Superior epigastric artery. It descends between the costal and xiphoid slips of the diaphragm, anterior to the lower fibres of the transversus thoracis and the upper fibres of the transversus abdominis. Entering the rectus sheath, at first behind the muscle and then perforating and supplying it, it anastomoses with the inferior epigastric branch of the external iliac. Branches perforate the sheath to supply the abdominal skin; a branch anterior to the xiphoid process anastomoses with its fellow. The artery supplies the diaphragm; on the right small branches reach the falciform ligament to anastomose with the hepatic artery.

3. Thyrocervical trunk

This short, wide artery, from the front of the subclavian's first part near the medial border of the scalenus anterior, divides almost at once into the inferior thyroid, suprascapular and superficial cervical arteries (**10.73**, 154).

Inferior thyroid artery. This is looped; first it **ascends** anterior to the medial border of the scalenus anterior, turns **medially** just below the sixth cervical transverse process, passing anterior to the vertebral vessels and posterior to the carotid sheath and its contents and usually the sympathetic trunk, whose middle cervical ganglion usually adjoins the vessel. It finally **descends** on the longus colli to the lower border of the thyroid gland. As it approaches this, its relation to the recurrent laryngeal nerve is surgically important (p. 1252). Nearing the gland the artery usually passes behind the nerve, but nearer the gland, on the right, the nerve is with equal frequency anterior or posterior to or amongst the branches of the artery; the left nerve is usually posterior. Relations between the terminal branches of artery and nerve are very variable (Bowden 1955). On the left, near its origin, the artery is crossed anteriorly by the thoracic duct, curving inferolaterally to its end.

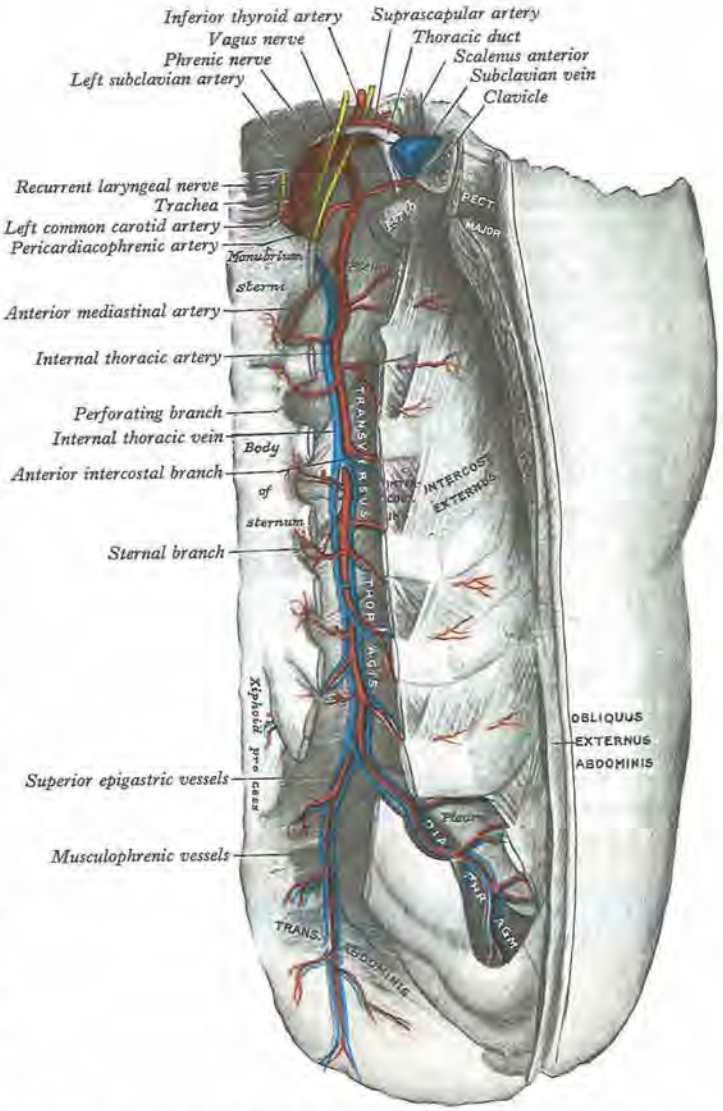
Muscular branches. These supply the infrahyoid muscles, longus colli, scalenus anterior and the inferior pharyngeal constrictor.

Ascending cervical artery. A small branch, it arises as the inferior thyroid turns medially behind the carotid sheath and ascends on the anterior tubercles of the cervical transverse processes between the scalenus anterior and the longus capitis. It supplies the adjacent muscles and has one or two spinal branches which enter the vertebral canal through the intervertebral foramina to supply the spinal cord and membranes and vertebral bodies, as do the spinal branches of the vertebral artery. The ascending cervical artery anastomoses with the vertebral, ascending pharyngeal, occipital and deep cervical arteries.

Inferior laryngeal artery. It ascends on the trachea with the recurrent laryngeal nerve, enters the larynx at the inferior constrictor's lower border and supplies the laryngeal muscles and mucosa, anastomosing also with its contralateral fellow, and with the superior laryngeal branch of the superior thyroid artery.

Pharyngeal branches. These supply the lower pharynx: *tracheal branches* the trachea (anastomosing with the bronchial arteries), and *oesophageal branches* the oesophagus (anastomosing with the oesophageal branches of thoracic aorta). Inferior and ascending *glandular branches* supply the posterior and inferior regions of the thyroid gland, anastomosing with the opposite inferior and ipsilateral superior thyroid arteries. The ascending branch also supplies the parathyroid glands.

Suprascapular artery (**10.92**). This first descends laterally across the scalenus anterior and phrenic nerve, posterior to the internal jugular vein and sternocleidomastoid; it then crosses anterior to the subclavian artery and brachial plexus, posterior and parallel to the clavicle and subclavius and the inferior belly of the omohyoid, to reach the superior scapular border. Here it passes above (sometimes under) the superior transverse ligament, separating it from the suprascapular nerve, to enter the supraspinous fossa (**10.96**), where it lies on the bone, supplying the supraspinatus. It descends behind the scapular neck, through the great scapular notch deep to the inferior transverse ligament to the deep surface of the infraspinatus, where it anastomoses with the circumflex scapular and deep branch of the transverse cervical artery. Besides supplying the sternocleidomastoid, subclavius and infraspinatus, it has a *suprasternal branch* which crosses the sternal end of the clavicle to the skin of the upper thorax and an *acromial branch* which pierces the trapezius to supply the skin over the shoulder, anastomosing with the thoracoacromial and posterior circumflex humeral arteries. As the suprascapular artery passes the superior transverse ligament, a branch of it enters the subscapular fossa beneath the subscapularis; this anastomoses with the subscapular artery and the deep branch of the transverse cervical. It also supplies the acromioclavicular and glenohumeral joints, the clavicle and scapula. It may arise from the third part of the subclavian artery.



10.95 The left internal thoracic artery and vein and their main branches. The lateral end of the resected clavicle has been artificially elevated.

Superficial cervical artery (**10.92**). At a higher level than the suprascapular, it crosses anterior to the phrenic nerve, the scalenus anterior and brachial plexus and is covered by the internal jugular vein, sternocleidomastoid and platysma. It crosses the posterior triangle's floor to the anterior margin of the levator scapulae, ascending deep to the anterior part of the trapezius, supplying it, the adjoining muscles and the cervical lymph nodes. It anastomoses with the superficial ramus of the descending branch of the occipital artery. (See also p. 1536: variations of superficial cervical and dorsal scapular arteries.)

4. Costocervical trunk

On the right, this short vessel arises posteriorly from the second part of the subclavian artery, and, on the left, from its first part (**10.91**, 92). It arches back above the cervical pleura to the first rib's neck, dividing here into superior intercostal and deep cervical branches.

Superior intercostal artery. It descends between the pleura and necks of the first and second ribs to anastomose with the third

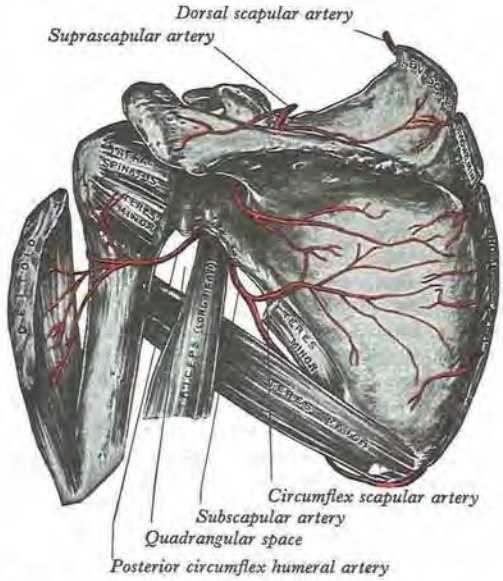
posterior intercostal artery (**10.91**). Crossing the neck of the first rib it is medial to the ventral branch of the first thoracic spinal nerve, which it crosses at a lower level, and lateral to the stellate ganglion. In the first space it provides the first posterior intercostal artery, similar in distribution to the lower posterior intercostals. It descends to become the second posterior intercostal artery, usually joining a branch from the third; it is not constant, and is more common on the right; when absent, it is replaced by a direct aortic branch.

Deep cervical artery (**10.84**). Usually arising from the costocervical trunk, it is analogous in its first segment to a posterior branch of a posterior intercostal artery: occasionally it is a separate branch of the subclavian. Passing back above the eighth cervical spinal nerve between the seventh cervical transverse process and the neck of the first rib (sometimes between the sixth and seventh cervical transverse processes), it then ascends between the semispinales capitis and cervicis to the second cervical level. It supplies adjacent muscles and anastomoses with the deep branch of the descending branch of the occipital artery (p. 1519) and branches of the vertebral. A spinal branch enters the vertebral canal between the seventh cervical and first thoracic vertebrae.

5. Dorsal scapular artery

This arises from the third or less often second part of the subclavian, passing laterally through the brachial plexus in front of the scalenus medius and then deep to the levator scapulae to the superior scapular angle; here it descends with the dorsal scapular nerve under the rhomboids along the medial scapular border to the inferior angle (**10.92**, **96**). It supplies the rhomboids, latissimus dorsi and trapezius and anastomoses with the suprascapular, subscapular and posterior branches of some posterior intercostal arteries. It has a small branch, sometimes arising directly from the subclavian, for the scalenus anterior.

Variations. About a third of the superficial cervical and dorsal scapular arteries arise in common from the thyrocervical trunk as a *transverse cervical artery*, with a superficial (*superficial cervical artery*) and a deep branch (*dorsal scapular artery*); the latter passes laterally anterior to the brachial plexus and then posterior to the levator scapulae.



10.96 Scapular anastomoses of the left side: dorsal aspect.

Axilla

The axilla is a pyramidal region between the upper thoracic wall and the arm. Its blunt **apex** continues into the root of the neck (*cervico-axillary canal*) between the external border of the first rib, superior scapular border, posterior surface of the clavicle and the medial aspect of the coracoid process; through it pass the axillary vessels and nerves. Its imaginary **base**, facing down, is broad at the chest, narrow at the arm and corresponds to the skin and a thick layer of *axillary fascia*, between the inferior borders of the pectoralis major in front and the latissimus dorsi behind. It is of course convex up, conforming to the armpit's concavity. The *anterior wall* is formed by the pectorales major et minor, the former covering the whole wall, the latter its intermediate part. The interval between the upper border of the pectoralis minor and clavicle is occupied by the clavipectoral fascia. The *posterior wall* is formed by the subscapularis above, teres major and latissimus dorsi below. **Medial** are the first four ribs with their intercostal muscles and the upper part of serratus anterior; this 'wall' is convex laterally. **Laterally** anterior and posterior walls converge, the 'wall' being narrow, consisting of the humeral intertubercular sulcus; the lateral angle lodges the coracobrachialis and biceps.

The axilla contains axillary vessels, the infraclavicular part of the brachial plexus and its branches, lateral branches of some intercostal nerves, many lymph nodes and vessels, loose adipose areolar tissue and in many instances the 'axillary tail' of the breast. The axillary vessels and brachial plexus run from the apex to the base along the lateral wall and nearer to the anterior wall, the axillary vein being anteromedial to the artery. Owing to the obliquity of the upper ribs, the neurovascular bundle, emerging from behind the clavicle, crosses the first intercostal space; its relations are therefore different at upper and lower levels. Thoracic branches of the axillary artery are in contact with the pectoral muscles; along the lateral margin of the pectoralis minor the lateral thoracic artery reaches the thoracic wall. Subscapular vessels descend on the posterior wall at the lower margin of the subscapularis, and subscapular and thoracodorsal nerves cross the anterior surface of the latissimus dorsi at different inclinations; circumflex scapular vessels wind round the lateral scapular border; posterior circumflex humeral vessels and the axillary nerve curve back and laterally around the humeral surgical neck. No large vessel lies on the medial 'wall', which is crossed proximally only by small branches of the superior thoracic artery. The long thoracic nerve descends on the serratus anterior and the intercostobrachial nerve perforates the upper anterior part of this wall, crossing the axilla to its lateral 'wall'. The position and arrangement of lymph nodes are described on page 1613, nerves on page 1266 et seq.

Clinical Anatomy. When axillary suppuration occurs, fascial arrangement affects the spread of pus. As described on page 839, the clavipectoral fascia, between the clavicle and superomedial border of the pectoralis minor, splits to enclose the muscle, blending at its lateral border with the axillary fascia in the anterior axillary fold. Suppuration may be superficial or deep to this layer, either between the pectoral muscles or behind the pectoralis minor; in the former an abscess would appear at the edge of the anterior axillary fold or the groove between the deltoid and pectoralis major; in the latter, pus would tend to surround vessels and nerves and ascend into the neck, the direction of least resistance; pus may also track along vessels into the arm. When an axillary abscess is incised, a knife should enter the axillary 'base', midway between the anterior and posterior margins and near the thoracic side to avoid the lateral thoracic, subscapular and axillary vessels on the anterior, posterior and lateral walls. Relations of vessels and nerves in the axilla are important when lymph nodes are removed from the axilla in operations for mammary carcinoma; the positions of major structures in the lateral wall must be remembered.

AXILLARY ARTERY

The axillary artery (**10.97**), a continuation of the subclavian, begins at the first rib's outer border, ending nominally at the interior border of the teres major where it becomes brachial. Its direction varies with the limb's position: thus it is almost straight when the arm is raised at right angles, concave up when the arm is elevated above this and convex up and laterally with the arm pendent. At first deep, it becomes superficial, covered only by the skin and fasciae. The pectoralis minor crosses it and divides it into **three parts**: proximal, posterior and distal to the muscle.

Relations of the first part. **Anterior** are the skin, superficial fascia, platysma, supraclavicular nerves, deep fascia, clavicular fibres of the pectoralis major and the clavipectoral fascia. This part is crossed anteriorly by the lateral pectoral nerve, the loop of communication between it and the medial pectoral nerve, and by the thoraco-acromial and cephalic veins. **Posterior** are the first intercostal space and external intercostal, the first and second digitations of the serratus anterior, the long thoracic and medial pectoral nerves and the medial cord of the brachial plexus. **Lateral** is the posterior cord of the brachial plexus. **Anteromedial** is the axillary vein. The first part is enclosed with the axillary vein and brachial plexus in a fibrous *axillary sheath*, continuous with the prevertebral layer of the deep cervical fascia.

Relations of the second part. **Anterior** are the skin, superficial and deep fascia, pectoralis major and minor. Posterior are the posterior cord of the brachial plexus and the areolar tissue between it and the subscapularis. **Medial** is the axillary vein, separated from it by the medial cord of the brachial plexus and medial pectoral nerve. **Lateral** is the lateral cord of the brachial plexus, separating it from the coracobrachialis. The cords of the brachial plexus thus surround the second part on three sides, with the dispositions implied by their names, and separate it from the vein and adjacent muscles.

Relations of the third part. **Anterior** are pectoralis major, distal to this skin and fasciae. **Posterior** are the lower part of the subscapularis and tendons of the latissimus dorsi and teres major. **Lateral** is the coracobrachialis. **Medial** is the axillary vein. Branches of the brachial plexus are arranged as follows: **laterally** the lateral root and then trunk of the median nerve and, for a short distance, the musculocutaneous nerve; **medially** the medial cutaneous nerve of the forearm between the axillary artery and vein anteriorly, between them posteriorly the ulnar nerve; the medial cutaneous nerve of upper arm is medial to the vein; anterior is the medial root of the median nerve and posterior are radial and axillary nerves, the latter only to the distal border of the subscapularis.

BRANCHES OF THE AXILLARY ARTERY

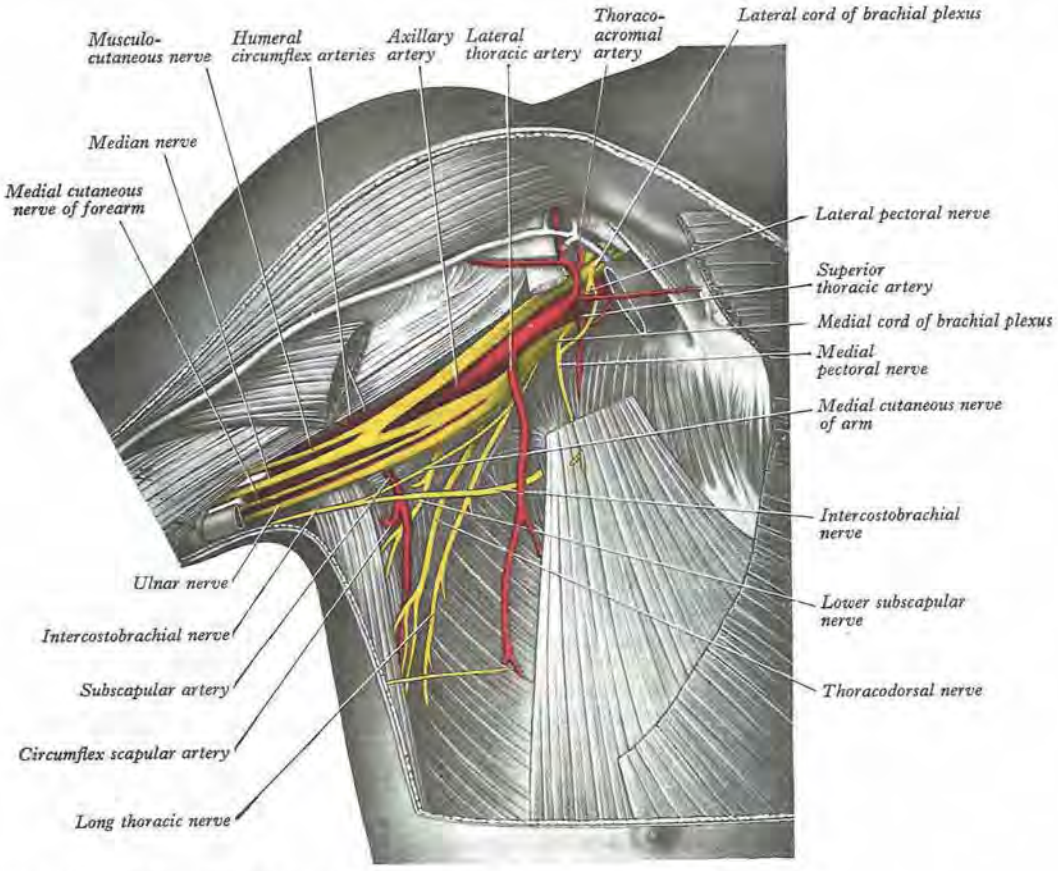
The artery's branches are superior thoracic, thoraco-acromial, lateral thoracic, subscapular, anterior and posterior circumflex humeral.

Superior thoracic artery (**10.97**). A small vessel from the first part of the axillary near the lower border of the subclavius (sometimes from the thoraco-acromial), it runs anteromedially above the medial border of the pectoralis minor, then passes between it and the pectoralis major to the thoracic wall. It supplies these muscles and the thoracic wall, anastomosing with the internal thoracic and upper intercostal arteries.

Thoraco-acromial (acromio-thoracic) artery (**10.92, 97**). A short branch from the second part, it is at first overlapped by the pectoralis minor; skirting its medial border, it pierces the clavipectoral fascia and divides into the pectoral, acromial, clavicular and deltoid branches.

Pectoral branch. This descends between the pectoral muscles, is distributed to them and the breast and anastomoses with the intercostal branches of the internal thoracic and lateral thoracic arteries.

Acromial branch. It crosses the coracoid process under the deltoid,



10.97 The right axillary and its branches. The pectoralis major and part of the pectoralis minor have been removed. Prominent but unlabelled features are the medial and lateral roots of the median nerve.

which it supplies, pierces the muscle and ends on the acromion, anastomosing with rami of the suprascapular, deltoid branch of the thoraco-acromial and posterior circumflex humeral arteries.

Clavicular branch. Ascending medially between the clavicular part of the pectoralis major and clavipectoral fascia, it supplies the sternoclavicular joint and subclavius.

Deltoid branch. It often arises with the acromial, crossing the pectoralis minor to accompany the cephalic vein between the pectoralis major and deltoid, supplying both.

Lateral thoracic artery (10.97). Following the lateral border of the pectoralis minor to the thoracic wall, it supplies the serratus anterior and pectoral muscles, the axillary lymph nodes and subscapularis; it anastomoses with the internal thoracic, subscapular, and intercostal arteries and the pectoral branch of the thoraco-acromial artery. In females it is large and has lateral mammary branches which curve round the lateral border of the pectoralis major to the mammary gland.

Subscapular artery (10.96, 97). The largest branch of the axillary, it usually arises at the distal (inferior) border of the subscapularis which it follows to the inferior scapular angle, where it anastomoses with the lateral thoracic and intercostal arteries and the deep branch of the transverse cervical. It supplies adjacent muscles and the thoracic wall. It is accompanied distally by the nerve to the latissimus dorsi; about 4 cm from its origin it divides into the circumflex scapular artery and the thoracodorsal artery. The *circumflex scapular artery*, the larger of the two, curves backwards around the lateral scapular border, traversing a *triangular space* between subscapularis above and teres major below and the long head of the triceps laterally. It enters the infraspinous fossa under the teres minor and then divides. One branch (*infrascapular*) enters the subscapular fossa deep to the subscapularis, anastomosing with the suprascapular and dorsal scapular arteries (or deep branch of the transverse cervical); the other continues along the lateral scapular border between the teres major and minor and, dorsal to the inferior angle, anastomoses with the deep branch of the transverse cervical artery. Small branches supply the posterior part of the deltoid and the long head of the triceps, anastomosing with an ascending branch of the arteria profunda brachii. The other terminal branch of the subscapular artery, the *thoracodorsal artery*, follows the lateral margin of the scapula, posterior to the lateral thoracic, between the latissimus dorsi and serratus anterior. It supplies these two muscles and teres major and intercostales, anastomosing with intercostal arteries.

Anterior circumflex humeral artery (10.97). Arising from the lateral side of the axillary artery at the distal border of the subscapularis, runs horizontally behind coracobrachialis and short head of biceps, anterior to the surgical neck of the humerus. Reaching the intertubercular sulcus, it sends an ascending branch to supply the humeral head and shoulder joint. It continues laterally under the long head of biceps and deltoid, anastomosing with the posterior circumflex humeral artery.

Posterior circumflex humeral artery (10.96). Larger than the anterior, it branches from the third part of the axillary at the distal border of the subscapularis and runs back with the axillary nerve through a *quadrangular space*, bounded by the subscapularis, the capsule of the shoulder joint and the teres minor above, the teres major below, the long head of triceps medially and the surgical neck of the humerus laterally. It curves round the humeral neck and supplies the shoulder joint, deltoid, teres major and minor, and long and lateral heads of triceps, giving off a descending branch to anastomose with the deltoid branch of the arteria profunda brachii and with the anterior circumflex humeral and acromial branches of the suprascapular and thoraco-acromial arteries.

Surface anatomy. Pulsation of the axillary artery can be felt against the axillary lateral wall. Its upper segment can be mapped out, when the arm is raised, by a line from this to the midpoint of the clavicle.

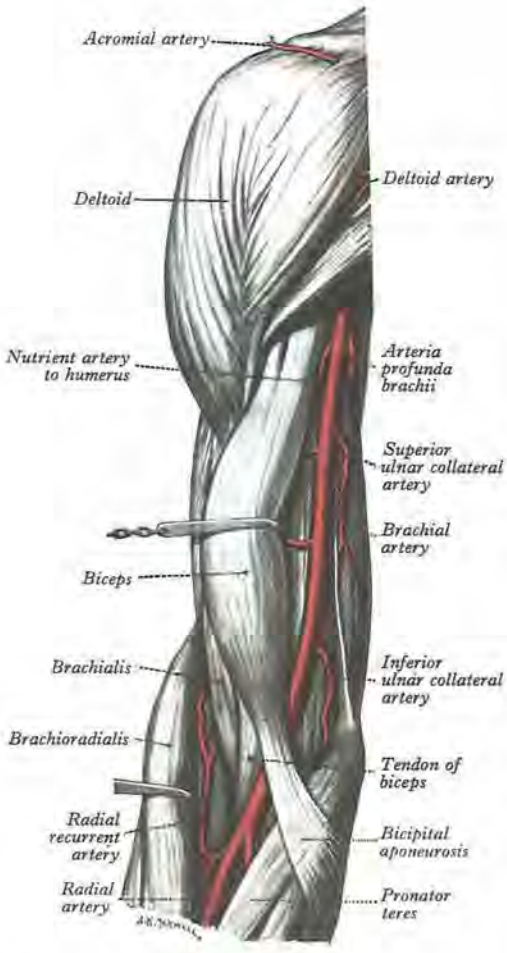
Variations. Branches vary considerably; an alar thoracic, often from the second part, may supply fat and lymph nodes in the axilla. Occasionally the subscapular, circumflex humeral and arteria profunda arise in common and then branches of the brachial plexus surround this instead of the axillary artery. The posterior circumflex humeral artery may be from the arteria profunda brachii, passing back below the teres major instead of traversing the quadrangular space. Sometimes (anomalous 'high division') the axillary divides into radial and ulnar arteries and is occasionally the source of the anterior interosseous artery.

Clinical anatomy. Axillary compression is most effective against the humerus. Except for the popliteal, the axillary artery is more frequently lacerated by violence than any other, being most susceptible when diseased. It has been ruptured in attempts to reduce old dislocations, especially when the artery is adherent to the articular capsule.

BRACHIAL ARTERY

The brachial artery (10.98, 102), a continuation of the axillary, begins at the distal (inferior) border of the tendon of teres major and ends about a centimetre distal to the elbow joint (at the level of the neck of the radius) by dividing into radial and ulnar arteries. At first it is medial to the humerus, but gradually spirals anterior to it until it lies midway between the humeral epicondyles. Its pulsation can be felt throughout.

Relations. The artery is wholly superficial, covered **anteriorly** only by skin and superficial and deep fasciae; the bicipital aponeurosis crosses it anteriorly at the elbow, separating it from the median cubital vein; the median nerve crosses it **lateromedially** near the distal attachment of coracobrachialis. **Posterior** are the long head of triceps, separated by the radial nerve and arteria profunda brachii and then successively by: the medial head of triceps, the attachment of coracobrachialis and the brachialis. **Lateral** are: proximally the median nerve and coracobrachialis and distally the biceps and the muscles overlapping the artery. **Medial** are: proximally the medial cutaneous nerve of forearm and ulnar nerve, distally the median nerve and basilic vein (separated distally by the deep fascia). With



10.98 The right brachial artery and its branches.

the artery are two venae comitantes, connected by transverse and oblique branches.

At the elbow the brachial artery sinks deeply into the triangular intermuscular cubital fossa. The fossa's base is an inter-epicondylar line, the sides being the medial edge of the brachioradialis and the lateral margin of pronator teres; the 'floor' consists of brachialis and supinator. The fossa contains the tendon of the biceps, the terminal part of the brachial artery and accompanying veins, the commencement of the radial and ulnar arteries and parts of the median and radial nerves. The brachial artery is central and it divides near the neck of the radius into its terminal branches, the radial and ulnar arteries. **Anterior** to it are the skin, superficial fascia and median cubital vein, separated by the bicipital aponeurosis. **Posteriorly** the brachialis separates it from the elbow joint. The median nerve is **medial** proximally but is separated from the ulnar artery by the ulnar head of the pronator teres. **Lateral** are the tendon of biceps and the radial nerve, the latter concealed between supinator and brachioradialis.

Variations. The brachial artery, with the median nerve, may diverge from the medial border of the biceps, descending towards the medial humeral epicondyle, usually behind a *supracondylar process* from which a fibrous arch crosses the artery, and which then runs behind or through the pronator teres to the elbow. This resembles the normal arrangement in some carnivores (p. 626). Occasionally the artery divides proximally into two trunks which reunite. Frequently it divides more proximally than usual into radial, ulnar and common interosseous arteries. Most often the radial branches arise proximally, leaving a common trunk for the ulnar and common interosseous; sometimes the ulnar arises proximally, the radial and common interosseous forming the other division; the common interosseous may also arise proximally. Sometimes slender *vasa aberrantia* connect the brachial to the axillary artery or to one of the forearm arteries, usually the radial. The brachial artery may be crossed by muscular or tendinous slips from the coracobrachialis, biceps, brachialis or pronator teres.

Branches. These are arteria profunda brachii, nutrient, superior and inferior ulnar collateral, muscular, radial and ulnar arteries.

Arteria profunda brachii (10.98, 99, 102). A large branch from the posteromedial aspect of the brachial, distal to the teres major, follows the radial nerve closely, at first back between the long and medial heads of the triceps, then in the nerve's groove covered by the lateral head of triceps; here it divides into terminal branches (10.102). Apart from the muscular branches, it supplies the following: the nutrient, deltoid, middle collateral and radial collateral arteries.

Nutrient artery. This enters the humerus posterior to the deltoid tuberosity but may be absent.

Deltoid (ascending) branch. Ascending between the lateral and long heads of triceps, it anastomoses with a descending branch of the posterior humeral circumflex artery.

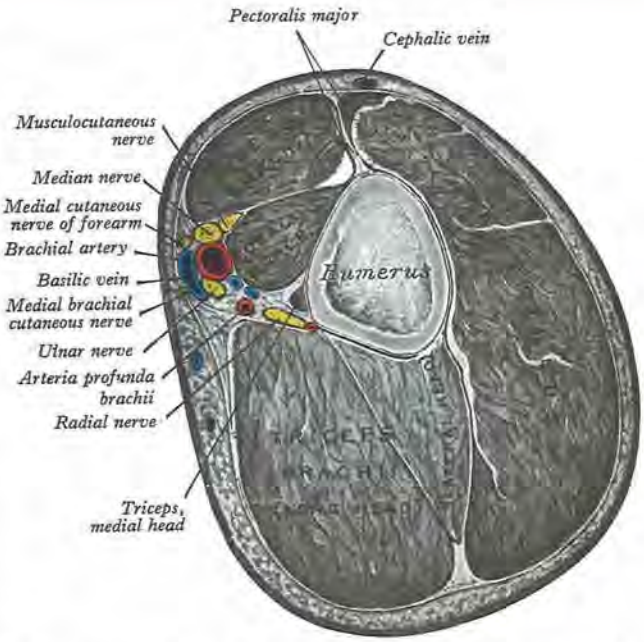
Middle collateral (posterior descending) branch. The larger terminal vessel, it arises behind the humerus and descends in the medial head of the triceps to the elbow (10.100), anastomosing with the interosseous recurrent artery behind the lateral epicondyle; it often has a small branch which accompanies the nerve to the anconeus.

Radial collateral. The other terminal branch, this is the artery's continuation (10.101). It accompanies the radial nerve through the lateral intermuscular septum, descending between the brachialis and brachioradialis anterior to the lateral epicondyle, anastomosing with the radial recurrent artery.

Nutrient artery of the humerus. This arises near the mid-level of the upper arm, and enters the nutrient canal near the attachment of coracobrachialis; it is directed distally.

Superior ulnar collateral artery (10.98, 100, 102). It arises a little distal to the upper arm's mid-level, often as a branch from the arteria profunda brachii. It accompanies the ulnar nerve, piercing the medial intermuscular septum to descend between the medial epicondyle and olecranon, ending deep to flexor carpi ulnaris by anastomosing with the posterior ulnar recurrent and inferior collateral arteries; sometimes a branch of it passing anterior to the medial epicondyle anastomoses with the anterior ulnar recurrent artery.

Inferior ulnar collateral (supratrochlear) artery (10.98, 102, 103). It begins about 5 cm proximal to the elbow, passes medially between the median nerve and brachialis and, piercing the medial intermuscular septum, curls round the humerus between the triceps and bone, forming, by its junction with the middle collateral branch of arteria profunda brachii, an arch proximal to the olecranon fossa. As it lies on brachialis it has branches descending anterior to the medial epicondyle to anastomose with the anterior ulnar recurrent artery. Behind the epicondyle a branch anastomoses with the superior ulnar collateral and posterior ulnar recurrent arteries.

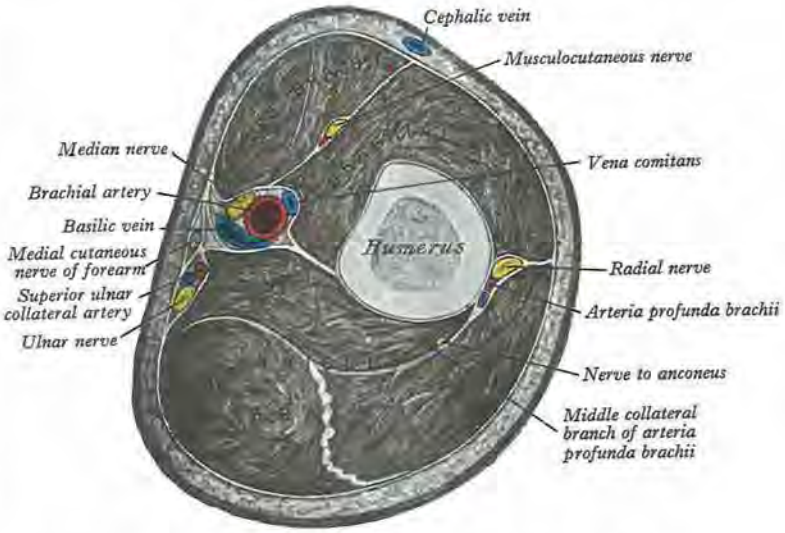


10.99 Transverse section through the right arm at the junction of the proximal and middle thirds of the humerus: proximal aspect.

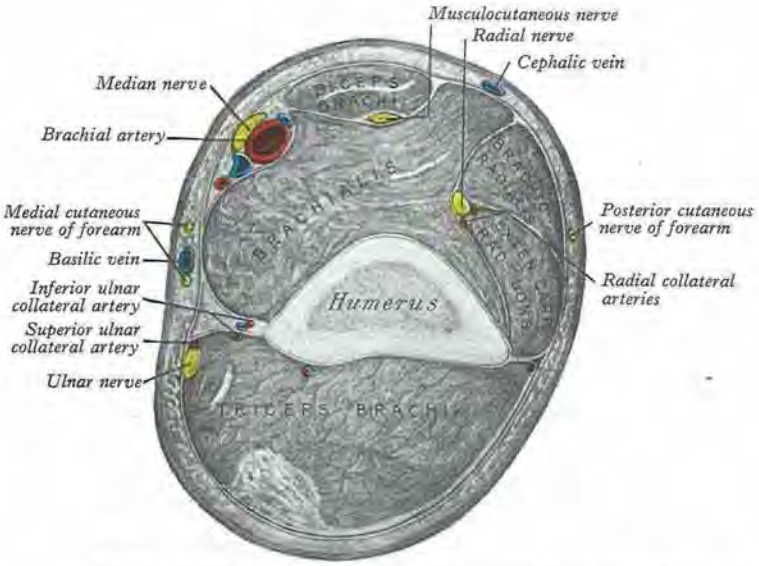
Muscular arteries from the brachial. These are distributed to the coracobrachialis, biceps and brachialis.

Clinical anatomy

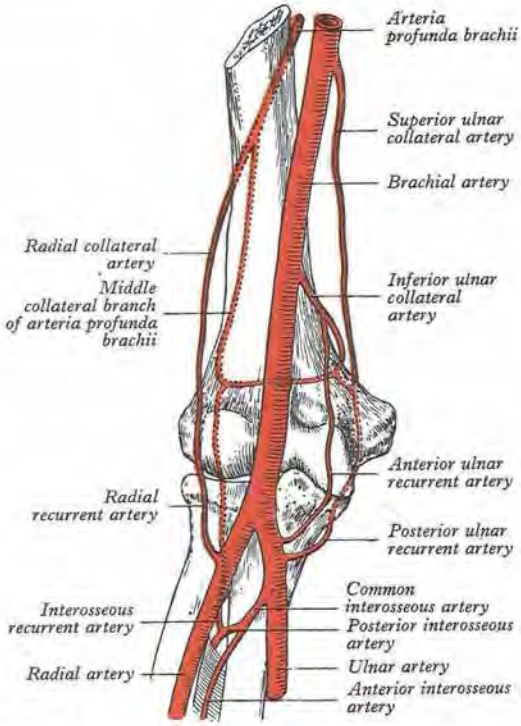
Compression of the brachial artery may be effected at almost any level; if proximal, it should be directed laterally, if distal, backwards. The most favourable site is about midway, where the artery is on the tendon of the coracobrachialis and still medial to the humerus; pressure should be exerted slightly posterolaterally.



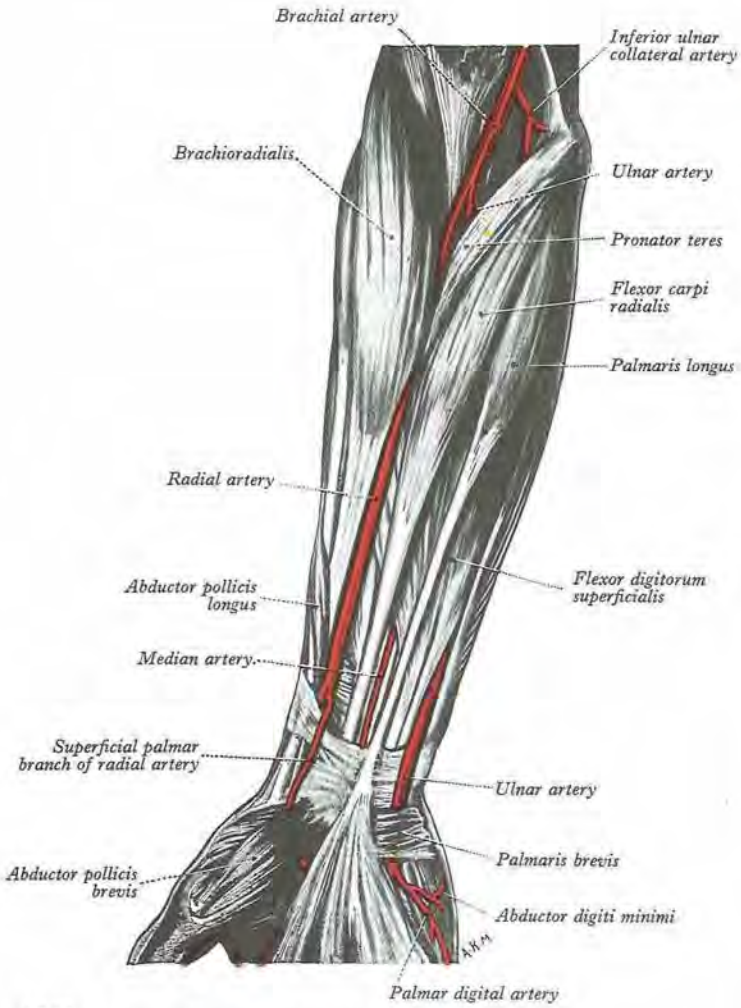
10.100 Transverse section through the right arm, a little below the middle of the shaft of the humerus: proximal aspect.



10.101 Transverse section through the right arm, 2 cm above the medial epicondyle of the humerus: proximal aspect.



10.102 The arterial anastomoses around the (right) elbow joint. Anterior side seen from the front.



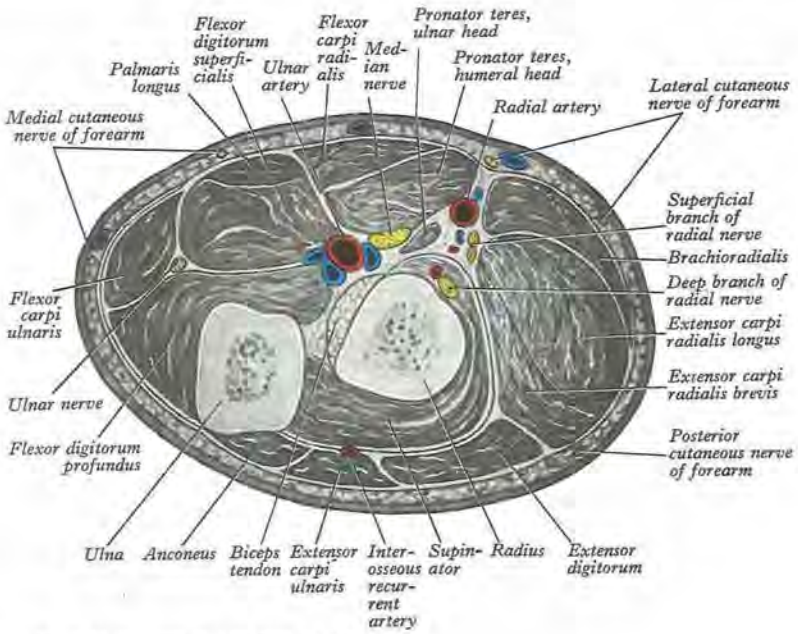
10.103 The right radial and ulnar arteries, superficial dissection.

RADIAL ARTERY

The radial artery (**10**.103–105), though smaller than the ulnar, appears a more direct continuation of the brachial. It begins about 1 cm distal to the bend of the elbow (level of the neck of the radius, **10**.102), then descends along the lateral side of the forearm to the wrist, where it is palpable between the flexor carpi radialis medially and the salient anterior border of the radius. It then curls posterolaterally round the carpus, beneath the tendons of abductor pollicis longus and extensor pollicis brevis and longus, to the proximal end of the first intermetacarpal space, swerving medially between the heads of the first dorsal interosseous into the palm and then crossing medially to form the deep palmar arch with the deep branch of the ulnar artery. The radial artery is thus divisible into parts: in the forearm, wrist and hand.

In the forearm (**10**.103–106) the artery extends from the medial side of the neck of the radius to the front of its styloid process, being medial to the radial shaft proximally, but anterior to it distally. Proximally it is overlapped anteriorly by the belly of brachioradialis, whereas the rest is covered only by the skin, superficial and deep fasciae. Posterior are successively: the tendon of biceps, supinator, the distal attachment of pronator teres, radial head of flexor digitorum superficialis, flexor pollicis longus, pronator quadratus and the lower end of the radius (where its pulsation is most accessible). Proximally pronator teres is medial, brachioradialis lateral; distally the tendon of flexor carpi radialis is medial, that of brachioradialis lateral. The superficial branch of the radial nerve is lateral in the vessel's middle third, and filaments of the lateral cutaneous nerve of the forearm run along its distal part as it curves round the carpus. The vessel is accompanied by paired venae comitantes.

At the wrist (**10**.107, 108) the radial artery passes on to the dorsal aspect of the carpus between the lateral carpal ligament and tendons of abductor pollicis longus and extensor pollicis brevis. It crosses the scaphoid bone and trapezium (in the 'anatomical snuff-box'), where again its pulsation is obvious, and as it passes between heads of the first dorsal interosseous it is crossed by the tendon of extensor pollicis longus. Between the thumb extensors it is crossed by the beginning of the cephalic vein and the digital branches of the radial nerve supplying the thumb and index.



10.104 Transverse section through the right forearm at the level of the radial tuberosity: distal aspect.

In the hand (10.109) the radial artery, having traversed the first interosseous space between the heads of the first dorsal interosseous, crosses the palm, at first deep to the oblique head of adductor pollicis and then between its oblique and transverse heads or through the transverse head. At the fifth metacarpal base it anastomoses with the deep branch of the ulnar artery, completing the *deep palmar arch* (10.105).

Variations. Sometimes the radial artery arises proximally, usually from the axillary or beginning of the brachial artery. In the forearm it is sometimes superficial to the deep fascia and occasionally superficial to the thumb extensor tendons (see also under 'Variations of the Brachial Artery', above).

Radial recurrent artery (10.102, 105). This arises just distal to the elbow, passing between superficial and deep branches of the radial nerve to ascend behind the brachioradialis, anterior to the supinator and brachialis; it supplies these muscles and the elbow joint, anastomosing with the radial collateral branch of the arteria profunda brachii.

Muscular branches. These are distributed to muscles on the radial side of the forearm.

Palmar carpal branch (10.105). A small vessel, it arises near the distal border of pronator quadratus and crosses the anterior surface of the distal end of the radius, near the palmar carpal surface, passing medially to anastomose behind the long flexor tendons with the palmar carpal branch of the ulnar; this transverse anastomosis is joined by longitudinal branches from the anterior interosseous and recurrent branches from the deep palmar arch, forming a *cruciate palmar carpal arch*, which, by descending branches, supplies the carpal articulations and bones. (Although so named this is usually sited near the wrist joint on the distal forearm bones.)

Superficial palmar branch (10.109). Arising from the radial artery just before it curves round the carpus, it passes through and occasionally over the thenar muscles, which it supplies, sometimes anastomosing with the end of the ulnar artery to complete a superficial palmar arch.

Dorsal carpal branch. This arises deep to the pollicial extensor tendons, runs medially across the dorsal carpal surface under them and anastomoses with the ulnar dorsal carpal branch and also with the anterior and posterior interosseous arteries to form a *dorsal carpal arch*. The carpal arches are both close to bone and supply the distal epiphyseal parts of the radius and ulna. From the dorsal arch three *dorsal metacarpal arteries* descend on the second to fourth dorsal interosseous muscles and bifurcate into the *dorsal digital branches* for the adjacent sides of all four fingers; they anastomose with the palmar digital branches from the superficial palmar arch; near their origins they also anastomose with the deep palmar arch by the *proximal perforating arteries* and, near their bifurcation, with the palmar digital rami of the superficial palmar arch by *distal perforating arteries*.

First dorsal metacarpal artery (10.108). A branch of the radial just before it passes between the heads of the first dorsal interosseous, it divides almost at once into two branches supplying the adjacent sides of the pollex and index; the radial side of the pollex receives a branch direct from the radial artery itself (see below).

Arteria princeps pollicis (10.105). This arises from the radial as it turns into the palm, and descends on the palmar aspect of the first metacarpal under the oblique head of adductor pollicis lateral to the first palmar interosseous. At the base of the proximal phalanx, deep to the tendon of flexor pollicis longus, it divides into two branches, appearing between the medial and lateral attachments of the oblique head of adductor pollicis to run along both sides of the pollex, forming, on the palmar surface of its distal phalanx, a pollicial arch supplying the skin and subcutaneous tissue. The arterial princeps pollicis is the usual nutrient of supply to the first metacarpal bone.

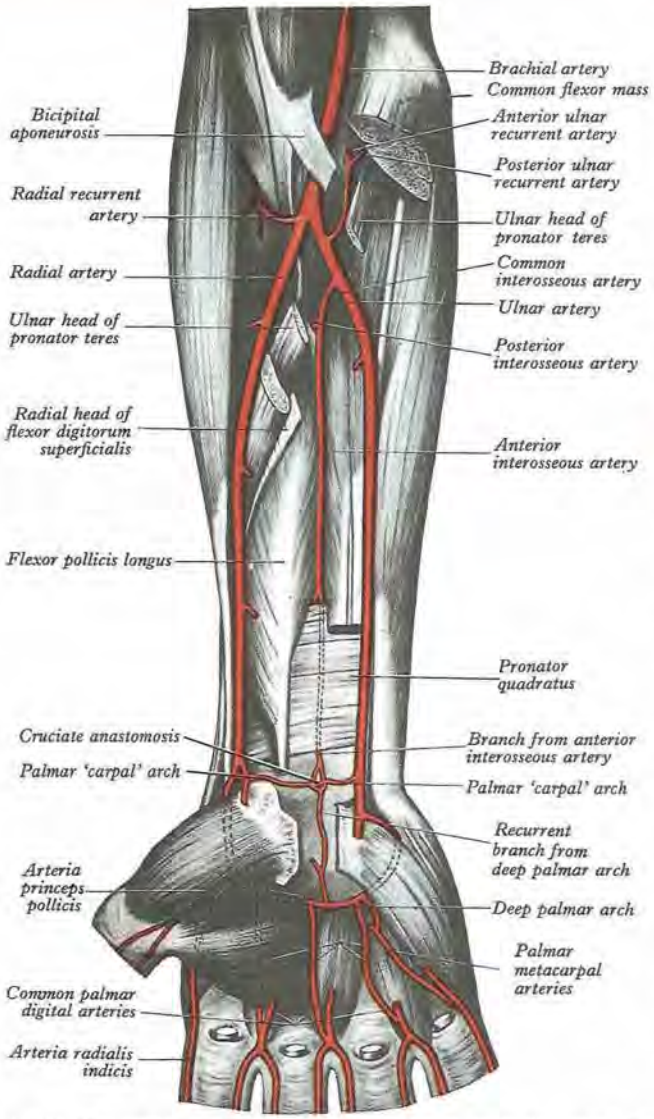
Arteria radialis indicis (10.105, 109). Often a proximal branch of the arteria princeps pollicis, it descends between the first dorsal interosseous and transverse head of adductor pollicis, and along the lateral side of the index finger to its end; it anastomoses with the indicial medial digital artery. At the distal border of the transverse head of the adductor pollicis it anastomoses with the arteria princeps pollicis and links with the superficial palmar arch.

The arteriae princeps pollicis et radialis indicis may be combined as the *first palmar metacarpal artery*.

Deep palmar arch

This is formed by anastomosis of the end of the radial with the deep palmar branch of the ulnar artery (10.105). It crosses the bases of the metacarpal bones and interossei, covered by the oblique head of adductor pollicis, the digital flexor tendons and lumbricals. In its concavity, running laterally, is the deep branch of the ulnar nerve. The arch was incomplete in six of 200 arches (Coleman & Anson 1961). Variation is chiefly in the size of contribution from the ulnar artery.

Surface anatomy. The deep palmar arch is indicated by a horizontal line about 4 cm long from a point just distal to the hamate's hook (10.110). It is about 1 cm proximal to the superficial arch.



10.105 The arteries of the right forearm and hand: deep dissection. The palmar 'carpal' arch lies across forearm bones.

Branches of the deep palmar arch are the palmar metacarpal, perforating and recurrent.

Palmar metacarpal arteries (**10**.105). The three arteries run distally from the convexity of the arch on the interosseous muscles of the second to fourth spaces; at the digital clefts they join the *common digital branches* of the superficial arch. They supply nutrient branches to the medial four metacarpals.

Perforating branches. These three branches from the deep palmar arch traverse the second to fourth interosseous spaces between the heads of the corresponding dorsal interossei to anastomose with the dorsal metacarpal arteries.

Recurrent branches (**10**.105). They ascend proximally from the deep palmar arch anterior to the carpus to supply the carpal bones and intercarpal articulations, ending in the palmar carpal arch (mentioned above).

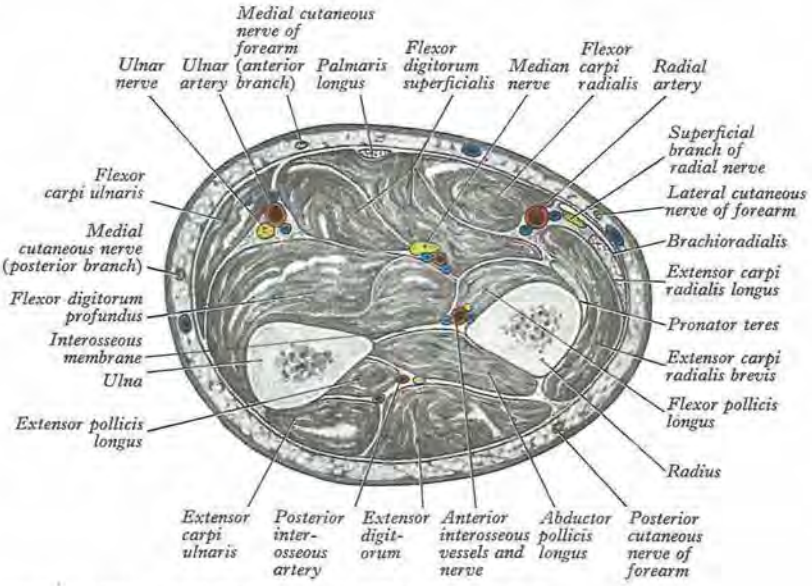
ULNAR ARTERY

The ulnar artery (**10**.102–109), the larger terminal branch of the brachial, begins just distal to the bend of the elbow. It reaches the medial side of the forearm midway between elbow and wrist, which it passes vertically, crossing the flexor retinaculum lateral to the ulnar nerve and pisiform bone; distal to this it has a deep branch and then continues across the palm as the superficial palmar arch.

Relations. In the forearm the **proximal half** of the artery (**10**.103–106) passes posterior to the pronator teres, flexor carpi radialis, palmaris longus and flexor digitorum superficialis; medially it is overlapped in its middle third by flexor carpi ulnaris; it lies in front of the brachialis and flexor digitorum profundus. Distal to the elbow the median nerve is medial for about 2.5 cm and then crosses it but is separated by the ulnar head of pronator teres. The artery's **distal half** (**10**.103, 105, 109) lies on the flexor digitorum profundus, covered by the skin, superficial and deep fasciae, between the flexor carpi ulnaris and flexor digitorum superficialis. It is accompanied by venae comitantes; the ulnar nerve lies medial to its distal two-thirds and its palmar cutaneous branch descends along it to the hand.

At the wrist (**10**.105, 107, 109) the artery is covered by skin, fasciae and palmaris brevis, and it lies between the superficial and main parts of the flexor retinaculum (p. 852); the ulnar nerve and pisiform bone are medial.

Surface anatomy. A line from a point in the limb's midline just distal to the elbow's fold descends medially to meet a line stretching from the medial epicondyle to the pisiform bone, from the junction of its upper and middle thirds. Together these represent the artery's upper third and distal two-thirds respectively.



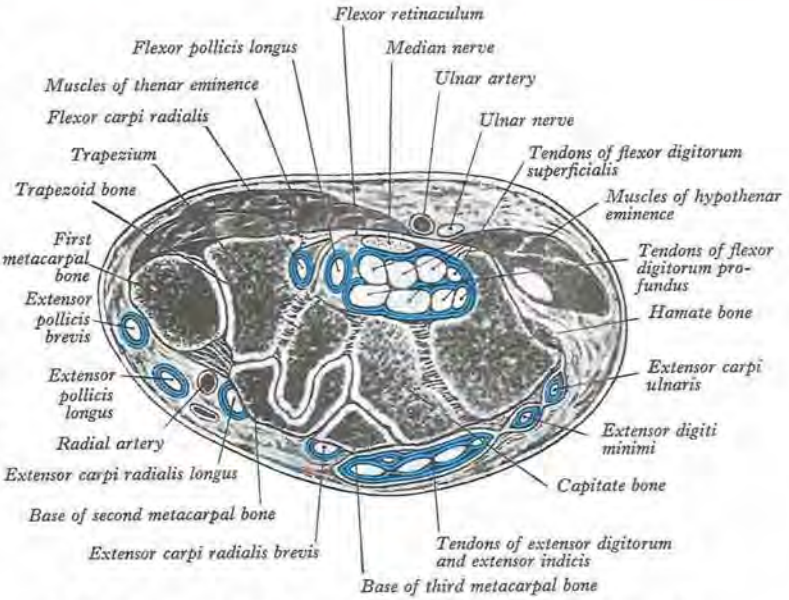
10.106 Transverse section through the middle of the left forearm: proximal aspect.

Variations. The ulnar artery may arise proximal to the elbow, the brachial being more often its source than the axillary artery; it is then usually superficial to the forearm flexors, commonly under the deep fascia, and is rarely subcutaneous; the brachial artery then supplies the common interosseous and this the ulnar recurrent arteries.

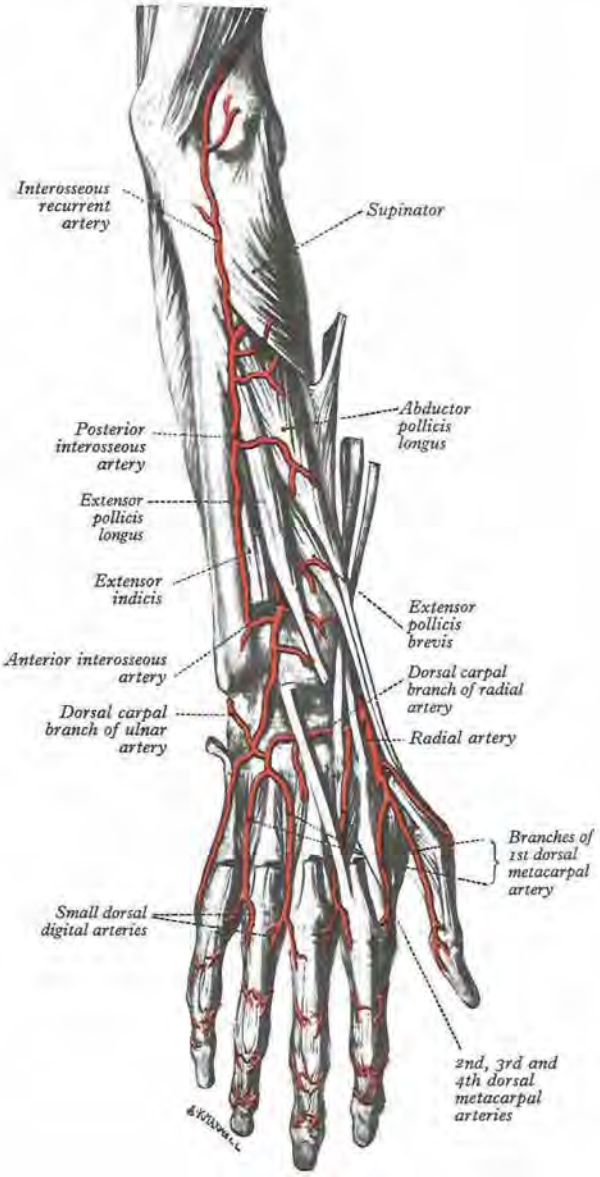
Branches. The artery supplies medial muscles in the forearm and hand, the common flexor synovial sheath and ulnar nerve (Blunt 1959), including the following named branches:

Anterior ulnar recurrent artery (10.102, 105). This arises just distal to the elbow, ascends between the brachialis and pronator teres, supplies them and anastomoses with the inferior ulnar collateral artery anterior to the medial epicondyle.

Posterior ulnar recurrent artery (10.102, 105). A larger artery, it arises distal to the anterior recurrent, and passes dorsomedially between the flexores digitorum profundus and superficialis, ascending behind the medial epicondyle; between this and the olecranon it is deep to the flexor carpi ulnaris, ascending between its heads with the ulnar nerve. Supplying adjacent muscles, nerve, bone and elbow joint, it anastomoses with the ulnar collateral and interosseous recurrent arteries (10.102).



10.107 Transverse section through the left wrist: proximal aspect. The section is slightly oblique and divides the distal row of the carpus and the bases of the first, second and third metacarpal bones. The arrangement of the tendons of the flexors of the fingers shown in the figure represents the actual condition in the specimen. Observe that the carpometacarpal joint of the thumb is separate from the joint between the trapezium and the base of the second metacarpal bone.



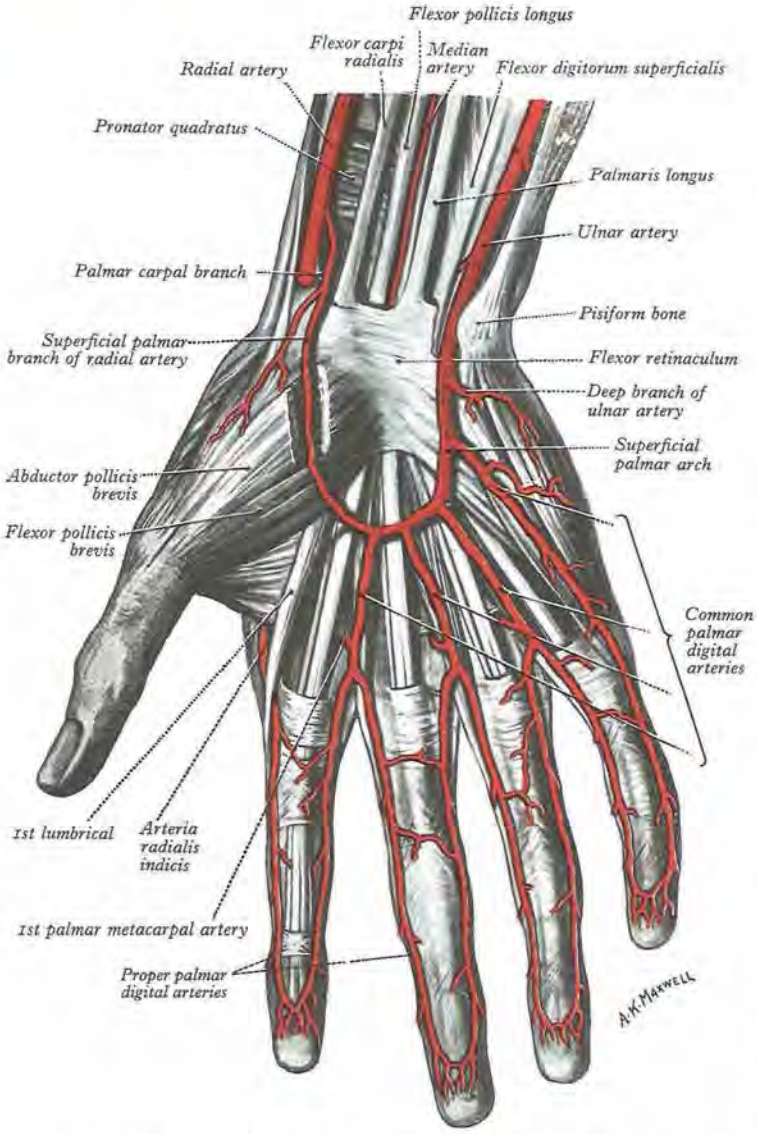
10.108 The arteries of the posterior surface of the right forearm and hand.

Common interosseous artery (10.102, 105). A short branch of the ulnar, just distal to the radial tuberosity, it passes back to the proximal border of the interosseous membrane, dividing into the *anterior* and *posterior interosseous arteries*.

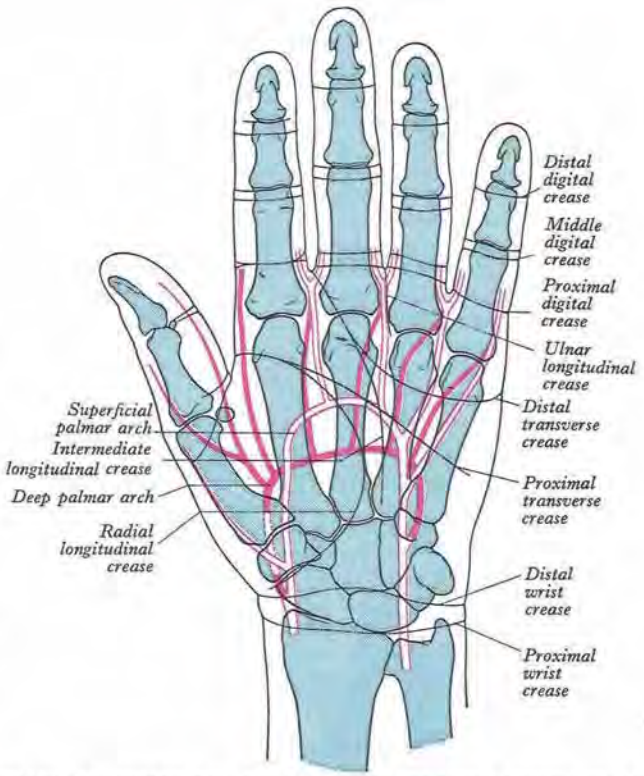
Anterior interosseous artery (10.102, 105). Descending on the anterior aspect of the interosseous membrane with the median nerve's anterior interosseous branch, it is overlapped by contiguous sides of flexor digitorum profundus and flexor pollicis longus; it has *muscular branches* and *nutrient branches* for the radius and ulna. On the membrane, branches leave to pierce it and supply deep extensor muscles. Proximal to pronator quadratus its continuation also traverses the membrane to the back of the forearm where it anastomoses with its own posterior interosseous branch, descending over the carpal dorsum to join the dorsal carpal arch. It is in the extensor retinacular compartment with the tendons of digital extensors. Before it pierces the interosseous membrane, a branch descends behind the pronator quadratus to the anterior 'carpal' arch. (Strictly, as mentioned, the latter is **proximal** to the line of the wrist joint.) The slender *median artery*, from the start of the anterior interosseous, accompanies and supplies the median nerve; it often arises from the common interosseous, sometimes much enlarged, reaching the palm with the nerve (p. 319), where it may join the superficial palmar arch or end as one or two palmar digital arteries.

Posterior interosseous artery (10.105, 108). Usually smaller than the anterior, it passes dorsally between the oblique cord and proximal border of the interosseous membrane and then between supinator and abductor pollicis longus, descending deep to the superficial extensors, which it supplies. On abductor pollicis longus it accompanies the deep branch of the radial nerve. Distally it anastomoses with the end of the anterior interosseous and dorsal carpal arch. Near its origin the *interosseous recurrent artery* leaves it to ascend between the lateral epicondyle and olecranon, either on or through the supinator but deep to anconeus, to anastomose with the middle collateral branch of the arteria profunda brachii, posterior ulnar recurrent and ulnar collateral arteries.

Muscular branches. These arise directly from the main vessel and distribute to muscles in the ulnar region.



10.109 The superficial palmar arch and its branches in the right hand. A part of the abductor pollicis brevis has been excised to expose the superficial palmar branch of the radial artery.



10.110 The relation of the skin flexure lines and palmar arterial arches to the bones of the left hand (simplified).

Palmar carpal branch (10.105). A small vessel, it crosses the distal ulna behind the tendons of flexor digitorum profundus; it anastomoses with a palmar carpal branch of the radial to make a so-called palmar carpal arch (p. 1541).

Dorsal carpal branch (10.108). Arising just proximal to the pisiform bone, it curves deep to the tendon of flexor carpi ulnaris to the carpal dorsum to pass laterally across it under the extensor tendons, anastomosing with the radial dorsal carpal branch to complete the dorsal carpal arch (p. 1541). Near its origin it sends a small digital branch along the ulnar side of the fifth metacarpal to supply the medial side of the dorsal surface of the fifth finger.

Deep palmar branch (10.105, 109). Often double, it passes between the abductor and flexor digiti minimi, through or deep to the opponens digiti minimi; it anastomoses with the radial, completing the deep palmar arch, accompanied by the deep branch of the ulnar nerve.

Superficial palmar arch (10.109, 110)

This anastomosis is fed mainly by the ulnar artery, entering the palm with the ulnar nerve, anterior to the flexor retinaculum and lateral to the pisiform, passing medial to the hamate's hook, then curving laterally to form an arch, convex distally and level with a transverse line through the distal border of the fully extended pollicial base. About a third of the superficial palmar arches are formed by the ulnar alone; a further third are completed by the superficial palmar branch of the radial and a third either by the arteria radialis indicis, a branch of arteria princeps pollicis or by the median artery (Coleman & Anson 1961). It is covered by the palmaris brevis and palmar aponeurosis and it is superficial to the flexor digiti minimi, branches of the median nerve and to the long flexor tendons and lumbrical muscles.

Branches. Three common palmar digital arteries (**10.109**) from the convexity of the superficial palmar arch proceed distally on the second to fourth lumbricals, each joined by a corresponding palmar metacarpal artery from the deep palmar arch and dividing into two *proper palmar digital arteries.* These run along the contiguous sides of all four fingers, dorsal to the digital nerves, anastomosing in the subcutaneous tissue of the finger tips and near the interphalangeal joints. Each digital artery has two *dorsal branches* anastomosing with the *dorsal digital arteries* and supplying the soft parts dorsal to the middle and distal phalanges, including the matrices of the nails. The *palmar digital artery* for the medial side of minimus leaves the arch under the palmaris brevis. Palmar digital arteries supply metacarpophalangeal and interphalangeal joints and nutrient rami to the phalanges. They are the main digital supply, the dorsal digital arteries (p. 1541) being minute.

Anastomoses between the radial and ulnar arteries occur:

- at the wrist by the palmar and dorsal carpal arches
- in the hand through the superficial and deep palmar arches
- between their digital and metacarpal branches.

Wounds of the palmar arches. Ligature of **one** forearm artery may be ineffective in wounds of the palmar arches; simultaneous tying of both proximal to the carpus may also fail, because of interosseo–carpal anastomoses. If local pressure fails the brachial artery may be compressed (p. 1538) as a temporary expedient.

ARTERIES OF THE TRUNK

THORACIC AORTA

The thoracic aorta (**10**.111) is the segment of *descending aorta* confined to the posterior mediastinum. It begins level with the fourth thoracic vertebra's lower border, continuous with the aortic arch, ending anterior to the twelfth thoracic's lower border in the diaphragmatic aortic aperture. At its origin it is left of the vertebral column; as it descends it approaches the midline and at its termination is directly anterior to it.

Relations. **Anterior**, from above down, are the left pulmonary hilum, the pericardium separating it from the left atrium, oesophagus and diaphragm; **posterior** are the vertebral column and hemiazygos veins; **right lateral** are the azygos and thoracic duct and below, the right pleura and lung; **left lateral** are the pleura and lung. The oesophagus, with its plexus of nerves, is right lateral above but becomes anterior in the lower thorax; close to the diaphragm it is **left anterolateral**. Thus, to a limited degree, the descending aorta and oesphagus are mutually spiralized.

Surface anatomy. The vessel is projected as a band 2.5 cm broad from the sternal end of the second left costal cartilage to a median position about 2 cm above the transpyloric plane (p. 1733).

