Anatomy

MBBS Recap: high-yield notes for revision

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Revision notes for the MD/MS entrance on gross anatomy, neuroanatomy, embryology and histology: the facts an examiner asks, set out to be revised fast.

Upper limb

Brachial plexus

- Roots C5–T1; trunks upper (C5–C6), middle (C7), lower (C8–T1); then divisions, cords (lateral, posterior, medial, named by their relation to the axillary artery) and terminal branches.
- **Branches from the roots**: dorsal scapular (C5, rhomboids, levator scapulae), **long thoracic (C5–C7, serratus anterior)** and the phrenic contribution (C5).
- **Branches from the upper trunk**: **suprascapular nerve (C5–C6; supraspinatus, infraspinatus)** and the nerve to subclavius. No branches arise from the divisions.
- **Erb's point** (on the plexus): the junction of the C5 and C6 roots to form the upper trunk, where six nerves meet (the two roots, the two divisions of the trunk, the suprascapular nerve and the nerve to subclavius); not the nerve point of the neck on sternocleidomastoid, which is also called Erb's point.
- Lateral cord: lateral pectoral, musculocutaneous, lateral root of median. Medial cord: medial pectoral, medial cutaneous nerves of arm and forearm, ulnar, medial root of median. Posterior cord: upper and lower subscapular, thoracodorsal, axillary, radial.
- Mnemonic of public type: "Randy Travis Drinks Cold Beer" for roots, trunks, divisions, cords, branches.

Injuries to know

Lesion	Cause	Findings
Erb–Duchenne (C5–C6, upper trunk)	Birth traction, fall on the shoulder	Arm hangs adducted and medially rotated, forearm pronated ("waiter's tip"): loss of deltoid, supraspinatus, **infraspinatus and teres minor** (lateral rotators), biceps, brachialis. Sensory loss over the lateral arm and forearm.
Klumpke (C8–T1, lower trunk)	Hyperabduction, cervical rib, Pancoast tumour	Claw hand, small hand muscles paralysed, **Horner syndrome** if T1 sympathetic fibres are involved.
Long thoracic nerve	Axillary clearance, mastectomy	**Winged scapula**: medial border sticks out on pushing the arm forward; arm cannot be raised above the horizontal.
Axillary (C5–C6)	**Surgical neck fracture**, anterior shoulder dislocation	Deltoid and teres minor paralysed; sensory loss over the **regimental-badge area** (upper lateral cutaneous nerve of arm); accompanied by the posterior circumflex humeral artery.
Radial	Mid-shaft humeral fracture (spiral groove), crutches, Saturday-night palsy	**Wrist drop**, loss of finger and thumb extension; sensory loss at the dorsum of the first web space. **Triceps is spared in a shaft fracture** because its branches leave above the groove; a high (axillary) lesion paralyses triceps too.
Median	Supracondylar fracture, wrist laceration	**High lesion (elbow and above)**: "hand of benediction" on attempting a fist (index and middle fingers stay straight, flexor digitorum superficialis and lateral profundus lost), forearm pronation weak. **Low lesion (wrist)**: "ape hand" (thenar wasting, thumb in line with the fingers), loss of opposition. In an extension-type supracondylar fracture in a child the **anterior interosseous nerve** (motor only: flexor pollicis longus, lateral profundus, pronator quadratus; cannot make the "OK" sign) is the nerve most often injured.
Ulnar	Medial epicondyle fracture, elbow (cubital tunnel), wrist (Guyon canal)	Claw hand, Froment's sign (adductor pollicis), loss of finger abduction and adduction.

- **Ulnar paradox**: a lesion at the **wrist** gives a *more marked* claw than one at the elbow, because at the wrist flexor digitorum profundus to the ring and little fingers is spared and flexes the interphalangeal joints, while the paralysed lumbricals cannot extend them. At the elbow the profundus is paralysed too, so the fingers do not curl.
- **Carpal tunnel syndrome**: median nerve under the flexor retinaculum. Nocturnal paraesthesia of the lateral three and a half digits, thenar wasting. **Sensation over the thenar eminence is spared** (the palmar cutaneous branch arises proximal to the retinaculum and passes over it).
- **Median nerve motor supply in the hand**: the "LOAF" muscles: first and second **l**umbricals, **o**pponens pollicis, **a**bductor pollicis brevis, **f**lexor pollicis brevis (superficial head). All other intrinsic muscles of the hand are ulnar. The recurrent (thenar) branch supplies the thenar group.
- Ulnar muscles of the hand: adductor pollicis, deep head of flexor pollicis brevis, all interossei (**PAD: palmar interossei adduct; DAB: dorsal interossei abduct**, about the axis of the middle finger), third and fourth lumbricals, hypothenar muscles, palmaris brevis.
- **Cutaneous nerves of the arm**: upper lateral cutaneous nerve of arm from the **axillary**; lower lateral and posterior cutaneous nerves of arm and the posterior cutaneous nerve of

forearm from the **radial**; medial cutaneous nerves of arm and forearm from the **medial cord** (with the intercostobrachial, T2, in the axilla); lateral cutaneous nerve of forearm is the end of the **musculocutaneous**.

- **Klumpke** follows a pull on an abducted arm (breech delivery, grabbing a branch): claw hand with Horner syndrome from the T1 sympathetic fibres; Erb gives the waiter's-tip posture with a normal hand.
- **Wrist lacerations** (the 'wrist slash') endanger, from the radial side: radial artery, flexor carpi radialis, palmaris longus and the **median nerve** (the most superficial of the nerves, just deep to palmaris longus), then the flexor digitorum superficialis tendons, and on the ulnar side the ulnar artery and nerve beside flexor carpi ulnaris.
- **Allen's test** checks that the radial and ulnar arteries are in continuity through the palmar arches (compress both, blanch the hand, release one: colour returns if that artery and the arch are patent); it is done before radial arterial puncture or harvest.
- **Scapular retractors** (rhomboids, C4–C5, dorsal scapular nerve) are tested by asking the patient to push the elbow back against resistance with the hand on the hip; the muscle is felt tight beside the vertebral border.
- **Rotator cuff** ('SITS'): **s**upraspinatus, **i**nfraspinatus, **t**eres minor and **s**ubscapularis; teres major is not part of it. Supraspinatus starts abduction (first 15°) and is the most injured.

Shoulder

- Rotator cuff: **supraspinatus**, infraspinatus, teres minor, subscapularis (SITS). Supraspinatus is the most commonly torn (impingement under the acromion; painful arc 60°–120°).
- **Abduction**: supraspinatus starts the **first 15°** (it also holds the head in the glenoid); deltoid carries on from about 15° to 90°; trapezius and serratus anterior rotate the scapula for abduction above 90°. Electromyography shows deltoid active from the start too, so the "initiator" is a classical answer.
- Anterior dislocation of the glenohumeral joint is by far the commonest (the inferior capsule is weakest); the axillary nerve is stretched, with numbness over the lateral upper arm.
- Suprascapular nerve passes through the suprascapular notch under the superior transverse scapular ligament; the artery goes above it ("Army over the bridge, Navy under").
- **Quadrangular space**: teres minor (and subscapularis in front) above, teres major below, long head of triceps medially, surgical neck of the humerus laterally; transmits the **axillary nerve and posterior circumflex humeral artery**. Upper triangular space: circumflex scapular artery. Lower triangular space (triangular interval): **radial nerve and profunda brachii artery**.
- Muscle actions asked: biceps flexes the elbow and is the **chief supinator** (of the flexed forearm); **brachialis is the chief flexor of the elbow**; triceps extends; infraspinatus and teres minor rotate laterally, subscapularis medially; trapezius elevates and retracts the scapula; sternocleidomastoid turns the face to the **opposite** side.

Cubital fossa and forearm

- Cubital fossa: bounded by a line between the epicondyles above, brachioradialis laterally and pronator teres medially. Contents, lateral to medial: **radial nerve (under brachioradialis, at the lateral edge), biceps tendon, brachial artery (dividing into radial and ulnar at the neck of the radius), median nerve**. Roof: skin, fascia with the median cubital vein, **bicipital aponeurosis** (which protects the brachial artery and median nerve from the vein during venepuncture). Floor: brachialis and supinator.
- Radial nerve divides into the superficial branch (sensory) and the posterior interosseous nerve (motor, through supinator).
- Anatomical snuffbox: scaphoid in the floor (fracture there risks avascular necrosis of the proximal pole, since blood enters distally), radial artery, borders by extensor pollicis longus (ulnar side) and abductor pollicis longus plus extensor pollicis brevis (radial side).
- Dermatomes: C5 lateral arm (over the deltoid); C6 lateral forearm, thumb and index finger; **C7 middle finger**; C8 ring and little fingers and the lower medial forearm; T1 medial side of the arm and forearm about the elbow; T2 the axilla. Reflexes: **biceps and brachioradialis C5–C6** (biceps chiefly C5, brachioradialis chiefly C6); **triceps C6–C8, chiefly C7**. So weak triceps with middle-finger paraesthesia is C7 (C6–C7 disc).
- Axilla: the axillary artery is divided by pectoralis minor into three parts (1 branch, 2 branches, 3 branches: superior thoracic; thoracoacromial and lateral thoracic; subscapular and two circumflex humerals). Lymph nodes: anterior (pectoral), posterior (subscapular), lateral, central, apical.

Other

- Clavicle: most often fractured at the junction of the middle and lateral thirds (the middle third in most series); the medial fragment is pulled up by sternocleidomastoid, the lateral fragment down by the weight of the arm and medially by pectoralis major. It is the first bone to ossify (membranous, weeks 5–6).
- Venous drainage: cephalic vein runs up the lateral side to enter the axillary vein through the clavipectoral fascia; basilic vein pierces deep fascia at mid-arm.
- **Composite muscles** (two nerve supplies): **brachialis** (musculocutaneous, plus a small lateral part from the radial nerve, so elbow flexion is weakened, not lost, after a musculocutaneous injury), flexor digitorum profundus (ulnar for the medial half, anterior interosseous for the lateral half), pectineus (femoral and obturator), adductor magnus (obturator and tibial), biceps femoris (tibial and common peroneal), digastric (mylohyoid nerve and facial nerve).
- **Muscle architecture**: unipennate (extensor digitorum longus, flexor pollicis longus), bipennate (rectus femoris, dorsal interossei; soleus is usually described as bipennate or multipennate), multipennate (deltoid), fusiform (biceps), strap (sartorius), triangular (pectoralis major, temporalis). The more pennate a muscle, the more force and the less range.
- **Anconeus** (radial nerve) helps extend the elbow and steadies the ulna in pronation. **Poland syndrome** is unilateral absence of the sternocostal head of pectoralis major, often with a short, webbed hand on the same side.
- **Joint types** with the examples asked: fibrous (suture; gomphosis = tooth in socket; syndesmosis = tibiofibular); cartilaginous (primary synchondrosis = epiphyseal plate; secondary = symphysis, intervertebral disc); synovial: plane (acromioclavicular), hinge (elbow, interphalangeal), pivot (atlanto-axial, proximal radio-ulnar), condylar (knee, temporomandibular), ellipsoid (wrist, metacarpophalangeal), saddle (first carpometacarpal, sternoclavicular, incudomalleolar), ball and socket (shoulder, hip).

- **Arteries divided into three parts** by a landmark muscle: axillary (pectoralis minor), subclavian (scalenus anterior), maxillary (lateral pterygoid) and lingual (hyoglossus).

Hand sheaths and bone growth

- **Ulnar bursa**: the common flexor synovial sheath of the palm and wrist, enclosing the tendons of flexor digitorum superficialis and profundus; it is **usually continuous with the synovial sheath of the little finger**, so suppurative tenosynovitis of the little finger spreads to the palm and carpal tunnel. The **radial bursa** is the sheath of flexor pollicis longus and is usually continuous with the thumb's sheath; in some people the two bursae communicate (**horseshoe abscess**). The index, middle and ring finger sheaths are separate and end blindly at the palm. Spread beyond the wrist goes to **Parona's space** deep to the flexor tendons in the distal forearm.
- Deep palmar spaces: **thenar** (index finger side, behind the flexor tendons of the index) and **midpalmar** (behind the tendons of the middle, ring and little fingers), separated by the fibrous septum attached to the third metacarpal.
- **Ossification**: bones form by **intramembranous** (flat skull bones, the clavicle's shaft, mandible) or **endochondral** ossification (long bones). The **clavicle is the first bone to start ossifying** (about week 5 to 6 of intrauterine life, by both routes); primary centres of most long bones appear by week 8 to 12. **Secondary centres**: the lower femoral epiphysis appears just before birth (about 36 weeks) and is used as a sign of term maturity.
- **Law of nutrient arteries**: the nutrient artery runs away from the growing end, so it points towards the elbow in the arm and forearm bones and away from the knee in the thigh and leg bones. The growing end of a long bone is the epiphysis that fuses last.
- **Carpal ossification**: the capitate first (about 2 months after birth) and the hamate soon after (about 3 months), then, triquetral, lunate, scaphoid, trapezium, trapezoid, and the **pisiform last (about 9 to 12 years)**; the hand and wrist radiograph is the usual basis of bone age.
- **Extensor compartments of the wrist**: 1 abductor pollicis longus and extensor pollicis brevis (de Quervain tenosynovitis: radial styloid pain, positive Finkelstein test); 2 extensor carpi radialis longus and brevis; 3 extensor pollicis longus (round Lister's tubercle; may rupture after a distal radius fracture); 4 extensor digitorum and extensor indicis; 5 extensor digiti minimi; 6 extensor carpi ulnaris.
- **Epiphyses**: pressure (at joint surfaces, transmit weight: head of femur), traction (non-articular, muscle pull: trochanters, tubercles of the humerus), atavistic (once a separate bone in other animals: coracoid process, os trigonum) and aberrant (not seen in the usual form: head of the first metacarpal).

