flexor retinaculum into the palm. In the forearm it is accompanied by the median branch of the anterior interosseous artery. Its course can be marked on the surface by a line from the medial side of the brachial artery in the cubital fossa along the forearm's midline (7.246).

Relations as the median nerve enters the forearm are variable. According to Anson (1963) the route described above occurred in 82.8% of 1000 dissections; in 10.8% the nerve was posterior to the humeral head of the pronator teres, the ulnar slip being absent. In 4.6% the nerve was posterior to both heads, and in 1.8% traversed *through* the humeral head.

Branches of the Median Nerve in the Arm

These are vascular branches to the brachial artery and usually a branch to the pronator teres, a variable distance proximal to the elbow joint.

Branches of the Median Nerve in the Forearm

These are muscular, articular, anterior interosseous, palmar cutaneous and communicating. **Muscular branches**, except one, are given off proximally (near the elbow) to the superficial flexor muscles (except the flexor carpi ulnaris), i.e. to the pronator teres, flexor carpi radialis, palmaris longus and the flexor digitorum superficialis. The branch to the part of the flexor digitorum superficialis for the index finger arises near mid-forearm but may be from the anterior interosseous nerve. **Articular branches**, arising at or just distal to the elbow joint, supply it and the proximal radio-ulnar joint.

The anterior interosseous nerve branches posteriorly from the median nerve between the two heads of pronator teres, just distal to the origin of branches to the superficial forearm flexors. With the anterior interosseous artery it descends anterior to the interosseous membrane, between and deep to the flexors pollicis longus and digitorum profundus and supplying both; branches to the latter are limited to its lateral part, which sends tendons to the index and middle fingers. Terminally it is posterior to the pronator quadratus, supplying its deep surface, and supplies the distal radio-ulnar, radio-carpal and carpal joints.

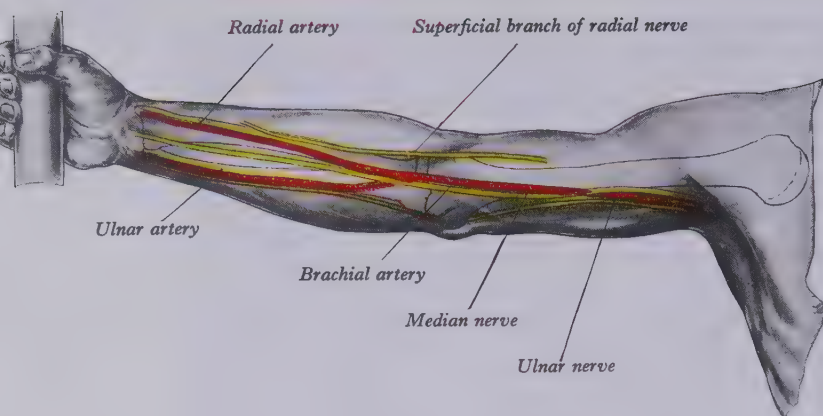
The palmar cutaneous branch starts just proximal to the flexor retinaculum, pierces it or the deep fascia and divides into *lateral branches* supplying the thenar skin and connecting with the lateral cutaneous nerve of the forearm; and *medial branches* supplying the central palmar skin and connecting with the palmar cutaneous branch of the ulnar nerve.

A communicating branch, which may be multiple, often arises (sometimes from the anterior interosseous branch) in the proximal forearm and passes medially between flexors digitorum superficialis and profundus and behind the ulnar artery to join the ulnar nerve. It is a factor in explaining anomalous muscular innervation in the hand (p. 1135).

The Median Nerve in the Hand

Proximal to the flexor retinaculum the nerve is lateral to the tendons of flexor digitorum superficialis but further distally it lies between the retinaculum and tendons in the 'carpal tunnel' (see p. 625), i.e. the space between the flexor retinaculum and the anterior carpal surface. The nerve may become compressed here (p. 1137). Distal to the retinaculum the nerve enlarges and flattens, usually dividing into five or six branches but the mode and level of division are variable.

The muscular branch, short and thick, is from the nerve's lateral side; it may be the first palmar or a terminal branch arising level with the digital branches. It runs laterally, just distal to the



7.246 The anterior aspect of the right upper limb, showing the position of the principal nerves and vessels projected on to the surface.

flexor retinaculum, with a slight recurrent curve beneath the part of the palmar aponeurosis covering the thenar muscles. It turns round the distal border of the retinaculum to lie superficial to the flexor pollicis brevis, usually supplying it and either continuing superficial to it or traversing it. It gives a branch to the abductor pollicis brevis, which enters the muscle's medial edge and then passes deep to it to supply the opponens pollicis, entering its medial edge. Its terminal part occasionally gives a branch to the first dorsal interosseous, which may be its sole or partial supply. The muscular branch may arise in the carpal tunnel and pierce the flexor retinaculum, a point of surgical importance (Papathanassion 1968).

The palmar digital branches. (In this account of cutaneous innervation of the digits, the distinction between proximal, penultimate, undivided rami, termed *common palmar digital nerves*, and their ultimate branches to individual digits, the *proper palmar digital nerves*, must be noted. The corresponding terms for the foot are *common plantar digital nerves* and *proper plantar digital nerves*.) The median nerve divides into four or five digital branches, though it often divides first into two: a lateral ramus providing digital branches to the pollex and the radial side of the index finger; and a medial, supplying digital branches to adjacent sides of the index, medius and annularis. Other modes of termination occur (Poisel 1974). Digital branches are commonly arranged as follows. They pass distally, deep to the superficial palmar arch and its digital vessels, at first anterior to the long flexor tendons. Two *proper* palmar digital nerves, sometimes from a common stem, pass to the sides of the pollex, that supplying its lateral side crossing in front of the tendon of flexor pollicis longus. The *proper* palmar digital nerve to the lateral side of the index also supplies the first lumbrical muscle. Two *common* palmar digital nerves pass distally between the long flexor tendons: the lateral divides in the distal palm into two *proper* palmar digital nerves traversing adjacent sides of the index and medius; the medial one divides into two *proper* palmar digital nerves supplying adjacent sides of the medius and annularis. The lateral common digital nerve supplies the second lumbrical muscle; the medial receives a communicating twig from the common palmar digital branch of the *ulnar* nerve and may supply the third lumbrical muscle. In the distal part of the palm, the digital arteries pass deeply between the divisions of the digital nerves; on the sides of the digits the nerves are anterior to the arteries. The median nerve usually supplies palmar cutaneous digital branches to the lateral three and one-half digits (pollex, index, medius and the lateral side of the annularis); sometimes the lateral side of the ring finger is supplied by the ulnar nerve. The proper palmar digital nerves that pass along the medial side of the index, both sides of the medius and the lateral side of the annularis, enter these digits in fat between slips of the central palmar aponeurosis (p. 627). They pass, with the lumbricals and palmar digital arteries, dorsal to the superficial transverse metacarpal ligament (p. 629) and ventral to the deep transverse metacarpal ligament (p. 515). In the digits, the nerves run distally beside the long flexor tendons, outside their fibrous

sheaths, level with the anterior phalangeal surfaces and anterior to the digital arteries. Each nerve gives off several branches to the skin on the front and sides of the digit, many ending in lamellated corpuscles (p. 911), and branches to the metacarpophalangeal and interphalangeal joints. They also supply the fibrous sheaths of the long flexor tendons, digital arteries (vasomotor) and sweat glands (secretomotor). Distal to the base of the distal phalanx the digital nerve gives off a branch passing dorsally to the nail bed, the main nerve dividing to supply the pulp and skin of the terminal part of the digit. Distal to the base of the proximal phalanx, each *proper* digital nerve also gives off a dorsal branch to supply the skin over the back of the middle and distal phalanges (7.245). The *proper* palmar digital nerves to the pollex and the lateral side of the index emerge with the long flexor tendons from under the lateral edge of the central palmar aponeurosis and are arranged in the digits as described above; but in the pollex small distal branches supply the skin on the back of the distal phalanx only.

In addition to the branches of the median nerve described above, variable vasomotor branches supply the radial and ulnar arteries and their branches. Some of the intercarpal, carpo-metacarpal and intermetacarpal joints are said to be supplied by the median nerve or its anterior interosseous branch, the precise details being uncertain.

THE ULNAR NERVE

The ulnar nerve (7.247) arises from the medial cord (C8, T1) but, as described above (p. 1131), it often receives fibres from the ventral ramus of C7. It runs distally through the axilla medial to the axillary artery and between it and the vein, continuing distally medial to the brachial artery as far as mid-arm; here it pierces the medial intermuscular septum, inclining medially as it descends anterior to the medial head of the triceps to the interval between the medial epicondyle and the olecranon, with the superior ulnar collateral artery. At the elbow it is in a groove on the dorsum of the epicondyle. It enters the forearm between the two heads of the flexor carpi ulnaris superficial to the posterior and oblique parts of the ulnar collateral ligament. It descends the medial side of the forearm on the flexor digitorum profundus, covered proximally by the flexor carpi ulnaris; its lower half, covered by skin and fasciae, is lateral to this muscle. In the upper third of the forearm, it is distant from the ulnar artery but distal to this is close to its medial side (7.247). About 5 cm proximal to the wrist it gives off a dorsal branch which continues distally into the hand, anterior to the flexor retinaculum on the lateral to the pisiform bone and posteromedial to the ulnar artery. It passes behind the superficial part of the retinaculum with the artery and divides into superficial and deep terminal branches. Its relation to the brachial artery and medial epicondyle makes it easy to map out in its proximal course; a line from the medial epicondyle to the lateral edge of pisiform represents its distal course (7.246).

Its *branches* are: articular, muscular, palmar cutaneous, dorsal, superficial terminal and deep terminal.

Articular branches to the elbow joint issue from the nerve between the medial epicondyle and olecranon. Others are described below.

Muscular branches, usually two, begin near the elbow; one supplies the flexor carpi ulnaris (p. 617), the other the medial half of the flexor digitorum profundus.

The palmar cutaneous branch arises about mid-forearm, descends on the ulnar artery (7.247), which it supplies, and perforates the deep fascia to end in the palmar skin, after communicating with the palmar branch of the median nerve. It sometimes supplies the palmaris brevis.

The dorsal branch arises about 5 cm proximal to the wrist, passes distally and backwards, deep to the flexor carpi ulnaris, perforates the deep fascia, descends along the medial side of the back of the wrist and hand and then divides into two, or often three, dorsal digital nerves. One supplies the medial side of the minimus, the second adjacent sides of minimus and annularis, while the third, when present, supplies adjoining sides of the annularis and medius but may be replaced, wholly or partially, by a branch of the radial nerve, always communicating with it on the dorsum of the hand (7.245). In the minimus the dorsal digital

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nerves extend only to the base of the distal phalanx and in the annularis to the base of the middle phalanx; more distal parts of these digits are supplied by dorsal branches of the proper digital branches of the ulnar and, on the lateral side of the annularis, medial nerves.

The **superficial terminal branch** supplies the palmaris brevis and the medial palmar skin, dividing into two palmar digital nerves, which can be palpated against the hook of the hamate bone (p. 418); one of these supplies the medial side of minimus, the other (a *common* palmar digital nerve) sends a twig to the median nerve and divides into two *proper* digital nerves for the adjoining sides of minimus and annularis (7.247). The proper digital branches are distributed like those of the median nerve. Murakami (1969) has described articular branchlets from the superficial terminal branch of the ulnar nerve.

The **deep terminal branch**, with the deep branch of the ulnar artery, passes between the abductor digiti minimi and flexor digiti minimi and then perforates the opponens digiti minimi to follow the deep palmar arch dorsal to the flexor tendons. At its origin it supplies the three short muscles of the minimus. As it crosses the hand, it supplies the interossei and the third and fourth lumbricals; it ends by supplying the adductor pollicis, the first palmar interosseous and usually (p. 630) the flexor pollicis brevis. It sends articular filaments to the wrist joint.

The medial part of the flexor digitorum profundus is supplied by the ulnar nerve, as are the third and fourth lumbricals which are connected with the tendons of this part of the muscle. Similarly, the lateral part of the flexor digitorum profundus and the first and second lumbricals are supplied by the median nerve. The third lumbrical is often supplied by both nerves. The deep terminal branch is said to give branches to some intercarpal, carpometacarpal and intermetacarpal joints, though, as with the median nerve, precise details are uncertain. Vasomotor branches, arising in the forearm and hand, supply the ulnar and palmar arteries.

The Anomalous Nerve Supply of the Hand Muscles

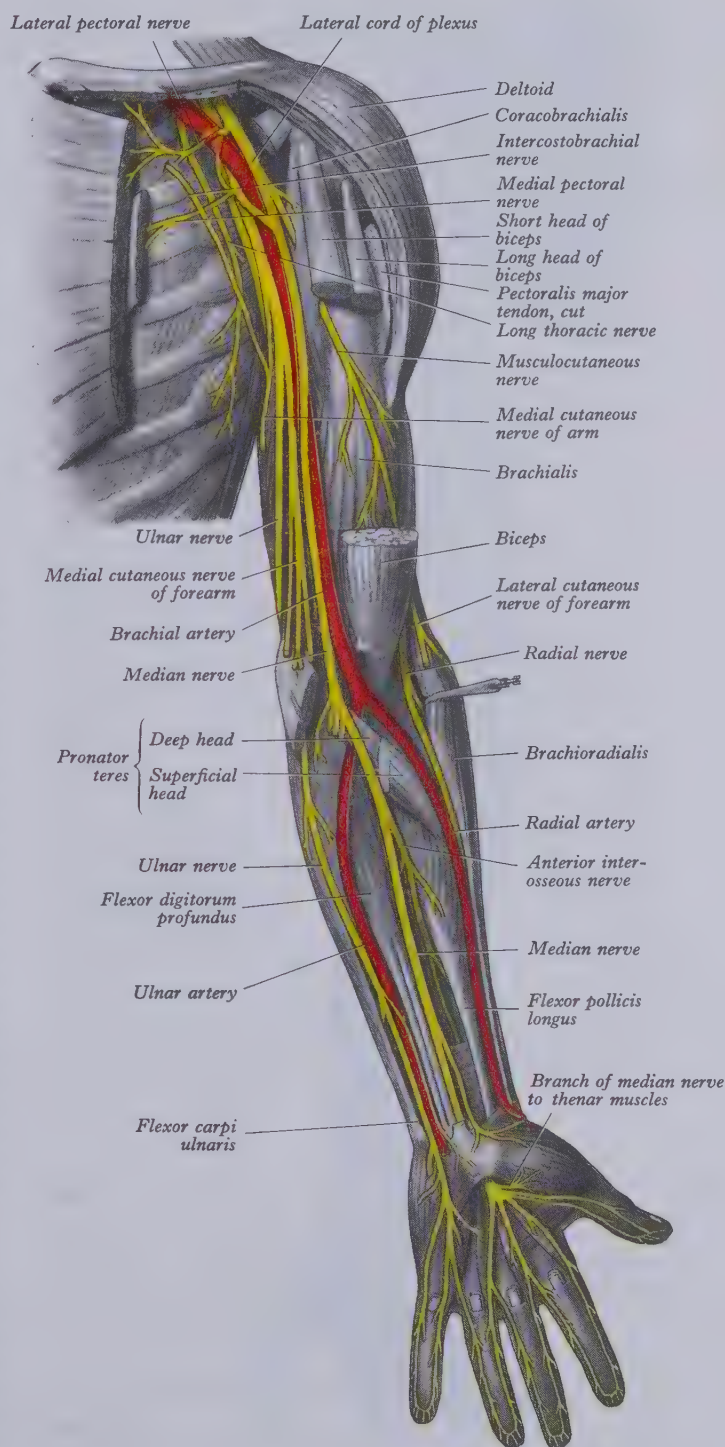
The nerve supply to the short thenar muscles varies. From the results of lesions of the median and ulnar nerves in the forearm (Rowntree 1949, Day & Napier 1961) the following variations were deduced, expressed here in percentages of 226 hands examined and regarding innervation of the thenar muscles by median, ulnar or both nerves: flexor pollicis brevis—median 36, ulnar 48, both 17; abductor pollicis brevis—median 95, ulnar 2.5, both 2; opponens pollicis—median 83, ulnar 9, both 7.5. The usual description is that all three are supplied by the median nerve; the results cited are possibly explicable, in part, by the variable connections between the median and ulnar nerves in the axilla, arm or forearm, by which median fibres are aberrantly conveyed in the ulnar nerve. An arcuate connecting nerve has long been recognized between median and ulnar nerves in the substance of the flexor pollicis brevis (Cannieu 1886), either part of which, superficial or deep, may be supplied by both nerves. In a more recent survey (Harness & Sekeles 1971) of the considerable literature, the results of dissections in 35 hands showed a loop in 77%, suggesting that it should be a feature of 'normal' description. Clinically variations are important; even with a complete lesion of the median nerve some of these muscles may escape paralysis, leading to erroneous conclusions. Clinical evidence reveals that the short thenar muscles receive their segmental supply from the eighth cervical and first thoracic spinal cord segments. Variations in both the motor and sensory supply of the thumb have been examined by Falconer & Spinner (1985).

THE RADIAL NERVE

The radial nerve (7.248) arises from the posterior cord, C5,6,7,8, (T1). The largest branch of the brachial plexus, it descends behind the third part of the axillary artery and the upper part of the brachial, anterior to the subscapularis and the tendons of the latissimus dorsi and teres major. With the arteria profunda brachii and, later, its radial collateral branch, it inclines dorsally between the long and medial heads of the triceps, after which it passes obliquely across the back of the humerus, first between the

lateral and medial heads of the triceps, then in a shallow groove deep to the lateral head. On reaching the lateral side of the humerus it pierces the lateral intermuscular septum to enter the anterior compartment; it then descends deep in a furrow between the brachialis and proximally the brachioradialis, then more distally the extensor carpi radialis longus. Anterior to the lateral epicondyle it divides into *superficial* and *deep* terminal rami.