Branches. The thoracic aorta provides visceral branches to the pericardium, lungs, bronchi, oesophagus and parietal branches to the thoracic wall.

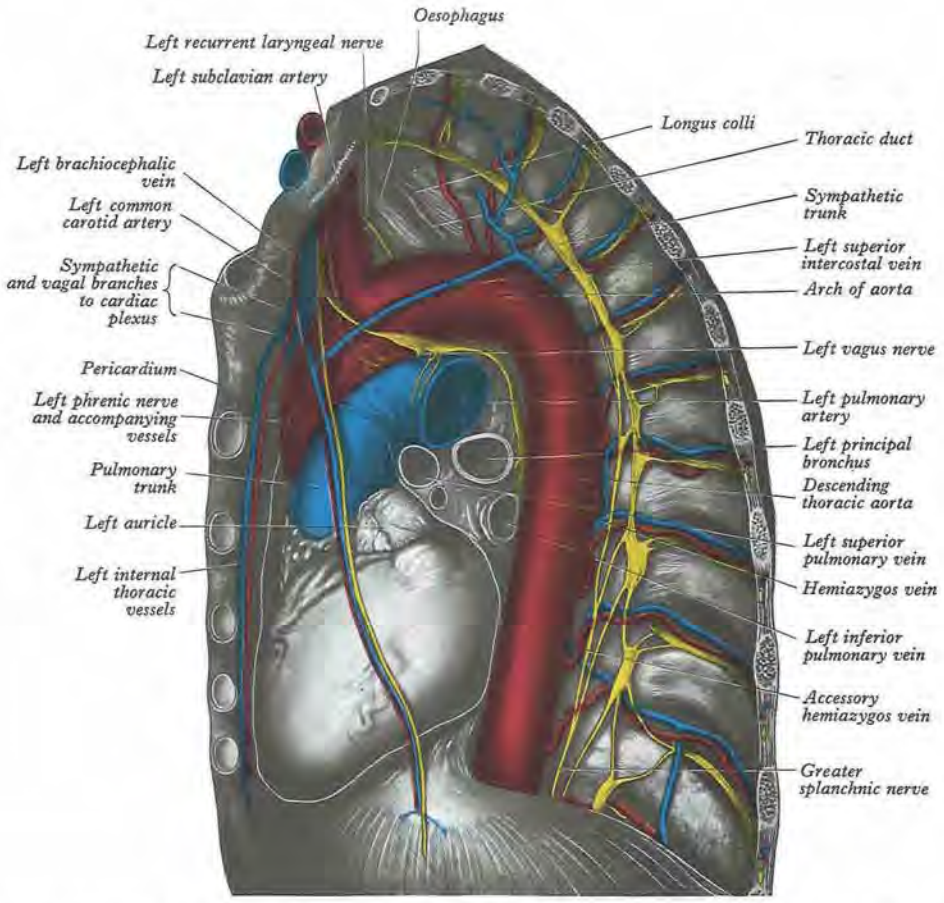
Pericardial branches. A few small vessels: they are distributed to the posterior pericardial aspect.

Bronchial arteries. These vary in number, size and origin. Usually one *right bronchial artery*, from the third posterior intercostal or upper left bronchial artery, runs posteriorly on the right bronchus and its branches, supplying them, the pulmonary areolar tissue and the bronchopulmonary lymph nodes, pericardium and oesophagus. The *left bronchial arteries*, usually two, arise from the thoracic aorta, the upper near the fifth thoracic vertebra, the lower below the left bronchus. They run posteriorly to the left bronchus and are distributed as on the right. Cauldwell et al (1948) found this arrangement in 40% of 150 cadavers; less frequent (at about 20% each) were two left and two right bronchial arteries or one on each side, all direct branches of the thoracic aorta, arising near the third and fourth intercostal arteries. In about 10%, one left and two right bronchial arteries existed. Complex variations consisted chiefly of more numerous aortic branches. Very rarely a bronchial artery arose from the aortic arch.

Oesophageal arteries. These are four or five, which arise anteriorly from the aorta and descend obliquely to the oesophagus, forming a vascular chain on it which anastomoses above with the oesophageal branches of the inferior thyroid arteries and below with the ascending branches from the left phrenic and gastric.

Mediastinal branches. These are numerous small vessels supplying lymph nodes and areolar tissue in the posterior mediastinum.

Phrenic branches. These arise from the lower thoracic aorta and are distributed posteriorly to the superior diaphragmatic surface and anastomose with the musculophrenic and pericardiacophrenic arteries.



10.111 The left aspect of the mediastinum. The left lung and pleura have been removed and an extensive opening has been made into the pericardial sac to expose the heart. Note the oblique orientation of the thoracic inlet, and the forward inclination of the longus colli, upper oesophagus and thoracic duct.

Posterior intercostal arteries

Usually nine pairs of posterior intercostal arteries derive from the posterior aspect of the descending thoracic aorta. They are distributed to the lower nine intercostal spaces, the first and second being supplied by the superior intercostal artery (p. 1535). *Right posterior intercostal arteries* are longer, due to aortic deviation to the left; they cross the vertebral bodies behind the oesophagus, thoracic duct and azygos vein, right lung and pleura. *Left posterior intercostal arteries* turn backwards on the vertebral bodies in contact with the left lung and pleura, the upper two crossed by the left superior intercostal vein, the lower by the hemiazygos and accessory hemiazygos veins. Their further course is the same on both sides. Anterior to the heads of the ribs the sympathetic trunk descends in front of them and additionally the splanchnic nerves in front of the lower arteries.

Each artery crosses its intercostal space obliquely towards the angle of the rib above and continues forward in its costal groove (**10**.111). At first between the pleura and internal (posterior) intercostal membrane as far as the costal angle, it passes between the intercostalis internus and intercostalis intimus muscles (p. 815), anastomosing with an anterior intercostal branch from an internal thoracic or musculophrenic artery. It has a vein above and a nerve below, except in the upper spaces where the nerve is at first above the artery. The third anastomoses with the superior intercostal artery and may largely supply the second space. The lower two arteries continue anteriorly into the abdominal wall to anastomose with the subcostal, superior epigastric and lumbar arteries. Each posterior intercostal artery has dorsal, collateral, muscular and cutaneous branches.

Dorsal branch. This runs dorsally between the necks of adjoining ribs, with a vertebral body and a superior costotransverse ligament lying medial and lateral, respectively. It has a spinal branch entering the vertebral canal by the intervertebral foramen to supply vertebrae, spinal cord and meninges; it anastomoses with the spinal arteries above and below and with its fellow. It then crosses a transverse process with the dorsal branch of a thoracic spinal nerve to supply the dorsal muscles; a cutaneous twig accompanies the cutaneous branch of the spinal nerve's dorsal ramus.

Collateral intercostal branch. It leaves its posterior intercostal near the costal angle and descends to the upper border of the subjacent rib, along which it courses to anastomose with an anterior intercostal branch of the internal thoracic or musculophrenic artery.

Muscular branches. These supply intercostal and pectoral muscles and the serratus anterior, anastomosing with the superior and lateral thoracic branches of the axillary artery. Lateral cutaneous branches accompany the same branches of the thoracic spinal nerves. Mammary branches from the vessels in the second to fourth spaces supply the pectoral muscles, skin and mammary tissue; they enlarge during lactation.

Unnamed branches. They supply all other tissues constituting the thoracic wall, e.g. costal periosteum, bone and bone marrow of ribs, tissues of synovial and synarthrodial joints and parietal pleura.

Right bronchial artery. It may arise from the right third posterior intercostal artery (see above).

Clinical anatomy. A thoracic puncture needle should not be introduced posteriorly medial to the costal angles, as the intercostal artery (and vein) crosses its space medial to this. Laterally, however, it is in the upper part of its intercostal space; therefore puncture should be through the **lateral** chest wall in the *lower* half of a space.

Subcostal arteries. The last paired branches of the thoracic aorta, in series with the posterior intercostal arteries, they are below the twelfth ribs. Each runs laterally anterior to the twelfth thoracic vertebral body and posterior to the splanchnic nerves, sympathetic trunk, pleura and diaphragm; the right is also posterior to the thoracic duct and azygos vein, the left to the accessory hemiazygos vein. Each then enters the abdomen posterior to the lateral arcuate ligament with the twelfth thoracic (subcostal) nerve at the lower border of the twelfth rib, anterior to quadratus lumborum and posterior to the kidney. The right artery courses posterior to the ascending colon, the left to its descending part. Piercing the aponeurosis of the transversus abdominis each proceeds between this and the obliquus internus, anastomosing with the superior epigastric, lower posterior intercostal and lumbar arteries. Each has a dorsal branch, distributed like those of the posterior intercostal arteries.

Aberrant artery. A small artery sometimes leaves the thoracic aorta on its right near the right bronchial. It ascends to the right behind the trachea and oesophagus and may anastomose with the right superior intercostal. It is a vestige of the right dorsal aorta (p. 316); occasionally it is enlarged as the first part of a right subclavian (p. 1530).

VARIATIONS OF THORACIC AORTA

The aortic lumen is occasionally partly or completely obliterated, above (preductal or infantile type), opposite or just beyond (postductal or adult type) the entry of the ductus arteriosus. The condition, *coarctation of the aorta*, is congenital; the ductus arteriosus may remain patent, but rarely compensates, systemic blood pressure being usually much higher than pulmonary.

In the *preductal* type, the coarctation's length is variable and may involve the left subclavian and even the brachiocephalic artery, with little scope for the development of an effective collateral circulation to regions distal to the stenosis. Many cases are incompatible with survival for more than a few months and surgical problems are great. However, coarctation may be restricted to a short segment between the brachiocephalic and left subclavian arteries, pressures in the left arm being lower than in the right; a collateral circulation may develop through branches of the brachiocephalic.

The *postductal* type of coarctation has been attributed to abnormal extension of the ductal tissue into the aortic wall, stenosing both vessels as the duct contracts after birth. This form can permit many years of normal life, allowing the development of an extensive collateral circulation to the aorta distal to the stenosis. High vascularity of the thoracic wall is important and clinically characteristic; many arteries arising indirectly from the aorta, proximal to the coarctation segment, anastomose with vessels connected with it distal to the block; these become greatly enlarged. In the anterior thoracic wall the thoraco-acromial, lateral thoracic and subscapular arteries from the axillary, the suprascapular from the subclavian and the first and second posterior intercostal arteries from the costocervical trunk anastomose with other posterior intercostal arteries; the internal thoracic artery and its terminal branches anastomose with the lower posterior intercostal and inferior epigastric arteries. Posterior intercostal arteries are always involved, and enlargement of their dorsal branches may eventually groove ('notch') the inferior margins of the ribs. The radiograph shadow of the enlarged left subclavian artery is also increased. Enlargement of the scapular vessels and anastomoses may lead to widespread interscapular pulsation (easily appreciated with the palm of the hand, and sometimes heard on auscultation).

ABDOMINAL AORTA

The abdominal aorta (**10.112, 113, 115, 128**) begins at the median, aortic hiatus of the diaphragm, anterior to the twelfth thoracic vertebra's inferior border and the thoracolumbar intervertebral symphysis ('disk'), descending anterior to the vertebrae to end at the fourth lumbar, a little left of the midline, by dividing into two common iliac arteries. It diminishes rapidly in calibre, since its branches are large. Measurements of casts of the abdominal aorta in 100 individuals, from 16–70 years, showed a widening with age. In males superior and inferior ends measured 9.8–14.1 mm and 8.1–14.6 mm; in females luminal diameters were 9.7–15.7 mm and 9.1–14.6 mm (Aleksandrowicz et al 1974). These values conflict with radiological observation of 61 adults (17–41 years) by Leithner et al (1975), who recorded 26 mm and 19 mm (averages) for both ends of the abdominal aorta; they also gave a mean value of 37 for the angle of aortic bifurcation. Dimensions are of interest in attempts to estimate a suspected hydrodynamic ('haemodynamic') factor in the genesis of atherosclerosis (Newman et al 1971; Lallemand & Newman 1973). Theoretically, the pressure pulse wave in arteries is reflected at any junction, at certain values of combined arterial luminal areas of the branch or branches relative to that of the parent vessel; this is the area ratio of a junction. At an equal bifurcation, such as the aortic, with an area ratio of 1:1.5, reflection of the pressure pulse wave is near to zero; the vessels are said to be 'matched'. Oscillations and possibly turbulence set up by 'mismatching' (at other ratios), perhaps also influenced by asymmetry of bifurcation, may cause intimal damage, predisposing to aortic atheroma. Luminal and other dimensions of the bifurcation may assume special significance, as may changes in these during life. Measurement of aortico–iliac junctions in humans, dogs and domestic fowls (free from vascular disease) has shown area ratios usually close to the theoretical value for 'matching' and independent of age in dog and fowl (Gosling et al 1971). However, the human aortic bifurcation appears to be 'matched' only in infancy; it is 1.11 ± 0.02 at birth, diminishing with advancing age to a value of about 0.7 in the fifth decade, at which theory predicts a 'mismatch' reflecting pulse pressure wave at about one-third of its amplitude. These studies give special interest to a study of the geometry of aortic bifurcation by Shah et al (1978), containing the most extensive data so far recorded, including diameters and angles of deviation, iliac lengths and curvatures and dorsal angulations of these vessels as they enter the pelvis. Unfortunately, diameters were external and only on a small series of cadavers at autopsy, and cannot be compared with those cited above. These interesting observations should be carried further with improved techniques and greater cohesion between different groups involved.

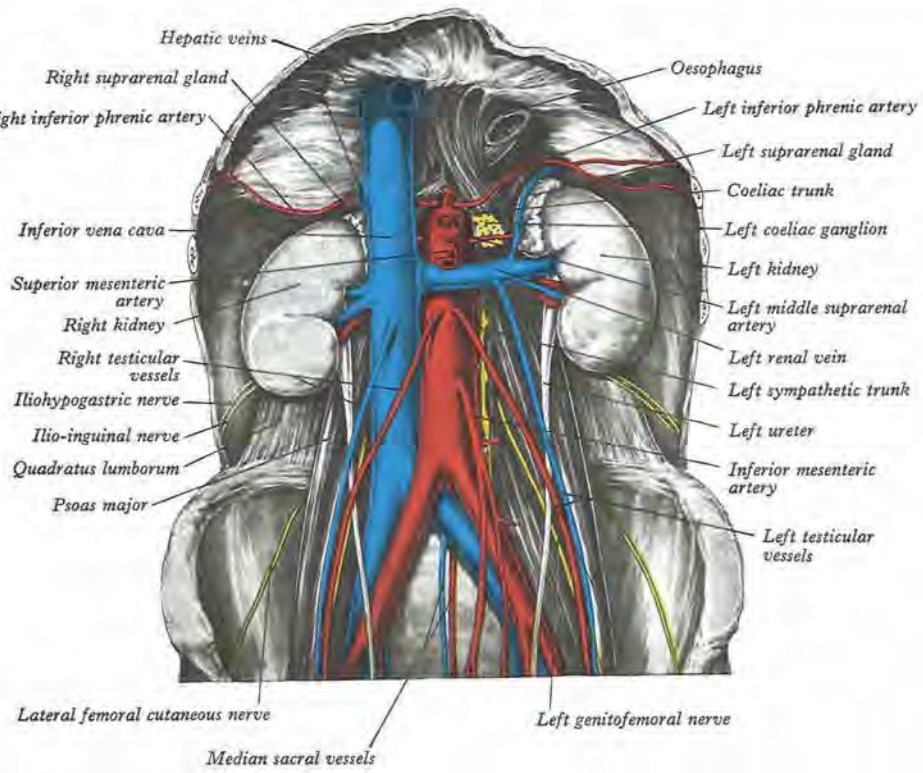
Relations. The abdominal aorta has at first **anterior** to it the coeliac trunk and its branches, with the coeliac plexus and the lesser sac (omental bursa) which intervenes between it and the hepatic papillary process and lesser omentum. Below this the superior mesenteric artery leaves the aorta, crossing anterior to the left renal vein. The body of the pancreas, with splenic vein applied posteriorly, extends obliquely up and left across the abdominal aorta, separated from it by the superior mesenteric artery and left renal vein. Below the pancreas, the proximal parts of its testicular (or ovarian) arteries, and the horizontal part of the duodenum are anterior. In its lowest part it is covered by the posterior parietal peritoneum and crossed by the oblique parietal attachment of the mesentery.

Posterior to the abdominal aorta are the thoracolumbar intervertebral 'disk', the upper four lumbar vertebrae, intervening intervertebral discs and the anterior longitudinal ligament. Lumbar arteries, arising from its dorsal aspect, and the third and fourth (sometimes second) left lumbar veins, crossing behind it to reach the inferior vena cava, separate it from the ligament. It may overlap the anterior border of the left psoas major.

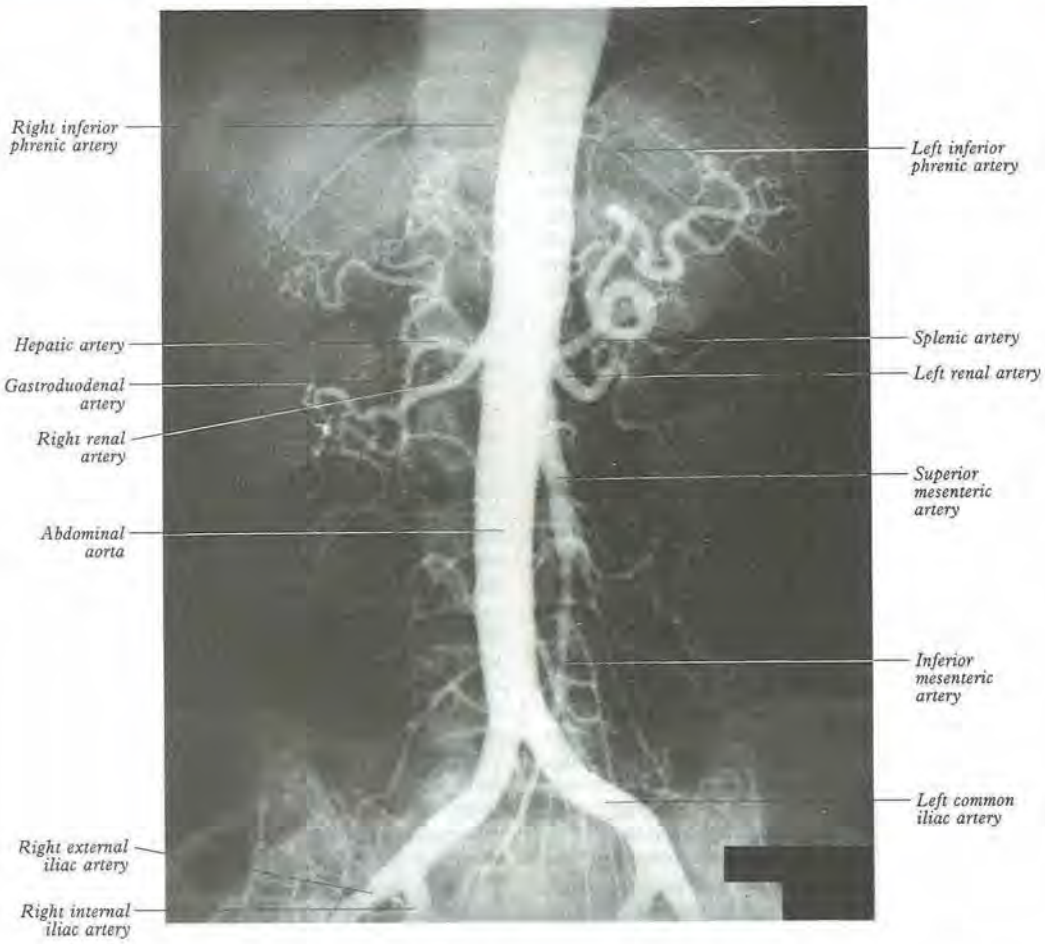
On the right the aorta is related above to the cisterna chyli and thoracic duct, azygos vein and right crus of diaphragm, which overlaps and separates it from the inferior vena cava and right coeliac ganglion. Below the second lumbar vertebra it adjoins the inferior vena cava.

On the left it is related above to the left diaphragmatic crus and left coeliac ganglion. Level with the second lumbar vertebra are the duodenojejunal flexure and sympathetic trunk descending, at its left side, and the ascending duodenum and inferior mesenteric vessels.

Surface anatomy. The vessel is indicated by a band about 2 cm wide from a median level 2.5 cm above the transpyloric plane to one about 1 cm below and left of the umbilicus. When the abdominal wall



10.112 The abdominal aorta and its branches in the male.



10.113 Aorto-iliac angiogram. (Supplied by Shaun Gallagher, Guy's Hospital; photography by Sarah Smith.)

is relaxed the aorta may be felt pulsating just above its bifurcation and its pulsation may be visible. This is frequently the case in thin subjects. An easily palpable aorta in someone who is obese should raise the suspicion of an aneurysm, to be checked by ultrasound scan.

Branches (**10**.112, 113)**.** These may be described as ventral, lateral, dorsal and terminal; ventral and lateral are distributed to the viscera, the dorsal branches supplying the body wall, vertebral column, canal and its contents:

Ventral:	Coeliac, superior and inferior mesenteric
Dorsal:	Lumbar and median sacral
Lateral:	Inferior phrenic, middle suprarenal, renal, ovarian or testicular
Terminal:	Common iliac.

COELIAC TRUNK

The coeliac trunk (**10**.114–117), a wide ventral branch, about 1.25 cm long, just below the aortic hiatus, passes almost horizontally forwards and slightly right above the pancreas and splenic vein, dividing into:

- *left gastric*
- *common hepatic*
- *splenic arteries.*

It may also give off one or both inferior phrenic arteries. The superior mesenteric may arise with the coeliac trunk, or the latter's usual branches may be direct independent branches of the aorta.

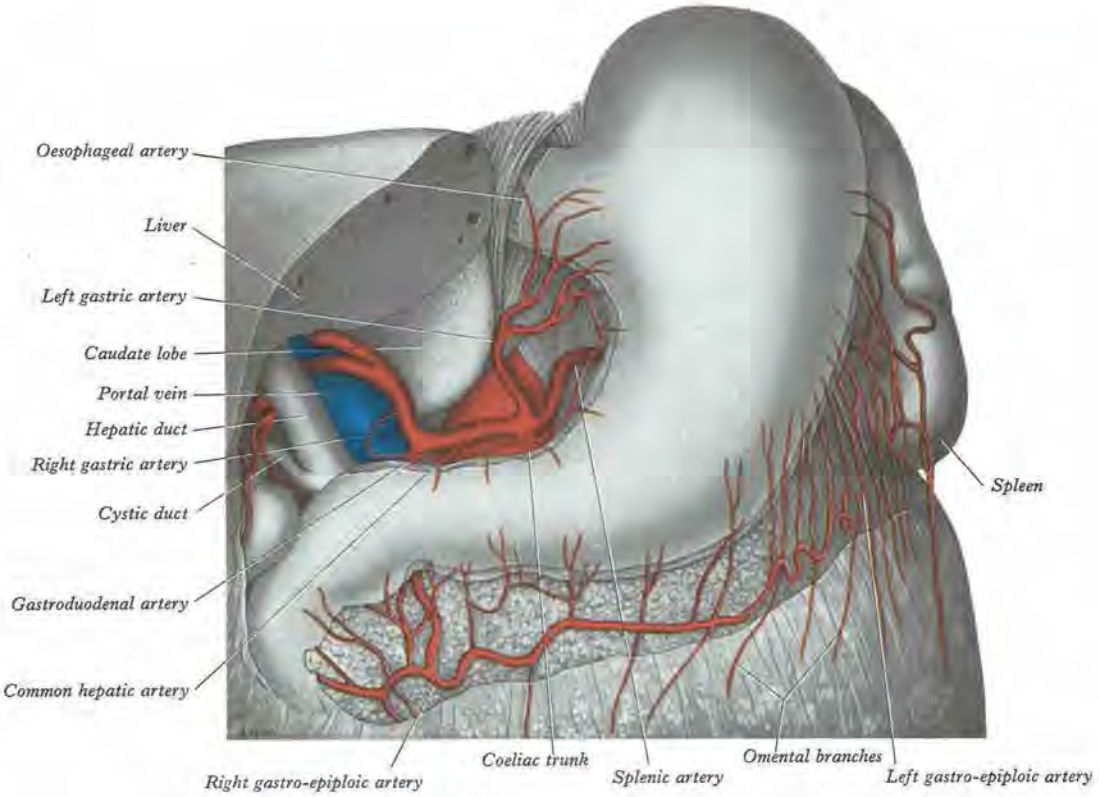
Relations. **Anterior** is the omental bursa (lesser sac); the coeliac plexus surrounds the trunk, sending extensions along its branches. **Right lateral** are the right coeliac ganglion, right crus and hepatic caudate process; **left lateral** are the left coeliac ganglion, left crus and cardiac end of the stomach. The right crus may compress the origin of the coeliac trunk, giving the appearance of a stricture. Symptoms have been attributed to this (the 'coeliac axis compression syndrome'), and operations designed to relieve it, but the concept is of doubtful validity. **Inferior** are the pancreas and splenic vein. The duodenum's suspensory muscle (p. 1763) may encircle the coeliac artery but is usually on its left.

Left gastric artery

The left gastric artery, the smallest coeliac branch, ascends to the left, posterior to the omental bursa, to the cardiac end of the stomach (**10**.114, 115). It is near the left inferior phrenic artery and medial or anterior to the left suprarenal gland. Near the stomach two or three *oesophageal branches* ascend through the oesophageal opening to anastomose with the aortic oesophageal branches; others supply the cardiac part of the stomach and anastomose with the splenic branches. The artery then turns antero-inferiorly into the left gastropancreatic fold to run (often doubled) curving to the right near the gastric lesser curvature to the pylorus between layers of the lesser omentum; it supplies both gastric surfaces and anastomoses with the right gastric artery. An *accessory left gastric* artery may arise from the left branch of the hepatic, also reaching the lesser curvature through the lesser omentum.

Hepatic artery

The hepatic artery is intermediate in size between the left gastric and splenic arteries; but in **later** fetal and early postnatal life it is the largest coeliac branch (**10**.114–116, 118). Accompanied by the hepatic autonomic plexus it first passes forwards and right, below the epiploic



10.114 The coeliac trunk and its branches. Part of the liver and all the lesser omentum have been removed, as well as the posterior wall of the omental bursa and part of the anterior layer of the greater omentum.

foramen to the upper aspect of the superior part of the duodenum (**10**.114). Crossing the portal vein, it ascends between layers of the lesser omentum, anterior to the epiploic foramen, to the porta hepatis, where it divides into right and left branches to the hepatic lobes, accompanying the ramifications of the portal vein and hepatic ducts. In the lesser omentum it is anterior to the portal vein and left of the bile duct, its right branch crossing posterior (occasionally anterior) to the common hepatic duct (**10**.115). The artery may be subdivided into:

- the *common hepatic artery*, from the coeliac trunk to the origin of the gastroduodenal artery
- the *hepatic artery proper*, from that point to its bifurcation.

In embryonic and early fetal life, the hepatic artery arises from the left gastric (in 67% of 56 individuals; Godlewski et al 1975). This condition rarely persists, but the hepatic may arise from the superior mesenteric, or the hepatic's right or left branches may be from other vessels; the former from the superior mesenteric, the latter from the left gastric. For other variations consult Quain (1865, 1899) and Woodburne (1962) (see also pp. 1550, 1810). The hepatic artery has right gastric, gastroduodenal and cystic branches, branches to the bile duct from the right hepatic and sometimes the supraduodenal artery (see below).

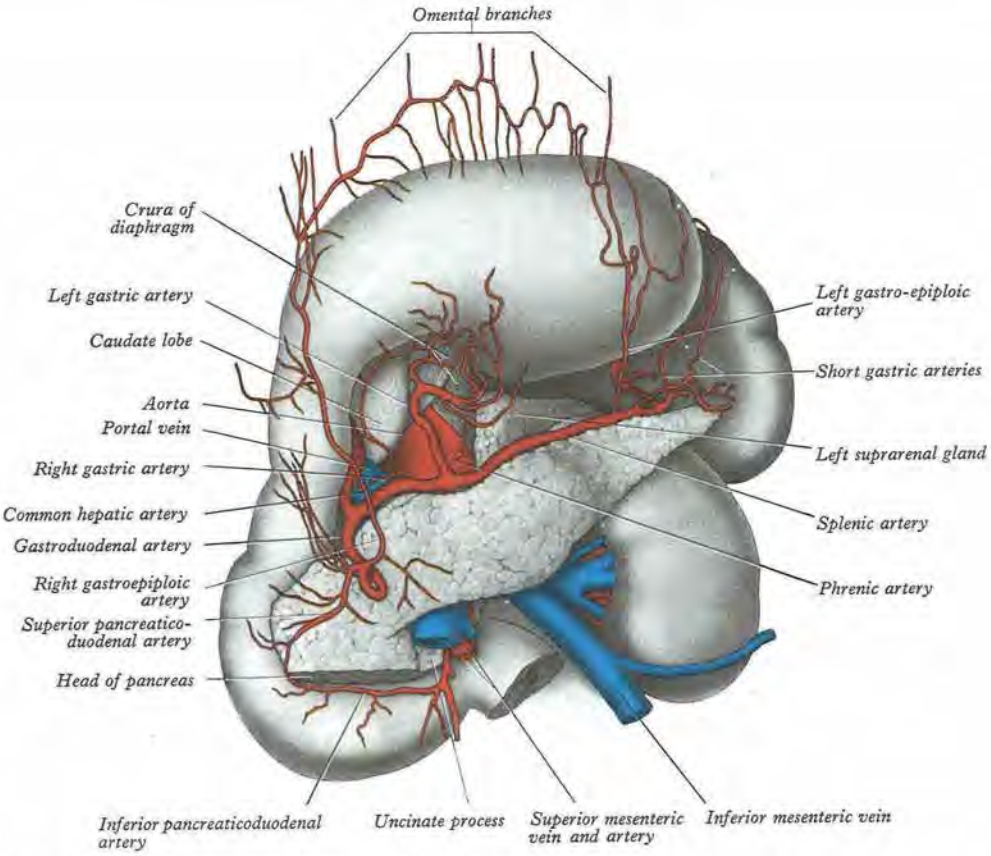
Right gastric artery (**10**.114). It arises above the duodenum's superior part, usually before, or sometimes beyond the gastroduodenal, descending in the lesser omentum to the pyloric end of the stomach; it passes left along the lesser gastric curvature, supplying the upper parts of the anterior and posterior gastric surfaces. It ends by anastomosing with the left gastric; the supraduodenal artery may be a branch (see below).

Gastroduodenal artery (**10**.114–116). Arising behind, sometimes above, the superior part of the duodenum, it is short and wide. It descends between the duodenum and the neck of the pancreas, immediately to the right of the peritoneal reflection from the posterior duodenal surface. It is usually left of the bile duct but sometimes anterior. At the lower border of the duodenum's superior part it divides into the *right gastro-epiploic* and *superior pancreaticoduodenal* arteries, after supplying small branches to the pyloric end of the stomach and to the pancreas, retroduodenal branches to the superior part of the duodenum, and sometimes providing the supraduodenal artery (see below). The first branch of the common hepatic artery is usually the gastroduodenal artery, but this may come from the superior mesenteric, coeliac trunk or an aberrant right hepatic artery (p. 1552); its most invariable feature is its intermediate position between the **neck** of the pancreas and the duodenum, this being clinically important due to its frequent involvement in duodenal ulceration (Bradley 1973).

The *supraduodenal artery*, sometimes double, is variable; it may arise from the gastroduodenal, hepatic (common, proper or the latter's branches) or from the right gastric artery. It supplies the superior half circumference of the proximal half or more of the duodenum's superior part; but the duodenum is often invaded proximally by branches of the right gastric artery (p. 1765).

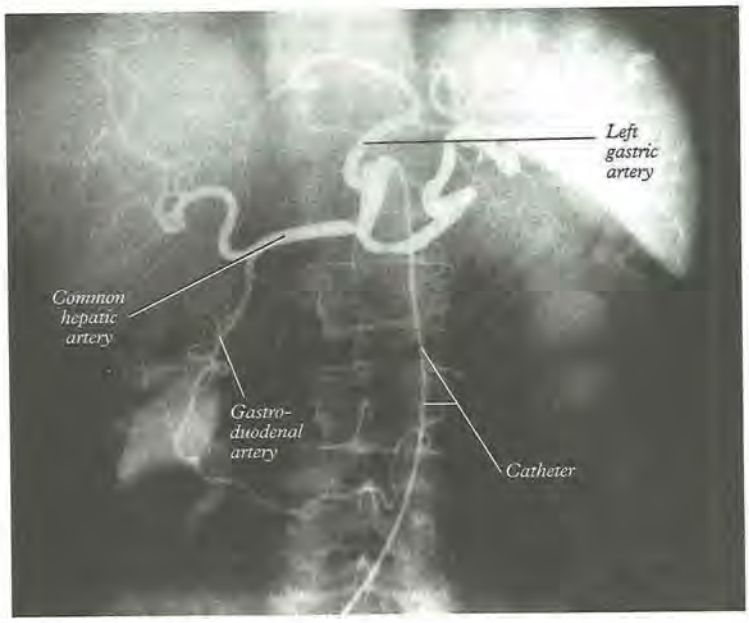
Right gastro-epiploic artery (**10**.114, 115, 118). The larger terminal branch of the gastroduodenal, it skirts the right margin of the omental bursa and then turns left along the greater curvature, between the (anterior two) layers of the greater omentum. It ends in direct anastomosis with the left gastro-epiploic branch of the splenic. Except at the pylorus, where it adjoins the stomach, it is about 2 cm from the greater curvature. Of its many branches some ascend to both gastric surfaces, others descend into the greater omentum. It also supplies the inferior aspect of the duodenum's superior part.

Superior pancreaticoduodenal arteries (**10**.115). These are usually double: the *anterior* descends anteriorly between the duodenum and head of the pancreas. It supplies both, and anastomoses with the anterior division of the inferior pancreaticoduodenal branch of the superior mesenteric. The *posterior superior pancreaticoduodenal artery*, which is usually a separate branch of the gastroduodenal arising at the upper border of the superior part of the duodenum, descends to the right, anterior to the portal vein and bile duct and



10.115 The coeliac trunk and its branches exposed by turning the stomach upwards and removing the peritoneum on the posterior abdominal wall.

then posterior to the head of the pancreas, supplying branches to it and the duodenum; it crosses posterior to the bile duct, piercing the duodenal wall to end by anastomosing with the posterior division of the inferior pancreaticoduodenal artery. The artery supplies several branches to the lower part of the common bile duct (p. 1810).

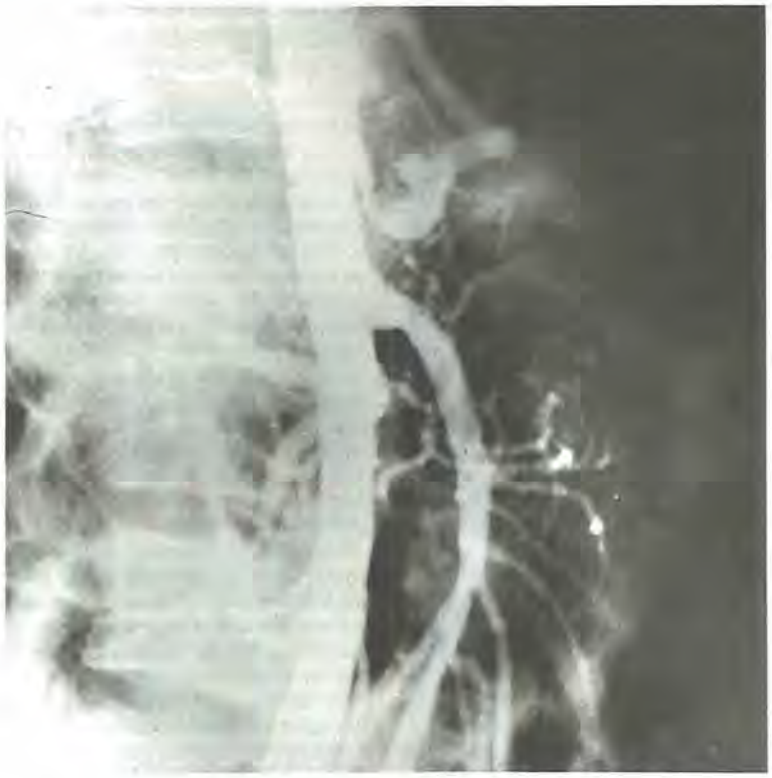


10.116 Arteriogram of the coeliac trunk.

Cystic artery (10.118). Usually from the right branch of the hepatic proper, it passes behind the common hepatic and over the cystic duct to the superior aspect of the gallbladder's neck, on which it descends to divide into *superficial* and *deep* branches. The former ramifies on the inferior, the latter on the superior aspect. The cystic artery may arise from the hepatic artery itself (rarely from the gastroduodenal), crossing anterior or posterior to the bile or common hepatic duct to reach the gallbladder. Direct origin from the hepatic artery varies from its beginning to its bifurcation. An *accessory cystic artery* may arise from the common hepatic or one of its branches. The cystic artery supplies the hepatic ducts and upper part of the common bile duct (p. 1810). A comparative study of its distribution in various reptilian, avian and mammalian species included 74 injected and cleared human gallbladders (Gordon 1967). The cystic artery in man reaches the gallbladder at its neck but is not in contact with the cystic duct.

Anteriorly, two to five ascending vessels arise from the retroduodenal branch of the gastroduodenal artery, as it crosses the anterior surface of the duct at the upper border of the duodenum. Three or four descending branches of the right hepatic and cystic arteries arise from them as these vessels pass close to the lower common hepatic duct. These ascending and descending arteries form long narrow anastomotic channels along the length of the duct, which are roughly disposed into medial and lateral trunks which some authors have described as 'three o'clock and nine o'clock' vessels. From the point of view of applied anatomy, the surgeon should dissect very carefully this area, and should keep the vessels under close endoscopic control.

Posteriorly, the 'retroportal artery' arises from the coeliac axis or superior mesenteric artery (or one of their major branches) close to the origin from the aorta, and runs upwards on the back of the portal vein. It can end in two different ways. In 20% of cases it passes up behind the bile duct to join the right hepatic artery, but in the majority it ends by joining the retroduodenal artery close to



10.117 The origin of the coeliac trunk is compressed by the median arcuate ligament of the diaphragm, formed by the right crus.

the lower end of the supraduodenal bile duct. When present, the retroportal artery plays a definite role in the blood supply of the supraduodenal duct system.

Terminal, intrahepatic branches. These display a pattern of branching relatively constant in its major details (p. 1797), which justifies a segmental description of the liver; it is the result, as in other organs, of growth and branching of an epithelial blastema, its pattern accompanied by vascular branches and nerve trunks. Arterial hepatic segmentation is described on page 1798. Consult also Woodburne (1962).

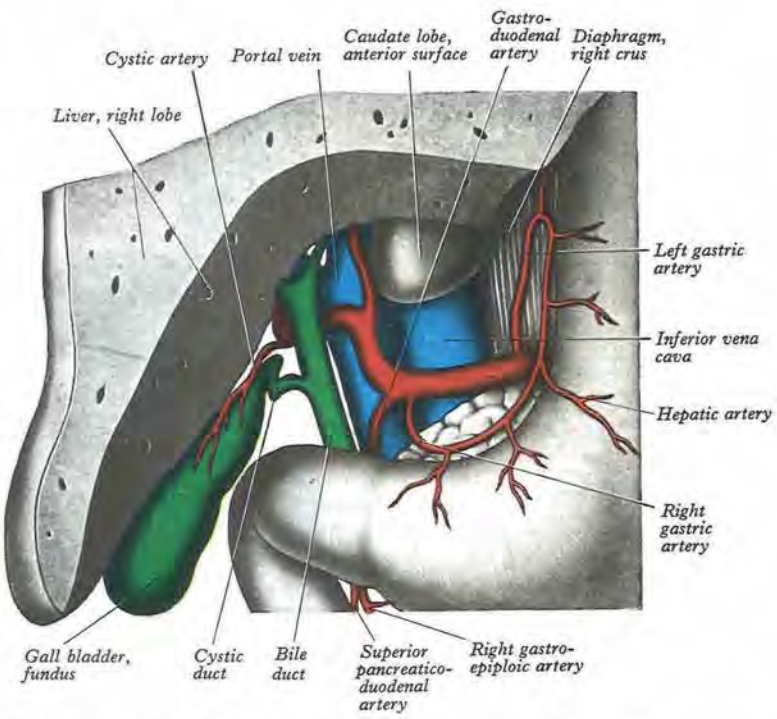
Splenic artery

The largest branch of the coeliac axis, the splenic is remarkably tortuous (**10.114–116**). Surrounded by a splenic nerve plexus and accompanied by the straight splenic vein, it ascends to the left, behind the stomach and omental bursa, along the superior border of the pancreas; it is anterior to the left suprarenal gland and upper part of the left kidney and enters the lienorenal ligament. Nearing the spleen it divides into five or more *segmental* branches which enter its hilum (p. 1438).

Branches of the splenic artery are as follows:

Pancreatic branches (**10.115**). Numerous and small, they supply the neck, body and tail of the pancreas, leaving the splenic artery as it runs along its superior border. A *dorsal branch* (sometimes from the superior mesenteric, middle colic, hepatic or, more rarely, coeliac artery) descends posterior to the pancreas, dividing into right and left branches. The former, usually double, runs between the neck and uncinate process to form a *prepancreatic arterial arch* with a branch from the anterior superior pancreaticoduodenal; the left branch runs along the inferior border to the pancreatic tail; it anastomoses with branches (*arteria pancreatica magna* and *arteria caudae pancreatis*) from the splenic artery which supply the left part of the body and the tail.

Short gastric arteries (**10.115**). Five to seven, these arise terminally from the splenic and its final divisions or from the left gastro-epiploic artery. They pass between layers of the gastrosplenic



10.118 The relations of the hepatic artery, bile duct and portal vein exposed by removal of the lesser omentum and the peritoneum on the posterior abdominal wall.

ligament to supply the gastric fundus, anastomosing with branches of the left gastric and gastro-epiploic arteries.

Posterior gastric artery. This arises from any part of the splenic but most commonly its middle section; it has been described by many authorities (e.g. Quain 1844) but many subsequent texts have omitted it. Susuki et al (1978), also surveying reports on it, found it present in 38 (62.3%) of 61 adult cadavers; the incidence from 14 reports (1904–1968) varied from 12.7 to 77%, with an average of 58% in a total of 870 cadavers. They described the vessel as ascending behind the peritoneum of the omental bursa towards the gastric fundus to reach the posterior gastric wall in the gastrophrenic fold; it was usually about 2 mm in diameter.

Left gastro-epiploic artery (10.114, 115). The splenic's largest branch, it arises near the splenic hilum and runs antero-inferiorly and right, sending branches through the gastrosplenic ligament to supply the proximal third of the greater curvature; these are necessarily longer than the gastric branches of the right gastro-epiploic artery and may be 8–10 cm long. A large terminal omental branch descends to the right in the greater omentum. The main vessel curves forwards at a higher level to join the right gastro-epiploic. This loop leaves part of the greater curvature devoid of branches. At partial gastrectomy the greater omentum is divided below the right gastro-epiploic artery, cutting all omental branches; the greater omentum survives because its supply from this large omental branch of left gastro-epiploic usually escapes damage (Horton 1952). Vessels supplying the greater omentum are epiploic (omental) branches of the right and left gastro-epiploic arteries. The right, middle and left colic arteries do not supply the greater omentum; the transverse mesocolon, though usually adherent to the greater omentum, is separable from it (p. 1743).

Terminal splenic branches. These enter the hilum in the lieno-renal ligament. Their distribution is described with the spleen (p. 1439).

Variations of the splenic and hepatic arteries

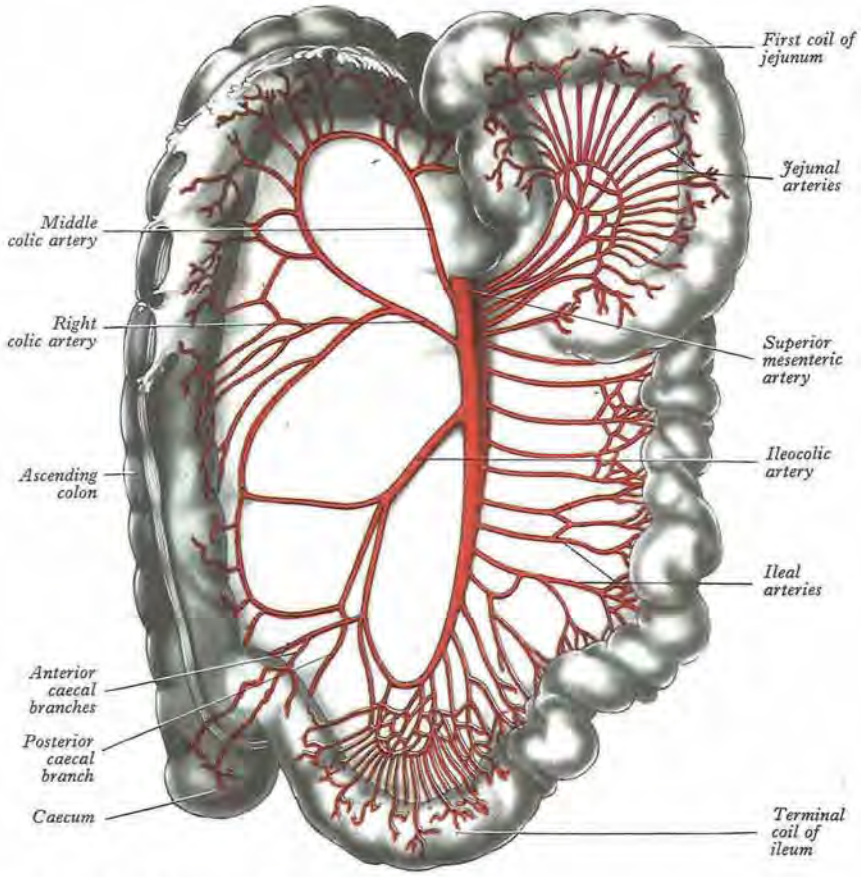
Variations in the arrangement of these arteries and their branches are common and surgically important. They include:

- the origin of the common hepatic from the superior mesenteric or, less often, from the aorta; it usually passes behind the portal vein to enter the lesser omentum
- an *accessory left hepatic artery* most often from the left gastric artery passing right in the lesser omentum to the porta hepatis, and easily damaged during partial gastrectomy
- an *accessory right hepatic artery* most often from the superior mesenteric, usually running behind the portal vein and bile duct in the lesser omentum to the porta hepatis.

Accessory left or right hepatic arteries may also arise from the gastroduodenal or aorta. They may be combined with 'normal' branches of the hepatic artery or replace them as the sole supply to parts of the liver, being called '*aberrant replacing arteries*'.

Clinical anatomy

Collateral circulation after hepatic ligature or obstruction: although blockage of the hepatic artery may lead to necrosis, this is by no means inevitable, because some two-thirds of the oxygen demands of the liver are met by the portal vein. The effect will depend on the site of the block. Occlusion of the common hepatic artery, proximal to the origin of the right gastric, allows collateral circulation to the liver through the left and right gastric, left and right gastro-epiploic, pancreaticoduodenal and gastroduodenal arteries, and so necrosis is unlikely. If, however, an obstruction of the hepatic artery proper occurs beyond the origin of the gastroduodenal artery, any collateral circulation is limited to the small inferior phrenic arteries (p. 1558).



10.119 The superior mesenteric artery and its branches. The first coil of the jejunum and the terminal coil of the ileum have been spread out to show the arrangement of their arteries.

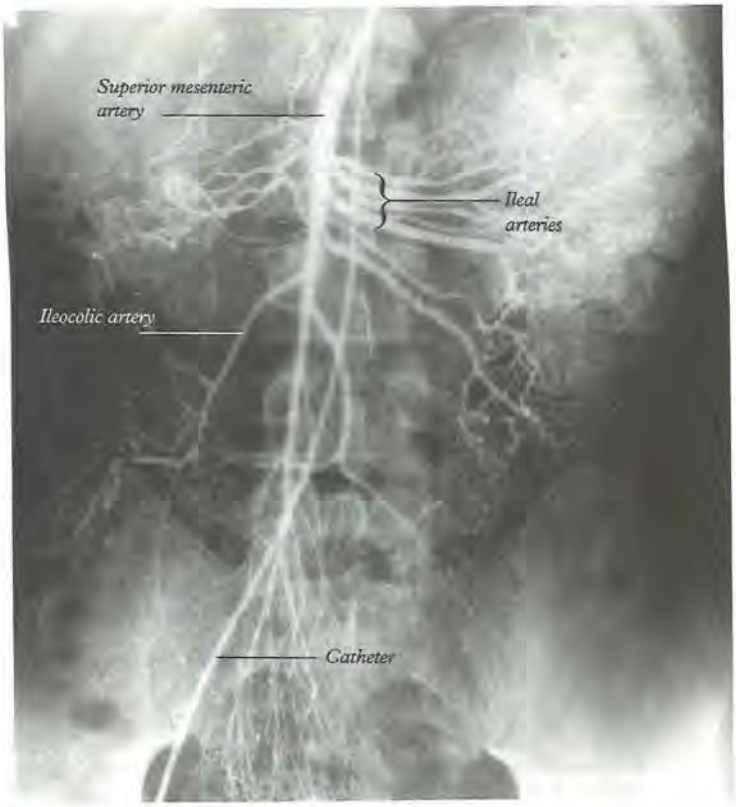
If, of course, the portal vein has been compromised as a result of thrombosis or of surgery, then the liver is entirely dependent on the hepatic artery for its survival.

SUPERIOR MESENTERIC ARTERY

The superior mesenteric artery (**10**.119–121) is by far the most important of the arteries to the alimentary tract, as it supplies the whole of the small intestine from the superior part of the duodenum to the midtransverse colon, and is functionally an end artery. It leaves the front of the aorta about 1 cm below the coeliac trunk, at the level of the L1–L2 vertebral disk, and is crossed anteriorly by the splenic vein and the body of the pancreas, separated from the aorta by the left renal vein. It runs downwards and forwards, anterior to the uncinate process, and passes in front of the transverse part of the duodenum. This can sometimes be seen on a radiograph as an area of translucency, running across the duodenum, and was at one time thought to represent a sphincter (the sphincter of Ochsner) to which all manner of symptoms were attributed. Endoscopy has disproved this concept. As it descends in the root of the small bowel mesentery, the artery crosses in front of the inferior vena cava, the right ureter, and psoas major, becoming steadily narrower in its course, and eventually joins its own ileocolic branch. It is accompanied by the superior mesenteric vein and is surrounded by a plexus of nerves. A fibrous strand from the region of its last branch runs to the umbilicus, and represents a vestige of the embryonic artery which originally connected it to the yolk sac.

Inferior pancreaticoduodenal artery (**10**.115)**.** It leaves the superior mesenteric, or its first jejunal branch, near the superior border of the horizontal part of the duodenum, usually dividing at once into anterior and posterior branches. The *anterior branch* passes to the right, anterior to the head of the pancreas, and ascends to anastomose with the anterior superior pancreaticoduodenal artery. The *posterior branch* ascends to the right, posterior to the head of the pancreas, which it sometimes traverses, and then anastomoses with the posterior superior pancreaticoduodenal artery. Both branches supply the pancreatic head, its uncinate process and the adjoining duodenum.

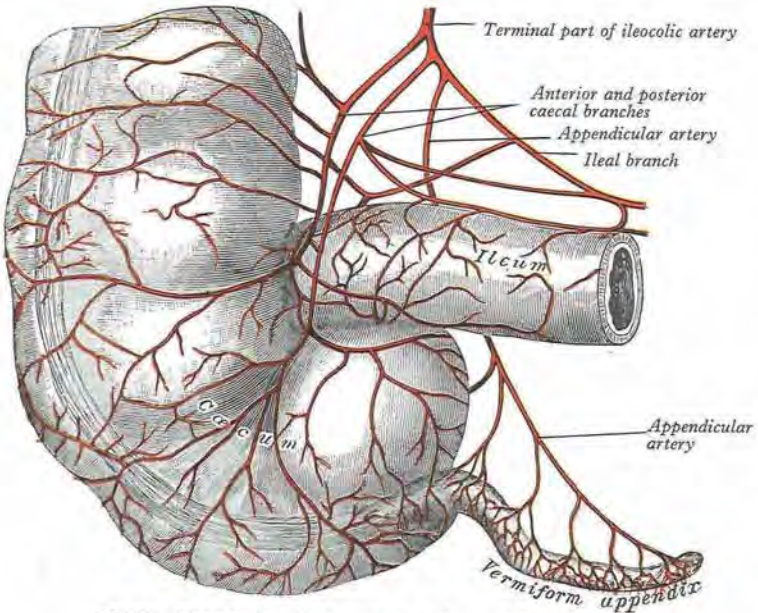
Jejunal and ileal branches (**10**.119, 120)**.** These arise from the left side of the superior mesenteric; usually 12–15 are distributed to the jejunum and ileum, except in the latter's terminal part, which is supplied by the ileocolic artery. They run almost parallel in the mesentery, each dividing to unite with adjacent branches in a series of arches (**10**.119). Branches from these unite to form a second series and this may be repeated three or four times. In the short, upper part of the mesentery one set of arches exists but, as the mesentery increases in depth, a second, third, fourth and even fifth series appear. From the terminal arches numerous *straight* vessels supply the intestine, distributed alternately to opposite aspects of its wall. Adjacent branches do not anastomose. Jejunal arteries are longer and fewer in number. Small twigs supply regional lymph nodes and other structures in the mesentery.



10.120 A superior mesenteric arteriogram with filling of ileal arteries (including several small branches) and of the ileocolic artery.

Ileocolic artery (**10**.119)**.** The last branch from the right side of the superior mesenteric, it descends to the right under the parietal peritoneum to the right iliac fossa, where it divides; its *superior branch* anastomoses with the right colic, the inferior with the end of the superior mesenteric. The ileocolic artery crosses anterior to the right ureter, testicular or ovarian vessels and psoas major. Its *inferior branch* approaches the superior border of the ileocolic junction and branches as follows (**10**.119, 122):

10.121 Ultrasonogram through the origin of the superior mesenteric artery. (Provided by Shaun Gallagher, Guy's Hospital; photography by Sarah Smith.)



10.122 The arteries of the caecum and vermiform appendix.

- *ascending* (*colic*) passing up on the ascending colon
- *anterior* and *posterior caecal*
- an *appendicular artery*, descending behind the terminal ileum to enter the mesoappendix; after giving off a recurrent branch anastomosing with one from the posterior caecal artery, it runs close to and then in the edge of the mesoappendix, its terminal part being in actual contact with the appendix
- an *ileal* branch ascending to the left on the lower ileum, supplying it and anastomosing with a terminal twig of the superior mesenteric artery.

Right colic artery (10.119). This is a small vessel and it may be absent. It arises near the middle of the superior mesenteric, or in common with the ileocolic and passes to the right behind the parietal peritoneum and anterior to the right ovarian or testicular artery and vein, right ureter and psoas major, towards the ascending colon. Sometimes it is higher and crosses the descending duodenum and right inferior renal pole. Near the colon it divides into a descending branch, which anastomoses with the ileocolic, and an ascending branch anastomosing with the middle colic. These form arches, from which vessels are distributed to the ascending colon, supplying its upper two-thirds and the right colic flexure.

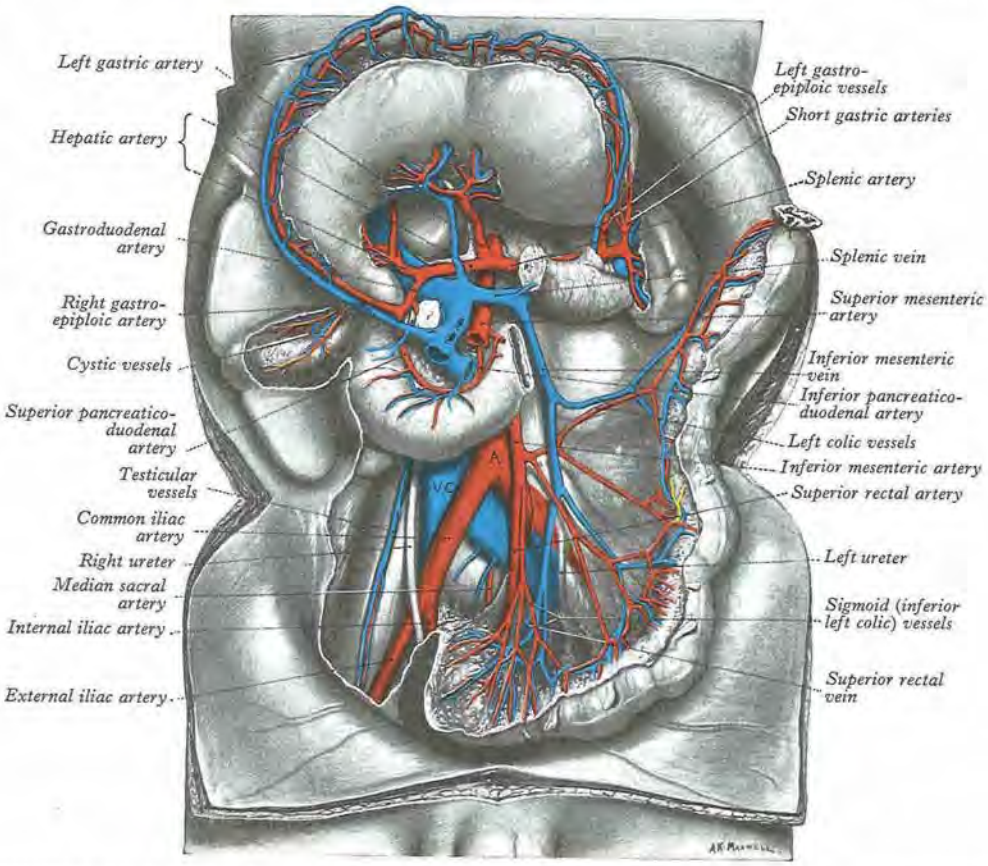
Middle colic artery (10.119). It leaves the superior mesenteric just inferior to the pancreas; descending in the transverse mesocolon it divides into a right and left branch; the former anastomoses with the right colic artery, the latter with the left, a branch of *inferior* mesenteric. Arches thus formed are 3 or 4 cm from the transverse colon, which they supply.

Variations

The superior mesenteric artery may be the source of the common hepatic, gastroduodenal, accessory right hepatic, accessory pancreatic or splenic arteries. It may arise from a common coeliaco–mesenteric trunk (Mangoushi 1975).

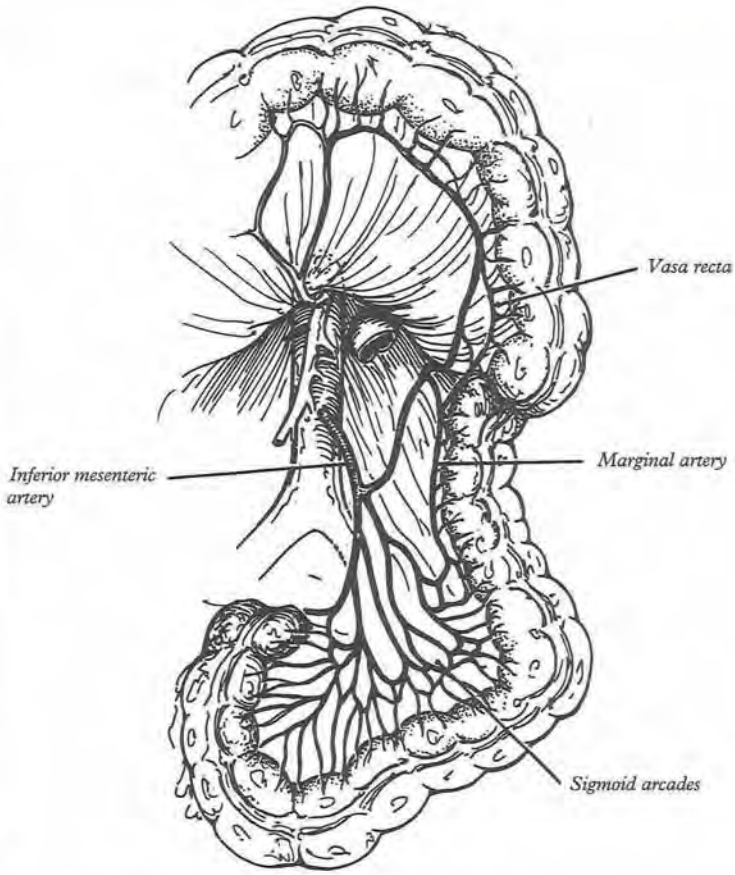
INFERIOR MESENTERIC ARTERY

The inferior mesenteric artery (10.123–127) supplies the left third of the transverse colon, all the descending colon, sigmoid colon and most of the rectum. It is smaller than the superior mesenteric, arising



10.123 The inferior mesenteric vessels and their branches (male subject). Note the stomach has been turned upwards and the whole of the jejunum and ileum, the caecum, ascending colon and transverse colon have been removed, together with part of the pancreas.

10.124 Inferior mesenteric arteriogram. When the superior mesenteric artery is blocked, the marginal artery to the colon enlarges and the inferior mesenteric artery then becomes the blood supply to the midgut.



10.125 Sigmoid colon and rectum, showing the distribution of the branches of the inferior mesenteric artery and their anastomoses.

3 or 4 cm above the aortic bifurcation, posterior to the horizontal part of the duodenum. It descends behind the peritoneum, at first anterior to the aorta, then on its left, crosses the left common iliac artery medial to the left ureter and then enters and continues in the sigmoid mesocolon into the lesser pelvis as the *superior rectal artery*. Distally the inferior mesenteric vein is lateral. The artery has left colic, sigmoid and superior rectal branches.

Left colic artery (10.123–127). It ascends subperitoneally to the left, anterior to the psoas major, and divides into ascending and descending branches. The trunk and its branches cross the left ureter and ovarian or testicular vessels. The ascending branch passes anterior to the left kidney into the transverse mesocolon, where it anastomoses with the middle colic artery; the descending branch anastomoses with the highest sigmoid artery. From arches thus formed, branches supply the left half of the transverse and the descending colon. Territories of supply by middle and left colic arteries show reciprocal variation; the left branch of the middle colic may take over the supply of the splenic flexure (in 19 of 100 cadavers, according to Sierociński 1975).

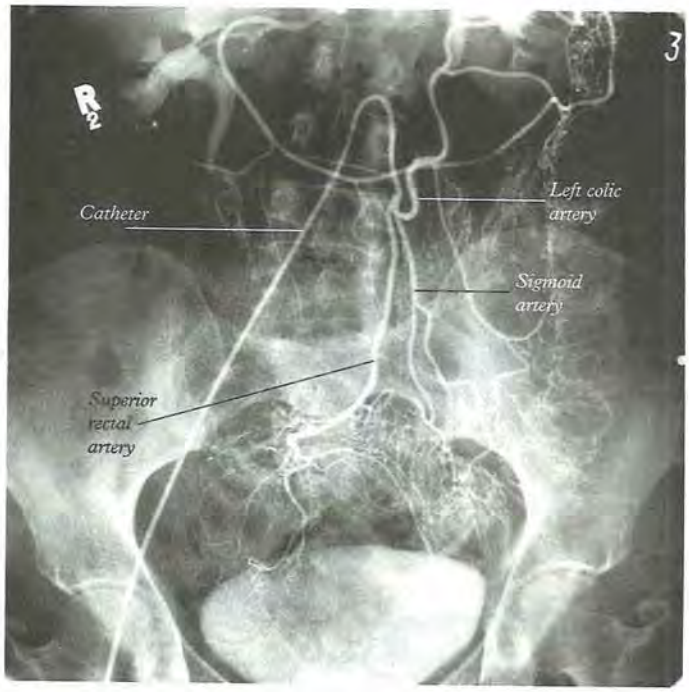
Sigmoid (inferior left colic) arteries (10.123–127). Two or three in number, they descend obliquely to the left under the peritoneum anterior to the left psoas major, ureter and testicular or ovarian vessels. Branches supply the lower descending colon and sigmoid colon, anastomosing above with the left colic artery, below with the superior rectal artery.

Superior rectal artery (10.123–126). A continuation of the inferior mesenteric, it descends into the pelvis in the sigmoid mesocolon, crossing the left common iliac vessels. It divides, near the third sacral vertebra, into two branches descending one on each side of the rectum; about halfway they divide into smaller branches, which pierce the muscular rectal wall to descend vertically, at submucosal level, to the sphincter ani internus; here, by mutual anastomoses, they form loops around the lower rectum, communicating with the middle rectal artery, a branch of the internal iliac, and with the inferior rectal from the internal pudendal (p. 1561).

Marginal artery of the colon. This is formed by the union of the three main colonic branches described above, which arise from the right side of the superior mesenteric artery and then continue around the splenic flexure to join the upward running left colic branch of the inferior mesenteric artery. This is an important vessel from the clinical point of view, because in the event of an occlusion of the two upper vessels (the coeliac trunk and the superior mesenteric artery) it represents the only surviving route of supply to the alimentary tract, flow proceeding retrograde from the inferior mesenteric artery to the superior mesenteric artery (see 10.124–126). The arrangement of vessels along the right colon is fairly constant, there being one marginal artery giving off *vasa recta* and *vasa brevia*, which occasionally communicate, although the anastomoses are less well developed than they are in the small bowel. It is at the point of junction of the superior and inferior mesenteric system (at the splenic flexure) that confusion and variability occur.

Relations

The inferior mesenteric artery divides into two or three branches, the uppermost of which (the left colic) almost always reaches the



10.126 Arteriogram of the inferior mesenteric.

splenic flexure. Here it bifurcates, the slender outer branch joining the left branch of the middle colic from the marginal artery (of Drummond) of the colon, the inner (larger) branch running back into the trunk of the middle colic artery to form an additional arcade, the *arc of Riolan*. The outer anastomosis is here often small or incomplete, so that the continuity of the marginal artery is broken. If the arc of Riolan is not well developed, then there exists a critical area of anastomotic supply, so that impairment of flow either in the superior mesenteric artery or the inferior mesenteric artery will not be compensated, and ischaemic damage may ensue. This explains the relative frequency of ischaemic lesions in the region of the splenic flexure. It used to be taught that there was a critical point (of Sudek) between the last sigmoid branch and the first rectal branch of the superior haemorrhoidal artery, but that is now known not to be the case. The arterial anastomosis here is well-developed (see **10.127**) and if a critical point exists at all then it is at the splenic flexure, as already described.

Clinical anatomy

When the superior mesenteric artery is completely occluded, then the marginal artery to the colon may become enormously dilated (see **10.124**) as it is required to supply the whole of the midgut loop. Alternatively, occlusion of the aorta or common iliac arteries may result in a similar dilatation of the marginal artery, which then becomes an important source of collateral supply to the legs.

ANTEROLATERAL VISCERAL ARTERIES

Middle suprarenal arteries

These two small vessels arise laterally from each side of the aorta, level with the superior mesenteric, ascending slightly over the crura

10.127 An inferior mesenteric arteriogram showing details of the intramural colonic circulation and the occurrence of good anastomotic connections around Sudek's point.

of the diaphragm to the suprarenal glands, where each anastomoses with the suprarenal branches of the phrenic and renal arteries. The right passes behind the inferior vena cava and near the right coeliac ganglion; the left is related to the left coeliac ganglion, splenic artery and superior border of the pancreas.

Renal arteries

These two large vessels branch laterally from the aorta just below the inferior mesenteric; both cross the corresponding crus at right angles to the aorta (**10**.112, 113, 128). The **right** is longer and often higher, passing posterior to the inferior vena cava, right renal vein, head of the pancreas and descending part of the duodenum. The **left** is a little lower; it passes behind the left renal vein, the body of the pancreas and splenic vein and may be crossed anteriorly by the inferior mesenteric vein. Nearing its renal hilum, each divides into four or five branches, most between the renal vein and ureteric pelvis, the vein being anterior, the pelvis posterior, but one or more usually behind the pelvis. Each renal artery supplies small *inferior suprarenal branches* (p. 204) and also the ureter, surrounding cellular tissue and muscles. The distribution of the renal arteries is described on page 1826.

Surface anatomy. The renal arteries can be projected as broad lines running laterally for 4 cm from the aorta (**10**.112) just inferior to the transpyloric plane; the left inclines across the plane.