Lower limb

Nerves and their injuries

- **Femoral nerve** from the posterior divisions of **L2, L3, L4**: quadriceps, sartorius, pectineus; sensory to the anterior thigh and (saphenous) medial leg. Injury: weak knee extension, loss of knee jerk.
- Obturator nerve (anterior divisions of L2–L4): adductor longus, brevis, the adductor part of magnus, gracilis and obturator externus; skin of the medial thigh. It also supplies the hip and knee joints, so **hip disease may be felt in the knee**; an obturator hernia or an ovarian lesion on the lateral pelvic wall refers pain to the medial thigh (Howship–Romberg sign).
- **Sciatic nerve** (L4–S3) leaves through the greater sciatic foramen **below piriformis**, runs behind the thigh and divides into the tibial and common fibular nerves, usually at the apex of the popliteal fossa. Intramuscular injections are placed in the upper outer quadrant of the buttock to avoid it.
- **Common fibular (peroneal) nerve** winds round the **neck of the fibula**: injury (fracture, tight plaster) gives **foot drop** with loss of dorsiflexion and eversion and sensory loss over the lateral leg and dorsum of the foot. The deep branch supplies dorsiflexors and gives sensation to the first web space; the superficial branch the evertors.
- **Tibial nerve** injury: loss of plantar flexion and toe flexion, weak inversion, loss of sole sensation; a lesion at the ankle (tarsal tunnel, behind the medial malleolus under the flexor retinaculum) paralyses the intrinsic muscles of the sole and clawing of the toes follows.
- **Foot drop** with a high-stepping gait is loss of **tibialis anterior** (deep fibular nerve, L4–L5), the main dorsiflexor; it also inverts. Fibularis (peroneus) longus and brevis evert (superficial fibular nerve); fibularis tertius dorsiflexes and everts. Gastrocnemius plantar flexes and flexes the knee; soleus is the postural plantar flexor; gluteus maximus extends and laterally rotates the hip (inferior gluteal nerve) and is needed for rising from sitting and climbing stairs.
- **Superior gluteal nerve** (L4–S1): gluteus medius, minimus and tensor fasciae latae. **Trendelenburg sign**: on standing on the affected leg, the **pelvis drops on the opposite (unsupported) side**; the patient compensates by leaning the trunk over the affected side. Also positive in hip dislocation, coxa vara and poliomyelitis.
- **Structures through the greater sciatic foramen**: above piriformis only the **superior gluteal nerve and vessels**; below it the sciatic, inferior gluteal, pudendal, posterior femoral cutaneous nerves, nerves to obturator internus and quadratus femoris, and the inferior gluteal and internal pudendal vessels.
- **Lesser sciatic foramen**: the tendon of obturator internus (leaving), and three structures that leave by the greater foramen and turn back in round the ischial spine or sacrospinous ligament: the **pudendal nerve, internal pudendal vessels and nerve to obturator internus**. These three are the answer to "through both foramina"; the superior gluteal nerve passes through the greater only.
- Root values: L4 medial leg and medial malleolus, knee extension, **knee jerk (L2–L4, chiefly L3–L4)**; L5 dorsum of the foot and great toe, **extensor hallucis longus** (big-toe extension), heel walking; **S1 lateral foot, little toe and sole, plantar flexion (toe walking), ankle jerk (S1–S2)** (the root compressed when weak calf, lateral foot numbness and a reduced ankle jerk follow a lifting injury). Lower limb dermatomes: L1 groin, L2–L3 front of the thigh, L4 medial leg, L5 dorsum, S1 lateral foot and heel, S2 back of the thigh, S3–S5 saddle area.
- Lumbar disc prolapse most commonly L4–L5 or L5–S1; the nerve compressed is usually the root *below* the disc (L5 at L4–L5) in a posterolateral prolapse.

Knee

- Both menisci are fibrocartilage, vascular only in their outer third (the red zone, where a tear can heal). **Medial meniscus**:

C-shaped, firmly attached to the **deep part of the tibial collateral ligament** and capsule, so it is less mobile and torn more often than the lateral meniscus (which is O-shaped, more mobile and attached to popliteus tendon, not the fibular collateral ligament).

- **Unhappy triad (O'Donoghue)**: valgus stress with a planted foot tears the **tibial collateral ligament, the anterior cruciate ligament and the medial meniscus**. (MRI series show that lateral meniscal tears may be more frequent in acute ACL injuries, but the classic answer is medial meniscus.)
- ACL stops anterior tibial translation (anterior drawer, Lachman test, the more sensitive one); PCL stops posterior translation and is the main stabiliser of a flexed knee.
- **Popliteus** unlocks the knee: it **laterally rotates the femur on a fixed tibia** at the beginning of flexion. Locking (screw-home) is medial rotation of the femur at the end of extension. Nerve supply: tibial nerve.
- Patellar tap; quadriceps tendon, patella and patellar ligament form the extensor mechanism; the vastus medialis obliquus prevents lateral displacement of the patella.

Hip and others

- Blood supply of the femoral head: mainly the **medial circumflex femoral artery** (retinacular branches), so intracapsular femoral neck fractures risk avascular necrosis; the artery of the ligament of the head (from the obturator artery) is small in adults.
- Femoral triangle: inguinal ligament above, sartorius lateral, adductor longus medial; contents lateral to medial: **N**erve, **A**rtery, **V**ein, **E**mpty space (femoral canal), **L**ymphatics. Femoral sheath surrounds artery, vein and canal but not the nerve.
- Adductor canal (Hunter): femoral vessels, saphenous nerve and the nerve to vastus medialis.
- Great saphenous vein: begins at the medial end of the dorsal venous arch, passes in front of the medial malleolus (cut-down site) and ends in the femoral vein at the saphenofemoral junction. Short saphenous vein passes behind the lateral malleolus to the popliteal vein; the sural nerve accompanies it.
- Arches of the foot: medial longitudinal arch is kept by the **spring (plantar calcaneonavicular) ligament**, tibialis posterior, flexor hallucis longus and the plantar aponeurosis; the lateral arch and the transverse arch by fibularis longus. Tibialis posterior is the chief invertor; its dysfunction is the commonest cause of acquired flat foot in adults.
- Compartment syndrome is commonest in the anterior compartment of the leg (after a tibial fracture); pain on passive stretch is the early sign.
- **Femoral sheath** (a funnel of transversalis fascia in front and fascia iliaca behind; the **femoral nerve lies outside it**, lateral): lateral compartment the femoral artery and the femoral branch of the genitofemoral nerve; intermediate the femoral vein; medial the **femoral canal** with lymphatics and the **lymph node of Cloquet (Rosenmüller)**, the highest deep inguinal node. **Femoral ring**: inguinal ligament in front, pectineal ligament behind, **lacunar ligament medially** (the edge that strangles a femoral hernia and must be divided), femoral vein laterally. **Femoral (Scarpa) triangle**: inguinal ligament above, medial border of sartorius laterally, medial border of adductor longus medially; floor iliopsoas, pectineus and adductor longus (adductor magnus takes no part); roof the fascia lata with the cribriform fascia.
- **Hamstrings** (true): semitendinosus, semimembranosus and the long head of biceps femoris, from the ischial tuberosity, crossing hip and knee, tibial part of the sciatic nerve; the short head of biceps (linea aspera, common peroneal part, knee only) is not a hamstring.
- **Hip ligaments**: the **iliofemoral (Y-shaped) is the strongest** and limits hyperextension; the pubofemoral limits abduction; the **ischiofemoral is the weakest and limits medial rotation**, but in a posterior dislocation (dashboard injury) the head leaves through the thinnest posterior capsule, the ischiofemoral part.
- **Sesamoid bones** lie within tendons: the patella (largest), pisiform (flexor carpi ulnaris), two under the first metatarsal head (flexor hallucis brevis), the fabella (lateral head of gastrocnemius) and the cyamella (popliteus tendon).
- **Intramuscular gluteal injection** goes into the **upper outer quadrant** of the buttock to avoid the sciatic nerve (lower medial) and the superior gluteal vessels. Current nursing practice prefers the **ventrogluteal** site (gluteus medius, between the anterior superior iliac spine and the iliac crest tubercle), away from both.

Foot arches

- **Medial longitudinal arch** (higher): calcaneus, talus, navicular, the three cuneiforms and the medial three metatarsals; **the talus is the keystone**. It is held by the **spring (plantar calcaneonavicular) ligament**, the **tibialis posterior** tendon and the plantar aponeurosis, with the flexor hallucis longus tendon below the sustentaculum tali, abductor hallucis and the deltoid ligament; the long and short plantar ligaments belong mainly to the lateral arch.
- **Lateral longitudinal arch** (lower, weight-bearing): calcaneus, cuboid and the lateral two metatarsals, its keystone the cuboid, kept by the **long and short plantar ligaments**, the plantar aponeurosis and peroneus longus. **Transverse arch**: the cuneiforms, cuboid and metatarsal bases, held by peroneus longus and the adductor hallucis (transverse head).
- **Flat foot (pes planus)** follows failure of the spring ligament and tibialis posterior (posterior tibial tendon dysfunction in adults); **pes cavus** is a high arch seen in Charcot-Marie-Tooth disease and Friedreich ataxia.
- **Congenital talipes equinovarus (clubfoot)**: the four components are **cavus, adductus of the forefoot, varus (inversion) of the heel and equinus**, remembered as CAVE; first-line treatment is the **Ponseti** serial casting method with Achilles tenotomy, started in the first weeks of life.
- **Medial longitudinal arch**: calcaneus, talus, navicular, three cuneiforms and three medial metatarsals; held by the spring ligament, tibialis posterior, the plantar aponeurosis and flexor hallucis longus. **Lateral arch**: calcaneus, cuboid and two lateral metatarsals; lower and stiffer, held by the long and short plantar ligaments and peroneus longus. Transverse arch at the metatarsal heads and cuneiforms (peroneus longus sling).
- **Gait cycle**: stance about 60% (heel strike, foot flat, midstance, heel-off, toe-off) and swing about 40%; the dorsiflexors act eccentrically after heel strike, the gastrocnemius–soleus pushes off.
- The **spring (plantar calcaneonavicular) ligament** supports the head of the talus, the keystone of the medial arch; failure gives acquired flat foot.

Thorax

Surface and thoracic wall

- **Sternal angle** (manubriosternal joint) is level with the **T4–T5 disc** and the **second costal cartilage**. At this level: the trachea bifurcates (carina), the aortic arch begins and ends, the azygos vein arches over the right main bronchus into the superior vena cava, the thoracic duct crosses to the left, and the superior mediastinum meets the inferior. The jugular notch lies at T2–T3.
- **Intercostal neurovascular bundle**: order from above down is **V**ein, **A**rtery, **N**erve, in the costal groove at the *lower* border of the rib, between the innermost and internal intercostal muscles. A chest drain or needle goes just **above the upper border of the lower rib**. **Triangle of safety** (BTS): the lateral border of pectoralis major in front, the lateral (anterior) border of latissimus dorsi behind, a horizontal line at the level of the nipple (fifth intercostal space) below, the apex just below the axilla; the drain goes in the fourth or fifth space, in the anterior to mid-axillary line. A needle decompression of tension pneumothorax: classically the second space in the midclavicular line; ATLS 10th edition (2018) moved the adult site to the fourth or fifth space just anterior to the mid-axillary line.
- Typical ribs (3–9) have a head with two facets, neck, tubercle and angle; atypical ribs are 1, 2, 10, 11, 12. The first rib is the broadest and shortest, grooved by the subclavian vessels (vein in front of scalenus anterior, artery behind it, with the lower trunk).
- Thoracic outlet syndrome: cervical rib or first rib compressing the lower trunk and subclavian artery.
- **Ribs**: 1–7 true (attached directly to the sternum), 8–12 false, of which 8–10 are vertebrochondral (joined to the cartilage above) and 11–12 floating; **inspiration**: diaphragm and external intercostals (primary), with sternocleidomastoid and scalenes accessory; quiet expiration is passive, forced expiration uses the abdominal wall and internal intercostals.
- **Vertebral levels**: thyroid cartilage C4–C5, cricoid C6 (start of the oesophagus and trachea), sternal angle and carina T4–T5, xiphisternal joint T9, transpyloric plane L1, subcostal plane L3, umbilicus L3–L4, aortic bifurcation L4, origin of the inferior vena cava L5, cord end L1 in the adult and L3 in the newborn. The vocal folds lie at about C5.
- **Valve sites**: the valves lie behind the sternum (mitral at the left fourth costal cartilage, aortic and pulmonary near the left third); the classic auscultation sites (apex at the left fifth space, aortic and pulmonary at the right and left second spaces) are where the sound is heard best, not where the valves lie.
- **Aberrant right subclavian artery** (arteria lusoria): from the left side of the arch, passing behind the oesophagus; a cause of dysphagia lusoria (from regression of the right fourth arch artery).

Heart

- **Surfaces**: sternocostal (anterior) surface is formed mostly by the **right ventricle**, plus right atrium and a strip of left ventricle; the left ventricle forms the apex (fifth intercostal space, midclavicular line) and the left border; the right atrium forms the right border; the left atrium forms most of the base (posterior surface); the diaphragmatic surface is mostly left ventricle with some right.
- Valve auscultation sites: aortic, right second intercostal space; pulmonary, left second; tricuspid, left lower sternal edge; mitral, apex. Valves lie behind the sternum at a more oblique line.
- **Coronary arteries**: the right coronary artery gives the SA nodal branch, the right (acute) marginal and, in a right-dominant heart, the posterior interventricular (descending) artery. **Dominance** is defined by which artery gives the posterior interventricular artery: **right in about 70–85%** (figures differ by series and definition; exam books give 85–90%), left (from the circumflex) in about 10%, codominant in the rest. The RCA supplies the right atrium, most of the right ventricle, the posterior third of the septum, the inferior wall of the left ventricle and the posteromedial papillary muscle, the **SA node in about 60%** (the left circumflex in about 40%) and the **AV node in about 80–90%** (from the dominant artery at the crux), so inferior infarcts cause bradycardia and heart block. Left coronary: **left anterior descending** (anterior two-thirds of the septum, the anterior wall and apex, the anterolateral papillary muscle, and with its septal branches the **bundle of His and the right and left bundle branches**; the commonest artery occluded) and **circumflex** (left atrium, lateral and posterior walls of the left ventricle). So of the conducting system, the SA node and AV node are usually the RCA's and the bundle branches the LAD's.
- Veins: **great cardiac vein in the anterior interventricular groove** with the LAD, **middle cardiac vein in the posterior interventricular groove**, small cardiac vein with the right marginal artery; they drain through the **coronary sinus** (in the posterior atrioventricular groove, opening into the right atrium between the IVC orifice and the tricuspid orifice); the **anterior cardiac veins and venae cordis minimae (Thebesian veins) open directly** into the chambers. A persistent left superior vena cava drains into the coronary sinus.
- Right atrium: crista terminalis separates the smooth sinus venarum (from the embryonic sinus venosus) from the rough pectinate part; the fossa ovalis marks the foramen ovale; the Eustachian valve guards the IVC orifice; the opening of the coronary sinus has the Thebesian valve. Triangle of Koch locates the AV node (tendon of Todaro, septal tricuspid leaflet, coronary sinus mouth).
- Conducting system: SA node (at the junction of SVC and right atrium, upper end of the crista terminalis) → AV node → bundle of His → right and left bundle branches → Purkinje fibres. The moderator band carries the right bundle branch to the anterior papillary muscle.
- Pericardium: fibrous plus serous; the **transverse sinus** lies behind the aorta and pulmonary trunk and in front of the superior vena cava and left atrium (a finger or ligature passed through it lets the surgeon clamp both great arteries in cardiac surgery), the **oblique sinus** behind the left atrium. The fibrous and parietal serous layers are supplied by the phrenic nerve, so pericarditis may refer pain to the shoulder tip; the visceral layer is insensitive.

Referred cardiac pain

- Cardiac pain afferents travel with the sympathetic cardiac nerves and enter the cord at **T1–T4 (T5)**, mainly on the left, the segments that also receive skin afferents from the medial arm (T1, and T2 through the intercostobrachial nerve) and the chest, so ischaemic pain is felt in the **chest and inner left arm**. Inferior wall ischaemia often presents as epigastric pain,

and its nausea, vomiting and bradycardia are vagal reflexes from the inferior wall (the Bezold–Jarisch reflex).

- Diaphragmatic irritation is referred to the shoulder tip (C3–C5, phrenic).