In the arm the radial nerve is indicated by a posterior line from the start of the brachial artery distally and laterally to the junction of the upper and middle thirds of a line between the lateral epicondyle and the deltoid tuberosity; the line is continued anteriorly as far as the lateral epicondyle, 1 cm or less lateral to the biceps tendon.



7.247 The nerves of the left upper limb, dissected from the anterior aspect.

The *branches* of the radial nerve are: muscular, cutaneous, articular and superficial and deep terminal.

Muscular branches supply the triceps, anconeus, brachioradialis, extensor carpi radialis longus and brachialis in *medial, posterior* and *lateral* groups. *Medial* muscular branches arise from the radial nerve on the medial side of the arm. They supply the medial and long heads of the triceps, the branch to the medial being a long, slender filament which, lying close to the ulnar nerve as far as the distal third of the arm, is often termed the

ulnar collateral nerve. A large *posterior* muscular branch arises from the nerve as it lies in the humeral groove. It divides to supply the medial and lateral heads of the triceps and the anconeus, that for the latter being a long nerve which descends in the medial head of the triceps and partially supplies it; it is accompanied by the middle collateral branch of the arteria profunda brachii and passes behind the elbow joint to end in the anconeus. *Lateral* muscular branches arise in front of the lateral intermuscular septum; they supply the lateral part of the brachialis, brachioradialis and extensor carpi radialis longus.

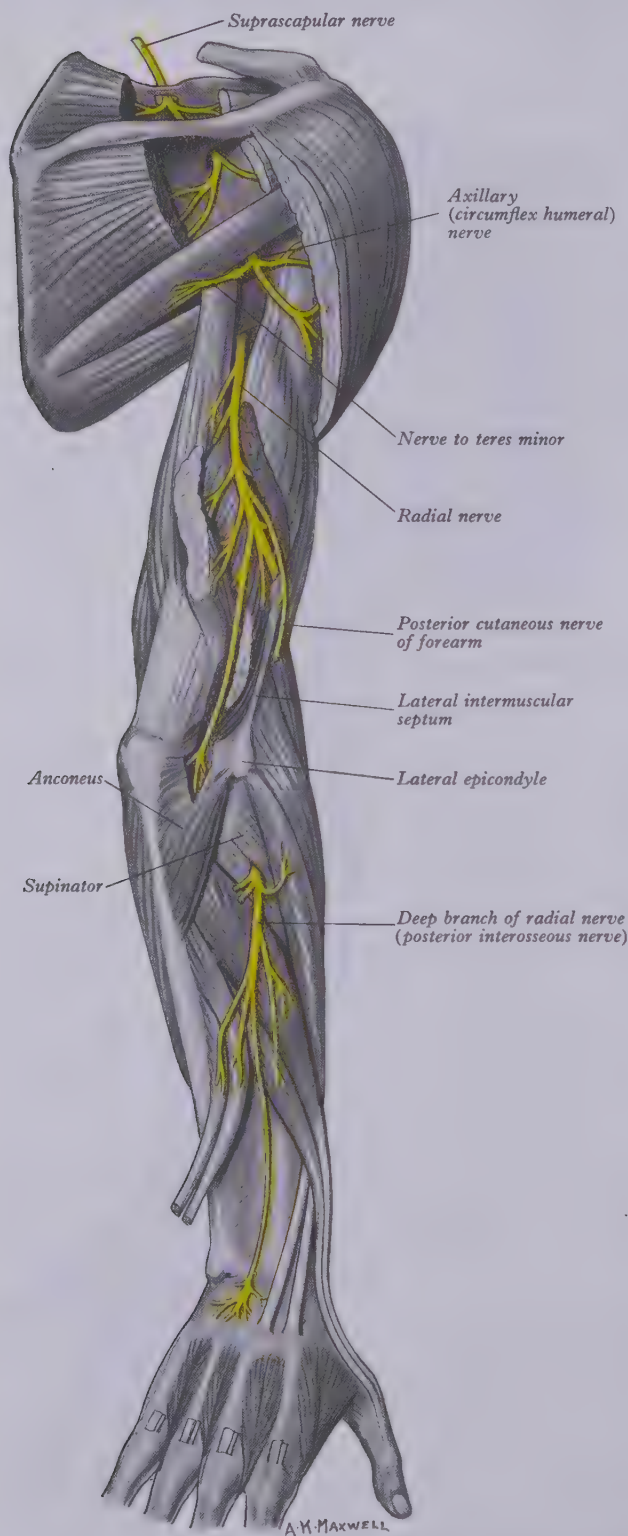
The cutaneous branches are the posterior and lower lateral cutaneous nerves of the arm and the posterior cutaneous nerve of the forearm. The small **posterior cutaneous nerve of the arm** arises in the axilla and passes medially to supply the skin on the dorsal surface of the arm nearly as far as the olecranon. It crosses posterior to and communicates with the intercostobrachial nerve. **The lower lateral cutaneous nerve of the arm** perforates the lateral head of the triceps distal to the deltoid tuberosity, passes to the front of the elbow close to the cephalic vein and supplies the skin of the lateral part of the lower half of the arm (7.244). **The posterior cutaneous nerve of the forearm** arises from the preceding nerve. Perforating the lateral head of the triceps, it descends first lateral in the arm, then along the dorsum of the forearm to the wrist, supplying the skin in its course and joining, near its end, with dorsal branches of the lateral cutaneous nerve of the forearm (7.244).

The articular branches are distributed to the elbow joint.

The superficial terminal branch descends from the lateral epicondyle anterolaterally in the proximal two-thirds of the forearm, at first on the supinator, lateral to the radial artery and behind the brachioradialis; in the middle third of the forearm it is behind the brachioradialis, close to the lateral side of the artery, successively anterior to the pronator teres, the radial head of the flexor digitorum superficialis and the flexor pollicis longus. It leaves the artery about 7 cm proximal to the wrist, passes deep to the tendon of the brachioradialis, curves round the lateral side of the radius as it descends, pierces the deep fascia and divides into five, sometimes four, dorsal digital nerves. On the dorsum of the hand it usually communicates with the posterior and lateral cutaneous nerves of the forearm.

The *dorsal digital nerves*, usually four or five, are small. The first supplies the skin of the radial side of the pollex and the adjoining thenar eminence, communicating with branches of the lateral cutaneous nerve of the forearm; the second supplies the medial side of the pollex; the third, the lateral side of the index; the fourth, the adjoining sides of the index and medius; the fifth communicates with a ramus of the dorsal branch of the ulnar nerve and supplies the adjoining sides of the medius and annularis but is frequently replaced by the dorsal branch of the ulnar nerve. The pollicial digital nerves reach only to the root of the nail, those in the index midway along the middle phalanx, those to the medius and the lateral part of the annularis not further than the proximal interphalangeal joints. The remaining distal dorsal areas of the skin in these digits are supplied by palmar digital branches of the median and ulnar nerves (7.245). The superficial terminal branch of the radial nerve may supply the whole dorsum of the hand; for variations consult Sayfi (1967).

The deep terminal branch (posterior interosseous nerve) (7.248) reaches the back of the forearm round the lateral aspect of the radius and between the two planes of the fibres of the supinator. It supplies the extensor carpi radialis brevis and the supinator before entering it; as it traverses the muscle it supplies it with additional branches. The branch to the extensor carpi radialis brevis may arise from the beginning of the superficial branch of the radial nerve. As it emerges from the supinator posteriorly it gives off three short branches, to the extensor digitorum, extensor digiti minimi and extensor carpi ulnaris, and two longer branches, a *medial* to the extensor pollicis longus and extensor indicis and a *lateral*, supplying the abductor pollicis longus and ending in the extensor pollicis brevis. The nerve is at first between the superficial and deep extensor muscles; but at the distal border of the extensor pollicis brevis it passes deep to the extensor pollicis longus and, diminished to a fine thread, descends on the interosseous membrane to the dorsum of the carpus, where



7.248 The suprascapular, axillary and radial nerves of the right upper limb, dissected from the posterior aspect.

it presents a flattened and somewhat expanded termination or 'pseudoganglion', from which filaments supply the carpal ligaments and articulations (7.248).

Articular branches from the deep branch of the radial nerve supply the carpal, distal radio-ulnar and some intercarpal and intermetacarpal joints; digital branches supply the metacarpophalangeal and proximal interphalangeal joints.

Applied Anatomy. The brachial plexus may be injured in falls on the side of the head and shoulder, nerves in the plexus being violently stretched; its upper trunk sustains the greatest injury and paralysis may be confined to muscles supplied by the fifth cervical ramus: the deltoid, biceps, brachialis and brachioradialis, with sometimes also supraspinatus, infraspinatus and supinator. The arm typically hangs in medial rotation, with the forearm extended and pronated. It cannot be abducted; flexion of the elbow and supination of the forearm are lost. This is *Erb's paralysis* and a similar condition occasionally appears in newborn children, from injury to the upper trunk by obstetric forceps or from traction in breech presentations. A second variety is *Klumpke's paralysis*, in which the eighth cervical and first thoracic rami are injured, before or after they join to form the lower trunk. Paralysis mainly affects the intrinsic muscles of the hand and the flexors of the wrist and fingers.

The plexus may also be injured by direct violence or gunshot wounds, by violent traction on the arm or in reducing a glenohumeral dislocation. The extent of paralysis depends on the injury. When the entire plexus is involved, the whole of the upper extremity is paralysed and anaesthetic. Sometimes injury appears to be an avulsion of nerves from the spinal cord; where this involves the first thoracic ramus the ipsilateral pupil may be constricted, due to damage to the preganglionic fibres in it which supply the dilatator pupillae. The plexus is often damaged in the axilla by pressure of a crutch, producing '*crutch paralysis*', in which the radial is most frequently implicated, followed by the ulnar. The median and radial nerves often suffer '*sleep palsies*', paralysis due to pressure during alcoholic or narcotic stupor.

Damage of the long thoracic nerve paralyses the serratus anterior; it may afflict porters carrying heavy weights on the shoulder, the nerve being exposed to injury in the posterior triangle of the neck. The inferior scapular angle is drawn medially by unopposed action of the rhomboids and the levator scapulae and tends to project ('winging' of the scapula) when the horizontal arm is used for forward pushing movements. The arm cannot be raised above the horizontal.

The *axillary (circumflex humeral) nerve*, in its course round the surgical neck of the humerus, is liable to injury in fractures and dislocations; paralysis of the deltoid and anaesthesia of the skin over the lower part of the muscle result. Effective abduction of the arm is impossible. Paralysis of the teres minor occurs but is not easily demonstrated.

The *median nerve* may be involved in forearm injury. When it is divided proximal to its muscular and anterior interosseous branches, flexion of the second phalanges in all digits is lost, and of the terminal phalanges of the index and medius. Terminal phalanges in the annularis and minimus are flexed by the part of the flexor digitorum profundus supplied by the ulnar nerve. Proximal phalanges may be flexed by the interossei. The pollex cannot be opposed or abducted, nor flexed at its interphalangeal

joint (see p. 1134); it remains extended and adducted. Forearm pronation is weakened, for the brachioradialis can effect only mid-pronation. The wrist can be flexed by the flexor carpi ulnaris but this is combined with adduction. Sensation is lost or impaired on the palmar surfaces of all except the medial one and a half digits and on dorsal surfaces of the same over the distal two phalanges, except in the pollex where loss is limited to the dorsum of the distal phalanx. Owing to paralysis of pollicial intrinsic muscles and the unopposed action of the extensor pollicis longus, an '*ape-like*' hand exists. Injury of the median nerve in the mid-forearm may cause only weakness in flexion of the index ('*pointing*' index finger), since the branch to the part of the flexor digitorum superficialis distributed to this finger arises at about that level (p. 1133); more commonly the nerve is injured proximal to the flexor retinaculum, when flexion of the fingers and pronation of the forearm remains intact, unless the flexor tendons are also divided; the main effect of such lesions is usually an inability to oppose the pollex, though the intact abductor pollicis longus and adductor pollicis may combine to imitate this. Deep to the flexor retinaculum the median nerve is in the restricted space between the retinaculum and the carpal bones (carpal tunnel, p. 625). Any condition diminishing this space (e.g. carpal dislocation, arthritis, tenosynovitis, etc.) may cause pressure on the nerve with resultant pain and slight sensory impairment in the digits supplied and sometimes slight wasting of the thenar muscles—the '*carpal tunnel syndrome*'. Commonly no cause is apparent; division of the retinaculum is curative.

The *ulnar nerve* may also be injured in forearm wounds, the commonest site of complete or partial division being behind the medial epicondyle, leading to impaired adduction; in attempts to flex the wrist the hand is abducted by the flexor carpi radialis; owing to paralysis of the dorsal interossei the fingers cannot be spread or flexed at the metacarpophalangeal joints or extended at the interphalangeal joints (especially the annularis and minimus); the hand assumes a '*clawed*' shape from the active opposing muscles. Flexion in the fourth and fifth digits is weakened and the pollex cannot adduct. Hypothenar muscles waste. Sensation is lost or impaired, in skin supplied by the nerve.

The *radial nerve* also is often injured but seldom torn in fractures of the humerus, due to its close relationship to this bone. In repair callus formation seldom interferes with the nerve. In fractures of the mid-humerus, the triceps is not paralysed, since its nerve supply arises more proximally from the radial nerve. It may also be contused against bone by kicks or blows or be divided in incised wounds. When paralysed, the hand is flexed at the wrist and flaccid, a condition known as *wrist drop*. The digits are also flexed and in attempted extension only the middle and distal phalanges are extended (by lumbrical and interosseous muscles), the proximal phalanges remaining flexed. Carpal extension is impossible. Supination is completely lost in the extended forearm, but flexion allows the biceps to act as a supinator. Extension of the forearm is lost if injury near the nerve's origin causes the triceps to be paralysed. As the radial nerve has only a small area of exclusive supply, anaesthesia is similarly small and confined to a limited lateral region on the dorsum of the hand.

Dislocations and epiphysal separations at the elbow and supracondylar fractures of the humerus in children often lead to ulnar, median or posterior interosseous injury.

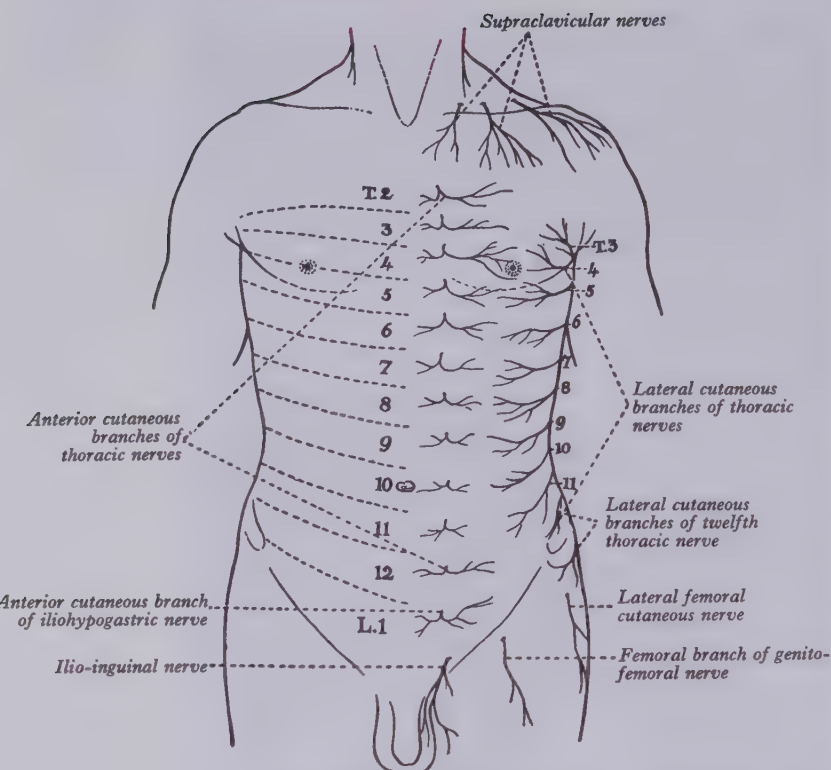
THORACIC VENTRAL RAMI

There are twelve pairs of thoracic ventral rami (7.249, 250); all but the twelfth are between the ribs (*intercostal nerves*), the twelfth being below the last rib (*subcostal nerve*). Each is connected with an adjacent sympathetic ganglion by grey and white rami communicantes: the grey ramus joins the nerve proximal to the exit of the white ramus. Intercostal nerves are distributed chiefly to the thoracic and abdominal walls; the first two supply the upper limb in addition, the next four are limited to the thoracic wall, while the lower five supply the thoracic and abdominal walls (p. 1138). The subcostal nerve supplies the abdominal wall and

gluteal skin. Communicating branches link intercostal nerves posteriorly in the intercostal spaces; the lower five communicate freely in the abdominal wall (Davies et al 1932).