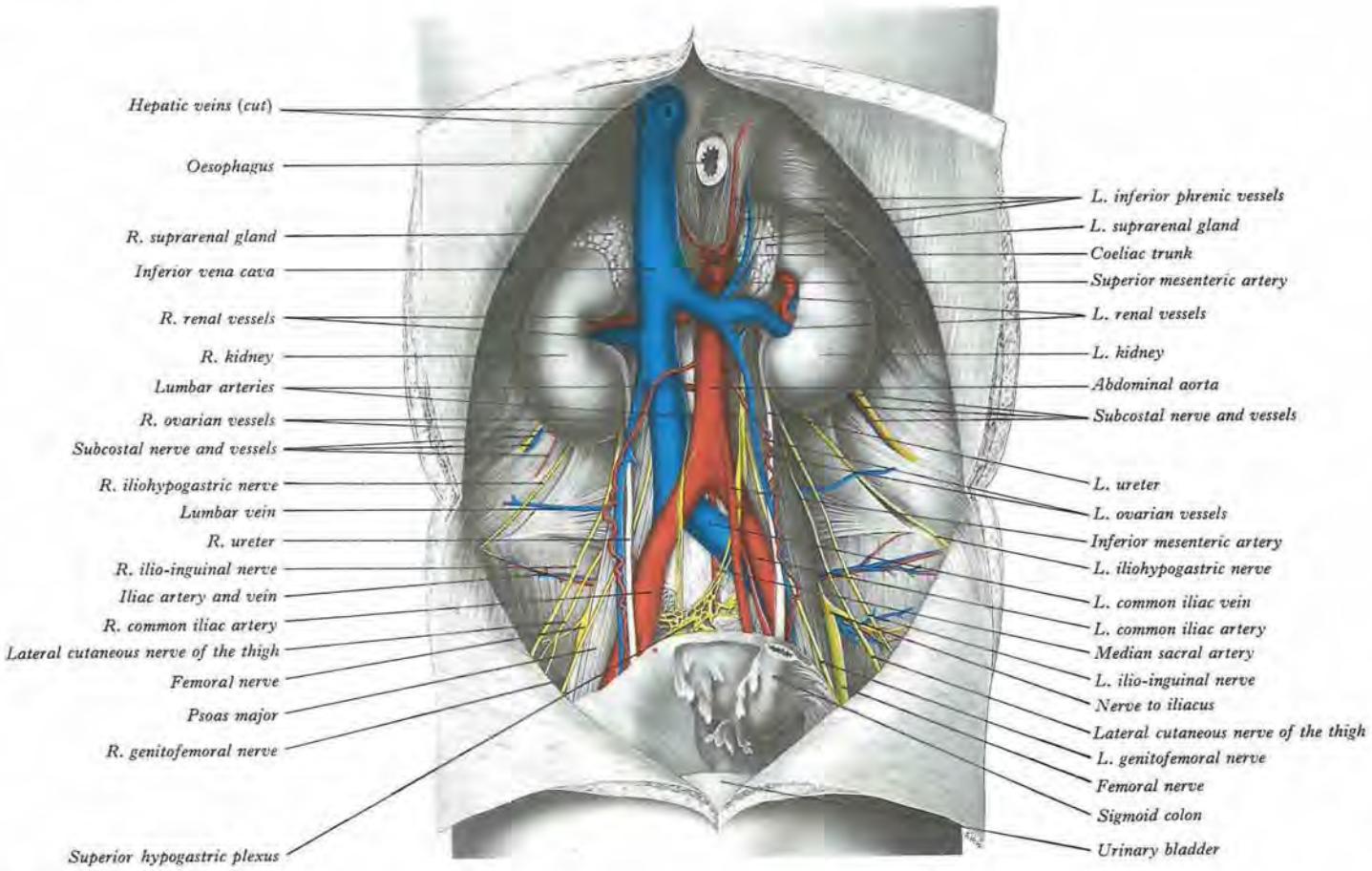
Variations. One or two *accessory renal arteries* frequently occur, especially on the left, usually from the aorta above or below the main artery, the former slightly more often. They usually enter above or below the renal hilum; if below, the vessel crosses anterior to the ureter and, on the right, usually also anterior to the inferior vena cava.

Testicular arteries

These two long, slender vessels arise anteriorly from the aorta a little inferior to the renal arteries (**10**.112, 113, 128). Each passes inferolaterally under the parietal peritoneum on the psoas major; the *right* lies anterior to the inferior vena cava and posterior to the horizontal part of the duodenum, right colic and ileocolic arteries, root of the mesentery and terminal ileum; the *left* testicular artery lies posterior to the inferior mesenteric vein, left colic artery and lower part of the descending colon. Each crosses anterior to the genitofemoral nerve, ureter and the lower part of the external iliac artery, passing to the deep inguinal ring to enter the spermatic cord with other constituents, via which the vessel traverses the inguinal canal to the scrotum. At the posterosuperior aspect of the testis it divides into two branches on its medial and lateral surfaces, which pass through its tunica albuginea to ramify in the tunica vasculosa. Terminal branches enter the testis over its surface. Some pass into the mediastinum testis and loop back before reaching their distribution (Harrison & Barclay 1948). In the abdomen the testicular artery supplies perirenal fat, ureter and iliac lymph nodes; in the inguinal canal it supplies the cremaster.

Sometimes the right testicular artery passes **posterior** to the inferior vena cava. Both arteries represent persistent lateral splanchnic aortic branches (p. 318) which enter the mesonephros and cross ventral to the supracardinal but dorsal to the subcardinal vein. Normally the lateral splanchnic artery which persists as the *right* testicular passes **caudal** to the suprasubcardinal anastomosis forming part of the inferior vena cava (p. 318). When it passes **cranial** to this, the right testicular artery is behind the inferior vena cava.

Clinical anatomy. The testicular artery is not the sole supply to the testis, which also receives some blood from the cremasteric branch of the inferior epigastric artery (see p. 1563). Thus interference with the testicular artery high in the abdomen usually leaves the testis unharmed, whereas interruption in the region of the spermatic cord involves both sets of vessels and leads to infarction.



10.128 Dissection to show the relations of structures on the posterior abdominal wall (female subject).

Ovarian arteries

These correspond to the testicular arteries but enter the pelvis to supply the ovaries (10.132). Initially they resemble the testicular arteries but at the brim of the lesser pelvis each crosses the lower external iliac artery and vein to enter the true pelvic cavity, turning medially in the ovarian suspensory ligament to continue into the uterine broad ligament, below the uterine tube. At ovarian level it passes back in the mesovarium and divides into branches to the ovary. Small branches supply the ureter and uterine tube and one passes to the side of the uterus to unite with the uterine artery. Others accompany the round ligament through the inguinal canal to the skin of the labium majus and the inguinal region.

Early in intrauterine life, when testes or ovaries flank the vertebral column inferior to the kidneys, the testicular and ovarian arteries are relatively short; but with descent of the gonads into the pelvis and beyond, they gradually lengthen.

(Inferior) phrenic arteries

These two small vessels help to supply the diaphragm (10.112, 113, 128), They may arise separately from the aorta, just above its coeliac trunk, by a common aortic stem or from the coeliac trunk; sometimes one is from the aorta, the other from a renal artery. Each artery ascends laterally anterior to a crus of the diaphragm, near the medial border of the suprarenal gland. The **left** passes behind the oesophagus and forwards on the left side of its diaphragmatic opening. The **right** phrenic passes posterior to the inferior vena cava then along the right of its opening. Near the posterior border of the diaphragm's central tendon each divides into medial and lateral branches. The medial curves forwards to anastomose with its fellow in front of the central tendon and with the musculophrenic and pericardiacophrenic arteries; the lateral approaches the thoracic wall, anastomosing with the lower posterior intercostal and musculophrenic arteries. The lateral branch of the right artery supplies the inferior vena cava while the left sends ascending branches to the oesophagus. Each has two or three small *superior suprarenal branches.* The liver (p. 1556) and spleen also receive small branches from the phrenic arteries.

Lumbar arteries

These are in series with the posterior intercostal arteries (10.128). Usually four on each side, they arise posterolaterally from the aorta, opposite the lumbar vertebrae. A fifth, smaller pair occasionally arise from the median sacral artery but lumbar branches of the iliolumbar arteries usually take their place. The lumbar arteries run posterolaterally on the four upper lumbar vertebral bodies, behind the sympathetic trunks, to intervals between the lumbar transverse processes and continue into the abdominal wall. The right arteries pass posterior to the inferior vena cava; the upper two right and first left are also posterior to the corresponding crus. Arteries of both sides pass under tendinous arches (which span the lateral concavities of the vertebral bodies, p. 870) for attachment of psoas major, proceeding posterior to the muscle and the lumbar plexus. They then cross the quadratus lumborum, the upper three posterior, the last usually anterior to it. At its lateral border they pierce the posterior aponeurosis of the transversus abdominis, advancing between it and the internal oblique. They anastomose with one another and the lower posterior intercostal, subcostal, iliolumbar, deep circumflex iliac and inferior epigastric arteries.

Branches. Each lumbar artery has a *dorsal branch* passing back between the adjacent transverse processes to supply the dorsal muscles, joints and skin; this also has a spinal branch entering the vertebral canal to supply its contents and adjacent vertebra, anastomosing with the arteries above and below it and across the midline. The *spinal branch* of the first lumbar supplies the terminal spinal cord itself; the remainder supply the cauda equina, meninges and vertebral canal. Branches of the lumbar arteries and their dorsal branches supply the adjacent muscles, fasciae, bones, red marrow, ligaments and joints (symphyses, syndesmoses and synovial joints).

Median sacral artery

This small posterior branch leaves the aorta a little above its bifurcation (10.112, 113, 128). It descends in the midline, anterior to the fourth and fifth lumbar vertebrae, sacrum and coccyx, ending in the coccygeal body. At fifth lumbar level it is crossed by the left common iliac vein and often gives off a small lumbar artery (*arteria lumbalis ima*), minute branches of which reach the rectum. Anterior to the last lumbar vertebra the median sacral anastomoses with a lumbar branch of the iliolumbar; anterior to the sacrum it anastomoses with the lateral sacral arteries and sends branches into the anterior sacral foramina.

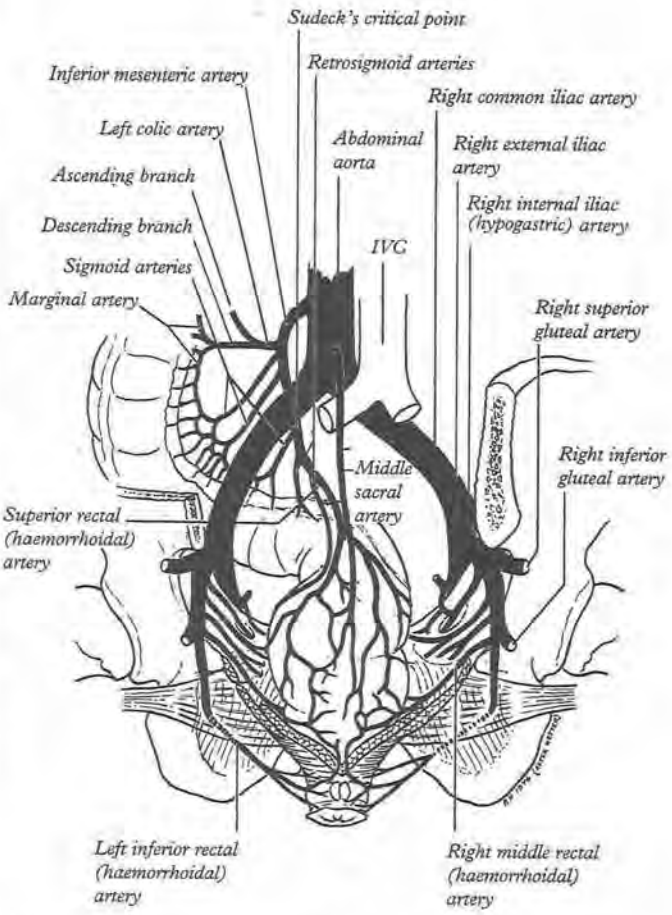
COMMON ILIAC ARTERIES

The abdominal aorta bifurcates, anterolateral to the **left** side of the **fourth** lumbar vertebral body, into the right and left common iliac arteries (10.112, 113, 128, 129). These diverge as they descend to divide near the level of the lumbosacral intervertebral disc (between the last lumbar and first sacral vertebrae) into external and internal iliac arteries; the former supplies most of the lower limb, the latter the pelvic viscera and walls, perineum and gluteal region. The division of the common iliac is anterior to its sacro-iliac joint.

A collateral circulation may be established, in young adults, after ligature of the common iliac artery; when arterial walls degenerate in older patients it is unlikely to supply the leg adequately.

Right common iliac artery

This is about 5 cm long and passes obliquely across part of the fourth and the fifth lumbar vertebral body (10.112, 113, 128, 129). **Anteriorly**, it is crossed by the sympathetic rami to the pelvic plexus and, at its division, by the ureter; it is covered by the parietal peritoneum, which separates it from the coils of the small intestine. **Posteriorly**, it is separated from the fourth and fifth lumbar vertebral bodies and their intervening disc by the sympathetic trunk, the terminal parts of the common iliac veins and the commencement of the inferior vena cava; the obturator nerve, lumbosacral trunk and iliolumbar artery are also posterior, traversing fatty tissue between



10.129 Schematic representation of the main vessels in the pelvic cavity, seen from the back (after Netter).

the fifth lumbar vertebra and the psoas major. **Lateral** to its upper part are the inferior vena cava and the right common iliac vein to which it has a surgically important relationship (see above); lateral to its lower part is the right psoas major; **medial** to its upper part is the left common iliac vein.

Left common iliac artery

The artery is about 4 cm long (**10**.112, 113, 128, 129). **Anterior** are the peritoneum, ileum, the sympathetic rami to the pelvic plexus, the superior rectal artery and, at its terminal bifurcation, the ureter. Posterior are the sympathetic trunk, fourth and fifth lumbar vertebral bodies and intervening disc; the obturator nerve, lumbosacral trunk and iliolumbar artery are more posterior (i.e. deeply situated). The left common iliac vein is partly **medial**, partly **posterior** to the artery; **lateral** and closely related is the left psoas major.

Surface anatomy. The vessel corresponds to the superior third of a broad line from the aortic bifurcation (p. 1547) to a point midway between the anterior superior iliac spine and the pubic symphysis. The *external iliac artery* corresponds to the inferior two-thirds of this line, which is laterally slightly convex.

Branches. In addition to the terminal branches, each common iliac artery gives small branches to the peritoneum, psoas major, ureter, adjacent nerves and surrounding areolar tissue; occasionally it has the iliolumbar and accessory renal arteries as branches.

INTERNAL ILIAC ARTERIES

Each internal iliac artery (**10**.130, 131), about 4 cm long, begins at the common iliac bifurcation, level with the lumbosacral intervertebral disc and anterior to the sacro-iliac joint; it descends posteriorly to the superior margin of the greater sciatic foramen, dividing here into: an *anterior trunk*, which continues in the same line towards the ischial spine; and a *posterior trunk*, passing back to the foramen (Braithwaite 1952). **Anterior** are the ureter and, in females, the ovary and fimbriated end of the uterine tube; **posterior** are the internal iliac vein, lumbosacral trunk and sacro-iliac joint; **lateral** is the external iliac vein, between the artery and the psoas major and inferior to this the obturator nerve; **medial** is the parietal peritoneum, separating it from the terminal ileum on the right and the sigmoid colon on the left, and tributaries of the internal iliac vein.

In the fetus the internal iliac artery is twice the size of the external and is the direct continuation of the common iliac. It ascends on the anterior abdominal wall to the umbilicus, converging on its fellow. Having traversed the opening, the two arteries, now umbilical, enter the umbilical cord, coil round the umbilical vein and ultimately ramify in the placenta. At birth, when placental circulation ceases, only the pelvic segment remains patent as the internal iliac artery and part of the superior vesical, the remainder becoming a fibrous *medial umbilical ligament* raising the peritoneal *medial umbilical fold* from the pelvis to the umbilicus. In males, the patent part usually gives off an artery to the ductus deferens (see below).

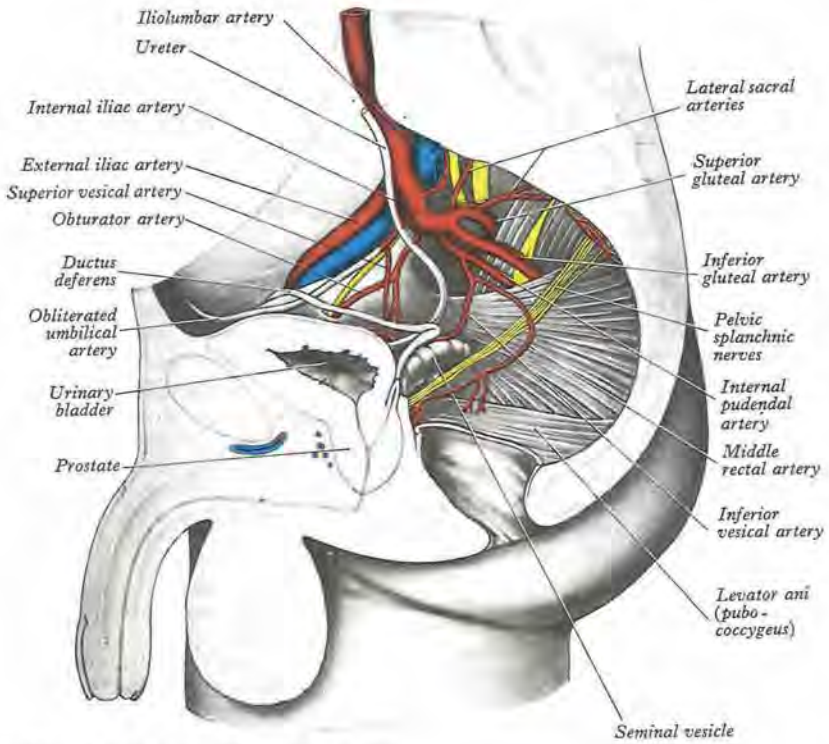
BRANCHES OF ANTERIOR TRUNK OF INTERNAL ILIAC ARTERY

Superior vesical artery (**10**.130, 131). This supplies many branches to the vesical fundus (Braithwaite 1951); from one the *artery to the ductus deferens* occasionally starts and accompanies the ductus to the testis, anastomosing with the testicular artery. Others supply the ureter. The beginning of the superior vesical artery is the proximal, patent section of the fetal umbilical artery (see above).

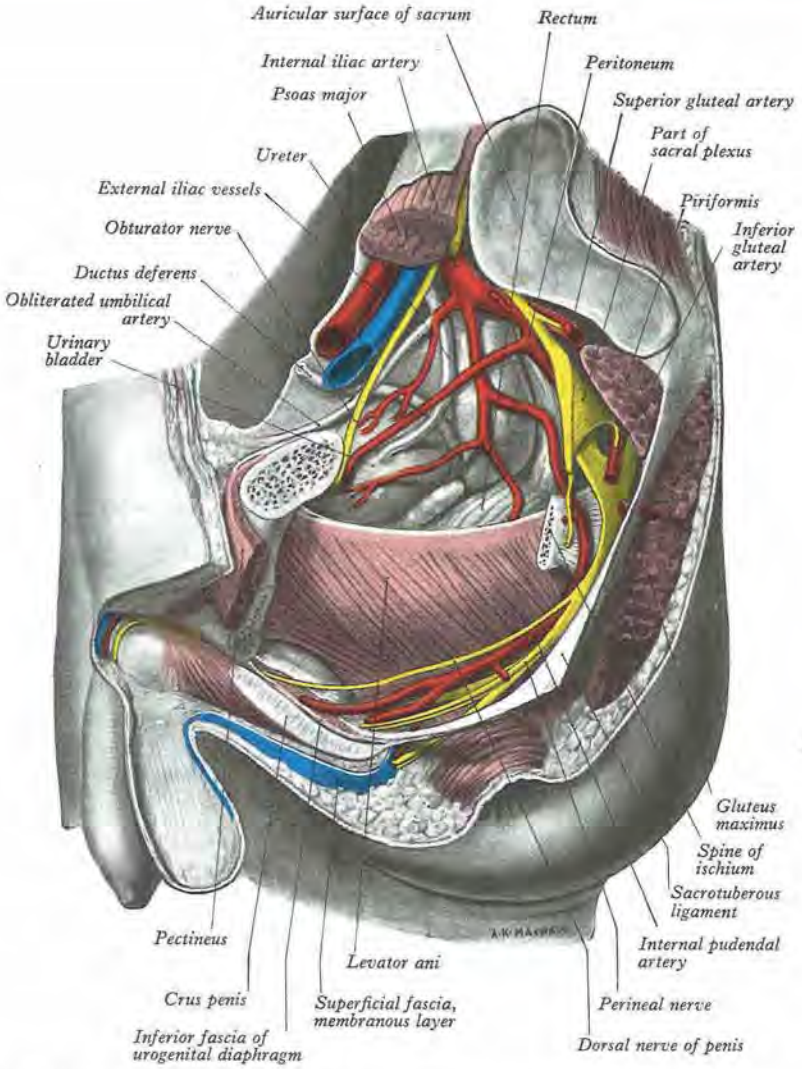
Inferior vesical artery (**10**.130, 131). Often arising with the middle rectal, it supplies the vesical fundus, prostate, seminal vesicles and lower ureter. Prostatic branches communicate across the midline. The inferior vesical may sometimes provide the artery to the ductus deferens.

Middle rectal artery (**10**.125, 130). It usually arises with the inferior vesical. It vascularizes muscular tissue in the lower rectum, anastomosing with the superior and inferior rectal arteries. It supplies the seminal vesicles and prostate by branches which join those of the inferior vesical.

Uterine artery (**10**.132). This runs medially on the levator ani to the cervix uteri; about 2 cm from this it crosses above the *ureter*, to which it supplies a small branch, and above the *lateral vaginal fornix*. It ascends tortuously lateral to the uterus in its broad ligament to the junction of the uterine tube and uterus, turning laterally towards



10.130 The arteries of the male pelvis (right side). The internal iliac vein and its tributaries have been removed; the rectum has been divided just above the anal canal and its upper part has been taken away.



10.131 Structures of the male pelvic contents from the left side. Most of the left innominate bone has been removed together with the obturator internus. The sciatic nerve has been cut away close to its origin from the sacral plexus. All the vessels and nerves exposed are those of the left side. Note the superior vesical, obturator, inferior vesical and middle rectal arteries which are, for technical reasons, unlabelled.

the ovarian hilum, and ends by joining the ovarian artery. It supplies the cervix uteri and branches descend on the vagina, anastomosing with branches of the vaginal arteries to form two median longitudinal vessels, the *azygos arteries of the vagina*; one descends anterior, the other posterior, to the vagina. The uterine artery supplies the body of the uterus, uterine tube and round ligament of the uterus. Terminal branches in the uterine muscle are tortuous *helicine arteries*.

Vaginal artery. Often double or triple, it corresponds to the inferior vesical in males; it descends on the vagina, supplying mucous membrane, and sends branches to the vestibular bulb, vesical fundus and the adjacent part of the rectum. It assists in forming the azygos arteries of the vagina (see above).

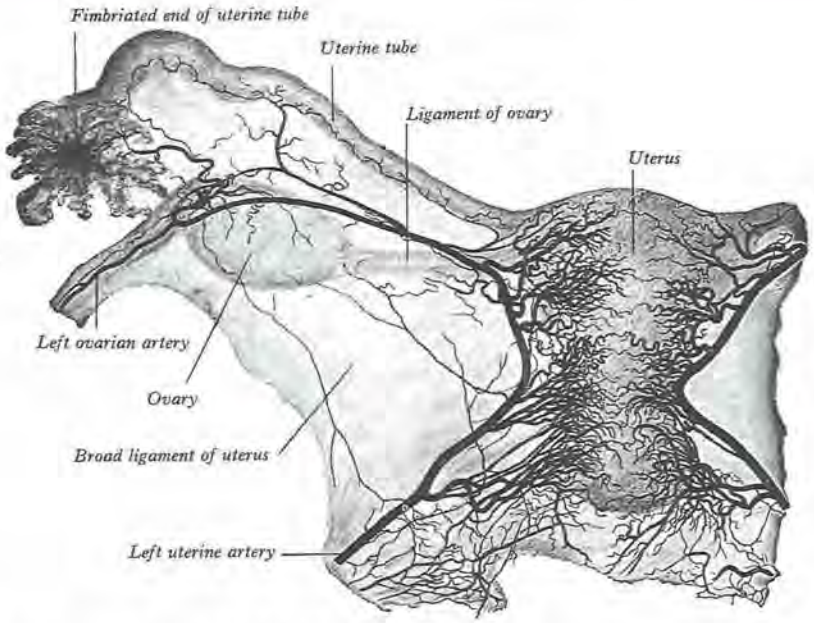
Obturator artery (10.130). It inclines antero-inferiorly on the lateral pelvic wall to the upper part of the obturator foramen. Leaving the pelvic cavity by the obturator canal, it divides into anterior and posterior branches. In the pelvis it is related laterally to the obturator fascia, separating it from the obturator internus; it is crossed medially by the ureter and the ductus deferens, separating it from the parietal peritoneum. In the nullipara the ovary is medial. The obturator nerve is above, the vein below.

Branches. In the pelvis, the obturator artery provides:

- *iliac branches* to the iliac fossa, supplying the bone and iliacus and anastomosing with the iliolumbar artery
- a *vesical branch* passing medially to the bladder, sometimes replacing the inferior vesical branch of the internal iliac
- a *pubic branch* just before it leaves the pelvis, which ascends over the pubis to anastomose with its fellow and the pubic branch of the inferior epigastric.

Outside the pelvis its anterior, and posterior terminal branches encircle the foramen between the obturator externus and the obturator membrane. The *anterior branch* curves forwards on the membrane and then down along its anterior margin, supplying branches to the obturator externus, pectineus, femoral adductors and gracilis and anastomosing with the posterior branch and the medial circumflex femoral artery. The *posterior branch* follows the foramen's posterior margin and turns forwards on the ischial branch to anastomose with the anterior. It supplies the muscles attached to the ischial tuberosity and anastomoses with the inferior gluteal. An *acetabular branch* enters the hip joint at the acetabular notch, ramifies in the fat of the acetabular fossa and sends a branch along the ligament of the femoral head.

Variations. In 20–30% of subjects the obturator artery is replaced by an enlarged pubic branch of the inferior epigastric (p. 1563); this descends almost vertically to the obturator foramen. Such an abnormal obturator artery is usually near the external iliac vein, lateral to the femoral ring, and is then safe in herniotomy. Sometimes



10.132 The left uterine and ovarian arteries of a nullipara of $17\frac{1}{2}$ years: posterior aspect. (From a preparation by Hamilton Drummond.)

it curves along the edge of the lacunar part of the inguinal ligament, partly encircling the neck of a hernial sac, and may be inadvertently cut during enlargement of the femoral ring in reducing a femoral hernia.

Internal pudendal artery in the male (10.130, 131, 133, 134)

The artery descends laterally to the inferior rim of the greater sciatic foramen, where it leaves the pelvis between piriformis and coccygeus and enters the *gluteal region*; then curving around the dorsum of the ischial spine to enter the perineum by the lesser sciatic foramen, it traverses the pudendal canal in the lateral wall of the *ischiorectal fossa*, medial to the obturator internus, about 4 cm above the ischial tuberosity's lower limit. Approaching the margin of the ischial branch, it proceeds above or below the inferior fascia of the urogenital diaphragm along the medial margin of the inferior pubic ramus and ends behind the inferior pubic ligament, dividing into the *deep* and *dorsal arteries of the penis*. It may descend through the inferior fascia before its division. (The internal pudendal distal to its perineal branch has been named *artery of the penis*, appropriately in view of its distribution; see below.)

Relations. In the pelvis the internal pudendal artery crosses anterior to the piriformis, sacral plexus and inferior gluteal artery. Behind the ischial spine it is covered by the gluteus maximus, with the pudendal nerve medial and the nerve to obturator internus lateral. In the pudendal canal (p. 832) it travels at first with companion veins and the pudendal nerve; beyond this the dorsal nerve of the penis is above, the perineal nerve below.

Muscular branches (10.133, 134). These leave the artery in the pelvis and gluteal region to supply the adjacent muscles and nerves.

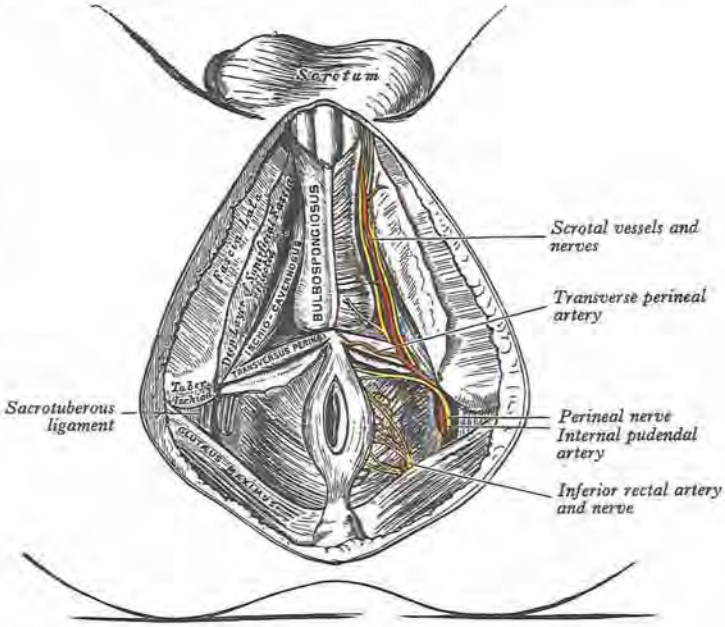
Inferior rectal artery. This arises above the ischial tuberosity. Escaping from the pudendal canal (p. 832), it divides into two or three branches crossing the ischiorectal fossa medially to supply the anal skin and musculature. Small branches skirt the lower edge of the gluteus maximus to supply the gluteal skin. The inferior rectal anastomoses with its fellow, and with the superior, middle rectal and perineal arteries.

Perineal artery (10.133). It leaves the internal pudendal near the anterior end of its canal, turns down through the inferior fascia of the urogenital diaphragm (p. 834) and approaches the scrotum in the superficial perineal region, between the bulbospongiosus and ischiocavernosus. Beyond the diaphragm, and near its base, a small *transverse branch* passes medially inferior to the superficial transverse perineal muscle to anastomose with its fellow and the posterior scrotal and inferior rectal arteries, supplying tissues between the anus and the penile bulb. The posterior *scrotal arteries*, distributed to the scrotal skin and dartos muscle, are usually terminals of the perineal but may also arise from its transverse branch; they also supply the perineal muscles.

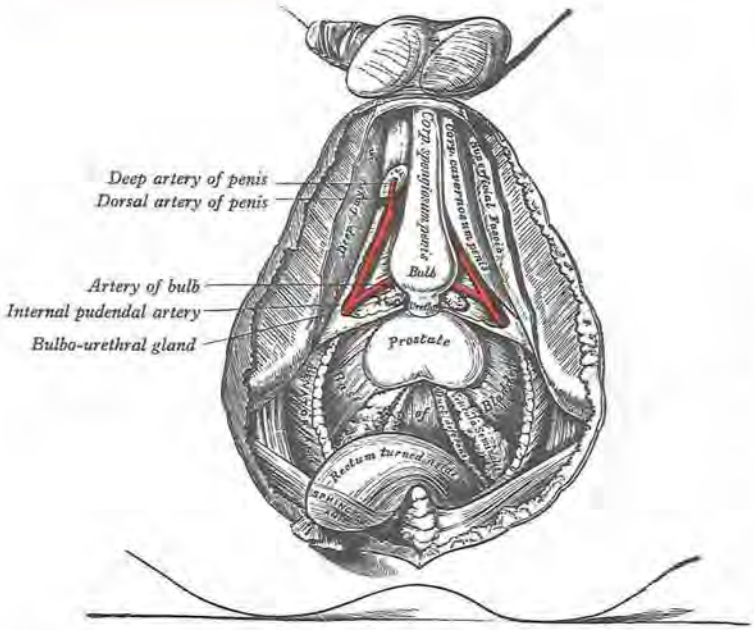
Artery of the bulb of the penis. Short but wide, it runs medially through the deep transverse perineal muscle and inferior urogenital fascia to the penile bulb. Penetrating this, it supplies the posterior part of the corpus spongiosum and the bulbo-urethral gland.

Urethral artery. This traverses the urogenital diaphragm's inferior fascia and enters the corpus spongiosum, reaching the glans penis. It supplies the urethra and erectile tissue around it.

Deep artery of the penis. A terminal branch of the internal



10.133 The superficial branches of the internal pudendal artery, in the male.



10.134 The deeper branches of the internal pudendal artery, in the male.

pudendal, it passes through the inferior fascia of the urogenital diaphragm to enter the crus penis. It traverses the corpus cavernosum and supplies its erectile tissue.

Dorsal artery of the penis. The other terminal branch of the internal pudendal, it leaves the inferior aspect of the urogenital diaphragm, **ascends** between the crus penis and pubic symphysis, and traverses the suspensory ligament of the penis to run along its dorsum to the glans, where it forks into branches to the glans and prepuce. In the penis it lies between its dorsal nerve and deep dorsal vein, the latter being most medial. It supplies penile skin and the fibrous sheath of the corpus cavernosum, anastomosing through the sheath with the deep penile artery.

Inferior gluteal artery

The larger terminal branch of the anterior internal iliac trunk, it chiefly supplies the buttock and thigh. It descends anterior to the sacral plexus and piriformis, posterior to the internal pudendal artery (**10**.129, 135). Passing between the first and second or second and third sacral anterior spinal nerve rami, then between the piriformis and coccygeus, it traverses the lower part of the greater sciatic foramen to reach the gluteal region. Descending between the greater trochanter and ischial tuberosity with the sciatic and posterior femoral cutaneous nerves, deep to the gluteus maximus, it continues down the thigh, supplying the skin and anastomosing with branches of the perforating arteries. The inferior gluteal and internal pudendal arteries are often a common stem from the internal iliac, sometimes including the superior gluteal artery.

Surface anatomy. The inferior gluteal artery leaves the pelvis near the midpoint of a line joining the posterior superior iliac spine and the ischial tuberosity.

Branches. Inside the pelvis there are branches to the following:

- the piriformis, coccygeus and levator ani
- the perirectal fat, occasionally replacing the middle rectal artery
- the vesical fundus, seminal vesicles and prostate.

Outside the pelvis muscular branches supply the gluteus maximus, obturator internus, gemelli, quadratus femoris and the proximal parts of the hamstring muscles, anastomosing with the superior gluteal, internal pudendal, obturator and medial circumflex femoral arteries. *Coccygeal branches* run medially through the sacrotuberous ligament to supply the gluteus maximus and the structures attached to the coccyx. The *artery to the sciatic nerve* runs on the nerve for a short distance, then descends in it to the lower thigh. An *anastomotic branch* descends obliquely across obturator internus, gemelli and quadratus femoris, to join the *cruciate anastomosis* (p. 1567) linking with the first perforating and medial and lateral circumflex femoral arteries. This may become an important route of collateral supply in cases of occlusion of the aorto-iliac system. An *articular branch*, usually from the anastomotic, is distributed to the hip joint. *Cutaneous branches* supply the buttock and back of the thigh.

Internal pudendal artery in the female

The internal pudendal in the female is naturally smaller but its origin, course and branches are similar, including the *posterior labial branches*, the *artery of the bulb* (distributed to the erectile tissue of the vestibular bulb and vagina), *deep artery of the clitoris*, supplying the corpus cavernosum, and a *dorsal artery* to the glans and prepuce of the clitoris.

Variations

Branches of the internal pudendal are sometimes derived from an *accessory pudendal*, usually a branch of the pudendal before its exit from the pelvis.

BRANCHES OF POSTERIOR TRUNK OF INTERNAL ILIAC ARTERY

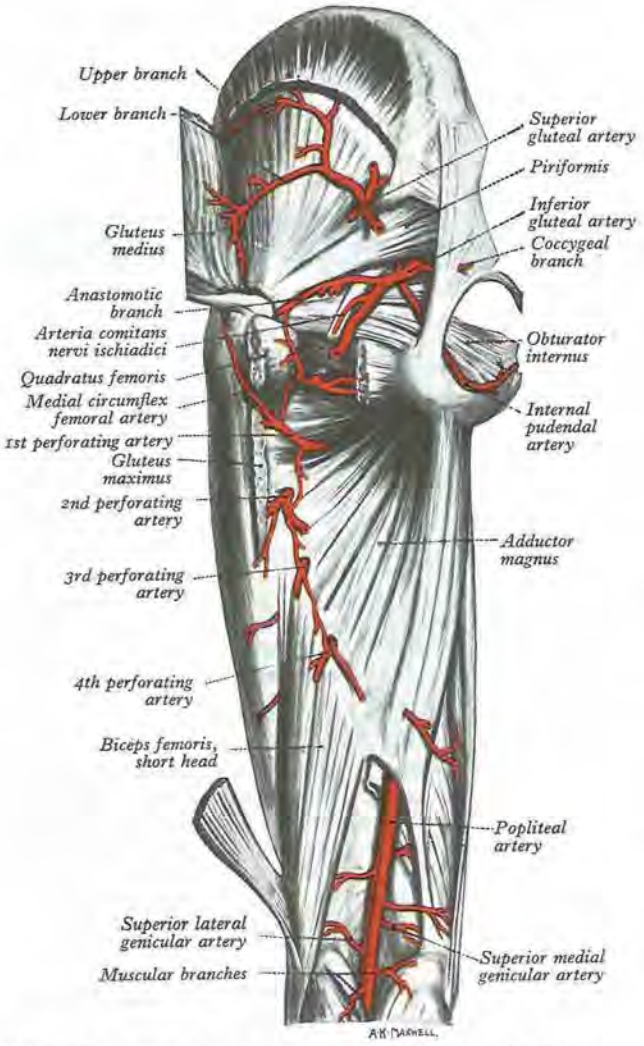
Iliolumbar artery (**10**.130). This ascends laterally **anterior** to the sacro-iliac joint and lumbosacral trunk, **posterior** to the obturator nerve and external iliac vessels, to reach the medial border of psoas major, dividing behind it into the lumbar and iliac branches. The *lumbar branch* supplies the psoas major and quadratus lumborum, anastomoses with the fourth lumbar artery and sends a small *spinal branch* through the intervertebral foramen between the fifth lumbar and first sacral vertebrae, which supplies the cauda equina. The *iliac branch* supplies the iliacus; between the muscle and bone it anastomoses with the iliac branches of the obturator. A large nutrient branch enters an oblique canal in the ilium; others skirt the iliac crest, supplying the gluteal and abdominal muscles and anastomosing with the superior gluteal, circumflex iliac and lateral circumflex femoral arteries.

Lateral sacral arteries (**10**.130). These are from the posterior trunk of the internal iliac, usually as a superior and an inferior branch. The *superior* and larger passes medially into the first or second anterior sacral foramen, supplies the sacral vertebrae and contents of the sacral canal and escapes via the corresponding dorsal foramen to supply the skin and muscles dorsal to the sacrum. The *inferior lateral sacral artery* crosses obliquely anterior to the piriformis and the sacral anterior spinal rami, then descends lateral to the sympathetic trunk to anastomose with its fellow and the median sacral artery anterior to the coccyx. Its branches enter the anterior sacral foramina, distributed like those of the superior artery.

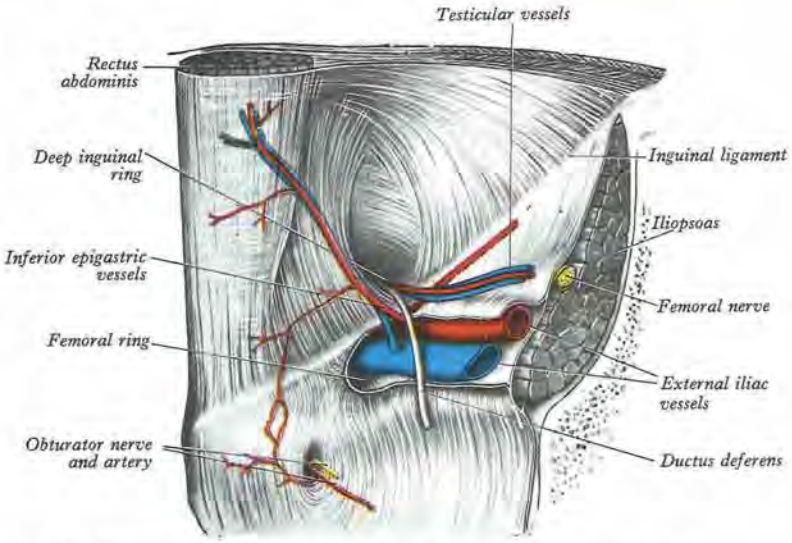
Superior gluteal artery (**10**.129, 130, 135). The largest branch of the internal iliac and the continuation of its posterior trunk, it runs back between the lumbosacral spinal trunk and the first sacral ramus or between the first and second rami, leaving the pelvis by the greater sciatic foramen above the piriformis and dividing into *superficial* and *deep branches*. In the pelvis it supplies the piriformis, obturator internus and an innominate nutrient artery. The superficial branch enters the deep surface of the gluteus maximus; its numerous branches supply the muscle and anastomose with the inferior gluteal, others perforating its tendinous medial attachment to supply the skin over the sacrum, anastomosing with the posterior branches of the lateral sacral arteries. The deep branch is between the gluteus medius and the bone, soon dividing into superior and inferior branches. The *superior* skirts the superior border of the gluteus minimus to the anterior superior iliac spine, anastomosing with the deep circumflex iliac artery and the ascending branch of the lateral circumflex femoral. The *inferior branch* traverses the gluteus minimus obliquely and supplies it and also the gluteus medius, anastomosing with the lateral circumflex femoral; a branch enters the trochanteric fossa to join the inferior gluteal and ascending branch of the medial circumflex femoral; other branches pierce the gluteus minimus to supply the hip joint.

The superior gluteal artery may arise from the internal iliac with the inferior gluteal and sometimes the internal pudendal.

Surface anatomy. The artery's pelvic exit corresponds to the



10.135 The arteries of the left gluteal and posterior femoral regions.



10.136 Dissection of the deep aspect of the lower part of the abdominal wall of the right side with the thinner posterior wall of the rectus sheath. The femoral and deep inguinal rings are displayed together with the vessels and other structures in relation to them and also the opening into the obturator canal.

junction of the upper and middle thirds of a line joining the posterior superior iliac spine to the apex of the greater trochanter.

EXTERNAL ILIAC ARTERIES

The external iliac arteries (**10**.129–131, 136) are larger than the internal. Each descends laterally along the medial border of the psoas major from the common iliac bifurcation (anterior to the sacro-iliac joint at lumbosacral disc level) to a point midway between the anterior superior iliac spine and the symphysis pubis, entering the thigh posterior to the inguinal ligament to become the femoral artery.

Anteromedially the artery is related to the parietal peritoneum and extraperitoneal tissue, separating the right from the terminal ileum and often the appendix, the left from the sigmoid colon and coils of the small intestine. At its origin the artery may be crossed by the ureter, in females by ovarian vessels. Testicular vessels are anterior for some distance near its distal end, and it is crossed here by the genital branch of the genitofemoral nerve, the deep circumflex iliac vein and the ductus deferens or round ligament. **Posteriorly** the iliac fascia separates it from the medial border of the psoas major. The external iliac vein is partly posterior to its upper part, medial to it below. **Laterally** it is related to the psoas major, the iliac fascia lying between them. Numerous lymph vessels and nodes lie on its front and sides.

Branches. Apart from very small vessels to the psoas major and neighbouring lymph nodes, the artery has no branches until the inferior epigastric and deep circumflex iliac arise near to its termination. Besides supplying the psoas major and neighbouring lymph nodes, the artery has inferior epigastric and deep circumflex iliac branches.

Inferior epigastric artery (7.84, **10**.136)**.** This leaves the external iliac just proximal to the inguinal ligament, curves forwards in extraperitoneal tissue, ascends obliquely along the medial margin of the deep inguinal ring, continues up to pierce the transversalis fascia and the attenuated part of the rectus sheath (p. 825) and ascends between the rectus abdominis and the posterior lamina of its sheath. It divides into numerous branches, which anastomose with those of the superior epigastric and lower posterior intercostal arteries. The artery thus skirts the deep inguinal ring inferomedially, passing posterior to the spermatic cord but separated from it by the transversalis fascia. It raises the parietal peritoneum of the anterior abdominal wall as the *lateral umbilical fold* (p. 1737). The ductus deferens, or round ligament, winds laterally round it. It supplies the following branches:

- The *cremasteric artery* (see above) accompanies the spermatic cord, supplies the cremaster and other coverings of the cord and anastomoses with the testicular artery. In females it is small and accompanies the round ligament.
- A *pubic branch*, near the femoral ring, descends posterior to the pubis and anastomoses with the pubic branch of the obturator. In 20–30% of subjects, the pubic branches of the inferior epigastric are larger than, and replace, those of the obturator artery (p. 1560).
- *Muscular branches* supply the abdominal muscles and peritoneum, anastomosing with the circumflex iliac and lumbar arteries.
- *Cutaneous branches* perforate the aponeurosis of the external oblique, supply the skin and anastomose with branches of the superficial epigastric artery.

Variations. The artery may arise from the femoral and then ascend, anterior to the femoral vein, to the abdomen. It often arises from the external iliac artery in common with an abnormal obturator and, rarely, directly from the obturator artery.

Clinical anatomy. The inferior epigastric artery is a main route, through anastomosis with the internal thoracic, for collateral circulation after ligature of either the common or the external iliac arteries. It is **medial** to the neck of an oblique inguinal hernia but **lateral** to that of a direct inguinal hernia (p. 1560).

Deep circumflex iliac artery. This branches laterally from the external iliac almost opposite the inferior epigastric. It ascends

laterally to the anterior superior iliac spine posterior to the inguinal ligament in a sheath formed by the junction of the transversalis and iliac fasciae. There it anastomoses with the ascending branch of the lateral circumflex femoral artery, pierces the transversalis fascia and skirts the internal lip of the iliac crest; about halfway it perforates the transversus abdominis and runs between this and the internal oblique to anastomose with the iliolumbar and superior gluteal arteries. At the anterior superior iliac spine it has a large *ascending branch*, which runs between the internal oblique and the transversus, supplying them and anastomosing with the lumbar and inferior epigastric arteries.

ARTERIES OF THE LOWER LIMBS

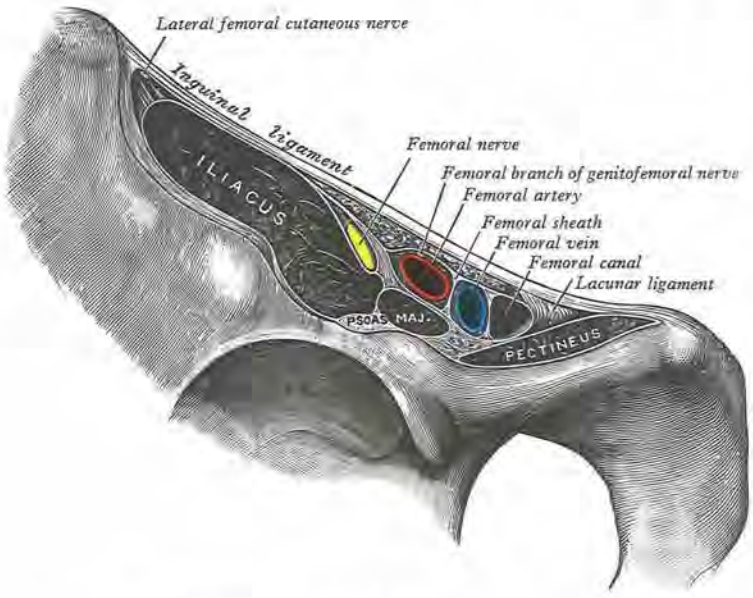
The main artery of the thigh is the continuation of the external iliac, extending from the inguinal ligament to the distal border of the popliteus, where it divides into the anterior and the posterior tibial artery. Its proximal section, the femoral artery, lies among the knee extensor muscles; its continuation, the popliteal artery, is among the knee flexors.

FEMORAL ARTERY

The femoral artery (**10**.137–142), a continuation of the external iliac, begins behind the inguinal ligament, midway between the anterior superior iliac spine and the pubic symphysis, descends along the anteromedial part of the thigh in the femoral triangle and becomes the popliteal as it passes through the adductor canal, an opening in the adductor magnus near the junction of the middle and distal thirds of the thigh. Its first 3 or 4 cm are enclosed, with its vein, in the femoral sheath.

FEMORAL SHEATH

Distal prolongations, behind the inguinal ligament, of the transversalis fascia, anterior to the femoral vessels, and of the iliac fascia, posterior, together form a short funnel, wider proximally, its distal end fusing with the vascular fascia 3 or 4 cm distal to the ligament (**10**.137). At birth the sheath is shorter, elongating when extension at the hips becomes habitual. Its vertical lateral wall is perforated by the femoral branch of the genitofemoral nerve; the medial wall slopes laterally and is pierced by the great (long) saphenous vein and lymphatic vessels. Like the carotid sheath, the femoral sheath encloses a mass of connective tissue in which the vessels are embedded. Three compartments are described: a lateral one containing the femoral artery; an intermediate one for the femoral vein; medial and smallest is the femoral canal, containing the lymph vessels and a lymph node embedded in areolar tissue, probably to allow the vein to distend. This canal is conical, about 1.25 cm in length; its proximal end is the outer femoral ring, bounded in front by the inguinal ligament, behind by the pectineus and its fascia, medially by the crescentic edge of the lacunar ligament and laterally by the femoral vein (p. 1789). The spermatic cord, or the round ligament, is just above its anterior margin; the inferior epigastric vessels are near its anterolateral rim. It is larger in women than in men due partly to the greater breadth of the pelvis, partly to the smaller size of the femoral vessels, in women. The ring is filled by condensed extraperitoneal tissue, the femoral septum, covered by the parietal peritoneum (p. 1788). The femoral septum is traversed by numerous lymph vessels connecting the deep inguinal to the external iliac lymph nodes.



10.137 The structures passing posterior to the right lacunar ligament: inferior (distal) aspect. Note the lacuna musculorum and the lacuna vasorum.

Femoral triangle (**10**.138–140)

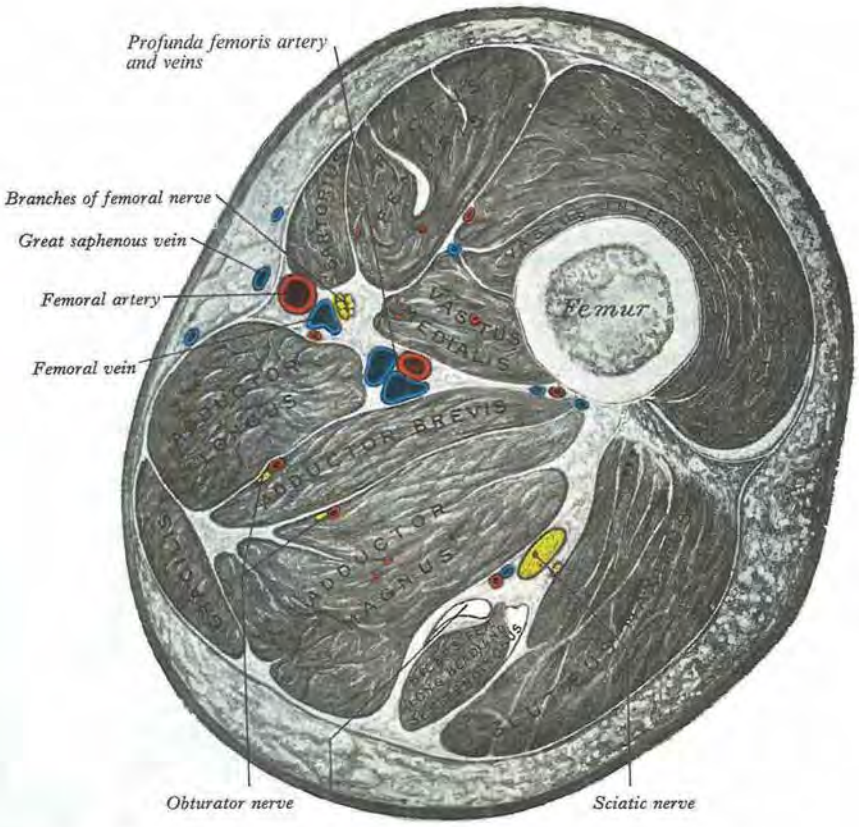
The femoral triangle is a depressed area of the thigh lying distal to the inguinal fold. Its apex is distal, its limits being laterally the medial margin of sartorius, medially the medial margin of adductor longus; proximally (the base) is the inguinal ligament. Its floor is provided laterally by iliacus and psoas major, medially by pectineus and adductor longus. The femoral vessels, passing from midbase to apex, are in the deepest part of the triangle. Lateral to the artery the femoral nerve divides. The triangle also contains fat and lymph nodes.

Relations of the femoral artery in the femoral triangle (**10**.140). **Anterior** to the artery are the skin, superficial fascia, superficial inguinal lymph nodes, fascia lata, femoral sheath, superficial circumflex iliac vein (crossing in the superficial fascia) and the femoral branch of the genitofemoral nerve (at first lateral then anterior). Near the apex the medial femoral cutaneous nerve crosses the artery from the lateral to the medial side. **Posterior** are the femoral sheath and the tendons of psoas, pectineus and adductor longus. The artery is separated from the hip joint by the tendon of psoas major, from the pectineus by the femoral vein and profunda vessels and from the adductor longus by the femoral vein. Proximally, the nerve to the pectineus passes medially behind the artery; **lateral** to it is the femoral nerve. The femoral vein is **medial** in the proximal part of the triangle, becoming posterior near its apex, distally.

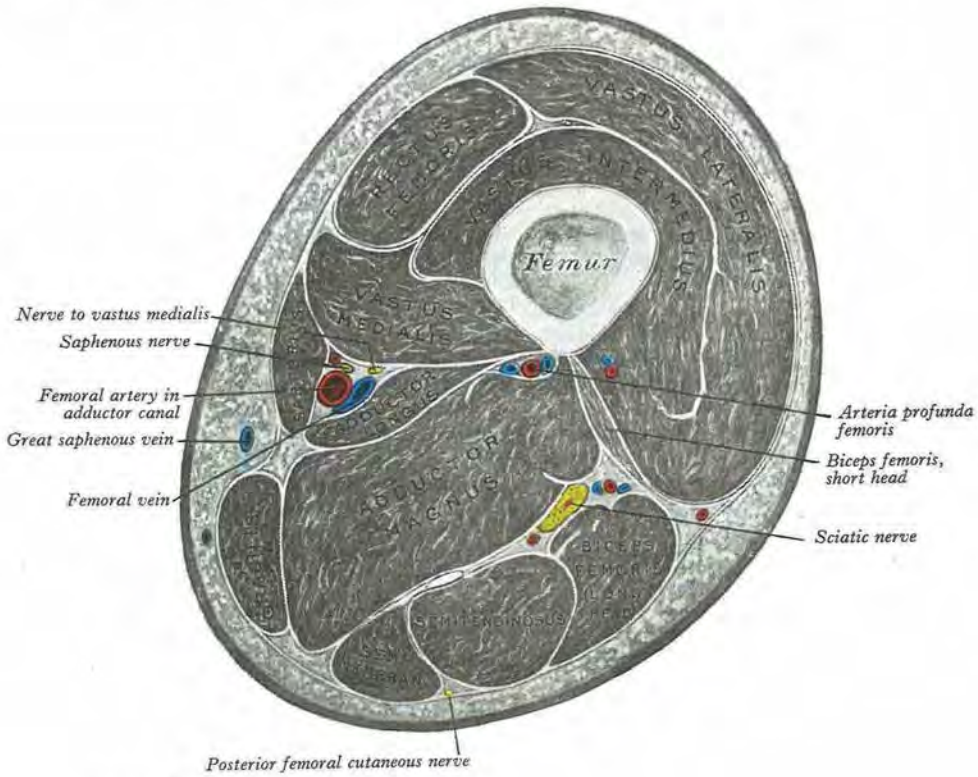
Adductor canal (**10**.138–140). It is an aponeurotic tunnel in the middle third of the thigh, from the apex of the femoral triangle to the opening in adductor magnus, through which femoral vessels reach the popliteal fossa. Triangular in section, it is bounded **anterolaterally** by vastus medialis, **posteriorly** by adductor longus, distally by adductor magnus and **anteromedially** by a strong aponeurosis extending between the adductors across the vessels to vastus medialis. The sartorius is anterior. The canal contains the femoral artery and vein, the saphenous nerve, and the nerve to vastus medialis until it enters its muscle.

Relations of the femoral artery in the adductor canal (**10**.139–141). **Anterior** to the artery are the skin, superficial and deep fasciae, sartorius and fibrous roof of the canal. The saphenous nerve is first lateral, then anterior and finally medial. **Posterior** are the adductor longus and adductor magnus; the femoral vein is also posterior proximally, but becoming lateral distally. Anterolateral are the vastus medialis and its nerve.

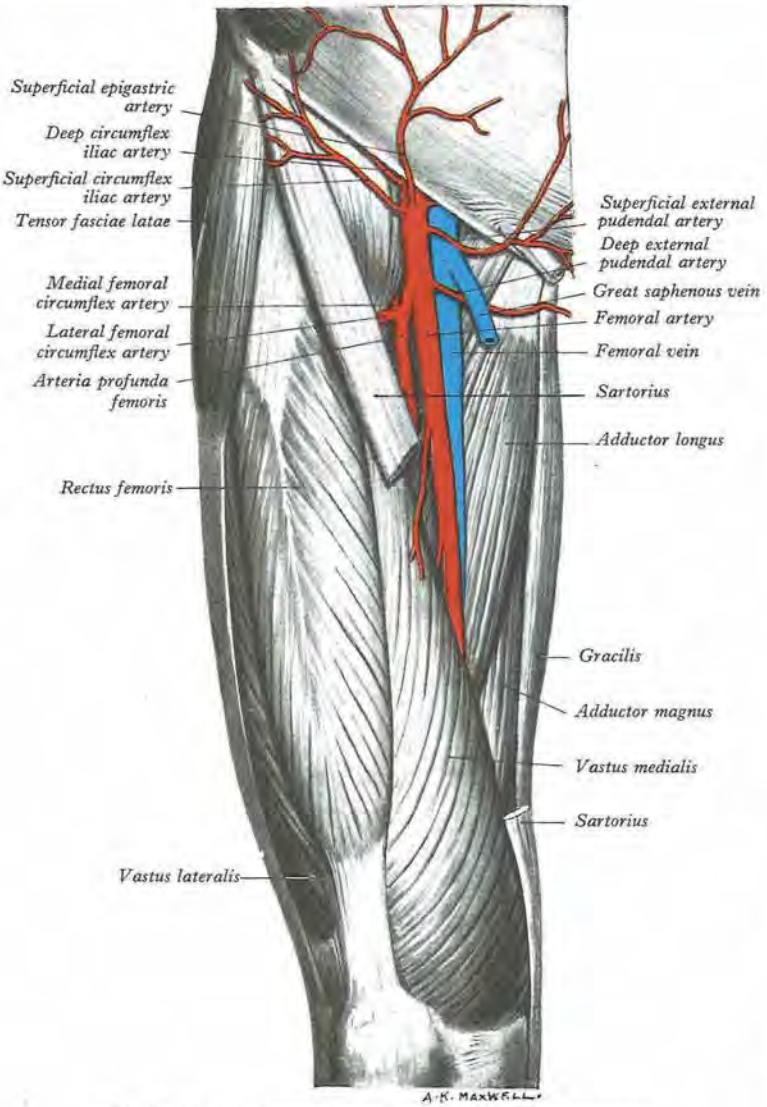
Surface anatomy. The artery corresponds to the proximal two-thirds of a line drawn from the midpoint between the anterior–superior iliac spine and the pubic symphysis to the adductor tubercle



10.138 Transverse section through the right thigh at the level of the apex of the femoral triangle: superior (proximal) aspect. About three-fifths of the natural size. The cutaneous nerves are omitted.



10.139 Transverse section through the middle of the right thigh: superior (proximal) aspect. About three-fifths of the natural size.



10.140 The right femoral vessels and some of their branches.

above the medial condyle of the femur, with the thigh semiflexed, abducted and laterally rotated. Its pulsation is easily palpable in its proximal course.

Variations. Rarely, the femoral artery divides, distal to the origin of the arteria profunda femoris, into two trunks reuniting near the adductor opening. It may be replaced by the inferior gluteal artery, accompanying the sciatic nerve to the popliteal fossa and representing a proximal persistence of the original axial artery (p. 318); the external iliac is then small, ending as the arteria profunda femoris.

Clinical anatomy. Compression of the femoral artery is most effective just distal to the inguinal ligament, where it is superficial and separated from the bone (iliopubic eminence) only by the psoas tendon.

Branches. These are as follows:

Superficial epigastric artery (10.140). Arising anteriorly from the femoral about 1 cm distal to the inguinal ligament, it traverses the cribriform fascia to ascend anterior to the ligament and run in the abdominal superficial fascia almost to the umbilicus. It supplies the superficial inguinal lymph nodes and superficial fascia and skin, anastomosing with branches of the inferior epigastric and its fellow.

Superficial circumflex iliac artery (10.140). This is the smallest superficial branch of the femoral; it arises near or with the superficial epigastric. Usually emerging through the fascia lata, lateral to the saphenous opening, it turns laterally distal to the inguinal ligament towards the anterior–superior iliac spine; it supplies the skin, superficial fascia and superficial inguinal lymph nodes, anatomosing with the deep circumflex iliac, superior gluteal and lateral circumflex femoral arteries.

10.141 Femoral arteriogram. (Supplied by Shaun Gallagher, Guy's Hospital; photography by Sarah Smith.)

Superficial external pudendal artery (10.140). It arises medially from the femoral, close to the preceding branches. Emerging from the cribriform fascia, it passes medially, usually deep to the great saphenous vein, across the spermatic cord (or round ligament) to supply the lower abdominal, penile, scrotal or labial skin, anastomosing with branches of the internal pudendal.

Veins accompanying the superficial epigastric, superficial circumflex iliac and external pudendal arteries join the great saphenous vein before it enters the saphenous opening.

Deep external pudendal artery (10.140). This artery passes medially across the pectineus and anterior or posterior to the adductor longus, covered by fascia lata, piercing it to supply the skin of the perineum and scrotum or labium majus; its branches anastomose with the posterior scrotal or labial branches of the internal pudendal.

Muscular branches. These supply the sartorius, the vastus medialis and the adductors.

ARTERIA PROFUNDA FEMORIS

The arteria profunda femoris is a large branch arising laterally from the femoral about 3.5 cm distal to the inguinal ligament (**10.139–142**). At first lateral to the femoral artery, it spirals posterior to this and the femoral vein to the medial side of the femur; it passes between pectineus and adductor longus, then between the latter and adductor brevis and then descends between adductor longus and adductor magnus to finally pierce the latter and anastomose with the upper muscular branches of the popliteal. This terminal part is sometimes named the *fourth perforating artery*.

The deep femoral artery is the main supply to the adductor,

extensor and flexor muscles; it also anastomoses with the internal and external iliac arteries above and the popliteal artery below.

Relations. Posterior, in proximodistal order, are: the iliacus, pectineus, adductor brevis and adductor magnus. Anterior are the femoral and profunda veins and distally the adductor longus, separating it from the femoral artery. Laterally vastus medialis separates its proximal part from the femur.

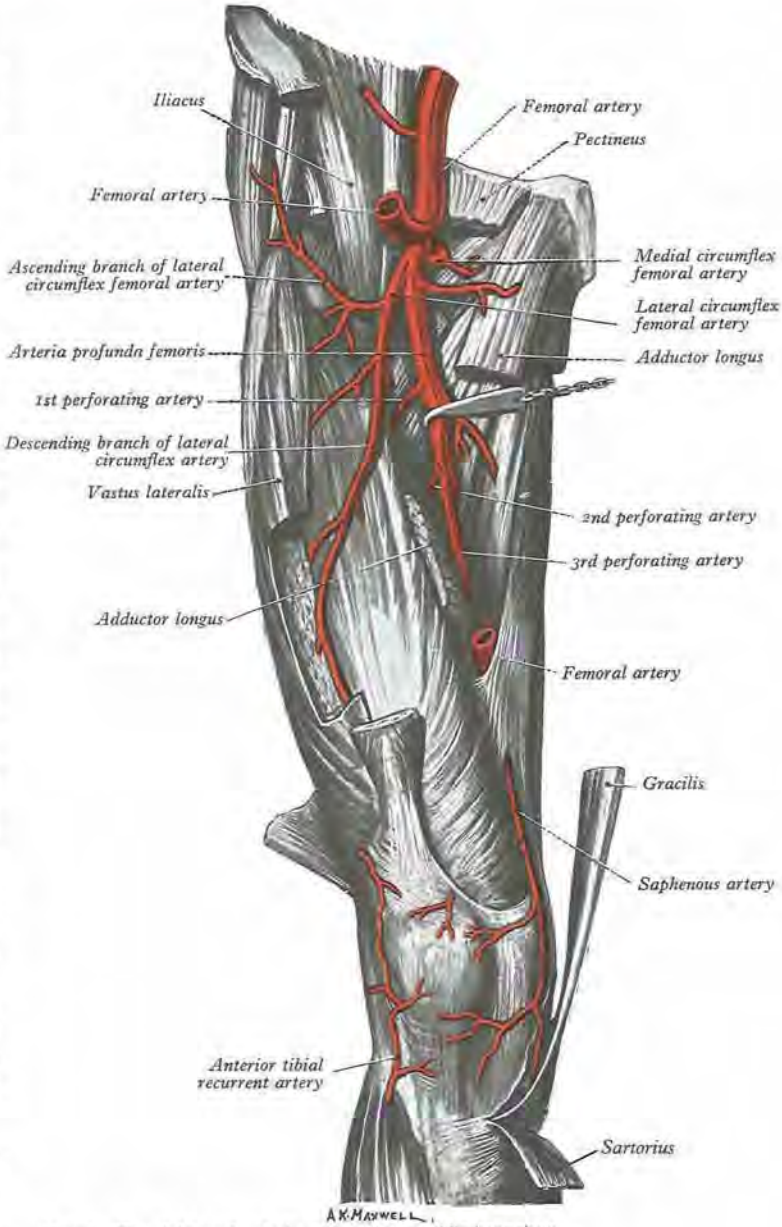
Variations. Its origin is sometimes medial, or rarely posterior on the femoral artery; if the former, it may cross anterior to the femoral vein and then pass backwards around its medial side.

Branches. These are as follows:

Lateral circumflex femoral artery (10.142). A lateral branch near the root of the profunda, it inclines laterally between divisions of the femoral nerve, posterior to sartorius and rectus femoris, dividing into ascending, transverse and descending branches. It may arise from the femoral. The *ascending branch* ascends along the intertrochanteric line, under the tensor fasciae latae, lateral to the hip joint; it anastomoses with the superior gluteal and deep circumflex iliac arteries, supplying the greater trochanter, and forms an anastomotic ring round the femoral neck with branches of the medial circumflex femoral; from this ring the femoral neck and head are supplied. The *descending branch*, sometimes direct from the profunda or the femoral, descends posterior to the rectus femoris, along the anterior border of the vastus lateralis, which it supplies: a long ramus descends in vastus lateralis to the knee, anastomosing with the lateral superior genicular branch of the popliteal, accompanied by the nerve to vastus lateralis. The *transverse branch*, the smallest, passes laterally anterior to vastus intermedius, pierces vastus lateralis to wind round the femur, just distal to the greater trochanter, anastomosing with the medial circumflex, inferior gluteal and first perforating arteries (cruciate anastomosis).

Medial circumflex femoral artery (10.142). Originating usually from the posteromedial aspect of the profunda but often the femoral artery, this artery supplies the adductor muscles and curves medially round the femur between pectineus and psoas major and then obturator externus and adductor brevis, finally appearing between quadratus femoris and upper border of adductor magnus, dividing into transverse and ascending branches. The *transverse branch* takes part in the cruciate anastomosis. The *ascending branch* ascends on the tendon of the obturator externus, anterior to the quadratus femoris, to the trochanteric fossa, where it anastomoses with branches of the gluteal and lateral circumflex femoral arteries. An acetabular branch at the proximal edge of the adductor brevis enters the hip joint under the transverse acetabular ligament with one from the obturator artery; it supplies the fat in the fossa, and reaches the femoral head along its ligament. For blood supply of the proximal end of the femur consult Crock (1965).

Perforating arteries (10.135). Usually three, they perforate the attachment of adductor magnus to reach the thigh's flexor aspect. They pass close to the linea aspera under small tendinous arches and issue muscular, cutaneous and anastomotic branches. Diminished, they pass deep to the short head of biceps femoris (the first usually through the attachment of gluteus maximus), traverse the lateral intermuscular septum and enter vastus lateralis. The first arises proximal to the adductor brevis, the second anterior and the third distal. The *first perforating artery* passes back between the pectineus and adductor brevis (sometimes through the latter), piercing the adductor magnus near the linea aspera to supply adductor brevis, adductor magnus, biceps femoris and gluteus maximus, anastomosing with the inferior gluteal, medial and lateral circumflex femoral and second perforating arteries. The larger *second perforating artery*, often arising with the first, pierces the attachments of adductor brevis and magnus, divides into the ascending and descending branches supplying the posterior femoral muscles and anastomoses with the first and third perforating arteries. The *femoral nutrient artery* usually arises from it; when two nutrient arteries exist, they usually come from the first and third. The *third perforating artery* starts distal to adductor brevis, pierces the attachment of adductor magnus and divides into branches to the posterior femoral muscles; it anastomoses proximally with the perforating arteries, distally with the end of the profunda and muscular branches of the popliteal. The femoral nutrient artery may arise from it. Side branches of the diaphyseal nutrient and other branches of the profunda also provide subsidiary cortical arteries (Crock 1967).



10.142 The right profunda femoris artery and its branches.

The end of arteria profunda femoris is the *fourth perforating artery*. The perforating arteries form a double chain of anastomoses:

(1) in the adductor muscles
(2) near the linea aspera.

Muscular branches. These are numerous and arise from the arteria profunda femoris; some end in the adductors, others pierce adductor magnus, supply the flexors and anastomose with the medial circumflex femoral artery and superior muscular branches of the popliteal. The profunda is thus the **main** supply to the femoral muscles.

Anastomosis on the back of the thigh. This important chain of anastomoses stretches from the gluteal region to the popliteal fossa, formed in proximodistal order by anastomoses between:

- gluteal arteries and terminals of the medial circumflex femoral
- circumflex femoral arteries and the first perforating artery
- perforating arteries and each other
- the fourth perforating artery and the superior muscular branches of the popliteal.

Descending genicular artery (10.146). It arises from the femoral just proximal to the adductor opening, at once supplying a saphenous branch and then descending in the vastus medialis, anterior to the tendon of adductor magnus, to the medial side of the knee, anastomosing with the medial superior genicular artery. Muscular branches supply vastus medialis and adductor magnus and have articular branches, which anastomose round the knee joint. One articular branch crosses above the femoral patellar surface, forming an arch with the lateral superior genicular artery and supplying the knee joint. The saphenous branch emerges distally through the roof of the adductor canal to accompany the saphenous nerve to the medial side of the knee. Passing between sartorius and gracilis it supplies the skin of the proximomedial area of the leg, anastomosing with the medial inferior genicular artery.

Collateral circulation. After ligation of the femoral artery proximal to the origin of the arteria profunda femoris, the main anastomotic channels available are:

- superior and inferior gluteal branches of the internal iliac with the medial and lateral circumflex femoral and the first perforating branch of the arteria profunda femoris
- the obturator branch of the internal iliac with the medial circumflex femoral of the arteria profunda femoris
- the internal pudendal branch of the internal iliac with superficial and deep external pudendal branches of the femoral
- a deep circumflex iliac branch of the external iliac with the lateral circumflex femoral branch of the arteria profunda femoris and the superficial circumflex iliac branch of the femoral
- the inferior gluteal branch of the internal iliac with perforating branches of the arteria profunda femoris.