Lungs, airways and lymph

- **Right main bronchus**: **wider, shorter and more vertical** than the left, so foreign bodies enter it more often (right lower lobe or right intermediate bronchus). The carina is at T4–T5.
- Right lung: three lobes, two fissures (oblique and horizontal); left lung: two lobes with the lingula and the cardiac notch. Bronchopulmonary segments: ten on the right, eight to ten on the left.
- Pleura: the lower limit in the midclavicular line is rib 8, midaxillary 10, paravertebral 12; the lung is two ribs higher. The costodiaphragmatic recess is where effusion collects first.
- Hilum: from front to back, **vein, artery, bronchus** on both sides; the pulmonary veins are also the lowest. From above down: on the right the eparterial (upper lobe) bronchus, then the artery, then the main bronchus, then the veins; on the left the artery is highest, then the bronchus, then the veins.
- **Thoracic duct**: begins at the cisterna chyli (L1–L2), passes through the aortic opening of the diaphragm (T12), ascends in the posterior mediastinum, crosses to the left at T4–T5 and drains at the **junction of the left internal jugular and left subclavian veins** (the left venous angle). It drains all lymph below the diaphragm and the left side of the thorax, head, neck and left arm. The right lymphatic duct drains the right side of the head, neck and thorax and the right upper limb into the right venous angle. Injury (oesophagectomy, trauma) leads to chylothorax: on the right if the duct is torn below T5, on the left above it.
- Diaphragm openings: **caval T8**, in the central tendon (IVC, branches of the right phrenic nerve); **oesophageal T10**, in the muscle of the right crus (oesophagus, anterior and posterior vagal trunks, oesophageal branches of the left gastric vessels, lymphatics); **aortic T12**, behind the median arcuate ligament between the crura and so not truly in the diaphragm (aorta, thoracic duct, azygos vein). The left phrenic nerve pierces the muscle of the left dome; the greater, lesser and least splanchnic nerves pierce the crura; the sympathetic trunk passes behind the medial arcuate ligament. Motor supply of the diaphragm (crura included) is the **phrenic nerve, C3–C5**; the periphery's sensory supply is the lower intercostal nerves.
- **Foreign-body aspiration**: the right main bronchus is wider, shorter and more vertical. Upright or sitting, an object lodges in the **posterior basal segment of the right lower lobe**; lying supine, in the superior segment of the lower lobe or the posterior segment of the upper lobe. Each bronchopulmonary segment (10 right, 8–10 left) has its own bronchus and artery and is a resectable unit.
- **Pleural reflections and lung margins** (surface lines): midclavicular lung 6th rib, pleura 8th; mid-axillary lung 8th, pleura 10th; paravertebral (mid-scapular) lung 10th, pleura 12th.
- **Pleural tap**: the needle goes along the **upper border of the lower rib**, because the intercostal vein, artery and nerve run in the costal groove under the rib above; an **intercostal nerve block** is given just below the rib for the same reason. A chest drain goes in the triangle of safety.

Mediastinum

- Posterior mediastinum: oesophagus, descending thoracic aorta, thoracic duct, azygos and hemiazygos veins, sympathetic trunks, splanchnic nerves.
- The oesophagus is about 25 cm long (C6 to T11) and has four constrictions, measured from the upper incisors: **cricopharyngeus at 15 cm** (the narrowest), the **aortic arch at 22.5 cm**, the **left main bronchus at 27.5 cm** and the **diaphragm at 37.5–40 cm**; foreign bodies and strictures lodge at these. Oesophageal varices form at the lower end (left gastric veins with oesophageal tributaries of the azygos).
- Left recurrent laryngeal nerve hooks round the arch of the aorta just behind (lateral to) the ligamentum arteriosum, so it can be stretched by an aortic aneurysm, a large left atrium (Ortner syndrome) or hilar nodes; the right hooks round the right subclavian artery (the distal right sixth arch artery regresses, so the right nerve slips up to the fourth-arch artery).

Breast, suprapleural membrane and nodes

- **Breast**: lies on the second to sixth ribs over pectoralis major and serratus anterior, with an **axillary tail (of Spence)** entering the axilla; **suspensory ligaments of Cooper** run from the skin to the pectoral fascia, and their shortening by cancer gives skin dimpling. Blood from the perforating branches of the **internal thoracic artery** (a branch of the subclavian; the medial part), the **lateral thoracic** and thoracoacromial branches of the axillary artery, and the posterior intercostal arteries.
- **Lymphatic drainage of the breast**: about **75% to the axillary nodes** (mainly the anterior or pectoral group), the medial part and inner quadrants to the **internal thoracic (parasternal) nodes**, some to the opposite breast and to the supraclavicular nodes. The axillary nodes are divided into **levels I, II and III** by their position lateral to, behind and medial to **pectoralis minor**; the interpectoral (Rotter) nodes lie between the two pectoral muscles. Current practice stages the axilla by **sentinel node biopsy** rather than clearing all the nodes (the first node draining the tumour).
- **Suprapleural membrane (Sibson's fascia)**: a thickened extension of the endothoracic fascia over the cervical pleura, attached to the inner border of the first rib and the transverse process of C7; it roofs the thoracic inlet and protects the pleural dome, with scalenus minimus attached to it.

Abdomen and pelvis

Peritoneum and viscera

- **Retroperitoneal**: **primarily** retroperitoneal (never had a mesentery): kidneys, ureters, adrenals, aorta, IVC, the rectum's lower part. **Secondarily** retroperitoneal (had a mesentery and lost it by fusion): the **duodenum's 2nd–4th parts**, the **pancreas except its tail**, the **ascending and descending colon**, and the upper rectum (covered in front and at the sides). Intraperitoneal: stomach, the first 2–3 cm of the duodenum (the cap), jejunum, ileum, appendix, caecum (usually), transverse and sigmoid colon, liver, gallbladder (mostly), spleen, and the **tail of the pancreas, which lies in the splenorenal (lienorenal) ligament**.
- Lesser sac (omental bursa) opens by the epiploic foramen of Winslow: in front the free edge of the lesser omentum (hepatoduodenal ligament with the bile duct to the right,

hepatic artery to the left and the portal vein behind both), behind the IVC, above the caudate process of the liver, below the first part of the duodenum. Pressing the free edge (**Pringle manoeuvre**) controls hepatic inflow bleeding. **At the porta hepatis, from front to back: bile duct (hepatic ducts), hepatic artery, portal vein.** The portal vein forms **behind the neck of the pancreas** by the union of the superior mesenteric and splenic veins (L1–L2).

- Embryonic gut divisions and their supply: foregut (coeliac, down to the major duodenal papilla), midgut (superior mesenteric, to the junction of the proximal two-thirds and distal third of the transverse colon), hindgut (inferior mesenteric, to the **pectinate line** of the anal canal).
- **Riedel lobe**: a tongue-like downward extension of the right lobe of the liver, a normal variant (more common in women) that can be mistaken for a mass. **Appendices epiploicae** are fat-filled peritoneal tags found on the colon but absent from the caecum, appendix and rectum.
- **Accessory organs of digestion**: salivary glands, liver, gallbladder and pancreas; the spleen is not one.
- **Liver supply**: about **75% of the blood from the portal vein** and 25% from the hepatic artery, but the two give about equal shares of the oxygen. Each Couinaud segment has its own portal pedicle (branches of the portal vein, hepatic artery and bile duct) at its centre, with the hepatic veins running between segments, so it can be resected alone.
- **Epiploic foramen (Winslow)**: boundaries are the hepatoduodenal ligament in front, the IVC behind, the caudate process above and the first part of the duodenum below (the floor).
- **Root of the mesentery** (about 15 cm, duodenojejunal flexure to the right sacro-iliac joint) is crossed in order by the third part of the duodenum, aorta, IVC, right ureter, right psoas and right gonadal vessels; the left ureter is not crossed.
- **Appendix**: retrocaecal in about 65–75% (commonest), then pelvic; its base lies where the three taeniae coli converge.
- **Diaphragm minor openings**: psoas major passes deep to the **medial arcuate ligament**, quadratus lumborum deep to the lateral arcuate ligament and the aorta behind the median arcuate ligament; the left crus is pierced by the hemiazygos vein, the lumbocostal triangle (Bochdalek) and the sternocostal gap (Morgagni, Larrey) are weak spots.
- **Gallbladder fundus**: tip of the **ninth costal cartilage** at the lateral border of rectus abdominis (Murphy sign).
- **Enteric plexuses**: the **submucosal (Meissner)** plexus lies between the circular muscle and the muscularis mucosae and controls secretion and local blood flow; the **myenteric (Auerbach)** plexus lies between the circular and longitudinal muscle layers and controls motility; absence of ganglion cells in the distal part is Hirschsprung disease.
- **Kidney, posterior relations**: the diaphragm above, then psoas major, quadratus lumborum and transversus abdominis; nerves behind it are the subcostal (T12) and, from the lumbar plexus, the iliohypogastric and ilioinguinal (L1), whereas the anterior rami of L2–L4 are not met in a posterior (loin) approach.

Arterial supply

- **Coeliac trunk** (T12): left gastric (the **smallest**), splenic (the **largest**), common hepatic (gastroduodenal, then the proper hepatic, which gives the right gastric and the right and left hepatic arteries). An aberrant (replaced) right hepatic artery usually comes from the SMA, an aberrant left hepatic from the left gastric. The coeliac and SMA territories join through the **superior (from the gastroduodenal) and inferior (from the SMA) pancreaticoduodenal arcades** round the head of the pancreas. **SMA** (L1): inferior pancreaticoduodenal, middle colic, right colic, ileocolic, jejunal and ileal branches. **IMA** (L3): left colic, sigmoid, superior rectal.
- The **marginal artery of Drummond** joins the **superior and inferior mesenteric arteries** along the colon; the weak points are the splenic flexure (**Griffiths point**) and the rectosigmoid (**Sudeck point**), watersheds prone to ischaemic colitis.
- **Cystic artery**: usually from the **right hepatic artery**, in the hepatocystic triangle (cystic duct, common hepatic duct and the inferior surface of the liver; the original Calot's triangle of 1891 had the cystic artery as its upper border; the two names are now used for the same space). It may arise from the left hepatic, the gastroduodenal or a replaced right hepatic artery, or be double. The **cystic lymph node (Lund's node, also called Calot's or Mascagni's node)** lies in this triangle beside the cystic duct and artery: it is the gallbladder's sentinel node, often enlarged in cholecystitis, and a landmark for the cystic artery, which runs just above or behind it. The **critical view of safety** (SAGES; Strasberg) is the current standard in laparoscopic cholecystectomy: the triangle cleared of fat, the lower third of the gallbladder off the liver bed, and only two structures entering the gallbladder before anything is clipped.
- Appendicular artery: from the ileocolic artery, runs in the mesoappendix.
- Kidney: renal artery gives five segmental end arteries (apical, upper anterior, middle anterior, lower, posterior), so segmental infarction follows a block; accessory renal arteries are common (about a quarter of people). Left renal vein crosses in front of the aorta just below the SMA (compression there: nutcracker syndrome) and receives the left gonadal and left adrenal veins.

Portosystemic anastomoses

Site	Portal	Systemic	Clinical
Lower oesophagus	Left gastric	Oesophageal (azygos)	Oesophageal varices
Anorectal junction	**Superior rectal (via IMV)**	Middle and inferior rectal	**Haemorrhoids**
Umbilicus	**Paraumbilical veins**	**Superficial and inferior epigastric, thoracoepigastric**	**Caput medusae**
Retroperitoneum	Colonic veins	Renal, lumbar	Retroperitoneal varices
Bare area of liver	Portal radicles in the liver	Diaphragmatic (phrenic) veins	Rarely significant

- Normal portal pressure is 5–10 mmHg; current practice measures the **hepatic venous pressure gradient**: above 5 mmHg is portal hypertension, **10 mmHg or more clinically significant** (varices may form), and above 12 mmHg varices may bleed (Baveno VII, 2022).
- Internal haemorrhoids above the pectinate line are painless (visceral supply, inferior hypogastric plexus) and drain to portal; external haemorrhoids below are painful (inferior rectal nerve, somatic) and drain to the systemic system.

Pain, referred and visceral

- Foregut pain is epigastric, midgut periumbilical, hindgut suprapubic.
- **Appendicitis**: early pain is central and vague because the appendix's visceral afferents (sympathetic, with the superior mesenteric plexus) enter the cord at **T10**; later, as the parietal peritoneum is irritated, pain shifts to McBurney's point (one-third of the way from the right anterior superior iliac spine to the umbilicus) via somatic afferents.
- **Pancreas**: autonomic supply from the **coeliac plexus** (sympathetic fibres from the greater and lesser splanchnic nerves, vagal parasympathetic); pain is epigastric, radiating to the back, and coeliac plexus block relieves pancreatic cancer pain.
- **Splanchnic nerves**: greater T5–T9 (to the coeliac ganglion), lesser T10–T11 (aorticorenal), least T12 (renal); the vagus supplies the gut to the junction of the middle and left third of the transverse colon, the pelvic splanchnic nerves (S2–S4) the rest. Foregut, midgut and hindgut pain travels with the sympathetic afferents (about T6–T9, T8–T11 and T11–L2) and is felt in the epigastric, umbilical and suprapubic regions; their arteries (coeliac, superior and inferior mesenteric) arise at T12, L1 and L3.

Inguinal region

- **Inguinal canal**: about 4 cm long, from the deep ring (in the transversalis fascia, about 1.25 cm above the midinguinal point, lateral to the inferior epigastric artery) to the superficial ring (a gap in the external oblique aponeurosis above the pubic tubercle). Walls: anterior external oblique aponeurosis throughout (reinforced laterally by internal oblique), posterior transversalis fascia throughout with the conjoint tendon medially, floor the inguinal ligament (and the lacunar ligament medially), roof the arching fibres of internal oblique and transversus.
- **Contents in men**: spermatic cord (ductus deferens, testicular and cremasteric arteries, artery to the ductus, pampiniform plexus, genital branch of the genitofemoral nerve, lymphatics) and the **ilioinguinal nerve** (outside the cord; it enters the canal through its wall, between the internal and external obliques, **not through the deep ring**, and leaves by the superficial ring); in women the round ligament of the uterus and the ilioinguinal nerve. The **femoral artery does not pass through the canal**: it passes behind the inguinal ligament. **Cremasteric reflex (L1–L2)**: afferent the femoral branch of the genitofemoral (and the ilioinguinal), efferent the **genital branch of the genitofemoral nerve**; lost in testicular torsion.
- **Hesselbach's triangle**: lateral border **inferior epigastric vessels**, medial border the lateral edge of rectus abdominis, inferior border the inguinal ligament. **Direct hernias** pass medial to the inferior epigastric artery through the triangle; **indirect hernias** pass lateral to it through the deep ring, down the canal and may reach the scrotum.
- Femoral hernia: through the femoral ring and canal; its neck lies **below and lateral to the pubic tubercle** (an inguinal hernia's is above and medial); the rigid lacunar ligament gives it the highest risk of strangulation. Commoner in women than in men, though even in women the inguinal hernia is the commonest groin hernia.
- **Laparoscopic hernia repair triangles**: the **triangle of doom** between the vas deferens medially and the gonadal vessels laterally, apex at the deep ring, holds the **external iliac vessels** (no tacks or staples); the **triangle of pain** between the gonadal vessels and the iliopubic tract holds the **lateral femoral cutaneous nerve, femoral branch of the genitofemoral and the femoral nerve**.
- **Lumbar triangle of Petit** (inferior): latissimus dorsi, external oblique and the iliac crest, the site of an inferior lumbar hernia; the superior (Grynfeltt) triangle is larger and the commoner site.
- **Gastrinoma (Passaro) triangle**: the junction of cystic and common bile ducts, the junction of the second and third parts of the duodenum, and the junction of the neck and body of the pancreas; most duodenal and pancreatic gastrinomas lie in it.
- **Coverings of the testis and cord**: skin, dartos (smooth muscle), external spermatic fascia (external oblique), cremasteric muscle and fascia (internal oblique), internal spermatic fascia (transversalis fascia), then the tunica vaginalis.

