Review paper

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Anatomical aspects of epidural and spinal analgesia

Abstract

Regional anaesthesia seems to be the future of the anaesthesia in this century. The knowledge of the anatomy of the epidural and other spinal spaces seems to play the crucial role in success of regional anaesthesia. It's important in perioperative medicine and cancer pain treatment. Up to date there is not too many datas considering anatomy of these compartments. Many of the results obtained by researchers in the past are still not mentioned in the clinical textbooks. This article is an attempt to resolve this problem.

Key words: epidural anesthesia, spinal anesthesia, human anatomy, epidural space

Adv. Pall. Med. 2009; 8, 4: 135–146

Introduction

Successful a hinges on successfully reaching neural tissue. The sensation of pain traveling from nociceptor to sensory cortex follows an elaborate and complex path before being registered by our brains: from the nociceptor to the peripheral (sensory) nerve, peripheral nervous plexus, anterior branches of spinal nerves, spinal nerves, dorsal root of spinal nerve, dorsal root ganglion, and onwards to the nucleus proprius of dorsal horn. This pathway continues through the white comissure to the opposite side of the medulla and reaches the lateral funicle, continuing onwards to the dorsal part of medulla oblongata, dorsal part of pons, dorsal part of midbrain, thalamus (postero-lateral nucleus of ventral group), thalamocortical tract, before finally arriving at the sensory cortex (parietal lobe).

The epidural space is situated between the walls of the vertebral canal, which assimilated the external lamina of the dura mater, and the dural sac which consists of the internal lamina of dura mater and arachnoid. Many fragments of this space are empty (they contain only air). It can be found in all places where the dural sac reaches the vertebral pedicles, vertebral lamina or ligamentum flava. Besides air, the epidural space also contains fat, veins, arteries, and spinal nerve roots encircled by processes of dural sac and fibrousness structures. The main content of the epidural space is fat. It differs from fat found in other areas of the human body in that it does not contain fibrous tissue and is of almost homogenous structure.

At cervical level fat is absent while in the lumbar region, fat in the anterior and posterior aspects of the epidural space forms two unconnected structures. Fat cells are found also in the thickness of dural sleeves enveloping spinal nerve roots but not in the region of the dural sac. Epidural lipomatosis is characterized by an increase in epidural fat con-

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Advances in Palliative Medicine 2009, 8, 135–146

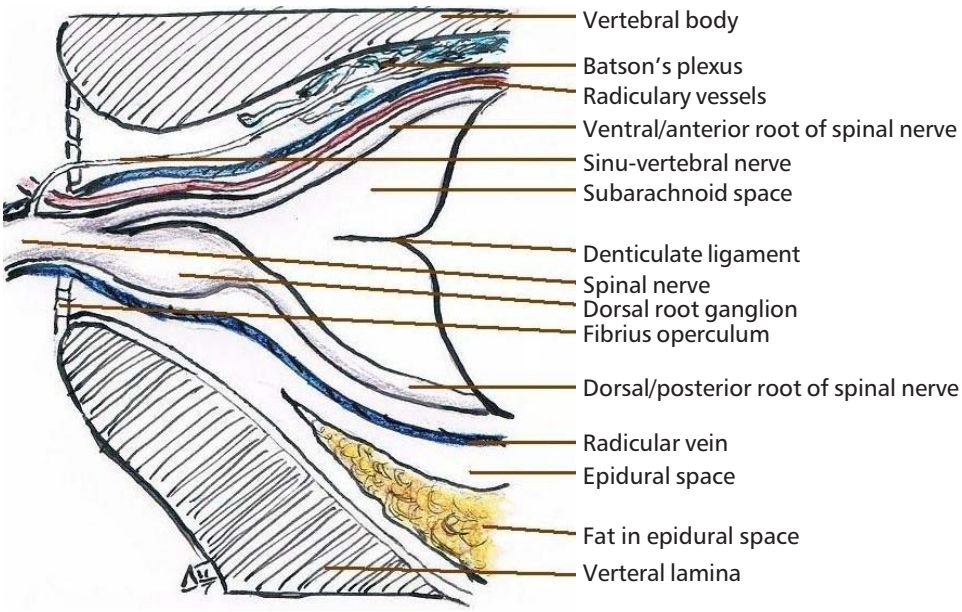

Figure 1. The horizontal view of vertebral foramen containing epidural and subarachnoid space

tent. When a patient has a combination of kyphosis and scoliosis of the spine, the epidural fat distributes asymmetrically. Spinal stenosis is frequently accompanied by a reduction in the amount of epidural fat around the stenotic area. The epidural space contains abundant epidural fat that distributes along the spinal canal in a predictable pattern. Fat cells are also abundant in the dura that forms the sleeves around spinal nerve roots but they are not embedded within the laminas that form the dura mater of the dural sac. Drugs stored in fat, inside dural sleeves, could have a greater impact on nerve roots than drugs stored in epidural fat, given that the concentration of fat is proportionally higher inside nerve root sleeves than in the epidural space, and that the distance between nerves and fat is shorter. Similarly, changes in fat content and distribution caused by different pathologies may alter the absorption and distribution of drugs injected in the epidural space.