POPLITEAL FOSSA

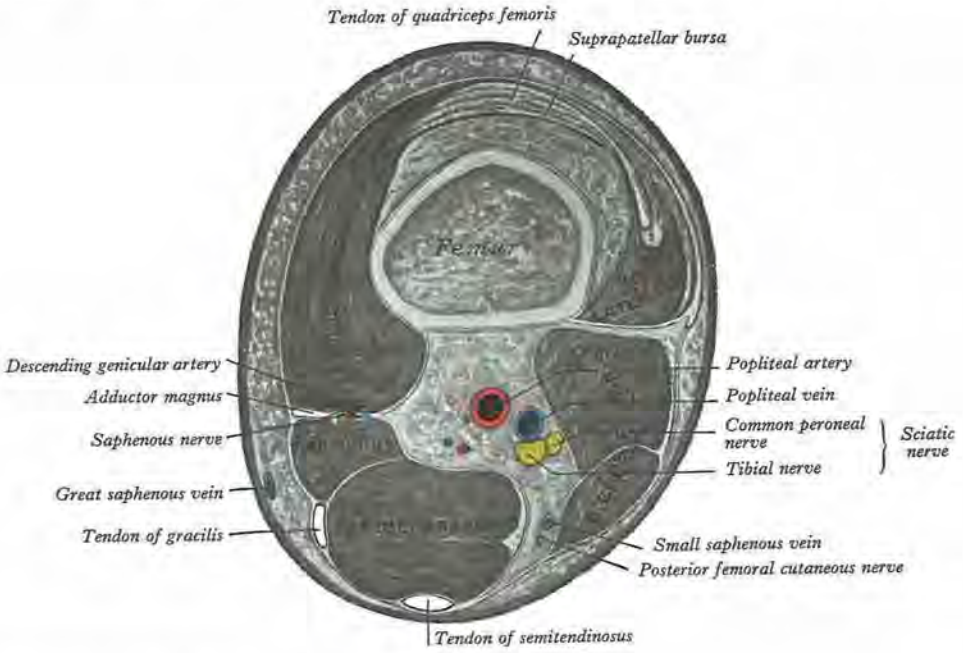
The popliteal fossa is a rhomboidal region posterior to the knee joint, more apparent when disturbed by dissection (7.136, 8.384, 8.385, 10.144). **Lateral** are proximally the biceps femoris and distally the plantaris and lateral head of gastrocnemius; **medial** and proximally are the semitendinosus and semimembranosus, and distally the medial head of the gastrocnemius; **anterior** are the femoral popliteal surface, oblique popliteal ligament, back of the proximal end of the tibia and the fascia covering the popliteus, collectively forming a so-called floor. The fossa is covered **posteriorly** by the popliteal fascia. (Note that 'popliteal fascia' refers to part of the general investing layer of deep fascia that forms a 'roof' for the fossa; to be carefully distinguished from the 'fascia of popliteus' which forms part of the floor.)

Contents (8.260, 10.144). Until disturbed, the popliteal fossa is about 2.5 cm wide and its contents are largely hidden, especially in its distal part, where the heads of gastrocnemius are in contact. When its boundaries are separated its contents are seen to be the popliteal vessels, the tibial and common peroneal nerves, the small saphenous vein, posterior femoral cutaneous nerve, an obturator articular branch, lymph nodes and fat. The tibial nerve descends centrally immediately anterior to the popliteal fascia, crossing the vessels posteriorly from lateral to medial. The common peroneal nerve descends laterally near the tendon of biceps femoris. Popliteal vessels are deep on the floor, the vein superficial to the artery, and united by dense areolar tissue. The vein is thick-walled, proximally lateral to the artery, and crossing to its medial side distally; sometimes it is double with the artery between the veins, the latter usually being interconnected. An articular branch from the obturator nerve descends on the artery to the knee. Six or seven popliteal lymph nodes are embedded in the fat, one under the popliteal fascia near the end of the small saphenous vein, one between the popliteal artery and knee joint, others around the popliteal vessels.

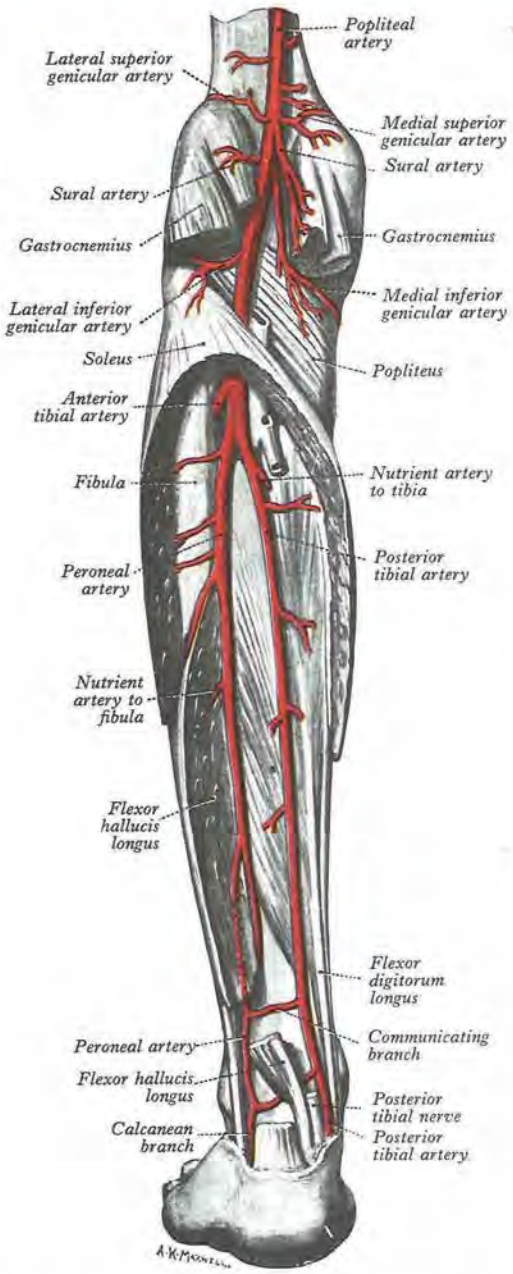
POPLITEAL ARTERY

The popliteal artery (10.143–145), continuing the femoral, traverses the popliteal fossa; from the opening in adductor magnus it descends laterally to the intercondylar fossa, inclining obliquely to the distal border of the popliteus, where it divides into the *anterior* and *posterior tibial arteries* (10.144). This division is at the proximal end of the crural interosseous space (which is asymmetrical) between the wide tibial metaphysis and the slender fibular metaphysis. Thus the popliteal artery extends from the medial border of the femur to the laterally placed interosseous space, accounting for its oblique descent (10.145).

Relations. **Anterior**, proximodistally, is fat covering the femoral popliteal surface, the capsule of the knee joint, and the fascia of popliteus. **Posterior** are, proximally, the semimembranosus and, distally, the gastrocnemius and plantaris. At intermediate level the artery is separated from the skin and fasciae by fat and crossed from



10.143 Transverse section through the right thigh, 4 cm above the adductor tubercle of the femur: superior (proximal) aspect. About three-fifths of the natural size.



10.144 The left popliteal, posterior tibial and peroneal arteries: dorsal aspect.

10.145 Popliteal arteriogram: anteroposterior view of adult male of 63 years. The following arteries can be identified: 1. popliteal; 2. descending genicular; 3. superior medial and lateral genicular; 4. inferior medial and lateral genicular; 5. middle genicular; 6. anterior tibial; 7. posterior tibial; 8. peroneal. Note the (normal) obliquity of the popliteal artery.

lateral to medial by the tibial nerve and popliteal vein, the vein veing between the nerve and artery and adherent to the latter. **Lateral** are proximally the biceps femoris, tibial nerve, popliteal vein and lateral femoral condyle and distally the plantaris and lateral head of gastrocnemius. **Medial** are the semimembranosus and medial femoral condyle and distally the tibial nerve, popliteal vein and medial head of gastrocnemius. Relations of the popliteal lymph nodes are described on page 1616.

Variations. The artery may divide into terminal branches **proximal** to the popliteus, the anterior tibial artery then descending **anterior** to the muscle. Sometimes it divides into the anterior tibial and peroneal arteries, the posterior tibial being absent or rudimentary; it may divide into the anterior and posterior tibial and peroneal.

Surface anatomy. The popliteal artery is approximately represented as extending from the junction of the middle and lower thirds of the thigh, 2.5 cm medial to its posterior midline, to the midpoint between the femoral condyles, continuing inferolaterally to the level of the tibial tuberosity, medial to the fibular neck.

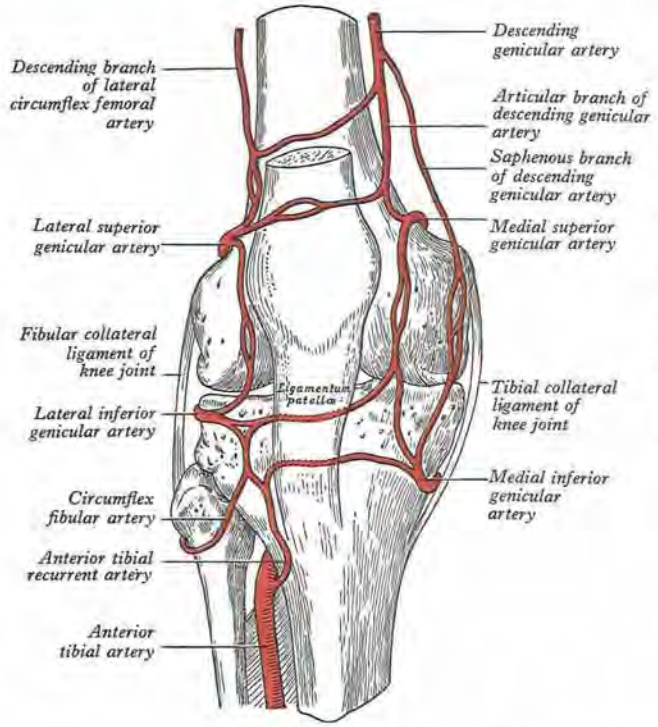
Branches. These are the cutaneous, muscular and genicular branches which reach the tibiofibular interosseous gap.

Cutaneous branches. They leave the popliteal or its side branches, descend between the heads of gastrocnemius and perforate the deep fascia to supply the skin on the back of the leg; one usually accompanies the small saphenous vein.

Superior muscular branches. Two or three in number, they arise proximally and pass to the adductor magnus and femoral flexors, anastomosing with the termination of the arteria profunda femoris.

Sural arteries. Two in number, these are large and arise behind the knee joint to supply gastrocnemius, soleus and plantaris.

Superior genicular arteries (10.144, 146)**.** They diverge from the popliteal, curving round proximal to both femoral condyles, to the anterior aspect of the knee. The *medial superior genicular artery* lies



10.146 The arterial anastomosis around the knee joint (schematic).

under semimembranosus and semitendinosus, proximal to the medial head of gastrocnemius and deep to the tendon of adductor magnus. It divides into a branch to the vastus medialis which anastomoses with the descending genicular and medial inferior genicular arteries, and one ramifying on the femur and anastomosing with the lateral superior genicular artery. Its size varies inversely with that of the descending genicular. The *lateral superior genicular artery* passes under the tendon of biceps femoris, dividing into superficial and deep branches; the superficial supplies the vastus lateralis, anastomosing with the descending branch of the lateral circumflex femoral and lateral inferior genicular; the deep branch anastomoses with the medial superior genicular, forming an anterior arch across the femur with the descending genicular.

Middle genicular artery. This small artery arises from the popliteal near the posterior centre of the knee joint; it pierces the oblique popliteal ligament to supply the cruciate ligaments and synovial membrane.

Inferior genicular arteries (10.144, 146). They arise from the popliteal deep to the gastrocnemius. The medial is deep to its medial head, descending along the proximal margin of the popliteus, which it supplies, and passing inferior to the medial tibial condyle and under the tibial collateral ligament, at the anterior border of which it ascends anteromedial to the joint; it supplies this and the tibia, anastomosing with the lateral inferior and medial superior genicular arteries and also with the anterior tibial recurrent artery and saphenous branch of the descending genicular. The lateral inferior genicular artery runs laterally across the popliteus and forwards over the fibula's head to the front of the knee joint, passing under the lateral head of gastrocnemius, the fibular collateral ligament and tendon of biceps femoris. Its branches anastomose with the medial inferior and lateral superior genicular, anterior and posterior tibial recurrent and circumflex fibular arteries.

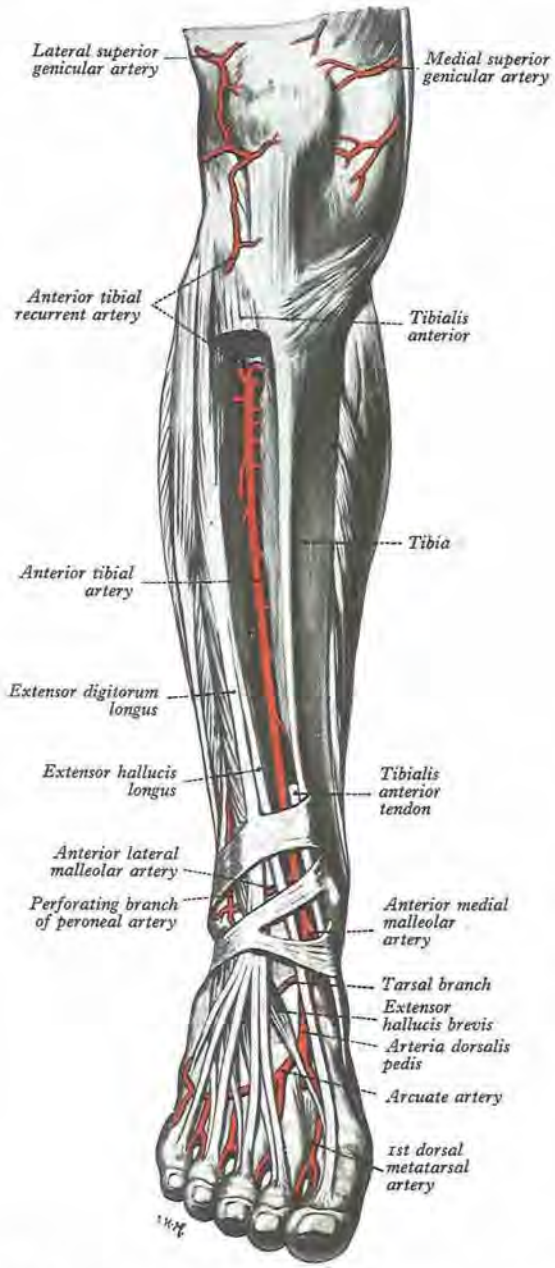
Genicular anastomosis

Around the patella and femoral and tibial condyles an intricate anastomosis exists. A superficial network spreads between the fascia and skin around the patella and in the fat deep to the ligamentum patellae. A deep network lies on the femur and tibia near the adjoining articular surfaces, supplying the bone and marrow, the articular capsule and synovial membrane. The vessels involved are the medial and lateral genicular, descending genicular, the descending branch of the lateral circumflex femoral, circumflex fibular and the anterior and posterior tibial recurrent arteries.

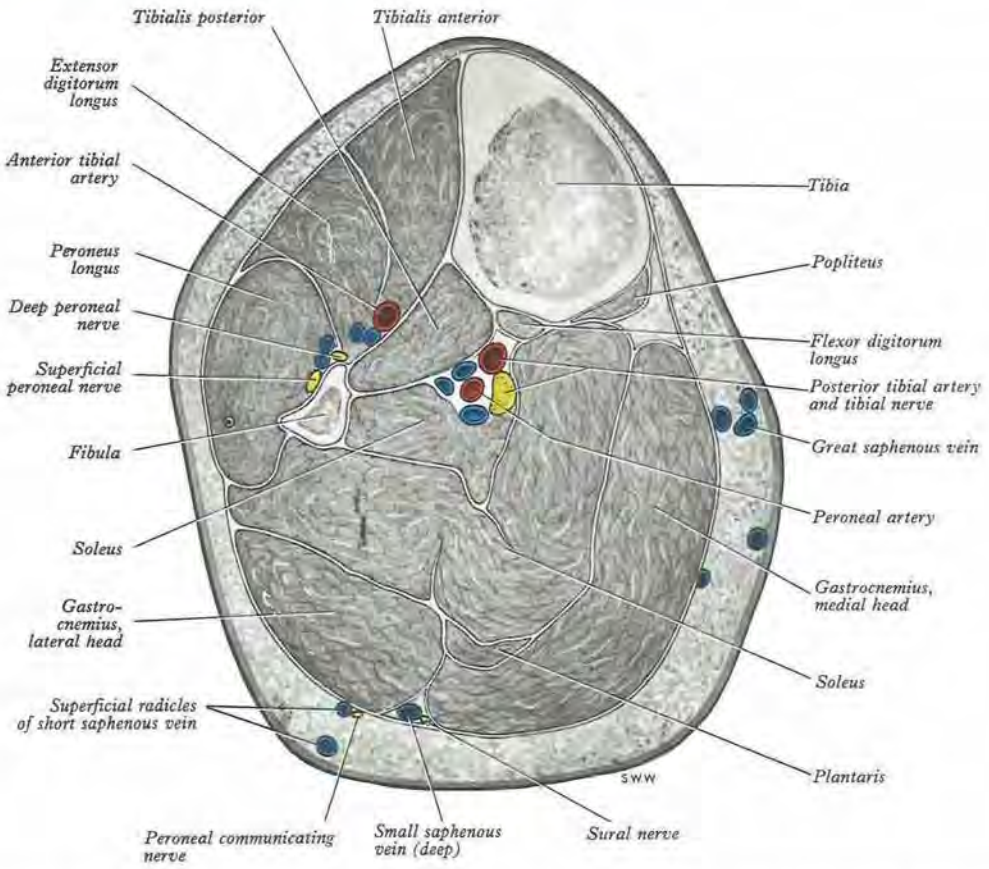
ANTERIOR TIBIAL ARTERY

The anterior tibial artery is the terminal branch of the popliteal and arises at the distal border of the popliteus (**10.144–148**). At first in the flexor compartment, it passes between the heads of tibialis posterior and through the oval aperture in the proximal part of the interosseous membrane (p. 712) to the extensor region, passing medial to the fibular neck. Descending anteriorly on the membrane it approaches the tibia and, distally, lies anterior to it (**10.149**). At the ankle it is midway between the malleoli, continuing on the dorsum of the foot as the *arteria dorsalis pedis*.

Relations. In its proximal two-thirds the artery descends on the interosseous membrane, in its distal third anterior to the tibia and ankle joint. Proximally it is between tibialis anterior and extensor



10.147 The right anterior tibial and dorsalis pedis arteries. A large part of the tibialis anterior has been excised and the extensor hallucis longus retracted laterally to expose the anterior tibial artery.



10.148 Transverse section through the right leg, about 10 cm below the knee joint: inferior (distal) aspect. At a slightly lower level the flexor digitorum longus intervenes between the soleus and the fascia on the posterior surface of the tibialis posterior.

digitorum longus, then between tibialis anterior and extensor hallucis longus. At the ankle it is crossed superficially from the lateral side by the tendon of extensor hallucis longus and is then between this and the first tendon of the extensor digitorum longus. Its proximal two-thirds are covered by adjoining muscles and deep fascia, its distal third by the skin, fasciae and extensor retinacula. Venae comitantes accompany it. The deep peroneal nerve, curling laterally round the fibular neck, reaches the lateral side of the artery where it enters the extensor region but in the middle third of the leg becomes anterior to it and distally again becomes lateral.

Surface anatomy. Surface projection of the anterior tibial artery begins 2.5 cm distal to the medial side of the fibular head and ends midway between the malleoli. It can be felt pulsating lateral to the tendon of extensor hallucis longus.

Variations. This vessel may be small or even absent, replaced by perforating branches from the posterior tibial or the perforating branch of the peroneal. It occasionally deviates laterally, regaining its usual position at the ankle.

Branches. These are the anterior and posterior tibial recurrent; muscular; and anterior medial and lateral malleolar.

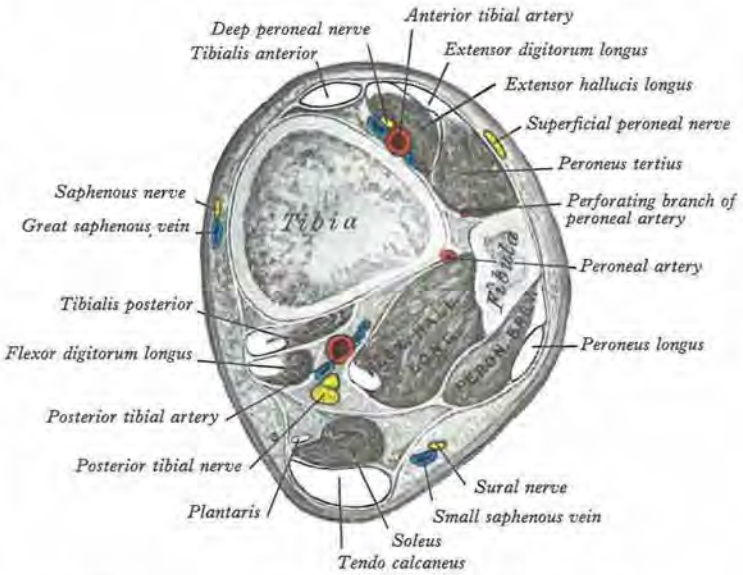
Posterior tibial recurrent artery. It is an inconstant branch, which arises before the anterior tibial reaches the extensor compartment, ascending anterior to the popliteus with the muscle's recurrent nerve, anastomosing with the inferior genicular branches of the popliteal. It supplies the superior tibiofibular joint.

Anterior tibial recurrent artery (10.147). Arising near the preceding vessel, it ascends in tibialis anterior, ramifies on the front and sides of the knee joint and joins the patellar network, anastomosing with the genicular branches of the popliteal and circumflex fibular arteries.

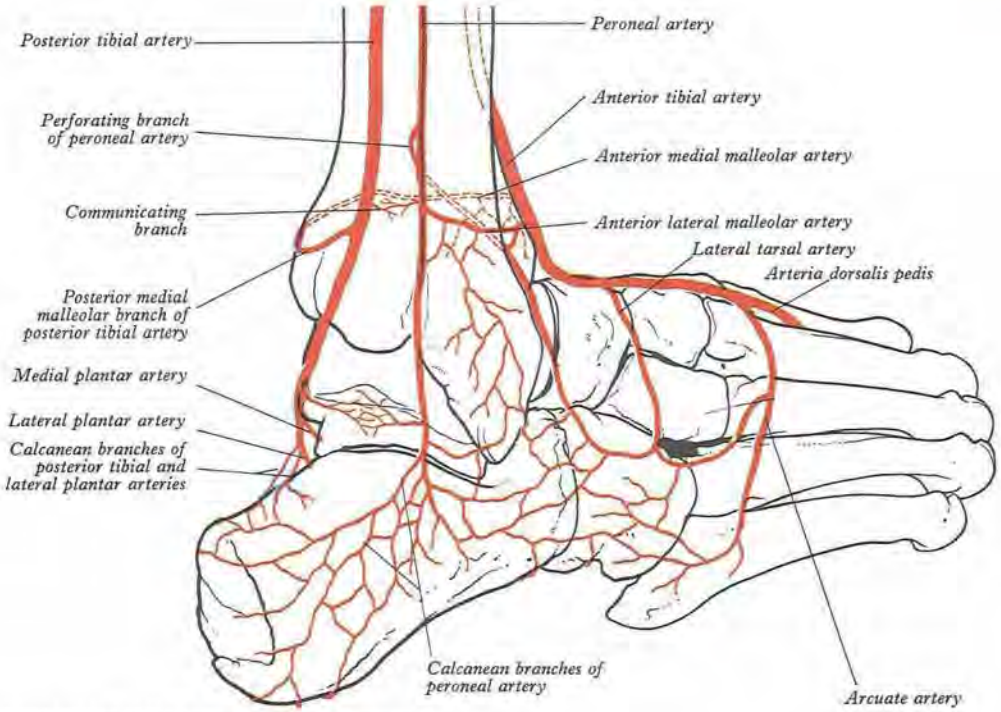
Muscular branches. These numerous branches supply the adjacent muscles; some pierce the deep fascia to supply the skin, others traverse the interosseous membrane to anastomose with branches of the posterior tibial and peroneal arteries.

Anterior medial malleolar artery (10.147, 150). It arises about 5 cm proximal to the ankle, passing posterior to the tendons of extensor hallucis longus and tibialis anterior medial to the joint, where it joins branches of the posterior tibial and medial plantar arteries.

Anterior lateral malleolar artery (10.147, 150). This artery pro-



10.149 Transverse section through the right leg, about 6 cm above the tip of the medial malleolus: superior (proximal) aspect.



10.150 The arterial anastomoses of the ankle, tarsus and metatarsus.

ceeds posterior to the tendons of extensor digitorum longus and peroneus tertius to the lateral side of the ankle, anastomosing with the perforating branch of the peroneal and ascending branches of the lateral tarsal artery.

Anastomosis at the ankle joint (**10.150**). This consists of vascular networks around the malleoli. The *medial malleolar network* is formed by the anterior medial malleolar branch of the anterior tibial, the medial tarsal branches of the arteria dorsalis pedis, the malleolar and calcaneal branches of the posterior tibial and branches of the medial plantar artery. The *lateral malleolar network* is formed by the anterior lateral malleolar branch of the anterior tibial, lateral tarsal branch of arteria dorsalis pedis, the perforating and calcaneal branches of the peroneal and side branches of the lateral plantar artery.

Arteria dorsalis pedis

The dorsal artery of the foot (**10.147**), it is the continuation of the anterior tibial distal to the ankle. It passes medially along the dorsum to the proximal end of the first intermetatarsal space, where it turns into the sole between the heads of the first dorsal interosseous muscle to complete the plantar arch, where it provides the first plantar metatarsal artery.

Relations. The dorsal artery successively crosses the talocrural articular capsule, talus, navicular and intermediate cuneiform and their ligaments; **superficial** are the skin, fasciae, inferior extensor retinaculum and, near its termination, extensor hallucis brevis. **Medial** is the tendon of extensor hallucis longus, **lateral** the medial tendon of extensor digitorum longus and medial terminal branch of the deep peroneal nerve.

Surface anatomy. The pulsation of the dorsal artery of the foot is palpable from the midpoint between the malleoli to the proximal end of the first intermetatarsal space.

Variations. The artery may be larger to compensate for a small lateral plantar artery or replaced by a large perforating branch of the peroneal. It often diverges laterally from its usual route.

Branches. These are the tarsal, arcuate and first dorsal metatarsal arteries.

Tarsal arteries. These two arteries, lateral and medial (**10.147**), arise as the arteria dorsalis pedis crosses the navicular; the former runs laterally under the extensor digitorum brevis; it supplies this and the tarsal articulations, anastomosing with branches of the arcuate, anterior lateral malleolar, lateral plantar and the perforating branch of the peroneal. Two or three medial tarsal arteries ramify on the foot's medial border and join the medial malleolar network.

Arcuate artery (**10.147**). It arises near the medial cuneiform, passing laterally over the metatarsal bases, deep to the tendons of the digital extensors, and anastomosing with the lateral tarsal and plantar arteries. It supplies the *second* to *fourth dorsal metatarsal arteries*, running distally superficial to the corresponding dorsal interosseous muscles; in the interdigital clefts each divides into two *dorsal digital branches* for the adjoining toes. Proximally, in the interosseous spaces, they receive *proximal perforating branches* from the plantar arch and distally are joined by the *distal perforating branches* from the plantar metatarsal arteries. The fourth dorsal metatarsal sends a branch to the lateral side of the fifth toe.

First dorsal metatarsal artery (**10.147**). It arises just before the arteria dorsalis pedis enters the sole; it runs distally on the first dorsal interosseous; at the cleft between the first and second toes it divides, one branch passing under the tendon of extensor hallucis longus and supplying the medial side of the hallux and one bifurcating to supply the adjoining sides of hallux and the second toe.

POSTERIOR TIBIAL ARTERY

The posterior tibial artery begins at the distal border of the popliteus, between tibia and fibula, descending medially in the flexor compartment to divide midway between the medial malleolus and the medial tubercle of calcaneus, under abductor hallucis, into the medial and lateral plantar arteries (**10.144, 145, 148**).

Relations. The artery is successively **posterior** to tibialis posterior, flexor digitorum longus, tibia and ankle joint. Proximally, gastrocnemius, soleus and the deep transverse fascia of the leg are **superficial** and distally only the skin and fascia. It is parallel with and about 2.5 cm anterior to the medial border of the tendo calcaneus; terminally it is **deep** to the flexor retinaculum and abductor hallucis. It is accompanied by two veins and the tibial nerve, the latter first medial, but soon crossing posterior, and then largely posterolateral. The arrangement of structures passing from the leg to the sole is described on page 890.

Surface anatomy. The posterior tibial artery corresponds to a line joining a point 1–2 cm lateral to the calf's midline at the fibular neck's level, extending downwards and medially to the midpoint between the medial malleolus and the heel (medial calcaneal tubercle).

Branches. These are circumflex fibular, peroneal, nutrient, medial and lateral plantar.

Circumflex fibular artery. This artery, which sometimes arises from the anterior tibial artery, passes laterally round the fibula's neck through the soleus to anastomose with the lateral inferior genicular, medial genicular and anterior tibial recurrent arteries. It supplies bone and articular structures.

Peroneal artery (10.144, 148, 149)**.** It arises about 2.5 cm distal to popliteus, and passes obliquely to the fibula, descending along its medial crest in a fibrous canal between tibialis posterior and flexor hallucis longus or in the latter. Reaching the inferior tibiofibular syndesmosis, it divides into the calcaneal branches, ramifying on the lateral and posterior surfaces of the calcaneus. **Proximally** it is covered by the soleus and deep transverse fascia, between this and the deep muscles; **distally** it is overlapped by flexor hallucis longus.

Variations. The artery may spring earlier from the posterior tibial, or even the popliteal, sometimes 7 or 8 cm **distal** to popliteus. It is more often enlarged and either joins and reinforces the posterior tibial artery or replaces it in the distal leg and foot.

Muscular branches. These supply soleus, tibialis posterior, flexor hallucis longus and peronei.

Nutrient artery. This runs proximally into the fibula.

Perforating branch. It traverses the interosseous membrane about 5 cm proximal to the lateral malleolus to enter the extensor compartment, where it anastomoses with the anterior lateral malleolar artery; descending anterior to the inferior tibiofibular syndesmosis, it supplies the tarsus, anastomosing with the lateral tarsal artery. This branch is sometimes enlarged and may replace the arteria dorsalis pedis. A *communicating branch* connects it about 5 cm proximal to the ankle to a *communicating branch* of the posterior tibial. The calcaneal or terminal branches anastomose with the anterior lateral malleolar and calcaneal branches of the posterior tibial artery.

Nutrient artery of the tibia. It arises from the posterior tibial near its origin; supplying a few muscular branches it descends into the bone immediately distal to the soleal line. It is one of the largest of the nutrient arteries.

Muscular branches. These are distributed to the soleus and deep flexors of the leg.

Communicating branch of the posterior tibia. This runs posteriorly across the tibia about 5 cm above its distal end, deep to flexor hallucis longus, to join a communicating branch of the peroneal.

Medial malleolar branches. These pass round the tibial malleolus to the medial malleolar network.

Calcaneal branches. They arise just proximal to the terminal division of the posterior tibial; they pierce the flexor retinaculum to supply the fat and skin behind the tendo calcaneus and in the heel and muscles on the tibial side of the sole; they anastomose with medial malleolar arteries and calcaneal branches of the peroneal.

Medial plantar artery (10.151A, B)**.** It is the smaller terminal branch of the posterior tibial, which passes distally along the medial side of the foot with the medial plantar nerve lateral to it. At first deep to abductor hallucis, it runs distally between this and flexor digitorum brevis, supplying both. Near the first metatarsal base, its calibre, diminished by muscular branches, is further diminished by a superficial stem and it then passes to reach the medial border of the hallux where it anastomoses with a branch of the first plantar metatarsal artery (see below). Its superficial stem trifurcates and supplies three superficial digital branches accompanying the digital branches of the medial plantar nerve to join the first to third plantar metatarsal arteries.

Surface anatomy. The trunk of the artery begins midway between the medial malleolus and heel (medial calcaneal tubercle) extending towards the first interdigital cleft as far as the navicular bone.

Lateral plantar artery (10.151A, B)**.** The larger terminal branch of the posterior tibial passes distally and laterally to the fifth metatarsal base, the lateral plantar nerve medial to it. (Note that the plantar nerves lie between the plantar arteries.) Turning medially, with the nerve's deep branch, to the interval between the first and second metatarsal bases, it unites with the arteria dorsalis pedis to complete the plantar arch. As it passes laterally, it is first between the calcaneus and abductor hallucis, then between flexor digitorum brevis and flexor accessorius; running distally to the fifth metatarsal base it passes between flexor digitorum brevis and abductor digiti minimi

10.151A The plantar arteries of the right foot: superficial dissection.

10.151B The plantar arteries of the right foot: deep dissection.

and is covered by the plantar aponeurosis, superficial fascia and skin.

Branches. *Muscular branches* supply the adjoining muscles; *superficial branches* emerge along the lateral intermuscular septum to supply the skin and subcutaneous tissue lateral in the sole; *anastomotic branches* run to the lateral border, joining branches of the lateral tarsal and arcuate arteries. Sometimes a *calcaneal branch* pierces abductor hallucis to supply the skin of the heel.

PLANTAR ARCH

The plantar arch is deeply situated, extending from the fifth metatarsal base to the proximal end of the first interosseous space. Convex distally, it is plantar to the bases of the second to fourth metatarsal bones and corresponding interossei but dorsal to the oblique part of adductor hallucis.

Branches. Three perforating and four plantar metatarsal branches, and numerous branches supply the skin, fasciae and muscles in the sole. Three *perforating branches* ascend through the proximal ends of the second to fourth intermetatarsal spaces, between the heads of the dorsal interosseous muscles, anastomosing with the dorsal metatarsal arteries. Four *plantar metatarsal arteries* (10.151B) extend distally between the metatarsal bones in contact with the interossei. Each divides into two *plantar digital arteries*, supplying the adjacent digital aspects. Near its division each plantar metatarsal sends dorsally a *distal perforating branch* to join a dorsal metatarsal artery. The *first plantar metatarsal artery* springs from the junction between the lateral plantar and dorsalis pedis arteries, sending a digital branch to the medial side of the hallux. The lateral digital branch for the fifth toe arises directly from the lateral plantar artery near the fifth metatarsal base.

Surface anatomy. Beginning between the heel and medial malleolus, the lateral plantar artery crosses obliquely to a point 2.5 cm medial to the fifth metatarsal's tuberosity and with a slight distal convexity reaches the proximal end of the first intermetatarsal space.

Clinical anatomy. Haemorrhage from the plantar arch is difficult to stem, due to the depth of the vessel and its important close relations. It must be treated like the palmar arches (p. 1544).

PULSE

Palpating the pulse must surely be one of the most important aspects of the physical examination of a patient, giving information about both the state of the circulation and the rhythm of the heart. Prior to modern diagnostic techniques such as echocardiography and cardiac catheterization, feeling the pulse was (and still is in many circumstances) extremely helpful in diagnosing and assessing the state of diseased cardiac valves. The pulse is usually felt in the upper part of the body to assess the state of the circulation or cardiac output, and in the lower part of the body to evaluate the vascular tree with special reference to arteriosclerotic disease. The following are the commonly felt and most useful pulses in clinical practice. Most of them are found where an artery is superficial and overlying bone.

Superficial temporal pulse (10.73). This pulse is of special value to anaesthetists as their access to patients is frequently restricted to the head. It is palpable anterior to the tragus of the ear as it crosses the zygomatic process of the temporal bone. The artery may be thickened and tender when involved by an arteritis.

Carotid pulse (10.75). This important pulse is palpable at the carotid bifurcation which usually lies at the level of the upper border of the thyroid cartilage just lateral to it. The pulse that one feels is formed by a complex of vessels: the common, internal and external carotid arteries plus the roots of the initial branches of the external carotid at that site. The carotid and femoral pulses are the ones usually sought in cases of suspected cardiac arrest.

Brachial pulse (10.98). Usually easily felt, it is in the cubital fossa lying medial to the tendon of biceps before disappearing under the bicipital aponeurosis. Many feel that this is the ideal site at which to assess the quality of the cardiac output. This is also a useful site at which to pass an arterial catheter for coronary angiography or cardiac catheterization.

Radial pulse (10.109). This is the most accessible pulse for palpation under normal clinical circumstances and it is usually of sufficient calibre to enable good quality information to be derived from it. Because of the palmar arches it is a safe site for cannulation for blood pressure monitoring and arterial blood sampling, as thrombosis there will not normally jeopardise the circulation of the hand. It is most easily felt on the ventral aspect of the wrist between the tendon of flexor carpi radialis and the lower lateral aspect of the radius.

Femoral pulse (10.140). Like the carotid pulse the femoral is of great value in assessing whether there is any significant cardiac output in cases of circulatory collapse. However, as with the other lower limb pulses, it may be reduced or obliterated by arteriosclerotic disease. It is a common site for coronary angiography and cardiac catheterization and is also a useful site for arterial puncture for blood gas analysis. It can usually be felt in the femoral triangle just below the inguinal ligament half way between the symphysis pubis and the anterior superior iliac spine.

Popliteal pulse (10.144). Lying deep in the popliteal fossa this is the most difficult of the peripheral pulses to feel. It is important, however, when assessing the state of the arterial supply to the lower limb especially in the presence of peripheral vascular disease, most commonly arteriosclerosis. The pulse is best felt with the knee flexed to relax the popliteal fascia when it may then be felt in the midline against the popliteal surface of the lower end of the femur.

Posterior tibial pulse (10.144). This may be felt behind and below the medial malleolus at the ankle between the tendons of flexor hallucis longus and flexor digitorum longus.

Dorsalis pedis pulse (10.147). Like the posterior tibial pulse, the dorsalis pedis may frequently be obliterated by peripheral vascular disease. It is normally palpable lateral to the tendon of extensor hallucis longus as it overlies the tarsal bones.

VENOUS SYSTEM

The veins as a whole form three main systems: pulmonary, systemic and portal. The *pulmonary veins* carry oxygenated blood from the lungs to the heart. The *systemic veins* return venous blood to the heart from much of the rest of the body. *Superficial veins* are located in the superficial fascia, especially in the limbs, and are variable in disposition. *Deep veins* lie beneath the deep fascia and are usually enclosed in connective tissue sheaths with accompanying arteries, the latter assisting venous return (p. 1468). Smaller arteries are accompanied by paired veins flanking them (*venae comitantes*); larger arteries are usually associated with single veins, although some run separately. Veins are usually more variable, in course and structure, than arteries. In many regions, such as the pelvis and vertebral column, veins form extensive plexuses devoid of valves. These plexuses are the basis of anastomosis between the veins of the trunk; they may also act as blood reservoirs of variable capacity. At many points, such as the junctional regions between the trunk and limbs and near joints, valved *connecting veins* join superficial and deep systemic veins.

The *portal vein* receives tributaries draining venous blood from the subdiaphragmatic part of the oesophagus, the small intestine and the large intestine, the pancreas and the spleen: the blood from this vast area passes through the liver (hepatic circulation) before returning to a general systemic vein, the inferior vena cava.

PULMONARY VEINS

The pulmonary veins return oxygenated blood to the left atrium. Usually four, two from each lung, and devoid of valves, they originate from capillary networks in the alveolar walls. By repeated

junctions tributary veins finally form a single trunk in each lobe, i.e. three in the right lung, and two in the left. The right middle and superior lobar veins usually join so that two veins, superior and inferior, leave each lung; they perforate the fibrous pericardium and open separately in the posterosuperior aspect of the left atrium (10.32, 39, 56B). Occasionally the three right lobar veins remain separate. Sometimes the two left pulmonary veins form a single trunk. Occasionally the two left pulmonary veins form a single trunk. Occasionally the two left pulmonary veins, each draining a lobe, may be augmented by an accessory lobar vein from each lobe and these may unite to form a third left pulmonary vein (Cory & Valentine 1959).

In the pulmonary hilum (pp. 1659, 1674) the superior pulmonary vein is antero-inferior to the pulmonary artery, the inferior being the most inferior hilar structure and also slightly posterior. The principle bronchus is posterior to the pulmonary artery. On the right the superior pulmonary vein passes posterior to the superior vena cava, the inferior behind the right atrium. On the left both pass anterior to the descending thoracic aorta. In the pericardium, they are partly covered by serous pericardium. Between the terminations of the right, and left veins is, centrally, the oblique pericardial sinus and, laterally, directed medially and upwards, smaller and variable pulmonary venous pericardial recesses (p. 1471).

SYSTEMIC VEINS

In the following description the systemic veins are divided into six groups: cardiac veins, which drain directly into the heart; veins of the head and neck; veins of the upper limbs and veins of the thorax, all three groups draining into the superior vena cava; and veins of the lower limbs and veins of the abdomen and pelvis, both groups draining into the inferior vena cava.

CARDIAC VEINS

Veins draining the heart can be grouped as:

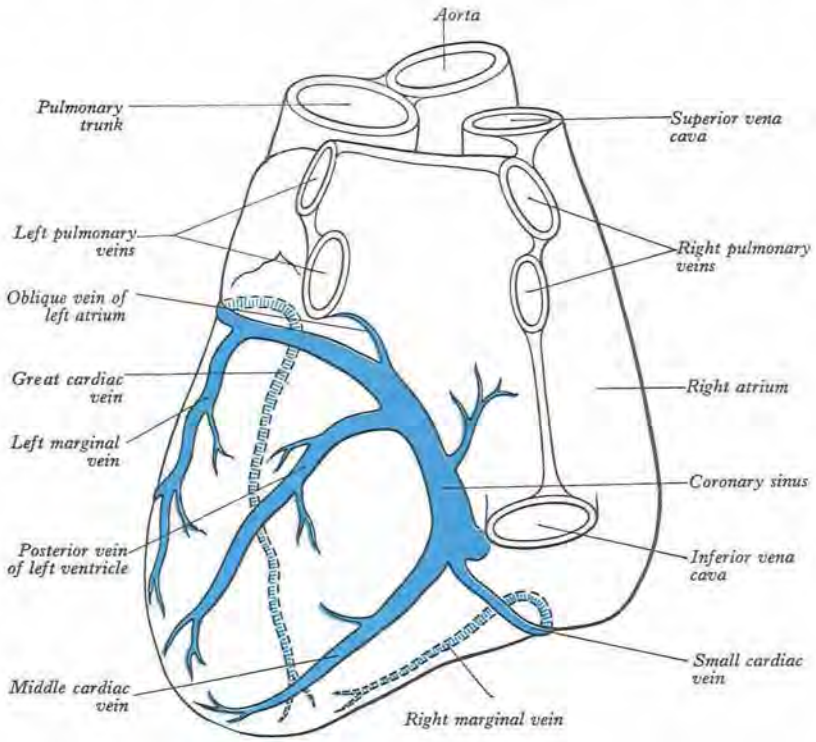
- the *coronary sinus* and *tributaries*, returning blood to the right atrium from the whole heart (including its septa) except the anterior region of the right ventricle and small, variable parts of both atria and left ventricle
- the *anterior cardiac veins* draining an anterior region of the right ventricle and a region around the right cardiac border when the right marginal vein joins this group, ending principally in the right atrium
- the *venae cordis minimae* (Thebesius' veins), opening into the right atrium and ventricle and, to a lesser extent, the left atrium and sometimes left ventricle.

CORONARY SINUS

The large majority of cardiac veins drain into the wide coronary sinus, about 2 or 3 cm long, lying posterior in the coronary sulcus (atrioventricular groove) between the left atrium and ventricle (10.32, 152). The sinus opens into the right atrium between the opening of the inferior vena cava and the right atrioventricular orifice, and its opening is guarded by an endocardial fold (*semilunar valve of the coronary sinus*; 10.33). Its tributaries are the great, small and middle cardiac veins, the posterior vein of the left ventricle and the oblique vein of the left atrium, all except the last having valves at their orifices.

Great cardiac vein (10.152). It begins at the cardiac apex, ascends in the anterior interventricular sulcus to the coronary sulcus and follows this to the left and round posterior to the heart to enter the coronary sinus at its origin. It receives tributaries from the left atrium and both ventricles, including the large *left marginal vein* ascending the left aspect ('obtuse border') of the heart.

Small cardiac vein (10.152). This lies posterior in the coronary



10.152 The principal veins of the heart.

sulcus between the right atrium and ventricle and opens into the coronary sinus near its atrial end. It receives blood from the back of the right atrium and ventricle; the *right marginal vein* passes right, along the inferior cardiac margin ('acute border'), and may join the small cardiac vein in the coronary sulcus but more often opens directly into the right atrium.

Middle cardiac vein (10.152). Beginning at the cardiac apex, it runs back in the posterior interventricular groove to end in the coronary sinus near its atrial end.

Posterior vein of the left ventricle (10.152). Found on the diaphragmatic surface of the left ventricle a little left of the middle cardiac vein, it usually opens into the centre of the coronary sinus but sometimes into the great cardiac vein.

Oblique vein of the left atrium. This small vessel descends obliquely on the back of the left atrium to join the coronary sinus near its end; it is continuous above with the *ligament of the left vena cava* (p. 1472); the two structures are remnants of the left common cardinal vein.

ANTERIOR CARDIAC VEINS

The anterior cardiac veins drain the anterior part of the right ventricle. Usually two or three, sometimes even five (Baroldi & Scomazzoni 1967), they ascend in subepicardial tissue to cross the right part of the atrioventricular sulcus, passing deep or superficial to the right coronary artery. They end in the right atrium, near the sulcus, separately or in variable combinations. A subendocardial collecting channel, into which all may open, has been described (James 1961). The right marginal vein courses along the inferior ('acute') cardiac margin, draining adjacent parts of the right ventricle, and usually opens separately into the right atrium but may join the anterior cardiac veins or, less often, the coronary sinus. Because it is commonly independent it is often grouped with the venae cordis minimae but, since it is larger in calibre, it is comparable with the anterior cardiac veins or even wider. It is perhaps better considered one of the latter, which also sometimes drain with it into the coronary sinus. Mechanik (1934) described all cardiac veins as draining into the coronary sinus in the early fetal period.

VENAE CORDIS MINIMAE

The existence of venae cordis minimae, opening into all cardiac cavities, has been confirmed by many subsequent to their first recording by Thebesius (1708); they are more difficult to demonstrate than larger cardiac vessels. Their numbers and size are highly variable. Aho (1950) demonstrated 'minimal' veins of up to 2 mm in diameter opening into the right atrium and of about 0.5 mm into the right ventricle. He found venae minimae numerous in the right atrium and ventricle, occasional in and often absent from the left atrium, and rare in the left ventricle. Grant and Regnier (1926) considered venae minimae as derived from the intertrabecular spaces of the developing heart.

Cardiac venous anastomoses

There are widespread anastomoses at all levels of cardiac venous circulation, on a scale exceeding that of the arteries and amounting to a veritable venous plexus, according to some investigators (Baroldi & Scomazzoni 1967). Not only are adjacent veins often connected but connections also exist between tributaries of the coronary sinus and those of the anterior cardiac veins (Mierzwa & Kozielec 1975). Regions of abundant anastomoses are the apex and its anterior and posterior aspects. Like coronary arteries (p. 1505) cardiac veins connect with extracardiac vessels, chiefly the vasa vasorum of the large vessels continuous with the heart.

Variation in cardiac veins

Attempts to categorize variations in cardiac venous circulation (Aho 1950) into 'types' have not produced any accepted pattern. Major variations concern the general directions of drainage. The coronary sinus may receive all cardiac veins (except the venae minimae), including the anterior cardiac veins (33%), which may be reduced by diversion of some into the small cardiac vein and then to the coronary sinus (28%); the remainder (39%) represent the 'normal' pattern, as described above. Baroldi and Scomazzoni (1967) distinguished two major variants: a majority (70%) in which the small cardiac vein is independent, small or absent and a less frequent pattern (30%) in which this vein, though variable in size, connects with both coronary and anterior cardiac 'systems'.

VEINS OF THE HEAD AND NECK

The veins of the head and neck can be subdivided into three groups:

- veins of the exterior of the head and face
- cervical veins
- diploic, meningeal, intracranial veins and dural venous sinuses.

This classification is particularly significant at cranial level, where veins, like arteries, are arranged as a three-layered system:

- vessels of the scalp
- dural vessels
- cerebral and cerebellar vessels.

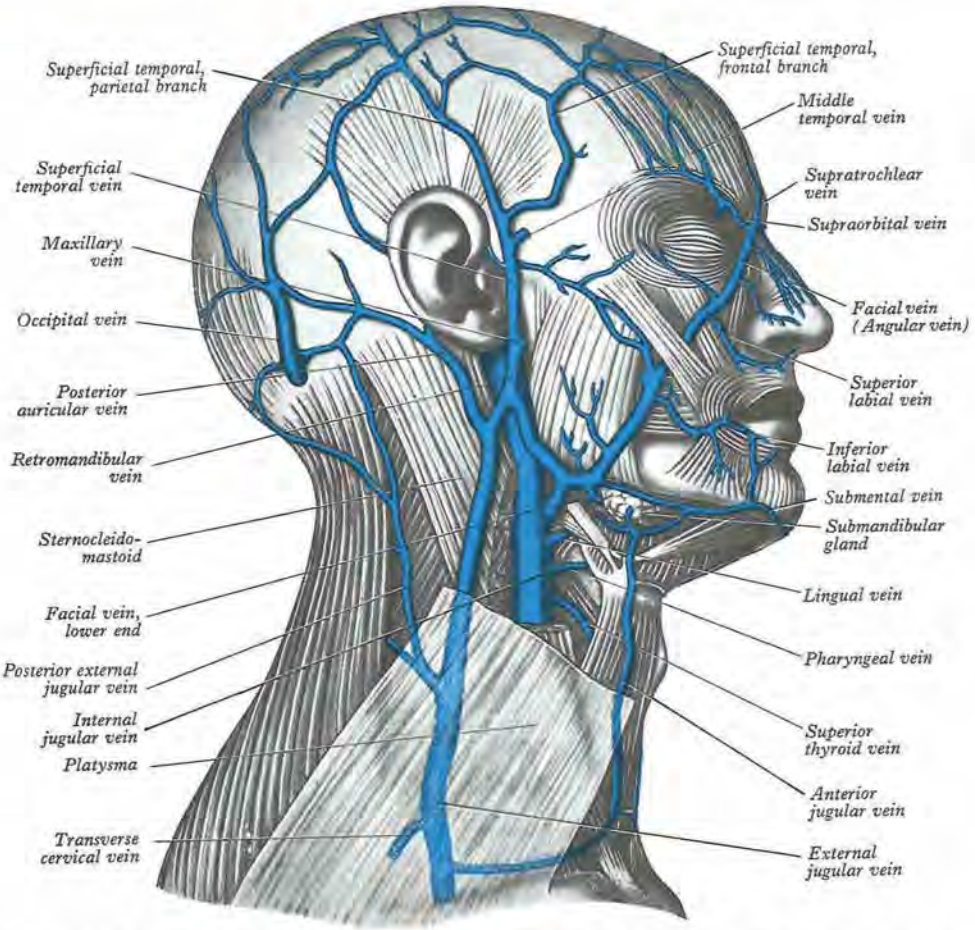
By comparison with the corresponding arteries, the veins of the scalp and dura are very variable and usually intercommunicate more extensively (emissary veins, p. 1589). Dural or meningeal arteries, on the other hand, are independent of cerebral and cerebellar arteries, the latter being derived from the internal carotid, whereas dural venous sinuses share a drainage to the internal jugular vein which is also common to veins of the cerebrum and cerebellum. The diploic veins constitute a hypothetical fourth venous tier; however, since these drain into dural veins, they are here grouped with them, following Browder and Kaplan (1976). It is to be noted that intracranial veins communicate at many points with extracranial vessels via the emissary and other veins (p. 1589).

Developmentally the venous sinuses emerge as venous plexuses; and it is clear, from angiographic studies and corrosion casts, that most sinuses preserve a plexiform arrangement to a variable degree, rather than being simple vessels with a single lumen. Browder and Kaplan (1976), examining human venous sinuses in hundreds of corrosion casts, have observed vascular plexuses adjoining, in particular, the superior and inferior sagittal and straight sinuses and, with a lesser incidence, the transverse sinuses. Details show much individual variation; departures from 'average' patterns are frequent in earlier years; for example, the falx cerebelli may in infancy contain large plexiform channels and venous lacunae, augmenting the occipital sinus. Such variations cannot be detailed in a general text; in any case they must be established for the individual by angiography when clinical necessity arises; but the wide variation possible in the structure of cranial venous sinuses, with their plexiform nature and wide connections with cerebral and cerebellar veins, must be emphasized. Another kind of connection may be noted here; experiment shows (Rowbotham & Little 1962; Browder & Kaplan 1976) that parts of sinuses (and even diploic veins) can be filled by forcible internal carotid injection, suggesting the existence of arteriovenous shunts. Browder and Kaplan, by injection of the middle meningeal arteries, established a connection between these and the superior sagittal sinus at sites still unknown.

EXTERNAL VEINS OF THE HEAD AND FACE

As with most superficial veins these are subject to variations, far too numerous to illustrate. Some major features are, however, relatively constant; a common pattern is shown in (10.153).

Supratrochlear vein. This starts on the forehead from a venous network connected to the frontal tributaries of the superficial tem-



10.153 The veins of the right side of the head and neck. Parts of the right sternocleidomastoid and platysma have been excised to expose the trunk of the internal jugular vein. The external jugular vein is visible through the lower part of the platysma.

poral vein. Veins from this form a single trunk, descending near the midline parallel with its fellow to the radix nasi, across which they are joined by a nasal arch draining the dorsum nasi. The veins then diverge, each joining a supraorbital vein to form the facial vein near the medial canthus. Supratrochlear veins may join, dividing again on the radix nasi to form the two facial veins.

Supraorbital vein. It begins near the zygomatic process of the frontal bone, connecting with radicles of the superficial and middle temporal veins. Passing medially above the orbital opening under orbicularis oculi, it pierces this to form the facial vein by joining the supratrochlear near the medial canthus. A branch through the supraorbital notch joins the superior ophthalmic vein, receiving in the notch veins from the frontal sinus and frontal diploë.

Facial vein. After receiving the supratrochlear and supraorbital veins, this vessel descends obliquely near the side of the radix nasi, receding from the ala, and then turns posterolaterally below the orbital opening, passing downwards and backwards behind the facial artery, being less tortuous. It passes under zygomaticus major, risorius and platysma and then descends on to the anterior border and then the surface of the masseter, crosses the body of the mandible and runs obliquely back under the platysma but superficial to the submandibular gland, digastric and stylohyoid. A little antero-inferior to the mandibular angle it is joined by the anterior division of the retromandibular vein; descending superficial to the lingual artery's loop, the hypoglossal nerve and external and internal carotid arteries, it enters the internal jugular near the greater cornu of the hyoid bone (i.e. in the upper angle of the carotid triangle). Near its end a large branch often descends along the anterior border of sternocleidomastoid to the anterior jugular vein. Its uppermost segment, above its junction with the superior labial vein (see below), is often termed the *angular vein*.

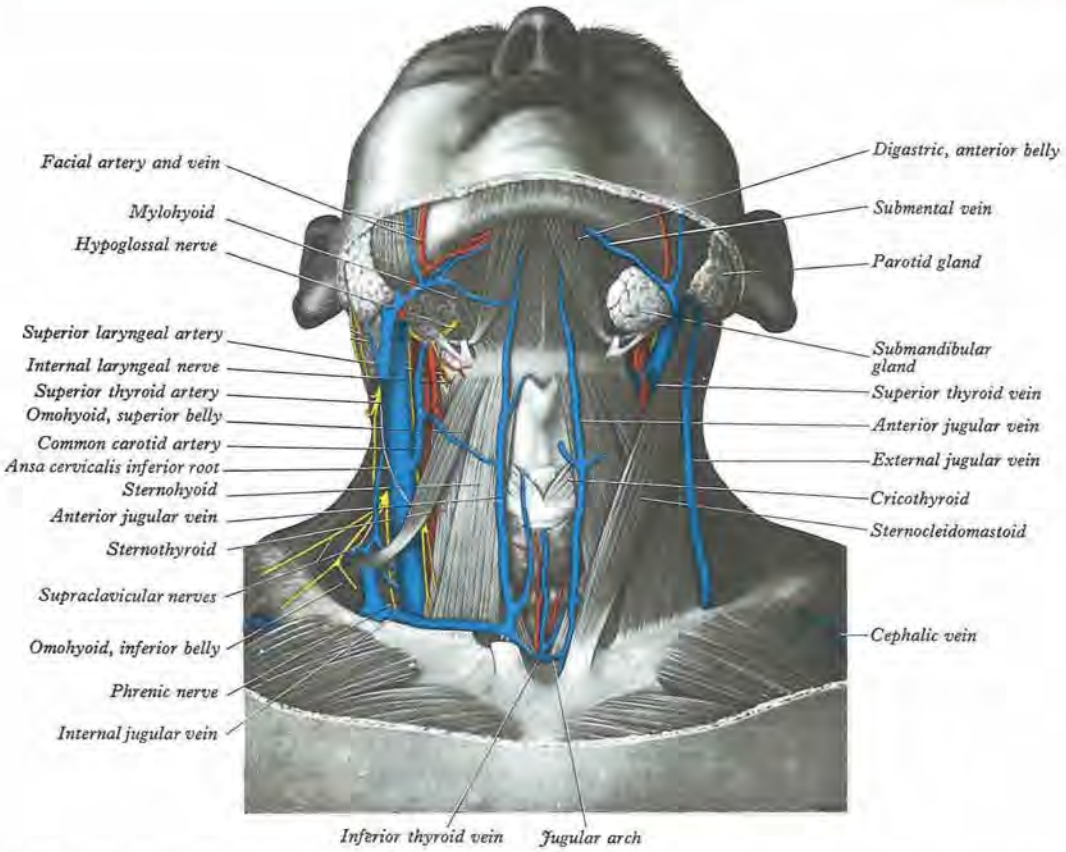
Tributaries. Near its beginning the facial vein connects with the superior ophthalmic directly and via the supraorbital; it is thus connected to the cavernous sinus. It receives veins of the ala nasi and, lower, a large deep facial vein from the pterygoid venous plexus and also the inferior palpebral, superior and inferior labial, buccinator, parotid and masseteric veins. Below the mandible, submental, tonsillar, external palatine (paratonsillar) and submandibular veins join it and sometimes the vena comitans of the hypoglossal nerve, and the pharyngeal and superior thyroid veins.

Clinical anatomy. The facial vein has no valves. It connects, as noted, with the cavernous sinus by two routes: through the ophthalmic vein or its supraorbital tributary, or by the *deep facial vein* to the pterygoid plexus and hence the cavernous sinus. Infection may thus spread from the face to the intracranial venous sinuses.

Superficial temporal vein (10.153). This begins in a widespread network joined across the scalp to the contralateral vein and to the ipsilateral supratrochlear, supraorbital, posterior auricular and occipital veins, all draining the same network. Anterior and posterior tributaries unite above the zygoma to form the superficial temporal, joined here by the *middle temporal vein*. It crosses the posterior root of the zygoma and enters the parotid gland to join the maxillary vein, to form the *retromandibular vein*.

Tributaries. These are the parotid veins, rami for the temporomandibular joint, anterior auricular veins, and transverse facial vein. The middle temporal vein, after receiving the orbital vein which is formed by the lateral palpebral veins, passes back between layers of temporal fascia, piercing this to join the superficial temporal vein.

Pterygoid venous plexus. It is found partly between temporalis and the lateral pterygoid, and partly between the pterygoids. Sphenopalatine, deep temporal, pterygoid, masseteric, buccal, dental, greater palatine and middle meningeal veins and a branch or branches from



10.154 Anterior view of the veins of the neck.

the inferior ophthalmic are all tributaries. The plexus connects by the *deep facial vein* with the facial and with the cavernous sinus through the sphenoidal emissary foramen, foramen ovale and foramen lacerum. Its deep temporal tributaries often connect with tributaries of the anterior diploic (p. 1580) and thus with the middle meningeal veins.

Maxillary vein. This short trunk accompanies the first part of the maxillary artery; it derives from the confluence of veins from the pterygoid plexus, passing back between the sphenomandibular ligament and mandibular neck, uniting with the superficial temporal to form the retromandibular vein.

Retromandibular vein. It descends in the parotid gland, between the external carotid artery and, superficially, the facial nerve. It divides into an anterior branch going forwards to join the facial and a posterior branch, joining the posterior auricular to form the *external jugular vein*. Occasionally it is not connected to the external jugular, which is then small, the anterior jugular often being enlarged.

Posterior auricular vein (10.153)**.** Beginning in a parieto-occipital network, it also drains into tributaries of the occipital and superficial temporal veins. It descends behind the auricle to join the posterior division of the retromandibular vein in or just below the parotid gland, to form the external jugular. It receives a stylomastoid vein and tributaries from the cranial surface of the auricle.

Occipital vein (10.153)**.** It begins in a posterior network in the scalp, pierces the cranial attachment of trapezius, turns into the suboccipital triangle and joins the deep cervical and vertebral veins. It may follow the occipital artery to end in the internal jugular; sometimes it joins the posterior auricular and hence the external jugular vein. Parietal and mastoid emissary veins link it with the superior sagittal and transverse sinuses. The occipital diploic vein sometimes joins it (see above).

VEINS OF THE NECK

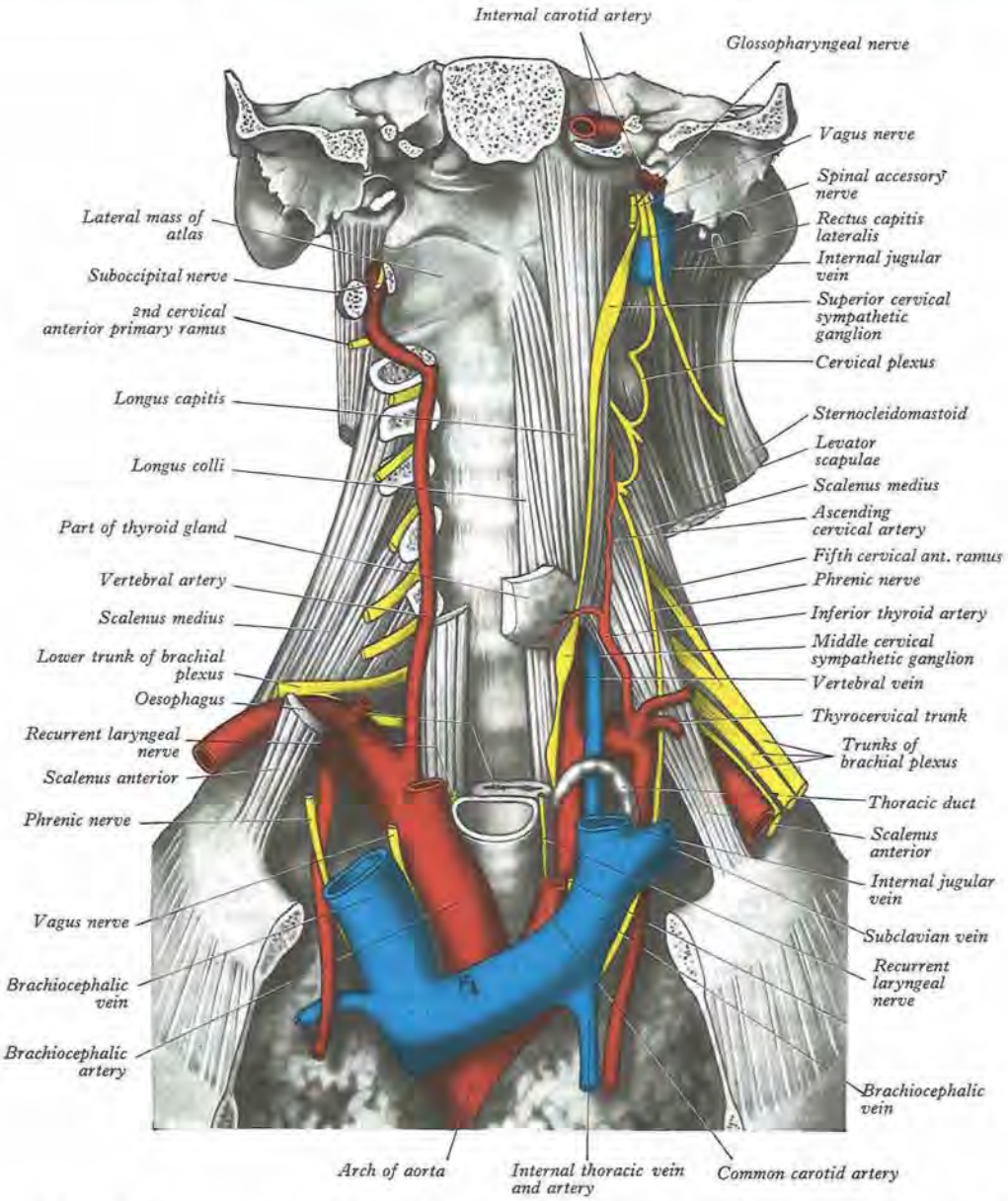
1578 Veins of the neck are superficial or deep to the deep fascia but they are not entirely separate (10.153, 154, 170). *Superficial veins*, tributaries (some with specific names, given below) of the external jugular, drain a much smaller volume of tissue than the *deep veins*, which drain all but the subcutaneous structures, mostly into the internal jugular vein (but some into the vertebral veins).

External jugular vein (10.153)**.** This largely drains the scalp and face but also some deeper parts. The union of the posterior division of the retromandibular and posterior auricular veins begins near the mandibular angle just below or in the parotid gland, descending from the angle to the midclavicle. It crosses obliquely, superficial to sternocleidomastoid, to the subclavian triangle, where it traverses the deep fascia to end in the subclavian vein, lateral or anterior to scalenus anterior. Its wall is adherent to the rim of the fascial opening. It is covered by platysma, superficial fascia and skin, separated from sternocleidomastoid by deep cervical fascia; it crosses the transverse cervical nerve and is parallel with the great auricular nerve, ascending posterior to its upper half. In size the vein is inversely proportional to other veins in the neck; it is occasionally double. It has valves at its entrance into the subclavian vein and about 4 cm above the clavicle, between which it is often dilated, is a so-called sinus. The valves do not prevent regurgitation.

Tributaries. In addition to formative tributaries, the external jugular receives the posterior external jugular and, near its end, transverse cervical, suprascapular and anterior jugular veins; in the parotid gland it is often joined by a branch from the internal jugular. The occipital vein occasionally joins it.

Posterior external jugular vein. It begins in the occipital scalp and drains the skin and the superficial muscles posterosuperior in the neck. It usually joins the middle part of the external jugular.

Anterior jugular vein (10.153, 154)**.** This vein starts near the hyoid bone by the confluence of the superficial submandibular veins. It descends between the midline and the anterior border of sternocleidomastoid; turning laterally, low in the neck, posterior (deep) to the muscle but superficial to the hyoid depressors, it joins the end of the external jugular vein or the subclavian vein directly. In size it is usually inverse to the external jugular. It communicates with the



10.155 A dissection to show the prevertebral region and the superior mediastinum. On the right the costal elements of the upper six cervical vertebrae have been removed to expose the cervical part of the vertebral artery. On the left most of the deep relations of the common carotid artery and the internal jugular vein are exposed. Details of the terminal parts of the left lymphatic trunks have been omitted.

internal jugular, receiving the laryngeal veins and sometimes a small thyroid vein. There are usually two anterior jugular veins, united just above the manubrium by a large transverse jugular arch, receiving the inferior thyroid tributaries. They have no valves and may be replaced by a midline trunk.

Surface anatomy. Usually the external jugular vein is visible where it crosses the sternocleidomastoid; it can be distended and made more visible by expiring against resistance (Valsalva's manoeuvre) or by gentle supraclavicular digital pressure. Similarly, the anterior jugular vein can often be made visible in the upper two-thirds of the neck. The end of the facial vein runs from a point where the anterior border of the masseter meets the inferior mandibular border, to the greater hyoid cornu.

Internal jugular vein (10.153, 154)**.** This large vein collects blood from the skull, brain, superficial parts of face and much of the neck. It begins at the cranial base in the posterior compartment of the jugular foramen, continuous with the sigmoid sinus. At its origin is its *superior bulb*, which is below the posterior part of the tympanic floor. The vein descends in the carotid sheath (p. 804), uniting with the subclavian, posterior to the sternal end of the clavicle, to form the brachiocephalic vein. It is also dilated near its end as its *inferior bulb*, above which it contains a pair of valves. **Posterior** to the vein, from above, are: the rectus capitis lateralis, transverse process of atlas, levator scapulae, scalenus medius and cervical plexus, scalenus anterior, phrenic nerve, thyrocervical trunk, vertebral vein and first part of subclavian artery; on the left it also crosses anterior to the thoracic duct (10.155). **Medial** to the vein are the internal and common carotid arteries and the vagus nerve between vein and arteries but posterior to them. **Superficially** the vein is overlapped above, then covered below by sternocleidomastoid and crossed by the posterior belly of the digastric and the superior belly of omohyoid. Superior to the digastric, the parotid gland and styloid process are superficial, the accessory nerve, posterior auricular and occipital arteries crossing the vein. Between the digastric and the omohyoid, the sternocleidomastoid arteries and inferior root of the ansa cervicalis cross it, but the nerve often passes between the vein and the common carotid. Below the omohyoid, it is covered by the infrahyoid muscles and the sternocleidomastoid and it is crossed by the anterior

jugular vein. Deep cervical lymph nodes lie along the vein, mainly on its superficial aspect. At the root of the neck the right internal jugular is separated from the common carotid, but the left usually overlaps its artery. At the base of the skull the internal carotid artery is **anterior**, separated from the vein by the *ninth* to *twelfth cranial nerves*.