Pelvis and perineum

- **Male urethra** (18–20 cm): preprostatic, **prostatic** (about 3 cm, the **widest and most dilatable**, with the **verumontanum (seminal colliculus)** on its posterior wall, where the prostatic utricle and the two ejaculatory ducts open; the verumontanum marks the distal limit of resection in TURP, since the external sphincter lies just beyond it; posterior urethral valves lie just distal to it), **membranous** (about 1.5 cm, the **shortest and least dilatable**, through the deep perineal pouch with the external sphincter), **spongy** (about 15 cm, the **longest**: the dilated **bulbar** part, the **commonest site of stricture**, then the penile part and the navicular fossa). The **external urethral meatus is the narrowest part** of the whole urethra; the membranous part is the narrowest after it. The **prostatic utricle** comes from the paramesonephric ducts (the male homologue of the uterus and upper vagina).
- **Rupture of the bulbar urethra** (straddle injury): blood at the meatus; urine extravasates into the **superficial perineal pouch**, limited by **Colles' fascia** (continuous with Scarpa's fascia), and so flows over the scrotum, penis and lower abdominal wall, not into the thigh (fascia lata attachment) or the anal region (the perineal membrane and fascia fuse at the posterior border). A **pelvic fracture urethral injury** tears the posterior urethra at or just above the membranous part (the bulbomembranous junction); urine and blood collect **above the perineal membrane**, in the deep pouch and the extraperitoneal retropubic space around the bladder, not in the scrotum, and the prostate may ride high on rectal examination. Blood at the meatus in either injury means a retrograde urethrogram before any catheter (Bailey & Love; EAU guidelines on urological trauma).
- **Deep perineal pouch** (classically between the perineal membrane and the superior fascia of the urogenital diaphragm; current texts such as Gray's describe it as open above to the pelvis, bounded only by the perineal membrane below) contains the membranous urethra, **sphincter urethrae**, deep transverse perinei and the **bulbourethral glands** (in the male), the dorsal nerve of the penis, the internal pudendal vessels and the artery to the bulb (in the female: part of the urethra and vagina, compressor urethrae and sphincter urethrovaginalis). The bulbourethral glands lie in the deep pouch, but their ducts open into the **bulbar (spongy) urethra**. The **corpora cavernosa (crura) and bulb are in the superficial pouch, not the deep**. The **superficial pouch** has the root of the penis (bulb, crura),

ischiocavernosus, bulbospongiosus, superficial transverse perinei and the greater vestibular glands in the female.

- **Pudendal nerve (S2–S4)** leaves the pelvis by the greater sciatic foramen below piriformis, crosses the sacrospinous ligament near the ischial spine and enters the perineum by the lesser sciatic foramen, runs in the pudendal (Alcock's) canal on the lateral wall of the ischioanal fossa, and supplies the external anal sphincter (inferior rectal nerve), the external urethral sphincter and perineal muscles (perineal nerve), and the skin of the perineum and the penis or clitoris (dorsal nerve). A pudendal block is given near the ischial spine.
- Lymphatic drainage: **testis → para-aortic (lumbar) nodes** at L1–L2 (it develops near the kidney; the right testis to the interaortocaval nodes, the left to the left para-aortic nodes below the left renal vein); scrotal and penile skin → superficial inguinal nodes; glans penis and the erectile tissue → deep inguinal nodes (including Cloquet's) and external iliac; ovary → para-aortic; uterine fundus → para-aortic, with the region near the cornua → superficial inguinal along the round ligament; body → external iliac; cervix → internal and external iliac, obturator and sacral; vagina, upper part → iliac, lower third → superficial inguinal; anal canal above the pectinate line → internal iliac, below → superficial inguinal; prostate and bladder → internal iliac (and obturator, external iliac).
- **Urethra**: lymph of the **anterior urethra (penile and the navicular fossa) → superficial and deep inguinal nodes**; the **bulbar → deep inguinal and external iliac**; the **posterior urethra (membranous and prostatic) → pelvic nodes (obturator, internal and external iliac)**. In the female the distal third → inguinal, the proximal two-thirds → pelvic.
- **Male urethral carcinoma** (rare; more common after stricture and chronic inflammation, HPV): **commonest in the bulbomembranous urethra (about 60%)**, then the penile (about 30%) and prostatic (about 10%). Most bulbomembranous and penile tumours are **squamous cell carcinoma**; prostatic ones are urothelial. So an anterior tumour spreads to the inguinal nodes, a bulbomembranous one to the deep inguinal and pelvic nodes. Exam books that ask "bulbar" against "membranous" mean the same bulbomembranous segment; the bulbar urethra is the commonest site of stricture.
- **Anal canal**: pectinate (dentate) line is the junction of endoderm and ectoderm; above it columnar mucosa, autonomic supply and portal-type drainage; below it stratified squamous, somatic (pain-sensitive) and caval drainage.
- Uterus: supported by the cardinal (Mackenrodt's, the most important), uterosacral and pubocervical ligaments and the pelvic floor (levator ani); the broad and round ligaments give little support. The **ureter passes under the uterine artery** ("water under the bridge") about 1.5–2 cm lateral to the cervix, at the level of the internal os, a point of surgical injury in hysterectomy.
- Ovarian artery from the aorta; right ovarian vein drains into the IVC, left into the left renal vein.
- Ligaments of the liver: falciform contains the ligamentum teres (obliterated umbilical vein); ligamentum venosum is the ductus venosus remnant.
- Spleen: lies against ribs 9–11, lienorenal and gastrosplenic ligaments, supplied by the splenic artery; the tail of the pancreas lies in the lienorenal ligament and may be injured in splenectomy.
- Kidney: the right is lower (about T12–L3; the left T11–L2); perirenal fat within the renal fascia of Gerota; the hilum is at L1 (transpyloric plane). Order at the hilum, front to back: renal vein, artery, pelvis. Ureteric colic radiates loin to groin (T11–L2). The ureter narrows at the pelviureteric junction, at the pelvic brim (crossing the iliac vessels) and at the vesicoureteric junction (the narrowest), where stones lodge.
- **Hilton white line**: the palpable intersphincteric groove at the lower border of the internal anal sphincter, at the junction of the transitional zone and the true skin of the lower canal; the pectinate line lies about 1.5 cm higher. The anal canal is about 4 cm: upper part (columnar, with the anal columns of Morgagni), a transitional zone and a lower keratinised skin part.
- **Male urethra**: preprostatic about 1 cm; prostatic about 3 cm and widest; **membranous about 1.5 cm and narrowest** (apart from the external meatus); spongy about 15 cm, with the terminal glans part of surface-ectoderm origin (the classic answer; recent developmental studies find the whole urethra endodermal). The female urethra is about 4 cm.
- **Median (midline) episiotomy** cuts the central perineal tendon (perineal body) and the superficial and deep transverse perineal muscles and bulbospongiosus; it enters the anal sphincter only if the tear extends (a third-degree tear). Current practice (RCOG Green-top 29, 2015; WHO 2018) uses a **mediolateral** cut at about 60° from the midline when an episiotomy is needed, since a midline one is more often extended into the sphincter, and advises against routine episiotomy.
- **Batson plexus**: the valveless internal vertebral venous plexus, linking pelvic veins (prostate) and the thoracic veins to the vertebrae, explains spread of prostate (and breast) cancer to the vertebrae, bypassing the lungs.

Remnants as ligaments

- Median umbilical ligament = urachus; medial umbilical ligaments = obliterated umbilical arteries; lateral umbilical folds = inferior epigastric vessels.

Suprarenal and gonadal veins, and the rectus sheath

- **Suprarenal veins**: the **right** is very short and opens **directly into the inferior vena cava** (so it is hard to ligate in right adrenalectomy); the **left** is longer, receives the left inferior phrenic vein and joins the **left renal vein**. Arterial supply of each gland: superior (inferior phrenic), middle (aorta) and inferior (renal) suprarenal arteries.
- **Testicular and ovarian veins**: the right drains into the IVC just below the renal vein and the **left into the left renal vein at a right angle**. The left vein is longer, its column of blood is taller and it is crossed by the sigmoid colon, so **varicocele is commoner on the left (about 85 to 90%)**; the left renal vein is also compressed between the aorta and the superior mesenteric artery (nutcracker). A **right-sided or sudden varicocele** in an older man that does not empty on lying down suggests a retroperitoneal mass or renal tumour thrombus compressing the vein.
- **Rectus sheath**: **above the arcuate line** (about halfway between the umbilicus and the pubic symphysis) the anterior wall is the external oblique aponeurosis plus the anterior lamina of the internal oblique, and the posterior wall the posterior lamina of the internal oblique plus transversus abdominis; **below the arcuate line** all three aponeuroses pass in front of the muscle and the posterior wall is only

transversalis fascia. Above the costal margin the muscle lies directly on the costal cartilages (fifth to seventh) with no posterior sheath. The muscle has **three tendinous intersections** adherent to the anterior sheath (not the posterior), the inferior epigastric vessels enter the sheath at the arcuate line, and the **linea semilunaris** (the lateral border of the rectus) is the site of **Spigelian hernia**, usually near the arcuate line.

Head and neck

Skull foramina

Foramen	Transmits
Cribriform plate	Olfactory nerve filaments, anterior ethmoidal nerve and vessels
Optic canal	Optic nerve, ophthalmic artery
Superior orbital fissure	III, IV, VI, V1 (lacrimal, frontal, nasociliary), superior ophthalmic vein, sympathetic fibres
Inferior orbital fissure	Infraorbital and zygomatic branches of V2, infraorbital vessels, inferior ophthalmic vein to the pterygoid plexus
Foramen rotundum	**Maxillary nerve (V2)**
Foramen ovale	**Mandibular nerve (V3)**, accessory meningeal artery, lesser petrosal nerve, emissary vein (cavernous sinus to pterygoid plexus); not the maxillary nerve or the middle meningeal artery
Foramen spinosum	**Middle meningeal artery** and vein, meningeal branch of V3 (nervus spinosus)
Foramen lacerum	Nothing passes through it (greater petrosal and deep petrosal nerves form the nerve of the pterygoid canal as they cross its upper surface)
Carotid canal	Internal carotid artery, sympathetic plexus
Internal acoustic meatus	VII, VIII, labyrinthine artery
Jugular foramen	IX, X, XI (middle part); the **inferior petrosal sinus** (front part) and the sigmoid sinus becoming the internal jugular vein, with meningeal branches of the occipital and ascending pharyngeal arteries (back part)
Hypoglossal canal	XII
Stylomastoid foramen	Facial nerve, stylomastoid artery
Petrotym-panic fissure	Chorda tympani (leaving the middle ear), anterior tympanic artery
Foramen magnum	Lower medulla with its meninges, vertebral arteries, anterior and posterior spinal arteries, spinal roots of XI, apical and alar ligaments and tectorial membrane

- **Arnold nerve** is the auricular branch of the **vagus** (from the jugular ganglion, through the mastoid canaliculus) to the floor of the external meatus; **Jacobson nerve** is the tympanic branch of the glossopharyngeal (tympanic canaliculus).
- The **foramen lacerum** transmits no major structure through its full length (the internal carotid crosses its upper part and the nerve of the pterygoid canal forms there). Greater palatine foramen: greater palatine nerve and vessels; lesser palatine foramina: lesser palatine nerves to the soft palate.

Mastication and the tongue

- All muscles of mastication (temporalis, masseter, medial and lateral pterygoids) come from the first arch and are supplied by the mandibular nerve: **medial pterygoid from the main trunk**, the other three from the anterior division.
- **Lateral pterygoid** is the only one that **opens the mouth** (protrudes the mandible by drawing the head and the articular disc forwards), helped by gravity and the suprahyoids; masseter, temporalis and medial pterygoid close it. Lateral pterygoid acting on one side produces the side-to-side grinding movement.
- **Tongue**: all intrinsic and extrinsic muscles are supplied by the **hypoglossal nerve** except **palatoglossus**, which is supplied through the **pharyngeal plexus (vagus, with cranial accessory fibres)**. Hypoglossal lesion: the tongue deviates **towards the side of the lesion** on protrusion (genioglossus is the protrusor; it is the "safety muscle" of the tongue, whose paralysis lets the tongue fall back and block the airway). Papillae: circumvallate (in a V in front of the sulcus terminalis, the largest, supplied by IX although they lie on the anterior two-thirds), fungiform, foliate (lateral margins) and filiform (the most numerous, **no taste buds**); von Ebner's serous glands open round the circumvallate papillae. Sensory: anterior two-thirds general sensation from the lingual nerve (V3), taste from the chorda tympani (VII); posterior third both from IX; the valleculae and posterior-most part from the internal laryngeal nerve (X).
- Tongue lymph: tip to submental nodes, sides of the anterior two-thirds to submandibular, central part to the deep cervical nodes of both sides, posterior third to the jugulodigastric nodes bilaterally; the **jugulo-omohyoid node** is the "lymph node of the tongue".
- **Parotid gland**: duct (Stensen's) crosses the masseter, pierces buccinator and opens in the vestibule of the mouth **opposite the upper second molar**. The facial nerve divides the gland into superficial and deep lobes (it runs through but is not a supply of it); parotid secretomotor fibres come from the glossopharyngeal nerve through the lesser petrosal nerve, otic ganglion and the auriculotemporal nerve. Submandibular duct (Wharton's) opens at the sublingual papilla beside the frenulum; the lingual nerve hooks beneath it.
- **Parasympathetic supply of glands**: the **superior salivatory nucleus** (facial) sends fibres via the greater petrosal nerve to the **pterygopalatine ganglion** (lacrimal gland, nasal and palatine glands) and via the chorda tympani to the **submandibular ganglion** (submandibular and sublingual glands); the **inferior salivatory nucleus** (glossopharyngeal) sends fibres via the lesser petrosal nerve to the **otic ganglion** (parotid).

Larynx and thyroid

- Sensory: **internal laryngeal nerve** (internal branch of the superior laryngeal, piercing the thyrohyoid membrane) supplies the mucosa **above the vocal folds** and is the afferent limb of the cough reflex; the **recurrent laryngeal nerve** supplies below them and all intrinsic muscles **except cricothyroid**, which is supplied by the **external laryngeal nerve**.
- **Cricothyroid** tenses the vocal folds: external laryngeal nerve injury (close to the superior thyroid artery near the upper pole) leads to loss of **high-pitched voice** and easy voice fatigue, which is why the surgeon ligates the artery on the

gland. After thyroidectomy with recurrent nerve injury the cord is paralysed (median or paramedian) but **cricothyroid still works**; bilateral injury gives stridor. The inferior thyroid artery lies close to the recurrent nerve at the lower pole.

- Posterior cricoarytenoid is the only abductor of the vocal folds (safety muscle). Lateral cricoarytenoid and interarytenoids adduct; thyroarytenoid relaxes.
- **Superior thyroid artery**: first anterior branch of the **external carotid artery**; inferior thyroid artery from the thyrocervical trunk (subclavian); the internal carotid gives no branches in the neck; a thyroidea ima artery is present in a few. Veins: superior and middle drain to the internal jugular; inferior to the brachiocephalic.
- Branches of the external carotid (in order): superior thyroid, ascending pharyngeal, lingual, facial, occipital, posterior auricular, then the terminal branches, maxillary and superficial temporal. The **superficial temporal artery is a terminal branch, not a branch of the maxillary artery**.
- **Maxillary artery** branches: first part (mandibular) gives the **middle meningeal**, inferior alveolar and anterior tympanic; second part (pterygoid) to the muscles of mastication; third part (pterygopalatine) gives the posterior superior alveolar, infraorbital, descending palatine, sphenopalatine (the main supply of the nasal septum) and others.
- Kiesselbach's plexus (Little's area) on the anterior inferior septum: anastomosis of the anterior ethmoidal, sphenopalatine (septal branch), greater palatine and the septal branch of the superior labial arteries; the commonest site of epistaxis, especially in the young. Posterior bleeding in older adults comes from **Woodruff's plexus** (sphenopalatine and posterior pharyngeal branches) under the posterior end of the inferior turbinate.