The First to the Sixth Thoracic Ventral Rami

The first thoracic ventral ramus divides unequally; a large branch ascends across the first rib's neck, lateral to the superior intercostal



7.249 The approximate segmental distribution of the cutaneous nerves on the front of the trunk. The contribution from the first thoracic spinal nerve is not shown and the considerable overlap which occurs between adjacent segments is not indicated. For the latter see 7.264.

artery, to enter the brachial plexus (p. 1130). The smaller *first intercostal nerve* runs in the first intercostal space and ends as the first anterior cutaneous nerve of the thorax. A lateral cutaneous branch pierces the chest wall in front of the serratus anterior to supply the axillary skin; it may communicate with the intercostobrachial nerve and sometimes joins with the

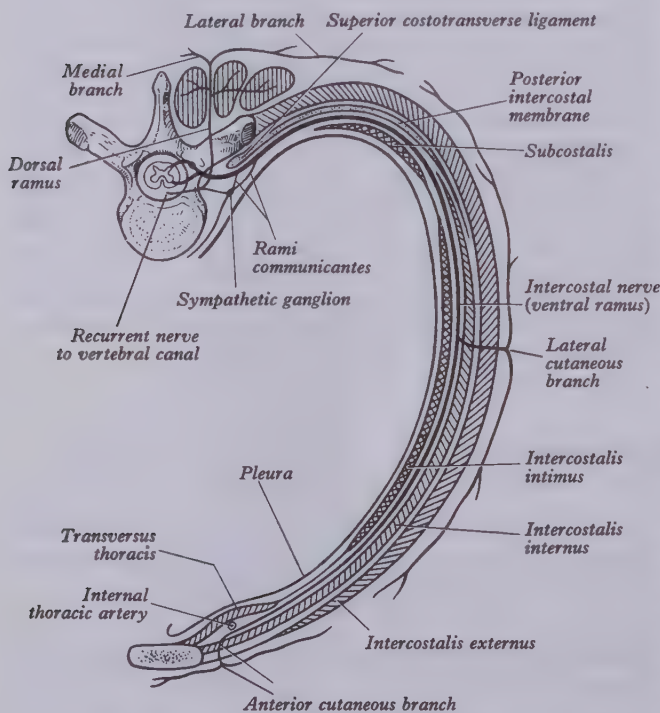
medial cutaneous nerve of the arm (Cave 1929). The first thoracic ramus often connects with the second across the neck of the second rib.

The second to sixth thoracic ventral rami proceed (7.244) in their intercostal spaces below the intercostal vessels. Posteriorly they are between the pleura and posterior intercostal membranes but in most of their course run between the internal intercostals and the subcostales and intercostales intimi (7.249). Near the sternum, they cross anterior to the internal thoracic vessels and the transversus thoracis, pierce the internal intercostals, external intercostal membrane and pectoralis major, ending as the **anterior cutaneous nerves of the thorax**, which supply the skin on the front of the thorax. The second anterior cutaneous nerve may be connected to the medial supraclavicular nerves; twigs from the sixth supply abdominal skin in the upper part of the infrasternal angle.

Branches. Numerous muscular rami supply the intercostals, serratus posterior superior and transversus thoracis. Anteriorly some cross the costal cartilages from one intercostal space to another.

From each intercostal nerve a collateral and a lateral cutaneous branch leave before the main nerve reaches the costal angle. The *collateral branch* follows the inferior border of its space in the same intermuscular plane as the main nerve, which it may rejoin before distribution as an additional anterior cutaneous nerve. The *lateral cutaneous branch* accompanies the main nerve a little way and then pierces the intercostal muscles obliquely; except for the first and second, each divides into anterior and posterior rami which pierce the serratus anterior. *Anterior branches* run forwards over the border of the pectoralis major to supply the overlying skin, the fifth and sixth also supplying twigs to a variable number of upper digitations of the obliquus abdominis externus. *Posterior branches* run back to supply the skin over the scapula and latissimus dorsi.

The second lateral cutaneous branch is the *intercostobrachial nerve* (7.247). It crosses the axilla to the medial side of the arm, joins with a branch of the medial cutaneous nerve of the arm, pierces the deep fascia and supplies the skin of the upper half of the posterior and medial aspects of the arm, connecting with the posterior brachial cutaneous branch of the radial nerve. Its size is in inverse proportion to the size of the medial brachial cutaneous nerve. A second intercostobrachial nerve often branches off from the anterior part of the third lateral cutaneous nerve; it supplies the axilla and the medial side of the arm.



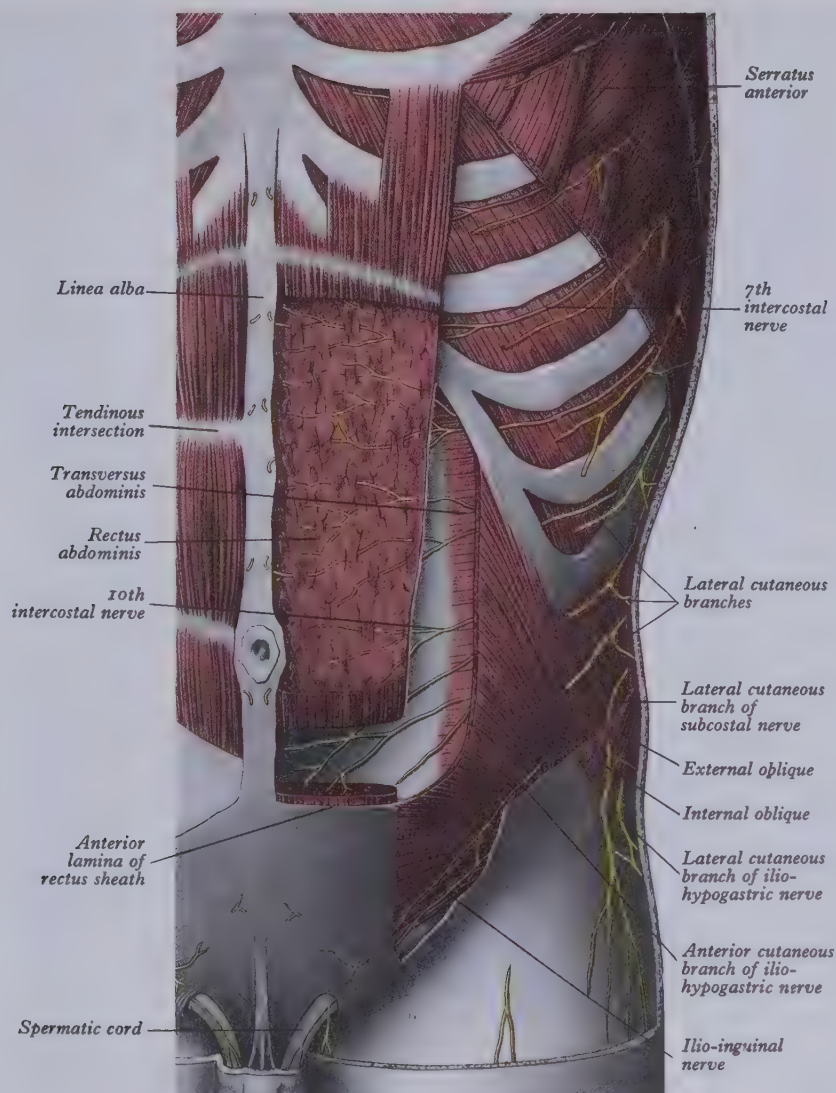
7.250 The course of a typical intercostal nerve. The muscular and the collateral branches are not shown.

The Seventh to the Twelfth Thoracic Ventral Rami

These lower thoracic ventral rami continue anteriorly from the intercostal spaces into the abdominal wall. Approaching the anterior ends of their spaces, the seventh and eighth curve *superomedially* across the deep costal surface between the digitations of the transversus abdominis to reach the deep aspect of the posterior layer of the internal oblique aponeurosis. Piercing this they are posterior to the rectus abdominis and continue (7.251) for a short distance parallel with the costal margin. Both supply the rectus abdominis and, having traversed it near its lateral edge, pierce its anterior sheath to supply the skin. Both the seventh and eighth nerves cross the costal margin medial to the lateral border of the rectus abdominis and hence enter its sheath from behind.

The ninth to eleventh intercostal nerves pass between digitations of the diaphragm and transversus abdominis to gain the interval between the transversus and the internal oblique. Here the ninth nerve runs forwards almost *horizontally*, while the tenth and eleventh pass *inferomedially*. At the lateral edge of the rectus abdominis they pierce the posterior layer of the internal oblique aponeurosis and pass behind the muscle, ending like the seventh and eighth intercostal nerves. The tenth supplies a band of skin which includes the umbilicus (7.249, 264).

These lower intercostal nerves supply intercostal, subcostal and abdominal muscles and the last three supply the serratus posterior inferior. They also provide sensory fibres to the costal



7.251 The course of the lower intercostal and the cutaneous branches of some lumbar nerves. Portions of the muscles of the anterior abdominal wall have been removed, including most of the anterior layer of the rectus sheath and parts of the rectus abdominis.

parts of the diaphragm and related parietal pleura and peritoneum. Like the upper intercostal nerves they give off *collateral* and *lateral cutaneous branches* before they reach the costal angles. The collateral may rejoin its nerve but, if it does, it leaves it again near lateral border of the rectus abdominis to run forward below it (7.251), piercing the muscle and its anterior sheath near the linea alba to supply the skin. The lateral cutaneous branches pierce the intercostals and external oblique in the same line as the upper branches, dividing also into anterior and posterior rami, distributed to the skin of the abdomen and back; the anterior also supply digitations of the external oblique, extending antero-inferiorly nearly to the margin of the rectus abdominis; the posterior branches pass back to supply the skin over the latissimus dorsi. Each lateral cutaneous nerve descends as it pierces the external oblique and superficial fascia, reaching the skin on a level with the segment's anterior and posterior cutaneous nerves (p. 1126 and 7.239).

The ventral ramus of the **twelfth thoracic nerve** (subcostal nerve) is larger than the others; it connects with the first lumbar ventral ramus (*dorsolumbar nerve*). Like an intercostal nerve it has a collateral branch. It accompanies the subcostal vessels along the inferior border of the twelfth rib, passing behind the lateral arcuate ligament and kidney (8.168), anterior to the upper part of the quadratus lumborum, perforates the aponeurosis of the origin of the transversus and proceeds

between the transversus and the obliquus internus, to be distributed like the lower intercostal nerves. It connects with the iliohypogastric nerve and supplies the pyramidalis. Its *lateral cutaneous branch* pierces the internal and external oblique muscles, supplies the latter's lowest slip, crosses the iliac crest about 5 cm behind the anterior superior iliac spine (7.258) and supplies the anterior gluteal skin, some filaments reaching the greater trochanter of the femur.

Applied Anatomy. In many conditions affecting spinal rami at or near their origins, pain is referred to their peripheral distributions. Thus, in tuberculosis of the lower thoracic vertebrae, pain is referred to the abdominal wall. When confined to a single pair of nerves the sensation is constrictive, as if a cord were tied round the abdomen; the site of the fenur this sensation may help to localize vertebral diseases. Where two or more nerves are involved, the pain is more diffused.

Subluxation of the interchondral joints between the lower costal cartilages may trap the intercostal nerves, causing referred abdominal pain. Abrahams (1976) has reviewed the literature on this subluxation or 'clicking rib syndrome'.

Nerves supplying the abdominal skin also supply the planes of underlying muscle, an important fact in protection of the abdominal viscera. A forceful blow will not injure the viscera if the muscles are contracted; but when a blow is unexpected, with the abdominal muscles relaxed, a force insufficient to

damage the abdominal wall may rupture some of these viscera. Immediate reflex contraction is obviously important; the origin of the cutaneous and motor fibres from the same spinal segments accelerates the response.

Branches supplying abdominal muscles and skin, derived from from the lower intercostal nerves, are intimately connected with

the sympathetic nerves supplying the abdominal viscera through the lower thoracic ganglia, from which the splanchnic nerves are derived. Hence in injuries or acute infection of the abdominal viscera, the muscles of the abdominal wall become firmly contracted, resting and protecting the abdominal contents.

LUMBAR VENTRAL RAMI

Lumbar ventral rami increase in size from first to last and are joined, near their origins, by *grey rami communicantes* from the four lumbar sympathetic ganglia. These rami, long and slender, accompany the lumbar arteries round the sides of the vertebral bodies, behind the psoas major. Their arrangement is irregular: one ganglion may give rami to two lumbar nerves, one lumbar nerve may receive rami from the ganglia; rami often leave the sympathetic trunk between ganglia. The first and second, sometimes the third, lumbar ventral rami are each connected with the lumbar sympathetic trunk by a *white ramus communicans*.

The lumbar ventral rami descend laterally into the psoas major. The first three and most of the fourth form the *lumbar plexus*; the smaller moiety of the fourth joins the fifth as a *lumbosacral trunk*, which joins the *sacral plexus*. The fourth is often termed the *nervus furcalis*, being divided between the two plexuses; but the third is occasionally the *nervus furcalis*; or both third and fourth may be furcal nerves, when the plexus is termed *prefixed*. More frequently the fifth nerve is furcal, the plexus then being termed *postfixed*. These variations modify the sacral plexus. Piasecka-Kacperska & Gladyskowska-Rzeczycka (1972) have reviewed the variations in primates, including mankind.

The Lumbar Plexus

This plexus (7.252, 253) is in the posterior part of the psoas major, anterior to the lumbar transverse processes and formed by the

first three lumbar ventral rami and most of the fourth; the first receives a branch from the last thoracic. The *paravertebral* part of psoas major has a *posterior* mass attached to the transverse processes and an *anterior* mass attached to the lips of the vertebral bodies, intervertebral discs and tendinous arches (p. 635); the lumbar plexus is between these masses and hence in 'line' with the intervertebral foramina.

The plexus varies; in its usual arrangement the first lumbar ramus, joined by a branch from the twelfth thoracic, bifurcates; the upper and larger part divides again into iliohypogastric and ilio-inguinal nerves; the lower unites with a second lumbar branch to form the genitofemoral nerve. The remainder of the second, third and the part of the fourth ramus joining the plexus divide into ventral and dorsal branches. Ventral branches of the second to fourth rami form the obturator nerve. Dorsal branches of the second and third rami each divide into smaller and larger parts; the smaller parts unite as the lateral femoral cutaneous nerve, the larger join with the dorsal branch of the fourth to form the femoral nerve. The accessory obturator, when it exists, arises from the third and fourth ventral branches. For details of the blood supply of the lumbar plexus see Day (1964).

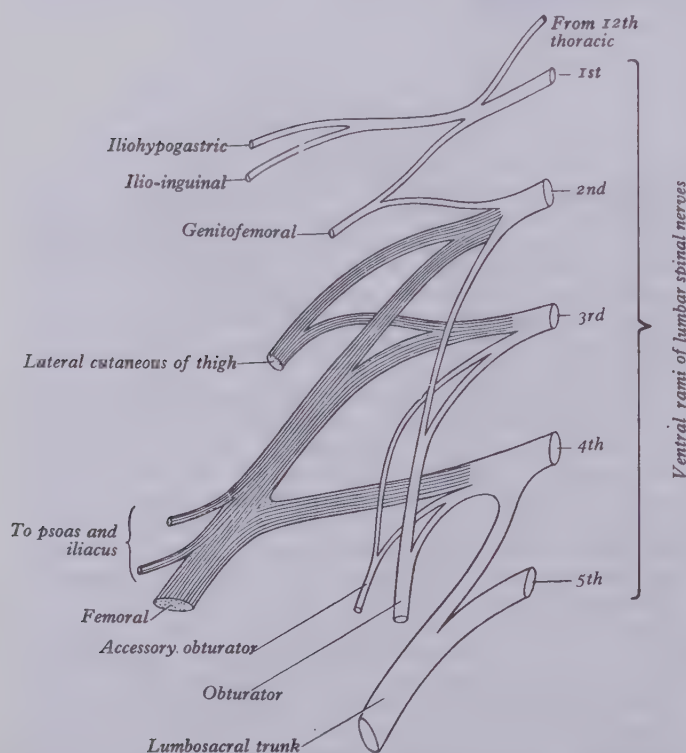
The *branches* of the lumbar plexus may be summarized as follows:

Muscular	T12, L1, 2, 3, 4
Iliohypogastric	L1
Ilio-inguinal	L1
Genitofemoral	L1, 2
	Dorsal divisions:
Lateral femoral cutaneous	L2, 3
Femoral	L2, 3, 4
	Ventral divisions:
Obturator	L2, 3, 4
Accessory obturator	L3, 4

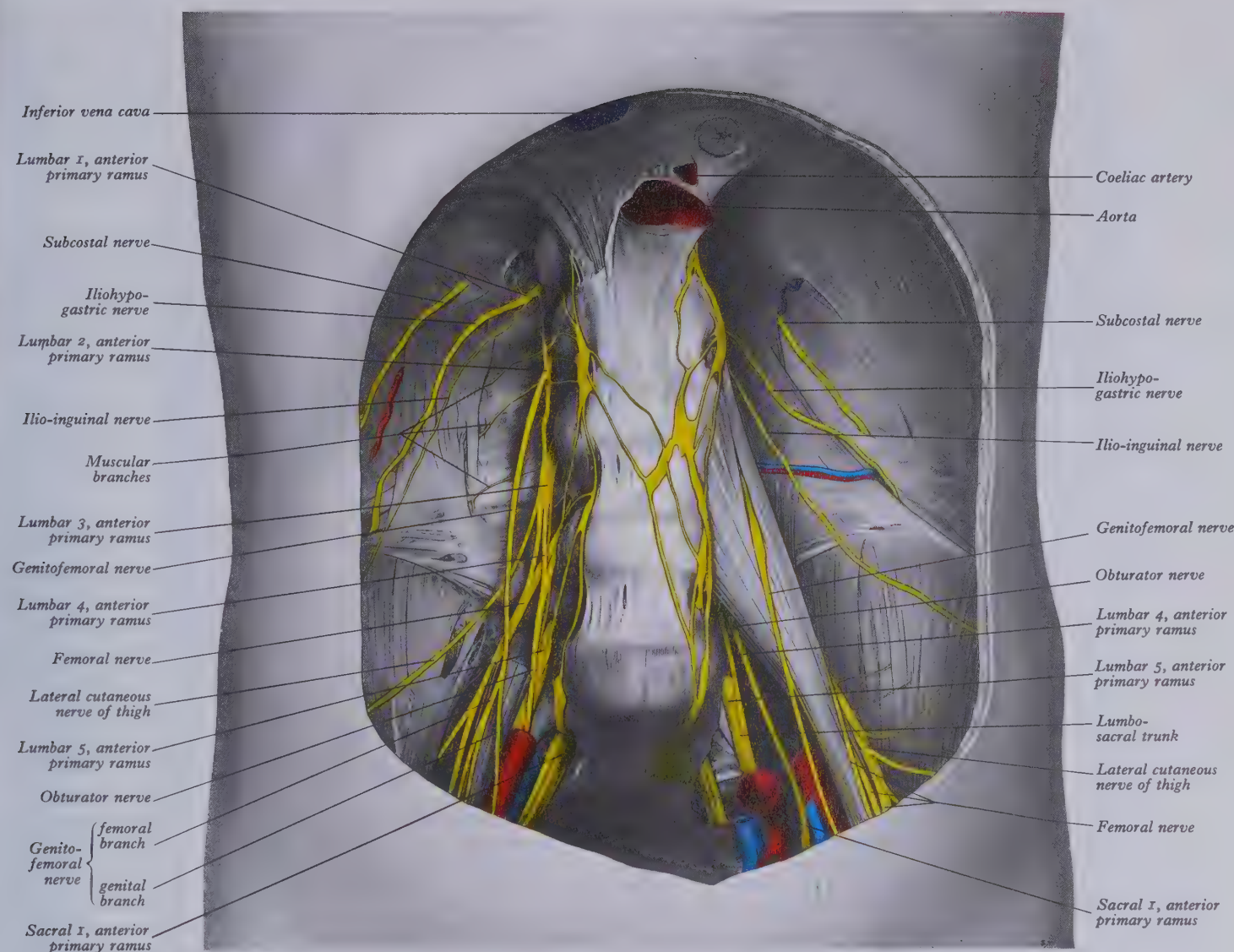
Muscular branches supply the quadratus lumborum (T12, L1-4), psoas minor (L1), psoas major (L2, 3(4)) and iliacus (L2, 3).