Clinical anatomy. The vein is represented in surface projection by a broad band from the ear's lobule to the medial end of the clavicle; its inferior bulb is in the depression between the sternal and clavicular heads of the sternocleidomastoid, the lesser supraclavicular fossa, where a needle can be inserted with precision in the living subject.

Tributaries. These are: the inferior petrosal sinus, facial, lingual, pharyngeal, superior and middle thyroid veins, sometimes the occipital. The internal jugular vein may communicate with the external. The thoracic duct opens near the union of the left subclavian and internal jugular veins; the right lymphatic duct is at the same site on the right.

Inferior petrosal sinus. It leaves through the anterior part of the jugular foramen, crosses lateral or medial to the ninth to eleventh cranial nerves and joins the superior jugular bulb.

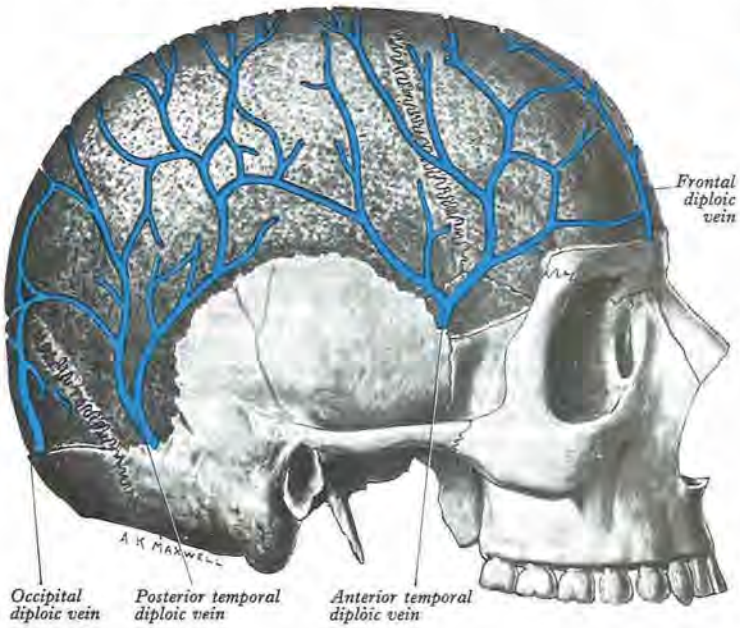
Lingual veins. These veins follow two routes:

- *Dorsal lingual veins* drain the dorsum and sides of the tongue and join the lingual veins accompanying the lingual artery between hyoglossus and genioglossus. Near the greater cornu of the hyoid bone they join the internal jugular.
- The *deep lingual vein* begins near the tip and runs back near the mucous membrane on the tongue's inferior surface. Near the anterior border of hyoglossus it joins a *sublingual vein*, from the salivary gland, to form the *vena comitans nervi hypoglossi* which runs back between the mylohyoid and hyoglossus with the hypoglossal nerve to join the facial, internal jugular or lingual vein.

Pharyngeal veins. These begin in a pharyngeal plexus external to the pharynx. After receiving meningeal veins and a vein from the pterygoid canal, they end in the internal jugular but sometimes in the facial, lingual or superior thyroid vein.

Superior thyroid vein (10.153,154). Formed by deep and superficial tributaries corresponding to the arterial branches, this vein accompanies the artery and receives the *superior laryngeal* and *cricothyroid veins*, ending in the internal jugular or facial vein.

Middle thyroid vein (10.154). It drains the lower part of the gland and also receives veins from the larynx and trachea. It crosses anterior to the common carotid artery to join the internal jugular vein behind the superior belly of omohyoid.



10.156 The veins of the diploë, displayed by the removal of the outer table of the skull.

Facial and occipital veins. These are described on pages 1577–1578.

Inferior thyroid veins. See page 10.142.

Vertebral vein. In the suboccipital triangle many small tributaries from internal vertebral plexuses leave the vertebral canal above the posterior atlantal arch and join small veins from local deep muscles making a vessel which enters the foramen in the atlantal transverse process and forms a plexus around the vertebral artery, descending through successive transverse foramina. This ends as the vertebral vein, emerging from the sixth cervical transverse foramen, whence it descends, at first anterior then anterolateral to the vertebral artery, to open superoposteriorly into the brachiocephalic vein; the opening has a paired valve. The vertebral vein descends behind the internal jugular, passing in front of the first part of the subclavian artery (**10**.155). A small accessory vertebral vein usually descends from the vertebral plexus, traverses the seventh cervical transverse foramen and turns forwards between the subclavian artery and the cervical pleura to join the brachiocephalic vein.

Tributaries. The vein connects with the sigmoid sinus by a vessel in the posterior condylar canal, when this exists. It also receives branches from the occipital vein, prevertebral muscles, internal and external vertebral plexuses. It is joined by anterior vertebral and deep cervical veins (see below) and sometimes near its end by the first intercostal vein.

Anterior vertebral vein. Starting in a plexus around the upper cervical transverse processes, it descends near the ascending cervical artery between attachments of scalenus anterior and longus capitis and opens into the end of the vertebral vein.

Deep cervical vein. It accompanies its artery between the semispinales capitis et cervicis. It begins in the suboccipital region from communicating branches of the occipital and veins from suboccipital muscles and also from plexuses around the cervical spines. It passes forwards between the seventh cervical transverse process and the neck of the first rib to end in the lower part of the vertebral vein.

Clinical anatomy

When the superior jugular bulb thromboses (e.g. in otitis media), the glossopharyngeal, vagus and accessory nerves may be affected. The internal jugular vein may be endangered during removal of tuberculous or neoplastic lymph nodes.

Venous pulsation may be visible in the external jugular at the root of the neck. There are no valves in the brachiocephalic veins or the superior vena cava; hence the right atrial systole causes a wave of distension up these vessels, which may appear as a feeble flicker over the external jugular vein. This atrial systolic impulse is much increased when the right atrium is abnormally distended or hypertrophied, as in diseases of the mitral valve.

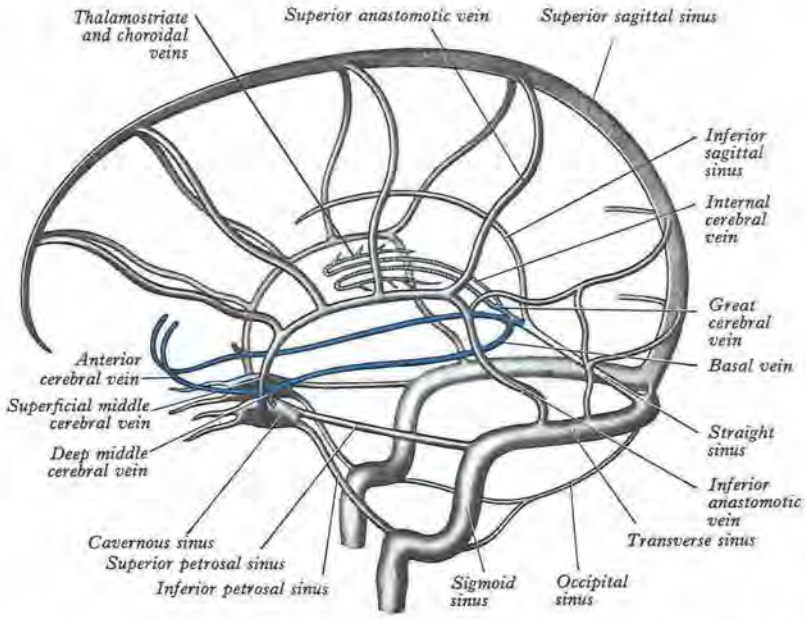
CRANIAL AND INTRACRANIAL VEINS

DIPLOIC VEINS

Diploic veins occupy channels in the diploë of some cranial bones (**10**.156) and are devoid of valves. They are large, with dilatations at irregular intervals; their thin walls are merely endothelium supported by elastic tissue. Radiographically they may appear as relatively transparent bands 3 or 4 mm wide. Absent at birth, they begin to develop with the diploë at about 2 years. They communicate with meningeal veins, dural sinuses and pericranial veins. Recognizably regular channels are:

- a *frontal diploic vein*, emerging from bone in the supraorbital foramen to join the supraorbital vein
- an *anterior temporal* (*parietal*) *diploic vein*, confined chiefly to the frontal bone, which pierces the greater wing of the sphenoid to end in the sphenoparietal sinus or anterior deep temporal vein
- a *posterior temporal* (*parietal*) *diploic vein*, in the parietal bones, descending to the parietal mastoid angle to join the transverse sinus through a foramen at the angle or mastoid foramen
- an *occipital diploic vein*, the largest, confined to the occipital bone, opening into occipital veins or the transverse sinus near the confluence of sinuses or into an occipital emissary vein.

Numerous small diploic veins emerge near the superior sagittal sinus to end in its venous lacunae (p. 1583).



10.157 Schema of the venous sinuses of the dura mater and their connections with the cerebral vein: left side. The more deeply placed cerebral veins are shown in blue and those inside the brain are shown in interrupted blue.

MENINGEAL VEINS

Meningeal veins begin from plexiform vessels in the dura mater and drain into efferent vessels in the outer dural layer which connect with lacunae of the superior sagittal sinus and with other cranial sinuses, including those accompanying the middle meningeal arteries (p. 1519), and with diploic veins.

CEREBRAL AND CEREBELLAR VEINS

The veins of the brain (p. 1220) have no valves; their thin walls have no muscular tissue. They pierce the arachnoid mater and the inner dural layer to open into the cranial venous sinuses. They comprise cerebral and cerebellar veins and veins of the brainstem.

The cerebral veins (**10.157**), external and internal, drain the surfaces and the interior of the hemispheres.

External cerebral veins (10.157)

The external cerebral veins form superior, middle and inferior groups.

Superior cerebral veins. Eight to twelve to each hemisphere, they drain their superolateral and medial surfaces and mainly follow the sulci, though some cross the gyri. Ascending to the superomedial border, they receive small veins from the medial surface and open into the superior sagittal sinus; *anterior veins* open almost at right angles; the larger, *posterior veins* are directed obliquely forwards against the current in the sinus. This may resist the collapse of thin-walled cerebral veins which might result from a rise of intracranial pressure; but another factor is the backward growth of the cerebral hemispheres and the consequent displacement of vessels during development.

Superficial middle cerebral vein. It begins on the lateral surface, following the posterior ramus and stem of the lateral sulcus to end in the cavernous sinus. A superior anastomotic vein runs posterosuperiorly between the middle cerebral vein and the superior sagittal sinus, thus connecting the superior sagittal and cavernous sinuses. An *inferior anastomotic vein* courses over the temporal lobe, connecting the middle cerebral vein to the transverse sinus.

Inferior cerebral veins. Those on the frontal orbital surface join the superior cerebral veins and thus drain to the superior sagittal sinus; those on the temporal lobe anastomose with basal and middle cerebral veins, draining to the cavernous, superior petrosal and transverse sinuses.

Basal vein. It begins at the anterior perforated substance by the union of:

- a small *anterior cerebral vein*, accompanying the anterior cerebral artery
- a *deep middle cerebral vein* receiving tributaries from the insula and neighbouring gyri and running in the lateral cerebral sulcus
- *striate veins* emerging from the anterior perforated substance.

The basal vein passes back round the cerebral peduncle to the great cerebral vein (**10.157**), receiving tributaries from the interpeduncular fossa, inferior cornu of the lateral ventricle, parahippocampal gyrus and midbrain.

Internal cerebral vein (10.157)

The internal cerebral vein is formed near the interventricular foramen primarily by the thalamostriate and choroid veins; it drains the deep parts of its hemisphere. Numerous smaller veins from surrounding structures also converge here; each runs back parallel to its fellow between the layers of the tela choroidea of the third ventricle and below the splenium, where they join to form the median great cerebral vein.

Thalamostriate vein. Running anteriorly between the caudate nucleus and thalamus, this vein receives many veins from both and unites behind the anterior column of the fornix with the choroid vein to form the internal cerebral.

Choroid vein. This runs along (curves or 'spirals' along) the whole choroid plexus, receiving veins from the hippocampus, fornix, corpus callosum and adjacent structures.

Great cerebral vein

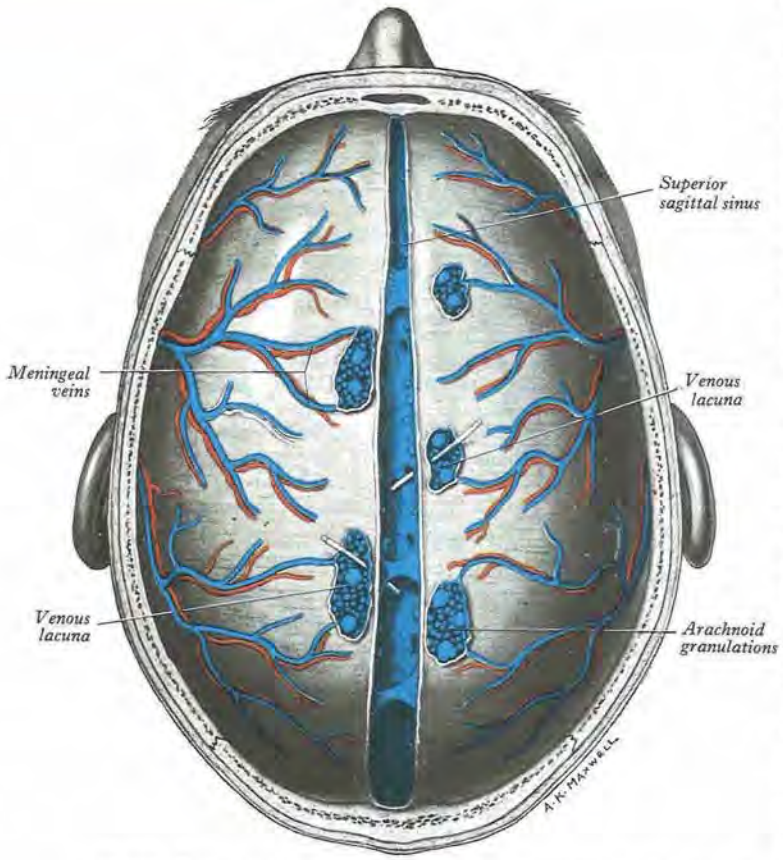
The great cerebral vein starts by union of the two internal cerebral veins as a short median vessel curving sharply up around the splenium to open into the anterior end of the straight sinus, after receiving the right and left basal veins.

Cerebellar veins

The cerebellar veins course on the cerebellar surface, and comprise superior and inferior sets.

Superior cerebellar veins. Some run anteromedially across the superior vermis to the straight sinus or great cerebral vein; others run laterally to the transverse and superior petrosal sinuses.

Inferior cerebellar veins. They include a small median vessel running backwards on the inferior vermis to enter the straight or (either) sigmoid sinus; laterally coursing vessels join the inferior petrosal and occipital sinuses.



10.158 The superior sagittal sinus laid open after removal of the cranial vault. Some of the fibrous bands which cross the sinus are clearly seen; from two of the venous lacunae, bristles are passed into the sinus.

Veins of the brainstem

The veins of the brainstem form a superficial venous plexus deep to the arteries. Veins of the midbrain may reach the great cerebral or basal vein. Over the pons they tend to form a lateral vein on each side which, with upper medullary veins, may enter the petrosal sinuses, transverse sinus, cerebellar veins or the venous plexus of the (sphenoidal) foramen ovale. A median pontine vein may exist and join one of the basal veins. Veins of the inferior medulla oblongata communicate with spinal veins and drain into the adjacent venous sinuses or along variable radicular veins following the last four cranial nerves to the inferior petrosal or occipital sinuses or the upper part of the internal jugular vein. Anterior and posterior median medullary veins may run along the anterior medial fissure or posterior median sulcus and are then continuous with the spinal veins in corresponding positions (p. 1220).

CRANIAL DURAL VENOUS SINUSES

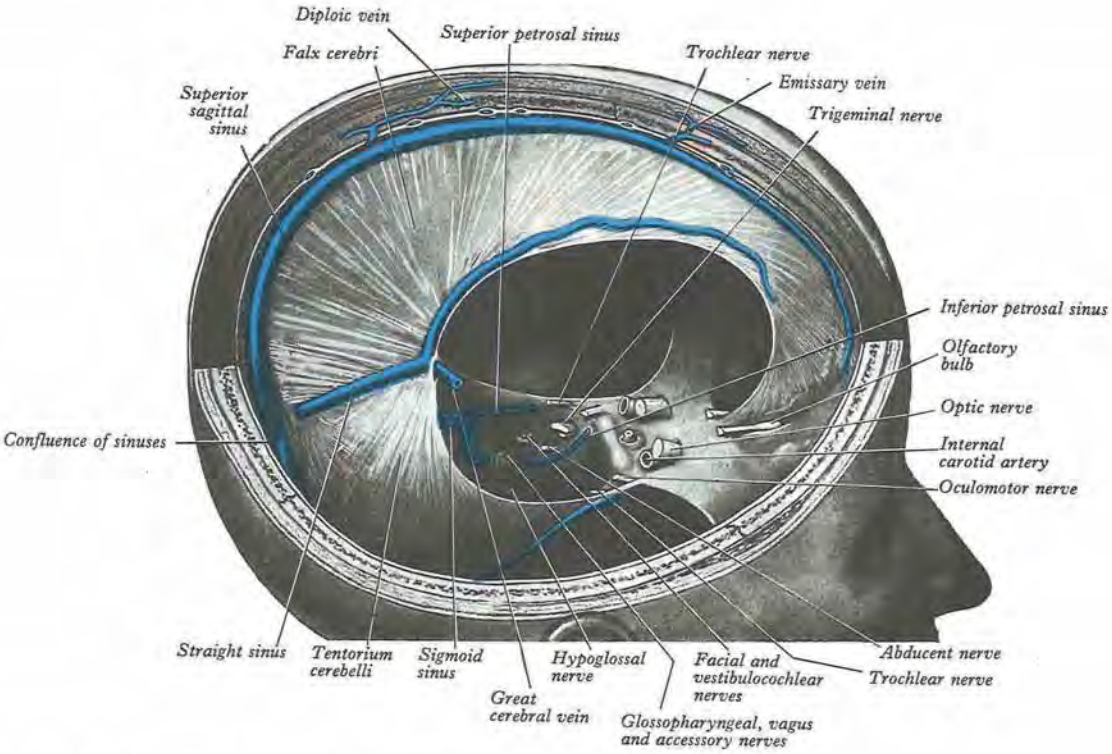
Dural sinuses are venous channels, draining blood from the brain and cranial bones, and lying between two layers of dura mater. They are lined by endothelium, they have no valves, and their wall is devoid of muscular tissue. Although most accounts describe sinuses as largely simple, smooth channels, a complex 'cavernous' or plexiform nature has been emphasized by Browder and Kaplan (1976), at least in some sites (p. 1585). They may be divided into:

- a posterosuperior group
- an antero-inferior group on the cranial base.

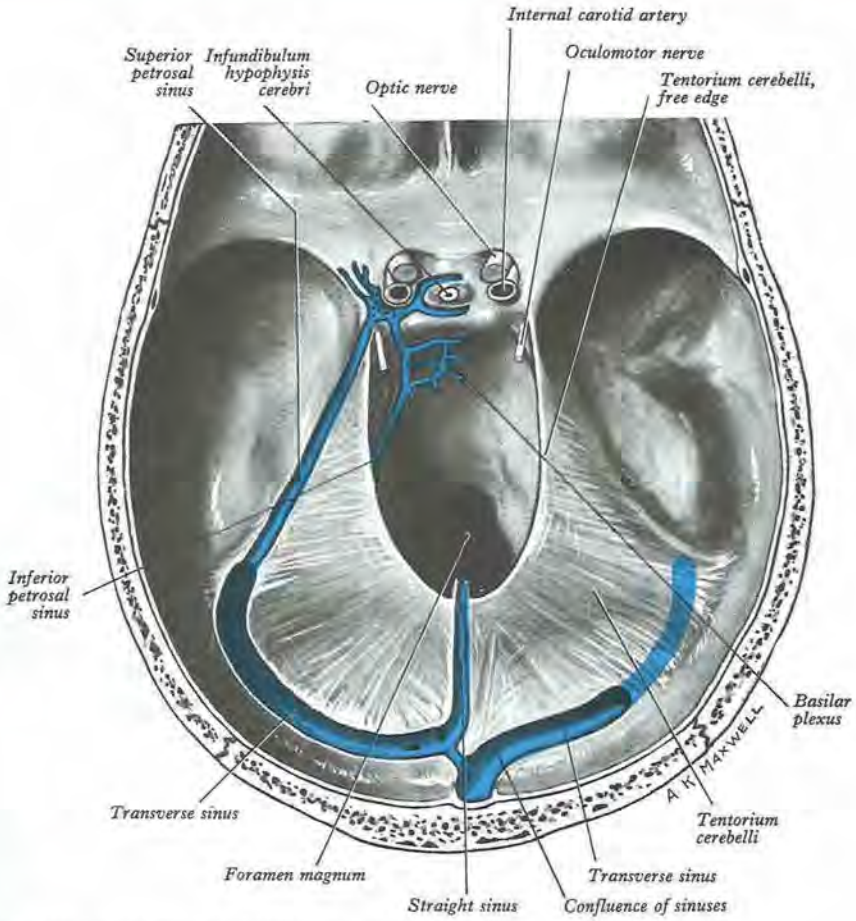
Posterosuperior group of venous sinuses

The posterosuperior group comprises the superior and inferior sagittal, straight, transverse, petrosquamous, sigmoid and occipital sinuses.

Superior sagittal sinus (10.157–159). It runs in the attached, convex margin of the falx cerebri. It is said to begin near the crista galli by receiving a vein from the nasal cavity when the foramen caecum is patent; but Kaplan et al (1973) found no such tributary in 201 specimens; in only 9% did the sinus extend as far as the



10.159 The dura mater, its processes and venous sinuses: right aspect. The cavernous and sphenoparietal sinuses are not represented.



10.160 The tentorium cerebelli and venous sinuses: superior aspect. Representation of the cavernous sinuses (or 'plexuses', see text) and their extensions is greatly simplified.

foramen; the first tributaries were cortical veins from the frontal lobes, the *ascending frontal veins* of Kravenbuhl (1967). The sinus usually begins a few millimetres posterior to the foramen caecum and runs back, grooving the internal surface of the frontal bone, the adjacent margins of the two parietal bones and the squamous occipital bone. Near the internal occipital protuberance it deviates, usually to the right, continuing as a transverse sinus. Triangular in cross-section, it gradually enlarges backwards. Its interior shows the openings of superior cerebral veins, projecting arachnoid granulations, and many fibrous bands across its inferior angle; it also communicates by small orifices with irregular *venous lacunae*, situated in the dura mater near the sinus, usually three on each side: a small frontal, a large parietal and an occipital intermediate in size. In the elderly, lacunae tend to become confluent as one elongated lacuna on each side. Fine fibrous bands cross them and numerous arachnoid granulations project into them. The superior sagittal sinus receives the superior cerebral veins and, near the posterior end of the sagittal suture, veins from the pericranium passing through the parietal foramina; the lacunae drain the diploic and meningeal veins.

The complexity of these lateral lacunae and of the sinus itself has been obscured by over-simplification in general texts; but this complexity has often been emphasized (Clark 1920; Baló 1950) and studies of corrosion casts (Browder & Kaplan 1976) and cerebral angiography have revived earlier descriptions. Lateral lacunae are often so complex as to be almost plexiform and rarely the simple venous spaces usually depicted. All more recent observers have described plexiform arrays of small veins adjoining the sagittal, transverse and straight sinuses. Clark and Baló regarded these masses as cavernous tissue, which commonly adjoin all sinuses intercommunicating at their confluence. Ridges of such 'spongy' venous tissue often project into the lumina of the superior sagittal and transverse sinuses. Their function can only be conjectured (p. 1214). The superior sagittal sinus is also invaded, in its intermediate third, by variable bands and projections from its dural walls, even extending as horizontal shelves dividing its lumen into superior and inferior channels. Such variable features make it impossible to give a simple description of this or other venous sinuses, whose variations have been detailed by Browder and Kaplan (1976) in a large series of corrosion casts; individual variations can only be shown by angiography.

Confluence of the sinuses (10.160). This term refers to the dilated posterior end of the superior sagittal sinus, situated to one side (usually right) of the internal occipital protuberance, where it turns to become a transverse sinus. It also connects with the occipital and contralateral transverse sinus. The size and degree of communication of the channels meeting at the confluence are variable (Browder & Kaplan 1976). In more than half of the specimens all venous channels converging towards the occiput do interconnect, including straight and occipital sinuses. In many instances, however, communication is absent or tenuous. Any sinus involved may be duplicated, narrowed or widened near the confluence. Variation is too great for useful description.

Clinical anatomy. Connections between the superior sagittal sinus and veins of the nose, scalp and diploë explain the occasional spread of infective thrombosis in these parts.

Inferior sagittal sinus. Located in the posterior half or two-thirds of the free margin of the falx cerebri, it increases in size posteriorly, ending in the straight sinus. It receives veins from the falx and sometimes from the medial cerebral surfaces.

Straight sinus (10.159, 160, 161). It lies in the junction of the falx cerebri with the tentorium cerebelli. Triangular in cross-section, it has a few transverse bands. It runs **postero-inferiorly**, continuing the

10.161 Internal carotid arteriogram (right), venous phase: lateral view. (Same subject as in **10.81** and **10.82**, pp. 1522, 1524.) 1. Superior cerebral veins. Note the anterior course at entry into the superior sagittal sinus. 2. An inferior cerebral vein ending in the straight sinus. 3. Region of venous anastomoses.

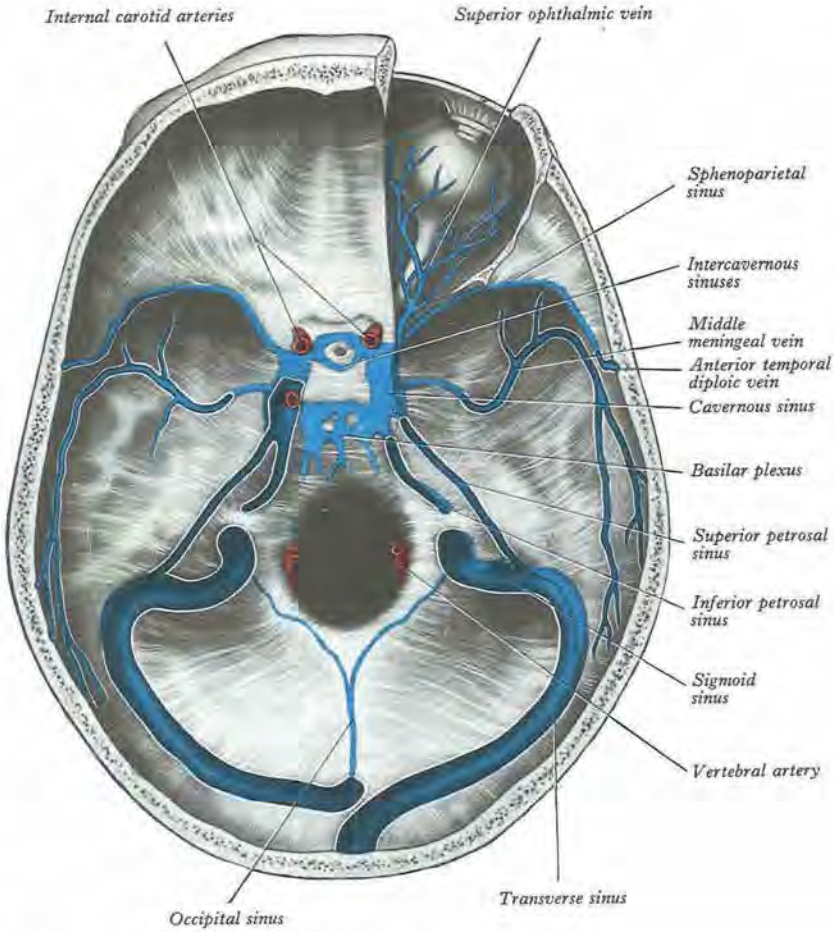
inferior sagittal sinus into that transverse sinus which is not, or only tenuously, continuous with the superior sagittal sinus. It may communicate terminally, but quite variably, at the confluence. Its tributaries include some superior cerebellar veins and the great cerebral; the site of the latter's opening is marked by a dilatation. A small body projects into the floor of the sinus at its junction with the great cerebral vein. This contains a sinusoidal plexus of vessels; it may become engorged and act as a valve controlling outflow from the great cerebral vein, affecting the secretion of cerebrospinal fluid in the lateral ventricles. As noted, other masses of cavernous tissue are related to other dural sinuses; engorgement possibly influences their blood flow but structural data make this unlikely (see above).

Transverse sinuses (**10**.160, 162)**.** They begin at the internal occipital protuberance, one (right) directly continuous with the superior sagittal sinus, the other with the straight sinus. Each curves anterolaterally to the posterolateral part of the petrous temporal bone, where it turns down as a sigmoid sinus. It is in the attached margin of the tentorium cerebelli, first on the occipital's squama, then on the parietal's mastoid angle. It has a gentle curve, convex upwards, and increases in size as it proceeds forwards. Transverse sinuses are triangular in section and usually unequal in size, the one draining the superior sagittal sinus being the larger. Where they continue as sigmoid sinuses, they are joined by the superior petrosal sinuses; they receive the inferior cerebral, inferior cerebellar, diploic and inferior anastomotic veins (p. 1581).

Petrosquamous sinus. It runs back in a groove, which sometimes becomes a canal posteriorly, along the junction of the squamous and petrous parts of the temporal bone, opening behind into the transverse sinus. Anteriorly it connects with the retromandibular vein through a postglenoid or squamous foramen (pp. 589, 590). The sinus may be absent; it may drain entirely into the retromandibular vein.

Sigmoid sinuses (**10**.162, 163)**.** They are continuations of the transverse sinuses, beginning where these leave the tentorium cerebelli. Each sigmoid sinus curves inferomedially in a groove on the mastoid temporal bone, crosses the occipital's jugular process and turns forwards to the superior jugular bulb, lying posterior in the jugular foramen. Anteriorly, a thin plate of bone alone separates its upper part from the mastoid antrum and air cells. It connects with pericranial veins via mastoid and condylar emissary veins.

Occipital sinus (**10**.162)**.** The smallest of the sinuses, it lies in the attached margin of the falx cerebelli, occasionally paired. It commences near the foramen magnum in several small channels, one



10.162 The sinuses at the base of the skull. The sinuses coloured dark blue have been opened up. See text and **10.165, 166** for alternative views on the construction of the cavernous sinuses.

joining the end of the sigmoid sinus; it connects with the internal vertebral plexuses and ends in the confluence of sinuses.

Antero-inferior group of venous sinuses

The antero-inferior group includes: cavernous, intercavernous, inferior petrosal, sphenoparietal, superior petrosal and basilar sinuses and middle meningeal 'veins'.

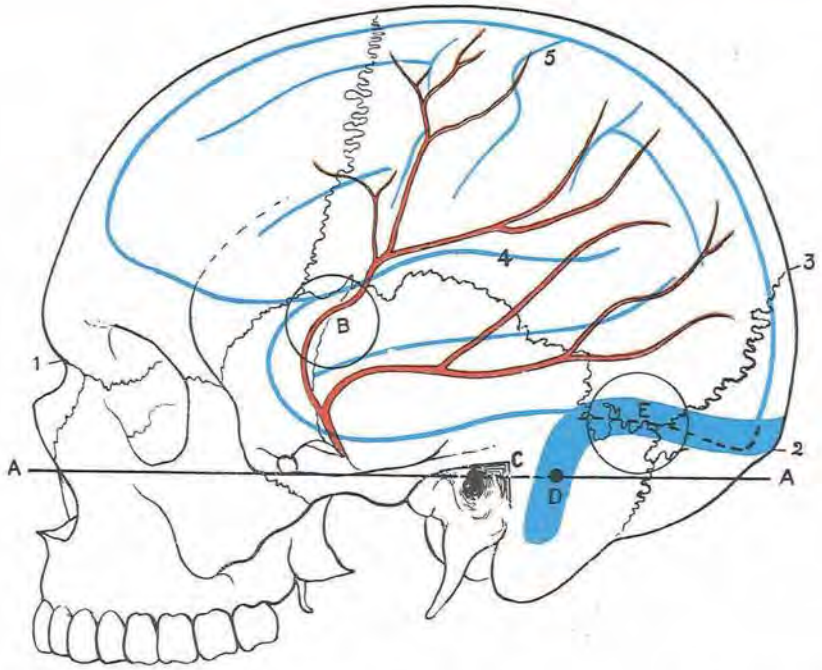
Cavernous sinuses (**10.158, 163–166**). They lie on the sides of the body of the sphenoid bone; their name refers to their internal structure. It has been asserted that a distended adult sinus contains a few trabeculae, mostly in its periphery near the entry of its tributaries, and that these are incorporations of plexiform tributaries during developmental expansion. When the sinus is collapsed, as is usual in cadavers, its cavity is encroached upon by the nerves and arachnoid granulations in its wall, creating a spurious resemblance to cavernous tissue (Butler 1957). From corrosion casts, however, Parkinson (1973) concluded that the sinus is usually a plexus (as it is during development), a finding in accord with some earlier descriptions; Pernkopf (1963) depicted the 'sinus' as a venous plexus (see **10.165, 166**). Browder and Kaplan (1976), from examination of many casts prepared in cadavers, described the sinus as 'reticulated'. It is not clear whether they meant plexiform or cavernous. The sinus extends from the superior orbital fissure to the apex of the petrous temporal bone, with an average length of 2 cm and width of 1 cm. The internal carotid artery, with a sympathetic plexus, passes forwards through the sinus, as does the abducent nerve, inferolateral to the artery; the oculomotor and trochlear nerves and ophthalmic and maxillary divisions of the trigeminal (**10.164**) are usually said to be in the thickness of its lateral wall; but they are of such diameters that they project into the sinus; while they may be surrounded by dural connective tissue, they are usually covered medially by little more than endothelium (McGrath 1977). The sphenoidal air sinus and hypophysis cerebri are medial; the trigeminal cave is near the inferoposterior part of its lateral wall, extending posteriorly beyond it and enclosing the trigeminal ganglion. The uncus is also lateral.

Tributaries. These are: the superior ophthalmic vein, a branch from the inferior ophthalmic vein (or the whole vessel), the superficial middle cerebral vein, inferior cerebral veins and sphenoparietal sinus; the central retinal vein and frontal tributary of the middle meningeal sometimes drain to it. The sinus drains to the transverse sinus via the superior petrosal sinus, to the internal jugular via the inferior petrosal sinus and a plexus of veins on the internal carotid, to the pterygoid plexus by veins traversing the emissary sphenoidal foramen, foramen ovale and foramen lacerum and to the facial vein via the superior ophthalmic. The two sinuses are connected by anterior and posterior intercavernous sinuses and the basilar plexus. All connections are valveless; the direction of flow in them is reversible.

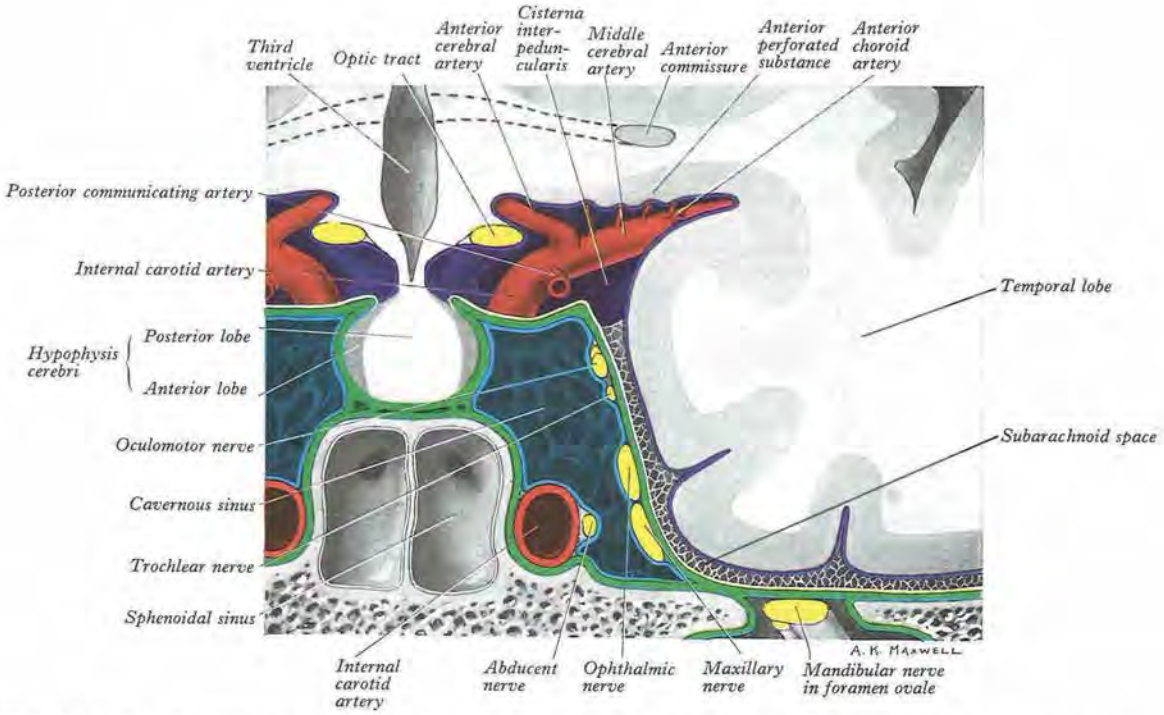
Propulsion of blood in the sinus is partly due to pulsation of the internal carotid artery. It is also influenced by gravity and hence by the position of the head.

Clinical anatomy. An arteriovenous leak may occur between the cavernous sinus and internal carotid artery, causing a pulsating orbital swelling. Ligation of the internal or common carotid artery has sometimes alleviated the condition. Suppuration in the upper nasal cavities and paranasal sinuses or near the medial canthus may lead to septic thrombosis of the cavernous sinuses.

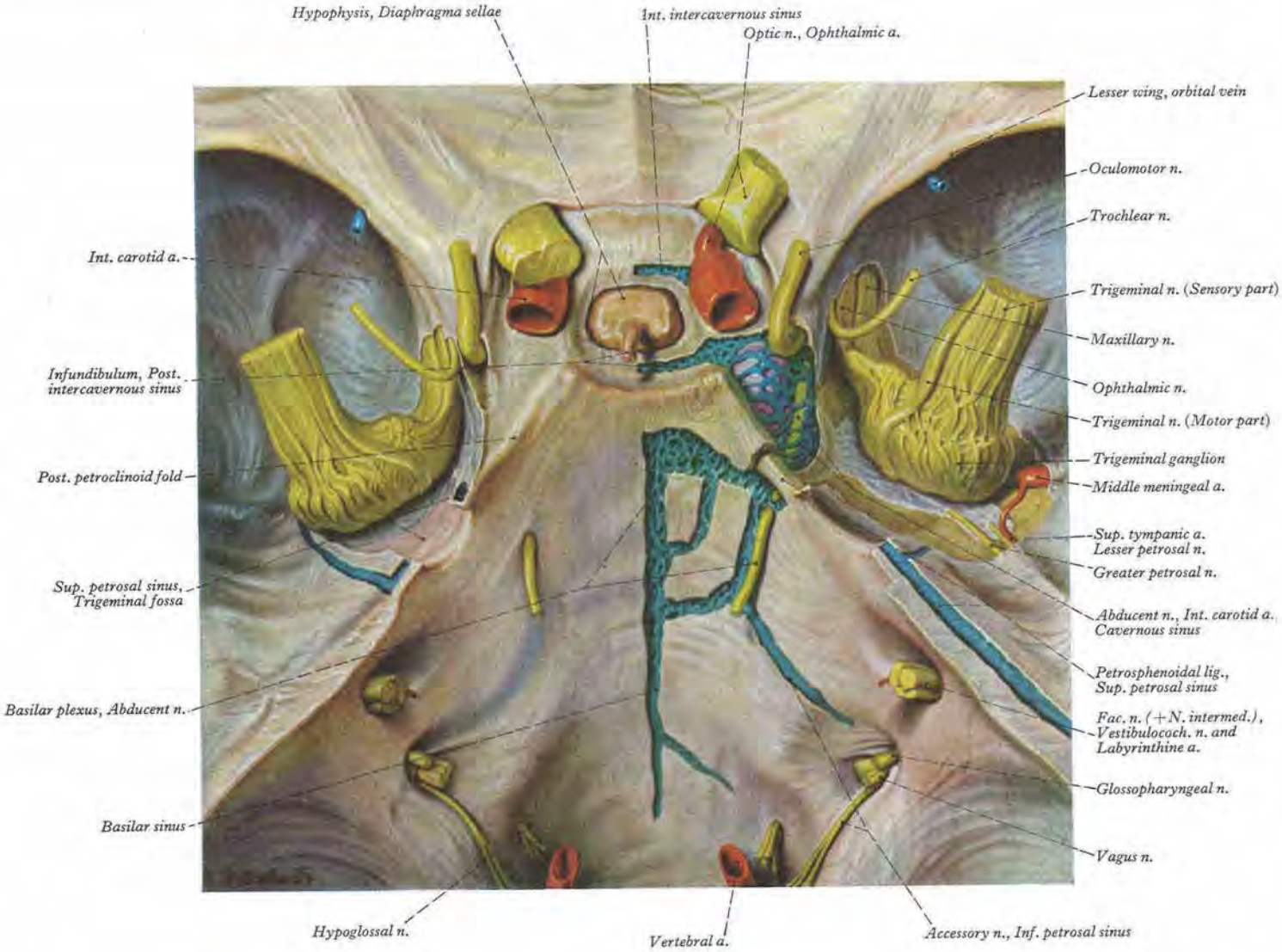
Ophthalmic veins (**10.163, 167**). There is a superior and an inferior, devoid of valves, linking the facial and intracranial veins. The *superior ophthalmic vein* forms posteromedial to the upper



10.163 The relations of the brain, the middle meningeal artery and the transverse and sigmoid sinuses to the surface of the skull. 1. Nasion. 2. Inion. 3. Lambda. 4. Lateral cerebral sulcus. 5. Central sulcus. AA = Frankfurt plane, which traverses the lower margin of the orbital opening and the upper margin of the external acoustic meatus; B = area (including the pterion) for trephining over the frontal branch of the middle meningeal artery and the cerebral Sylvian point; C = suprameatal triangle; D = sigmoid sinus; E = area for trephining over the transverse sinus, exposing the dura mater of both cerebrum and cerebellum. The outline of the cerebral hemisphere and its major sulci are indicated in blue; the course of the middle meningeal artery is in red.



10.164 Coronal, slightly oblique section through the middle cranial fossa, showing the cavernous and cerebral portions of the internal carotid artery and the cavernous sinus: mauve = pia mater; white = arachnoid mater; green = layers of dura mater (the mesothelium of the dura mater is not indicated); blue = endothelium of cavernous sinus.



10.165 The middle cranial fossa, viewed from above to show the termination of the internal carotid artery, its branches and the cavernous sinus. Note the plexiform nature of the 'sinus', which communicates with similar venous plexuses in the hypophyseal fossa and over the clivus. These have been exposed by partial removal of the dura mater. (See also **10.166.**)

lid from two tributaries connecting anteriorly with the facial and supraorbital veins (p. 1577). It runs with the ophthalmic artery, receiving corresponding tributaries, and traverses the superior orbital fissure to end in the cavernous sinus. The *inferior ophthalmic vein* begins in a network near the anterior region of the orbital floor and medial wall, receiving veins from the rectus inferior, obliquus inferior, lacrimal sac and eyelids; it runs back above the rectus inferior and often joins the superior ophthalmic vein but may reach the cavernous sinus. It connects with the pterygoid venous plexus by small rami through the inferior orbital fissure.

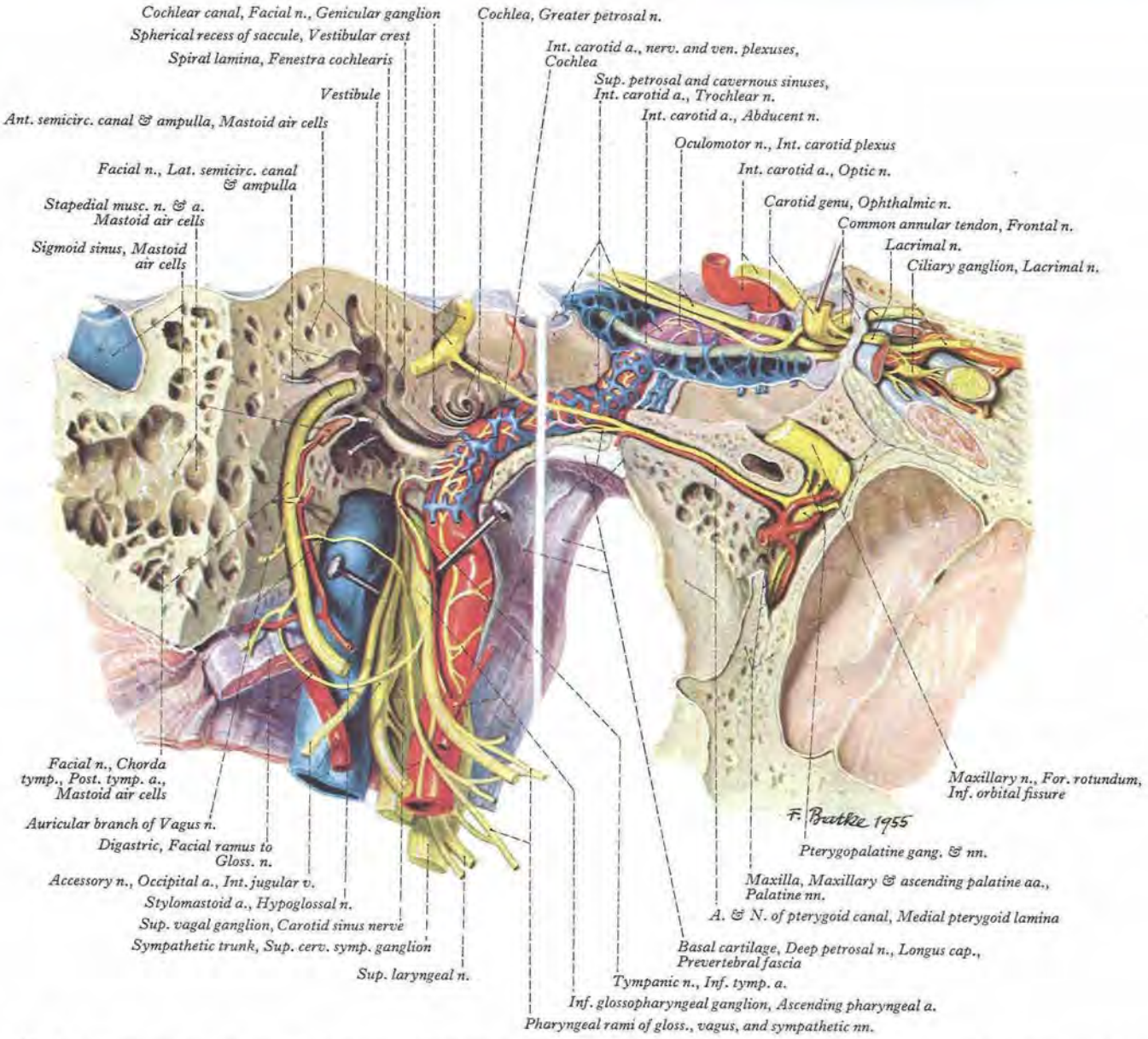
Central retinal vein. This vein first traverses the optic nerve then it leaves it to pursue a long course in the subarachnoid space before entering the cavernous sinus or the superior ophthalmic vein. It receives a *central vein* which drains the nerve while still within it.

Sphenoparietal sinuses (**10.163**). They are located below the periosteum of the lesser wings of the sphenoid bone, near their posterior edges. Each receives small veins from the adjacent dura mater and sometimes the frontal ramus of the middle meningeal vein; curving medially it opens into the anterior part of the cavernous sinus. It often receives connecting rami, in its middle course, from the superficial middle cerebral vein, sometimes veins from the temporal lobe and the anterior temporal diploic vein. When these connections are well developed it is a large channel.

Intercavernous sinuses. These two sinuses, anterior and posterior, interconnect the cavernous sinuses in the anterior and posterior attached borders of the diaphragma sellae; they thus complete a venous circular sinus (**10.163**). Small, irregular sinuses inferior to the hypophysis cerebri drain into them. Such *inferior intercavernous sinuses* were studied by Kaplan et al (1976), who emphasized their size and plexiform nature, features important in a surgical transnasal approach to the hypophysis.

Superior petrosal sinuses (**10.163**). These small and narrow sinuses drain the cavernous to the transverse sinuses. Leaving the posterosuperior part of the cavernous sinus, each runs posterolaterally in the attached margin of the tentorium cerebelli, crossing above the trigeminal nerve to a groove on the superior border of the petrous temporal bone; each ends by joining a transverse sinus where this curves down to become the sigmoid. It receives *cerebellar*, *inferior cerebral* and *tympanic veins*. It connects with the inferior petrosal sinus and basilar plexus.

Inferior petrosal sinuses. They drain the cavernous sinuses to the internal jugular veins. Each (**10.163**) begins postero-inferiorly at its cavernous sinus and runs back in a groove between the petrous temporal and basilar occipital bones. Traversing the anterior part of the jugular foramen it ends in the superior jugular bulb. It receives labyrinthine veins via the cochlear canaliculus and the vestibular



10.166 An oblique vertical section through the cranial base to display in lateral view the right internal carotid artery and the continuity of the venous plexus around the intraosseous and cavernous parts of the artery. (**10.165** and 166 are from Pernkopf 1963, by permission of W B Saunders and Urban & Schwarzenberg.)

aqueduct and tributaries from the medulla oblongata, pons and inferior cerebellar surface. According to Browder and Kaplan (1976) the sinus is more often a plexus and sometimes drains by a vein in the hypoglossal canal to the suboccipital vertebral plexus.

Relations of structures in the jugular foramen. These are as follows: the inferior petrosal sinus is anteromedial with a meningeal branch of the ascending pharyngeal artery, and the sinus descends obliquely backwards; the sigmoid sinus is situated at the lateral and posterior part of the foramen with a meningeal branch of the occipital artery; between the sinuses are in succession, posterolaterally: the glossopharyngeal, vagus and accessory nerves (p. 1254).

Basilar venous plexus (**10.163**). It consists of interconnecting channels between layers of dura mater on the clivus; it interconnects the inferior petrosal sinuses and joins with the internal vertebral venous plexus. It also usually connects with the cavernous and superior petrosal sinuses at its anterior end. When marginal sinuses (p. 1589) are large they communicate anteriorly with the plexus; an almost complete circular venous channel may then surround the foramen magnum, connecting the basilar plexus intracranially to the inferior petrosal, sigmoid and occipital sinuses and to variable extracranial vertebral plexuses in the suboccipital region.

Middle meningeal veins (or sinuses) (**10.163**). They communicate above with the superior sagittal sinus through its venous lacunae; below they converge and unite as frontal and parietal trunks, which accompany branches of the middle meningeal arteries in grooves on the internal parietal surfaces; but the veins are closer to bone and sometimes occupy separate grooves. The veins' situation has been said to make them liable to tears in fractures (Jones 1911). Their termination is variable. The parietal trunk may traverse the foramen spinosum to the pterygoid venous plexus; the frontal may also reach the plexus via the foramen ovale or may end in the sphenoparietal or cavernous sinus. Besides meningeal tributaries they receive small inferior cerebral veins and connect with the diploic and superficial middle cerebral veins. Browder and Kaplan (1976) state that middle meningeal 'veins' are histologically sinuses, in places almost surrounding the middle meningeal arteries; they also report frequent arachnoid granulations in them.

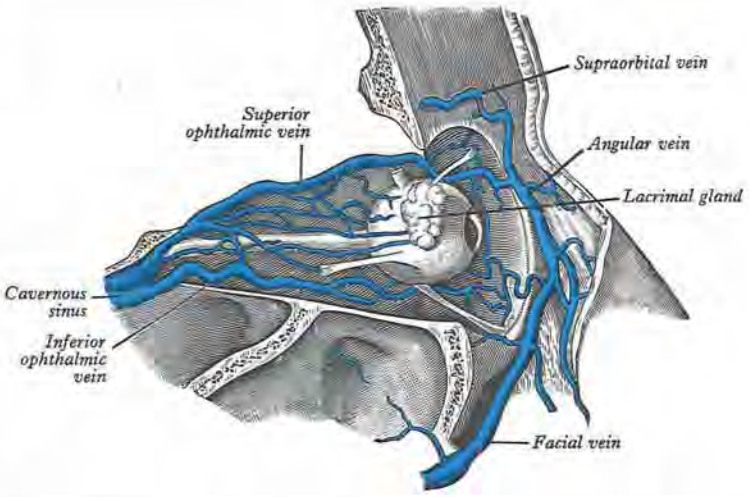
Surface anatomy. The superior sagittal sinus runs from the glabella

(p. 554) to the inion (6.168A). Narrow anteriorly, it widens to about 1 cm. The transverse sinus begins at the inion and runs laterally, with slight upward convexity, to the base of the mastoid process, from which the sigmoid sinus passes down just anterior to the posterior mastoid border to a point about 1 cm above its tip.

EMISSARY VEINS

Emissary veins traverse cranial apertures and make connections between venous sinuses and extracranial veins. Some are constant, others sometimes absent:

- A *mastoid emissary vein* in the mastoid foramen unites the sigmoid sinus with the posterior auricular or occipital vein.
- A *Perietal emissary vein* traverses the parietal foramen to connect the superior sagittal sinus with the veins of the scalp.
- The *venous plexus of the hypoglossal canal*, occasionally a single vein, connects the sigmoid sinus to the internal jugular vein.
- A *posterior condylar emissary vein* connects the sigmoid sinus with veins in the suboccipital triangle via the condylar canal.
- A plexus of emissary veins (*venous plexus of foramen ovale*) links the cavernous sinus to the pterygoid plexus via the foramen ovale.
- Two or three small veins traverse the foramen lacerum connecting the cavernous sinus with the pharyngeal veins and pterygoid plexus.
- A vein in the emissary sphenoidal foramen (of Vesalius) connects the same vessels.
- The *internal carotid venous plexus*, passing through the carotid canal, connects the cavernous sinus to the internal jugular vein.
- The petrosquamous sinus (p. 1584) connects the transverse sinus with the external jugular vein.
- A vein may traverse the foramen caecum (patent in about 1% of adult skulls) connecting nasal veins with the superior sagittal sinus.
- An *occipital emissary vein* usually connects the confluence of sinuses with the occipital vein through the occipital protuberance, receiving also the occipital diploic vein.
- The occipital sinus connects with variably developed veins around the foramen magnum (so-called *marginal sinuses*) and thus with the vertebral venous plexuses, an alternative venous drainage when the jugular vein is blocked or tied.
- The ophthalmic veins are potentially emissary, since they connect intracranial to extracranial veins; but parietal emissary veins, included here, are usually minute and do not appear to connect with veins of the scalp in corrosion casts.



10.167 The veins of the right orbit: lateral aspect.

These connections are significant in the spread of infection from extracranial foci to venous sinuses. The success of a ligature of the internal jugular vein, to limit the spread of some oral and pharyngeal pathologies, depends on the adequacy of the collateral drainage.

VEINS OF THE UPPER LIMBS

Veins are conveniently grouped as *superficial* and *deep* but these are widely interconnected. The superficial veins are subcutaneous in the superficial fascia; deep veins accompany arteries between the muscles of the limb. Both groups have valves, which are more numerous in deep veins.

SUPERFICIAL VEINS OF THE UPPER LIMB

Superficial veins (**10**.168, 169) include the cephalic, basilic, median cubital and additional antebrachial veins and their tributaries.

Dorsal digital veins pass along the sides of the fingers, joined by oblique branches; they unite from the adjacent sides of digits into three dorsal metacarpal veins (**10**.168), which form a *dorsal venous network* over the metacarpus; this is joined laterally by a dorsal digital vein from the radial side of the index finger and both dorsal digital veins of the thumb and is prolonged proximally as the cephalic vein. Medially a dorsal digital vein from the ulnar side of minimus joins the network, which drains proximally into the basilic vein. A vein often connects the central parts of the network to the cephalic near midforearm.

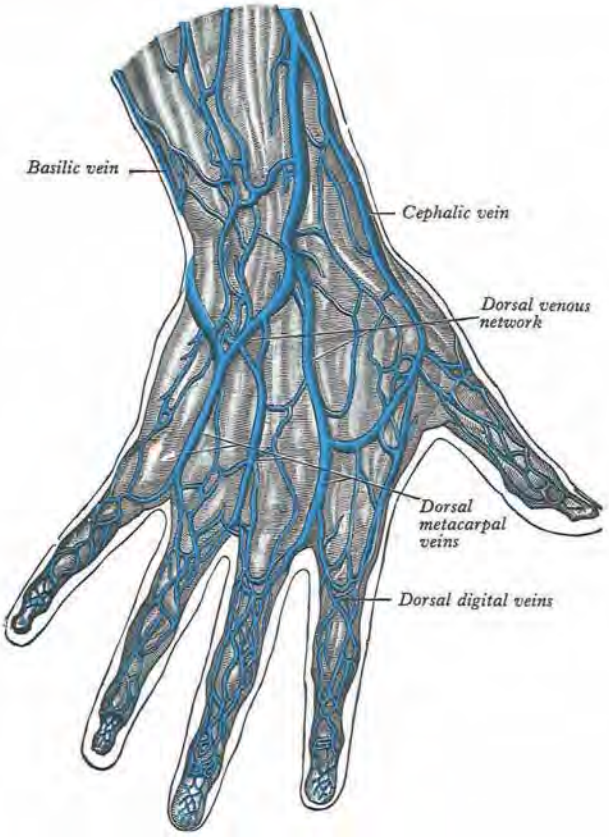
Palmar digital veins connect to the dorsal by oblique intercapitular veins passing between metacarpal heads; they also drain to a plexus superficial to the palmar aponeurosis, extending over both thenar and hypothenar regions.

Cephalic vein (**10**.168, 169). Commonly formed over the 'anatomical snuff box', it curves proximally from the radial end of the dorsal plexus round the forearm's radial side to its ventral aspect, receiving veins from both aspects. Distal to the elbow a branch, the *median cubital vein*, joined by a branch from the deep veins, diverges proximomedially to reach the basilic vein. The cephalic ascends in front of the elbow superficial to a groove between the brachioradialis and biceps, crosses superficial to the lateral cutaneous nerve of the forearm, ascends lateral to the biceps and between pectoralis major and the deltoid, where it adjoins the deltoid branch of the thoracoacromial artery. Entering the infraclavicular fossa to pass behind the clavicular head of pectoralis major, it pierces the clavipectoral fascia, crosses the axillary artery and joins the axillary vein just below clavicular level. It may connect with the external jugular by a branch anterior to the clavicle. Sometimes the median cubital vein is large, transferring most blood from the cephalic to the basilic vein, the proximal cephalic vein then being absent or much diminished.

Accessory cephalic vein. Arising in a dorsal forearm plexus or from the ulnar side of the dorsal venous network in the hand, this joins the cephalic distal to the elbow. It may spring from the cephalic proximal to the carpus and rejoin it later. A large oblique vein often connects the basilic and cephalic veins dorsally in the forearm.

Basilic vein (**10**.169). Beginning medially in the hand's dorsal venous network, it ascends posteromedially in the forearm inclining forwards to the anterior surface distal to the elbow. Joined by the median cubital vein, it ascends superficially to and between biceps and pronator teres; filaments of the medial cutaneous nerve of the forearm pass here, in front and behind it. It ascends medial to biceps and perforates the deep fascia about midway in the arm, continuing medial to the brachial artery to the lower border of teres major, there becoming the axillary vein. (Its relation to the brachial veins is variable; see p. 1590.)

Median vein of the forearm (**10**.169). It drains the superficial palmar venous plexus. It ascends anterior in the forearm to join the



10.168 The veins of the dorsum of the hand.

basilic or median cubital vein; it may divide distal to the elbow to join both.

Surface anatomy

Superficial veins are usually visible until they pierce the deep fascia. Larger ones are obvious when the limb is dependent and its muscles contracted, driving blood from the deep to the superficial veins.

Clinical anatomy

Blood sampling, blood transfusion and intravenous injection are commonly done near the elbow or more distally in the forearm; the largest vein is usually the median cubital. The cubital veins are also used for cardiac catheterization for many purposes. Equally useful for such procedures is the cephalic vein where it is superficial to the distal end of the radius in the 'anatomical snuffbox'. The cephalic vein, a little proximal to the snuff box, is the site with many advantages for an indwelling cannula or fine tube when a lengthy period is contemplated; the position of the arm, forearm and hand is optimal for this purpose.

DEEP VEINS OF THE UPPER LIMB

Deep veins (venae comitantes) accompany arteries, usually in pairs, flanking the artery and connected by short transverse links. Since much blood from the upper limb is returned by the superficial veins, the deep ones are relatively small.

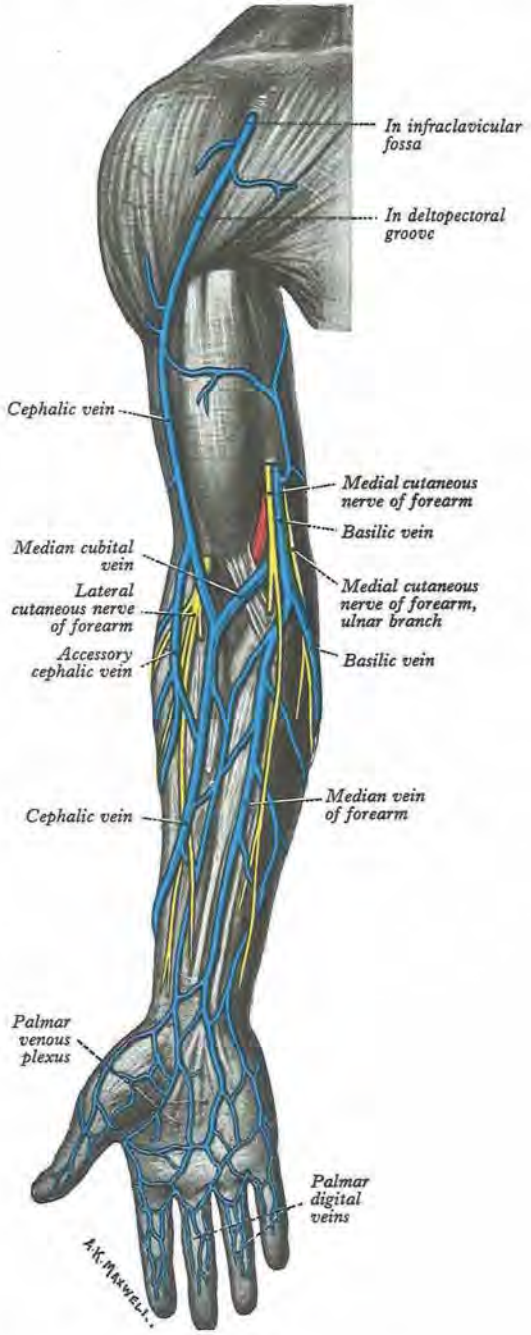
Deep veins of the hand. Superficial and deep palmar arterial arches are accompanied by superficial and deep palmar venous arches, receiving the corresponding branches. Thus common palmar digital veins join the superficial arch and palmar metacarpal veins join the deep arch. Deep veins accompanying the dorsal metacarpal arteries first receive perforating branches from the palmar metacarpal veins and then end in the radial veins and the dorsal venous network.

Deep veins of the forearm. Running with the radial and ulnar arteries they drain respectively the deep and superficial palmar venous arches; they unite near the elbow as paired *brachial veins.* The radial veins are smaller, receiving the deep dorsal veins of the hand; ulnar veins drain the deep palmar venous arch, connecting with superficial veins near the wrist; near the elbow they receive the anterior and posterior interosseous artery companion veins; a large branch connects them to the *median cubital vein.*

Brachial veins. They flank the brachial artery, with tributaries similar to the arterial branches; near the lower margin of subscapularis they join the axillary vein, the medial one, however, often joining the basilic before it becomes the axillary.

These deep veins have numerous anastomoses with each other and with the superficial veins.

Axillary vein. This large vein is the continuation of the basilic; it begins at the lower border of teres major, and ascends to the outer border of the first rib, where it becomes the subclavian. Near subscapularis the brachial vein joins it and, near its costal end, the cephalic; other tributaries follow the axillary arterial branches. It is



10.169 The superficial veins of the right upper extremity: anterior aspect.

medial to the axillary artery, which it partly overlaps; between them are the medial pectoral nerve, medial cord of the brachial plexus, the ulnar nerve and the medial cutaneous nerve of the forearm. The medial cutaneous nerve of the arm is medial to the vein; the lateral group of axillary lymph nodes is posteromedial. It has a pair of valves near its distal end; valves also occur near the ends of the cephalic and subscapular veins.

Subclavian vein (10.92). Continuing the axillary, this vein extends from the outer border of the first rib to the medial border of scalenus anterior, where it joins the internal jugular to form the brachiocephalic vein. **Anterior** are the clavicle and subclavius, **posterosuperior** the subclavian artery, separated by the scalenus anterior and phrenic nerve; **inferior** are the first rib and pleura. The vein usually has a pair of valves about 2 cm from its end. Its tributaries are the external jugular, dorsal scapular and sometimes the anterior jugular; occasionally a small branch ascends in front of the clavicle from the cephalic vein. At its junction with the internal jugular the left subclavian receives the thoracic duct, the right subclavian vein and the right lymphatic duct.

Surface anatomy

The vein can be projected as a broad band, convex upwards, from just medial to the midclavicular point to the medial edge of the clavicular attachment of sternocleidomastoid.

VEINS OF THE THORAX

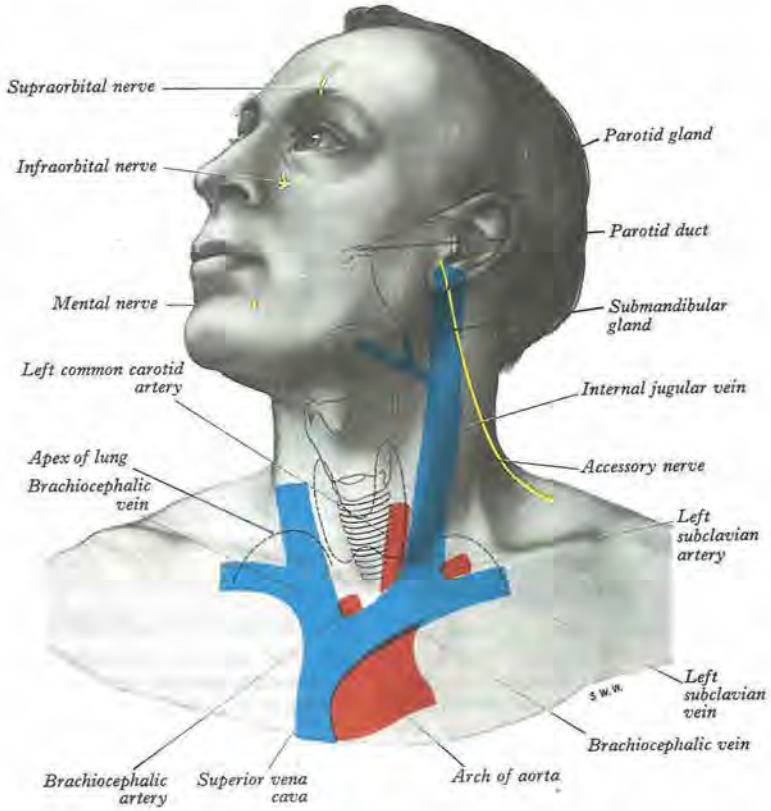
Brachiocephalic veins

The brachiocephalic (innominate) veins, two large vessels at the junction of the neck and thorax, are the united trunks of the internal jugular and subclavian veins. Both are devoid of valves.

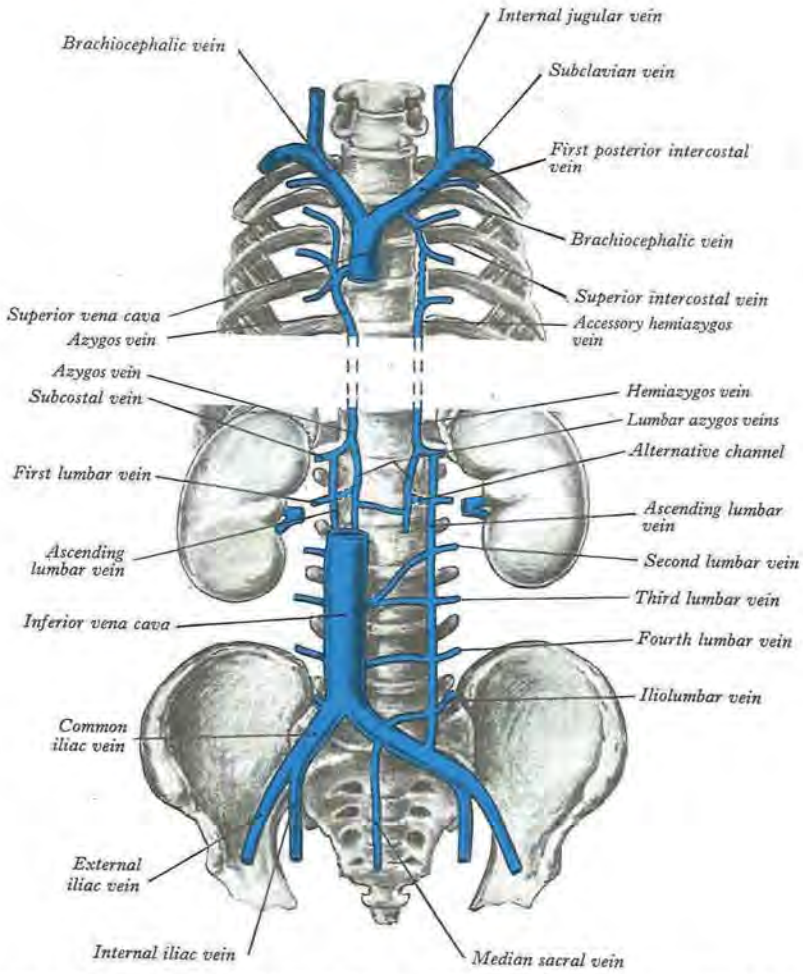
Right brachiocephalic vein (10.170). About 2.5 cm long, it begins posterior to the sternal end of the right clavicle, and descends almost vertically to join the left brachiocephalic forming the superior vena cava posterior to the lower border of the first right costal cartilage, near the right sternal border. It is anterolateral to the brachiocephalic artery and right vagus nerve. The right pleura, phrenic nerve and internal thoracic artery are posterior to it above, becoming lateral below. Its tributaries are the right vertebral, internal thoracic, inferior thyroid and sometimes the first right posterior intercostal veins.