Facial nerve and palsies

- **Upper motor neuron lesion**: lower face paralysed with the **forehead spared**, because the neurons of the facial nucleus for the upper face receive **bilateral corticobulbar** input. Lower motor neuron lesion paralyses the whole half of the face (Bell's palsy, the commonest).
- Branches by site of lesion in the facial canal: greater petrosal (lacrimation) at the geniculate ganglion; nerve to stapedius (**hyperacusis**); chorda tympani (**taste to the anterior two-thirds of the tongue**, submandibular and sublingual secretion). A lesion between the geniculate ganglion and the nerve to stapedius gives hyperacusis and loss of taste with **normal tear secretion**; at the stylomastoid foramen only motor loss. Branches in the parotid: temporal, zygomatic, buccal, marginal mandibular, cervical ("To Zanzibar By Motor Car").
- Ramsay Hunt syndrome: herpes zoster of the geniculate ganglion with ear vesicles and facial palsy.

Venous and spaces

- **Dangerous area of the face**: the facial vein communicates with the superior ophthalmic vein at the medial angle of the eye and with the pterygoid plexus through the deep facial vein; these veins are **valveless**, so infection of the upper lip and nose may reach the **cavernous sinus** (thrombophlebitis); the facial vein's normal outflow is down to the internal jugular vein. The cavernous sinus contains the internal carotid artery and VI in its lumen; III, IV, V1 and V2 in its lateral wall.
- Cervical fascia: the carotid sheath contains the common and internal carotid arteries, the internal jugular vein and the vagus nerve.
- Triangles of the neck: anterior (submental, submandibular, carotid, muscular); posterior (occipital, supraclavicular). The **spinal accessory nerve** crosses the roof of the posterior triangle superficially, leaving the posterior border of sternocleidomastoid just above the nerve point of the neck (where the cutaneous branches of the cervical plexus emerge, also called Erb's point); injury in lymph node biopsy paralyses trapezius, giving shoulder drop, weak shoulder shrug and abduction above 90°, and mild lateral winging of the scapula.
- **Tonsil**: the tonsillar bed is formed by the superior constrictor and the pharyngobasilar fascia; the **glossopharyngeal nerve** lies on the lateral wall of the tonsillar fossa, so injury in tonsillectomy gives loss of taste and sensation over the posterior third of the tongue and earache (referred, via Jacobson's tympanic branch). Arterial supply: tonsillar branch of the facial artery (main), plus the ascending pharyngeal, lingual, ascending palatine and greater palatine arteries; the paratonsillar vein is a source of post-tonsillectomy bleeding.
- Waldeyer's ring: pharyngeal tonsil (adenoids), tubal tonsils, palatine tonsils, lingual tonsil.
- Eustachian tube: about 36 mm in the adult; bony part (lateral third, at the middle ear) and cartilaginous part (medial two-thirds, opening into the nasopharynx); it is opened chiefly by **tensor veli palatini** (V3), helped by levator veli palatini and salpingopharyngeus; in infants it is shorter, wider and more horizontal, favouring otitis media.
- Middle ear: the tympanic cavity communicates with the mastoid antrum; chorda tympani crosses between the malleus and incus; stapedius (facial nerve) and tensor tympani (V3) dampen sound.
- Pharynx: all muscles supplied by the vagus (pharyngeal plexus) except **stylopharyngeus (glossopharyngeal)**; the gap of Killian's dehiscence between thyropharyngeus and cricopharyngeus is the site of a pharyngeal pouch (Zenker).
- The **common facial vein** is the facial vein joined by the anterior division of the retromandibular vein, draining to the internal jugular vein; the posterior division joins the posterior auricular vein to form the external jugular vein.

Paranasal sinuses, orbit muscles and the jaw joint

- **Paranasal sinuses**: the **maxillary sinus is the largest** (it is the first to appear, and the frontal and sphenoid sinuses are tiny at birth); it opens high on its medial wall into the **middle meatus** (hiatus semilunaris), which drains poorly when upright, so infection persists; its roof is the floor of the orbit (infraorbital nerve) and its floor lies near the roots of the upper molars. **Frontal and anterior ethmoidal** sinuses and the **maxillary** open into the middle meatus; **posterior ethmoidal** into the superior meatus; **sphenoid** into the sphenoethmoidal recess above the superior concha. The **nasolacrimal duct** opens into the **inferior meatus**. Pituitary tumours are removed through the sphenoid sinus (transsphenoidal approach).
- **Extraocular muscles**: all supplied by the oculomotor nerve except the **lateral rectus (abducens)** and **superior oblique (trochlear)** ("LR6 SO4"). Lateral and medial recti only abduct and adduct; the **superior and inferior recti elevate and depress mainly in abduction**, and the **obliques act mainly in adduction** (superior oblique depresses, inferior oblique elevates); the superior oblique also intorts the eye and the

inferior oblique extorts it. Test a superior oblique by looking down while adducted. The levator palpebrae superioris (oculomotor, with sympathetic Müller's muscle) lifts the lid.

- **Temporomandibular joint**: a synovial joint between the mandibular condyle and the articular fossa and tubercle, with a **fibrocartilaginous disc** dividing it into upper (gliding, translation) and lower (hinge) compartments. Opening is by the **lateral pterygoid**, which pulls the condyle and disc forward; **dislocation is anterior** (the condyle moves in front of the articular tubercle in yawning), the mouth stays open and reduction is by pressing the mandible down and back. Closure is by masseter, temporalis and medial pterygoid. Its sensory supply is the auriculotemporal and masseteric nerves, hence ear pain from joint disease.

Craniovertebral joints

- The **atlanto-occipital joint** (ellipsoid; nodding, 'yes') and the **atlanto-axial joints** (pivot at the median joint; rotation, 'no'). The **transverse ligament of the atlas** holds the dens against the anterior arch (its rupture, as in rheumatoid arthritis or Down syndrome, allows cord compression); the **alar ligaments** limit rotation and side-flexion; the **apical ligament** is a notochord remnant.
- The **tectorial membrane** is the upward continuation of the **posterior longitudinal ligament**, covering the dens from behind; the anterior longitudinal ligament continues as the anterior atlanto-occipital membrane.

Neuroanatomy

Ascending tracts

- **Dorsal column–medial lemniscus** (fine touch, vibration, proprioception): first-order neurons in the dorsal root ganglion ascend ipsilaterally in the gracile (medial: sacral, lumbar and lower thoracic fibres, below T6, so the lower limb) and cuneate (lateral: T6 and above, so the upper limb; present only above T6) fasciculi to their nuclei in the medulla; second-order neurons cross as **internal arcuate fibres in the lower medulla** (the sensory decussation) to form the medial lemniscus, ending in the VPL nucleus of the thalamus, then the primary somatosensory cortex.
- **Spinothalamic** (lateral: pain and temperature; anterior: crude touch and pressure): first-order neurons enter, may run up or down a segment in Lissauer's tract and synapse in the dorsal horn (substantia gelatinosa, nucleus proprius); the second-order axons **cross in the anterior white commissure** within one or two segments, then ascend contralaterally to the VPL nucleus. So a lateral cord lesion abolishes pain and temperature on the opposite side from one or two segments below it.
- A lesion of the dorsal column high in the neck (a stab to the back of the cervical cord) loses proprioception and vibration on the **same side**, in the arm and leg if both fasciculi are cut, the arm alone if only the cuneate is cut.
- Spinocerebellar tracts carry unconscious proprioception ipsilaterally (dorsal, via the inferior cerebellar peduncle; ventral crosses twice and enters via the superior peduncle).
- **Pseudounipolar neurons**: the dorsal root ganglion cells and the trigeminal mesencephalic nucleus cells (the single process divides in a T).
- **Somatotopy**: in the dorsal columns the gracile fasciculus (legs) is medial and the cuneate (arms) lateral; in the lateral corticospinal and spinothalamic tracts sacral fibres are lateral (superficial) and cervical medial, which is why a central cord lesion (syringomyelia) spares sacral pain and a compressing extrinsic mass affects sacral levels first.
- **Neuron and glia basics**: Nissl substance (rough endoplasmic reticulum) is in the cell body and dendrites but not the axon or axon hillock; **GFAP** marks astrocytes; microglia (yolk-sac derived) fuse into multinucleate giant cells in HIV encephalitis; **Schwann cells** myelinate one axon segment each (peripheral nerve; target of Guillain–Barré), whereas an **oligodendrocyte** myelinates about 30 central axons (target of multiple sclerosis and PML).

Descending tracts and cord lesions

- **Corticospinal**: 80–90% of fibres cross at the **pyramidal decussation** in the lower medulla and form the lateral tract; the rest form the anterior tract. UMN lesions: spasticity, hyperreflexia, extensor plantar response; LMN lesions: flaccid weakness, wasting, fasciculations, areflexia.
- **Brown-Séquard (hemisection)**: **ipsilateral** UMN weakness (corticospinal) and loss of vibration and position sense (dorsal column) below the lesion, **contralateral** loss of pain and temperature (spinothalamic, which crossed lower), starting one or two segments below; at the level of the lesion, ipsilateral LMN flaccid paralysis and segmental anaesthesia (anterior horn cells and root destroyed), which explains **flaccid muscles at the level and spasticity below**.
- **Syringomyelia**: a central cavity, usually in the cervical cord, cuts the crossing spinothalamic fibres in the **anterior white commissure**, giving a "cape" loss of pain and temperature in the arms with **preserved light touch and vibration**; later anterior horn damage gives wasting of the hands.
- Anterior spinal artery occlusion: bilateral motor loss and loss of pain and temperature with preserved dorsal columns. Subacute combined degeneration: dorsal columns and lateral corticospinal tracts (B12).
- **Lower end of the cord (conus medullaris)**: in the adult at the **lower border of L1 or the L1–L2 disc** (range T12 to L3). In the fetus it fills the whole canal at 3 months, lies at S1 at 6 months; **at birth it is at the upper border of L3** (the exam answer for "a child" or "newborn": L3), and it reaches the adult level in early infancy (ultrasound and MRI series: within the first 2–5 months). A conus below L2–L3 after infancy suggests a tethered cord. The **dural sac and subarachnoid space end at S2**; the filum terminale runs from the conus to the coccyx. Lumbar puncture is done at L3–L4 or L4–L5 (the supracristal (Tuffier) line joining the iliac crests crosses the L4 spine or the L4–L5 space); in neonates at L4–L5 or below.
- Other cord landmarks: cervical enlargement C4–T1 segments (the brachial plexus), lumbar enlargement L1–S3 segments (behind the T9–T12 vertebrae); the **artery of Adamkiewicz** (arteria radicularis magna) arises from a left posterior intercostal or lumbar artery at T9–T12 in most people and supplies the lower two-thirds of the cord, so its loss in aortic surgery gives anterior spinal artery syndrome; the watershed of the cord's blood supply is the mid-thoracic region (T4–T9). Sympathetic outflow T1–L2; sacral parasympathetic S2–S4.
- **Babinski sign** (extensor plantar response) indicates an upper motor neuron lesion; it is normal in infants up to about 1–2 years. **Cord motor levels**: C3–C5 diaphragm, C5–C6 deltoid and biceps, C7 triceps, L2–L4 quadriceps, L4–L5 ankle dorsiflexion, S1–S2 plantar flexion. There are 31 pairs of spinal nerves; C1–C7 leave above their vertebra, C8 between C7 and T1, and all the rest below.

Brainstem

- Midbrain: oculomotor (III) and trochlear (IV) nuclei, red nucleus, substantia nigra, **superior colliculus (visual reflexes)** and **inferior colliculus (auditory)**. The **inferior colliculus** relays the auditory pathway: cochlear nuclei → superior olivary complex → lateral lemniscus → **inferior colliculus** → medial geniculate body → auditory cortex (areas 41, 42 in the superior temporal gyrus; hearing is bilateral).
- Optic pathway: retina → optic nerve → chiasm (nasal fibres cross) → optic tract → **lateral geniculate body** → optic radiation → striate cortex (area 17, on the calcarine sulcus). The **pupillary light reflex** goes from the optic tract to the **pretectal nucleus** and on to both Edinger–Westphal nuclei, bypassing the geniculate body (so a pupil reacts in cortical blindness). The **superior colliculus** serves reflex eye and head turning towards a visual stimulus (reflex saccades); voluntary saccades are the frontal eye field's (area 8); smooth pursuit the parieto-occipital cortex with the cerebellum. Dorsal ("where", motion and space) stream to the parietal cortex, ventral ("what", objects and faces) to the inferior temporal cortex. The inferior colliculus and medial geniculate body are auditory, not visual.
- Pons: V, VI, VII, VIII nuclei. Medulla: IX, X, XI (cranial), XII.
- **Medial medullary syndrome** (occlusion of the **anterior spinal artery** or vertebral artery branches): pyramid lesion gives **contralateral hemiparesis**, medial lemniscus lesion **contralateral loss of vibration and position sense**, and hypoglossal nucleus or nerve lesion gives ipsilateral tongue deviation **towards the lesion** (so the tongue deviates to the side opposite the weakness). Lateral medullary (Wallenberg) syndrome, classically "PICA syndrome" but more often from occlusion of the **vertebral artery** (current series): ipsilateral facial pain and temperature loss, contralateral body pain and temperature loss, Horner syndrome, hoarseness and dysphagia (nucleus ambiguus), vertigo, ataxia.
- **Nucleus of the tractus solitarius**: taste from VII, IX, X (rostral gustatory part), visceral sensation. **Spinal nucleus of the trigeminal**: pain and temperature from the face (main sensory nucleus in the pons: touch; mesencephalic nucleus: proprioception from the muscles of mastication). **Nucleus ambiguus**: branchial motor fibres of IX, X and the cranial accessory. Dorsal motor nucleus of X: parasympathetic. Edinger–Westphal nucleus: parasympathetic III (pupillary constriction).
- **Trochlear nerve**: the only cranial nerve to leave the **dorsal** brainstem (below the inferior colliculus), the only one to **decussate** fully before emerging (nucleus supplies the contralateral superior oblique), the **thinnest**, and has the **longest intracranial course** (about 7.5 cm; vulnerable in head injury). Other superlatives asked: the longest intradural course, the **abducens**; the longest course in bone, the **facial**; the largest, the **trigeminal**; the longest overall and widest distribution, the **vagus**; the shortest, the olfactory.
- **Cranial nerve nuclei by level** ("rule of four"): midbrain III, IV; pons V, VI, VII, VIII; medulla IX, X, XI (cranial part), XII; I and II are outgrowths of the forebrain and have no brainstem nuclei. Purely sensory: I, II, VIII; purely motor: III, IV, VI, XI, XII; mixed: V, VII, IX, X. Palsy: **vertical diplopia worst when looking down and in** (reading, descending stairs) with a **head tilt away from the lesion** (towards the opposite shoulder).
- **Oculomotor palsy**: eye "down and out" with ptosis and a dilated pupil. Compression (e.g. **posterior communicating artery aneurysm**) affects the superficial parasympathetic fibres first, so a dilated pupil is early; ischaemic (diabetic) lesions spare the pupil. Uncal herniation also compresses III.
- Abducens palsy: medial deviation, horizontal diplopia; long course makes it vulnerable to raised intracranial pressure (false localising sign).
- **Weber syndrome** (ventral midbrain, cerebral peduncle): ipsilateral third-nerve palsy with contralateral hemiparesis; **Claude** is the tegmental version with contralateral ataxia from the red nucleus; **Millard–Gubler** (ventral pons): ipsilateral abducens and facial palsy with contralateral hemiplegia; Foville (dorsal pons) adds an ipsilateral gaze palsy. **Medial medullary (Dejerine)** syndrome, from the anterior spinal artery: ipsilateral tongue weakness, contralateral hemiplegia and loss of vibration and position sense; the lateral medullary one is Wallenberg.
- **Adie tonic pupil**: damaged **ciliary ganglion**, giving a large, slowly reacting pupil with slow near constriction, supersensitive to dilute pilocarpine; with absent knee jerks it is Holmes–Adie syndrome. The ciliary ganglion relays the Edinger–Westphal fibres that constrict the pupil.
- **Colliculi**: the superior colliculus is for visual reflexes and eye movements, the inferior colliculus a relay in the auditory pathway.