The dural sac contains spinal medulla embraced by pia mater, roots of spinal nerves, vessels, and some membranous structures, all suspended in cerebrospinal fluid.

The Peridural Membrane. The peridural membrane [1] is a little known fibrovascular sheath lying external to the dura lining the vertebral canal. It can be identified lying anterior to the posterior longitudinal ligament and attaching to the deep layer of the posterior longitudinal ligament. The veins of Batson lie on the posterior surface of this membrane but also penetrate it in many places, forming the basivertebral veins. The membrane also extends up the medial sides of pedicles and around on the undersurfaces of the laminae and ligamentum flavum. Thus, it truly surrounds the dura, leaving a potential space between it and the dura, which is called the epidural space. Along with the lateral expansions of the posterior longitudinal ligament, it is continuous with the sheath that lines the bony lateral canals, which is called by some authors the "circumneural sheath" [2].

The spinal medulla is divided into segments called neuromers. We distinguish 31 neuromers: 8 cervical (C), 12 thoracic (Th), 5 lumbar (L), 5 sacral (S) and 1 coccygeal (Co). The vertebral column, which contains and protects the spinal medulla, is also divided into segments. We distinguish a cervical segment consisting of 7 cervical vertebrae, a thoracical segment consisting of 12 thoracic verebrae, a lumbar segment consisting of 5 lumbar vertebrae, a sacral segment consisting of 5 sacral vertebrae which in adults unite to form the sacral bone, and a coccygeal segment made up of 4 to 5 coccygeal vertebrae which form the little coccygeal bone. In children, the spinal medulla extends from the occipital bone (foramen magnum) to almost the end of the spinal canal formed by all vertebral foramina and ligaments attached to laminae, corpuses, and pedicles of vertebrae.

With growth we observe enlargement of the vertebral column but not of the spinal cord. As such

Table 1. The relationship between the spinal cord and the vertebrae in adults. After [3]

Segment of spinal medulla	Corpus of vertebrae
C8	C7
Th 6	Th4
Th 12	Th 9
L 5	Th 12
Co	L1

we observe that the neuromers move above the corresponding parts of the vertebral column denoted in early childhood (refer to Table 1).

The level at which the spinal cord ends varies widely from Th12 to L3/L4 intervertebral disc [4] The spinal cord extends to the L1/L2 disc in 51% of people and to the L2/L3 disc or below in 12% [5]. A recent magnetic resonance imaging study of 136 adults [6] showed that the median level of termination of the spinal cord for both males and females was the middle of L1 vertebra, a level higher than usually reported [7].

The dura mater is a cylinder extending from the foramen magnum to the second segment of sacrum. [8]. It is a dense, connective tissue layer made up of collagen and elastic fibres, and contains the spinal cord and nerve roots that penetrate it. Classically the spinal dura mater consist of collagen fibres running in a longitudinal direction [9]. This has been supported by histological studies [10].

Arachnoid mater represents the most important and active meningeal barrier, delimitating the space of interest in spinal analgesia: the subarachnoid space. It is formed by two portions: a dense laminar portion covering the dural sac internal surface, and a trabecular portion extending like a spider web around the pia mater [11, 12]. The arachnoid mater must not be considered only as a passive container of the cerebrospinal fluid (CSF), but it also actively participates in the transport of anaesthetic agents and neurotransmitters involved in spinal block [13].

There is no uniform distribution of the components of the epidural space. This is as a result of it's division into smaller, unequal areas interrupted in a concentrical manner in the horizontal plane.

The posterior space is separated from the lateral spaces by the processes of dura mater which encircles the roots of the spinal nerves while adjacent compartments connect between the processes of

