The meninges and common pathology

Understanding the anatomy can lead to prompt identification of serious pathology

The meninges are three membranous layers that surround the structures of the central nervous system. They include the dura mater, the arachnoid mater, and the pia mater. Together they cushion the brain and spinal cord with cerebrospinal fluid and support the associated vascular structures.1 2 Although they are usually mentioned as a trio, there are subtle but important differences to the arrangement of the meninges in the spine and cranium. The aim of this introduction to the meninges is to clarify the anatomy and link these details to relevant clinical situations.

Dura mater
The outermost of the meninges (singular: meninx) is the dura mater, commonly called the dura.3 As its name suggests, the dura is a tough thick membrane composed of dense collagen fibres.2‑4

In the cranium, the dura is continuous with the periosteum of the inner surface of the skull and extends into folds that compartmentalise the skull.1 2 The large midline fold separates the two hemispheres and is called the falx.1 A smaller fold separates the cerebral hemispheres from the cerebellum and is known as the tentorium cerebelli usually abbreviated as “tentorium” (fig 1).1 3

Where the edges of the falx and tentorium meet the skull, the dura encloses large venous sinuses that are responsible for draining venous blood from the brain.1 4 These are not to be confused with the air filled cavities in the skull, which are also called sinuses.

Although the brain is insensitive to pain, the dura is well innervated by branches of the trigeminal nerve, which carries pain sensations experienced as headache.1 2

Outside the dura
In the normal cranium there is no space between the dura and the skull. However, arterial blood has sufficient pressure to separate the dura from the bare bone of the skull.1 The classic example of this is a severe blow to the temple that ruptures the middle meningeal artery, which has part of its course between the skull and the dura at a weak point called the pterion.1 2 4 This creates an extradural haematoma,2 a potentially lifethreatening injury that classically presents with decreased consciousness and vomiting after a lucid interval (an initial period of apparently normal consciousness). The lucid interval can be a falsely reassuring phenomenon, which can cause a fatal extradural haematoma to go unrecognised. With prompt identification and surgical decompression, however, the prognosis is usually good.2

In the spine (but not the cranium), there is a physiological space around the dura, known as the epidural space. This space is only a few millimetres wide but surrounds the dura all the way down the spine from the foramen magnum to the tip of the sacrum. It contains predominantly adipose tissue but also has a plexus of large, thin walled veins, the epidural venous plexus. In turn, the epidural space is surrounded by the bones of the vertebral canal.1

Insertion of a catheter into the epidural space, usually in the mid‑lumbar region, allows anaesthetic drugs to be delivered close to the spinal cord and its nerve roots. This technique is known as epidural analgesia and is a common method of pain relief in labour and after surgery.1 3

Arachnoid mater
Beneath and in direct contact with the dura, is the arachnoid mater. The arachnoid follows the dura closely throughout the cranium and spine down to the level of S2 where the two layers fuse and terminate. The arachnoid encloses the cerebrospinal fluid, which circulates around the brain and spinal cord. The space occupied by the cerebrospinal fluid is therefore known as the subarachnoid space.4 The dura and the arachnoid can together be referred to as the theca. The intrathecal space is an alternative term for the subarachnoid space (fig 2).

The arachnoid is a thin, semi-transparent membrane that gives off a very fine network of arachnoid granulations. These absorb excess cerebrospinal fluid and secrete it into the venous sinuses of the dura mater where it is drained into the circulation.
of filaments (arachnoid trabeculae), which traverse the subarachnoid space from the inner surface of the dura to the outer surface of the brain, where the pia mater lies. These trabeculae create the impression of cobwebs, which gives rise to the name “arachnoid.”

In adults, the spinal cord typically ends at the L1-2 interspace. In neonates, it can extend a segment or two further. In both adults and neonates, the dural sac extends down to S2. There is a degree of normal variation in these levels.

Circle of Willis
The brain receives its arterial supply from the circle of Willis. This arterial circuit, formed by the union of the basilar artery with the two internal carotid arteries, lies within the subarachnoid space at the base of the brain. This can be a site of aneurysm formation, which carries a risk of spontaneous rupture resulting in a subarachnoid haemorrhage. Subarachnoid haemorrhage is a crucial differential diagnosis to consider in anyone with a sudden and severe headache. It can be associated with vomiting, seizures, and loss of consciousness owing to the rise in intracranial pressure, and it is frequently fatal. In those who survive the initial haemorrhage, treatment is focused on stabilising the aneurysm to reduce the risk of rebleeding by applying clips to the aneurysm directly, or by using keyhole techniques to place thin coils of metal into the aneurysm cavity to cause thrombosis.

Spinal anaesthesia
The technique of spinal anaesthesia involves injecting a small volume of local anaesthetic into the subarachnoid space in the lumbar region. This produces a rapid onset of numbness of the lower abdomen and legs. This anaesthesia is sufficient for the performance of many types of surgery, such as knee joint replacement or caesarean section, without the need for general anaesthesia. Alternatively this technique can be used as an adjuvant to general anaesthesia to provide postoperative pain relief for similar procedures.

Between the dura and the arachnoid
Throughout the cranium and the spine of a healthy individual, the arachnoid and the dura are never separated. A potential space, the subdural space, exists between the two. Sandwiched between the dura and arachnoid lie veins that connect the brain’s venous system with the venous sinuses encased by the arachnoid. The force needed to separate the arachnoid from the dura is comparatively minor, and venous bleeding can create enough pressure to cause a subdural haematoma between the arachnoid and the dura.