Cortex, thalamus and basal ganglia

- **Broca's area** (areas 44, 45), **inferior frontal gyrus of the dominant hemisphere**: expressive (non-fluent) aphasia with comprehension preserved. **Wernicke's area** (area 22), posterior superior temporal gyrus: fluent aphasia with poor comprehension. Arcuate fasciculus joins them (conduction aphasia).
- Motor cortex: area 4, precentral gyrus; premotor area 6; frontal eye field area 8; primary sensory areas 3, 1, 2; primary visual cortex area 17.
- **Posterior parietal cortex** (areas 5, 7): spatial awareness and visually guided reaching; lesions give contralateral neglect (non-dominant side), optic ataxia (misreaching despite normal acuity and power), and constructional apraxia. Dominant parietal lesion: Gerstmann syndrome (agraphia, acalculia, finger agnosia, left-right disorientation).
- **Hypothalamus**: **ventromedial nucleus** is the satiety centre (bilateral lesion gives hyperphagia and obesity; leptin acts through the arcuate nucleus); **lateral hypothalamic area** is the feeding and thirst centre (lesion gives aphagia and weight loss); anterior hypothalamus (preoptic area) is the heat-loss centre (lesion gives hyperthermia), posterior is heat-conserving (lesion gives poikilothermia); suprachiasmatic nucleus controls circadian rhythm (from the retinohypothalamic tract); the ventrolateral preoptic nucleus promotes sleep; supraoptic (mainly ADH) and paraventricular (mainly oxytocin, and CRH and TRH from its parvocellular part) make the posterior pituitary hormones.
- Thalamic nuclei: **VPL** (body sensation), **VPM** (face and taste), **LGB** (vision), **MGB** (hearing), VL (cerebellar and pallidal motor input), anterior (Papez circuit, limbic).
- **Basal ganglia circuits**: the **direct pathway** (striatum → GPi/SNr → thalamus) facilitates movement; the **indirect pathway** (striatum → GPe → subthalamic nucleus → GPi) inhibits it. **Dopamine from the substantia nigra pars compacta excites the direct pathway through D1 receptors and inhibits the indirect pathway through D2 receptors**, so its loss in Parkinson disease makes the direct pathway underactive and

the indirect overactive, reducing thalamic excitation of the cortex (rigidity, bradykinesia, rest tremor). Hemiballismus: contralateral subthalamic nucleus lesion. Huntington disease: caudate atrophy.

- **Hippocampus** (medial temporal lobe) converts short-term into long-term (declarative) memory; bilateral damage gives **anterograde amnesia** (the case of H.M.). Its **CA1 field (Sommer's sector)** is the part of the brain most sensitive to hypoxia; Negri bodies of rabies are found in its pyramidal cells. **Amygdala**: fear and emotional memory; bilateral lesions give **Klüver–Bucy syndrome** (hyperorality, hypersexuality, placidity, visual agnosia). **Papez circuit**: hippocampus → fornix → mammillary body → (mammillothalamic tract) → anterior thalamic nucleus → cingulate gyrus → back to the hippocampus; the mammillary bodies are damaged in Wernicke–Korsakoff syndrome (thiamine).
- Cerebellum: vermis controls the trunk (lesion: truncal ataxia, usually in children with medulloblastoma), hemispheres the limbs (lesion: ipsilateral intention tremor, dysmetria, dysdiadochokinesia); deep nuclei from medial to lateral: fastigial, globose, emboliform, dentate (the mnemonic "Don't Eat Greasy Food" runs the other way, lateral to medial); the dentate is the largest and sends the main output through the superior cerebellar peduncle to the opposite VL thalamus.
- **Hypothalamus**: anterior (preoptic) area heat loss (cooling), posterior area heat conservation (a lesion causes poikilothermia), suprachiasmatic nucleus the circadian pacemaker (retinal input), supraoptic and paraventricular nuclei make ADH and oxytocin, lateral area hunger (ghrelin acts here), ventromedial area satiety (leptin). **Kallmann syndrome**: GnRH neurons fail to migrate with the olfactory placode, giving anosmia with hypogonadotropic hypogonadism; damage to the ventromedial area after craniopharyngioma surgery gives hyperphagia.
- The **pineal gland** secretes melatonin (corpora arenacea, 'brain sand', calcify with age); the **globus pallidus** arises from the diencephalon, the striatum from the telencephalon (the classic, Langman's, answer; current developmental work traces the pallidum to the medial ganglionic eminence of the telencephalon).

Vascular supply and CSF

- Circle of Willis: anterior communicating artery joins the two anterior cerebral arteries; posterior communicating joins the internal carotid and posterior cerebral. The commonest site of berry aneurysm is the **anterior communicating artery**, the second the posterior communicating artery. MCA supplies the lateral surface (face and arm motor and sensory areas, Broca and Wernicke); ACA the medial surface (leg area): ACA infarct gives contralateral leg weakness; PCA the occipital lobe (contralateral homonymous hemianopia with macular sparing).
- Lenticulostriate branches of the MCA supply the internal capsule and are the usual site of hypertensive haemorrhage (Charcot–Bouchard aneurysms) and lacunar infarcts. The posterior limb of the internal capsule carries the corticospinal tract.
- **CSF**: made mainly by the choroid plexus (about 500 mL a day, 0.35 mL a minute; total volume **125–150 mL**, of which about 25 mL is in the ventricles, so it turns over three to four times a day); flows lateral ventricles → interventricular foramen of Monro → third → aqueduct of Sylvius → fourth → foramina of Luschka (two lateral) and Magendie (median) → subarachnoid space → arachnoid granulations → superior sagittal sinus (current work adds drainage along cranial nerves to lymphatics and the meningeal lymphatics).
- **Hydrocephalus**: **non-communicating (obstructive)**, blocked within the ventricles, most often at the aqueduct; **communicating**, with the ventricles open to the subarachnoid space but absorption impaired (after meningitis or subarachnoid haemorrhage) or, rarely, CSF overproduced (choroid plexus papilloma). **Aqueductal stenosis is the commonest cause of congenital hydrocephalus**. Signs in an infant: a head growing too fast, bulging fontanelle, separated sutures, "setting-sun" eyes, the cracked-pot (Macewen) sign; ultrasound through the fontanelle in the newborn. **Normal pressure hydrocephalus** in the elderly: gait disturbance (magnetic gait), urinary incontinence and dementia ("wet, wobbly, wacky"), helped by a ventriculoperitoneal shunt.
- Extradural haemorrhage: middle meningeal artery with a fracture at the pterion (lucid interval; biconvex on CT); subdural: torn bridging (superior cerebral) veins (crescentic, the elderly and alcoholics); subarachnoid: trauma is the commonest cause overall, a ruptured berry aneurysm the commonest cause of a spontaneous one (about 85%).
- **Pain-sensitive intracranial structures**: the dura (at the base and along the sinuses), the dural venous sinuses, the falx, the middle meningeal and the large arteries at the base near the circle of Willis, and the cranial nerves V, IX, X. **Insensitive**: the brain parenchyma, the pia and arachnoid over the convexity, the choroid plexus, the ependyma and most of the dura over the convexity. The supratentorial dura refers pain through V (front of the head), the infratentorial through C2–C3 and IX, X (the back).
- Cranial nerve nuclei mnemonic by function: motor III, IV, VI, XII medial; sensory V, VII, IX, X lateral (sulcus limitans).
- **Blood–brain barrier**: tight junctions of capillary endothelium, its basement membrane and astrocyte foot processes. The **circumventricular organs** (area postrema, OVLT, subfornical organ, neurohypophysis) lack it; loss of tight junctions gives vasogenic oedema. The area postrema is the **chemoreceptor trigger zone**, activated by blood-borne emetics acting on D2, 5-HT3 and NK-1 receptors; the vomiting centre is in the medullary reticular formation.
- **Territories**: anterior cerebral artery (contralateral leg weakness more than arm, urinary incontinence, abulia), posterior cerebral artery (contralateral homonymous hemianopia with macular sparing; the thalamic syndrome from its perforators), the middle cerebral artery the face and arm.
- **Lumbar puncture needle** passes through skin, superficial fascia, supraspinous and interspinous ligaments, ligamentum flavum, epidural space, dura and arachnoid, into the subarachnoid space, at L3–L4 or L4–L5 in an adult (the cord ends at L1–L2) and in a child at L4–L5 or L3–L4, never higher (the cord ends at about L3 at birth and rises to the adult level during infancy); the roots below the cord form the **cauda equina**.

Perforating arteries of the basal ganglia

- **Charcot's artery of cerebral haemorrhage** is the **lateral lenticulostriate branch of the middle cerebral artery**: a long, thin end artery that arises at a right angle under high pressure and supplies the putamen, globus pallidus and the **posterior limb of the internal capsule**, so hypertensive bleeding here gives a contralateral hemiplegia. The **recurrent artery of**

Heubner (from the anterior cerebral artery) supplies the head of the caudate and the anterior limb of the capsule; the anterior choroidal artery (internal carotid) supplies the posterior limb's lower part and optic tract.

- **Pituitary and chiasma**: the optic chiasma lies just above the diaphragma sellae and the pituitary; a pituitary macroadenoma growing upwards compresses the crossing nasal retinal fibres, giving **bitemporal hemianopia** (upper outer quadrants first because the lower nasal fibres are pressed first); a craniopharyngioma pressing from above gives the lower quadrants first. The cavernous sinus lies laterally, so lateral extension gives ocular palsies.

Embryology

Early development

- Week 1: the oocyte stays fertilisable for about 24 hours and sperm survive about 48–72 hours; sperm undergo capacitation in the female tract, then the acrosome reaction at the zona pellucida. Fertilisation is in the **ampulla** of the uterine tube within about a day of ovulation; cleavage; morula (16 cells, day 3–4, entering the uterus); blastocyst (inner cell mass = embryoblast; trophoblast) by day 4–5, hatches from the zona pellucida (day 5; an IVF blastocyst is transferred on day 5); implantation begins around **day 6–7** (end of week 1) and is complete by days 10–12 (interstitial: the blastocyst sinks wholly into the endometrium). Implantation is normally in the posterior wall of the fundus; implantation near the internal os gives placenta praevia, in the tube gives ectopic pregnancy (ampulla commonest).
- Week 2 ("rule of twos"): bilaminar disc (epiblast, hypoblast; day 8), amniotic cavity and yolk sac (primary yolk sac day 9); trophoblast differentiates into **cytotrophoblast and syncytiotrophoblast** (which secretes hCG from implantation, detectable in maternal blood from about day 8–10 after fertilisation); lacunae open into maternal sinusoids, so the uteroplacental circulation begins about day 11–13. The prechordal plate (future oropharyngeal membrane, ectoderm and endoderm without mesoderm) forms at the end of the week.
- Week 3: **gastrulation** (from about day 15–16): primitive streak and node form the three germ layers (ectoderm, mesoderm, endoderm; trilaminar disc) and the notochord; neurulation begins (neural plate day 18, neural folds fuse from day 22, starting in the future cervical region); somites from paraxial mesoderm appear from day 20; the heart begins to beat at about day 22, so the **cardiovascular system is the first to function**. **Correct sequence: ovulation, fertilisation, implantation, gastrulation.**
- Fetal period from week 9; organogenesis in weeks 3–8 is the period most sensitive to teratogens (all-or-none effect in the first two weeks after fertilisation). Gestational sac on transvaginal ultrasound from about 4.5–5 weeks after the last period (about 5–6 weeks transabdominally).
- Germ layer derivatives: ectoderm gives epidermis, nervous system, lens, inner ear, anterior pituitary, enamel, adrenal medulla (neural crest); mesoderm (paraxial: somites, skeletal muscle, vertebrae, dermis of the back; intermediate: kidneys and gonads; lateral plate: body wall, limbs, gut wall, heart) gives muscle, bone, heart, blood, kidneys, gonads, spleen, adrenal cortex; endoderm gives the gut lining, liver, pancreas, lungs, thyroid, parathyroids, thymus, bladder lining.
- **Neural crest** derivatives: melanocytes, dorsal root, cranial sensory and autonomic ganglia, Schwann cells, adrenal medulla (chromaffin cells), the pia and arachnoid (the dura is mesoderm), aorticopulmonary and conotruncal septa, odontoblasts (dentine, pulp, cementum), the pharyngeal arch skeleton and most bones of the face and skull vault, the corneal stroma and endothelium, and enteric ganglia. **Neural tube** gives the brain, spinal cord (and cauda equina), retina, posterior pituitary, oligodendrocytes, astrocytes and ependyma. The thyroid C cells are classically neural crest (via the ultimobranchial body); lineage tracing in mice (2015) shows they come from endoderm, and the exam answer remains neural crest.
- Neural tube defects: failure of closure of the cranial (rostral) neuropore (**day 25**) gives anencephaly, of the caudal neuropore (**day 27–28**; texts give one or the other) spina bifida; raised maternal serum and amniotic fluid alpha-fetoprotein, with acetylcholinesterase; prevented by periconceptional folic acid (0.4 mg, 4 mg after a previous affected pregnancy).
- **Oogenesis**: primary oocytes are arrested in the **diplotene stage of prophase I** from fetal life until the LH surge (held by oocyte maturation inhibitor); meiosis I ends just before ovulation (first polar body), then the secondary oocyte is arrested in **metaphase II**, completing meiosis II and extruding the **second polar body only at fertilisation**. Counts: about 7 million oogonia and oocytes at 5 months, about 1–2 million at birth (Langman gives 600,000–800,000), a few hundred thousand at puberty (Langman gives about 40,000), and fewer than 500 ovulated; no oogonia remain at birth.
- **Spermatogenesis**: type A spermatogonia (Ad dark, reserve; Ap pale, active) divide to type B, which become primary spermatocytes; one primary spermatocyte gives **four spermatids** (one oocyte gives one ovum); the cycle takes about 64–74 days (sources differ) and sperm become motile in the **epididymis**, not in the tubules.
- **Fertilisation sequence**: capacitation in the female tract (1–10 hours, about 7 on average), penetration of the corona, binding to **ZP3** with the acrosome reaction (the classic answer; current work, much of it in mice carrying human zona proteins, puts the binding on ZP2, with the acrosome reaction often begun before the zona), passage through the zona, membrane fusion, then the **cortical granule release and zona reaction** that block polyspermy (in that work the granule protease ovastacin cleaves ZP2), and completion of meiosis II.
- **Milestones**: implantation begins about day 6 and is complete by day 10–12; primitive streak day 15; first somites day 20–21; heart beating day 22; limb buds days 26–28; physiological herniation of the midgut from week 6, returning by week 10–11; face formed by week 8; a recognisably human form by day 56 (end of week 8). Fetal swallowing, breathing movements and urine formation begin at about weeks 10–12, and the external genitalia are distinguishable by week 12.
- **Fetal haematopoiesis**: the yolk sac (from week 3) is first, then the liver (main site from about week 6 to the seventh month), spleen, and the bone marrow, which starts at about the fourth to fifth month and is the main site from the seventh.
- **Kartagener syndrome**: defective axonemal **dynein** (primary ciliary dyskinesia); nodal cilia fail to set left–right asymmetry, so situs inversus (in about half of patients with primary ciliary

dyskinesia) occurs with sinusitis, bronchiectasis and immotile sperm.