The **iliohypogastric nerve** (L1) (7.247) emerges from the upper lateral border of the psoas major, crosses obliquely behind the lower renal pole and in front of the quadratus lumborum (7.253, 8.168). Above the iliac crest it perforates the posterior part of the transversus abdominis, dividing between this and the internal oblique into lateral and anterior cutaneous branches, also supplying both muscles. The *lateral cutaneous branch* pierces the internal and external oblique muscles above the iliac crest a little behind the iliac branch of the twelfth thoracic nerve; it is distributed to the posterolateral gluteal skin. The *anterior cutaneous branch* (7.249) runs between and supplies the internal oblique and the transversus, pierces the internal oblique about 2 cm medial to the anterior superior iliac spine, and the external oblique aponeurosis about 3 cm above the superficial inguinal ring; it is distributed to the suprapubic skin. The iliohypogastric nerve connects with the subcostal and ilio-inguinal nerves.

The **ilio-inguinal nerve**, smaller than the iliohypogastric, arises with it from the first lumbar ventral ramus (7.252), emerges from the lateral border of the psoas major, with or just caudal to the iliohypogastric, passes obliquely across the quadratus lumborum and the upper part of the iliacus and perforates the transversus abdominis near the anterior end of the iliac crest, sometimes connecting with the iliohypogastric. It then pierces the internal oblique, supplying it, traverses the inguinal canal below



7.252 A plan of the lumbar plexus. The dorsal divisions of the second, third and fourth lumbar nerves are shaded.



7.253 A dissection of the posterior abdominal wall to show the lumbar plexus and sympathetic trunks. The right psoas major has been removed.

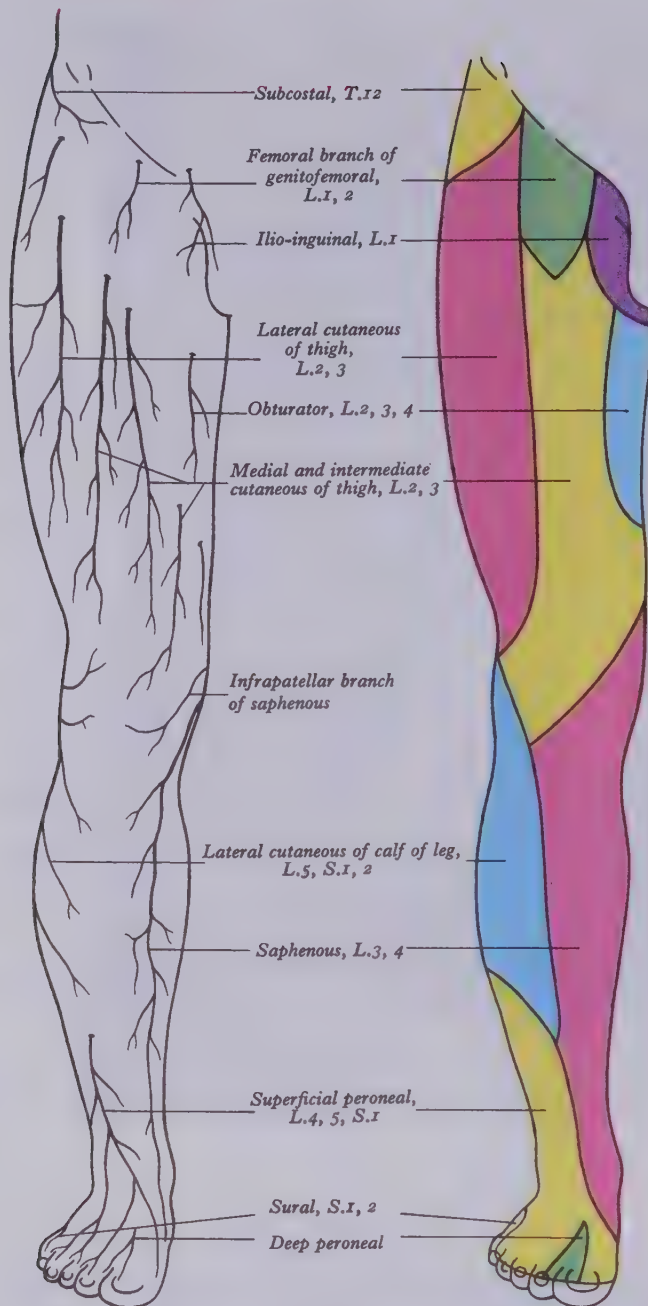
the spermatic cord, emerging with it from the superficial inguinal ring to supply the proximomedial skin of the thigh and either that over the penile root and upper part of the scrotum (7.249) or that covering the mons pubis and the adjoining labium majus.

The ilio-inguinal and iliohypogastric nerves are reciprocal in size. The former is occasionally very small and ends by joining the iliohypogastric, a branch of the latter taking its place; or the ilio-inguinal may be absent. By analogy the ilio-inguinal may be regarded as the collateral branch of the first lumbar nerve (Davies 1935) and the iliohypogastric as the main trunk, providing the lateral cutaneous branch.

The genitofemoral nerve (L1, 2) (7.252) descends obliquely forwards through the psoas major, emerging on the abdominal surface near its medial border, opposite the third or fourth lumbar vertebra; it descends subperitoneally on the psoas major, crosses obliquely behind the ureter, dividing variably above the inguinal ligament into genital and femoral branches. It often divides close to its origin, its branches then emerging separately from the psoas major. The *genital branch* crosses the lower part of the external iliac artery, enters the inguinal canal by its deep ring and supplies the cremaster and the scrotal skin. In females it accompanies the round ligament and ends in the skin of the mons pubis and labium majus. The *femoral branch* descends lateral to the external iliac artery, sending a few filaments round it; it then crosses the deep circumflex iliac artery, passes behind the inguinal ligament,

enters the femoral sheath lateral to the femoral artery, pierces the anterior layer of the femoral sheath and fascia lata and supplies the skin anterior to the upper part of the femoral triangle (7.254). It connects with the femoral intermediate cutaneous nerve and supplies the femoral artery.

The lateral femoral cutaneous nerve, from the dorsal branches of the second and third lumbar ventral rami (7.252), emerges from the lateral border of psoas major, crossing the iliacus obliquely towards the anterior superior iliac spine. It supplies the parietal peritoneum in the iliac fossa. The right nerve passes posterolateral to the caecum, separated from it by the fascia iliaca and peritoneum; the left passes behind the lower part of the descending colon. Both pass behind or through the inguinal ligament, variably medial to the anterior superior iliac spine (commonly about 1 cm) and anterior to or through the sartorius into the thigh, dividing into anterior and posterior branches (7.254). The *anterior branch* becomes superficial about 10 cm distal to the anterior superior iliac spine, supplying the skin of the anterior and lateral thigh as far as the knee. It connects terminally with the cutaneous branches of the anterior division of the femoral nerve and the infrapatellar branch of the saphenous nerve, forming the *patellar plexus*. The *posterior branch* pierces the fascia lata higher than the anterior, dividing to supply the skin on the lateral surface from the greater trochanter to about mid-thigh. It may also supply the gluteal skin.

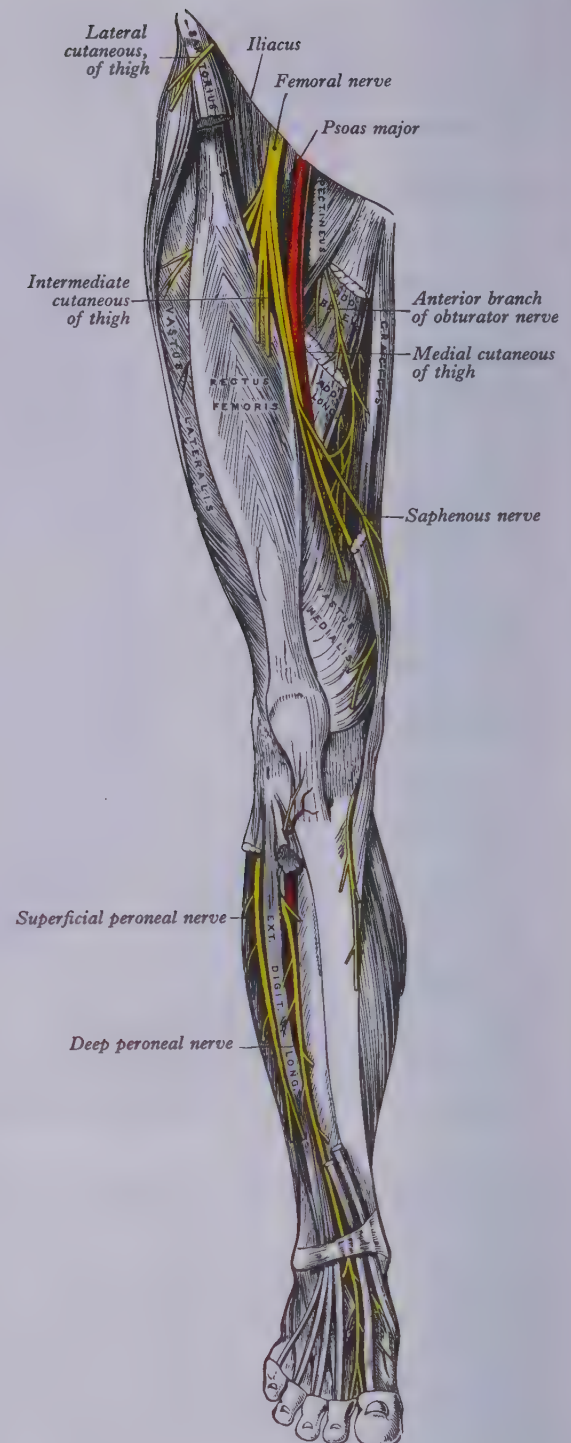


7.254 The cutaneous nerves of the right lower limb, their areas of distribution and segmental origins, viewed from the anterior aspect.

THE OBTURATOR NERVE

The obturator nerve arises from the ventral branches of the second to fourth lumbar ventral rami (7.252, 253), that from the third being the largest, the one from the second often very small. It descends in the psoas major, emerging from its medial border at the pelvic brim to pass behind the common iliac and lateral to the internal iliac vessels. It then descends forwards along the lesser pelvic lateral wall on the obturator internus, anterosuperior to the obturator vessels, to the obturator foramen, entering the thigh by its upper part. Near the foramen it divides into anterior and posterior branches, separated at first by part of the obturator externus, lower down by the adductor brevis.

The *anterior branch* (7.255) leaves the pelvis anterior to the obturator externus, descending in front of the adductor brevis, behind the pectineus and adductor longus; at the latter's lower border it communicates with the medial cutaneous and saphenous branches of the femoral nerve, forming a *subsartorial plexus*,



7.255 The nerves of the right lower limb, displayed from the anterior aspect.

which supplies the skin on the medial side of the thigh (7.254). It descends on the femoral artery, which its termination supplies. Near the obturator foramen the anterior branch supplies the hip joint. Behind the pectineus it innervates the adductor longus, gracilis, usually the adductor brevis and often the pectineus; it connects with the accessory obturator nerve when present. Occasionally the communicating branch to the femoral medial cutaneous and saphenous branches continues as a cutaneous branch to the thigh and leg, emerging from behind the distal border of the adductor longus to descend along the posterior margin of the sartorius to the knee, where it pierces the deep fascia, connects with the saphenous nerve and supplies the skin halfway down the medial side of the leg. The *posterior branch*

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pierces the obturator externus anteriorly, supplies it and passes behind the adductor brevis to the front of the adductor magnus, dividing into branches to this and the adductor brevis when the latter is not supplied by the anterior division. It usually sends an *articular filament* to the knee joint which perforates the adductor magnus distally or traverses its opening with the femoral artery to enter the popliteal fossa. Here it descends on the popliteal artery to the back of the knee, pierces its oblique posterior ligament and supplies the articular capsule. It gives filaments to the popliteal artery.

The **accessory obturator nerve** (7.252), occasionally present, is small and arises from the ventral branches of the third and fourth lumbar ventral rami. It descends along the medial border of the psoas major, crosses the superior pubic ramus behind the pectineus and divides into branches, one entering the deep surface of the pectineus, another supplying the hip joint and a third connecting with the obturator nerve's anterior branch; sometimes the accessory obturator nerve is very small and supplies only the pectineus. Any branch may be absent and others occur, one sometimes supplying the adductor longus. An accessory obturator nerve appeared in 69 of 800 dissections (p. 640, Woodburne 1960).

THE FEMORAL NERVE

The femoral nerve (7.252, 253), the largest branch of the lumbar plexus, arises from the dorsal branches of the second to fourth lumbar ventral rami. It descends through the psoas major, emerging low on its lateral border, and then passes between the psoas and iliacus, deep to the iliac fascia; passing behind the inguinal ligament into the thigh, it splits into anterior and posterior divisions. Behind the inguinal ligament it is separated from the femoral artery by part of the psoas major. In the abdomen the nerve supplies small branches to the iliacus and pectineus and a branch to the proximal part of the femoral artery; the latter branch may arise in the thigh.

The **nerve to the pectineus** branches from the medial side of the femoral nerve near the inguinal ligament, passes behind the femoral sheath and enters the muscle's anterior aspect.

Anterior division

The *anterior division* of the femoral nerve supplies intermediate and medial cutaneous femoral nerves (7.254, 255) and branches to the sartorius.

The **intermediate femoral cutaneous nerve** pierces the fascia lata about 8 cm below the inguinal ligament, either as two branches or as one trunk which quickly divides into two; these descend on the front of the thigh, supplying the skin as far as the knee and ending in the patellar plexus (p. 1141). The lateral branch of the intermediate cutaneous communicates with the femoral branch of the genitofemoral, frequently piercing the sartorius and sometimes supplying it.

The **medial femoral cutaneous nerve**, at first lateral to the femoral artery, crosses anterior to it at the apex of the femoral triangle, dividing into anterior and posterior branches. Before this it sends a few rami through the fascia lata to supply the skin of the medial side of the thigh, near the long saphenous vein; one

ramus emerges via the saphenous opening, another becomes subcutaneous about mid-thigh. The *anterior branch* descends on the sartorius, perforates the fascia lata beyond mid-thigh and divides into a branch supplying the skin as low as the medial side of the knee and another which crosses to the lateral side of the patella and connects with the saphenous nerve's infrapatellar branch. The *posterior branch* descends along the posterior border of the sartorius to the knee, pierces the fascia lata, connects with the saphenous nerve and supplies several cutaneous rami, some as far as the medial side of the leg. Deep to the fascia lata, at the lower border of the adductor longus, it forms a *subsartorial plexus* with branches of the saphenous and obturator nerves. When the obturator nerve's communicating branch is large and reaches the leg, the posterior branch of the medial cutaneous nerve is small, ending in the plexus and giving rise to a few cutaneous filaments.

The **nerve to the sartorius** arises in common with the intermediate femoral cutaneous nerve.

Posterior division

The *posterior division* of the femoral nerve supplies the saphenous nerve and branches to the quadriceps femoris and the knee joint.