Older people and people with alcoholism are particularly at risk of chronic subdural haematomas owing to their vulnerability to falls. Although surgical decompression is sometimes needed, the prognosis is usually more guarded than for an extradural haematoma.

Cerebrospinal fluid
Cerebrospinal fluid, which circulates in the subarachnoid space between the arachnoid and pia mater, surrounds and supports the delicate structures of the central nervous system. Although an adult brain weighs 1400 g, its apparent weight when cushioned by cerebrospinal fluid is only about 50 g. Cerebrospinal fluid is produced by a specialised tissue called the choroid plexus, which is present inside the ventricles of the brain. The ventricles are in direct communication with the subarachnoid space, which allows the cerebrospinal fluid to flow freely around the central nervous system.

The total volume of cerebrospinal fluid in an adult is about 150 mL. Cerebrospinal fluid is produced at about 500 mL/day. Cerebrospinal fluid is resorbed into the bloodstream by the arachnoid granulations, outpouchings of arachnoid thinly encased by dura mater that extend into the venous sinuses.

Cerebrospinal fluid is a transparent, colourless ultrafiltrate of plasma. Its electrolyte levels, glucose level, and pH are very similar to those of plasma, but it contains little protein and few cells. The presence of blood in cerebrospinal fluid is always abnormal.

The technique of lumbar puncture involves inserting a needle into the midline of the lumbar spine, into the subarachnoid space, to obtain a sample of cerebrospinal fluid for diagnostic analysis. The composition of cerebrospinal fluid varies in different illnesses, including malignancy, infection, and some neurological diseases such as multiple sclerosis.

Intracranial pressure
Intracranial pressure is the pressure inside the cranium. Normal intracranial pressure is about 7-17 mm Hg when supine. Intracranial pressure can be increased by several pathologies: meningitis, tumour, abscess, or haematoma. Above 25-30 mm Hg, raised intracranial pressure can interfere substantially with arterial blood entering the skull, reducing blood flow to the brain.

The optic nerves are invested in a sleeve of arachnoid and dura. The optic nerves join the retina at the optic disc (the “blind spot”), which is the only part of the central nervous system that is visible from the outside, by fundoscopy. If intracranial pressure is raised, the increased pressure is transmitted along the optic nerves to the optic disc, which could cause bulging of the optic disc. This appearance is known as papilloedema.
and is always extremely serious (fig 3). Severe pathology (including tumour, stroke, or brain injury) can cause highly elevated intracranial pressure. In this circumstance, brain structures might be compressed against the dural folds within the cranium. The compressible brain tissue can be forced around the edges of the falx or the tentorium. This is known as herniation and can cause compression of critical structures such as the brainstem. In addition, normal flow of cerebrospinal fluid might be blocked, compounding the problem. In this circumstance, lumbar puncture should not be performed, as drainage of cerebrospinal fluid from the spine could exacerbate the herniation. Downward herniation of the cerebellar tonsils can compress the brainstem forcibly into the foramen magnum. This is known as coning and can be fatal. If in doubt, a computed tomography scan should be done before lumbar puncture to exclude herniation.

Pia mater
The pia mater, or pia, is the thinnest of the three meninges. The pia is a monolayer of cells that invests all structures of the brain itself.5

Meningitis
Meningitis is inflammation of the meninges.6 It can be caused by any invading pathogen, commonly viruses and bacteria, or can be aseptic.7

Viral meningitis is most common and is usually caused by echovirus, mumps, coxsackie, herpes simplex virus type 2, and HIV.2 Viral meningitis is usually associated with a favourable prognosis unless it progresses to encephalitis, inflammation of the brain itself.2

In western Europe, bacterial meningitis is most commonly caused by Streptococcus pneumoniae (the “pneumococcus”) and Neisseria meningitidis (the “meningococcus”), both normal commensals of the upper respiratory tract.7 In areas with high prevalence of HIV, common causes of meningitis are Cryptococcus neoformans and tuberculous meningitis. Bacterial meningitis is associated with a grave prognosis, and the risk of death or brain damage is very high.6 Meningococcal meningitis refers to disease caused by the meningococcus. This highly virulent organism can also cause sepsicaemia and multiorgan failure in a matter of hours. The associated classic rash is often variable and a late sign.

Aseptic meningitis refers to meningitis where an infective agent cannot be identified. Causes of aseptic meningitis include inflammatory or malignant disease, drugs, and chemical irritants unintentionally introduced into the cerebrospinal fluid.

The clinical features of meningitis are the result of meningism, irritation of the meninges. The triad of suspicion for meningitis includes headache, neck stiffness, and fever.1 Other features of meningitis include nausea, raised intracranial pressure, and depressed level of consciousness. If bacterial meningitis is suspected, treatment should be started before definitive results are available. Conclusive diagnosis of meningitis relies on cerebrospinal fluid collected by lumbar puncture. If there is any suspicion of herniation, a computed tomography scan of the brain must be conducted to exclude this before a lumbar puncture is performed.1 4

Figure 3: Papilloedema. The optic disc bulges out of the plane of the retina. Retinal vessels can be seen to “climb over the edge” of the disc. It may be difficult to focus on the disc and the retina at the same time.

Key points
The dura and the arachnoid are stuck to each other throughout the cranium and the spine. The cerebrospinal fluid circulates in the subarachnoid space, between the arachnoid and the pia. The cranial extradural space and the subdural space are only potential spaces. Meningitis refers to inflammation of the meninges. Conclusive diagnosis requires lumbar puncture and cerebrospinal fluid analysis.