- The **notochord** induces the neural plate and its only adult remnant is the nucleus pulposus; **VACTERL** (vertebral, anal, cardiac, tracheo-oesophageal, renal, limb defects) is an association of unknown cause, usually attributed to an early mesodermal defect; **neural crest** derivatives: melanocytes, odontoblasts, enterochromaffin cells (in the classic lists; they are now known to be endodermal), arachnoid and pia, peripheral ganglia, Schwann cells, adrenal medulla, the aorticopulmonary septum and facial bones.

Placenta and membranes

- **Chorion frondosum** with the decidua basalis forms the placenta. The **maternal part is the decidua basalis** (the endometrium under the conceptus); the **fetal part is the chorion frondosum**. The decidua capsularis covers the conceptus on the side of the cavity (over the smooth chorion laeve) and fuses with the decidua parietalis (the rest of the lining) in the fourth month (sources put it between about 12 and 17 weeks), obliterating the uterine cavity. The amnion, chorion and villi are fetal; all three deciduae are maternal.
- Placenta: two umbilical arteries (deoxygenated blood to the placenta) and one umbilical vein (oxygenated blood from it); a single umbilical artery is linked with congenital anomalies. The placental barrier thins with age: in the fourth month the cytotrophoblast becomes discontinuous, so late in pregnancy the barrier is the syncytiotrophoblast, a thin and patchy cytotrophoblast, the basal laminae and the fetal capillary endothelium. IgG crosses (by FcRn), IgM does not. The placenta is haemochorial: maternal blood bathes the syncytiotrophoblast directly. Human placental villi are first seen as primary (trophoblast), secondary (with mesoderm) and tertiary (with vessels, by the end of week 3); the fetoplacental circulation works from about day 21.
- **Allantois** becomes the **urachus**, which connects the apex of the bladder with the umbilicus and persists as the **median umbilical ligament**. Patent urachus leaks urine at the umbilicus. **Vitelline duct** remnants: Meckel's diverticulum, vitelline fistula and cysts. Urine leaking at the umbilicus means a patent urachus; meconium means a patent vitelline duct. **Umbilical arteries** become the **medial umbilical ligaments** distally and stay open proximally as the **superior vesical arteries**; the (left) umbilical vein becomes the ligamentum teres, the ductus venosus the ligamentum venosum, the ductus arteriosus the ligamentum arteriosum, the foramen ovale the fossa ovalis. The vitelline arteries become the coeliac trunk and the superior and inferior mesenteric arteries; the vitelline veins the portal vein, superior mesenteric vein, hepatic sinusoids and the hepatic segment of the IVC. A single umbilical artery (about 1%) goes with renal and cardiac anomalies and trisomy 18.
- Twins: dizygotic twins have two amnions, two chorions and two placentas (they may fuse). Monozygotic twinning timing: 0–3 days dichorionic diamniotic, 4–8 days monochorionic diamniotic (commonest), 8–12 monochorionic monoamniotic, later conjoined. Twin-twin transfusion occurs in monochorionic placentas.

Pharyngeal apparatus

Arch	Nerve	Skeleton	Muscles
1 (mandibular)	V3 (and V2)	Meckel's cartilage: malleus, incus, sphenomandibular ligament; mandible, maxilla (membrane bone)	Muscles of mastication, **anterior belly of digastric**, mylohyoid, tensor tympani, tensor veli palatini
2 (hyoid)	VII	**Reichert's cartilage: stapes, styloid process, stylohyoid ligament, lesser horn and upper body of hyoid**	Muscles of facial expression, **posterior belly of digastric**, stylohyoid, stapedius, platysma
3	IX	Greater horn and lower body of hyoid	Stylopharyngeus
4 and 6	X (4th: superior laryngeal; 6th: recurrent laryngeal)	Laryngeal cartilages (thyroid, cricoid, arytenoid, corniculate, cuneiform)	4th: pharyngeal constrictors, cricothyroid, levator veli palatini; 6th: the other intrinsic laryngeal muscles

- **Arch arteries**: 1st, part of the maxillary; 2nd, the stapedial and hyoid (lost); 3rd, the common carotid and first part of the internal carotid; 4th, on the left the arch of the aorta between the left common carotid and left subclavian, on the right the proximal right subclavian; 6th, the pulmonary arteries and, on the left, the ductus arteriosus. The 5th arch forms nothing. The epiglottis comes from the hypobranchial eminence (3rd and 4th arches).
- **Germ layers**: clefts (grooves) are ectoderm, arches mesoderm and neural crest, pouches endoderm, membranes all three. **Treacher Collins** and **Goldenhar** (oculo-auriculo-vertebral) syndromes are first and second arch anomalies; Pierre Robin sequence follows a small mandible (first arch).
- **Pouches**: 1st gives the tympanic cavity and Eustachian tube; 2nd the palatine tonsil; **3rd the inferior parathyroids (dorsal wings) and thymus (ventral wings)**; 4th the **superior parathyroids** and the ultimobranchial body (C cells of the thyroid). The inferior glands migrate further, with the thymus, so they may end up in the mediastinum. **First membrane** gives the tympanic membrane. **Grooves**: only the first persists (external auditory meatus); the second arch overgrows the others to form the cervical sinus, whose persistence causes branchial cysts and fistulae. A **branchial cyst** (second cleft or sinus) lies at the **anterior border of sternocleidomastoid at the junction of its upper and middle thirds**, lined by squamous epithelium, with cholesterol crystals in its fluid. A **second branchial fistula** opens at the anterior border of sternocleidomastoid in its lower third and runs up **between the internal and external carotid arteries**, above the hypoglossal and glossopharyngeal nerves, to the **tonsillar fossa**.
- **DiGeorge syndrome** (22q11.2 deletion, the commonest microdeletion syndrome): third and fourth pouches and neural crest fail, giving thymic aplasia (T-cell deficiency), hypocalcaemia and tetany (neonatal seizures are often the first sign; parathyroid aplasia), conotruncal defects (interrupted aortic arch, truncus arteriosus, tetralogy of Fallot), cleft palate and abnormal facies ("CATCH-22").

- Thyroglossal duct cyst: midline, moves with swallowing and tongue protrusion; the thyroid arises at the foramen caecum and descends. Lingual thyroid is ectopic tissue.
- Cleft lip: failure of the maxillary prominence to fuse with the merged medial nasal prominences (the intermaxillary segment), so it lies lateral to the philtrum, usually on the left; the lip is complete by about week 7. Cleft palate: failure of the palatal shelves (lateral palatine processes) to fuse with each other and the primary palate; they rise and begin to fuse in week 7–8, fusion complete by about week 10 (the soft palate and uvula by week 12).

Gut and diaphragm

- **Meckel's diverticulum**: persistent proximal vitelline duct, on the antimesenteric border of the ileum, about 2 feet (60 cm) from the ileocaecal valve in adults, in 2% of people, about 2 inches long, symptomatic usually before age 2, twice as common in males; ectopic gastric (bleeding, painless rectal bleeding in children; **technetium-99m pertechnetate scan**) or pancreatic tissue. A true diverticulum (all layers).
- **Duodenal atresia**: failure of **recanalisation** of the duodenum, whose lumen is filled by proliferating epithelium in weeks 5–6 and normally reopens by the end of the embryonic period (about week 8–10); bilious vomiting, **double-bubble sign**, polyhydramnios; association with Down syndrome. Jejunoileal atresia: vascular accident. Normal midgut rotation is **270° counter-clockwise** (viewed from the front) round the axis of the SMA; incomplete rotation (malrotation) leaves the caecum high with **Ladd bands** across the duodenum and a narrow mesentery that can twist (midgut volvulus: bilious vomiting in a neonate, an emergency). Hirschsprung disease: failure of neural crest cells to migrate to the distal gut (aganglionic rectum and a variable length above; RET gene).
- Physiological umbilical herniation in weeks 6–10 (return by week 10–12); omphalocele (failure of the gut to return; covered by amnion and peritoneum, midline through the umbilical ring, often with trisomies 13, 18 and cardiac anomalies) versus gastroschisis (a body wall defect, uncovered, usually **to the right of the umbilicus**, rarely with other anomalies but with bowel damage from amniotic fluid).
- **Diaphragm**: septum transversum (central tendon), **pleuroperitoneal membranes**, oesophageal mesentery (crura) and body wall muscle. **Congenital (Bochdalek) hernia** is a failure of the **pleuroperitoneal membrane** to close the pericardioperitoneal canal, usually on the **left posterolateral** side (the right closes earlier and the liver protects it); bowel in the chest causes **pulmonary hypoplasia**. Morgagni hernia is anterior (retrosternal).
- Cardiac: the heart tube forms from the cardiogenic (splanchnic lateral plate) mesoderm and begins to beat at about day 22; it loops to the right (dextral looping). The septum primum and secundum form the atrial septum (ASD secundum the commonest ASD, patent foramen ovale in about 25% of adults); endocardial cushions form the membranous septum; spiralling aorticopulmonary septum (neural crest) divides the truncus; failure of the septum to spiral produces transposition of the great arteries. The sinus venosus forms the smooth part of the right atrium and the coronary sinus.
- Fetal circulation: the shunts are the **ductus venosus**, **foramen ovale** and **ductus arteriosus**; the umbilical vein carries blood with about 80% saturation. The ductus closes functionally within a day or two of birth, from the **rise in oxygen tension** and the **fall in prostaglandin E2** (the placenta gone, and the lungs now metabolising it), with bradykinin from the inflated lungs; anatomically in 1–3 months. To close it in a preterm infant, the classic answer is **indomethacin**; current practice prefers **ibuprofen** (fewer renal and gut effects), with **paracetamol** as an alternative (Cochrane reviews 2020–2023). **Prostaglandin E1 (alprostadil) keeps it open** in duct-dependent lesions. The foramen ovale closes functionally when left atrial pressure exceeds right at the first breath.
- **Pancreas**: the **ventral bud** forms the uncinate process and part of the head with the main duct's proximal part; the dorsal bud forms the upper head, isthmus, body and tail and the accessory duct; a ventral bud that fails to rotate gives an annular pancreas.
- **Liver**: the hepatic diverticulum from the foregut grows into the septum transversum; hepatocytes arise from it, but the Kupffer cells and haematopoietic cells come from the septum transversum mesenchyme, and the sinusoids from the vitelline and umbilical veins.
- **Fetal remnants**: ductus venosus → ligamentum venosum; umbilical vein → ligamentum teres (in the falciform ligament); umbilical arteries → medial umbilical ligaments; urachus → median umbilical ligament; foramen ovale → fossa ovalis (septum primum).
- **Veins and lymphatics**: the inferior vena cava is built from the hepatic, right subcardinal (prerenal), subcardinal–supracardinal (renal) and right supracardinal (postrenal) segments; the azygos and hemiazygos veins come from the supracardinal veins. The lymphatics begin as six sacs (two jugular, two iliac, one retroperitoneal, and the cisterna chyli) budding from veins.

Urogenital

- **Kidney** (intermediate mesoderm): pronephros (week 4, transient), mesonephros (works briefly; its duct persists in the male), **metanephros** (permanent, from week 5, working from about week 10–12): the **ureteric bud (metanephric diverticulum)**, an outgrowth of the mesonephric duct near the cloaca, gives the **ureter (from its stalk, sometimes called the metanephric duct)**, renal pelvis, major and minor calyces and collecting tubules; the **metanephric mesenchyme** gives the nephrons (glomerulus to distal convoluted tubule). The two induce each other. **Unilateral renal agenesis**: the **ureteric bud fails to induce** the metanephric mesenchyme (the bud is absent or fails to reach it); bilateral agenesis leads to Potter sequence (oligohydramnios, pulmonary hypoplasia). Duplex ureters follow a split bud; multicystic dysplastic kidney is a failure of the bud and mesenchyme connection.
- **Horseshoe kidney** (fusion of the lower poles in about 90%; about 1 in 400–600 births, the commonest fusion anomaly): the isthmus is trapped under the **inferior mesenteric artery** during ascent, so the kidney remains low; more common in Turner syndrome and trisomy 18; the ureters pass in front of the isthmus, so pelviureteric obstruction, stones and infection follow; Wilms tumour is more frequent. Pelvic kidney: failure to ascend. During ascent the kidney takes successively higher arterial supply, so persisting lower branches become accessory renal arteries.
- Urogenital sinus: bladder (upper), prostatic and membranous urethra (male), the vestibule (female). The bladder trigone is mesodermal (from the absorbed mesonephric ducts) but lined by endoderm in time.

- Gonads (from the genital ridge, intermediate mesoderm and coelomic epithelium; the primordial germ cells migrate from the yolk sac wall near the allantois): **SRY on the short arm of the Y chromosome** (testis-determining factor) drives Sertoli cells (anti-Müllerian hormone, which regresses the paramesonephric ducts) and Leydig cells (testosterone, supporting the mesonephric duct to form epididymis, vas, seminal vesicle; dihydrotestosterone for the external genitalia and prostate). Without these, the paramesonephric ducts form the uterine tubes, uterus and upper vagina; the lower vagina comes from the sinovaginal bulbs.
- **External genitalia** (indifferent until about week 9; male development needs dihydrotestosterone, made by 5α-reductase): the **genital tubercle** gives the **glans and corpora of the penis** in the male and the **clitoris** (glans and corpora) in the female; urogenital (urethral) folds give the ventral penis with the penile urethra, and the **labia minora**; labioscrotal swellings give the scrotum and **labia majora**; the urethral groove closes in the male (failure gives **hypospadias**, the urethra opening on the underside; **epispadias**, on the dorsum, comes from a tubercle forming too far back and goes with bladder exstrophy).
- **Homologues** (male / female): urogenital sinus → **prostate / paraurethral (Skene's) glands**, **bulbourethral (Cowper's) / greater vestibular (Bartholin's) glands**; genital ridge → testis / ovary; gubernaculum → (testis guide) / ovarian ligament and round ligament of the uterus; mesonephric duct → epididymis, vas, seminal vesicle / Gartner's duct (remnant); paramesonephric duct → appendix of the testis and prostatic utricle / tubes, uterus, upper vagina.
- Testis descent, guided by the gubernaculum and preceded by the processus vaginalis: transabdominal descent to the deep ring by about week 12 (anti-Müllerian hormone, insulin-like 3); it waits there until about the seventh month, passes through the inguinal canal at about weeks 26–28 (androgen-dependent) and reaches the scrotum by about weeks 32–35, so descent is usually complete at term (undescended in about 3% of term and up to 30% of preterm boys). Undescended testis is slightly more common on the right; persistent processus vaginalis gives indirect hernia and hydrocele.
- Uterine anomalies: failure of **fusion** of the paramesonephric ducts gives uterus didelphys (complete) and bicornuate uterus (partial); failure of **resorption** of the septum after fusion gives a **septate uterus**, the commonest uterine anomaly and the one most linked with miscarriage (treated by hysteroscopic resection); failure of one duct gives a unicornuate uterus. Mayer–Rokitansky–Küster–Hauser syndrome: agenesis of the Müllerian ducts with normal ovaries and 46,XX.
- Adrenal cortex from mesoderm (coelomic epithelium); medulla from neural crest.
- **Vagina**: the upper part from the Müllerian (uterovaginal) canal, the lower part from the sinovaginal bulbs of the **urogenital sinus**; the hymen is of endodermal origin. The external genitalia are indeterminate until week 7, distinguishable by week 12 and complete by about week 20; the phallic part of the urogenital sinus forms the vestibule and the Bartholin and Skene glands in the female.
- **Homologues and remnants**: the appendix testis (and hydatid of Morgagni) is a Müllerian remnant; the appendix epididymis, the paroophoron and epoophoron and Gartner's duct are mesonephric remnants.