The **saphenous nerve** (7.255), the largest femoral cutaneous branch, descends lateral to the femoral artery into the adductor canal (p. 781), where it crosses anteriorly to become medial to the artery. At the canal's distal end it leaves the artery, emerging through the aponeurotic covering with the saphenous branch of the descending genicular artery. It proceeds vertically along the medial side of the knee behind the sartorius, pierces the fascia lata between the tendons of the sartorius and gracilis and becomes subcutaneous. Thence it descends the leg's medial side with the long saphenous vein along the medial tibial border and divides distally into a branch continuing along the tibia to the ankle and into another passing anterior to the ankle to supply the skin on the medial side of the foot, often as far as the hallux metatarsophalangeal joint; it connects with the medial branch of the superficial peroneal nerve. Near mid-thigh the saphenous nerve gives a branch to the subsartorial plexus. As it leaves the adductor canal an *infrapatellar branch* (7.254) pierces the sartorius and fascia lata to supply the prepatellar skin; proximal to the knee it connects with medial and intermediate femoral cutaneous nerves while distal to it, it connects with other branches of the saphenous nerve; laterally it connects with the lateral cutaneous femoral nerve, forming a *patellar plexus*.

Muscular branches of the posterior division of the femoral nerve supply the quadriceps femoris. A branch to the rectus femoris enters its proximal posterior surface, also supplying the hip joint. A larger branch to the vastus lateralis forms a neurovascular bundle with the descending branch of the lateral circumflex femoral artery in its distal part and also supplies the knee joint. A branch to the vastus medialis descends through the proximal part of the adductor canal, lateral to the saphenous nerve and femoral vessels; it enters the muscle at about its midpoint, sending a long articular filament distally along the muscle to the knee. Two or three branches to the vastus intermedius enter its anterior surface about mid-thigh; a branchlet from one descends through the muscle to the articularis genu and the knee joint.

Vascular branches of the femoral nerve supply the femoral artery and its branches (p. 1163).

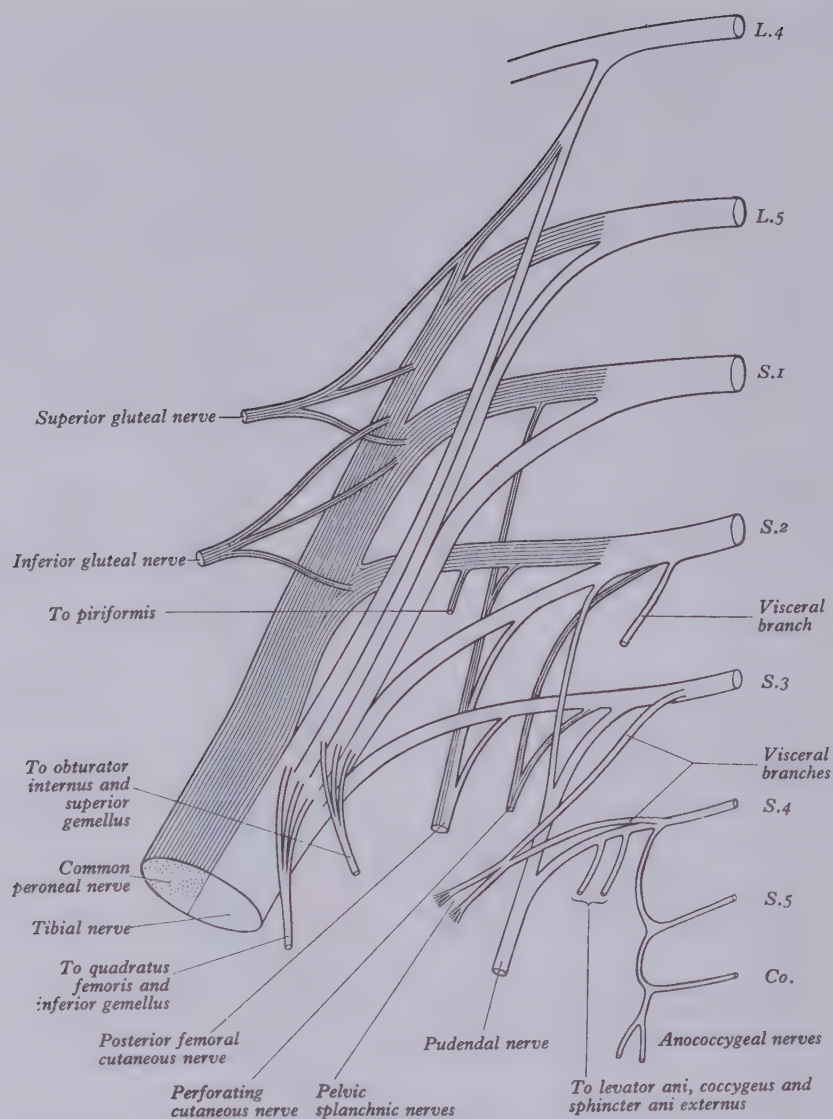
SACRAL AND COCCYGEAL VENTRAL RAMI

The ventral rami of the sacral and coccygeal spinal nerves form the *sacral and coccygeal plexuses*. The upper four sacral ventral rami enter the pelvis by the anterior sacral foramina, the fifth between the sacrum and coccyx, while that of the coccygeal nerve curves forwards below the rudimentary transverse process of the first coccygeal segment. The first and second sacral ventral rami are large, the third to fifth diminish progressively and the coccygeal is the smallest. Each receives a *grey ramus communicans* from a corresponding sympathetic ganglion. *Visceral efferent rami*

leave the second to fourth sacral rami as *pelvic splanchnic nerves* (7.277) containing parasympathetic fibres which reach minute ganglia in the walls of the pelvic viscera (p. 1156).

The Sacral Plexus

The sacral plexus (7.256) is formed by the lumbosacral trunk, the first to third sacral ventral rami and part of the fourth, the remainder of the last joining the coccygeal plexus.



7.256 A plan of the sacral and coccygeal plexuses. L4-5, S1-5 and Co, indicate the *ventral rami* of these lumbar, sacral and coccygeal spinal nerves. The *ventral divisions* of these rami are unshaded, the *dorsal*

divisions, and nerves derived from them, are shaded. The contribution from S2 to the pelvic splanchnic nerves is shown before joining those from 3 and 4.

The lumbosacral trunk comprises part of the fourth and all the fifth lumbar ventral rami; it appears at the medial margin of the psoas major, descending over the pelvic brim anterior to the sacro-iliac joint to join the first sacral ramus. These rami converge to the greater sciatic foramen and unite with little intermingling to form upper and lower bands. The upper, larger one is the union of the lumbosacral trunk with the first, second and greater part of the third sacral rami; it becomes the *sciatic nerve*. The lower band, smaller and more plexiform, is mainly the junction of the smaller part of the third sacral ramus with part of the fourth; it becomes the *pudendal nerve*; it has a small contribution from the second sacral ramus. The sciatic comprises tibial and common peroneal nerves, which usually separate in the thigh but can be pulled apart to their origins, when it can be demonstrated that the tibial is formed by the union of the ventral divisions of the lumbosacral trunk and the first three sacral rami, while the common peroneal is formed by dorsal divisions of the lumbosacral trunk and the first two sacral rami. The sciatic nerve may, however, divide anywhere; when division is at the plexus the common peroneal nerve usually pierces the piriformis in the greater sciatic foramen. (For the blood supply of the sacral plexus see Day 1964.)

Relations of the Sacral Plexus

The sacral plexus adjoins the posterior pelvic wall anterior to the piriformis (7.257), posterior to the internal iliac vessels and ureter and to the sigmoid colon on the left and the terminal ileal coils on

the right. The superior gluteal vessels lie between the lumbosacral trunk and first sacral ventral ramus or between the first and second sacral rami, while the inferior gluteal vessels lie between the first and second or second and third sacral rami.

Branches of the Sacral Plexus

These may be summarized as follows:

	Ventral Divisions	Dorsal divisions
To quadratus femoris and gemellus inferior	L4, 5, S1	
To obturator internus and gemellus superior	L5, S1, 2	
To piriformis		S(1), 2
Superior gluteal		L4, 5, S1
Inferior gluteal		L5, S1, 2
Posterior femoral cutaneous	S2, 3	S1, 2
Sciatic—tibial	L4, 5, S1, 2, 3	
—common peroneal		L4, 5, S1, 2
Perforating cutaneous		S2, 3
Pudendal	S2, 3, 4	
To levator ani, coccygeus and sphincter ani externus	S4	
Pelvic splanchnic	S2, 3, (4)	

The nerve to the quadratus femoris and gemellus inferior arises from the ventral branches of the fourth lumbar to the first sacral ventral rami (7.256), leaves the pelvis via the greater sciatic foramen below the piriformis, descends on the ischium deep to the sciatic nerve, gemelli and the tendon of the obturator internus and supplies the gemellus inferior, quadratus femoris and the hip joint.

The nerve to the obturator internus and gemellus superior arises from the ventral branches of the fifth lumbar and first and second sacral ventral rami (7.256), leaves the pelvis similarly to the above, supplies a branch to the upper posterior surface of the gemellus superior, crosses the ischial spine lateral to the internal pudendal vessels, re-enters the pelvis via the lesser sciatic foramen and enters the pelvic surface of the obturator internus.

The nerve to the piriformis usually arises from the dorsal branches of the first and second sacral ventral rami (sometimes only the second) and enters the anterior surface of the piriformis.

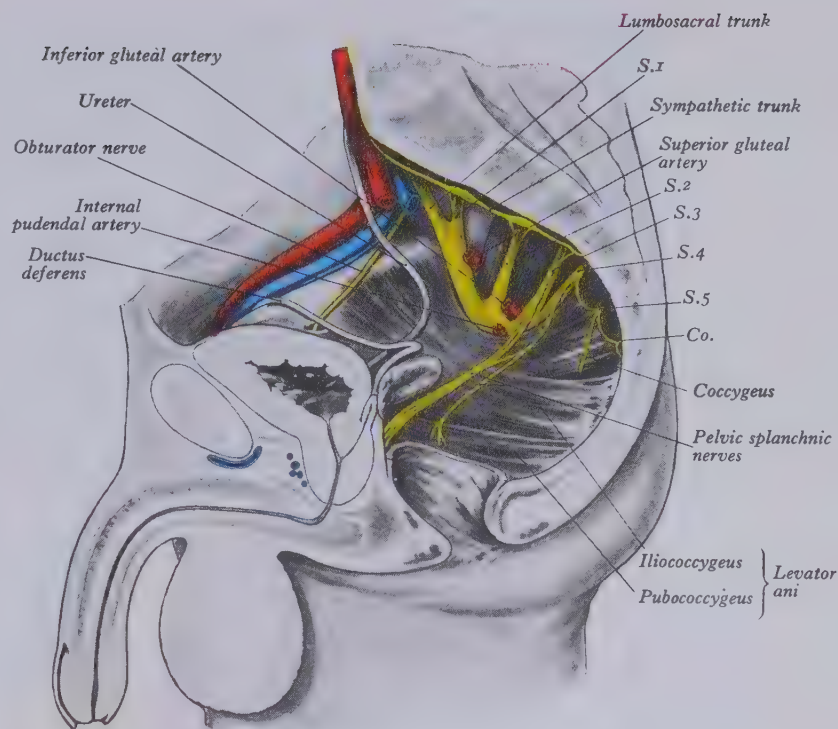
The superior gluteal nerve from the dorsal branches of the fourth and fifth lumbar and first sacral ventral rami (7.256) leaves the pelvis via the greater sciatic foramen above the piriformis with the superior gluteal vessels, dividing into superior and inferior branches. The superior branch accompanies the upper branch of the deep division of the superior gluteal artery to supply the gluteus medius and occasionally the gluteus minimus. The inferior branch runs with the lower ramus of the deep division of the superior gluteal artery across the gluteus minimus, supplying the glutei medius and minimus and ending in the tensor fasciae latae.

The inferior gluteal nerve, from the dorsal branches of the fifth lumbar and first and second sacral ventral rami, leaves the pelvis via the greater sciatic foramen below the piriformis, dividing into branches which enter the deep surface of the gluteus maximus.

The posterior femoral cutaneous nerve, from the dorsal branches of the first and second and the ventral branches of the second and third sacral rami (7.256), issues via the greater sciatic foramen below the piriformis, descends under the gluteus maximus with the inferior gluteal vessels, lying posterior or medial to the sciatic nerve. It descends in the back of the thigh superficial to the long head of the biceps femoris, deep to the fascia lata; behind the knee it pierces the deep fascia and accompanies the short saphenous vein to mid-calf, its terminal twigs connecting with the sural nerve. Its branches are all cutaneous, distributed to the gluteal region, perineum and the flexor aspect of the thigh and leg. Three or four gluteal branches curl round the lower border of the gluteus maximus to supply the skin over its inferolateral area. The perineal branch supplies the superomedial skin in the thigh, curves forwards across the hamstrings below the ischial tuberosity, pierces the fascia lata and runs in the superficial perineal fascia to the scrotal or labial skin, communicating with the inferior rectal and posterior scrotal branches of the perineal nerve. Branches to the back of the thigh and leg are numerous and from both sides of the posterior femoral cutaneous nerve; they supply the skin of the back and medial side of the thigh, the popliteal fossa and the proximal part of the back of the leg (7.258).

The Sciatic Nerve

The sciatic nerve (7.256, 259), 2 cm broad at its origin and the broadest in the body, is the continuation of the upper band of the sacral plexus. It leaves the pelvis via the greater sciatic foramen below the piriformis and descends between the greater trochanter and ischial tuberosity, along the back of the thigh, dividing into the tibial and common peroneal (fibular) nerves, proximal to the knee. Superiorly it is deep to the gluteus maximus, resting first on the posterior ischial surface with the nerve to quadratus femoris between them; it then crosses posterior to the obturator internus and the gemelli, then on to the quadratus femoris, separated by it from obturator externus and the hip joint; it is accompanied medially by the posterior femoral cutaneous nerve and the inferior gluteal artery. More distally it is behind the adductor magnus and is crossed posteriorly by the long head of the



7.257 A dissection of the side wall of the pelvis, showing the sacral and coccygeal plexuses. S.1-5 indicate the ventral rami of the sacral spinal nerves; Co. indicates the ventral ramus of the coccygeal spinal nerve.

biceps femoris. It corresponds to a line from just medial to the midpoint between the ischial tuberosity and greater trochanter to the apex of the popliteal fossa.

Articular branches arise proximally to supply the hip joint through its posterior capsule; these are sometimes derived directly from the sacral plexus. Muscular branches are distributed to the biceps femoris, semitendinosus, semimembranosus and the ischial part of the adductor magnus (p. 641), as detailed below.

THE TIBIAL NERVE

The tibial (medial popliteal) nerve (7.259), the larger sciatic division (from the ventral branches of the fourth and fifth lumbar and first to third sacral ventral rami), descends along the back of the thigh and popliteal fossa to the distal border of popliteus, passing anterior to the arch of soleus with the popliteal artery and continuing into the leg. In the thigh it is overlapped proximally by the hamstring muscles, but becomes more superficial in the popliteal fossa, where it is lateral to the popliteal vessels, becoming superficial to them at the knee and crossing to the medial side of the artery (7.260). Distally in the fossa it is overlapped by the junction of the two heads of gastrocnemius. Its surface projection is a line in the midline of the limb, vertical from the apex of the popliteal fossa to the level of the fibular neck and thence to a point midway between the medial malleolus and calcaneal tendon.

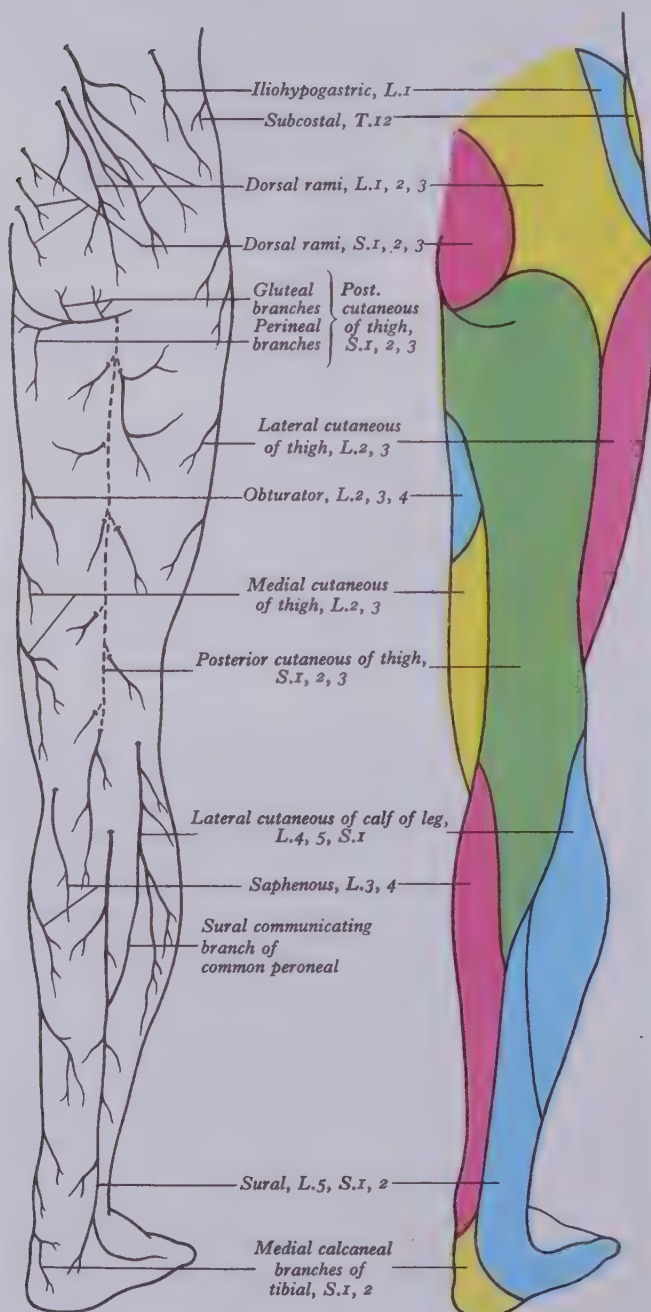
In the leg the tibial nerve descends with the posterior tibial vessels to lie between the heel and the medial malleolus, ending under the flexor retinaculum by dividing into medial and lateral plantar nerves. Proximally it is deep to the soleus and gastrocnemius, but in its distal third is covered only by skin and fasciae, overlapped sometimes by the flexor hallucis longus. At first medial to the posterior tibial vessels, it crosses behind them, descending lateral to them until it bifurcates. It lies on the tibialis posterior for most of its course, except distally, where it adjoins the posterior surface of the tibia.