Left brachiocephalic vein (10.170). Some 6 cm long, it begins posterior to the sternal end of the left clavicle, anterior to the cervical pleura. It descends obliquely to the right, posterior to the upper half of the manubrium sterni, to the sternal end of the first right costal cartilage, uniting here with the right brachiocephalic to form the superior vena cava. It is separated from the left sternoclavicular joint and manubrium by the sternohyoid and sternothyroid, the thymus or its remains and areolar tissue; terminally it is overlapped by the right pleura. It crosses anterior to the left internal thoracic, subclavian and common arteries, left phrenic and vagus nerves, trachea and brachiocephalic artery. The aortic arch is inferior to it. The vein's tributaries are the left vertebral, internal thoracic, inferior thyroid, superior intercostal, sometimes the first left posterior intercostal, thymic and pericardial veins.

Surface anatomy. The brachiocephalic veins can be projected as broad bands 1.5 cm wide from the sternal ends of the clavicles to the parasternal lower border of the first right costal cartilage.



10.170 The surface projections of some of the important structures in the face, neck and upper part of the thorax. The apices of the lungs, the thyroid, submandibular and parotid glands and the parotid duct are indicated in interrupted dotted outline; the hyoid bone, the thyroid and cricoid cartilages and the rings of the trachea are shown in continuous outline.



10.171 Schema showing the superior and inferior extremities of the azygos system of veins and their principal associated veins. The intervening parts have been omitted because schemata of this region are often topographically misleading. Much variation occurs in the transthoracic parts of the azygos and hemiazygos veins, in terms of numbers of radicles, levels of transmedian crossing, etc. Schemata are usually misleading. That depicted by painting in **10.172** is the most common condition.

Variations. The brachiocephalic veins may enter the right atrium separately, the right vein descending like a normal superior vena cava; a left superior vena cava may have a slender connection with the right and then cross the left side of the aortic arch to pass anterior to the left pulmonary hilum before turning to enter the right atrium. It replaces the oblique atrial vein and coronary sinus and receives all the latter's tributaries. This abnormality, due to persistence of an early fetal condition, is normal in birds and some mammals. The left brachiocephalic vein sometimes projects above the manubrium (more frequently in childhood), crossing the suprasternal fossa in front of the trachea.

Internal thoracic (mammary) veins

The internal thoracic veins are venae comitantes to the inferior half of the internal thoracic artery; they have several valves. Near the third costal cartilages the veins unite to ascend medial to the artery, ending in their brachiocephalic vein (**10.71**, 95). Tributaries correspond to branches of the artery (p. 1534), and include a pericardiophrenic vein.

Inferior thyroid veins

The inferior thyroid veins arise in a glandular venous plexus, which also connects with the middle and superior thyroid veins (**10.71**). These veins form a *pretracheal plexus* from which the left inferior vein descends to join the left brachiocephalic, the right descending obliquely across the brachiocephalic artery to the right brachiocephalic vein, at its junction with the superior vena cava; the inferior thyroid veins often open in common into the vena cava or left brachiocephalic vein. They drain the oesophageal, tracheal and inferior laryngeal veins and have valves at their terminations.

Left superior intercostal vein

The left superior intercostal vein drains the second and third (sometimes fourth) left posterior intercostal veins, ascending obliquely forwards across the left aspect of the aortic arch, lateral to the left vagus, medial to the left phrenic nerve, to open into the left brachiocephalic vein (**10.71**). It usually receives the left bronchial veins, sometimes the left pericardiacophrenic; it connects inferiorly with the accessory hemiazygos vein.

Superior vena cava

The superior vena cava is about 7 cm in length, formed by the junction of the brachiocephalic veins, and has no valves. It returns

to the heart blood from the superior half of the body. It begins behind the lower border of the first right costal cartilage near the sternum, descends vertically behind the first and second intercostal spaces, ending in the upper right atrium behind the third right costal cartilage; its inferior half is within the fibrous pericardium, which it pierces level with the second costal cartilage. Covered anterolaterally by serous pericardium from which projects a *retrocaval recess*, it is slightly convex to the right (**10**.66, 68–71).

Relations. Anterior are the anterior margins of the right lung and pleura, the pericardium intervening below; these separate the vein from the internal thoracic artery and first and second intercostal spaces, and second and third costal cartilages; posteromedial are the trachea and right vagus nerves and posterolateral the right lung and pleura; posterior is the right pulmonary hilum. Right lateral are the right phrenic nerve and pleura, left lateral the brachiocephalic artery and ascending aorta, the latter overlapping it.

Surface anatomy. The superior vena cava, 2 cm wide, is partly behind but projects well beyond the right sternal margin, from the lower border of the first to the lower border of the third right costal cartilage. Its lateral border is visible in anteroposterior radiographs.

Tributaries. These are: the azygos vein and small veins from the pericardium and other mediastinal structures.

Azygos vein (10.171–173).

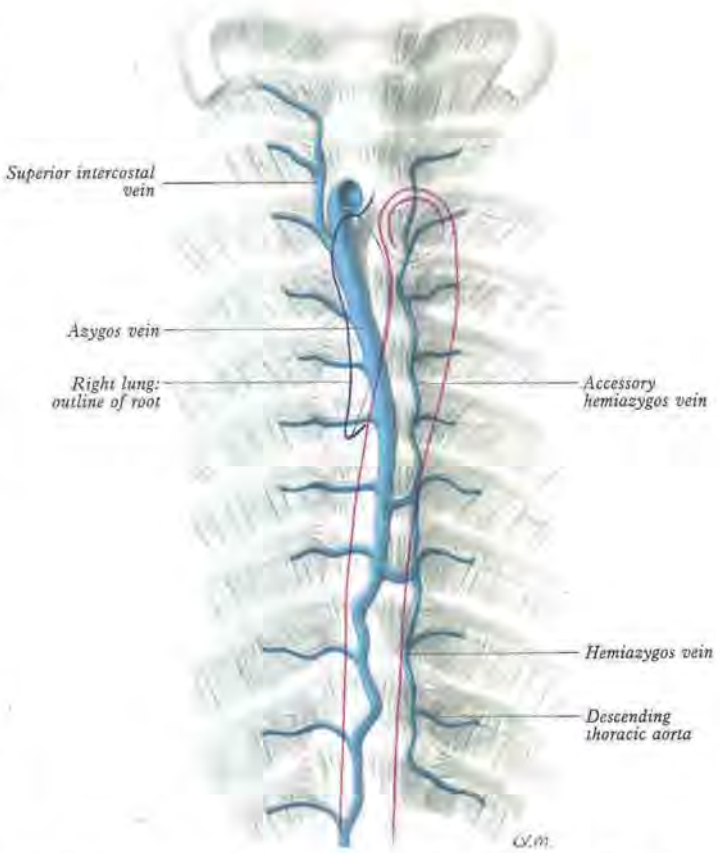
An origin from the posterior aspect of the inferior vena cava, at or below the level of the renal veins, is to be expected from its development but it is not constant (Gladstone 1929). Such a lumbar azygos vein frequently occurs, ascending anterior to the upper lumbar vertebrae. The vein may pass behind the right crus of the diaphragm or pierce it. It may traverse the aortic opening on the right of the cisterna chyli. Anterior to the twelfth thoracic vertebral body it is joined by a large vessel formed by the right ascending lumbar and right subcostal veins, which passes forward and right of the twelfth thoracic vertebra behind the right crus. This common trunk may, in the absence of a lumbar azygos, form the azygos itself. Whatever its origin, the azygos vein ascends in the posterior mediastinum to the fourth thoracic vertebra, arching forward above the right pulmonary hilum to end in the superior vena cava, before the latter pierces the pericardium. It is **anterior** to the lower eight thoracic vertebral bodies (see below), anterior longitudinal ligament and right posterior intercostal arteries. **Right lateral** are the right greater splanchnic nerve, lung and pleura; **left lateral** in most of its course are the thoracic duct and aorta and, where it arches forward, the oesophagus, trachea and right vagus. In the lower thorax it is covered anteriorly by a recess of the right pleural sac and oesophagus, emerging from behind the latter to ascend behind the right hilum (**10**.173). Because of the closeness of the azygos vein to the right posterolateral aspect of the descending thoracic aorta, aortic pulsations may assist venous return in azygos and hemiazygos veins.

Tributaries. The azygos vein drains: the right posterior intercostal veins except the first, the veins from the second to fourth intercostal spaces usually via a right superior intercostal vein, the hemiazygos and accessory hemiazygos veins, oesophageal, mediastinal and pericardial veins and, near its end, right bronchial veins. When it begins as a lumbar azygos, the common trunk formed by the right ascending lumbar and subcostal veins is its largest tributary. Imperfect valves occur in the azygos vein, some tributaries having complete valves.

Hemiazygos vein. It starts on the left like the azygos; ascending anterior to the vertebral column to the eighth thoracic level, it crosses the column posterior to the aorta, oesophagus and thoracic duct to end in the azygos vein. Its tributaries are the lower three posterior intercostal veins, a common trunk formed by the left ascending lumbar and subcostal veins and oesophageal and mediastinal rami. Its lower end often connects with the left renal vein.

Accessory hemiazygos vein. It descends to the left of the vertebral column, receiving veins from the fourth (or fifth) to eighth intercostal spaces and sometimes the left bronchial veins. It crosses the seventh thoracic vertebra to join the azygos vein. It sometimes joins the hemiazygos, their common trunk opening into the azygos vein.

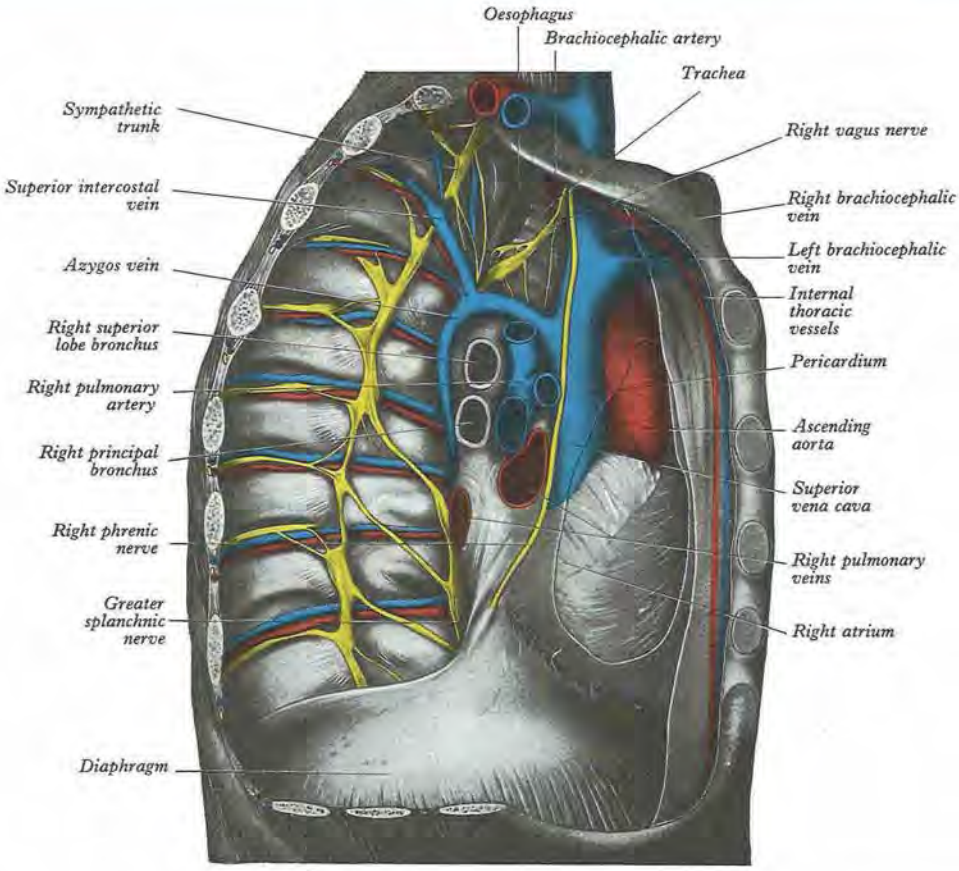
Variations of the azygos veins. They vary much in their mode of origin, course, tributaries, anastomoses and termination. For a survey consult Grzybiak et al (1975), who consider the accessory hemiazygos most variable, draining into the left brachiocephalic, azygos or hemiazygos. The arrangement shown in **10**.172 represents a common pattern. In about 1 or 2% of subjects according to Anson (1963) there are left and right independent azygos veins (the early embryonic form) and occasionally a single azygos without hemiazygos tributaries, in a midline position. In more than 95% a main 'right-sided' azygos and at least some representative of hemiazygos veins exist. The latter vary, one or the other being absent or poorly developed. Retro-aortic transvertebral connections from hemiazygos and accessory hemiazygos veins to the azygos are also extremely variable; there may be from one to five, or more; when either hemiazygos is absent, intercostal veins involved cross vertebral bodies to end in the azygos. These transvertebral routes are often very short, since the azygos vein is more commonly anterior to the vertebral column (Anson 1963) and often passes left of the midline in part of its course.



10.172 A frequent (perhaps the commonest) course followed by the intrathoracic azygos, hemiazygos and accessory hemiazygos veins. Outlines of the root of the right lung and descending thoracic aorta are included. (Dissection by M C E Hutchinson, Guy's Hospital Medical School, London.)

Posterior intercostal veins

The posterior intercostal veins accompany their arteries in eleven pairs. Approaching the vertebral column each vein receives a posterior tributary returning blood from the dorsal muscles and skin and vertebral venous plexuses (**10**.111, 173). On both sides the first posterior intercostal vein ascends anterior to the first rib's neck, arching forward above the pleural dome to end in the ipsilateral brachiocephalic or vertebral vein. On the right the second, third and often fourth, form a right superior intercostal vein joining the arch of the azygos vein. Veins from the lower spaces drain directly to it. On the left the second and third (sometimes fourth) form a left superior intercostal vein (p. 1592). Veins from the fourth (or fifth) to eighth spaces end in the accessory hemiazygos vein, veins from the lower three spaces in the hemiazygos.



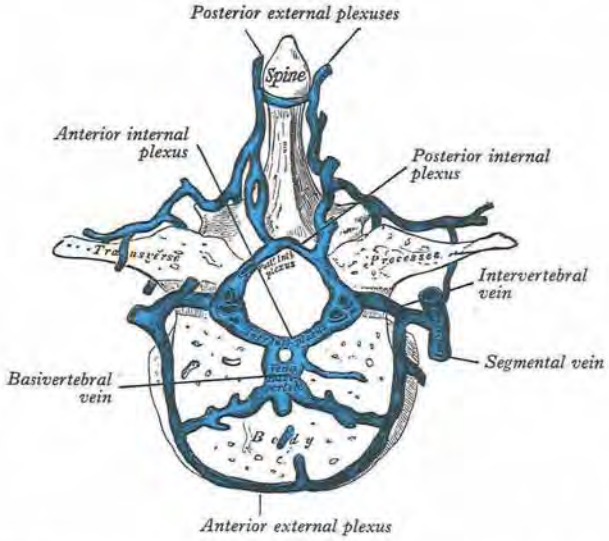
10.173 The right aspect of the mediastinum. The right lung and most of the right pleura have been removed and a large opening made into the pericardial sac to expose the heart. In this specimen the fourth right posterior intercostal vein did not join the superior intercostal vein.

Posterior intercostal veins are so called to distinguish them from small *anterior intercostal veins* which are tributaries of the internal thoracic and musculophrenic veins.

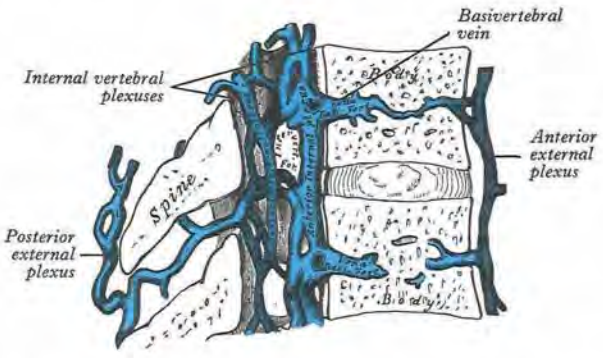
Clinical anatomy. In obstruction of the upper inferior vena cava, the azygos and hemiazygos veins and vertebral venous plexuses are the main collateral channels maintaining venous circulation, by connecting superior and inferior venae cavae and communicating with the common iliac by ascending lumbar veins and with many tributaries of the inferior vena cava.

Bronchial veins

Usually two on each side, the bronchial veins drain blood from larger bronchi and from hilar structures. The right bronchial veins join the end of the azygos, the left join the left superior intercostal or hemiazygos vein. Some blood carried to the lungs by bronchial arteries returns via the pulmonary veins (see p. 1674).



10.174 Transverse section through the body of a thoracic vertebra showing the vertebral venous plexuses and basivertebral veins.



10.175 Median sagittal section through two thoracic vertebrae showing the vertebral venous plexuses and basivertebral veins.

VEINS OF THE VERTEBRAL COLUMN

Veins of the vertebral column form intricate plexuses along the entire column, external and internal to the vertebral canal. Both groups are devoid of valves, anastomose freely with each other and join the intervertebral veins (**10**.174, 175). Interconnections are widely established between these plexuses and longitudinal veins early in fetal life (Loginova 1972).

External vertebral venous plexuses

The external vertebral venous plexuses are anterior and posterior, anastomosing freely, and are most developed in the cervical region. *Anterior external plexuses* are anterior to the vertebral bodies, communicating with basivertebral and intervertebral veins and receiving tributaries from vertebral bodies. *Posterior external plexuses* lie posterior to vertebral laminae and around spines, transverse and articular processes. They anastomose with the internal plexuses and join the vertebral, posterior intercostal and lumbar veins.

Internal vertebral venous plexuses

The internal vertebral venous plexuses occur between the dura mater and vertebrae, receiving tributaries from the bones, red bone marrow and spinal cord. They form a denser network than the external plexuses and are arranged vertically as four interconnecting longitudinal vessels, two in front, two behind.

The *anterior internal plexuses* are large plexiform veins on the posterior surfaces of vertebral bodies and intervertebral discs, flanking the posterior longitudinal ligament; under this they are connected by transverse branches, into which the large basivertebral veins open. The *posterior internal plexuses*, on each side in front of the vertebral arches and ligamenta flava, anastomose with the posterior external plexuses by veins passing through and between the ligaments. The internal plexuses interconnect by venous rings near each vertebra. Around the foramen magnum they form a dense network connecting with: vertebral veins, occipital and sigmoid sinuses, basilar plexus, venous plexus of the hypoglossal canal and the condylar emissary veins.

Basivertebral veins

The basivertebral veins emerge from the posterior foramina of vertebral bodies. They are large and tortuous channels in bone, like those in cranial diploë. The trabecular bone in vertebral bodies contains much haemopoietic tissue. The basivertebral veins also drain into the anterior external vertebral plexuses through small openings in the vertebral bodies. Posteriorly they form one or two short trunks opening into the transverse branches uniting anterior internal vertebral plexuses. They enlarge in advanced age.

Intervertebral veins

The intervertebral veins accompany the spinal nerves through intervertebral foramina, draining the spinal cord and internal and external vertebral plexuses, and ending in the vertebral, posterior intercostal, lumbar and lateral sacral veins. Whether the basivertebral or intervertebral veins contain effective valves is uncertain but experiment strongly suggests that their blood flow can be reversed (Batson 1957). This may explain how pelvic neoplasms, in particular, may metastasize in vertebral bodies, the cells spreading into the internal vertebral plexuses by connections with the pelvic veins when blood flow is temporarily reversed by raised intra-abdominal pressure or postural alterations.

Veins of the spinal cord

The veins of the spinal cord lie in the pia mater, forming a tortuous venous plexus. In this there are:

- two *median longitudinal veins*, one near the anterior median fissure, the other behind the posterior median septum
- two *anterolateral* and two *posterolateral longitudinal veins* respectively behind the ventral and dorsal spinal nerve roots.

They drain to internal vertebral plexuses, and thence to intervertebral veins. Near the skull they unite into two or three small veins joined to the vertebral veins and ending in inferior cerebellar veins or the inferior petrosal sinuses.

VEINS OF THE LOWER LIMBS

Veins of the lower limbs can be subdivided, like those of the upper, into *superficial* and *deep* groups, the superficial being subcutaneous in the superficial fascia, the deep veins (beneath the deep fascia) accompanying major arteries. Both have valves, more numerous in deep veins and also more numerous than in the upper limb.

SUPERFICIAL VEINS OF THE LOWER LIMBS

The principal named superficial veins are the great and small saphenous; their numerous tributaries are mostly (but not wholly) unnamed; named vessels will be noted (**10**.176, 177). (For variations consult Kosinski 1926.) As in the upper limb the vessels will be described centripetally from peripheral to major drainage channels.

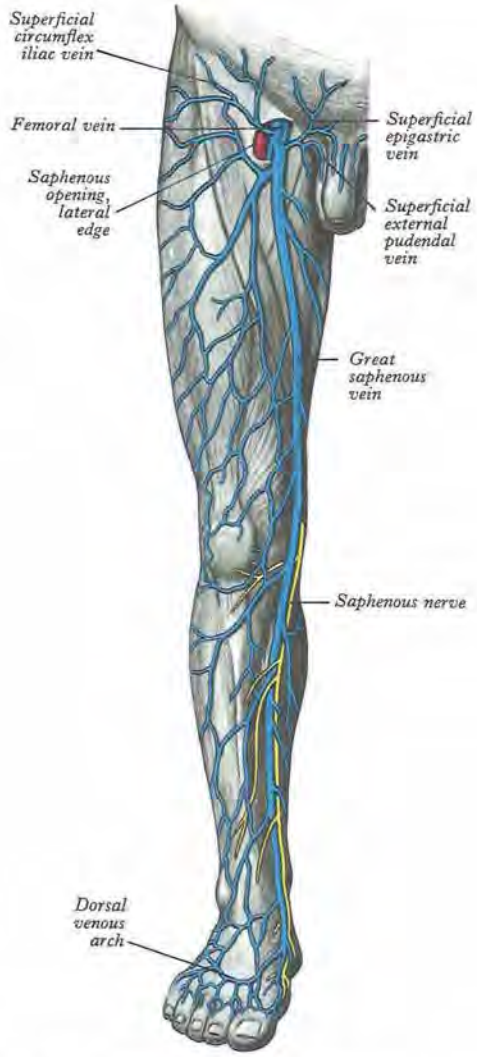
Dorsal digital veins receive, in the clefts between the toes, rami from the plantar digital veins and then join to form dorsal metatarsal veins, which are united across the proximal parts of the metatarsal bones in a *dorsal venous arch*. Proximal to this is an irregular *dorsal venous network* receiving tributaries from deep veins and continuous proximally with a venous network in the leg. At each side of the foot this network connects with *medial* and *lateral marginal veins*, both formed mainly by veins from more superficial parts of the sole. In the sole superficial veins form a *plantar cutaneous arch* across the roots of the toes and also drain into the medial and lateral marginal veins. Proximal to the plantar arch is a *plantar cutaneous venous plexus*, especially dense in the fat of the heel; this connects with the plantar cutaneous venous arch and other deep veins, but drains mainly into the marginal veins.

Great (long) saphenous vein

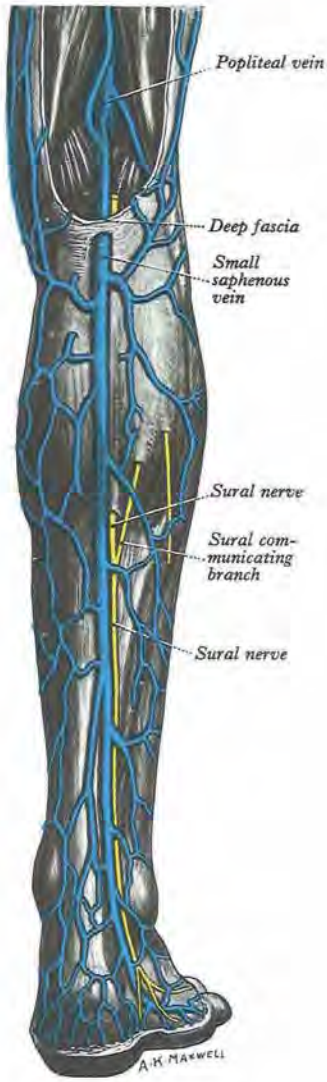
The great saphenous vein starts inferiorly (below) as a continuation of the medial marginal vein and ends in the femoral vein a short distance distal to the inguinal ligament (see below), being thus the body's longest vein (**10**.176). It ascends about 2.5–3 cm anterior to the tibial malleolus, crosses the distal third of the medial surface of the tibia obliquely to its medial border, then ascends a little behind the border to the knee; proximally it is posteromedial to the medial tibial and femoral condyles, then ascends the medial aspect of the thigh; after traversing the saphenous opening (p. 873) it finally opens into the femoral vein. The so-called 'centre' of the opening is often said to be 2.5–3.5 cm inferolateral to the pubic tubercle; and the vein is then held to be represented by a line drawn from this to the femoral adductor tubercle. However, the saphenous opening, as noted elsewhere, varies greatly in size and disposition and its imagined centre has proved a poor indicator of the saphenofemoral junction.

In its course through the thigh the great saphenous vein has branches of the medial femoral cutaneous nerve accompanying it: at the knee the saphenous branch of the descending genicular artery and, in the leg and foot, the saphenous nerve, are anterior to it. The vein is often duplicated, especially distal to the knee. It has from 10 to 20 valves, which are more numerous in the leg than the thigh. One is present just before it pierces the cribriform fascia, another at its junction with the femoral vein. In almost its entire extent the vein lies in superficial fascia, but it has many connections with the deep veins, especially in the leg (see below).

Clinical anatomy. Royle and Eisher (1981) made a careful quantitative study in 167 flush ligations in 136 subjects noting, in particular, the relative positions of the pubic tubercle, the venous junction and the inguinal skin crease. They concluded that a correctly placed incision for flush saphenofemoral ligation should be made



10.176 The great saphenous vein and its tributaries.



10.177 The small saphenous vein and its tributaries.

1 cm above, and parallel to, the inguinal skin crease, centring the incision at a point 4 cm lateral to and level with the pubic tubercle.

Tributaries. At the ankle the great saphenous drains the sole by medial marginal veins. In the leg it often connects with the small saphenous vein and with deep veins through *perforating veins*. Just distal to the knee it usually has three large tributaries: one from the front of the leg, a second from the tibial malleolar region (connecting with some of the 'perforating' veins) and a third from the calf (communicating with the small saphenous vein). The second of these forms below in a fine network or 'corona' of delicate veins over the medial malleolus and then ascends the medial aspect of the calf as the '*posterior arch vein*' of Dodd and Cockett (1976); the clinical importance of its connections with posterior tibial venae comitantes by a series of perforating (communicating) veins was emphasized by Platz and Adelmann (1976), who proposed the term '*vena arcuata cruris posterior*'. The clinical significance of the latter should be reaffirmed, with relevant points concerning other venous channels in the leg. Although Platz and Adelmann (1976) mentioned 3–6 perforating veins, it has been indicated that three are most usual, being equally spaced between the medial malleolus and the midcalf; more than three was termed 'most uncommon' and an arch vein perforator above midcalf 'extremely rare'. The posterior crural arch vein was first illustrated by Leonardo da Vinci and his name is often applied to the vein in some surgical circles.

Above the posterior crural arch vein, perforating veins join the great saphenous or one of its main tributaries at two main sites. The first is at a level in the upper calf indicated by its name, the *tibial tubercle perforator* (*Boyd's perforator*); the second is in the lower/intermediate third of the thigh where it perforates the deep fascial roof of the subsartorial canal to join the femoral vein (*Hunterian perforator*).

In the thigh the great saphenous vein receives many tributaries; some open independently, whilst others converge to form large named channels that frequently pass towards the basal half of the femoral triangle before joining the great saphenous near its termination. These may be grouped thus: one or more large posteromedial tributaries, one or more large anterolateral tributaries, four or more peri-inguinal veins. The *posteromedial vein of the thigh*, large and sometimes double, drains a large superficial region indicated by its name: it has (as have the other tributaries) radiological and surgical significance. One of its lower radicles is often continuous with the small saphenous vein. The posteromedial vein is sometimes (perhaps unhelpfully) named the *accessory saphenous vein* with greater emphasis on its variability of form and level of junction with the great saphenous. Some restrict the term accessory to a lower (more distal) posteromedial branch when two (or more) are present. Another large vessel, the *anterolateral vein of the thigh* (*anterior femoral cutaneous vein*), usually commences from an anterior network of veins in the distal thigh and crosses the apex and distal half of the femoral triangle to reach the great saphenous vein. As the latter traverses its saphenous opening (**10.176**), it is joined by the superficial epigastric, superficial circumflex iliac and superficial

external pudendal veins. Their mode of union varies. Superficial epigastric and circumflex iliac veins drain the inferior abdominal wall, the latter also receiving tributaries from the proximolateral region of the thigh; superficial external pudendal veins drain part of the scrotum, one being joined by the superficial dorsal vein of the penis. The deep external pudendal vein joins the great saphenous in its opening.

A *thoraco-epigastric vein* lies along the anterolateral aspect of the trunk and connects the superficial epigastric or femoral vein to the lateral thoracic veins, thus connecting femoral and axillary veins and hence the superior and inferior vena caval fields of drainage. It is held to be in line with the primitive mammary ('milk') ridge which extends from the axilla to the pubic region (p. 296).

Small (short) saphenous vein (10.177)

The small saphenous vein begins posterior to the lateral malleolus, as a continuation of the lateral marginal vein. In the lower third of the calf it ascends lateral to the tendo calcaneus, lying on the deep fascia and covered only by superficial fascia and skin. Inclining medially to the midline of the calf it penetrates into the deep fascia within which it ascends on the gastrocnemius, only emerging between the deep fascia and gastrocnemius gradually at about the junction of the intermediate and proximal thirds of the calf (usually well below the lower limit of the popliteal fossa). Continuing its ascent it passes between the heads of the gastrocnemius, then proceeds to its termination in the popliteal vein, 3–7.5 cm above the knee joint in the popliteal fossa.

Tributaries. The small saphenous vein connects with deep veins on the dorsum of the foot, receives many cutaneous tributaries in the leg and sends several rami proximally and medially to join the great saphenous vein. Sometimes a communicating branch from it ascends medially to the accessory saphenous vein (see above); this may be the main continuation of the small saphenous. In the leg the small saphenous lies near the sural nerve. It has 7–13 valves, one near its termination. Its mode of ending is variable; it may join the great saphenous vein in the proximal thigh or it may bifurcate, one branch joining the great saphenous, the other the popliteal or deep posterior femoral veins; sometimes it ends distal to the knee in the great saphenous or deep sural muscular veins.

Clinical anatomy. In a standing position, venous return from the lower limb depends largely on muscular activity (p. 1466), especially contraction of the calf muscles, known as the 'calf pump', whose efficiency is aided by the tight sleeve of deep fascia. 'Perforating' veins have been noted that connect the great saphenous with the deep veins, particularly near the ankle, distal calf and knee regions. In these channels valves are arranged to prevent flow of blood from deep to superficial veins. At rest, pressure in a superficial vein is equal to the height of the column of blood extending therefrom to the heart. When calf muscles contract, blood is pumped proximally in the deep veins but is normally prevented from flowing into superficial veins by the valves in the perforating veins; during relaxation blood can be aspirated from superficial into deep veins. If the valves in the perforating veins become incompetent, these veins become 'high pressure leaks' during muscular contraction; this transmission of high pressure in deep veins to superficial veins results in dilatation and blood stagnation in the latter, producing varicosities, anoxia of tissues and ultimately varicose ulceration. In operative treatment of severe varicose veins and ulcers, perforating veins must be ligatured. Similar perforating connections occur in the anterolateral region and varicosities may also occur here (Cockett 1956; Green et al 1958). Veins connecting the great saphenous to the femoral vein, in the adductor canal, may also become varicose (Dodd & Cockett 1956; Dodd 1959).

DEEP VEINS OF THE LOWER LIMBS

Deep veins of the lower limbs accompany the arteries and their branches; they have numerous valves (**10.178**). *Plantar digital veins* arise from plexuses in the plantar regions of the toes, connecting with dorsal digital veins and uniting into four *plantar metatarsal veins*; these run in the intermetatarsal spaces and connect by perforating veins with dorsal veins, then continue to form the *deep plantar venous arch*, accompanying the plantar arterial arch. From this *medial* and *lateral plantar veins* run near the corresponding

10.178 Venogram of the leg to show the deep veins; the valves are clearly demonstrated. (Supplied by Shaun Gallagher, Guy's Hospital; photography by Sarah Smith.)

arteries and, after communicating with the great and small saphenous veins, form behind the medial malleolus the posterior tibial veins.

Posterior tibial veins. They accompany the posterior tibial artery, receiving veins from sural muscles, especially the venous plexus in the soleus, connections from superficial veins and the *peroneal veins*. The latter, running with their artery, receive rami from the soleus and superficial veins.

Anterior tibial veins. Continuations of the venous companions of the dorsal pedal artery, they leave the extensor region between the tibia and fibula, pass through the proximal end of the interosseous membrane, and unite with the posterior tibial veins to form the *popliteal vein* at the distal border of the popliteus.

Popliteal vein. Ascending through the popliteal fossa to an aperture in adductor magnus, it becomes the femoral vein. Distally it is medial to the artery; between the heads of gastrocnemius it is superficial (dorsal) to it; proximal to the knee joint it is posterolateral. Its tributaries are: the small saphenous vein, veins corresponding to branches of the popliteal artery and muscular veins, including a large one from each head of gastrocnemius. There are usually four valves in the popliteal vein.

Femoral vein. It accompanies its artery, beginning at the adductor opening as the continuation of the popiteal, and ending posterior to the inguinal ligament as the external iliac. In the distal adductor canal, it is posterolateral to the femoral artery; more proximally in

the canal, and in the distal femoral triangle (i.e. its apex), it is posterior to it; at the triangle's base it is medial (10.137, 140). The vein occupies the middle compartment of the femoral sheath, between the femoral artery and canal, fat in the latter allowing expansion of the vein. It has many muscular tributaries: about 4–12 cm distal to the inguinal ligament the *vena profunda femoris* joins it posteriorly and then the great saphenous vein, which enters anteriorly. Lateral and medial circumflex femoral veins are usually tributaries. There are usually four or five valves in the femoral vein, the most constant being one just distal to the entry of the profunda femoris and one near the inguinal ligament.

Vena profunda femoris. It is anterior to its artery, its tributaries corresponding; through these it connects distally with the popliteal and proximally inferior gluteal veins. It sometimes drains medial and lateral circumflex femoral veins. It has a valve just before its end.

VEINS OF THE ABDOMEN AND PELVIS

EXTERNAL ILIAC VEIN

The proximal continuation of the femoral vein is the external iliac: it thus begins posterior to the inguinal ligament, ascends the pelvic brim and ends anterior to the sacro-iliac joint by joining the internal iliac to form the common iliac vein. On the right, it is first medial to the external iliac artery, gradually inclining behind it as it ascends; on the left, it is wholly medial. This is a point of great surgical importance. Disease of the external iliac artery may cause it to adhere closely to the vein at the point where it is in contact, and (especially on the right side) the walls of the vessels may become fused. Dissection in this area risks producing severe venous haemorrhage which may be difficult to control. Medially the external iliac vein is crossed by the ureter and internal iliac artery, and is elsewhere covered by parietal peritoneum. In males it is crossed by the ductus deferens, in females by the round ligament and ovarian vessels. Lateral is psoas major, except where the artery intervenes. The vein is usually valveless, but may contain a single valve.

Tributaries. These are: the inferior epigastric, deep circumflex iliac and pubic veins.

Inferior epigastric vein. It derives from the union of the venae comitantes of the inferior epigastric artery, which connect above with the superior epigastric veins; it joins the external iliac about 1 cm proximal to the inguinal ligament.

Deep circumflex iliac vein. It is formed from venae comitantes of the corresponding artery; it joins the external iliac about 2 cm proximal to the inguinal ligament after crossing anterior to the external iliac artery.

Pubic vein. Connecting the external iliac with the obturator vein in the obturator foramen, it ascends on the pelvic surface of the pubis with the pubic branch of the inferior epigastric artery. It sometimes replaces the normal obturator vein.

INTERNAL ILIAC VEIN

Veins converge superiorly in the great sciatic foramen to form the internal iliac vein, which ascends posteromedial to the internal iliac artery to join the external iliac vein, forming the common iliac at the pelvic brim, anterior to the lower part of the sacro-iliac joint. It is covered anteromedially by parietal peritoneum.

Tributaries. These are:

- gluteal, internal pudendal and obturator veins, with origins outside the pelvis
- lateral sacral veins, anterior to the sacrum
- middle rectal, vesical, uterine and vaginal veins, originating in the venous plexuses of pelvic viscera.

The superior gluteal veins, venae comitantes of the superior gluteal artery, receive rami corresponding to branches of the artery; entering the pelvis via the greater sciatic foramen, above piriformis, they join the internal iliac vein, frequently as a single trunk.

Clinical anatomy. The venous drainage of the leg is frequently blocked by thrombosis, usually originating in the soleal sinusoids, but frequently extending up into the external iliac systems and the inferior vena cava. Under these circumstances, the pelvic veins enlarge and provide a major avenue of venous return from the femoral system. Surgical interference with these veins (as for example in hysterectomy) may seriously compromise venous drainage and precipitate oedema of one or both legs.

Inferior gluteal veins. These venae comitantes of the inferior gluteal artery begin proximally and posterior in the thigh, where they anastomose with the medial circumflex femoral and first perforating veins; they enter the pelvis low in the greater sciatic foramen, joining to form a vessel opening into the distal (lower) part of the internal iliac vein. They connect with the superficial gluteal veins by perforating veins (Doyle 1970) similar to those in the calf (p. 1596). These *gluteal perforating veins* are, indeed, even more numerous than the sural ones. In addition to a probable venous 'pumping' role, they provide collaterals between the femoral and internal iliac veins.

Internal pudendal veins. These venae comitantes of the internal pudendal artery begin in the prostatic venous plexus (p. 1599), accompany the artery and unite as a single vessel ending in the internal iliac vein. They receive veins from the penile bulb and the scrotal (or labial) and inferior rectal veins. The deep dorsal vein of the penis connects with the internal pudendal but ends mainly in the prostatic plexus.

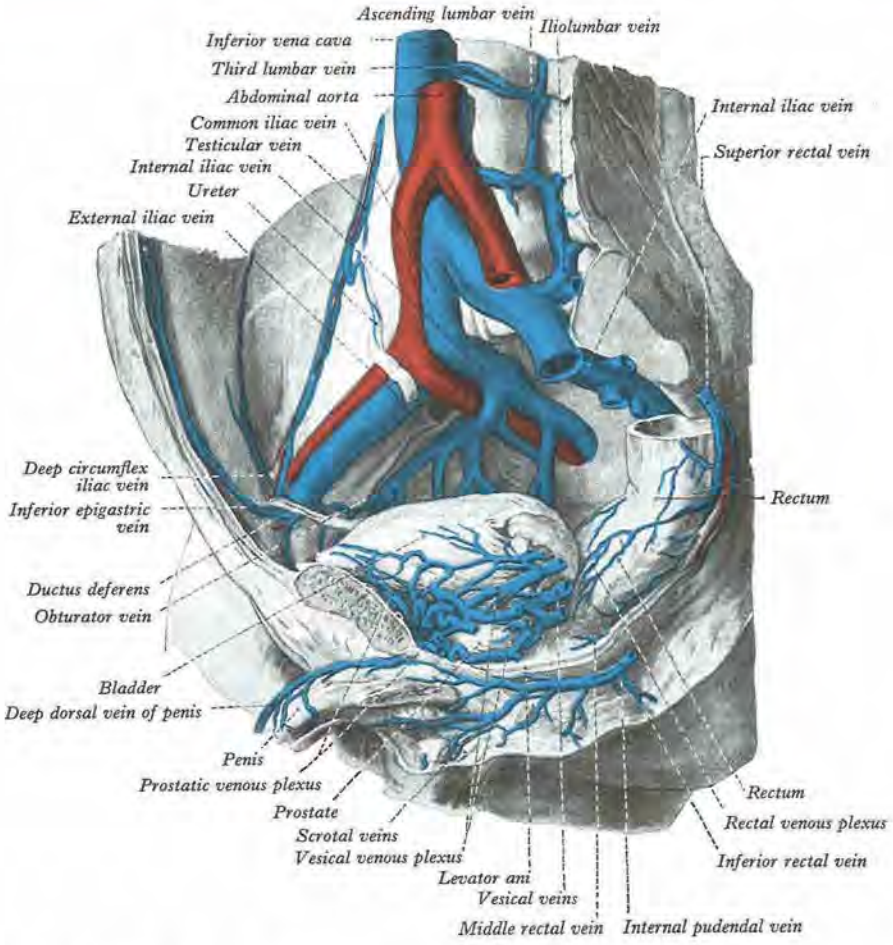
Obturator vein. This begins in the proximal adductor region, enters the pelvis superiorly in the obturator foramen, and runs back and up on the lateral pelvic wall below the obturator artery covered by peritoneum; it then passes between the ureter and internal iliac artery to end in the internal iliac vein. Sometimes it is replaced by an enlarged pubic vein, which joins the external iliac (see above).

Lateral sacral veins. They accompany the lateral sacral arteries, being interconnected by a sacral venous plexus.

Middle rectal vein. It begins in the rectal venous plexus, with tributaries from bladder, prostate and seminal vesicle; it is variable in size and runs laterally on the pelvic surface of levator ani to end in the internal iliac vein.

Rectal venous plexus. This plexus surrounds the rectum, connecting anteriorly with the vesical plexus in males and the uterovaginal plexus in females. It consists of an **internal** part beneath the rectal and anal epithelium and an **external** part outside the muscular stratum. In the anal canal the internal plexus has longitudinal dilatations, connected by transverse branches in circles immediately above the anal valves. The dilatations are most prominent in the left lateral, right anterolateral and right posterolateral sectors. The internal plexus drains mainly to the superior rectal vein but connects widely with the external plexus. The external plexus is drained inferiorly by the inferior rectal vein into the internal pudendal, its middle part by a middle rectal vein into the internal iliac, its superior part by the superior rectal vein, which is the commencement of the inferior mesenteric (a tributary of the portal vein). Communication between portal and systemic venous systems is thus established in the rectal plexus.

Clinical anatomy. Veins of the internal rectal plexus are apt to become varicose. The vessels lie in very loose areolar tissue, less supported by surrounding structures than most veins, and are less able to resist increased blood pressure; the superior rectal vein and the portal vein have no valves; rectal veins pass through muscular tissue and are liable to compression, especially during defecation; they are affected by every form of portal obstruction. A clear distinction cannot be made between rectal varices and haemorrhoids. *Varices* occur as a result of portal hypertension: they are dilated venous channels structurally similar to oesophageal varices, and caused by the same mechanism. *Internal haemorrhoids* are engorged arteriovenous cushions, which are thought to arise as a result of



10.179 The veins of the right half of the male pelvis (after Spalteholz).

faecal pressure against an abnormally resistant sphincter. They originate above the dentate line and are covered by rectal (columnar) epithelium. The term *external haemorrhoid* is probably a misnomer and refers to thrombosis or rupture of one of the veins in the subcutaneous part of the external plexus.

Prostatic venous plexus. It is posterior to the arcuate pubic ligament and lower part of symphysis pubis, anterior to the bladder and prostate (10.179). Its chief tributary is the deep dorsal vein of the penis; it also receives anterior vesical and prostatic rami, connecting with the vesical plexus and internal pudendal vein. It drains into vesical and internal iliac veins. The plexus is embedded in the lateral fascial prostatic sheath (p. 1859).

Vesical plexus. It envelops the lower bladder and, in males, the prostatic base, communicating with the prostatic plexus in males and the vaginal plexus in females. It is drained by several vesical veins which usually unite to enter the internal iliac vein.

Dorsal veins of the penis. They are unpaired, and are superficial and deep: the *superficial dorsal vein* drains the prepuce and penile skin; running back in subcutaneous tissue it inclines right or left, and opens into one of the external pudendal veins. The *deep dorsal vein* is inside the fibrous penile sheath; it receives blood from the glans penis and corpora cavernosa penis, coursing back in the midline between the paired dorsal arteries; near the radix penis it passes deep to the suspensory ligament and through a gap between the arcuate pubic ligament and anterior margin of the perineal membrane (inferior fascia of the urogenital diaphragm), dividing into right and left branches which enter the prostatic plexus after connecting below the symphysis pubis with the internal pudendal veins. The *dorsal vein of the clitoris*, after a similar course, ends in the vesical plexus.

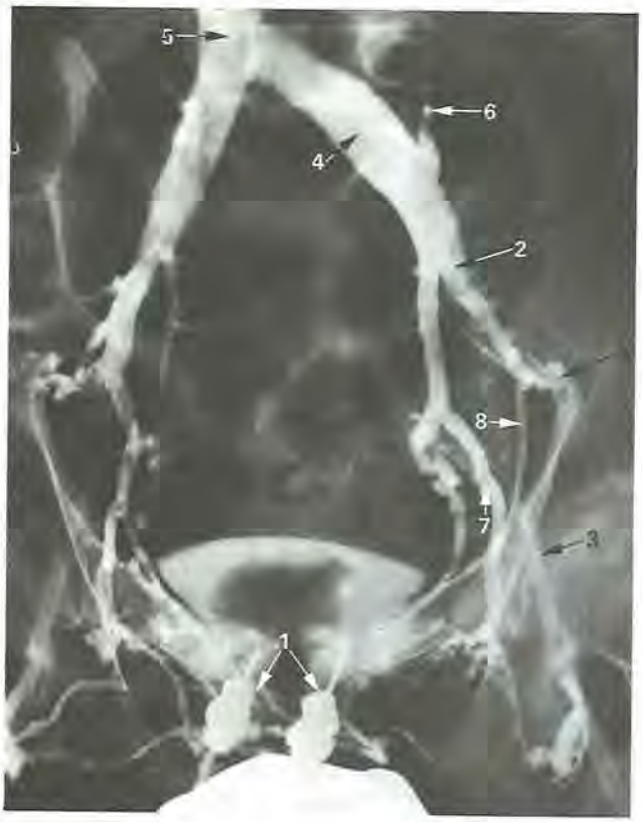
Uterine plexuses. They extend lateral to the uterus in the broad ligaments, communicating with the ovarian and vaginal plexuses. They are drained by two uterine veins on each side, arising inferiorly in the plexuses, level with the external os and draining to the internal iliac veins.

Vaginal plexuses. Flanking the vagina, they connect with uterine, vesical and rectal plexuses and are drained by vaginal veins, one each side, to the internal iliac veins. The uterine and vaginal plexuses may provide collateral venous drainage to the lower limb (see above).

Common iliac veins (10.180). They result from the union of external and internal iliac veins, anterior to the sacro-iliac joints. They ascend obliquely to end at the right side of the fifth lumbar vertebra, uniting at an acute angle to form the inferior vena cava. The *right common iliac vein*, the shorter, is nearly vertical, ascending posterior, then lateral to its artery. The right obturator nerve passes posterior, descending forward to its foramen. The *left common iliac vein*, longer and more oblique, is first medial to its artery, then posterior. It is crossed anteriorly by the attachment of the sigmoid mesocolon and superior rectal vessels. In the rest of its course it is covered only by peritoneum. Each vein receives iliolumbar and sometimes lateral sacral veins; the left common iliac drains the median sacral vein. There are no valves in these veins.

Variations. The left common iliac vein occasionally ascends left of the aorta to the level of the kidney where, receiving the left renal vein, it crosses anterior to the aorta to join the inferior vena cava. This vessel represents the persistent caudal half of the left postcardinal or supracardinal vein (p. 324).

Median sacral veins. These veins accompany the corresponding artery anterior to the sacrum, joining into a single vein usually ending in the left common iliac but sometimes at the common iliac junction.



10.180 Venogram showing the veins of the pelvis and groin. The contrast medium has been injected into the bodies of the pubic bones. 1. Injected contrast medium in pubic bones. 2. Internal iliac vein. 3. External iliac vein (faintly outlined). 4. Common iliac vein. 5. Inferior vena cava. 6. Ascending lumbar vein. 7. Obturator vein. 8. Internal pudendal vein. 9. Gluteal vein. (Radiograph supplied by M Lea Thomas.)

INFERIOR VENA CAVA

The inferior vena cava conveys blood to the right atrium from all structures below the diaphragm (**10.112, 179, 181**). It is formed by the junction of the common iliac veins anterior to the fifth lumbar vertebral body, a little to its right. It ascends anterior to the vertebral column, to the right of the aorta. Reaching the liver, it is contained in a deep groove on its posterior surface or sometimes in a tunnel completed by a band of liver tissue. It perforates the tendinous part of the diaphragm between its median and right 'leaves' and inclines slightly anteromedially. Passing through the fibrous pericardium and through a posterior inflexion of the serous pericardium it opens into the inferoposterior part of the right atrium. Anterior and left of its atrial orifice is a *semilunar valve of the inferior vena cava*, relatively less prominent in adults, but large and overtly functional in the fetus (p. 1501). The vessel is otherwise devoid of valves.

Relations of the abdominal part. **Anteriorly** the inferior vena cava is overlapped at its commencement by the right common iliac artery and covered, below the horizontal part of the duodenum, by the posterior parietal peritoneum. It is crossed obliquely by the root of the mesentery and its contained vessels and nerves and by the right testicular or ovarian artery. It ascends behind the head of the pancreas and then the superior part of the duodenum, separated from it by the common bile duct and portal vein. Above the duodenum it is again covered by peritoneum of the posterior wall of the epiploic foramen (**12.65**), separating it from the right free border of the lesser omentum and its contents. Above this the liver is anterior.

Posterior are the lower three lumbar vertebral bodies, their intervening 'discs' and the anterior longitudinal ligament, the right psoas major, right sympathetic trunk, and third and fourth right lumbar arteries; superior to these are the right crus (partially separated by the medial part of the right suprarenal gland and the right coeliac ganglion) and the right renal, suprarenal and inferior phrenic arteries.

Right lateral are the right ureter, the descending part of the duodenum, the medial border of the right kidney and right lobe of the liver. **Left lateral** are the aorta and above this the right crus and caudate lobe.

Relations of the thoracic part. This part of the inferior vena cava is very short, partly inside and partly outside the pericardial sac. The extrapericardial part is separated from the right pleura and lung by the right phrenic nerve. The intrapericardial part is covered, except posteriorly, by inflected serous pericardium.

Surface anatomy. The vein begins in, or just below, the transtubercular plane, its centre 2.5 cm right of the midline; about 2.5 cm wide, it ends behind the sternal end of the sixth right costal cartilage. A band from its lower end to a part of the inguinal ligament centred at a point 1 cm medial to the midinguinal point indicates the common and external iliac veins on each side.

Variations. Numerous anomalies occur and are attributable to arrests or errors in its complex formation. It is sometimes replaced, below the level of the renal veins, by two more or less symmetrical vessels, often associated with the failure of interconnection between the common iliac veins, and due to persistence on the left of a longitudinal channel (usually supra- or subcardinal) which normally disappears in early fetal life (p. 324). In complete visceral transposition, the inferior vena cava is left of the aorta.

Clinical anatomy. Thrombosis of the inferior vena cava leads to oedema of the legs and back, without ascites. Collateral venous circulation is soon established by enlargement of either the superficial or deep veins, or both; the epigastric, circumflex iliac, lateral thoracic, thoraco-epigastric (p. 1597), internal thoracic, posterior intercostal, external pudendal and lumbovertebral anastomotic veins connect it with the superior vena cava; deep connections are made through the azygos, hemiazygos and lumbar veins. Vertebral venous plexuses may also provide effective collateral circulation between the venae cavae (Batson 1957).

Tributaries. These are the common iliac, lumbar, right testicular or ovarian, renal, right suprarenal, inferior phrenic and hepatic veins.

Lumbar veins. Four pairs of lumbar veins collect blood by dorsal tributaries from lumbar muscles and skin, and by abdominal tributaries from the walls of the abdomen, where they connect with the epigastric veins. Near the vertebral column they drain the vertebral plexuses and are connected by the ascending lumbar vein, a longitudinal vessel anterior to the roots of the lumbar transverse processes. The third and fourth lumbar veins pass forward on the sides of the corresponding vertebral bodies to enter the posterior aspect of the inferior vena cava; the left veins pass behind the abdominal aorta and are therefore longer. First and second lumbar veins may join the inferior vena cava, ascending lumbar, or lumbar azygos veins; the first does not usually enter the inferior vena cava; it may turn down to join the second and so open into it indirectly, but more often it ends in the ascending lumbar vein or passes forward over the first lumbar vertebral body to the lumbar azygos vein (p. 1593). The second lumbar vein may join the inferior vena cava at or near the level of the renal veins; sometimes it joins the third lumbar vein or may end in the ascending lumbar. First and second lumbar veins are often connected to each other, to contralateral veins and to right and left lumbar azygos veins by a plexus on the upper lumbar vertebral bodies.

Ascending lumbar vein. It connects the common iliac, iliolumbar and lumbar veins. It lies between psoas major and roots of the lumbar transverse processes. Superiorly it joins the subcostal vein and the vessel so formed turns forward over the twelfth thoracic vertebral body and, passing deep to the crus, ascends as the azygos vein on the right and as the hemiazygos on the left. There is an angle on the vessel as it turns up; it is usually joined here by a small vessel from the back of the inferior vena cava (or left renal vein on the left). This little vein represents the azygos line (p. 325), already described as the lumbar azygos vein (p. 1593). Sometimes the ascending lumbar vein ends in the first lumbar, which then skirts the first lumbar vertebra with the first lumbar artery to join the lumbar azygos vein, the subcostal vein then joining the azygos vein on the right and the hemiazygos on the left.

Testicular veins (10.112). They emerge posteriorly from the testis,

10.181 Inferior vena cavogram in an adult male while performing the Valsalva manoeuvre. (Supplied by Shaun Gallagher, Guy's Hospital; photography by Sarah Smith.)

drain the epididymis and unite to form the pampiniform plexus, a chief component of the spermatic cord, ascending anterior to the ductus deferens. Distal to the superficial inguinal ring the plexus is drained by three or four veins traversing the inguinal canal to the abdomen through the deep inguinal ring; they coalesce into two veins, which ascend anterior to psoas major and ureter, behind the peritoneum, on each side of the testicular artery. These veins join and open into the inferior vena cava on the right at an acute angle just inferior to the level of the renal veins; the left testicular vein opens into the left renal vein at a right angle. The testicular veins contain valves; the left passes behind the lower descending colon and inferior margin of the pancreas and is crossed by the left colic vessels; the right passes behind the terminal ileum and horizontal part of the duodenum and is crossed by the root of the mesentery, ileocolic and right colic vessels.

Clinical anatomy. The testicular veins are frequently varicose; varicocele, which is almost always on the left, is perhaps due to the orthogonal junction of the left testicular and renal veins. There is evidence that the presence of a varicocele raises testicular temperature and impairs fertility, which is why an operation to correct it is often advised. After removal of a varicocele, venous return is by the small veins of the ductus deferens, cremaster and scrotal tissues.

Ovarian veins. Each of them forms a plexus in the broad ligament near the ovary and uterine tube, communicating with the uterine plexus. Two veins issue from this and ascend across the external iliac artery with the ovarian artery. Their further course is like that of the testicular veins. Valves may occur in them. Like the uterine veins, they are much enlarged in pregnancy.

Renal veins. These large veins lie anterior to the renal arteries and open into the inferior vena cava almost at right angles. The left is three times the right in length (7.5 cm and 2.5 cm); it crosses the posterior abdominal wall posterior to the splenic vein and body of pancreas and, near its end, is anterior to the aorta, just below the origin of the superior mesenteric artery. The left testicular or ovarian vein enters it from below and the left suprarenal vein, usually receiving one of the left inferior phrenic veins, enters it above but nearer the midline. The left renal vein enters the inferior vena cava a little superior to the right. The right renal vein is behind the

descending duodenum and sometimes the lateral part of the head of the pancreas.

Variations. The left renal vein may be double, one vein passing posterior, one anterior to the aorta to join the inferior vena cava, a condition named persistence of the 'renal collar' (p. 325); the anterior may be absent, representing persistence of the posterior limb of the renal collar combined with absence of an intersubcardinal anastomosis.

Clinical anatomy. Because of its close relationship with the aorta, the left renal vein may have to be ligated in the course of, for example, an operation for aneurysm. This seldom results in any harm to the kidney, provided that the ligature is placed to the right of the point of entry of the testicular and suprarenal veins.

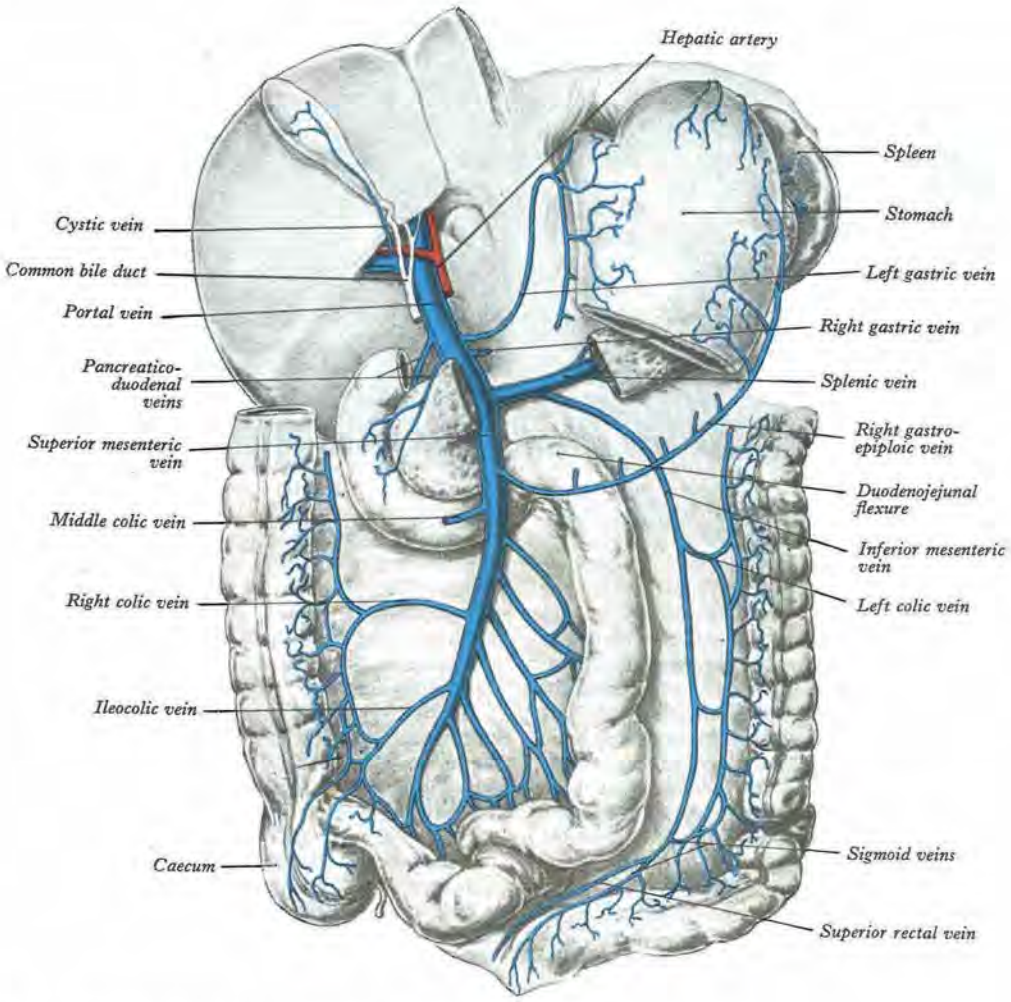
Suprarenal veins. They issue from each suprarenal hilum. The right is short, passing directly and horizontally into the posterior aspect of the inferior vena cava; the left descends medially anterior to lateral to the left coeliac ganglion, to pass posterior to the pancreatic body to reach the left renal vein. Whereas the suprarenal glands have a multiple arterial supply from the aorta, phrenic and renal arteries (see p. 1557), venous drainage is by one single drainage on each side. Damage to the suprarenal vein is thus likely to cause an infarction of the gland.

Inferior phrenic veins. Following the corresponding arteries on the inferior diaphragmatic surface, the right ends in the inferior vena cava; the left is often double, one branch ending in the left renal or suprarenal vein, the other passing anterior to the oesophageal opening to join the inferior vena cava.

Hepatic veins. They drain the liver, commencing as *intralobular veins*, draining the sinusoids of liver lobules (p. 1802); these lead to *sublobular veins*, which eventually unite into *hepatic veins*, emerging from the posterior hepatic surface to open at once into the inferior vena cava in its groove on the posterior hepatic surface. Hepatic veins are arranged in upper and lower groups. The **upper** are usually large veins, right, left and middle, the last from the caudate lobe; the **lower**, varying in number, are small and from the right and caudate lobes. The hepatic veins are contiguous with hepatic tissue and have no valves. Large 'accessory' hepatic veins of the lower group, draining a variable volume of the right lobe, have been studied in 93 adult livers by corrosion casts; they are usually single, occasionally double, with an incidence of 15% (Sledzinski & Tyszkiewicz 1975).

HEPATIC PORTAL SYSTEM

The portal system (**10**.182, 183) includes all the veins draining the abdominal part of the digestive tube (except the lower anal canal but including the abdominal part of the oesophagus) and spleen, pancreas and gallbladder. The portal vein conveys the blood from these viscera to the liver, where it ramifies like an artery, ending in the sinusoids, from which vessels again converge to reach the inferior vena cava via the hepatic veins. The blood therefore passes through two sets of 'exchange' vessels:



10.182 The portal vein and its tributaries (semi-diagrammatic). Portions of the stomach, pancreas and left lobe of the liver and the transverse colon have been removed.

- capillaries of the digestive tube, spleen, pancreas and gallbladder
- hepatic sinusoids.

In adults, the portal vein and its tributaries have no valves; in fetal life and for a short postnatal period valves are demonstrable in its tributaries; usually they atrophy but some may persist in atrophic form.

Portal vein

About 8 cm long, the portal vein begins at the second lumbar vertebral level from the convergence of superior mesenteric and splenic veins, anterior to the inferior vena cava, posterior to the neck of the pancreas (**10.182**). It inclines slightly right as it ascends behind the superior part of the duodenum, bile duct and gastroduodenal artery and is here directly anterior to the inferior vena cava; however, it enters the right border of the lesser omentum, ascending anterior to the epiploic foramen to the right end of the porta hepatis, dividing into right and left stems, which accompany the corresponding branches of the hepatic artery into the liver. In the lesser omentum it is posterior to both bile duct and hepatic artery, the former being to the right; it is surrounded by the hepatic nerve plexus and accompanied by many lymph vessels and some lymph nodes. The right branch enters the right hepatic lobe but usually first receives the cystic vein. The left branch, longer but of smaller calibre, branches into caudate, quadrate and left lobes. (See a discussion of hepatic lobation and lobulation, pp. 1796, 1797.) As it enters the left lobe it is joined by para-umbilical veins (p. 1604) and the *ligamentum teres*, which contains the functionless and partly obliterated left umbilical vein. It is connected to the inferior vena cava by the *ligamentum venosum*, a vestige of an obliterated ductus venosus, ascending in a fissure on the liver's posterior aspect (p. 1501). The small extrahepatic section of the left branch, from which veins to the quadrate and left lobes arise, is a persistent part of the left umbilical vein.

Tributaries. These are: splenic, superior mesenteric, left gastric, right gastric, para-umbilical and cystic veins.

Splenic vein

Large and **not** tortuous, the splenic vein is formed by five or six tributaries from the spleen (**10.182, 183**). It traverses the lienorenal ligament with the splenic artery and tail of the pancreas, and descends to the right, across the posterior abdominal wall inferior to its artery and posterior to the body of the pancreas (which it grooves), receiving numerous short rami from the gland. It crosses anterior to the left kidney and its hilar structures (or lower pole of the left suprarenal gland), separated from the left sympathetic trunk and crus by the left renal vessels and from the abdominal aorta by the superior mesenteric artery and left renal vein. It ends behind (lodged in) the neck of the pancreas, where it joins the superior mesenteric vein at a right angle to form the portal vein.

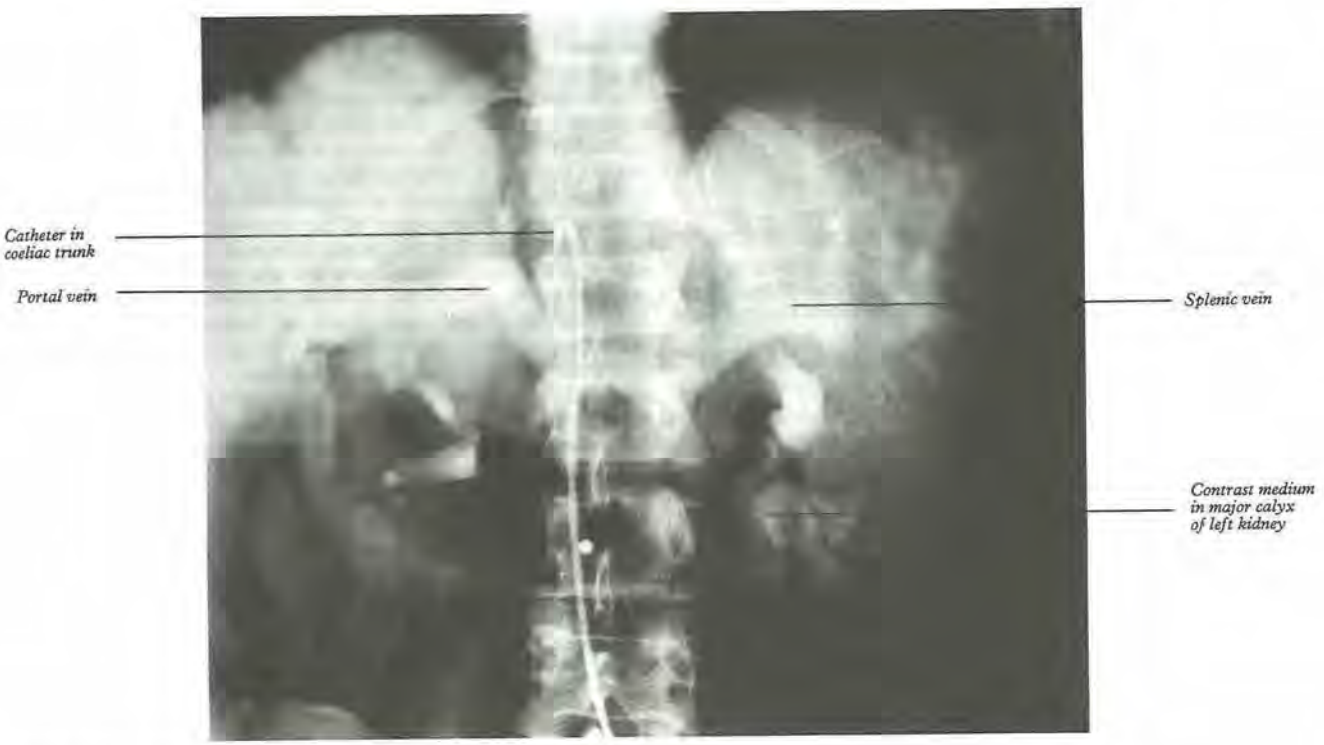
Tributaries. These are: short gastric, left gastro-epiploic, pancreatic and inferior mesenteric veins.

Short gastric veins. Four or five of these veins drain the gastric fundus and the left part of its greater curvature, traversing the gastrosplenic ligament to reach the splenic vein or one of its large tributaries.

Left gastro-epiploic vein. This drains both gastric surfaces and the adjacent greater omentum; it runs from right to left along the greater curvature, between the anterior two omental layers, ending in or near the beginning of the splenic vein.

Pancreatic veins. They drain the body and tail of the pancreas. They may be small and many or large and few. The former empty more or less directly into the splenic vein; in the latter case, superior and inferior arcades receive these larger veins, their ultimate drainage being into the splenic (Sow et al 1975, and p. 1795).

Inferior mesenteric vein (10.182). It drains the rectum, and sigmoid and descending parts of the colon. It begins as the superior rectal vein, from the rectal plexus (p. 1598), through which it connects with middle and inferior rectal veins. The superior rectal vein leaves the pelvis and crosses the left common iliac vessels medial to the left ureter with the superior rectal artery, continuing up as the inferior mesenteric vein. This is left of its artery, ascending behind the peritoneum anterior to the left psoas major; it may cross the testicular or ovarian vessels or be medial to them and then passes above, or behind, the duodenojejunal flexure, opening into the splenic vein posterior to the body of the pancreas; sometimes it ends at the union of the splenic and superior mesenteric veins. If a duodenal or paraduodenal fossa exists, the vein is usually in its anterior wall



10.183 Venous phase showing the splenic and portal veins after injection of contrast medium into the coeliac trunk.

(p. 1744). Its tributaries are sigmoid veins from the sigmoid colon and the left colic vein from the descending colon and the left colic flexure.