Nervous system and eye/ear

- Neural tube: alar plate (sensory, dorsal) and basal plate (motor, ventral), separated by the sulcus limitans. Brain vesicles: forebrain (telencephalon, diencephalon), midbrain, hindbrain (metencephalon: pons and cerebellum; myelencephalon: medulla). **Their cavities**: telencephalon → **lateral ventricles**; diencephalon → third ventricle; mesencephalon → cerebral aqueduct; metencephalon and myelencephalon (rhombencephalon) → fourth ventricle; the spinal cord's central canal is the neural tube's lumen.
- Retina and optic nerve: outgrowths of the diencephalon (so the optic nerve is a CNS tract, myelinated by oligodendrocytes and covered by meninges); the lens and the corneal epithelium are surface ectoderm; the **corneal stroma and endothelium** and the sclera are neural crest; the sphincter and dilator pupillae are neuroectoderm (from the optic cup), the only muscles in the body from it; the retinal pigment epithelium is the outer layer of the optic cup, the neural retina the inner; choroid fissure failing to close gives a coloboma.
- Microglia derive from mesoderm (classically "the monocyte lineage"; current work shows they come from yolk-sac macrophage progenitors that enter the brain before birth, not from blood monocytes: Ginhoux 2010); astrocytes, oligodendrocytes and ependyma from neuroectoderm (the neural tube); Schwann cells from neural crest.
- Pituitary: anterior (adenohypophysis) from the Rathke pouch (oral ectoderm); posterior (neurohypophysis) from the diencephalon. Craniopharyngioma arises from remnants of the Rathke pouch.
- Teeth: enamel from ectoderm (ameloblasts), dentine and pulp from neural crest mesenchyme.
- Limbs: limb buds appear in week 4; the apical ectodermal ridge (FGF) controls outgrowth, the zone of polarising activity (sonic hedgehog) the anteroposterior axis; thalidomide causes phocomelia. Upper limb buds appear about day 26, lower about day 28; the limbs rotate (upper laterally 90°, lower medially 90°, so the knee faces forward and the dermatomes of the leg spiral).
- Teratogens: warfarin (nasal hypoplasia, stippled epiphyses), valproate and carbamazepine (neural tube), phenytoin (fetal hydantoin syndrome), ACE inhibitors and ARBs (fetal renal failure, oligohydramnios; second and third trimesters), tetracycline (teeth, bone), isotretinoin (craniofacial, cardiac, CNS), lithium (Ebstein anomaly, the risk now thought small), thalidomide (phocomelia), alcohol (fetal alcohol syndrome: smooth philtrum, thin upper lip, short palpebral fissures), diethylstilboestrol (clear-cell vaginal carcinoma in daughters), maternal diabetes (caudal regression, cardiac defects), rubella (cataract, deafness, PDA; worst in the first 12 weeks).
- **Neural tube layers**: ventricular (ependyma), mantle (grey matter) and marginal (white matter) zones. **Myelination** starts in the fourth month in the motor roots, the corticospinal tracts are complete by about two years and the association cortex goes on into the third decade. **Placodes**: otic (the first to appear, about day 22), lens, olfactory and the epibranchial/trigeminal placodes.

Chromosomes, ducts and arches asked again

- **Robertsonian translocation**: fusion of the **long arms of two acrocentric chromosomes (13, 14, 15, 21 and 22)** with loss of both short arms (which carry only ribosomal RNA genes), leaving 45 chromosomes; the carrier is normal but may have a

child with **translocation Down syndrome (14;21)**, risk of recurrence much higher than in trisomy 21 from non-disjunction.

- **Mesonephric (Wolffian) duct derivatives in the male**: **epididymis, ductus deferens, seminal vesicle, ejaculatory duct** (under testosterone); the ureteric bud also sprouts from its lower end. The prostate and bulbourethral glands are **endodermal** outgrowths of the urogenital sinus, and the paramesonephric duct regresses by Sertoli AMH. In the female the mesonephric duct regresses leaving Gartner's duct cysts.
- **Left sixth arch artery**: its distal part forms the **ductus arteriosus**, later the ligamentum arteriosum; on the right the distal sixth arch regresses, so the **right recurrent laryngeal nerve** hooks round the right subclavian (fourth arch) and the left one round the ligamentum arteriosum.

Limb development and malformation terms

- **Limb patterning**: HOX genes (the cranio-caudal axis and the limb's proximal-to-distal segments; mutations put structures in the wrong place), **FGF-8** from the apical ectodermal ridge (proximodistal outgrowth), **Sonic hedgehog** from the zone of polarising activity (anteroposterior axis; mutation causes holoprosencephaly and polydactyly), **Wnt-7** from the dorsal ectoderm (dorsoventral axis), TBX5 (forelimb; Holt–Oram syndrome with atrial septal defect) and TBX4 (hindlimb); IGF-1 and IGF-2 drive growth.
- **Terms**: **malformation** (intrinsic abnormal development), **disruption** (a normal structure destroyed, as by amniotic bands), **deformation** (abnormal mechanical force, as in Potter sequence from oligohydramnios), **sequence** (a chain from one defect), agenesis (the organ and its primordium absent), aplasia (the primordium formed but the organ did not develop) and hypoplasia (underdeveloped).

Histology

Epithelia

- **Simple squamous** (endothelium, mesothelium, Bowman capsule parietal layer, the thin loop of Henle, type I pneumocytes); simple cuboidal (thyroid follicles, renal tubules, the ovary's surface epithelium); simple columnar (stomach to the upper anal canal, with microvilli and goblet cells in the intestine; gallbladder; **ciliated in the uterine tubes**); pseudostratified columnar ciliated with goblet cells (nasal cavity, trachea, bronchi); **pseudostratified columnar with stereocilia** (epididymis and **ductus deferens**); stratified squamous non-keratinised (oesophagus, vagina, ectocervix, cornea, oral cavity); keratinised (skin); stratified cuboidal (sweat gland ducts); stratified columnar (large ducts of salivary and mammary glands, the conjunctival fornix, the male penile urethra); **transitional (urothelium)** from the renal calyces through the ureters and bladder to the proximal urethra (the prostatic urethra in the male).
- The thyroid follicle's lining changes with activity: flat in an inactive gland, **cuboidal at rest (the usual answer)** and columnar when actively secreting. The epiglottis: stratified squamous on its oral (lingual) surface and the upper laryngeal surface, respiratory epithelium lower on the laryngeal surface; the true vocal folds are stratified squamous.
- **Urothelium** suits the bladder because the large dome-shaped (umbrella) surface cells **flatten and stretch as the wall distends, while remaining impermeable** thanks to uroplakin plaques and tight junctions; in the empty bladder the surface is thick with many cell layers.
- **Metaplasia** is the reversible replacement of one adult epithelium by another, in response to chronic irritation: **Barrett's oesophagus** (non-keratinised stratified squamous replaced by **columnar epithelium with goblet cells**: intestinal metaplasia, a precursor of adenocarcinoma); squamous metaplasia of the bronchi in smokers; of the cervix at the transformation zone.
- Cell junctions: tight (zonula occludens: claudin, occludin), adherens (cadherin), desmosome (macula adherens: cadherin, desmoglein; defect in pemphigus), gap (connexons), hemidesmosome (integrin; defect in bullous pemphigoid).
- **Rule**: epithelium that a finger can reach is **stratified squamous** (oral cavity, oesophagus, anal canal below the pectinate line, vagina), non-keratinised when moist and keratinised in the skin, palms and soles. **Myoepithelial (basket) cells** contract around acini of salivary, mammary and sweat glands to expel secretion. Exocrine glands are classified as unicellular (goblet) or multicellular; by duct simple or compound; and by secretion serous, mucous or mixed.

Glands

- **Merocrine** (exocytosis: salivary glands, eccrine sweat glands, pancreas), **apocrine** (apical part is shed: the lipid of the lactating mammary gland; the axillary apocrine sweat glands are called apocrine though electron microscopy shows they secrete mostly by exocytosis; the milk proteins are merocrine), **holocrine** (the whole cell fills with product and breaks down to become the secretion: **sebaceous glands**, Meibomian and Zeis glands).
- Serous cells (zymogen granules, basophilic basal cytoplasm: parotid, pancreas acini); mucous cells (pale, foamy: sublingual); the submandibular gland is mixed, mostly serous.
- Exocrine glands in the oesophagus: mucous glands in the submucosa. **Brunner's glands** in the duodenal submucosa; **Paneth cells** in the crypts of the small intestine (lysozyme); **Peyer's patches** in the ileum; plicae circulares in the jejunum most.
- **Herring bodies**: dilated axon terminals of the hypothalamo-hypophyseal tract in the posterior pituitary, storing oxytocin and vasopressin with neurophysins; the pituicytes are the glial cells.
- **Glands of Moll**: modified apocrine sweat glands of the eyelid margin; the glands of **Zeis** are the sebaceous glands of the lashes, and the Meibomian (tarsal) glands are large sebaceous glands of the tarsal plate.

Respiratory

- Trachea: C-shaped hyaline cartilage open behind (trachealis), ciliated pseudostratified epithelium with goblet cells and seromucous glands; bronchi have cartilage plates; **bronchioles have no cartilage or glands**, ciliated columnar becoming cuboidal epithelium with **club (Clara) cells** (secretory, detoxifying, progenitors of the bronchiolar lining); respiratory bronchioles have alveoli opening from their walls.
- **Alveolus**: **type I pneumocytes** (flat, about 95% of the surface, gas exchange); **type II pneumocytes** (cuboidal, secrete **surfactant** from lamellar bodies, and **are the progenitors that regenerate the alveolar epithelium after injury**, differentiating into type I cells); alveolar macrophages (dust cells); the blood-air barrier is the type I cell, fused basal

laminae and capillary endothelium. Surfactant synthesis begins at about 20 weeks (First Aid) or by the end of the sixth month (Langman) and reaches mature levels at about 35 weeks; respiration is possible from about 25 weeks; antenatal corticosteroids hasten maturation. Fetal lung maturity: a lecithin:sphingomyelin ratio above 2 and phosphatidylglycerol in amniotic fluid (now rarely tested).

Other tissues

- **Cartilage**: hyaline (articular, costal, trachea, type II collagen), elastic (epiglottis, ear, type II and elastic fibres), fibrocartilage (intervertebral disc, pubic symphysis, menisci, type I collagen). Bone: osteoblast (forms), osteocyte, osteoclast (resorbs, from monocytes, RANK-L).
- Muscle: skeletal (multinucleate, peripheral nuclei, striated), cardiac (central single nuclei, intercalated discs, branched), smooth (spindle, central nucleus, no striations, dense bodies).
- Lymphoid organs: thymus (cortex dense, medulla pale with **Hassall's corpuscles**), lymph node (cortex B cells in follicles, paracortex T cells, medulla with plasma cells), spleen (white pulp: PALS T cells, follicles B cells; red pulp for filtration of old erythrocytes; marginal zone).
- Kidney: proximal convoluted tubule has a brush border (pink, acidophilic cuboidal cells); distal tubule lacks it and has the macula densa; collecting ducts have clear cuboidal cells; thin limb is simple squamous.
- **Testis**: seminiferous tubules lined by Sertoli cells (blood-testis barrier by tight junctions, supporting, AMH, inhibin) and germ cells; Leydig cells in the interstitium (testosterone). The rete testis is lined by simple cuboidal epithelium, the efferent ductules by alternating ciliated and non-ciliated cells. **Epididymis and ductus deferens**: pseudostratified columnar with stereocilia; the deferens has a thick three-layered muscle coat (inner and outer longitudinal, middle circular).
- Skin: epidermis layers, from deep to superficial: **stratum basale, spinosum, granulosum, lucidum (thick skin only), corneum**; melanocytes (neural crest) in the basal layer; Langerhans cells (dendritic) in the spinosum; Merkel cells (touch).
- Thyroid follicles with colloid and parafollicular (C) cells; parathyroid chief and oxyphil cells; adrenal cortex: **zona glomerulosa (aldosterone), fasciculata (cortisol), reticularis (androgens)**, medulla chromaffin cells ("salt, sugar, sex").
- Liver: hepatocytes in plates, sinusoids lined by fenestrated endothelium with Kupffer cells, space of Disse with the Ito (stellate) cells storing vitamin A (activated, they make the collagen of fibrosis); the portal triad at the lobule corners. **Acinus zones**: **zone 1 (periportal)** is best oxygenated and is the zone **affected first in viral hepatitis** (the exam answer; chronic hepatitis is the periportal interface hepatitis, while severe acute hepatitis can be panlobular or centrilobular) and by ingested toxins such as phosphorus, cocaine and iron overload; **zone 2** in yellow fever; **zone 3 (centrilobular)** is the least oxygenated and richest in cytochrome P450, so it suffers first from ischaemia, congestion (nutmeg liver), alcohol, and paracetamol, carbon tetrachloride and halothane toxicity.
- **Eponyms**: **Bowman membrane** (anterior limiting lamina of the cornea) and **Descemet membrane** (basement membrane of the corneal endothelium); cords of Billroth (splenic red pulp); **corpora amylacea** (prostate, brain; concretions) and corpora arenacea (pineal); ducts of Bellini (papillary ducts of the kidney); columns of Bertin (renal cortex between pyramids); Kohn pores (between alveoli); crypts of Lieberkühn (intestine); Wharton jelly (umbilical cord mucoid connective tissue); **Meissner corpuscles** (dermal papillae, light touch), Merkel discs (touch, basal epidermis), Krause end bulbs (cold).
- **Collagen**: type I (bone, tendon, skin; osteogenesis imperfecta), II (hyaline and elastic cartilage, vitreous), III (reticular fibres, vessels; vascular Ehlers–Danlos), IV (basement membrane; Alport syndrome and Goodpasture disease).

Skeletal muscle ultrastructure and bone

- **Sarcomere** (Z line to Z line): the **A band** is the length of the thick (myosin) filaments and stays the same in contraction; the **I band** (thin actin only, bisected by the Z line) and the **H zone** (thick filaments only, with the M line at its centre) both shorten. Thin filaments bear troponin and tropomyosin; **T tubules lie at the A–I junction** in mammalian skeletal muscle, forming **triads** with two terminal cisternae of the sarcoplasmic reticulum, and calcium release triggers contraction.
- **Bone**: osteoblasts (make osteoid, alkaline phosphatase), osteocytes (in lacunae, connected by canaliculi) and **osteoclasts** (multinucleate, from monocyte-macrophage cells, in Howship's lacunae with a ruffled border, controlled by RANKL and osteoprotegerin). Compact bone is built of **Haversian systems (osteons)** with Volkmann's canals joining them; woven bone is disorganised and is the first bone laid down in fractures, replaced by lamellar bone.

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