Its branches are articular, muscular, sural, medial calcaneal and medial and lateral plantar.

Articular branches accompany the superior, inferior medial and middle genicular arteries to the knee joint. The three form a

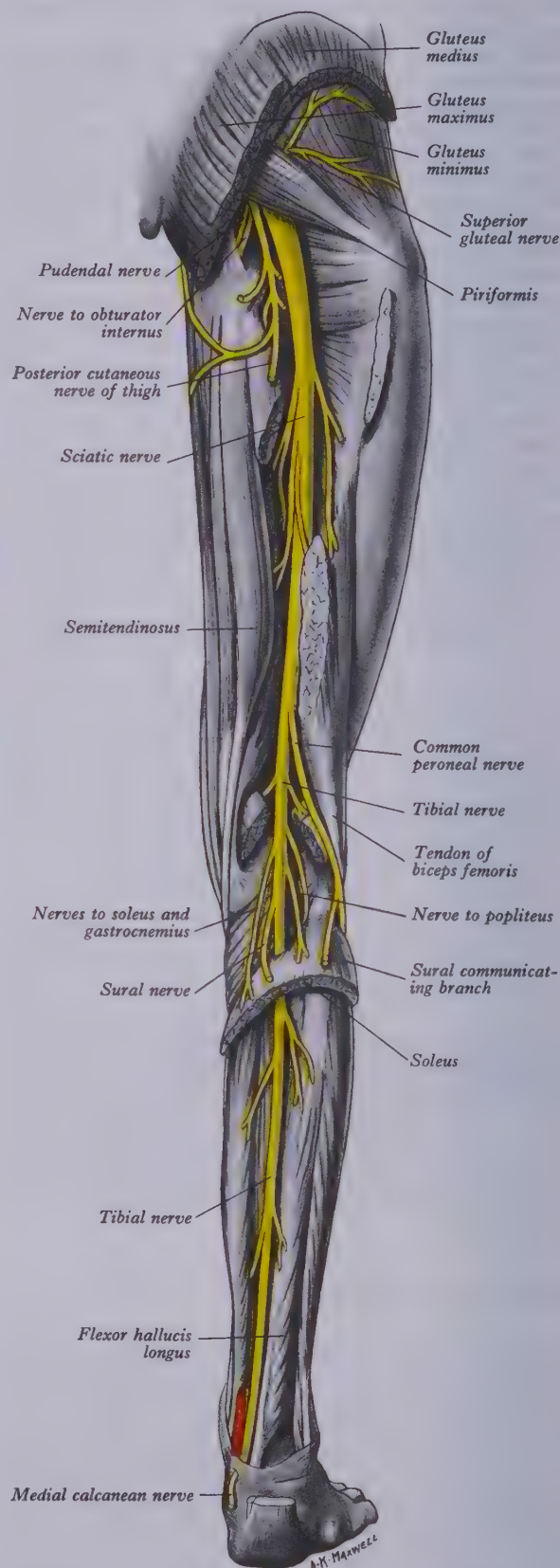
plexus with an obturator branch, supplying the oblique posterior ligament; those with the superior and inferior medial genicular arteries supply the medial part of the capsule. Just before the tibial nerve bifurcates it supplies the ankle joint. Champetier & Descours (1968) have surveyed these articular nerves. Gardner & Lenn (1977) assessed the ratios of myelinated to non-myelinated fibres in genual articular nerves in monkeys as about 4:1; they suggested that most are nociceptive.

Muscular branches, arising between the heads of the gastrocnemius, supply this, the plantaris, soleus and popliteus. The nerve to the soleus enters its superficial aspect; the branch to the popliteus descends obliquely across the popliteal vessels, curling round the muscle's distal border to its anterior surface and also supplying the tibialis posterior, the proximal tibiofibular joint, the tibia and an interosseous branch which descends near the fibula to reach the distal tibiofibular joint.



7.258 The cutaneous nerves of the right lower limb and their areas of distribution and segmental origins, viewed from the posterior aspect. The major part of the trunk of the posterior cutaneous nerve of the thigh lies deep to the deep fascia and is therefore shown by an interrupted line.

Muscular branches in the leg, independent or by a common trunk, supply the soleus (on its deep surface), the tibialis posterior, flexor digitorum longus and flexor hallucis longus, the branch to the last-named accompanying the peroneal vessels.



7.259 The nerves of the right lower limb: posterior aspect. In this figure the gluteus maximus, the gluteus medius and the superficial muscles of the calf of the leg have been removed and the middle part of the long head of the biceps femoris has been excised.

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The **sural nerve** descends between the heads of the gastrocnemius, pierces the deep fascia proximally in the leg and is joined by a sural communicating branch of the common peroneal (7.258). It descends lateral to the tendo calcaneus, near the small saphenous vein, to the region between the lateral malleolus and the calcaneus; it supplies the posterior and lateral skin of the leg's distal third, proceeding distal to the lateral malleolus along the lateral side of the foot and little toe; it connects on the dorsum of the foot with the superficial peroneal nerve, and in the leg with the posterior femoral cutaneous nerve. The fibre spectrum and ultrastructure of fetal sural nerves were described by Ochoa (1971) and in adults by Ochoa & Mair (1969a, b). The three-dimensional distribution of Schwann cells associated with unmyelinated nerve fibres in adult human sural nerves has been analysed by Carlsen & Behse (1980).

Medial calcaneal branches perforate the flexor retinaculum to supply the skin of the heel and medial side of the sole.

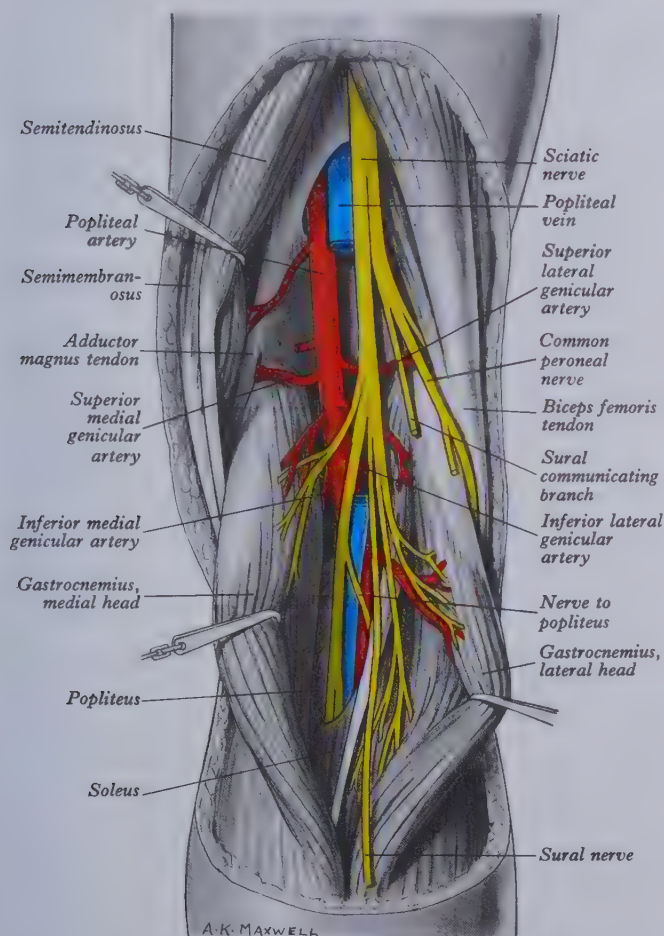
Vascular branches supply arteries accompanying the tibial nerve and its branches (p. 1163).

The **medial plantar nerve** (7.261), the larger terminal division of the tibial nerve, lies lateral to the medial plantar artery. From its origin under the flexor retinaculum it passes deep to the abductor hallucis, appears between it and the flexor digitorum brevis, gives off a medial proper digital nerve to the hallux and divides near the metatarsal bases into three common plantar digital nerves.

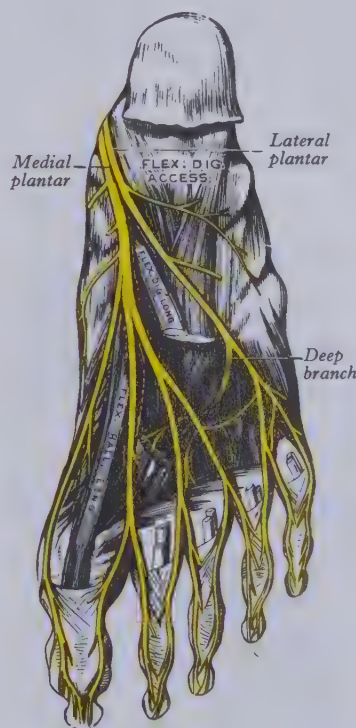
Cutaneous branches pierce the plantar aponeurosis between the abductor hallucis and the flexor digitorum brevis to supply the skin of the sole of the foot. **Muscular branches** supply the abductor hallucis, flexor digitorum brevis, flexor hallucis brevis and the first lumbrical; the first two arise near the nerve's origin and enter the deep surfaces of the muscles; the branch to the flexor hallucis

brevis is from the hallucial medial digital nerve, and that to the first lumbrical from the first common plantar digital nerve. **Articular branches** supply the joints of the tarsus and metatarsus.

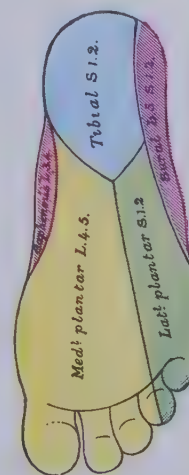
Three common plantar digital nerves pass between the slips of the plantar aponeurosis, each dividing into two proper digital branches, the first supplying adjacent sides of the hallux and secundus, the second adjacent sides of the secundus and tertius, the third adjacent sides of the tertius and quartus and also connecting with the lateral plantar nerve. The first gives a branch to the first lumbrical. Each proper digital nerve has cutaneous and articular branches; near the distal phalanges a dorsal branch supplies structures around the nail; the end of each nerve supplies the ball of the toe. Note that the common digital branches of the medial plantar are like those of the median nerve; muscles supplied by both correspond closely. In the hand the median nerve supplies the abductor and flexor pollicis brevis, the opponens pollicis and the first and second lumbricals. The opponens is absent in the foot but the abductor hallucis, flexor hallucis brevis and the first lumbrical are all supplied by the medial plantar.



7.260 A dissection of the right popliteal fossa. The two heads of gastrocnemius and the semitendinosus and semimembranosus have been retracted in order to expose the contents of the fossa more fully.



7.261 The plantar nerves of the right foot.



7.262 A diagram showing the distribution of the cutaneous nerves in the sole of the right foot.

Since the flexor digitorum brevis and flexor digitorum superficialis (median nerve) correspond, only the innervation of the second lumbrical differs.

The **lateral plantar nerve** (7.261) supplies the skin of the digitus quintus, and of the lateral half of the quartus and most deep muscles, like the ulnar nerve in the hand. It passes laterally forwards with the lateral plantar artery lateral to it, towards the fifth metatarsal's tubercle and then between the flexores digitorum brevis and accessorius, to end between the former and the abductor digiti minimi, dividing into superficial and deep branches. Before division it supplies the flexor digitorum accessorius and abductor digiti minimi and gives rise to small branches which pierce the plantar fascia to supply the skin of the lateral part of the sole (7.262). The *superficial branch* splits into two common plantar digital nerves: the *lateral* supplies the lateral side of the digitus quintus, flexor digiti minimi brevis and the two interossei in the fourth intermetatarsal space; the *medial* connects with the third common plantar digital branch of the medial plantar nerve, dividing into two to supply the adjoining sides of the digitus quartus and quintus. The *deep branch* accompanies the lateral plantar artery deep to the flexor tendons and the adductor hallucis, supplying the second to fourth lumbricals, the adductor hallucis and all interossei (except those of the fourth intermetatarsal space); branches to the second and third lumbricals pass

distally deep to the transverse head of the adductor hallucis, curling round its distal border to reach them (7.263).

THE COMMON PERONEAL (FIBULAR) NERVE

The common peroneal (fibular or lateral popliteal) nerve (7.260), about half the size of the tibial, is derived from the dorsal branches of the fourth and fifth lumbar and first and second sacral ventral rami. It descends obliquely along the popliteal fossa's lateral side to the fibular head, medial to the biceps femoris and lying between its tendon and the lateral head of the gastrocnemius. It curves lateral to the fibular neck deep to the peroneus longus and divides into superficial and deep peroneal nerves. Its course can be indicated by a line from the fossa's apex, passing distally medial to the biceps tendon to the back of the fibula's head, where the nerve can be rolled against the bone. Before division it gives off articular and cutaneous branches.

Of the three *articular branches* two accompany the superior and inferior lateral genicular arteries; they may arise in common. The third, termed the recurrent articular nerve, arises near the division of the common peroneal and ascends with the anterior recurrent tibial artery through the tibialis anterior to supply the anterolateral part of the genua capsule and the proximal tibiofibular joint. Two *cutaneous branches* (7.258), often from a common trunk, are the lateral sural and sural communicating nerves.

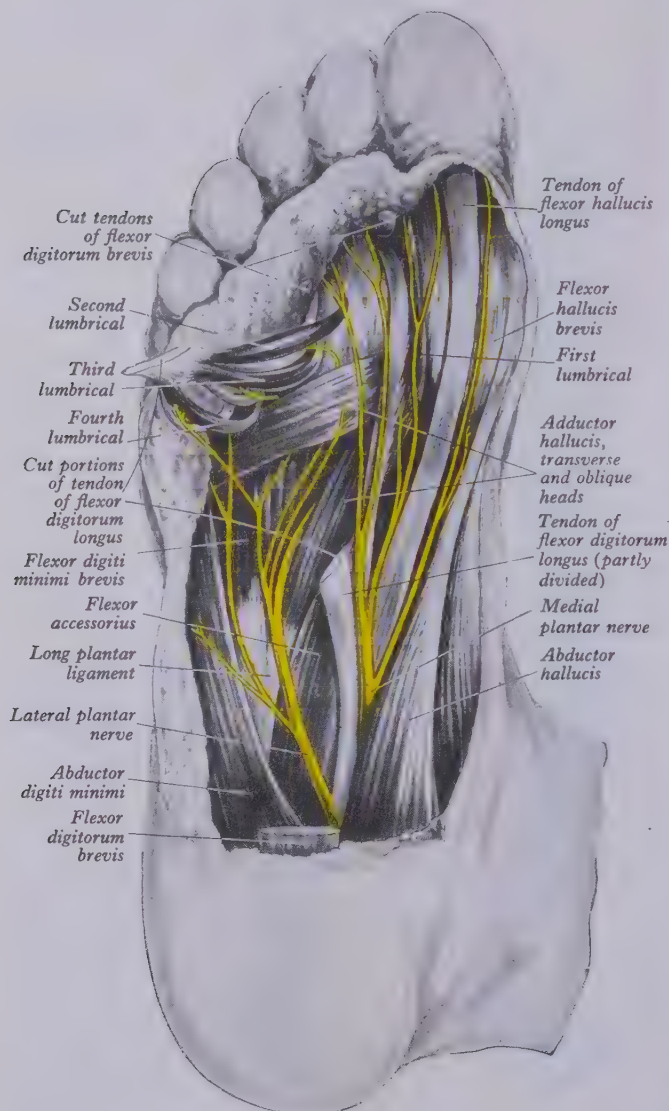
The *lateral sural nerve* (lateral cutaneous nerve of the calf) supplies the skin on the anterior, posterior and lateral surfaces of the proximal leg. The *sural communicating nerve* arises near the fibula's head and crosses the lateral head of the gastrocnemius to join the sural nerve (p. 1147). It may descend separately as far as the heel.

The **deep peroneal (anterior tibial) nerve** (7.255) begins at the common peroneal bifurcation, between the fibula and the proximal part of the peroneus longus and passes obliquely forwards deep to the extensor digitorum longus to the front of the interosseous membrane, reaching the anterior tibial artery in the proximal third of the leg; it descends with it to the ankle, dividing there into lateral and medial terminal branches. It is first lateral to the artery, then anterior and again lateral at the ankle. It supplies *muscular branches* to the tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius and an *articular branch* to the ankle joint.

The *lateral terminal branch* crosses the tarsus deep to the extensor digitorum brevis, enlarges as a pseudoganglion (cf. other sites p. 1132) and supplies the extensor digitorum brevis. From the enlargement three minute *interosseous branches* supply the tarsal and metatarsophalangeal joints of the middle three toes; the first branch supplies the second dorsal interosseous muscle.

The *medial terminal branch* runs distally on the dorsum of the foot lateral to the arteria dorsalis pedis, connecting at the first interosseous space with the medial branch of the superficial peroneal nerve and dividing into two dorsal digital nerves to supply adjacent sides of the hallux and secundus; before dividing it gives off an *interosseous branch* which supplies the hallucal metatarsophalangeal joint and the first dorsal interosseous. The deep peroneal nerve may end as *three* terminal branches (Geller & Barbato 1970).