Superior mesenteric vein

The superior mesenteric vein drains the small intestine, caecum and ascending and transverse parts of the colon (**10.182**). Beginning in the right iliac fossa by the union of tributaries from the terminal ileum, caecum and vermiform appendix, it ascends in the mesentery on the right of the superior mesenteric artery, passing anterior to the right ureter, inferior vena cava, the horizontal part of the duodenum and uncinate process of the pancreas, joining the splenic vein behind its neck to form the portal vein (**10.182, 183**).

Tributaries. These are: jejunal, ileal, ileocolic, right and middle colic, right gastro-epiploic and pancreaticoduodenal veins.

Right gastro-epiploic vein. This drains the greater omentum and distal part of the stomach, passing right on the gastric greater curvature between the anterior layers of the greater omentum to join the superior mesenteric vein below the neck of the pancreas.

Pancreaticoduodenal veins. They accompany their corresponding arteries: the inferior often joins the right gastro-epiploic vein; the superior usually ascends to the left behind the bile duct to end in the portal vein. Sow et al (1975) have observed anterior intraglandular and posterior venous arcades between the superior and inferior pancreaticoduodenal veins in about 70% of 157 pancreatic corrosion preparations.

Left gastric vein. It drains both gastric surfaces, ascending the lesser curvature to the left in the lesser omentum, to the oesophageal opening, where it receives the oesophageal veins. It then curves back down and to the right behind the omental bursa to end in the portal vein at the upper border of the superior part of the duodenum.

Right gastric vein. This is small and runs to the right along the pyloric section of the lesser curvature in the lesser omentum, ending in the portal vein. It is joined by a prepyloric vein ascending anterior to the pylorus (a surgical guide to the pyloric opening).

Para-umbilical veins. Connecting veins of the anterior abdominal wall and portal vein, they extend along the ligamentum teres and median umbilical ligament (p. 1838). Best developed is one beginning at the umbilicus and running in or on (the hepatic) ligamentum teres in the falciform fold to end in the left branch of the portal vein.

Cystic veins. These veins which drain the gallbladder vary. Those from its superior surface are in areolar tissue between the gallbladder and liver, usually entering the liver through the vesical fossa to join the hepatic veins. The remainder form one or two cystic veins which commonly also enter the liver either directly or after joining the veins draining the hepatic ducts and upper bile duct. Only rarely does a single or double cystic vein drain into the right portal branch.

Clinical anatomy

Portal obstruction may cause ascites, whether obstruction is intra- or extrahepatic. In cirrhosis, radicles of the portal vein are compressed by contraction of the fibrous tissue in their portal canals. In valvular cardiac disease, back-pressure on the hepatic veins, and thus on the whole hepatic circulation, has similar effects. The portal vein may be compressed by hepatic tumours, enlarged lymph nodes in the lesser omentum or carcinoma of the pancreatic head. Portal thrombosis may complicate various conditions. In portal obstruction anastomoses between portal and systemic circulations, which may offer effective collateral circulation, are as follows:

- On the abdominal oesophagus tributaries of the left gastric vein (portal) connect with oesophageal tributaries of the azygos and accessory hemiazygos veins (systemic). Enlargement of these may result in varicosity (oesophageal varices) and even fatal haematemesis (vomiting of blood).
- In the rectal wall opening up of connections between the inferior and middle rectal (systemic) and superior rectal (portal) veins may result in varicosity.
- At the umbilicus, veins running on the ligamentum teres to the left portal branch (p. 1603) connect with the epigastric veins (systemic); enlargement of these connections may produce varicosities of veins radiating from the umbilicus, the caput Medusae.
- Retroperitoneal veins communicate directly with venous radicles of the colon and bare area of the liver.
- Very rarely a patent ductus venosus connects the left branch of the portal vein to the inferior vena cava.

Portal obstruction and variceal haemorrhage were formerly treated by surgical anastomosis between the portal and systemic beds (portocaval or splenorenal anastomosis), but these shunts give rise to severe side-effects due to by-passing the hepatic circulation. They are nowadays best treated by introducing portosystemic connections into the liver substance, by means of an intravascular probe.

CENTRAL VENOUS ACCESS

In clinical practice access is frequently required to the superior vena cava and the right side of the heart. This may be for monitoring of central venous, intracardiac and pulmonary artery pressures, for long-term feeding, the safe administration of powerful drugs or for passing a cardiac pacing catheter or biopsy forceps. The first successful placement of a central venous catheter was via a peripheral vein but now it is common practice to use one of the larger and more central veins in the upper part of the body, the internal jugular and the subclavian being the most popular. The main advantage of cannulating one of the large central veins lies in the fact that they are almost constant in their position and are available when peripheral veins are thrombosed or collapsed. The following are some of the common venous sites of access.

Cephalic vein. At the wrist this is situated over the dorsolateral aspect of the lower end of the radius (**10.168**) just proximal to the anatomical snuffbox. This is one of the few constantly sited peripheral veins. However, it is sometimes difficult to negotiate a long catheter past the elbow, and in particular through the clavipectoral fascia where the cephalic vein turns almost through a right angle to join the axillary vein.

Median cubital and basilic veins. These may be identified in the cubital fossa (**10.168, 169**). They are, however, frequently covered by fat, especially in the female, which makes them difficult to see but they are usually palpable especially if the venous return is occluded proximally by a tourniquet. A catheter passed from this site will not always enter the intrathoracic veins though, and may turn upwards into the neck.

Subclavian vein. This is the second most commonly used vein for central venous cannulation, the internal jugular being the most common. There are two percutaneous approaches to the subclavian vein, the supraclavicular and the infraclavicular, though the infraclavicular is more popular.

Infraclavicular approach (**10.92**). With the patient lying supine and slightly head down to distend the vein, the catheterizing needle is inserted at a point 1 cm below the midpoint of the clavicle. Some prefer a point slightly more medial to this. The needle is initially introduced at a right angle to the skin, but once through is directed towards the posterior aspect of the suprasternal notch which may be made more obvious by placing a finger in it. The needle should enter the vein as it arches over the first rib anterior to scalenus anterior.

Supraclavicular approach (**10.92**). The most popular skin puncture site is immediately posterior to the clavicle at the lateral edge of the clavicular head of sternocleidomastoid. The needle is initially advanced caudally but then directed medially such that its proximal end (the portion outside the skin) bisects the angle between the clavicle and sternocleidomastoid. The advancing needle is also angled 10° anteriorly towards the retromanubrial area at the level of the sternal angle. Complications arising from attempted subclavian vein cannulation include damage to the brachial plexus, subclavian artery, thoracic duct and, not infrequently, pneumothorax. Fatalities have occurred.

Internal jugular vein (**10.154**). Percutaneous puncture of the internal jugular vein has become the most popular route for central venous access and it has the advantage of being very safe even when performed by relatively inexperienced operators. It is of particular value when seeking venous access in the patient with circulatory collapse.

There are many approaches to this vein and they may be categorized as high or low, medial, central or lateral. The high approach is at or above the level of the thyroid cartilage, while the low is about

1 cm above the clavicle. The terms medial, central and lateral refer to the puncture site relative to sternocleidomastoid. The high approach is popular because it is very unlikely to cause a pneumothorax.

Most commonly a high, right-sided, medial approach is used in which case the patient should be placed supine and tilted slightly head down to distend the neck veins. The head is turned to the left and the puncture site made just lateral to the upper border of the thyroid cartilage. Some operators like to place one finger on the carotid artery and another on the medial border of sternocleidomastoid and to introduce their needle between those two fingers. The needle is then advanced at 45° to the skin aiming at a point three to four fingers' breadth from the right lateral edge of the sternum until venous blood can be aspirated freely.

Femoral vein (10.176). While femoral venous puncture is relatively easy and supplies ready access to the right atrium, the use of this approach is relatively unpopular for long-term cannulation because of a higher incidence of thrombosis and sepsis. It is, however, a useful site for venous sampling in a patient with collapsed veins. For femoral venous cannulation the skin puncture site is approximately 1 cm medial to the femoral artery and just below the inguinal ligament. After skin puncture the needle is advanced with the syringe at an angle of 30° to the skin aiming cephalad.

LYMPHATIC SYSTEM

INTRODUCTION

Dispersed widely in the body are the tissues, fluids and cells concerned in a variety of interrelated functions, including the drainage of tissue fluid formed in the interstitial spaces, the removal by phagocytes of cell debris and foreign matter (p. 1414) and the immune responses of the lymphocytes (p. 1405) and other cells. In part these activities overlap and have a common cellular base with those of the blood vascular system. It is important to distinguish between *lymphatic vessels* or 'lymphatics' which are tubes of endothelial cells, lined externally by some connective tissue, and *lymphoid tissue*, consisting of large aggregates of lymphocytes and associated cells. These cells are in many instances intimately connected with the lymphatic channels, and process or add to their fluid and cellular contents, for example, in lymph nodes and lymphoid nodules. In other cases, lymphoid tissue may be quite separate from lymphatics, for example the spleen, which is concerned with modifying the blood, and the bone marrow and thymus, which produce lymphocytes and other cells to populate the lymphoid tissue elsewhere, with immunologically active cells of different classes. As stated elsewhere, most tissue fluid formed at the arterial ends of capillaries returns to the circulation via their venous ends, but 10–20% of such fluid passes instead into blind-ending lymphatic capillaries, then traverses one or more lymph nodes before returning to the venous system and thus the blood circulation. Before considering the detailed **topography** of lymphatic vessels and lymph nodes, we will consider the **general structure** of lymphatic vessels, lymph nodes, lymphatic nodules, the spleen and the thymus.

LYMPHATIC VESSELS

Lymphatic capillaries form plexuses in tissue spaces which have wider meshes than those of the adjacent blood capillaries. They often begin as dilated tubes with closed ends; the calibres are larger and cross-sectional appearances are less regular than those of blood capillaries, and they lack a basal lamina, though they have numerous vesicles within their cytoplasm, a typical endothelial feature. (See Leak 1984 for a review of lymphatic structure and physiology.) Their endothelium is generally quite permeable to much larger molecules (Allen 1967) and, unlike most blood capillaries, they are readily permeable to colloidal material and larger particles such as cell debris and micro-organisms from tissue spaces, and to cells. When lymph vessels are obstructed, the surrounding tissues become oedematous, i.e. distended with fluid containing much protein. Experiments suggest that the observed absorption of macromolecules and particles is via gaps between endothelial cells or by micropinocytosis through them. Lymph from most tissues is clear and colourless. In contrast, the lymph from the small intestine is dense and milky, due to the presence of lipid globules (*chylomicrons*) derived from fat absorbed by the mucosal epithelium; the terminal vessels in the mucosa of the small intestine are thus known as *lacteals* and the lymph as *chyle*. Lymphatic capillaries, though present in many tissues, are absent from avascular structures (epidermis, hair, nails, cornea, cartilages), and from central nervous tissue and bone marrow; there are very few in the endomysium of skeletal muscles.

Lymphatic capillaries join into larger vessels which pass to local or sometimes more remote lymph nodes. These are arranged largely in *regional groups*, sufficiently regular in position to be named. Each has its region of drainage but a local group is often bypassed. Nodes within a group are often interconnected (Kubik 1974). In general, lymph traverses a series of nodes before reaching a major collecting duct. There are exceptions to this: lymph vessels of the thyroid gland and oesophagus and of the coronary and triangular ligaments of the liver drain directly to the thoracic duct without passing through lymph nodes (Rusznyák et al 1960). The superficial lymphatics of skin adjoin the deep fascia and accompany superficial veins, but some run independently; they have few connections with deep lymphatics. Deep lymphatic trunks usually accompany arteries or veins, almost all reaching either the thoracic duct or the right lymphatic duct (p. 1609), which join the left and right brachiocephalic veins respectively at the root of the neck. Some observers have also reported additional entry points into the venous system through the inferior vena cava and the renal, suprarenal, azygos and iliac veins. As the lymphatic vessels are closely associated with veins in their development (p. 327), such additional connections would not be surprising, although they are likely to be variable. Most lymphatic vessels anastomose freely and across the midline; larger ones have their own plexiform vasa vasorum and nerve fibres. If their walls are acutely infected (lymphangitis) this plexus is congested, marking the paths of superficial vessels by red lines, visible through the skin and tender to the touch.

Lymphatic vessels repair easily and new vessels readily form after damage; these are at first solid cellular sprouts from the endothelial cells of persisting vessels, which later canalize.

Microscopic structure of lymphatic vessels

The wall of lymphatic capillaries consists of a single layer of endothelium, as in haemal capillaries. A continuous basal lamina is often lacking, and specialized intercellular junctions are few. Fenestrae have been demonstrated in subserosal lymphatics, though they are absent in well-fixed subcutaneous lymphatic vessels, except after trauma. Filopodia are frequent on the luminal surfaces and in lacteals similar projections may exist on their external surface. Bundles of extracellular filaments, lymphatic anchoring filaments, 5–10 nm in diameter, extend from the abluminal surface of the endothelial cells to the surrounding stroma. Pericytes are absent (Fraley & Weiss 1961). There is extensive structural variation between lymphatic capillaries in different tissues (Allen 1967; Leak & Burke 1968). As they unite into larger vessels, a thin external connective tissue coat supports the endothelium. Larger collecting trunks (>200 μm) have three layers, similar to those of small veins, although the lumen is considerably larger, relative to wall thickness, than in veins. The tunica intima consists of an endothelium with a thin subendothelial layer of fibrous tissue. The tunica media contains some smooth muscle cells, mostly arranged circumferentially; the tunica adventitia is mainly fibrous connective tissue, with collagen and elastic fibres and occasional nerve fibres (Boggon & Palfrey 1973). Elastic fibres are sparse in the tunica intima, but sufficient to form an external

elastic lamina in the tunica adventitia. Lymphatics differ from small veins in having many more valves, which are semilunar, generally paired and each composed of an extension of the intima. Their edges point in the direction of the current and the vessel wall downstream is expanded into a sinus, giving the vessels a beaded appearance when distended. Valves are important in preventing the backflow of lymph.

The thoracic duct is structurally similar to a medium-sized vein, but the smooth muscle in the tunica media is more prominent and pulsatile movements have been described (see below and p. 1609).

Satiukova and Rassokhina-Volkova (1972) have studied regeneration of lymphatic capillaries in dogs after autotransplantations of hindlegs and lungs; they observed early formation of buds from severed lymphatics in junctional scar tissue, concluding that lymph flow was largely restored.

Movement of lymph

Several factors aid the propulsion of lymph from tissue spaces to lymph nodes and the venous bloodstream:

- 'Filtration pressure' in tissue spaces is generated by filtration of fluid under pressure from blood capillaries.
- Contraction of neighbouring muscles compresses lymph vessels, moving lymph in the directions determined by their valves; extremely little lymph flows in an immobilized limb, whereas flow is increased by either active or passive movements. This fact has been used clinically to diminish dissemination of toxins from infected tissues by immobilization of the relevant regions. Conversely, massage aids the flow of lymph from oedematous regions.
- The pulsation of neighbouring arteries probably compresses adjacent lymphatic vessels, assisting flow in them.
- Respiratory movements and the negative blood pressure in the brachiocephalic veins also promote flow of lymph.
- Smooth musculature in the wall of the lymphatic trunks contracts when sympathetic nerves are stimulated, resulting in reduction of the lumen. Pulsatile contractions in the thoracic duct also occur (Kinmonth 1982) and, because of the numerous valves along this structure, lymph is forced unidirectionally by this muscular action. However, in markedly dilated vessels valves may become incompetent, allowing retrograde flow, perhaps explaining the observed retrograde spread of some malignant tumours.

Methods of study

Infective material and neoplastic cells often spread from an affected site along lymphatics, and so the details of their pathways from different regions and organs are clinically important. Dissection is not a suitable method for the tracing of these routes because lymphatic vessels are slender and difficult to see. More reliable information has been obtained as follows:

- Experimental injection of substances into organs or tissues of living or dead animals, including man. These enter the lymphatics draining the site of injection and render them and their related lymph nodes visible. The materials most commonly used for this purpose are suspensions of India ink, Neoprene latex or Prussian blue, the latter employed by Jamieson and Dobson (1907–1908, 1910, 1920) in extensive studies of human pathways. In living animals methylene blue and radio-opaque substances, such as lipiodol, have been injected, the latter requiring radiography. Lymphangiography in human subjects, following the injection of lipiodol into the appropriate peripheral lymphatic channels has much increased our knowledge of their routes and is much used diagnostically (Kinmonth 1964; Kinmonth & Taylor 1964).
- Clinical observation of lymph nodes involved in the spread of known inflammatory or malignant disease. However, it must be cautioned that retrograde spread of tumour cells after blockage of a channel limits the reliability of such observations by altering the normal directions of flow.

SPLEEN

(Although part of the cardiovascular system, the spleen is essentially concerned with immune functions and a filtering of blood. Its structure is dealt with on pages 1437–1442 in the Haemolymphoid system, Section 9.)

TOPOGRAPHY OF LYMPH NODES AND VESSELS

The detailed architecture of lymph nodes and lymphatic vessels is discussed on pages 1431–1432. The structure of lymph nodes is described on pages 1605–1626, that of the spleen on page 1439, and that of the thymus on pages 1424–1429. Lymph nodes occupy fairly well-defined topographical sites, specifically named, each with its area of drainage, interconnections with other nodes or groups and a predominant destination of its efferent vessels. A more detailed consideration of these matters is the concern of the remainder of this chapter; this must be prefaced by a summary, or sometimes a reiteration, of a few general principles. Lymphatic anatomy often appears an almost impossible plethora of topographical names for trunks, groups and subgroups of nodes and their connections. However, an elemental knowledge of general anatomy and a recognition of which of the general principles apply to the major organ systems make many of the difficulties evaporate. It is particularly useful to appreciate the overall pattern present in a particular organ, whole organ system or whole body segment. (Good examples are: the whole subdiaphragmatic alimentary tract, the foregut, the stomach, the tracheobronchopulmonary system, the similarities and contrasting features of the arm and leg and the head and neck as a whole.) These encompass all the main patterns and principles, include all the main terminal lymph trunks whereby lymph is returned to the venous system. The principal groups of lymph nodes towards which lymph converges from wide tissue areas (often through one or more subgroups) and knowledge of which, for many, is mandatory, are clarified. Thereafter, many (but not all) the lesser subgroups, in relation to their formal topographical names, assume a diminished importance in terms of mental retention; nevertheless, their distribution can usually be predicted with confidence. The criteria for the topographical naming of nodes will be mentioned below. Certain general names applied to nodes, although not universally used, often prove useful. Lymph circulating in lymphatic capillaries may be returned to the venous system (ignoring intralymphoidal venular events on a microscopic scale, p. 1432) almost entirely at bilateral sites at or near the junctions between internal jugular and subclavian veins forming right and left brachiocephalic veins; however, their routes vary enormously in length and complexity. In certain exceptional sites (thyroid, oesophagus, dorsal hepatic 'bare areas', p. 1800) the capillaries drain via a radicle of the thoracic duct with no intervening lymph node (an anodal route). In some, a single node provides uninodal routes; the majority of routes are multinodal with sometimes many nodes forming irregular cross-connected chains. In such a chain, the node or group nearest the tissue drained is termed *primary* (outlying, or peripheral), and the last group of the chain, whose efferents form a final uninterrupted principal lymph trunk, is termed *terminal*. Between its primary peripheral and its terminal groups intervening nodes are often segregated into *intermediary* groups; some use the collective term *regional lymph nodes* to include all three groups; others, peripheral and intermediary only. The significance of multinodal pathways is by no means clear; it should be noted that classifications may impose an artificial simplicity on a potentially highly complex monitoring and reacting system. Thus, briefly, a particular node is not one element in a simple chain but, receiving multiple afferent vessels, may, for example, be the primary node for various loci, number three in the chain for other loci, number five for others and so forth. Such considerations, of course, apply to other members of the chain and, summating for the whole chain, there emerges the notion of a system of lymphatic channels and lymphoid stations of great three-dimensional complexity. Differential lymphangiography amply confirms this complexity. This prompts the question: are lymph nodes in general roughly equivalent in their ranges of receptivity (monitoring) and reactivity or do they vary? If variation exists, to what degree? An extreme (and fanciful) extension of this is the possibility of individual nodes, or even sectors of nodes, being unique in their properties, as they unquestionably are in their locations and connections.

TOPOGRAPHICAL NAMING OF LYMPH NODES

Topographical naming of lymph nodes has not followed a single rigid classification; four main frames of reference have been found convenient, and sufficiently clear. These are:

- superficial or deep position
- related vasculature
- related organ's name and architecture
- general topographical location.

Superficial and deep position

Superficial and deep refer to the location of the nodes with respect to the deep fascia. As noted below, many superficial nodes are closely applied to prominent superficial veins. An interesting but unexplained fact is that the upper limb has few superficial nodes and its superficial lymphatic drainage mostly passes directly to deep axillary nodes; in contrast, in the leg the superficial lymphatic drainage passes, almost exclusively, to the large superficial inguinal nodes before continuing to the external iliac nodes.

Relation to vasculature

The majority of nodes and node groups are clustered around or abut a prominent blood vessel or one of its branches; from this (with many notable exceptions) the name of the group is derived. The association assists in recalling the location of the group and in many instances is a strong pointer to the main region of lymph drainage. Examples of superficial nodes associated with veins are: buccal nodes (facial vein), superficial cervical nodes (external jugular vein), anterior cervical nodes (anterior jugular vein), infraclavicular nodes (cephalic vein), supratrochlear nodes (basilic vein), superficial inguinal nodes (great saphenous vein). Deep nodes associated with vessels are so numerous that only a few illustrative examples can be given. The abdominal aorta and common, internal and external iliac arteries are surrounded by nodes. The whole consists of massive chains of nodes, interconnected by lymphatic vessels, predominantly vertically but also obliquely and transversely. Thus, the main groups are named with their vessels: external, internal and common iliac and circumaortic. The latter (often grouped with neighbouring nodes particularly scattered over the inferior vena cava as lumbar nodes) are divided, on sound developmental and lymphodynamic grounds, into a large median ventral aortic group, prominent right and left lateral aortic groups and a sparse retro-aortic group. Details are given in subsequent pages, but a few examples with comments and one possible synthetic approach to study are outlined here. The ventral aortic group aggregates around the three large subdiaphragmatic ventral splanchnic arteries (p. 1548) as coeliac, superior mesenteric and inferior mesenteric groups of nodes, which drain the subdiaphragmatic foregut, midgut and hindgut (and their derivatives), respectively. The foregut provides an excellent framework with respect to its extent and parts (terminal oesophagus, stomach, proximal duodenum); its derivatives (liver, gallbladder and biliary ducts, pancreas and the closely associated spleen); and the mutual disposition of the foregoing and their peritoneal reflexions, omenta and the lesser sac. To this is added the position of the upper abdominal aorta, the coeliac artery, its trifurcation into common hepatic, left gastric and splenic arteries and the courses and main branches of these. Groups of nodes named in relation to these are, for example, left gastric, right gastro-epiploic, hepatic and pancreaticosplenic; other related groups have visceral names, for example paracardial and pyloric (stomach), cystic (gallbladder), 'anterior border of epiploic foramen' (bile duct). The general (interconnected) areas of drainage of these groups are evident and their efferents discharge into the coeliac nodes. The latter also receive the efferents of the superior and inferior mesenteric groups, each of which has received the efferents from systematically named groups, aggregated along their branches, or scattered in the mesentery. The coeliac nodes are thus the terminal group for the whole subdiaphragmatic gut down to midrectal level and for most of the liver, the gallbladder and biliary ducts, pancreas and spleen. Their efferents join to form wide right and left intestinal lymph trunks; these coalesce and also join the right and left lumbar lymph trunks (see below) to form the morphologically variable *abdominal confluence of lymph trunks*, the cranial end of which is the entry to the thoracic duct. Briefly (details p. 1621), the lateral aortic groups drain the tissues supplied by the lateral splanchnic and dorsolateral somatic intersegmental aortic branches; caudally they receive the profuse efferents from the common iliac groups which in turn receive the efferents from the internal and external iliac groups, each with their extensive areas of drainage and further associated outlying groups of nodes. The cranial members of the lateral aortic groups are the terminal nodes for all these tissues; their efferents converge to form the bilateral lumbar lymph trunks which are the other main avenues forming the abdominal confluence of lymph trunks and thence the initial (caudal) end of the thoracic duct. Mention may be made of the nodes associated with drainage of the leg, often misrepresented. Some drainage first involves a limited outlying group of popliteal nodes (near their vessels), then traverses the superficial or deep inguinal nodes which are *intermediary* (**not** terminal) groups at the limb's root; thereafter the lymph node ascends the chains just described, i.e. via the external and common iliac, the lateral aortic to its upper terminal nodes, then the lumbar lymph trunk, confluence and thoracic duct. (Some deep gluteal lymph follows the internal iliac path to the same destination.) Prominent nodes in the thorax named in relation to vessels are the brachiocephalic group.

Relation to viscera

The names of the visceral lymph nodes are self-evident. Examples already mentioned are the paracardial and pyloric, gastric groups; others are the *superficial* and *deep parotid*, *submandibular* and *paracolic*. The best examples are concerned with, primarily, the drainage of the lower respiratory tract. Passing from the periphery these are named: *pulmonary* (at major bronchial divisions within the lung), *bronchopulmonary* (or simply 'hilar'), *inferior* and *superior tracheobronchial* (p. 1625) and paratracheal. Their ascending efferents are joined by some from the ipsilateral parasternal, brachiocephalic and posterior mediastinal nodes, forming the right and left bronchomediastinal lymph trunks; these incline over the trachea, then to the ventral aspect of their jugulosubclavian venous junctions. At or in either great vein, near the junction, the trunks usually open independently, but in about one-fifth of individuals the right trunk may join a right lymphatic duct; the left may join the thoracic duct or both may occur.

Names related to general topography

The groups of nodes most easily accessible to clinical palpation have widely used general positional names, which vary considerably in their precision. The relation of many (but not all) their subgroups to prominent blood vessels and their branches is close and this provides a more accurate reference system; in some notable sites this is seldom adopted.

Leg. Outlying *popliteal nodes*—here the name is used indiscriminately with respect to the vessels or the fossa; their palpation is by finger tips probing the fossa along the line of the popliteal vessels with the passively supported limb gradually moved from extension to semiflexion. *Inguinal nodes*: superficial and deep—here inguinal simply implies that they are 'related to the groin'. The deep nodes are few and applied to the medial aspect of the femoral vein; the superficial nodes comprise a lower vertical group clothing the upper great saphenous vein; an upper group parallel to but below the inguinal ligament (related to the superficial circumflex iliac and superficial external pudendal vessels). Palpation is done with the supported limb slightly flexed, abducted and laterally rotated, along a strip 1 cm below the inguinal ligament and a strip 1 cm medial to the central apicobasal line of the femoral triangle.

Arm. Outlying *supratrochlear nodes* (more aptly supra-epicondylar) are adjacent to the basilic vein. Palpation is done along the line of the vein a few centimetres above the elbow joint; many approaches are satisfactory: facing the subject, an elegant approach is to cup the back of the supracubital arm with the appropriate palm; the semiflexed fingers encircle the medial aspect and their aligned tips effortlessly probe along the vein. The *axillary nodes* have subgroups with alternative names; one system applies to their topographical positioning with respect to the 'walls' of the axilla, the second system to their disposition close to the axillary vessels and their branches (especially the veins). These are detailed on page 1613 and will not be pursued here. Palpation demands a systematic approach, exploring each wall of the axilla and any attendant vessels and nodes as

separate manoeuvres. The supported arm is slightly abducted, the examiner facing the lateral aspect of the shoulder; each fold of the axilla is examined with the appropriate hand, semiflexed fingertips invaginating the axillary floor while the thumb grips the fold externally. The fingertips of one or both hands next probe deeply, then down and laterally along the axillary vessels. Finally, the fingers of the pronated hand, inserted deeply, are drawn down the medial wall, i.e. the resistant thoracic wall and serratus anterior. It should be noted that most of the axillary groups are intermediary, with their wide areas of drainage, and the central group is preterminal; only the *apical group* is *terminal*. The latter's efferents form the *subclavian lymph trunk* which approaches and, with variable final morphology, opens at or near its jugulosubclavian junction. The trunk and its opening are on the anterior aspect of the venous walls.

Head and neck. Apart from a few retrovisceral nodes and some deep to the sternocleidomastoid, members of all the nodal groups in the head and neck are clinically palpable when enlarged and all receive regional topographical names. Many of the latter are appropriate and helpful; in the neck, however, the major groups have only the most generalized names, despite their principal relationship to large vessels. (Alternative names based on this merit consideration.) The various groups are detailed elsewhere (p. 1612); thus a simplified overall plan for the head and neck will be mentioned and some group names added to a suggested approach to their clinical examination. The relationship of craniocervical nodes to the deep fascia is discussed subsequently but in some important cases is implied in their names. At the junction of the head with the neck an encircling band extends bilaterally from the chin to the external occipital protuberance, the pericraniocervical ring (often shortened to 'pericervical ring'). Throughout, this encompasses topographically named regional groups with outlying nodes in the face; sequentially the groups are: submental, submandibular (with outlying buccal nodes), retromandibular (outlying parotid), retro-auricular (or mastoid) and occipital. As noted, verbal descriptions of their sites and areas of drainage are given (p. 1612) but in general are obvious from their names. Palpation is carried out from behind the seated subject, using both hands simultaneously, their fingers semiflexed and adducted and thumbs in partial opposition; the fingers explore systematically: the submental triangle, the submandibular glands and triangles (thumbs probing over buccinators), the retromandibular depressions (thumbs over parotids), the upper attachment of sternocleidomastoid and the occipital attachment of trapezius. Palpation now continues along the approximately vertical chains of cervical nodes, superficial and deep. The superficial chains of relatively few, small nodes are associated with the external jugular and anterior jugular veins, the superficial cervical and anterior cervical groups respectively; both drain finally into deep nodes. (These, and unqualified 'deep cervical' are indifferent, non-specific, unhelpful names; the relative precision of vascular or visceral names is preferable.) The main chain of deep cervical nodes is ranged along and embedded in, or in areolar tissue near, the carotid sheath but particularly those aspects surrounding the internal jugular vein. Customarily divided into upper and lower groups, they receive, in addition to their direct areas of drainage, all the efferents from the pericraniocervical ring, efferents from the superficial cervical nodes and efferents from other paravisceral deep nodes (e.g. *retropharyngeal*, *infrahyoid*, *prelaryngeal*, *pretracheal*, *paratracheal* and *subclavian*). All the lymph from the head and neck finally traverses its ipsilateral *lower deep cervical group*, which is the terminal group. Efferents from the latter converge, forming (right and left) jugular lymph trunks; each descends on its vein to its termination at the jugulosubclavian venous junction.

Lymph node numbers: regional distribution

Accurate, large statistical surveys are not available; the following are pooled data from many limited sources; nevertheless, the overall approximations allow interesting speculation. A normal young adult body contains some 400–450 lymph nodes. Of these the limbs and associated superficial body wall are least well served. The arm and superficial thoraco-abdominal wall (down to the umbilicus) contain about 30 nodes, the leg and superficial buttock, infra-umbilical abdominal wall and perineum only about 20 nodes. (This does not include the iliac and lateral aortic groups which have numerous additional intra-abdominal afferents.) The head and neck carry some 60–70 nodes. The remainder (about 330) is divided between the thorax (deep walls and contents, some 100 nodes or less), and the abdomen and pelvis (deep walls and contents, some 230 nodes or more). Most richly served by nodes is the gastrointestinal tract; also profusely served is the tracheobronchopulmonary tract.

CERVICAL LYMPHOVENOUS PORTALS

Lymph is returned to the venous blood circulation via the right and left lymphovenous portals which are sited at, or near, the junctions of the large internal jugular and subclavian veins forming the even larger right and left brachiocephalic veins. On the right, **three** main lymph trunks converge towards their venous junction; on the left **four** main trunks (three corresponding to the right-sided trunks, but additionally the largest trunk, the thoracic duct). The morphology of the venous termination of these trunks is subject to much variation and the account frequently given in textbooks is a fairly uncommon occurrence, hence the introduction of the generalized term lymphovenous portal.

On the right. The three trunks converging here are:

(1) The *right jugular trunk* which extends along the ventrolateral aspect of the internal jugular vein from the terminal lower deep cervical nodes and conveys all the lymph from the right half of the head and neck.

(2) The *right subclavian trunk* from the terminal apical axillary group extending along the axillary and subclavian veins and conveying lymph from the right upper limb and superficial tissues of the right half of the thoraco-abdominal wall down to the umbilicus anteriorly and iliac crest posteriorly (and including much of the mammary gland).

(3) The *right bronchomediastinal trunk* (p. 1625), which ascends over the trachea towards the portal and conveys lymph from the thoracic walls, the right cupola of the diaphragm and subjacent liver, the right lung, bronchi and trachea, the greater part of the 'right heart' (of clinical parlance, not the geometric right half, see p. 1625) and a proportionately small drainage from the thoracic oesophagus.

The *right venous termination* of the three lymphatic trunks is subject to great variation. In the great majority of subjects (80%) they open independently, their orifices clustered on the ventral aspect of the jugulosubclavian junction or in the nearby wall of either of the great veins. In a proportion of these one or more of the trunks may bifurcate (or even trifurcate) preterminally and then have multiple orifices. In one-fifth of subjects only, the three trunks fuse to form a short (1 cm) single right lymphatic duct that inclines across the medial border of scalenus anterior to the ventral aspect of the venous junction, where its orifice is preceded by a bicuspid semilunar valve. An incomplete right lymphatic duct may be present following fusion of, usually, the subclavian and jugular trunks, or any combination of their terminals when divided. In such cases the bronchomediastinal trunk almost invariably opens separately.

Summary. The **right** lymphovenous portal, whatever the final morphology of its trunks, receives lymph from: the right half of the head and neck, the thorax and its contents and superficial tissues of the abdomen and trunk down to the umbilicus and iliac crest, part of the right cupola of the diaphragm and convex surface (only) of the underlying liver and the whole of the right arm. The **left** portal receives much the greater volume of lymph from all the remainder of the body.

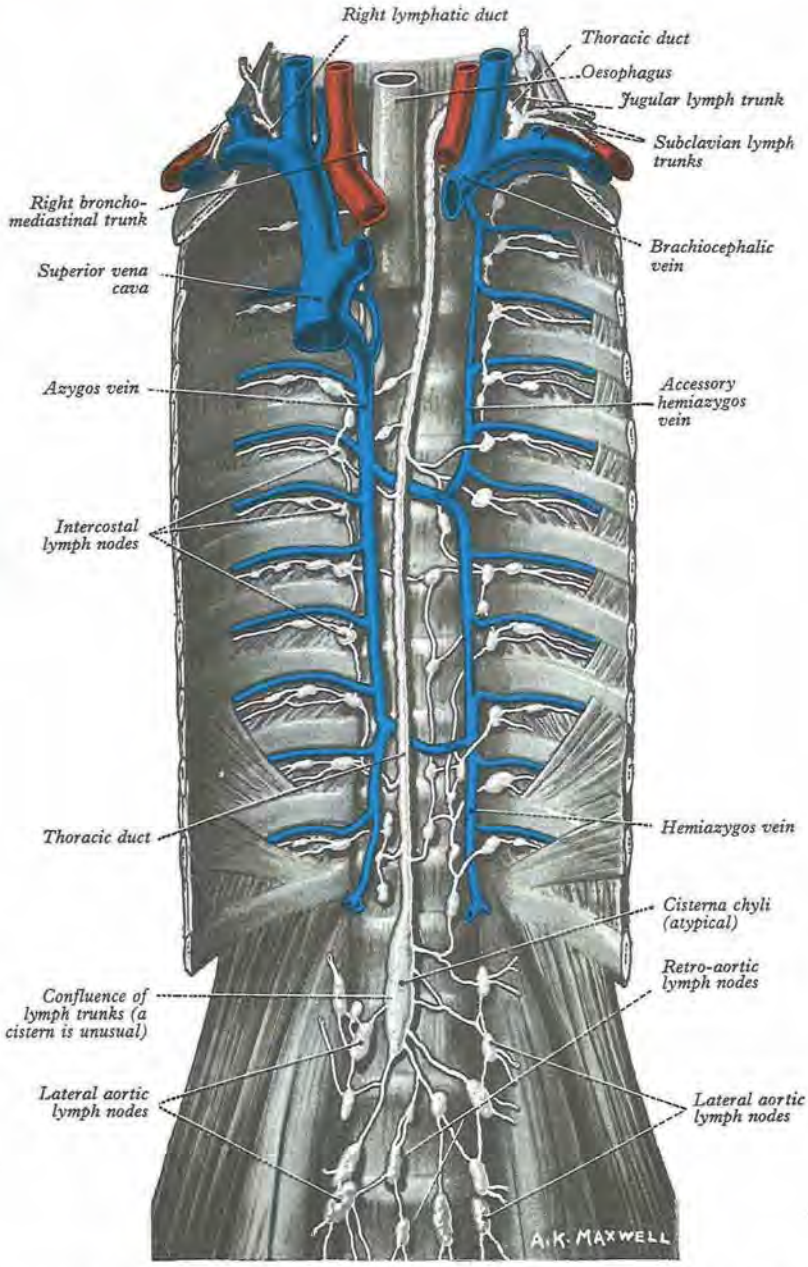
On the left. The four trunks converging here on the lymphovenous portal are:

(1) The left jugular trunk, mirroring its right fellow;

(2) the left subclavian trunk, also with a disposition corresponding to its contralateral fellow;

(3) the left bronchomediastinal trunk, similar to the right trunk, but draining more of the heart (the 'left' and part of the 'right hearts' of clinical parlance, p. 1474) and more of the oesophagus;

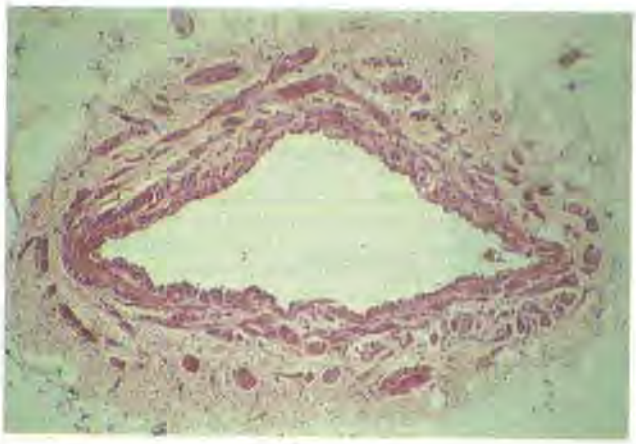
(4) the thoracic duct, which drains all the extensive remaining regions of the body. At its caudal origin as a continuation of the abdominal confluence of lymphatic trunks (see below), thoughout its course and at its cervical venous termination, it is subject to considerable variation.



10.184 The thoracic and right lymphatic ducts. The accessory hemiazygos vein is crossing the median plane lower and the hemiazygos higher than usual. Note also the comments concerning the more common course of the azygos vein made in illustration **10.171** and on page 1593. Two features are also uncommon: a single right lymphatic duct (usually two or more trunks open independently); a simple cisterna chyli is infrequent (it is usually a confluence of lymph trunks of varying morphology, page 1610).

THORACIC DUCT (10.184–186)

In adults the thoracic duct including the confluence of lymph trunks (or the cisterna chyli in the small proportion in whom the latter is saccular) is 38–45 cm in length, extending from the second lumbar vertebra to the base of the neck. Starting from the superior pole of the confluence near the lower border of the twelfth thoracic vertebra, it traverses the diaphragm's aortic aperture, then ascends the posterior mediastinum, right of the midline, between the descending thoracic aorta (on its left) and the azygos vein (on its right). **Posterior** to it is the vertebral column (vertebral bodies, symphyses, anterior longitudinal ligament), the right aortic intercostal arteries and terminal segments of the hemiazygos and accessory hemiazygos veins. **Anterior** to it are the diaphragm and oesophagus; a recess of the right pleural cavity may separate the duct and oesophagus. Reaching the level of the fifth thoracic vertebral body it gradually inclines to the left, enters the superior mediastinum and then ascends to the thoracic inlet along the left border of the oesophagus. In this part of its course the duct is first crossed anteriorly by the aortic arch and it then runs posterior to the left subclavian artery's initial segment, in close contact with the left mediastinal pleura. Passing into the neck it arches laterally at the level of the seventh cervical vertebral transverse process. Its arch rises 3 or 4 cm above the clavicle and curves anterior to the vertebral artery and vein, the left sympathetic trunk, thyrocervical artery or its branches and the left phrenic nerve and medial border of scalenus anterior (but is separated from the nerve and muscle by the prevertebral fascia). The arch passes posterior to: the left common carotid artery, vagus nerve and internal jugular vein. Finally, the duct descends anterior to the arched cervical 'first part' of the left subclavian artery and ends by opening into the junction of the left subclavian and internal jugular veins. However, the duct may open into either of the great veins,



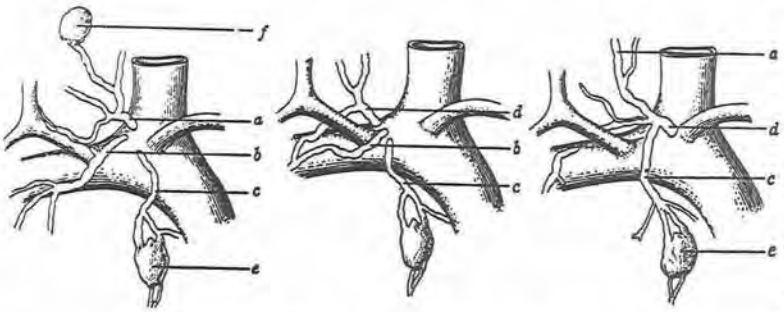
10.185 Transverse section of the thoracic duct showing the fibro-muscular coat (see text). Stained with haematoxylin and eosin. Magnification ×80. (Preparation by Millie Harrison, Department of Anatomy, UMDS, Guy's Campus, London.)

near the junction, or it may divide into a number of smaller vessels before terminating (see below).

At its abdominal origin the thoracic duct is about 5 mm in diameter but diminishes in calibre at mid-thoracic levels, then in about 50% of subjects is again slightly dilated before its termination. It is slightly sinuous, constricted at intervals and appears varicose. It may divide in its midcourse into two unequal vessels which soon reunite, or into several small branches which form a plexus before continuing as a single duct. At a higher level it occasionally bifurcates, the left branch ending as usual, the right branch diverging to join one of the right lymph trunks or, when present, a right lymphatic duct; the combined vessel usually opens into the right subclavian vein. The thoracic duct has several valves corresponding to sites exposed to pressure. At its termination a bicuspid valve faces into the vein to prevent or reduce reflux of blood. (After death blood regurgitates freely into the duct, which then looks like a vein.)

Termination

Kinnaert (1973) has collected accounts of 529 dissections (49 his own) of the thoracic duct's termination. In 0–4.5% of subjects no thoracic duct appeared on the left. Multiple terminal openings were frequent (10–40%, according to different observers). In Kinnaert's series the preterminal duct was multiple in 66%, but in only 21% were actual terminal openings multiple. Patterns varied greatly in different studies but, in the two largest by Jdanov (1959) and Kinnaert (1973), sites of termination were respectively 48% and 36% internal jugular vein, 9% and 17% subclavian vein, 35% and 34% jugulosubclavian junction. Termination in the left brachiocephalic (innominate) vein occurred in 8% of Jdanov's series, but never in Kinnaert's.



10.187 Variations in the terminal lymph trunks of the right side. a = jugular trunk; b = subclavian trunk; c = bronchomediastinal trunk; d = right lymphatic duct; e = lymph node of parasternal chain; f = lymph node of deep cervical chain. (After Poirier & Charpy.)

10.186 Lymphangiogram showing the entire length of the thoracic duct, approximately 24 hours after injection of lipiodol into a lymphatic vessel on the dorsum of each foot; the cisterna chyli is not evident. (Supplied by G I Verney, Addenbrooke's Hospital, Cambridge; photography by Sarah Smith, Department of Anatomy, UMDS, Guy's Campus, London.)

Origin and tributaries

The abdominal origin of the thoracic duct proper is, as stated, situated to the right of the midline at the level of the lower border of the twelfth thoracic vertebral body or the thoracolumbar intervertebral disc. It is the recipient of all the lymph delivered by the four main abdominal lymph trunks, which converge to an elongated arrangement of channels of variable morphology here given the generalized name, *abdominal confluence of lymph trunks.* This may be a simple duct-like extension or be duplicated, triplicated or plexiform; when it is wider than the thoracic duct its interior is sometimes irregular and bilocular or trilocular and may surround intercalated lymph nodes. Only in a small proportion of instances is it a simple, fusiform, saccular dilatation, and the widely-used name *cisterna chyli* should be reserved for these. A published thorough statistical study of the origin of the thoracic duct in mankind appears lacking. Anson (1963) depicted variations: in many a cisterna was absent; when present it was usually multilocular or plexiform; no statistics of incidence were given. Kubik (personal communication 1978) observed a 'cisterna' in 14 of 70 dissections. In only six was it single; it was double in five specimens and trilocular in three. In 56 dissections no cisterna was observed; in half of these collecting trunks formed a direct extension of the thoracic duct; in the other half intercalated nodes (also depicted by Anson 1963) simulated the profiles of cisternae.

The abdominal confluence extends from the caudal beginning of the thoracic duct, vertically, for 5–7 cm anterolateral to the right of the first and second lumbar vertebral bodies (and their intervening disc), and immediately to the right of the abdominal aorta. (Thus its site is overlapped by territories containing upper right lateral aortic lymph nodes and right-sided members of the coeliac and superior mesenteric pre-aortic groups.) The upper two right lumbar

arteries and the right lumbar azygos vein (p. 1593) are between the confluence and the vertebral column. Anterior to it is the medial edge of the right diaphragmatic crus. As mentioned, the confluence (and thence the thoracic duct) receives the right and left lumbar and intestinal lymph trunks. In summary:

(1) The *lumbar trunks* are formed by efferents from lateral aortic lymph nodes. Thus, either directly or after traversing intermediary groups, they carry lymph from: the lower limbs, the full thickness of the pelvic, perineal and infra-umbilical abdominal walls, the deep tissues of most of the supra-umbilical abdominal walls, the pelvic viscera, testes or ovaries, kidneys and suprarenals.

(2) The *intestinal lymph trunks* receive efferents from the coeliac nodes (terminal ventral aortic group) which, after traversing intermediary groups, drain the stomach, intestines (to midrectal levels), pancreas, spleen and the (greater) antero-inferior part of the liver.

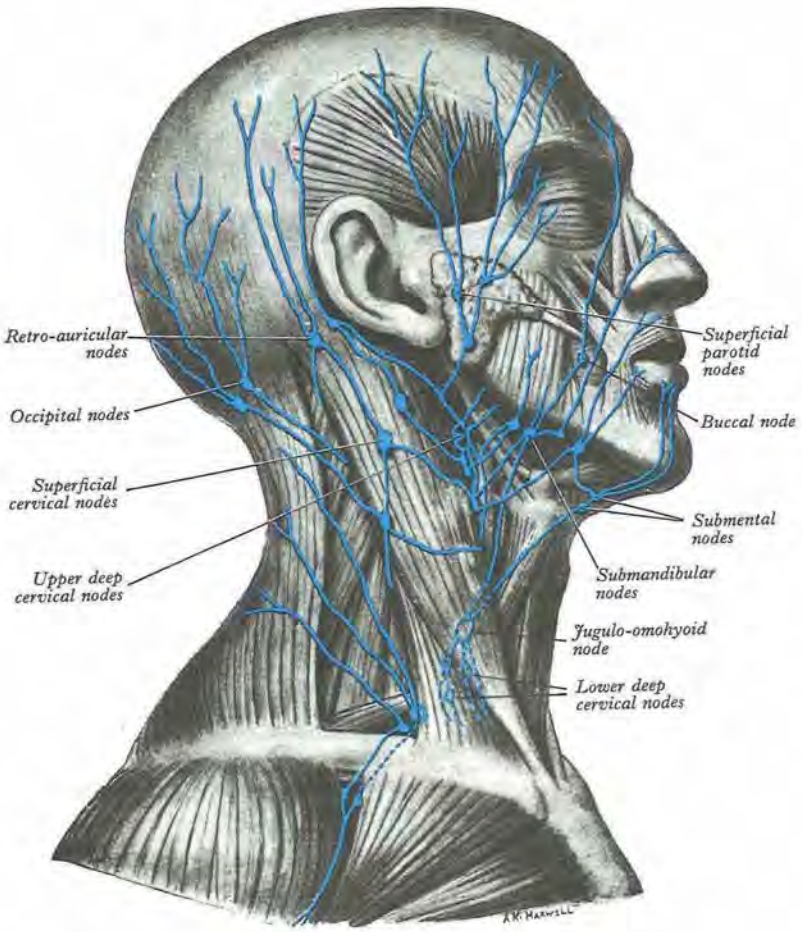
Tributaries of the thoracic duct proper (10.187). In summary these are:

- the *confluence of lymph trunks*, just described, the whole outflow of which enters the origin of the thoracic duct
- the bilateral *descending thoracic lymph trunks* from intercostal lymph nodes of the lower six or seven intercostal spaces of both sides which traverse the aortic orifice and join the lateral aspects of the thoracic duct in the abdomen immediately after its origin
- the bilateral *ascending lumbar lymph trunks* from the upper lateral aortic nodes which ascend and pierce their corresponding diaphragmatic crus, then join the the thoracic duct at a variable level within the thorax
- the *upper intercostal trunks* draining the intercostal nodes in the upper five or six left intercostal spaces
- the *mediastinal trunks* draining various nodal groups noted below and providing (amongst other tissues) paths to the thoracic duct from the convex diaphragmatic aspect of the liver, the diaphragm, the pericardium, heart and oesophagus
- the *left subclavian trunk* which usually joins the thoracic duct, but may open independently into the left subclavian vein
- the *left jugular trunk* which usually joins the thoracic duct, but may open independently into the left internal jugular vein
- the *left bronchomediastinal trunk* which occasionally joins the thoracic duct, usually having an independent venous opening.

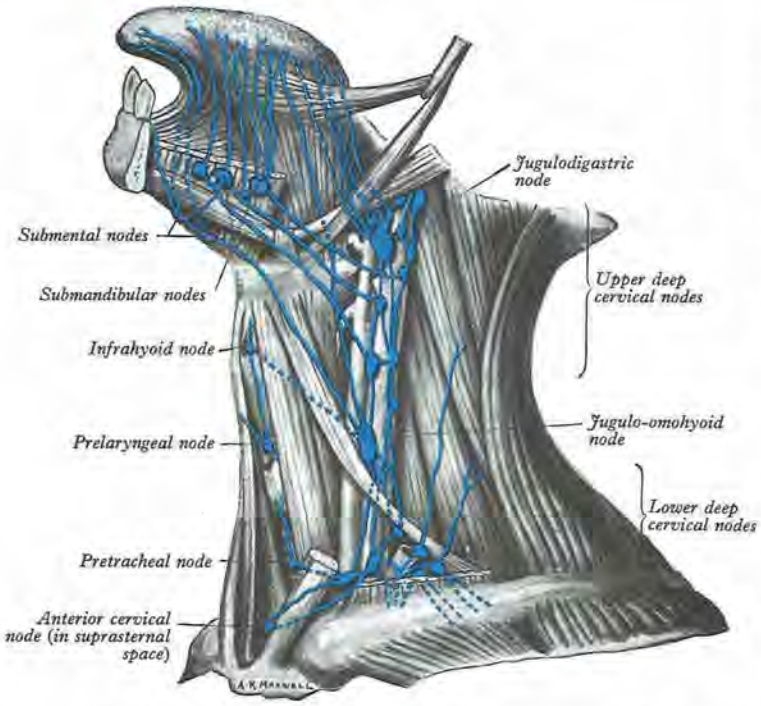
Many of the trunks listed above are described as possessing terminal bicuspid valves which possibly prevent reflux of lymph. However, Sapin and Borziak (1974) studied the behaviour of radio-opaque masses in thoracic ducts of 180 cadavers; they found that reflux into several groups of mediastinal and paravertebral groups was usual (under these conditions!).

LYMPHATIC DRAINAGE OF HEAD AND NECK

Nodes in the head and neck comprise a terminal (collecting) group and intermediary, outlying groups. The terminal group is related to the carotid sheath and is named deep cervical. All lymph vessels of the head and neck drain into this, directly from tissues or indirectly through nodes in outlying groups. Efferents of the deep cervical nodes form the *jugular trunk*, which on the right may end in the jugulosubclavian junction or right lymphatic duct; on the left it usually enters the thoracic duct but may join the internal jugular or subclavian vein. In lymphatic drainage the tissues of the head and neck, like other regions, can conveniently be considered as superficial and deep. (See also the generalized arrangement of a peri-craniocervical ring and vertical cervical chains, p. 1608.)



10.188 The superficial lymph nodes and lymph vessels of the head and neck.



10.189 The lymphatic drainage of the tongue. Removal of the sternocleidomastoid has exposed the whole chain of deep cervical lymph nodes. (After Jamieson & Dobson.)

DEEP CERVICAL LYMPHATIC NODES

The deep cervical lymphatic nodes are alongside the carotid sheath; they form superior and inferior groups.

Superior deep cervical nodes (10.188). These adjoin the upper internal jugular vein. Most are deep to the sternocleidomastoid; a few extend beyond it. One subgroup, of one large and several small nodes, is in a triangular region bounded by the posterior belly of the digastric and the facial and internal jugular veins; this jugulodigastric group is concerned specially with lingual drainage. Efferents from the upper deep cervical nodes drain to the lower group or direct to the jugular trunk.

Inferior deep cervical nodes. They are partly deep to the sternocleidomastoid, particularly related to the lower internal jugular vein but some, extending also into the subclavian triangle, are closely related to the brachial plexus and subclavian vessels. One node is on or just above the intermediate tendon of omohyoid, the *jugulo-omohyoid node*, and is concerned especially with the tongue (p. 1613). Efferents from this lower group join the jugular lymph trunk.

LYMPHATIC DRAINAGE OF SUPERFICIAL TISSUES OF HEAD AND NECK

Most superficial tissues in the region drain by vessels afferent to local groups of nodes, and efferents from these drain to the deep cervical nodes; but some structures drain directly to deep nodes (**10.188**). Groups concerned in superficial drainage are:

- in the *head*: occipital, retro-auricular (mastoid), parotid, buccal (facial)
- in the *neck*: submandibular, submental, anterior cervical, superficial cervical.

Lymphatic drainage of scalp and ear

Vessels from the frontal region above the root of the nose drain to the submandibular nodes (**10.188**) and are considered with the face. Vessels from the rest of the forehead, temporal region, upper half of the lateral auricular aspect and anterior wall of the external acoustic meatus drain to the superficial parotid nodes, just anterior to the tragus, on or deep to the parotid fascia. These also drain lateral vessels from the eyelids and skin of the zygomatic region. Their efferent vessels pass to the upper deep cervical nodes. A strip of scalp above the auricle, the upper half of the auricle's cranial aspect and margin and the posterior wall of the external acoustic meatus all drain to the upper deep cervical and retro-auricular nodes.

The *retro-auricular nodes* (**10.188**), superficial to the mastoid attachment of sternocleidomastoid and deep to auricularis posterior, drain to the upper deep cervical nodes. The auricular lobule, floor of the meatus and skin over the mandibular angle and lower parotid region are drained to the superficial cervical or upper deep cervical nodes. *Superficial cervical nodes* spread along the external jugular vein superficial to sternocleidomastoid, some efferents passing round the anterior border of sternocleidomastoid to the upper deep cervical nodes; others follow the external jugular vein to the lower deep cervical nodes in the subclavian triangle.

The occipital scalp is drained partly to the occipital nodes, partly by a vessel along the posterior border of sternocleidomastoid to the lower deep cervical nodes. Occipital nodes are occasionally in the superior angle of the posterior triangle but commonly superficial to the upper attachment of trapezius.

Lymphatic drainage of face

Lymph vessels draining the eyelids and conjunctiva commence in a subcutaneous plexus and a deep plexus around the tarsal plates; these communicate and medial and lateral vessels drain from them. Lateral vessels drain the whole thickness of both lids, except their medial parts and all the conjunctiva. They pass from the lateral commissure to the superficial parotid nodes and deep nodes embedded in the parotid gland, also receiving lymph from the middle ear (see below). The medial palpebral vessels drain the whole thickness of the medial parts of the lids and caruncula lacrimalis. Following the facial vein, they end in submandibular nodes.

There are usually three *submandibular nodes* (**10.188, 189**), internal to the deep cervical fascia in the submandibular triangle. There is one at the anterior pole of the submandibular gland, and two flanking the facial artery as it reaches the mandible. Other nodes are often embedded in the gland or deep to it. Submandibular nodes drain a wide area, including vessels from the submental, buccal and lingual groups of nodes; their efferents pass to the upper and lower deep cervical nodes. The external nose, cheeks, upper lip and lateral parts of the lower lip drain directly to the submandibular nodes; the afferent vessels may have a few *buccal nodes* along their course and near the facial vein. The mucous membrane of lips and cheeks also drains to the submandibular nodes. The lateral part of the cheek drains to the parotid nodes. The skin over the nasal radix and central forehead drains partly to the parotid nodes, partly to the submandibular.

The central part of the lower lip, buccal floor and lingual apex drain to the *submental nodes*, which are on the mylohyoid between the anterior bellies of the digastric muscles (**10.189**). They receive afferents from **both** sides, some decussating across the chin; their efferents pass to the submandibular and jugulo-omohyoid nodes.

Lymphatic drainage of neck

Many vessels draining the superficial cervical tissues skirt the borders of sternocleidomastoid to the superior or inferior deep cervical nodes; but some pass over sternocleidomastoid and the posterior triangle to the superficial cervical and occipital nodes. Lymph from the superior region of the anterior triangle drains to the submandibular and submental nodes; vessels from the anterior cervical skin inferior to the hyoid bone pass to the anterior cervical lymph nodes near the anterior jugular veins; their efferents go to the deep cervical nodes of both sides, including the infrahyoid, prelaryngeal and pretracheal groups (see below). An anterior cervical node often occupies the suprasternal space (p. 804).

LYMPHATIC DRAINAGE OF DEEP TISSUES OF HEAD AND NECK

Tissues of the head and neck internal to the deep fascia drain to the deep cervical nodes directly or through outlying groups which include, in addition to those named above: the retropharyngeal, paratracheal, lingual, infrahyoid, prelaryngeal and pretracheal groups.

Retropharyngeal nodes. These comprise a median and two lateral groups, the latter anterior to the lateral atlantal masses along the lateral borders of the longi capitis. All lie between the pharyngeal and prevertebral fasciae, receiving afferents from the nasopharynx, pharyngotympanic tube and atlanto-occipital and atlanto-axial joints. They drain to the upper deep cervical nodes.

Paratracheal nodes. They flank both trachea and oesophagus along the recurrent laryngeal nerves. Efferents pass to the corresponding deep cervical nodes.

Infrahyoid, prelaryngeal and pretracheal nodes. Found beneath the deep cervical fascia, they drain afferents from the anterior cervical nodes, their efferents joining the deep cervical nodes. The infrahyoid nodes are anterior to the thyrohyoid membrane, prelaryngeal on the conus elasticus and cricovocal membrane, pretracheal anterior to the trachea near the inferior thyroid veins.

Lingual nodes. Small and inconstant, they are situated on the external surface of hyoglossus and also between the genioglossi. They drain to the upper deep cervical nodes.

Lymphatic drainage of nasal cavity, nasopharynx and middle ear

Lymphatics of the nasal cavity can be injected from the subarachnoid space, via communications along the olfactory nerves. Lymph vessels from its anterior region pass superficially to join those of the external nasal skin, ending in the submandibular nodes. The rest of the cavity, paranasal sinuses, nasopharynx and pharyngeal end of the auditory tube drain to the upper deep cervical nodes, directly or through the retropharyngeal nodes. The posterior nasal floor probably drains to the parotid nodes.

Lymphatic vessels of the tympanic and antral mucosae drain to the parotid or upper deep cervical lymph nodes; vessels of the tympanic end of the auditory tube probably end in the deep cervical nodes; its vessels have been identified in the submucosa by injection and electron microscopy (Pulec et al 1975).

Lymphatic drainage of larynx, trachea and thyroid gland

Laryngeal lymphatic vessels form superior and inferior groups; on the lateral wall they are distinct, their division being at the level of the vocal fold; the two sets anastomose on the posterior wall. Superior vessels pierce the thyrohyoid membrane to accompany the superior laryngeal vessels, ending in the superior deep cervical nodes; inferior vessels pass between the cricoid cartilage and the first tracheal ring to the inferior deep cervical lymph nodes, or pierce the cricovocal membrane to reach the pretracheal and prelaryngeal nodes.

A dense network of lymph vessels exists in the tracheal wall; its cervical part drains to the pretracheal and paratracheal nodes, or directly to the inferior deep cervical nodes.

Thyroid lymphatic vessels communicate with the tracheal plexus, passing to the prelaryngeal nodes just above the thyroid isthmus and to the pretracheal and paratracheal nodes; some may drain into the brachiocephalic nodes, related to the thymus in the superior mediastinum. Laterally, the gland is drained by vessels along the superior thyroid veins to the deep cervical nodes. Some thyroid lymphatics may drain directly, with no intervening node, to the thoracic duct (p. 1609).

Lymphatic drainage of mouth, teeth, tonsil and tongue

Mouth. Gingival vessels drain to the submandibular nodes; those of the hard palate continue anteriorly into the superior gingival channels but also run back to pierce the superior constrictor, ending in the superior deep cervical and retropharyngeal nodes; from the soft palate they pass posterolaterally partly to the retropharyngeal, partly to the superior deep cervical nodes. The anterior part of the floor of the mouth drains to the lower nodes of the upper deep cervical group, either directly or via the submental nodes; vessels from the remainder of the floor drain to the submandibular and superior deep cervical nodes.

Teeth. Dental lymphatics pass to the submandibular and deep cervical nodes.

Tonsil. Vessels from the tonsil pierce the buccopharyngeal fascia and superior constrictor to pass between the stylohyoid muscle and the internal jugular vein to the superior deep cervical nodes. Most end in the jugulodigastric nodes; occasionally one or two vessels run to the small nodes on the lateral aspect of the internal jugular vein, deep or medial to sternocleidomastoid.

Tongue (10.189). A lymphatic plexus in the lingual mucosa is continuous with an intramuscular plexus. The anterior lingual region drains into the marginal and central vessels and behind the vallate papillae into the dorsal lymph vessels.

Vessels. These are divided into marginal, central and dorsal.

Marginal vessels. They come from the lingual apex and frenular region and descend under the mucosa to widely distributed nodes:

- Some pierce the mylohyoid in contact with the mandibular periosteum to enter the submental nodes and also pass anterior to the hyoid bone to the jugulo-omohyoid node. Vessels arising in the plexus on one side may cross under the frenulum to end in the contralateral nodes; efferent vessels of submental nodes, which are median, pass to both sides.
- Some vessels pierce the mylohyoid to enter the anterior or middle submandibular node.
- Some pass inferior to the sublingual gland and, accompanying the companion vein of the hypoglossal nerve, end in jugulodigastric nodes; one often descends further, superficial or deep to the intermediate tendon of the digastric, to reach the jugulo-omohyoid node.
- Some vessels from the lateral lingual margin cross the sublingual gland, pierce the mylohyoid and end in the submandibular nodes; others end in the jugulodigastric or jugulo-omohyoid nodes. Vessels from the posterior part of the lingual margin traverse the pharyngeal wall to the jugulodigastric lymph nodes.

Central vessels. The regions of the lingual surface draining into the marginal or central vessels are not distinct. Central vessels descend between the genioglossi, some turning laterally through the muscles; but most pass between them and diverge to the right or left, following the lingual veins to the deep cervical nodes, especially the jugulodigastric and jugulo-omohyoid. Some pierce the mylohyoid to enter the submandibular nodes.

Dorsal vessels. Vessels draining the region of the vallate papillae and behind them run postero-inferiorly, some near the median plane to both sides. They turn laterally to join the marginal vessels; all pierce the pharyngeal wall, passing around the external carotid arteries to reach the jugulodigastric and jugulo-omohyoid lymph nodes. One may descend posterior to the hyoid bone, perforating the thyrohyoid membrane to end in the jugulo-omohyoid node.

Lymphatic drainage of pharynx and cervical part of the oesophagus

Collecting vessels from the pharynx and cervical oesophagus pass to the deep cervical nodes, either directly or through the retropharyngeal or paratracheal nodes. From the epiglottic region lymph vessels run to the infrahyoid nodes.

LYMPHATIC DRAINAGE OF UPPER LIMBS

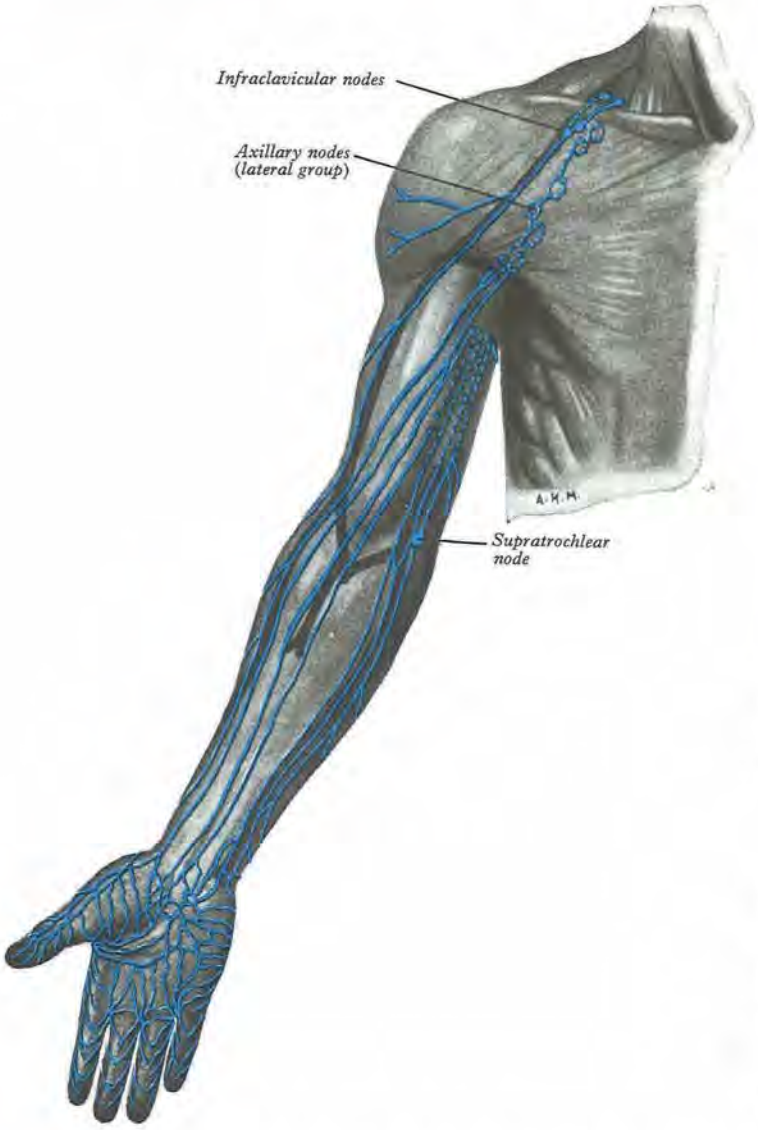
All lymphatic vessels from the upper limb (and superficial tissues of a wide area of the side of the trunk) drain to the axillary nodes, either directly or (a few) through a more peripheral group. Vessels internal to the deep fascia follow the principal vascular bundles; superficial vessels, except in the hand and dorsum of the forearm, converge towards the superficial veins, which they accompany.

Axillary nodes

Axillary nodes drain the whole upper limb and areas of the trunk indicated, are large, vary from 20 to 30 in number, and may be divided into five not wholly distinct groups (**10.191, 193**). Four of these groups are intermediary; only the apical group is terminal.

(1) A *lateral group* (**10.190, 191, 193**) of four to six nodes is posteromedial to the axillary vein, its afferents draining the whole limb except the vessels accompanying the cephalic vein. Efferent vessels pass partly to the central and apical axillary groups, partly to the inferior deep cervical nodes.

(2) An *anterior* or *pectoral group* of four or five nodes spreads along the inferior border of pectoralis minor near the lateral thoracic



10.190 The lymphatic drainage of the superficial tissues of the upper limb: anterior aspect (semi-diagrammatic).

10.191 Normal axillary lymphangiogram, four days after injection of ultrafluid lipiodol into a lymph vessel on the dorsum of the hand. 1 = lateral group of lymph nodes; 2 = pectoral group of lymph nodes; 3 = brachial lymph vessels. (Supplied by J B Kinmonth.)

vessels. Its afferents drain the skin and muscles of the supra-umbilical anterolateral body wall and mammary gland (centrolateral part, p. 1615); efferents pass partly to the central and partly to the apical axillary nodes.

(3) A *posterior* or *subscapular group* of six or seven nodes is deployed on the posterior axillary wall's inferior margin, along the subscapular vessels. Afferents drain the skin and superficial muscles of the inferior posterior region of the neck and the dorsal aspect of the trunk down to the iliac crest; efferents pass to the apical and central axillary nodes.

(4) A *central group* of three or four large nodes embedded in axillary fat receives afferents from all preceding groups: its efferents drain to the apical nodes.

(5) An *apical group* of six to twelve nodes is partly posterior to the superior part of pectoralis minor and partly above its superior border, extending to the axilla's apex medial to the axillary vein. The only direct territorial afferents are those with the cephalic vein and some draining the mammary gland (upper peripheral region); but the group drains all other axillary nodes. Its efferents unite as the subclavian trunk, draining directly to the jugulosubclavian venous junction, the subclavian vein, or to the jugular lymphatic trunk or on occasion to a right lymphatic duct; the left trunk usually ends in the thoracic duct. A few efferents from apical nodes usually reach the inferior deep cervical nodes.

Extra-axillary outlying groups in the upper limb are few, comprising: supratrochlear, infraclavicular (both interposed in superficial routes) and isolated nodes occasionally appearing along principal blood vessels.

(1) *Supratrochlear nodes*, only one or two, are superficial to the deep fascia proximal to the medial epicondyle and medial to the basilic vein; their efferents accompany the vein to join the deep lymph vessels.

(2) *Infraclavicular nodes* appear beside the cephalic vein, one or two in the groove between the pectoralis major and deltoid, just inferior to the clavicle; efferents pass through the clavipectoral fascia to apical axillary nodes; more rarely some pass anterior to the clavicle to reach the inferior deep cervical (supraclavicular) nodes.

(3) Small isolated nodes sometimes occur along the radial, ulnar and interosseous vessels, in the cubital fossa near the bifurcation of the brachial artery, or in the arm medial to the brachial vessels.

Lymphatic drainage of superficial tissues

Superficial lymphatic vessels in the upper limb begin in the cutaneous plexuses. In the hand, the palmar plexus is denser. Digital plexuses are drained along the digital borders to their webs, where they join the distal palmar vessels which pass back to the hand's dorsal aspect (**10**.190, 192). The proximal palm drains towards the carpus, medially by vessels along its ulnar border and laterally to join those of the thumb. Several vessels from the central palmar plexus form a trunk winding round the second metacarpal bone to join the dorsal vessels from the index and thumb. In the forearm and arm, superficial vessels run with superficial veins. Collecting vessels from the hand pass into the forearm on all carpal aspects. Dorsal vessels, after running proximally in parallel, curve successively round the borders of the limb to join the ventral vessels (**10**.192). Anterior carpal vessels traverse the forearm parallel with the median vein of the forearm to the cubital region, proximal to which they follow the medial border of the biceps, then pierce the deep fascia at the anterior axillary fold and end in the lateral axillary lymph nodes.

Vessels which are lateral in the forearm follow the cephalic vein

to the level of the tendon of the deltoid, where most incline medially to reach the lateral axillary nodes; a few, however, continue with the vein to the infraclavicular nodes. These lateral vessels receive those curving round the lateral border from the limb's dorsal aspect. Vessels which are medial in the forearm follow the basilic vein. Proximal to the elbow some end in supratrochlear lymph nodes, whose efferents, with the medial vessels which have bypassed them, pierce the deep fascia with the basilic vein to end in the lateral axillary nodes or deep lymphatic vessels. They are joined by vessels curving round the medial border of the limb.

Collecting vessels from the deltoid region pass round the anterior and posterior axillary fold to end in the axillary nodes. The scapular skin drains either to subscapular axillary nodes or by channels following the transverse cervical vessels to the inferior deep cervical nodes.

Lymphatic drainage of deep tissues of upper limb

Deep lymph vessels follow the main neurovascular bundles (radial, ulnar, interosseous and brachial) to the lateral axillary nodes. They are less numerous than the superficial vessels, communicating with them at intervals. A few lymph nodes occur along them. Scapular muscles drain mainly to the subscapular axillary nodes and pectoral muscles to the pectoral, central and apical nodes.

Mammary lymphatic drainage

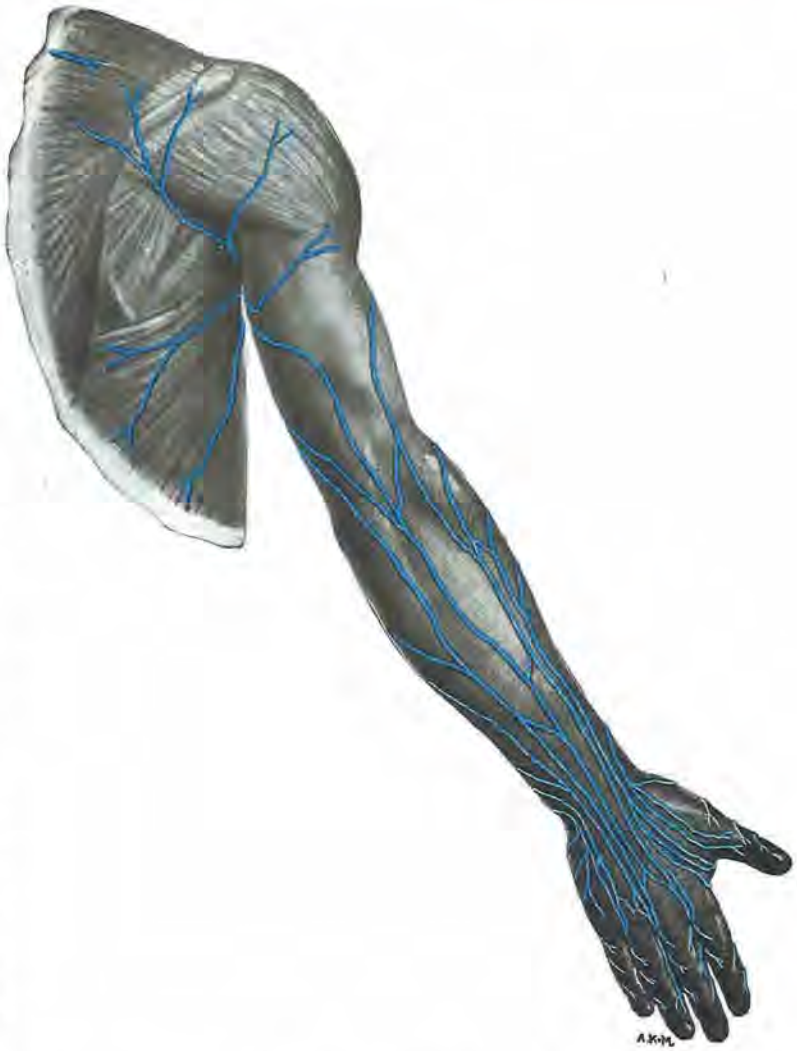
Lymph vessels of the mammary gland start in a plexus in the interlobular connective tissue and walls of the lactiferous ducts, communicating with a cutaneous subareolar plexus around the nipple (**10.193**). The gland is also said to connect with a plexus of minute vessels on the subjacent deep fascia; this connection plays little part in normal lymphatic drainage nor in early spread of carcinoma (Turner-Warwick 1959). It offers an alternative route when the usual pathways are obstructed. Efferent vessels directly from the gland pass round the anterior axillary border through the axillary fascia to the pectoral lymph nodes; some may pass directly to the subscapular nodes. From the gland's superior region a few vessels pass to the apical axillary nodes, sometimes interrupted in the infraclavicular nodes or in small, inconstant interpectoral nodes. Axillary nodes receive more than 75% of lymph from the gland, the remainder largely draining to parasternal nodes from the medial and lateral parts of the organ; these vessels accompany perforating branches of the internal thoracic artery. Lymphatic vessels occasionally follow lateral cutaneous branches of the posterior intercostal arteries to the intercostal nodes. Cutaneous lymphatic drainage is described on page 1624.

Clinical anatomy

Enlargement of the axillary nodes is frequent in malignant disease and infective processes affecting the upper back and shoulder, the front of the chest and mammary gland, upper anterolateral abdominal wall or upper limb (palpation, see p. 1607). In operations for mammary carcinoma, pectoralis major, its deep fascia and surrounding muscles are usually removed en bloc because of the wide ramifications of its lymphatics. Axillary nodes, the sternocostal head of pectoralis major and frequently pectoralis minor are also removed, to ensure complete removal of the affected lymphatics and nodes. (Some surgeons, relying on more effective diagnostic techniques, now advocate less radical extirpation.)

LYMPHATIC DRAINAGE OF LOWER LIMBS

Most lymph from the lower limb traverses a large intermediary inguinal group of nodes; some may first traverse a few more peripheral intermediary nodes, however, these are less numerous in the lower limb than elsewhere. The inguinal nodes are superficial and deep to the deep fascia. Although commonly stated as such, the inguinal nodes are not the terminal group for the lower limb; from them the lymph traverses the external and common iliac groups, followed by the lateral aortic group. Deep gluteal lymph reaches the same group through the internal and common iliac chains. The upper lateral aortic nodes are terminal, forming bilateral lumbar trunks which discharge lymph into the confluence of trunks (p. 1611) and thence the thoracic duct.



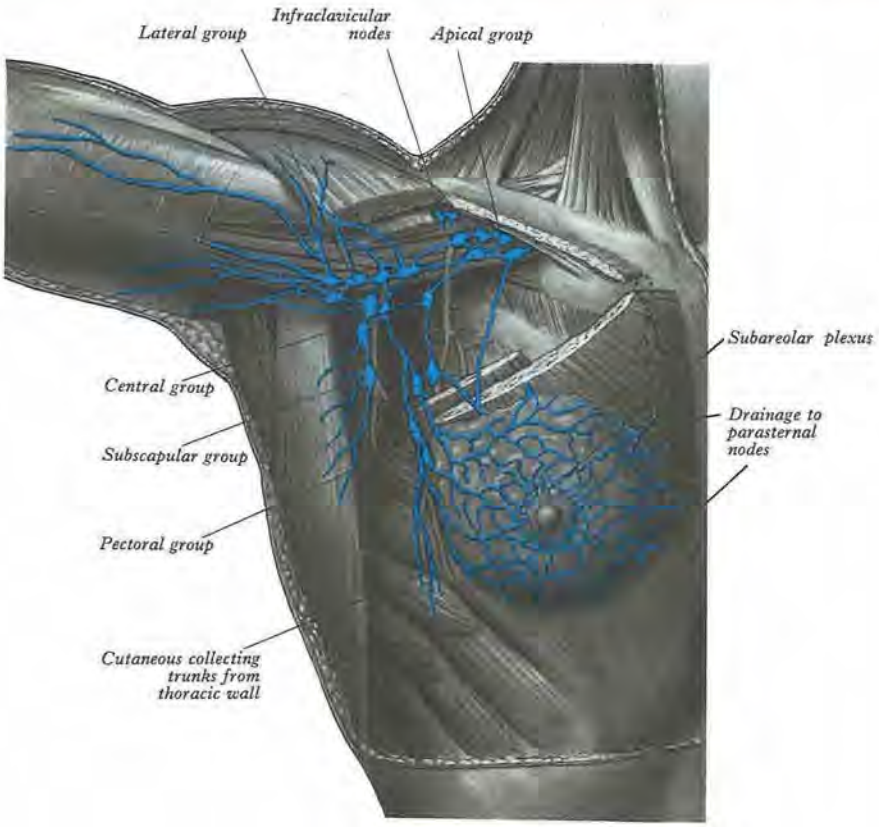
10.192 The lymphatic drainage of the superficial tissues of the upper limb: posterior aspect (semi-diagrammatic).

Superficial inguinal nodes

The superficial inguinal nodes form proximal and distal groups (**10.194A**, 195–197). The proximal is usually of five or six nodes just distal to the inguinal ligament. Its lateral members receive afferent vessels from the gluteal region and adjoining infra-umbilical anterior abdominal wall. Medial members receive superficial vessels from: the external genitalia (including the inferior vagina), inferior anal canal and perianal region, adjoining abdominal wall, umbilicus and the uterine vessels accompanying the round ligament. The distal group, usually four or five, along the termination of the great saphenous vein, receives all superficial vessels of the lower limb, except those from the calf's posterolateral region. All superficial inguinal nodes drain to the external iliac nodes, some via the femoral canal and others anterior or lateral to the femoral vessels. Numerous vessels interconnect individual nodes.

Deep inguinal nodes

The deep inguinal nodes vary from one to three, situated medial to the femoral vein. One is just distal to the saphenofemoral junction, one in the femoral canal; the most proximal one lies laterally in the femoral ring; the middle node is the most inconstant and the proximal node is often absent. All receive deep lymphatics accompanying the femoral vessels, lymph vessels from the glans penis (or clitoris) and



10.193 Lymph vessels of the mammary gland and the axillary lymph nodes.

a few efferents from the superficial inguinal nodes; their own efferents traverse the femoral canal to the external iliac nodes.

Peripheral nodes are few and are all deeply sited. Except for one sometimes proximal on the interosseous membrane near the anterior tibial vessels, they occur only in the popliteal fossa.

Popliteal lymph nodes

The small popliteal lymph nodes, usually six, are embedded in popliteal fat (**10.194B**). One, near the end of the small saphenous vein, drains the superficial region served by the vein. Another is between popliteal artery and posterior aspect of the knee joint, receiving direct vessels from the knee joint and those accompanying the genicular arteries. The remainder flank the popliteal vessels, receiving trunks accompanying the anterior and posterior tibial vessels. Popliteal efferents ascend close to the femoral vessels to reach the deep inguinal nodes but some may accompany the great saphenous vein to the superficial inguinal nodes.

Clinical anatomy. Inflammation of the popliteal nodes is often due to lateral lesions of the heel. Superficial inguinal nodes are frequently enlarged in disease or injury in their region of drainage (palpation, see p. 1607). Thus in malignant or infective disease of the prepuce, penis, labia majora, scrotum, abscess in the perineum, anus and lower vagina or in diseases affecting skin and superficial structures in these regions, or the infra-umbilical part of the abdominal wall, the gluteal region: in all these the proximal inguinal nodes are almost invariably affected, the distal group being implicated only in disease or injury of the limb.

Lymphatic drainage of superficial tissues in lower limbs

The superficial lymph vessels begin in subcutaneous plexuses. Collecting vessels leave the foot medially, along the great saphenous vein and, laterally, with the small saphenous.

Medial vessels are larger, more numerous and begin on the tibial side of the foot's dorsum, some ascending anterior and others posterior to the medial malleolus; thereafter both converge on the great saphenous vein and accompany it to the distal superficial inguinal nodes. *Lateral vessels* begin on the fibular side, some crossing anteriorly in the leg to join the medial vessels and so to the distal superficial inguinal lymph nodes; others accompany the small saphenous vein to the popliteal nodes. Superficial lymph vessels of the gluteal region circle anteriorly to the proximal superficial inguinal nodes.

Lymphatic drainage of deeper tissues in lower limbs

The deep vessels accompany the main blood vessels: anterior and posterior tibial, peroneal, popliteal and femoral. The deep vessels from the foot and leg are interrupted by popliteal nodes; those from the thigh pass to the deep inguinal nodes.

The deep lymph vessels of the gluteal and ischial regions follow their corresponding blood vessels. Those with the former end in a node near the intrapelvic part of the superior gluteal artery, near the superior border of the greater sciatic foramen; those which follow the inferior gluteal vessels traverse one or two of the small nodes below the piriformis and pass to the internal iliac nodes.

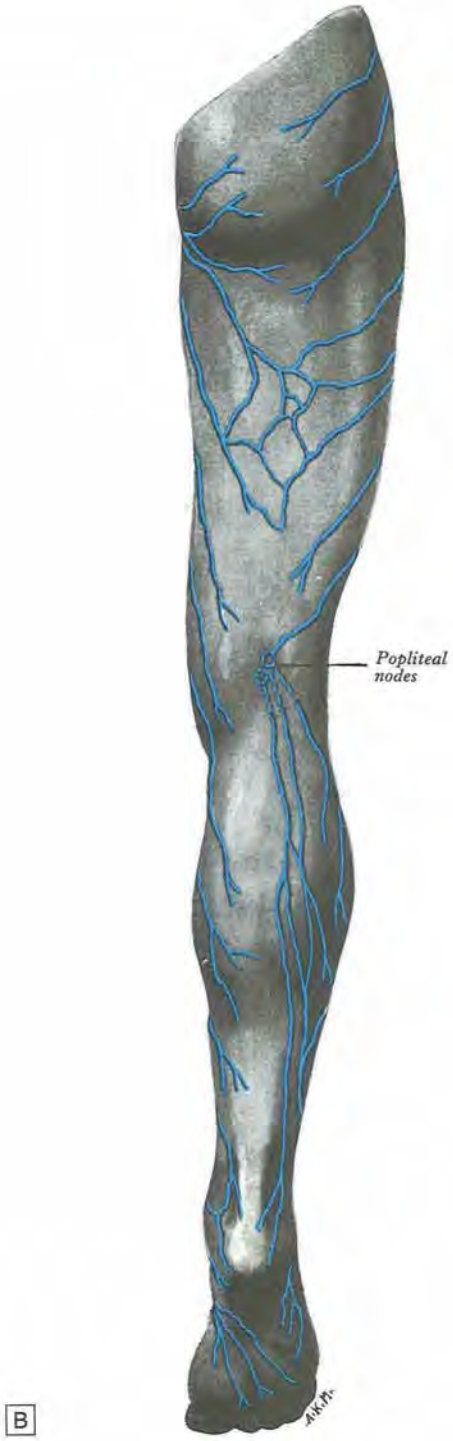
LYMPHATIC DRAINAGE OF ABDOMEN AND PELVIS

Lymph from most of the abdominal wall and all abdominal viscera (except a small hepatic region) is returned via the thoracic duct. Lymphatic vessels run with their corresponding arteries, the lymphatic nodes forming a large number of intermediary groups along the arteries concerned and a few terminal groups near the abdominal aorta. Although referred to as illustrative examples in the introductory paragraphs, they are summarized here with numerous additions.

Lumbar nodes

The lumbar nodes include three terminal groups, each of which although interconnected has its own large area of drainage, a number

10.194A The lymphatic drainage of the superficial tissues of the lower limb: anteromedial aspect (semi-diagrammatic).



10.194B The lymphatic drainage of the superficial tissues of the lower limb: posterior aspect (semi-diagrammatic).

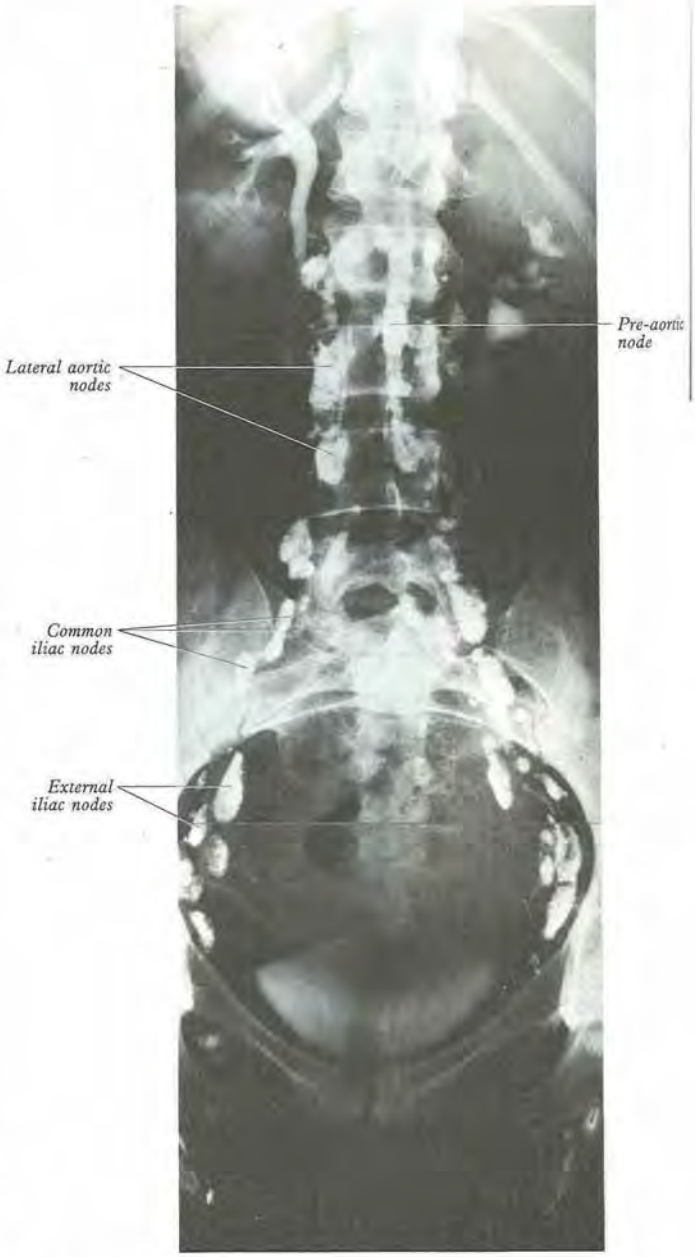
of intermediary groups and one 'subsidiary' group (**10**.196, 197). These groups are pre-aortic, lateral aortic (right and left) and retro-aortic.

The pre-aortic group. It drains viscera supplied by the ventral splanchnic aortic branches, i.e. the abdominal part of the alimentary canal (down to midrectum) and its derivatives.

The lateral aortic groups. They drain viscera and other structures supplied by the lateral splanchnic and dorsolateral somatic aortic branches, receiving efferents from the large intermediary groups associated with the iliac vessels; their upper members are therefore terminal groups for suprarenal glands, kidneys, ureters, testes, ovaries, pelvic viscera (apart from the gut) and the deeper tissues of the posterior abdominal wall, the full thickness of the subumbilical abdominal, pelvic and perineal walls and the whole of the lower limbs.

The retroaortic group. This has no special area of drainage; though it may have been primarily associated with drainage of the posterior abdominal wall, it may be regarded as comprising peripheral nodes of the lateral aortic groups and interconnecting surrounding groups.

10.195 Lymphangiogram showing the inguinal lymph vessels and nodes taken immediately following injection of ultrafluid lipiodol into a lymph vessel on the dorsum of the foot. 1. Inguinal lymph nodes. 2. External iliac lymph node. (Supplied by J B Kinmonth.)



10.196 Lymphangiogram showing the lateral aortic and proximal iliac lymph nodes, approximately 24 hours after the injection of lipiodol into a lymphatic vessel on the dorsum of each foot. Intravenous contrast was given to show the kidneys and ureters. (Supplied and photographed as in **10**.191.)

PRE-AORTIC LYMPH NODES

Pre-aortic lymph nodes are anterior to the abdominal aorta; they receive lymph from the regional nodes associated with the subdiaphragmatic part of the alimentary canal, pancreas, liver and spleen. Their cranial efferents form intestinal trunks entering the abdominal confluence of lymph trunks (p. 839). They are divisible into coeliac, superior mesenteric and inferior mesenteric groups, being near the origins of these arteries.

In the alimentary canal, lymph vessels begin as minute subepithelial radicles, blind at one end and opening into a *periglandular plexus.* In the small intestine each villus has a central vessel, known as a *lacteal* from its milky appearance. From the periglandular plexuses vessels pierce the muscularis mucosae to join a submucosal plexus, efferents from which traverse the muscularis, where they connect with or bypass the vessels draining it. The submucosal plexus is also joined by vessels from the lymph spaces at the bases of solitary lymphatic follicles. Lymphatics of intestinal muscle drain into a plexus mainly between the longitudinal and circular layers. Collecting vessels leave the gut through the muscle to enter the larger vessels following their mesenteric arteries. Collecting vessels from the alimentary canal pass through local nodes before reaching the pre-aortic group.

Coeliac nodes

Coeliac nodes lie anterior to the abdominal aorta around the origin of the coeliac artery. They are a terminal group, their efferents forming right and left intestinal lymph trunks. Their afferents are from the regional nodes along branches of the coeliac artery, forming three main groups: gastric, hepatic and pancreaticosplenic; and they also come from the lower pre-aortic groups.

Gastric nodes (**10**.198, 199)**.** They comprise the left gastric, right gastro-epiploic and pyloric groups. *Left gastric nodes*, along the left gastric artery, are divisible into subgroups: **superior** on the artery's

stem and **inferior** with descending branches along the cardiac half of the lesser curvature in the lesser omentum and paracardial, a chain around the cardiac orifice. They receive lymph both from the stomach and the abdominal part of the oesophagus; their efferents pass to the coeliac group of pre-aortic nodes. *Right gastro-epiploic lymph nodes*, four to seven, lying in the greater omentum along the pyloric half of the greater curvature, receive afferents from the stomach; their efferents mostly pass to the *pyloric* nodes. Four or five pyloric lymph nodes are near the gastroduodenal artery's bifurcation, in the angle between the superior and the descending parts of the duodenum; an outlying node is sometimes sited above the duodenum near the right gastric artery. These nodes drain the pyloric part of the stomach, the first part of the duodenum and finally the right gastro-epiploic nodes; their efferents end in coeliac nodes.

Hepatic nodes (10.198). These extend in the lesser omentum along the hepatic arteries and bile duct. They vary in number and site but almost constant are: one at the junction of the cystic and common hepatic ducts, the cystic node; and another alongside the upper bile duct, the node of the anterior border of the epiploic foramen. Hepatic nodes drain the stomach, duodenum, liver, gallbladder, bile ducts and pancreas; they drain to the coeliac nodes and thence to the intestinal trunks. Enlarged hepatic nodes may press on and obstruct the portal vein.

Pancreaticosplenic nodes (10.199). They accompany the splenic artery, near the posterior surface and superior border of the pancreas; one or two are in the gastrosplenic ligament. Their afferents are from the stomach, spleen and pancreas; their afferents join the coeliac nodes.

Lymphatic drainage of stomach and duodenum. Gastric lymphatics (**10.198, 199**) are continuous at the cardiac orifice with the oesophageal vessels and at the pylorus with the duodenal channels. They largely follow blood vessels and form four groups: vessels of the first group accompany branches of the left gastric artery, receive from a large area on both gastric surfaces and end in the left gastric lymph nodes; a second group drains the gastric fundus and body left of a vertical from the oesophagus, accompanying the short gastric and left gastro-epiploic vessels to end in the pancreaticosplenic nodes; the third group drains the right half of the greater curvature as far as the pylorus, ending in the right gastro-epiploic nodes which drain to pyloric nodes; the fourth group drains the pyloric part of the stomach and drains to the hepatic, pyloric and left gastric nodes. Although these vessels communicate, their valves direct lymph from the right part of the stomach to the lesser curvature and from the left part to the greater curvature.

Duodenal lymphatics run anteriorly and posteriorly into the small pyloric lymph nodes, lying in the anterior and posterior grooves between the pancreatic head and the duodenum. They drain up to the hepatic and down to the pre-aortic nodes around the origin of the superior mesenteric artery.

Lymphatic drainage of liver. Hepatic collecting vessels are divisible into superficial and deep systems.

Superficial hepatic vessels. These run in subserosal areolar tissue over the whole surface of the organ, draining in four directions:

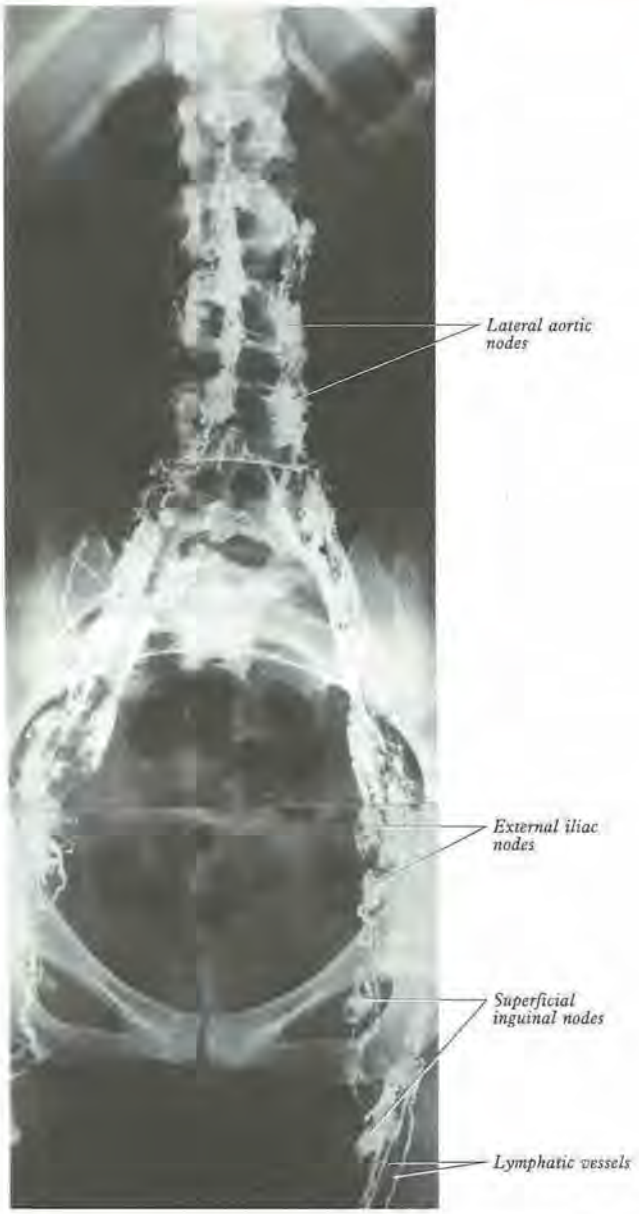
(1) From the middle part of its posterior surface, the caudate lobe, the posterior part of the convex surfaces of both lobes near the hepatic attachment of the falciform ligament, the posterior part of the inferior surface of the right lobe, vessels accompany the inferior vena cava to nodes around its terminal part. Vessels in the coronary and right triangular ligaments may directly enter the thoracic duct without any intervening node.

(2) Vessels from the rest of the inferior surface and anterior part of the convex surfaces of both lobes near the attachment of the falciform ligament all converge to the porta hepatis to end in the hepatic nodes.

(3) From the posterior region of the left lobe a few vessels pass towards the oesophageal opening to end in the paracardial nodes.

(4) From the remaining convex surface of the right lobe one or two trunks accompany the inferior phrenic artery across the right crus to the coeliac nodes.

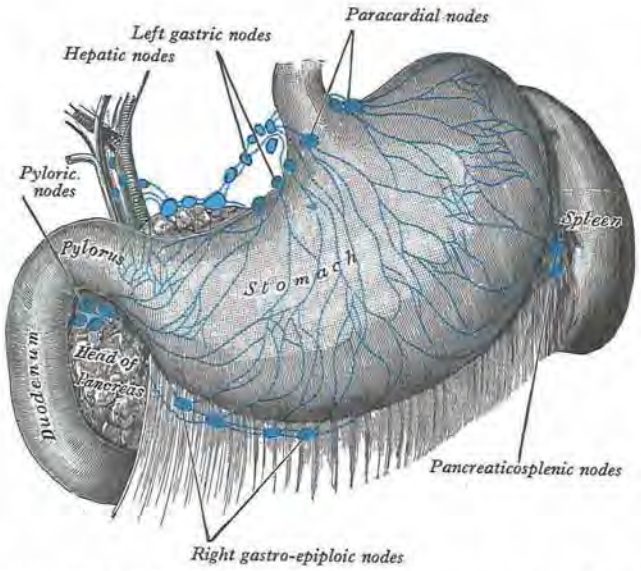
Deep hepatic lymphatics. They form the ascending and descending trunks; the ascending trunks accompany the hepatic veins and pass through the vena caval opening to end in the nodes round the end of the inferior vena cava; the descending trunks emerge from the porta hepatis to end in the hepatic nodes (p. 1802).



10.197 Lymphangiogram showing the lymphatic vessels and nodes of the iliac and lateral aortic regions taken approximately 3 hours after the injection of lipiodol into a lymphatic vessel on the dorsum of each foot. (Supplied by G I Verney, Addenbrooke's Hospital, Cambridge; photographs prepared by Sarah Smith and K Fitzpatrick, Guy's Hospital.)

Lymphatic drainage of gallbladder and bile ducts. Numerous vessels run from the submucosal and subserosal plexuses on all aspects of the gallbladder and cystic duct, those on the former's hepatic aspect connecting sparsely with the hepatic vessels. They pass to the hepatic nodes, especially the cystic node and node of the anterior epiploic border (see above). Hepatic nodes also collect from vessels accompanying the hepatic ducts and the upper part of the bile duct, those of its lower part draining into the inferior hepatic and upper pancreaticosplenic nodes.

Lymphatic drainage of pancreas. Lymph capillaries commence around the acini and their continuations, following the blood vessels; there are no lymphatics in the pancreatic islets. Most vessels end in the pancreaticosplenic nodes, some in nodes along the pancreaticoduodenal vessels and others in the superior mesenteric preaortic nodes.



10.198 The lymphatic drainage of the stomach and duodenum. (After Jamieson & Dobson.)

Lymphatic drainage of spleen. Collecting vessels from the capsule end in the pancreaticosplenic lymph nodes.

Superior and inferior mesenteric nodes

Located anterior to the aorta near the origins of these arteries, the superior and inferior mesenteric nodes are preterminal groups for the alimentary canal from the duodenojejunal flexure to the upper anal canal and collect from outlying groups, including the mesenteric, ileocolic, colonic and pararectal nodes. They discharge into the coeliac nodes and thence intestinal trunks, confluence and thoracic duct.

Mesenteric nodes. Numbering 100–150, the mesenteric nodes comprise three series: one close to the intestinal wall among the terminal rami of the jejunal and ileal arteries (mural); a second is among the loops and primary branches of the vessels (intermediate); and a third is along the upper trunk of the superior mesenteric artery (juxta-arterial). Vessels from the terminal centimetres of the ileum follow the ileal branch of the ileocolic artery to the ileocolic nodes.

Clinical anatomy. Enlargement of the mesenteric nodes occurs in many intestinal diseases, especially typhoid fever, tuberculous ulceration and malignant tumours. Enlarged nodes can often be palpated through the abdominal wall.

Ileocolic nodes (10.200, 201). They form a chain of 10–20 around the ileocolic artery but tend to form two groups: near the duodenum and along the artery's terminal part. The chain divides with the artery, into:

- *ileal nodes* close to the ileal branch;
- *anterior ileocolic nodes* (usually 3) in the ileocaecal fold, near the caecal wall;
- *posterior ileocolic nodes*, mostly in the angle between ileum and colon but partly behind the caecum at its junction with the ascending colon;
- an *appendicular node* in the mesoappendix.

Colic nodes. They form four groups: epicolic, paracolic, intermediate colic and preterminal colic.

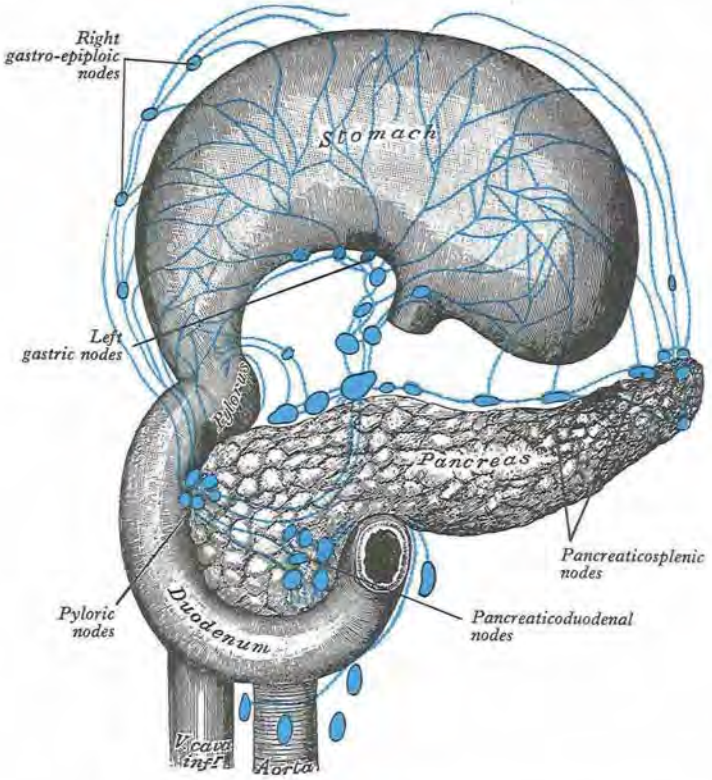
Epicolic nodes. They are merely minute nodules on the colonic wall, sometimes in the appendices epiploicae.

Paracolic nodes. These lie along the medial borders of the ascending and descending colon and along the mesenteric borders of the transverse and sigmoid colon.

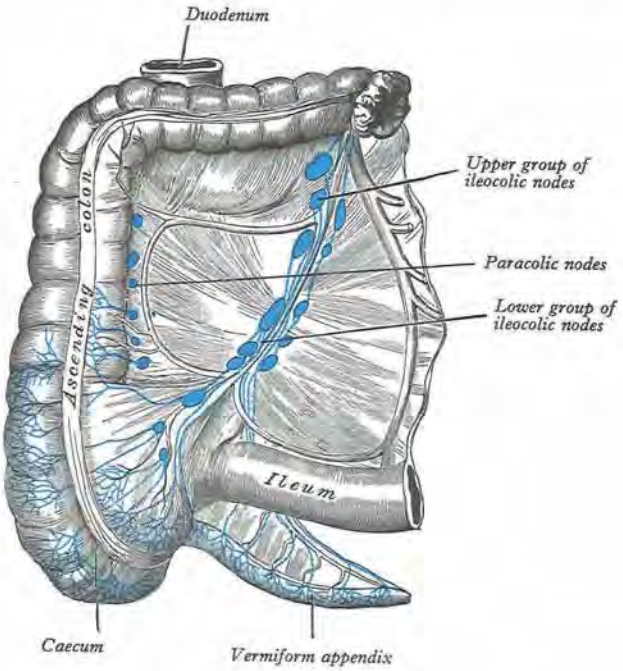
Intermediate colic nodes. They lie along the right, middle and left colic arteries.

Preterminal colic nodes. Adjoining the main trunks of the superior and inferior mesenteric arteries, they are near their corresponding pre-aortic nodes.

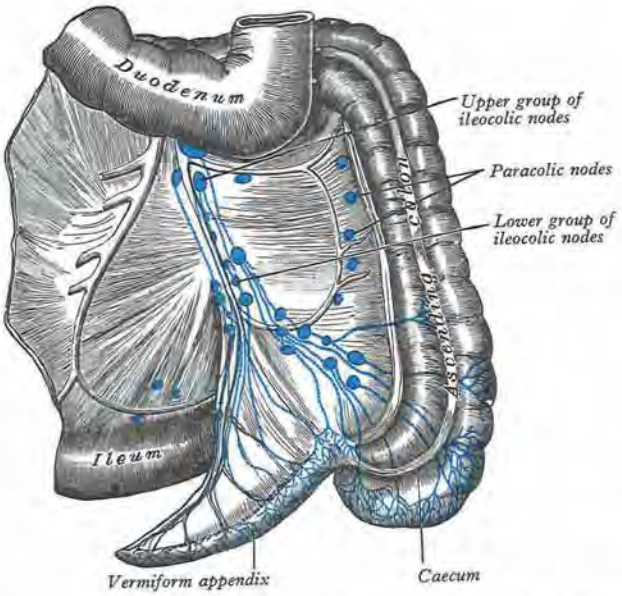
Pararectal nodes. These nodes, in contact with the rectal muscular wall, drain to an intermediate group around the superior rectal artery and thence to nodes near the origin of the inferior mesenteric. Others drain to nodes at the bifurcation of the common iliac artery.



10.199 The lymph vessels and nodes of the stomach, duodenum and pancreas. The stomach has been turned upwards. (After Jamieson & Dobson.)



10.200 The lymph vessels and nodes of the caecum and vermiform appendix: anterior aspect. (After Jamieson & Dobson.)



10.201 The lymph vessels and nodes of the caecum and vermiform appendix: posterior aspect. (After Jamieson & Dobson.)

Lymphatic drainage of jejunum and ileum. Lacteals pass between layers of the mesentery but, before reaching the superior mesenteric nodes, the lymph traverses the mesenteric nodes.

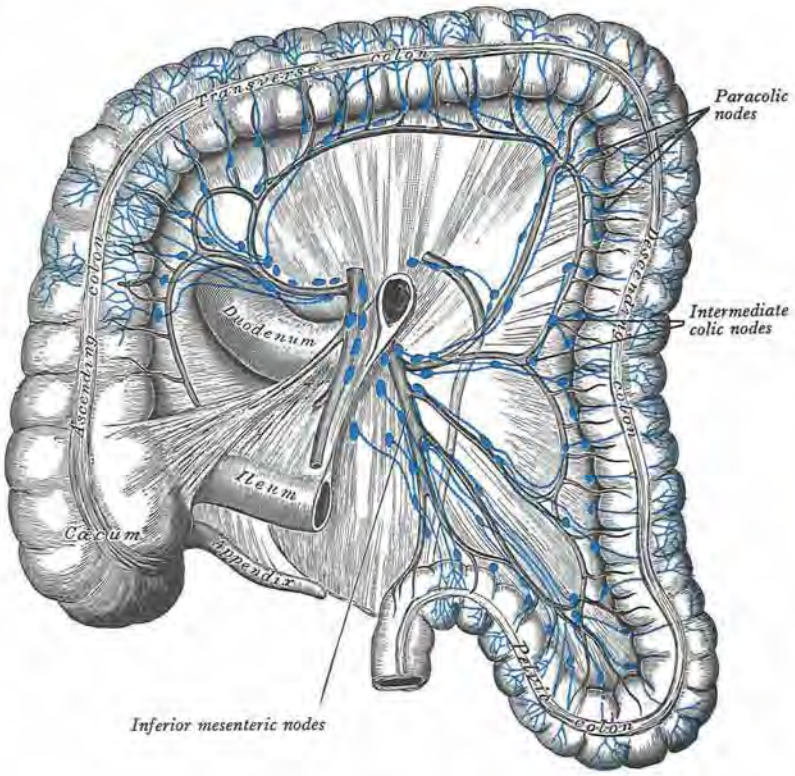
Lymphatic drainage of vermiform appendix and caecum (10.200, 201). Lymphatic vessels are numerous, since lymphoid tissue abounds in their walls. From the body and apex of the appendix 8–15 vessels ascend in the mesoappendix, a few interrupted by one or more nodes in it. They unite to form three or four larger vessels, ending in the inferior and superior nodes of the ileocolic chain. Vessels from the root of the appendix and caecum are anterior and posterior. Anterior vessels pass in front of the caecum to the anterior ileocolic nodes and nodes of the ileocolic chain; posterior vessels ascend behind the caecum to the posterior and inferior ileocolic nodes.

Lymphatic drainage of colon (10.200–203). Lymphatic vessels of ascending and transverse parts of the colon end in the superior mesenteric nodes, after traversing nodes along the right and middle colic arteries and their branches. Those of the descending and sigmoid parts are interrupted by small nodes on branches of the left colic arteries, ending in the pre-aortic nodes around the origin of the inferior mesenteric artery.

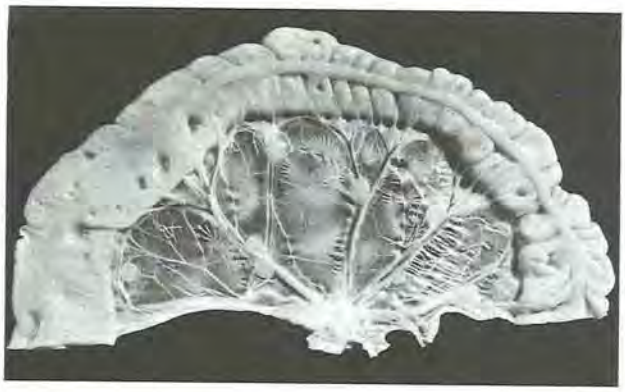
Lymphatic drainage of rectum and anal canal. From the upper half, or more, of the rectum vessels emerge from its wall to ascend with the superior rectal vessels through the pararectal nodes to nodes in the lower sigmoid mesocolon and along the inferior mesenteric artery. From the lower half of the rectum and the anal canal, above its mucocutaneous junction, lymph vessels ascend through the wall to accompany the middle rectal vessels to the internal iliac nodes. Some are said to traverse the levator ani into the ischiorectal fossa, to accompany the inferior rectal and internal pudendal vessels to the internal iliac nodes. Lymphatics of the anal canal below the mucocutaneous junction descend to the anal margin, curving laterally to reach the most medial superficial inguinal nodes.

LATERAL AORTIC NODES

The lateral aortic nodes flank the abdominal aorta anterior to the medial margins of the psoas major muscles, diaphragmatic crura and sympathetic trunks (10.196, 197). On the right, some are lateral to the inferior vena cava and anterior to it near the end of the right renal vein. Afferents reach these nodes from structures supplied by the lateral splanchnic and dorsolateral somatic aortic branches and from outlying nodes near the iliac arteries and their branches. Efferents form a *lumbar trunk* on each side, both terminating in the confluence of lymph trunks (occasionally a cisterna chyli, p. 1610); a few may pass to the pre-aortic and retro-aortic nodes. Some of the efferents of the right lumbar lymph trunk and its nodes may



10.202 The lymph vessels and nodes of the colon. (After Jamieson & Dobson.)



10.203 Preparation of the human colon and mesocolon displaying arterial arcades, neurovascular bundles, lymphatics and paracolic and intermediate lymph nodes. (Provided by S Kubic, University of Zürich.)

cross to their left counterparts; or both trunks may divide forming a loose plexus.

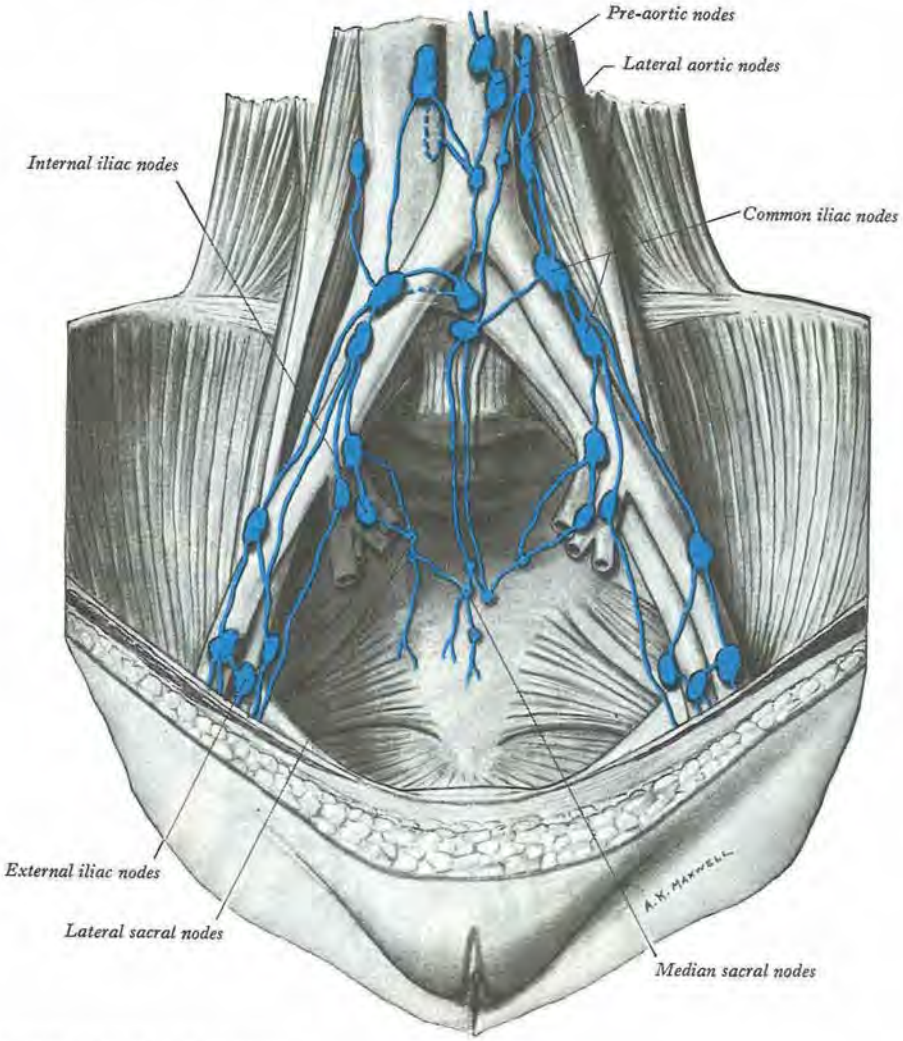
Lymphatic vessels from the kidney, suprarenal gland, abdominal ureter, posterior abdominal wall, testis and ovary, uterine tube and upper part of the uterus all pass directly to the lateral aortic nodes. Lymphatics from the pelvis, most pelvic viscera and the anterolateral abdominal wall pass first to regional nodes largely related to the internal iliac arteries and their branches. These include the following groups: common, external, internal and circumflex iliac, inferior epigastric and sacral. It must also be emphasized that the external iliac group receives the efferents from the inguinal nodes and the internal iliac group receives deep gluteal lymph; thus the lateral aortic groups ultimately drain the whole of both lower limbs.

Common iliac nodes. The 4–6 nodes are grouped around the artery, one or two inferior to the aortic bifurcation and anterior to the fifth lumbar vertebra or sacral promontory (**10.204**). They drain the external and internal iliac nodes and send efferents to the lateral aortic nodes. They are usually in medial, lateral and intermediate (anterior) chains, the lateral being the main route.

External iliac nodes (10.196, 197, 204). These 8–10 nodes usually form three subgroups, lateral, medial and anterior to the external iliac vessels; the anterior is inconstant. The medial nodes are considered the main channel of drainage, collecting from: the *inguinal nodes* (p. 1615), the deeper layers of the infra-umbilical abdominal wall, the adductor region of the thigh, the glans penis or clitoris, the membranous urethra, prostate, vesical fundus, cervix uteri and upper vagina. Their efferents pass to the common iliac nodes.

Inferior epigastric and circumflex iliac nodes. They are associated with their vessels and drain the corresponding areas, being outlying members of the external iliac group and inconstant in number.

Internal iliac nodes (10.204–206). Surrounding the vessels, they receive afferents from all the pelvic viscera, deeper parts of the perineum and gluteal and posterior femoral muscles. Efferents pass to the common iliac nodes.



10.204 The lymph vessels and nodes of the pelvis.

Sacral nodes. Found along the median and lateral sacral vessels and an obturator node, sometimes occurring in the obturator canal, they are outlying members of the internal iliac group. There is considerable bypassing in the iliac groups of lymph nodes. Lymphangiographic studies have demonstrated the connections between the right and left groups.

Lymphatic drainage of urinary tract

Renal. Renal lymphatic vessels begin in three plexuses: one around the renal tubules, a second under the renal capsule and a third in the perirenal fat connecting freely with the second plexus. Collecting vessels from the intrarenal plexus form four or five trunks following the renal vein to end in the lateral aortic nodes; as they leave the hilum they are joined by the subcapsular collecting vessels. The perirenal plexus drains directly into the same nodes.

Ureteric. Vessels begin in submucosal, intramuscular and adventitial plexuses which intercommunicate. Collecting vessels from the upper ureter may join the renal collecting vessels or pass directly to the lateral aortic nodes near the origin of the gonadal artery; those from its lower abdominal part go to the common iliac nodes; those from its pelvic part end in the common, external or internal iliac nodes.

Vesical. Lymphatics (10.205) begin in the mucosal, intermuscular and serosal plexuses. Collecting vessels, nearly all ending in the external iliac nodes, are in three sets:

- vessels from the trigone emerge on the vesical exterior to run superolaterally;
- those from the superior surface converge to the posterolateral angle and pass superolaterally across the lateral umbilical ligament to the external iliac nodes (one may go to the internal or common iliac group);
- those from the inferolateral surface ascend to join those from the superior surface.

Minute nodules of lymphoid tissue may occur along the vesical lymph vessels.

Urethral. These are of two sorts:

- Vessels from the prostatic and membranous urethra in males and the whole female urethra pass mainly to the internal iliac nodes; a few may end in the external iliac nodes. Vessels from the membranous urethra accompany the internal pudendal artery.
- Vessels of the male spongiose urethra accompany those of the glans penis, ending in the deep inguinal nodes. Some may end in superficial nodes, others may traverse the inguinal canal to the external iliac nodes.

Lymphatic drainage of male reproductive organs

Testis. Testicular vessels commence in a superficial plexus, under the tunica vaginalis, and a deep plexus in the substance of the testis and the epididymis. Four to eight collecting trunks ascend in the spermatic cord and accompany the testicular vessels on the psoas major, ending in the lateral aortic and pre-aortic nodes.

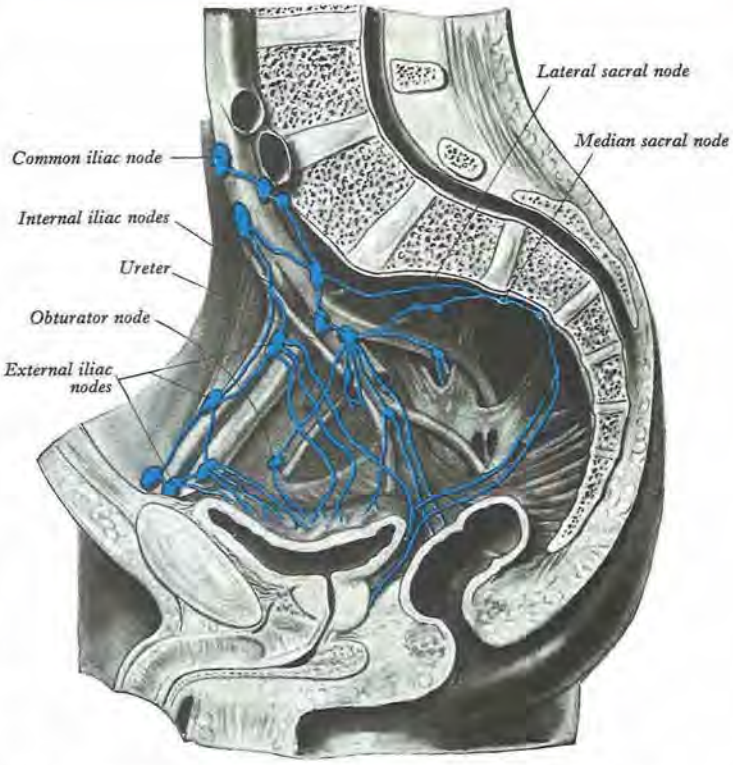
Ductus deferens, seminal vesicle and prostate gland. Collecting vessels from the ductus end in the external iliac nodes, while those from the seminal vesicle go to the internal and external iliac nodes. Prostatic vessels end mainly in internal iliac and sacral nodes; a vessel from the posterior surface accompanies the vesical vessels to the external iliac nodes and one from the anterior surface gains the internal iliac group by joining vessels of the membranous urethra.

Scrotum and penis. The skin of these parts is drained by vessels which, with those of all perineal skin, accompany the external pudendal blood vessels to the superficial inguinal nodes. Lymph vessels of the glans penis pass to the deep inguinal and external iliac nodes, from the erectile tissue and penile urethra to the internal iliac lymph nodes.

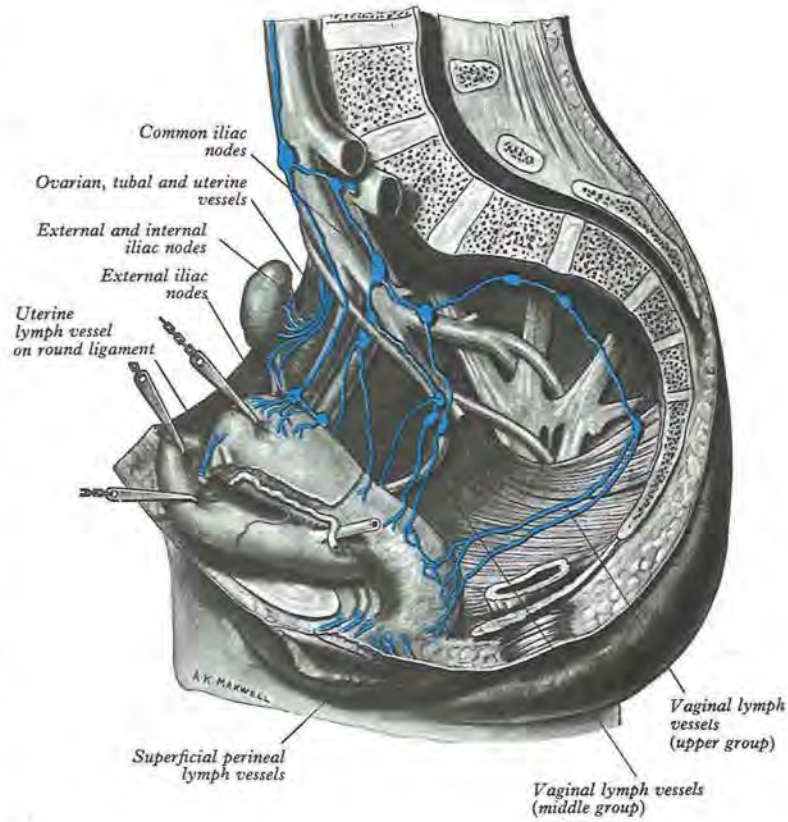
Lymphatic drainage of female reproductive organs (10.206)

Ovary. The vessels, like the testicular, ascend along the ovarian artery to the lateral aortic and pre-aortic nodes.

Uterus and uterine tube. Uterine lymphatics are superficial (or subperitoneal) and deep in the uterine wall. Collecting vessels from the cervix pass laterally in the parametrium to the external iliac



10.205 The lymphatic drainage of the urinary bladder (semi-diagrammatic).



10.206 The lymphatic drainage of the female reproductive organs (semi-diagrammatic). (After Cunéo & Marcille.)

nodes, posterolaterally to the internal iliac nodes and posteriorly in the sacrogenital fold to the rectal and sacral nodes. Some cervical efferents may reach the obturator or gluteal nodes. Vessels from the lower part of the uterine body pass mostly to the external iliac nodes, with those from the cervix. From the upper part of the body, the fundus and the uterine tubes, vessels accompany those of the ovaries to the lateral aortic and pre-aortic nodes, a few passing to the external iliac nodes. The region surrounding the isthmic part of the uterine tube is drained along the round ligament to the superficial inguinal nodes. Uterine lymph vessels enlarge greatly during pregnancy.

Vagina. Vaginal lymphatic vessels link with those of the cervix uteri, rectum and vulva. They form three groups but the regions drained are not sharply demarcated. Upper vessels accompany the uterine artery to the internal and external iliac nodes, intermediate vessels accompany the vaginal artery to the internal iliac nodes; vaginal vessels below the hymen, from the vulva and perineal skin, pass to the superficial inguinal nodes but the clitoris and labia minora drain to the deep inguinal nodes and direct clitoridial efferents may pass to the internal iliac nodes (Kubik 1967).

Lymphatic drainage of abdominal wall

The lymphatic vessels here are either superficial or deep to the deep fascia.

Superficial vessels. These accompany the subcutaneous blood vessels. Lumbar and gluteal vessels run with the superficial circumflex iliac vessels, those from the infra-umbilical skin with the superficial epigastric vessels. Both drain into the superficial inguinal nodes. The supra-umbilical region is drained by vessels running obliquely up to the pectoral and subscapular axillary nodes, a few to the parasternal nodes.

Deep vessels. They accompany the deep arteries, the posterior passing without interruption with the lumbar arteries to the lateral aortic and retro-aortic nodes; those from the upper anterior abdominal wall run with the superior epigastric vessels to the parasternal nodes; those of its lower part end in the circumflex iliac, inferior epigastric and external iliac nodes. Vessels of the pelvic wall follow the internal iliac artery and its parietal branches to end in the iliac or lateral aortic nodes.

LYMPHATIC DRAINAGE OF THORAX

LYMPHATIC DRAINAGE OF THORACIC WALLS

Superficial lymphatic vessels of the thoracic wall ramify subcutaneously and converge on the axillary nodes. Those superficial to the trapezius and latissimus dorsi unite to form 10 or 12 trunks ending in the subscapular nodes. Those in the pectoral region, including vessels from the skin covering the periphery of the mammary gland and its subareolar plexus, run back, collecting those superficial to serratus anterior, to reach the pectoral nodes. Vessels near the lateral sternal margin pass between the costal cartilages to the parasternal nodes but also anastomose across the sternum. A few vessels from the upper pectoral region ascend over the clavicle to the inferior deep cervical nodes. Lymph vessels from deeper tissues of the thoracic walls drain mainly to the parasternal, intercostal and diaphragmatic lymphatic nodes.

Parasternal (internal thoracic) nodes. Four or five on each side, they are at the anterior ends of the intercostal spaces, along each internal thoracic artery. They drain afferents from the mammary gland, deeper structures of the supra-umbilical anterior abdominal wall, the superior hepatic surface through a small group of nodes behind the xiphoid process and deeper parts of the anterior thoracic wall. Their efferents usually unite with those from the tracheobronchial and brachiocephalic nodes to form the bronchomediastinal trunk; this may open, on either side, directly into the jugulosubclavian junction into either great vein near the junction or may join the right subclavian trunk, the right lymphatic duct or, on the left, the thoracic duct.

Intercostal nodes. These occupy the intercostal spaces near the heads and necks of the ribs. They receive deep lymph vessels from the posterolateral aspects of the chest and the mammary gland; some are interrupted by small lateral intercostal nodes. Efferents of nodes in the lower four to seven spaces unite into a trunk descending to the abdominal confluence of lymph trunks or to the commencement of the thoracic duct (p. 1610). Efferents of nodes in the left upper spaces end in the thoracic duct, those of the right upper spaces end in one of the right lymph trunks.

Diaphragmatic nodes. Located on the thoracic surface of the diaphragm, they comprise: anterior, right and left lateral and posterior groups.

The anterior group. This consists of two or three small nodes behind the base of the xiphoid process, draining the convex hepatic surface, and one or two nodes on each side near the junction of the seventh rib and cartilage, which receive anterior lymph vessels from the diaphragm. The anterior group drains to the parasternal nodes.

The lateral groups. They each contain two or three nodes, close to the entry of the phrenic nerves into the diaphragm. On the right some nodes lie within the fibrous pericardium anterior to the intrathoracic end of the inferior vena cava. Their afferents are from the central diaphragm, the right also draining the convex surface of the liver. Their efferents pass to the posterior mediastinal, parasternal and brachiocephalic nodes.

The posterior group. It contains a few nodes on the back of the crura, connected with the lateral aortic and posterior mediastinal nodes.

Lymphatic drainage of deeper tissues

Collecting vessels of the deeper thoracic tissues include the following:

- Lymphatics of muscles attached to the ribs: most end in axillary nodes, some from pectoralis major in the parasternal nodes.
- Intercostal vessels draining the intercostal muscles and parietal pleura; those from the anterior thoracic wall and pleura end in the parasternal nodes, the posterior in intercostal nodes.
- Vessels of the diaphragm form two plexuses, thoracic and abdominal, anastomosing freely and best marked in areas covered respectively by pleurae and peritoneum. The thoracic plexus unites with lymph vessels of the costal and mediastinal pleura, its efferents being: *anterior*, passing to the anterior diaphragmatic nodes near the junctions of the seventh ribs and cartilages; *middle*, to nodes on the oesophagus and around the end of the inferior vena cava; *posterior*, to nodes around the aorta where it leaves the thorax. The abdominal plexus anastomoses with the hepatic lymphatics and peripherally with those of the subperitoneal tissue. Efferents from its right half end partly in a group of nodes on the inferior phrenic artery, others in the right lateral aortic nodes. Those from the left half of the abdominal diaphragmatic plexus pass to the pre-aortic and lateral aortic nodes and nodes near the terminal oesophagus.

LYMPHATIC DRAINAGE OF THORACIC CONTENTS

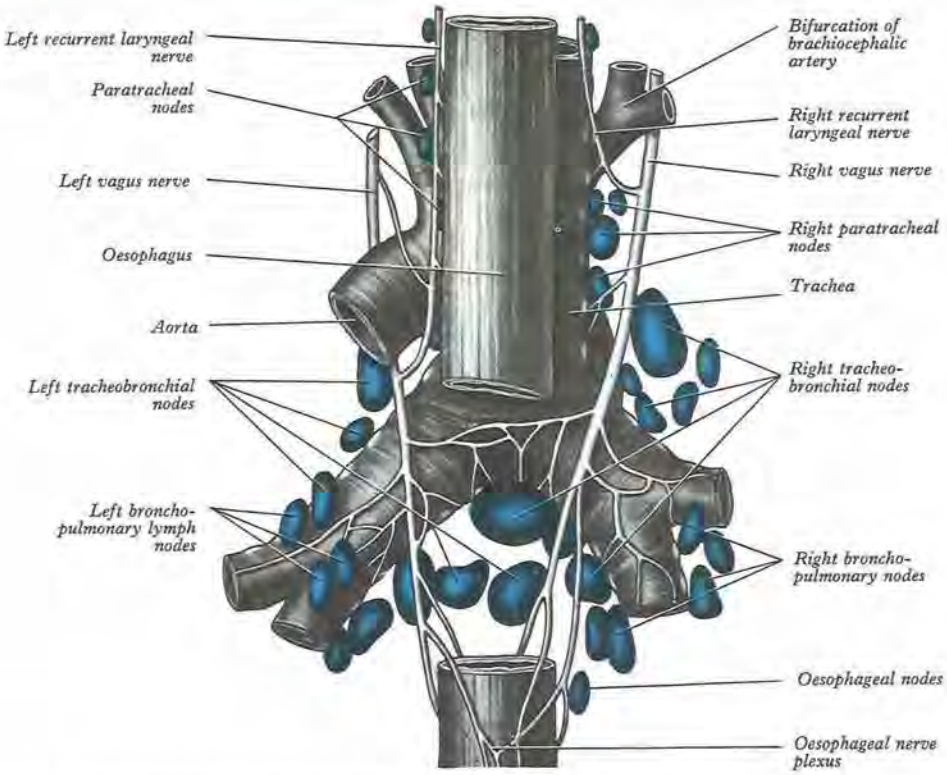
Lymph from thoracic viscera traverses one or other of three groups of nodes, brachiocephalic, posterior mediastinal or tracheobronchial, before entering the thoracic duct, the right lymphatic duct or some other lymph trunk entering one of the great veins at the root of the neck.

Brachiocephalic nodes. These are in the superior mediastinum, anterior to the brachiocephalic veins and large arterial trunks springing from the aortic arch. They drain the thymus and thyroid glands, pericardium, heart and lateral diaphragmatic nodes; their efferents unite with those of the tracheobronchial nodes to form the right and left bronchomediastinal trunks.

Posterior mediastinal nodes. Behind the pericardium, near the oesophagus and the descending thoracic aorta, their afferents are from: the oesophagus, posterior pericardium, diaphragm, lateral and posterior diaphragmatic nodes and sometimes the left lobe of the liver. They drain chiefly to the thoracic duct but some join the tracheobronchial nodes.

Tracheobronchial nodes (10.207). They are in five main groups (Naruke et al 1978), including some of the largest nodes:

- *paratracheal*, in front and to the sides of the thoracic portion of the trachea but continuous above with the cervical paratracheal nodes
- *superior tracheobronchial*, in the angles between the trachea and the bronchi



10.207 The lymph nodes of the trachea, bronchi and lungs. Note the large 'carinate' node lodged between the bifurcation of the principal bronchi.

- *inferior tracheobronchial* or *subcarenal nodes*, in the angle between the bronchi
- *bronchopulmonary* or *hilar nodes*, in the hilum of each lung around the main bronchi
- *pulmonary* or *intralobar*, in the lung substance on larger branches of the principal bronchi.

These groups are not sharply demarcated; pulmonary nodes become continuous with the bronchopulmonary and they in turn with the inferior and superior tracheobronchial nodes, continuous with the paratracheal group. Afferents of tracheobronchial nodes drain the lungs and bronchi, thoracic trachea, heart and some efferents of the posterior mediastinal nodes. Their efferent vessels ascend on the trachea to unite with efferents of the parasternal and brachiocephalic nodes as the right and left bronchomediastinal trunks; the right trunk may occasionally join a right lymphatic duct or another right-sided lymph trunk and on the left the thoracic duct; but more often they open independently in or near the jugulo-subclavian junction on their own side.

Clinical anatomy. In all town dwellers large quantities of dust and carbonaceous pigment may be freely inhaled and are continually swept into these nodes from the bronchi and alveoli.

Lymphatic drainage of heart

Cardiac lymphatic vessels form subendocardial, myocardial and subepicardial plexuses, the first two draining into the third, efferents of which form the left and right cardiac collecting trunks. Two or three left trunks ascend the anterior interventricular sulcus, receiving vessels from both ventricles; reaching the coronary sulcus, they are joined by a large vessel from the diaphragmatic surface of the left ventricle, which first ascends in the posterior interventricular sulcus and then turns left along the coronary sulcus. The vessel formed by the union of these two ascends between the pulmonary artery and the left atrium, usually ending in an inferior tracheobronchial node. The right trunk receives afferents from the right atrium and right border and diaphragmatic surface of the right ventricle. It ascends in the coronary sulcus, near the right coronary artery, and then anterior to the ascending aorta to end in a brachiocephalic node, usually on the left.

Lymphatic drainage of lungs and pleurae

Pulmonary lymphatic vessels originate in a superficial subpleural plexus and a deep plexus accompanies the branches of pulmonary vessels and bronchi. In larger bronchi the deep plexus has submucosal and peribronchial parts; in smaller bronchi a single plexus extends to the bronchioles but not to the alveoli, whose walls have no lymphatic vessels. Superficial efferents turn round borders and the margins of fissures to converge in the bronchopulmonary nodes; deep efferents reach the hilum along the pulmonary vessels and bronchi, ending mainly in the same nodes. There is little anastomosis between the superficial and deep lymphatics, except in the hilar regions. In peripheral parts of the lungs small channels connect superficial and deep lymphatic vessels, capable of dilatation to direct lymph from the deep to the superficial channels when outflow from deep vessels is obstructed by pulmonary disease. Deep in the fissures, lymphatic vessels of adjoining lobes connect; hence, though there is a tendency for vessels from the upper lobes to pass to the superior tracheobronchial nodes and those from lower lobes to the inferior tracheobronchial group, these connections are not exclusive. At the level of pulmonary lobation the arrangement of lymphatic vessels follows with the central artery of a lobule and its peripheral veins (Kubik 1970), confirming the findings of Celtis and Porter (1952). Policard (1950) has described lymphoid aggregations, non-follicular in appearance, in peribronchial sites and in 'placoid' formations adjoining pulmonary pleura.

Pleural lymphatic vessels exist in visceral and parietal layers, those of the visceral pleura draining to the superficial pulmonary efferents, forming a plexus beneath the pulmonary pleura (see above). Those of the parietal pleura end in three ways:

- those from the costal region join vessels of the internal intercostal muscles to reach the parasternal nodes;
- those of the diaphragmatic pleura form a plexus on its thoracic surface (p. 1624);

- those of the mediastinal pleura end in the posterior mediastinal nodes.

Lymphatic drainage of thymus

Thymic lymphatic vessels end in the brachiocephalic, tracheobronchial and parasternal nodes.

Lymphatic drainage of oesophagus

Efferent vessels from the cervical oesophagus drain to the deep cervical nodes, those from its thoracic part to the posterior mediastinal nodes and those from its abdominal part to the left gastric lymph nodes. Some may pass directly to the thoracic duct (p. 1610).