The **superficial peroneal (musculocutaneous) nerve** (7.254) begins at the common peroneal bifurcation. It is at first deep to the peroneus longus, passing antero-inferiorly between the peronei and extensor digitorum longus to pierce the deep fascia in the leg's distal third, where it divides into medial and lateral branches. Between the muscles it supplies the peroneus longus, peroneus brevis and the skin of the lower leg. The *medial branch* passes anterior to the ankle, dividing into two dorsal digital nerves, one supplying the medial side of the hallux and the other the adjacent sides of the secundus and tertius. It communicates with the saphenous nerve and deep peroneal nerves (7.254). The smaller *lateral branch* traverses the dorsum of the foot laterally, dividing into dorsal digital branches which supply the contiguous sides of the third to fifth toes, also supplying the skin of the ankle's lateral aspect and connecting with the sural nerve (7.254).



7.263 A dissection of the lateral and medial plantar nerves of the right foot. Most of the flexor digitorum brevis has been removed. The flexor digitorum longus has been partially divided and its distal end has been displaced together with the second, third and fourth lumbricals.

Superficial peroneal branches supply the dorsal skin of all the toes except that of the lateral side of the fifth and adjoining sides of the hallux and secundus, the former being supplied by the sural, the latter by the medial terminal branch of the deep peroneal. Frequently some of the superficial peroneal lateral rami are absent and replaced by sural branches.

Remaining Branches of the Sacral Plexus

The perforating cutaneous nerve (usually from the posterior aspects of the second and third sacral ventral spinal rami) pierces the sacrotuberous ligament, curves round the inferior border of the gluteus maximus and supplies the skin over the inferomedial aspect of this muscle. The nerve may arise from the pudendal or, if absent, may be replaced by a branch from the posterior femoral cutaneous nerve or from the third and fourth or fourth and fifth sacral ventral rami.

The pudendal nerve (6.121) (derived from the ventral divisions of the second, third and fourth sacral ventral rami) (7.255) leaves the pelvis via the greater sciatic foramen between the piriformis and coccygeus to enter the gluteal region, crossing the sacrospinous ligament close to the attachment to the ischial spine, sited medial to the internal pudendal vessels on the spine. It accompanies the internal pudendal artery through the lesser sciatic foramen into the pudendal canal (p. 606) on the ischiorectal fossa's lateral wall. In the posterior part of the canal it gives off the inferior rectal nerve, which divides into the perineal nerve and the dorsal nerve of the penis (or clitoris).

The *inferior rectal nerve* pierces the medial wall of the pudendal canal, crosses the ischiorectal fossa with the inferior rectal vessels and supplies the sphincter ani externus, the lining of the lower part of the anal canal and the circumanal skin. Its branches connect with the perineal branch of the posterior femoral cutaneous nerve and with the scrotal (or labial) nerves. It sometimes arises directly from the sacral plexus, may perforate the sacrospinous ligament (in 8 out of 40 dissections according to Roberts & Taylor 1973) and may re-connect with the pudendal nerve.

The *perineal nerve*, the inferior and larger terminal pudendal branch, runs forwards below the internal pudendal artery. It accompanies the perineal artery, dividing into posterior scrotal (labial) and muscular branches.

Posterior scrotal or labial nerves, medial and lateral, pierce or pass over the inferior fascia of the urogenital diaphragm and run forwards in the lateral part of the urethral triangle with the scrotal (or labial) branches of the perineal artery; they supply scrotal skin or that of the labius majus, connecting with the perineal branch of the posterior femoral cutaneous and inferior rectal nerve.

Muscular branches supply: the transversus perinei superficialis, bulbospongiosus, ischiocavernosus, transversus perinei profundus, sphincter urethrae and the anterior parts of the external sphincter and levator ani. In males a *nerve to the urethral bulb* leaves the nerve to the bulbospongiosus, piercing it to supply the corpus spongiosum penis; it ends in the urethral mucosa.

The *dorsal nerve of the penis* runs forwards in males above the internal pudendal artery along the ischial ramus and the margin of the inferior pubic ramus, deep to the inferior fascia of the urogenital diaphragm. It supplies the corpus cavernosum penis and, at the urogenital diaphragm's apex, is lateral in the hiatus between this diaphragm and the inferior pubic ligament. It accompanies the dorsal penile artery between the layers of the suspensory ligament to the dorsum of the penis, ending in the glans. In females the homologous *dorsal nerve of the clitoris* is very small.

Clinical evidence indicates that the pudendal nerve supplies sensory branches to the lower part of the vagina, probably by fibres in the inferior rectal nerve and posterior labial branches of the perineal nerve. Pudendal nerves can be 'blocked' by infiltration with a local anaesthetic applied via a needle passed through the vaginal wall towards the ischial spine and sacrospinous ligament, both palpable per vaginam (Huntingford 1959, Nakanishi 1967).

Sacral visceral branches arise from the second to fourth

sacral ventral rami to innervate the pelvic viscera; they are termed *pelvic splanchnic nerves* (p. 1056).

Sacral muscular branches, from the fourth sacral ventral ramus, supply the levator ani, coccygeus and sphincter ani externus. Those to the levator ani and coccygeus enter the pelvic surfaces of the muscles; the ramus to the sphincter ani externus (*perineal branch of the fourth sacral nerve*) reaches the ischiorectal fossa through the coccygeus or between that muscle and the levator ani, supplying the skin between the anus and coccyx via its cutaneous branches.

The Coccygeal Plexus

The coccygeal plexus is formed by a small descending branch from the fourth sacral ventral ramus and by the fifth sacral and coccygeal ventral rami. The fifth sacral ventral ramus emerges from the sacral hiatus, curving round the lateral margin of the sacrum below its cornu and piercing the coccygeus to reach its pelvic surface, where it is joined by a descending branch of the fourth sacral ventral ramus; the small trunk so formed descends on the pelvic surface of the coccygeus to join the minute coccygeal ventral ramus emerging from the sacral hiatus and curves round the lateral coccygeal margin to pierce the coccygeus and reach the pelvis. This small trunk is the *coccygeal plexus*. *Anococcygeal nerves* arise from it, a few fine filaments piercing the sacrotuberous ligament to supply the adjacent skin.

APPLIED ANATOMY OF LUMBAR, SACRAL AND COCCYGEAL PLEXUSES

The *iliohypogastric nerve* may be cut (p. 1140) by an incision for appendicectomy; consequent muscular weakness may predispose to the development of a direct inguinal hernia.

The *lateral femoral cutaneous nerve* may be compressed in the inguinal ligament (p. 596) or in the dense fascia lata; the consequent irritation is supposedly a cause of *meralgia paraesthetica*, a rare condition of pain on the lateral side of the thigh.

The *femoral nerve* is occasionally damaged, resulting in paralysis of the quadriceps femoris and sensory loss on the anterior and lateral aspects of the thigh.

The *obturator nerve* is sometimes divided to relieve adductor spasm in spastic paralysis, paraplegia or multiple sclerosis. Because it supplies the hip and knee joints and the medial side of the thigh, hip joint disease may cause referred pain in the thigh (medial side) or knee.

The *sacral plexus* and *lumbosacral trunk* may be compressed by pelvic tumours or the fetal head, causing pain in the lower limbs which, in the former case, may be most severe.

The *sciatic nerve* may be injured in posterior dislocations or fracture dislocations of the hip; if the lesion is complete, which is rare, all the muscles distal to the knee are paralysed and all cutaneous sensibility lost, except in the area supplied by the saphenous nerve. In sciatic nerve lesions in the mid-thigh, flexor muscles often escape because of their more proximal supply.

The *common peroneal* is the most commonly injured nerve in the lower limb because of its exposed position at the fibular neck. Injury here paralyses all the dorsiflexor and evertor muscles of the foot, i.e. the tibialis anterior, extensor hallucis longus, extensor digitorum longus, extensor digitorum brevis, peroneus longus and peroneus brevis, producing a 'drop foot'. There is a variable cutaneous loss on the anterolateral aspect of the leg and dorsum of the foot.

Owing to its deep position the *tibial nerve* is rarely injured although wounds in the popliteal fossa or posterior dislocation of the knee joint may damage it, producing paralysis of the flexors in the leg and of the intrinsic muscles in the sole; loss of sensation in the sole renders it liable to pressure sores.

Loss of sensation in the skin of the gluteal and coccygeal regions through damage to the nerves of supply (vide supra) can also lead to the development of pressure sores.

Morphology of the Spinal Nerves and Limb Plexuses

Spinal nerves conforming to a more primitive arrangement are naturally located in segments largely retaining a *metameric* (segmental) structure, e.g. the thoracic region. Such typical spinal nerves show a common plan. The dorsal, epaxial ramus passes back lateral to the articular processes and divides into medial and lateral branches penetrating the deeper muscles of the back; both innervate the adjacent muscles and supply a band of skin from the posterior median line to the scapular line (vide infra). The ventral, hypaxial ramus is connected to a corresponding sympathetic ganglion by white and grey rami communicantes. It innervates the prevertebral muscles and curves round in the body wall supplying the lateral muscles of the trunk; near the mid-axillary line it gives off a lateral branch which pierces the muscles to divide into anterior and posterior cutaneous branches. The main nerve advances in the body wall, supplying the ventral muscles and terminating in branches to the skin.

The arrangement of ventral rami in segments which have lost their obvious metamerism is greatly modified, especially by the union of adjacent nerves to form cervical, brachial, lumbosacral and coccygeal plexuses.

The cervical plexus. The cutaneous branches are homologous with the anterior terminal and lateral branches of ventral rami of typical spinal nerves. The cervical transverse cutaneous nerve and the medial supraclavicular nerves represent the anterior terminal branches; the lesser occipital and lateral supraclavicular represent lateral branches; the great auricular and intermediate supraclavicular probably represent elements of both.

The brachial plexus. Division of constituent ventral rami into ventral (anterior, flexor) and dorsal (posterior, extensor) branches occurs in both brachial and lumbosacral plexuses. In the brachial plexus division affects all three trunks (p. 1130) and conforms closely to the differentiation of the primitive musculature of the limb into ventral (flexor) and dorsal (extensor) groups. Branches of the ventral divisions largely supply dorsal skin in the limb, a discrepancy tentatively explained (Harris 1939) by assuming that each ventral ramus originally divided into ventral and dorsal branches and that, in human evolution, dorsal fibres entered the ventral branches of the *trunks*. As a result, fibres of the median and ulnar nerves have a wide dorsal area of supply in the hand.

The ventrolateral position of the limb buds and the arrangement of the first and second thoracic nerves support the view that the nerves of limb plexuses are only the *lateral* branches of typical ventral rami. The second thoracic ventral ramus gives off a lateral cutaneous branch which goes to the upper limb as the intercostobrachial nerve, its size inversely related to that of the *direct* contribution from the second thoracic to the brachial plexus. The second thoracic is otherwise typical. The first thoracic ventral ramus gives a large contribution to the brachial plexus and this could be homologous with a lateral branch; the remainder, despite its small size, is typical, but its anterior cutaneous branch is reduced and often absent.

The lumbosacral plexus. Division of constituent ventral rami into ventral and dorsal branches is not as clear here as in the brachial plexus, but anatomically the obturator and tibial nerves arise from ventral and the femoral and peroneal nerves from dorsal divisions. Lateral branches of the twelfth thoracic and first lumbar ventral rami are drawn into the gluteal skin but otherwise these nerves are typical. The second lumbar ramus is difficult to interpret; it not only contributes substantially to the lumbar plexus but also has an anterior terminal branch (genital branch of the genitofemoral) and a lateral cutaneous branch (lateral femoral cutaneous nerve and the femoral branch of the genitofemoral). Anterior terminal branches of the third to fifth lumbar and first sacral rami are suppressed but the corresponding parts of the second and third sacral rami supply the skin, etc. of the perineum. The posterior femoral cutaneous nerve poses an interesting problem: it arises from both ventral and dorsal divisions and supplies 'flexor' femoral skin and 'extensor' gluteal skin.

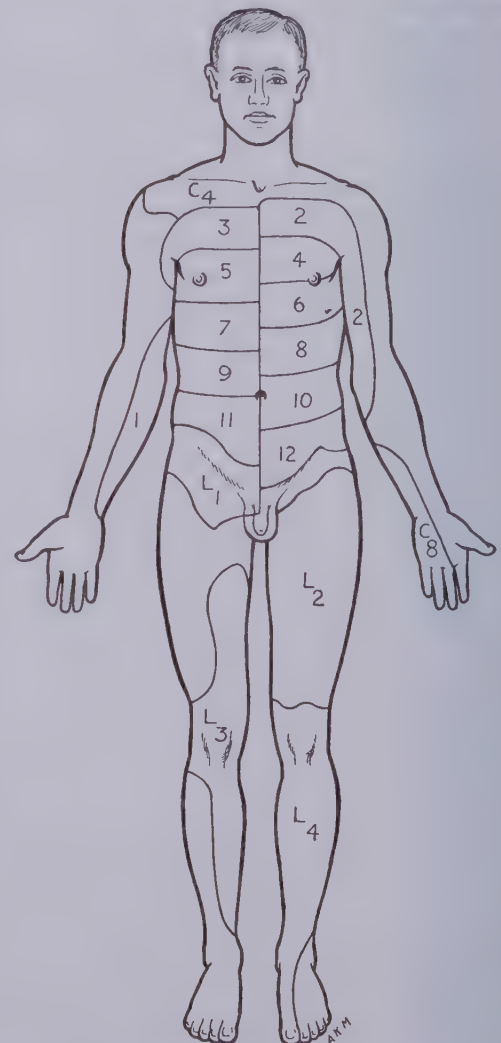
Segmental Innervation of the Skin

The cutaneous area supplied by *one* spinal nerve, through both rami, is a **dermatome**; typically, dermatomes extend round the body from the posterior to the anterior median line (7.249, 264, 267A,B). Dermatomes of adjacent spinal nerves overlap markedly, particularly in the segments least affected by development of the limbs, i.e. the second thoracic to the first lumbar (7.264, 267A,B).

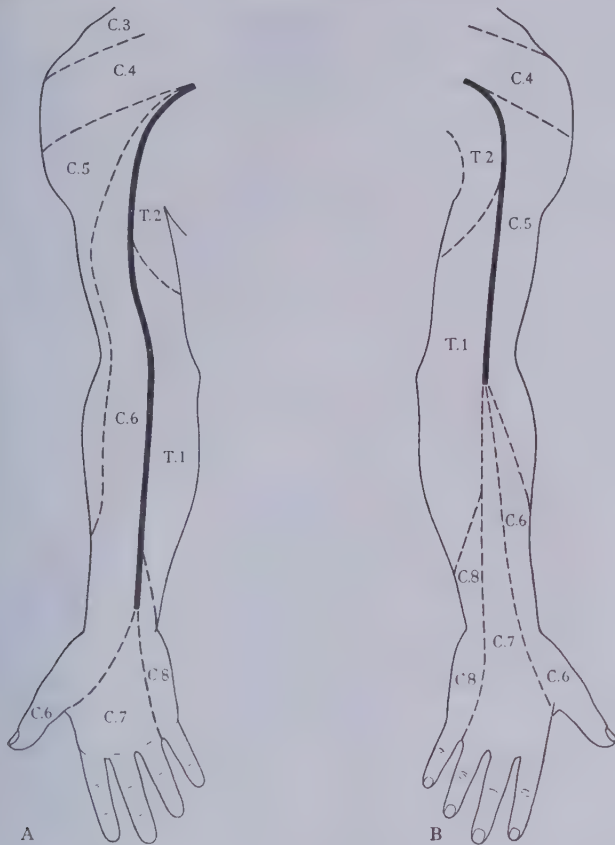
In some regions, e.g. the upper anterior thoracic wall, cutaneous nerves supplying adjoining areas are *not* from consecutive spinal nerves and the overlap is minimal. When the second thoracic spinal ramus is severed, anaesthesia is sharply demarcated but some overlap for painful and thermal sensibility may exist. Likewise, after section of a peripheral nerve (e.g. the ulnar nerve at the wrist) the area of tactile loss is always greater than that for pain and thermal sensibilities. Hence the area of total anaesthesia and analgesia following section of peripheral nerves is always less than might be anticipated from their anatomical distribution (Foerster 1933, Wollard et al 1940).

Cutaneous Innervation of the Neck and Upper Limbs

The first cervical spinal nerve supplies no skin. The second cervical usually supplies the skin of the head from the vertex to the superior nuchal line, almost all of the lateral aspect of the ear and the skin over the mandibular angle and below the chin (7.224). The third cervical supplies an oblique band from the back of the



7.264 The cutaneous areas supplied by the ventral rami of the thoracic and upper four lumbar nerves (after Foerster 1933). By comparing both sides the degree of overlapping and the area of exclusive supply of any individual nerve may be estimated. See text for the areas supplied by T1 on the trunk.



7.265 A. The arrangement of the dermatomes on the anterior aspect of the upper limb. The heavy black line represents the *ventral axial line* and the overlap across it is *minimal*. Across the interrupted lines, the overlap is considerable. B. The arrangement of the dermatomes on the posterior aspect of the upper limb. The heavy black line represents the *dorsal axial line* and the overlap across it is *minimal*. Across the interrupted lines the overlap may be, and often is, considerable.

scalp and upper neck, descending across the side of the neck and increasing in width, to the ventral median line from the hyoid bone to the first rib. The fourth cervical supplies the upper half of the back of the neck and an area widening down and forwards round the neck to the anterior thoracic aspect, supplying the skin over the clavicle, first intercostal space, acromion and the upper part of the deltoid. Each of these three areas is overlapped by the succeeding; the overlap is slight but greater for dorsal rami than for ventral.

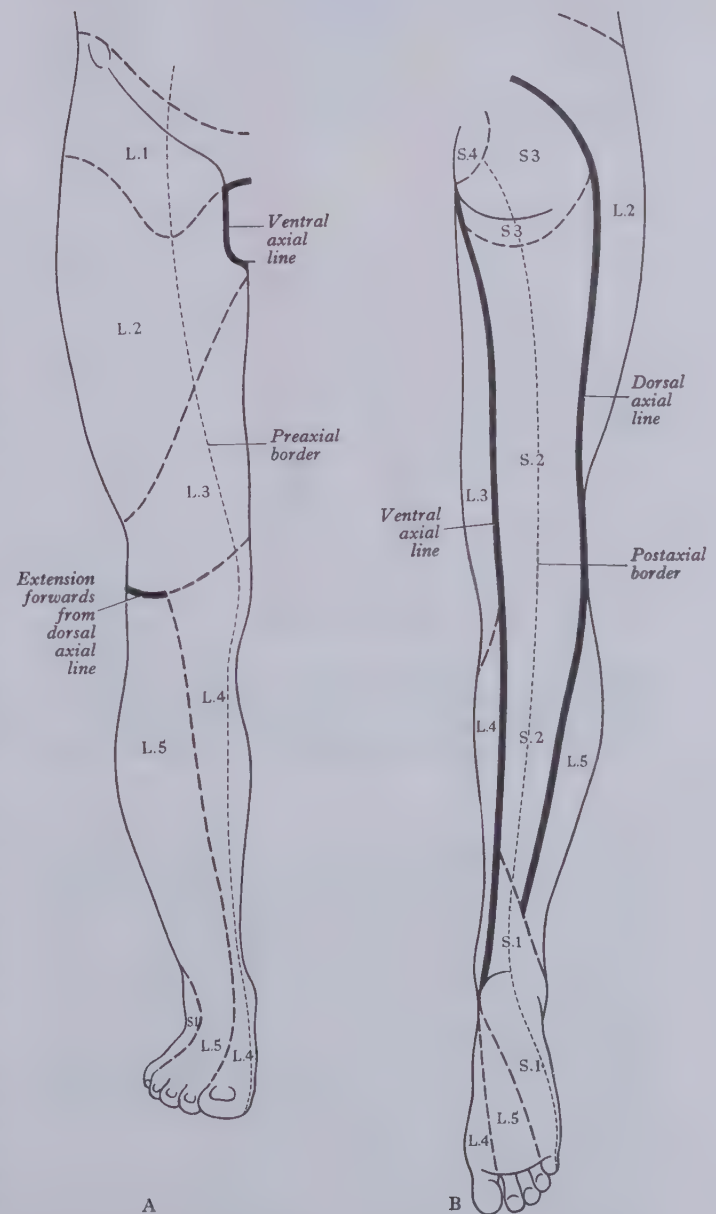
The cutaneous distribution of those spinal nerves contributing to the brachial plexus is explained by the early development of the upper limbs. In human embryos at the fourth week the upper limb is a small, flattened ventrolateral elevation on the trunk, level with the lower four cervical and first thoracic segments; its ectoderm is continuous with that of the trunk, taking its supply from the nerves of corresponding segments; its mesoderm is also continuous with that in the same segments. Lower limb buds appear slightly later and always lag behind the upper limb buds until after birth.

Limb buds have ventral and dorsal surfaces and *preaxial* (cranial) and *postaxial* (caudal) borders. In the upper limbs the *fifth cervical* ventral ramus supplies a strip of skin on the ventral and dorsal surfaces along the *preaxial* border; the *first thoracic* nerve has a similar distribution along the *postaxial* border. Intervening nerves supply almost parallel strips on the ventral and dorsal surfaces. As the limb elongates, central nerves of the plexus (C6, 7 and 8) become buried proximally, reaching the skin only in distal parts; nerves of segments C4 and T2 and 3 are drawn in to supply proximal skin, i.e. at the root of the limb. During growth the lengthening limb is rotated laterally through about 90° and adducted to the trunk (p. 175). Hence the *preaxial* border runs

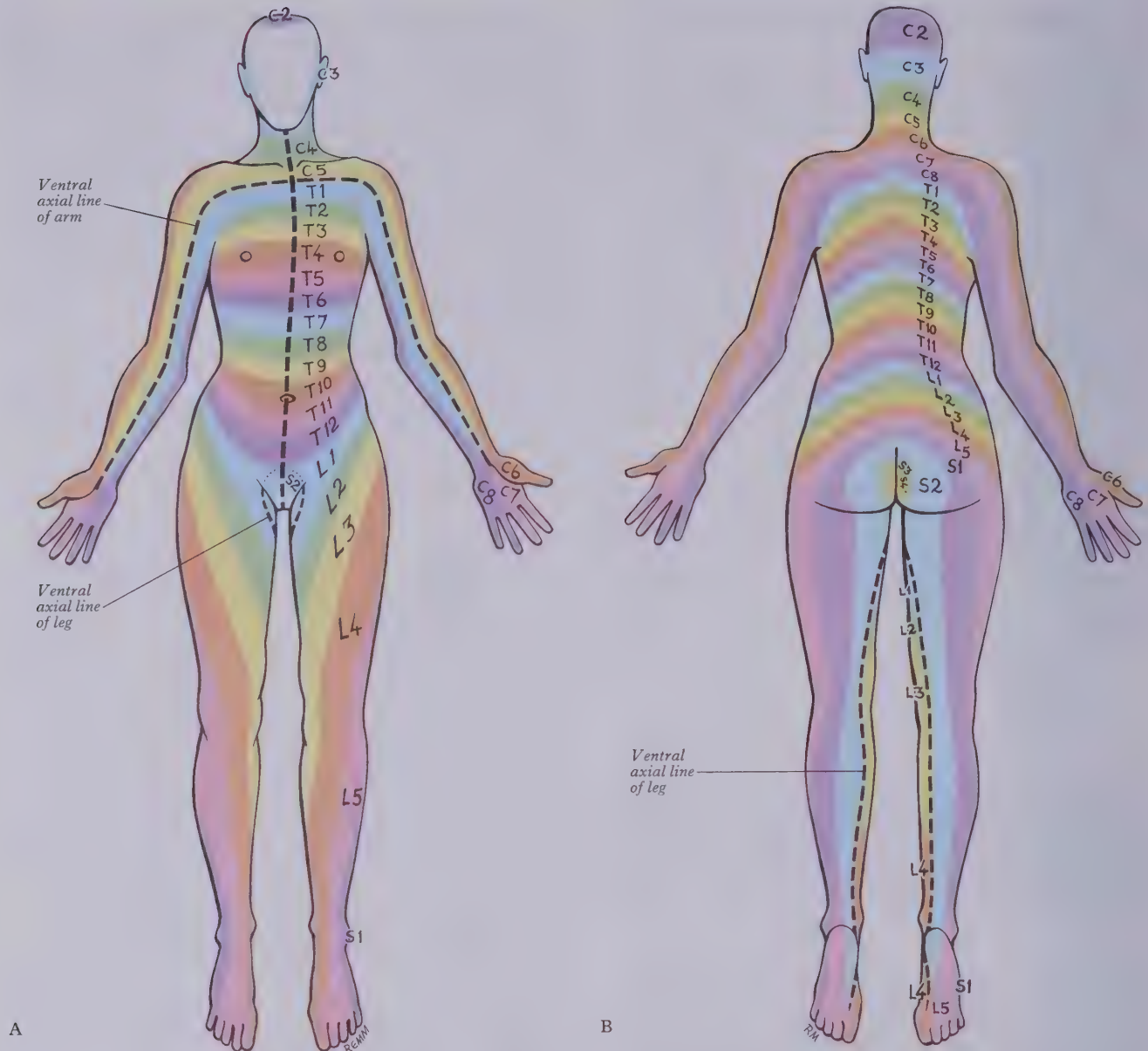
distally on the lateral aspect of a supinated limb to the thumb, the *preaxial digit*, while the *postaxial* border runs along the medial aspect to the digitus minimus, the *postaxial digit*. Therefore the cutaneous supply of the lateral aspect of adult limbs is from C4, drawn in at the root of the limb, then from C5 and C6; and its medial aspect is from T2, T1 and C8 (7.265). On the *front of the limb*, areas supplied by C5 and C6 adjoin those supplied by T2, T1 and C8; but at their frontier, the *ventral axial line*, overlap is minimal, for C7 is buried proximally and only reaches the skin a little proximal to the wrist (7.265). On the *back of the limb* the condition is similar; but C7 (in the posterior cutaneous nerve of the forearm) reaches the skin near the elbow, the *dorsal axial line* ending at a more proximal level (7.265). Pronation of the forearm affects these lines (p. 398).

Cutaneous Innervation of the Trunk

The skin of the trunk is supplied by spinal nerves T1–L1, S2–4 and Co1 in consecutive (7.249, 264, 267A,B), curved zones, the upper almost horizontal, the lower oblique. The upper half of



7.266 A. The segmental distribution of the nerves of the lumbar and sacral plexuses to the skin of the anterior aspect of the lower limb. B. The segmental distribution of the nerves of the lumbar and sacral plexuses to the skin of the posterior aspect of the lower limb. For the significance of the markings see caption to 7.265.



7.267 Ventral (A) and dorsal (B) views of the distributions of dermatomic innervation, modified from the studies of Keegan & Garrett (1948). Diagrams of this kind can only be approximate and cannot clearly indicate the degree of overlap; e.g., the overlap of the supraclavicular nerves (C4

and 5) into the upper pectoral region is not shown and it is possible that the pectoral area assigned to the first thoracic spinal nerve is here exaggerated.

each zone is supplemented by the nerve above, the lower half by the nerve below. No appreciable loss of sensibility follows section of any one spinal nerve. The zone including the subcostal angle is supplied by the seventh thoracic nerve; the umbilicus is in the upper part of a zone supplied by the tenth thoracic.

The area supplied by dorsal rami of these nerves is limited laterally by the dorsolateral line, descending laterally from the occiput to the medial end of the acromion, continued to the posterior aspect of the greater trochanter and curving medially to the coccyx (7.266). Cutaneous strips supplied by dorsal rami do not correspond exactly to those served by ventral rami, differing both in breadth and position.

On the upper ventral thoracic aspect, the third and fourth cervical areas adjoin the first and second thoracic areas (7.249), since the muscles and skin areas supplied by the intervening nerves have grown into the upper limb; a similar, less extensive posterior gap exists.

Similar arrangements exist in the lower trunk, but less obviously, due to approximation of the lower limbs, though apparent in the gluteal region. The first lumbar adjoins the second sacral area

at the root of the penis and scrotum in the male and their homologues in the female (see p. 1446), intervening nerves having been drawn away into the lower limbs during development.

Cutaneous Innervation of the Lower Limb

The skin in the lower limb is innervated by the nerves of its segments of origin, T12–S3 (7.266, 267A,B). The arrangement developmentally begins like that in the upper limbs but its identification in adults is obscured by rotation of the lower limb in early development (p. 175). Initially the *preaxial border* follows the cranial border of the limb bud to the hallux, the *preaxial digit*, the *postaxial border* following its caudal margin to the digitus minimus, the *postaxial digit*. The limb undergoes *medial rotation*, bringing the hallux to lie on the medial side of the foot. The tibia, though homologous with the radius, is also medial. Since rotation occurs at the hip, the gluteal region retains its dorsal (extensor) position.

The *preaxial border* starts near the thigh's mid-point and descends to the knee; it then curves medially, descending to the medial malleolus and the medial side of the foot and hallux. The

postaxial border commences in the gluteal region and descends to the centre of the popliteal fossa, deviating laterally to the lateral malleolus and the lateral side of the foot. *Ventral* and *dorsal axial lines* exhibit corresponding obliquity, the ventral starting proximally at the medial end of the inguinal ligament, descending the posteromedial aspect of the thigh and leg to end proximal to the heel; the dorsal axial line commences in the lateral gluteal region and descends posterolaterally in the thigh to the knee, inclining medially to end proximal to the ankle (7.266). The segmental cutaneous distribution of the nerves to the lower limb is shown in 7.266.

Knowledge of the extent of individual dermatomes, especially in the limbs, is largely based on clinical evidence, different authorities mapping variable areas for the same dermatomes, partly due to failure to adopt a common method in neurological examination and partly to individual differences in patients with similar lesions. There is more disagreement over dermatomes in the leg, perhaps because injuries to the brachial plexus are more frequent, affording greater opportunities of correlation between cutaneous defects and neural lesions. The figures for limb dermatomes inserted in 7.265, 266 are based on the Medical Research Council's *Report on Peripheral Nerve Lesions* 1942.

In using these figures it must be understood that *broken lines* indicate that the nerves on each side extend considerably beyond them, the overlap being difficult to define. But along *ventral* and *dorsal axial lines*, in *heavy black*, overlap is minimal; the nerves flanking a line are *not* derived from consecutive spinal nerves, the intervening nerve or nerves being buried in the limb and reaching the skin only at more distal points.

Some (Keegan & Garrett 1948) maintain that during the embryonic development of dermatomes in limbs, the sensory nerves grow spirally from the dorsal surface of each limb bud around its preaxial and postaxial borders, to meet anteriorly along the ventral axial line; they deny the existence of a dorsal axial line. By plotting areas of hyposensitivity, particularly hypalgesia following damage to *individual* nerve roots, they have constructed charts of limb dermatomes differing from those in 7.265, 266. Their views (7.267A,B) were based on many observations in hypalgesia due to herniation of intervertebral discs, including 165 cases in the upper limbs (47 verified surgically) and 1264 in the lower limbs (707 verified). They show dermatomes as more continuous strips extending from the trunk along the limbs.

Segmental Innervation of the Muscles

Each spinal nerve originally supplies the musculature derived from its own myotome. Where myotomal derivatives remain entities they retain the original segmental supply; but when derivatives from adjoining myotomes fuse, the resulting muscles do not always retain a supply from each, the corresponding spinal nerve, although they often do. Since muscles develop in situ in mesodermal cores of developing limbs, it is impossible to identify their original segments merely by a developmental study. The union of spinal nerves and branches in brachial and lumbosacral plexuses renders identification of segmental values impossible. The very concept of immutability of neuromuscular linkage, originally promoted by Furbinger (1873), has been criticized and exceptions recorded (Haines 1935, Minkoff 1974).

Segmental Innervation of the Muscles in Limbs

Most muscles in limbs are innervated from more than one segment of the spinal cord; the segments involved for individual muscles are noted in Myology (p. 569). In the list below the *predominant segmental origin* of the nerve supply is stated; damage to these segments or their motor roots results in maximum paralysis. Data are based chiefly on clinical evidence (Bumke & Foerster 1936, Villiger 1946, Sharrard 1955) but opinion differs for some muscles and not all are included. Though evidence for some muscles is incontrovertible, it is scant and uncertain in many instances. An important example is provided by the intrinsic

muscles of the hand, often regarded clinically as innervated solely by the first thoracic spinal segment, though the eighth cervical is also involved (vide infra).

Upper Limb Muscles

- C3, 4 Trapezius, levator scapulae.
- C5 Rhomboids, deltoids, supraspinatus, infraspinatus, teres minor, biceps.
- C6 Serratus anterior, latissimus dorsi, subscapularis, teres major, pectoralis major (clavicular head), biceps, coracobrachialis, brachialis, brachioradialis, supinator, extensor carpi radialis longus.
- C7 Serratus anterior, latissimus dorsi, pectoralis major (sternal head), pectoralis minor, triceps, pronator teres, flexor carpi radialis, flexor digitorum superficialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi.
- C8 Pectoralis major (sternal head), pectoralis minor, triceps, flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus, pronator quadratus, flexor carpi ulnaris, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, extensor indicis, abductor pollicis brevis, flexor pollicis brevis, opponens pollicis.
- T1 Flexor digitorum profundus, intrinsic muscles of the hand (except abductor pollicis brevis, flexor pollicis brevis, opponens pollicis).

Lower Limb Muscles

- L1 Psoas major, psoas minor.
- L2 Psoas major, iliacus, sartorius, gracilis, pectineus, adductor longus, adductor brevis.
- L3 Quadriceps, adductors (magnus, longus, brevis).
- L4 Quadriceps, tensor fasciae latae, adductor magnus, obturator externus, tibialis anterior, tibialis posterior.
- L5 Gluteus medius, gluteus minimus, obturator internus, semimembranosus, semitendinosus, extensor hallucis longus, extensor digitorum longus, peroneus tertius, popliteus.
- S1 Gluteus maximus, obturator internus, piriformis, biceps femoris, semitendinosus, popliteus, gastrocnemius, soleus, peronei (longus and brevis), extensor digitorum brevis.
- S2 Piriformis, biceps femoris, gastrocnemius, soleus, flexor digitorum longus, flexor hallucis longus, some intrinsic foot muscles.
- S3 Some intrinsic foot muscles (except abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, extensor digitorum brevis).

(See also p. 930 for table of lower limb innervation.)

Joint Movements

In terms of movements of joints, segmental innervation of limb muscles may be expressed in general as follows:

Shoulder:	Abductors and lateral rotators.	C5
	Abductors and medial rotators.	C6, 7, 8
Elbow:	Flexors.	C5, 6
	Extensors.	C7, 8
Forearm:	Supinators.	C6
	Pronators.	C7, 8
Wrist:	Flexors and extensors.	C6, 7
Digits:	Long flexors and extensors.	C7, 8
Hand:	Intrinsic muscles.	C8, T1
Hip:	Flexors, adductors, medial rotators.	L1, 2, 3
	Extensors, abductors, lateral rotators.	L5, S1
Knee:	Extensors.	L3, 4
	Flexors.	L5, S1
Ankle:	Dorsiflexors.	L4, 5
	Plantar flexors.	S1, 2
Foot:	Invertors.	L4, 5
	Evertors.	L5, S1
	Intrinsic muscles	S2, 3