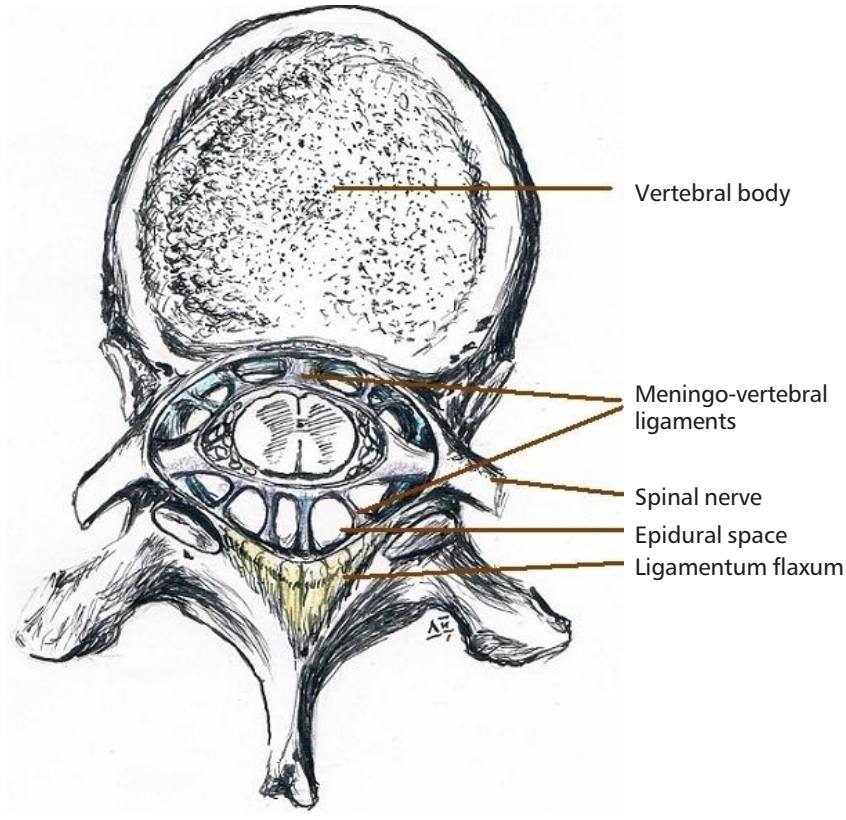

Figure 3. The presence of some fibrous structures in epidural space

the spinal nerves. Local anesthetics distribution in the epidural space may be influenced by fibrous septa which run from the dural sac to ligamentum flava and pedicles of vertebral arches. These septa are called meningo-vertebral ligaments and are found not only in the anterior epidural space as was previously described but also in posterior epidural space. The final effect of this subdivision is a formation of several posterior and lateral spaces.

The epidural space may be clinically further subdivided into posterior, lateral, and anterior spaces. In the posterior epidural space, the left and right ligamenta flava (yellow ligaments) merge in the median plane at an angle less than 90°. Because of its arch-like shape, the epidural space is most superficial in the median plane with gaps seen often in the cervical and from time to time in the lumbar parts of the vertebral column.

Small vessels penetrate the fat of the epidural space through these gaps. These gaps, thinner than in any other parts of the vertebral canal, are the only ones in which fat is attached to the wall of the vertebral canal. This fat is enveloped by a sac formed of epithelium, slightly touching the yellow ligaments and vertebral laminae. This fat provides a possible route for the transmission of fluids and other substances (eg. local anaesthetics, catheters). Fibrous structures which divide the epidural space in the median plane have been described in other publications, however it seems that their description is wrong.

The unilateral blockade is rather due to the preferential spreading of local anesthetic to the side from which the catheter is placed than to the divisions of the epidural space. It seems important to state that it is possible to enter the epidural space without passing through the yellow ligaments. This possibility occurs rather at cervical or upper thoracic levels and rather rarely in other portions. The lack of unilateral local anesthetic spread is not as a result of barriers separating the median plane.

The lateral epidural spaces are open spaces because they communicate through the intervertebral foramina. That foramina are clinically referred to as

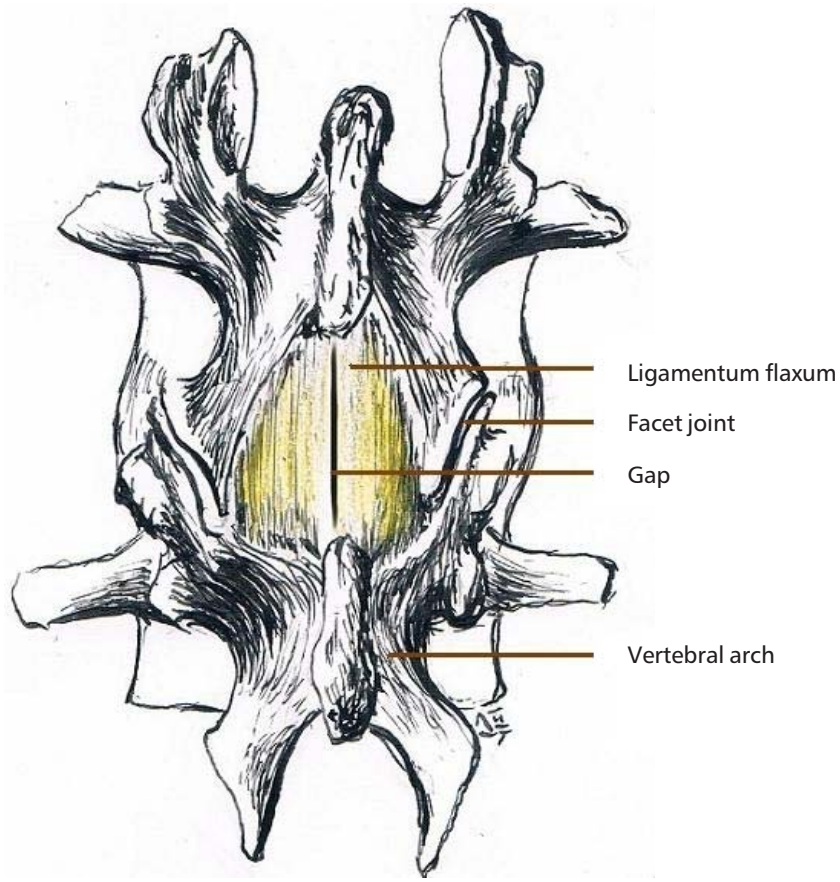

Figure 4. The presence of gaps in yellow ligaments (ligamenta flava). These gaps allow to enter the epidural space without passing through the yellow ligaments

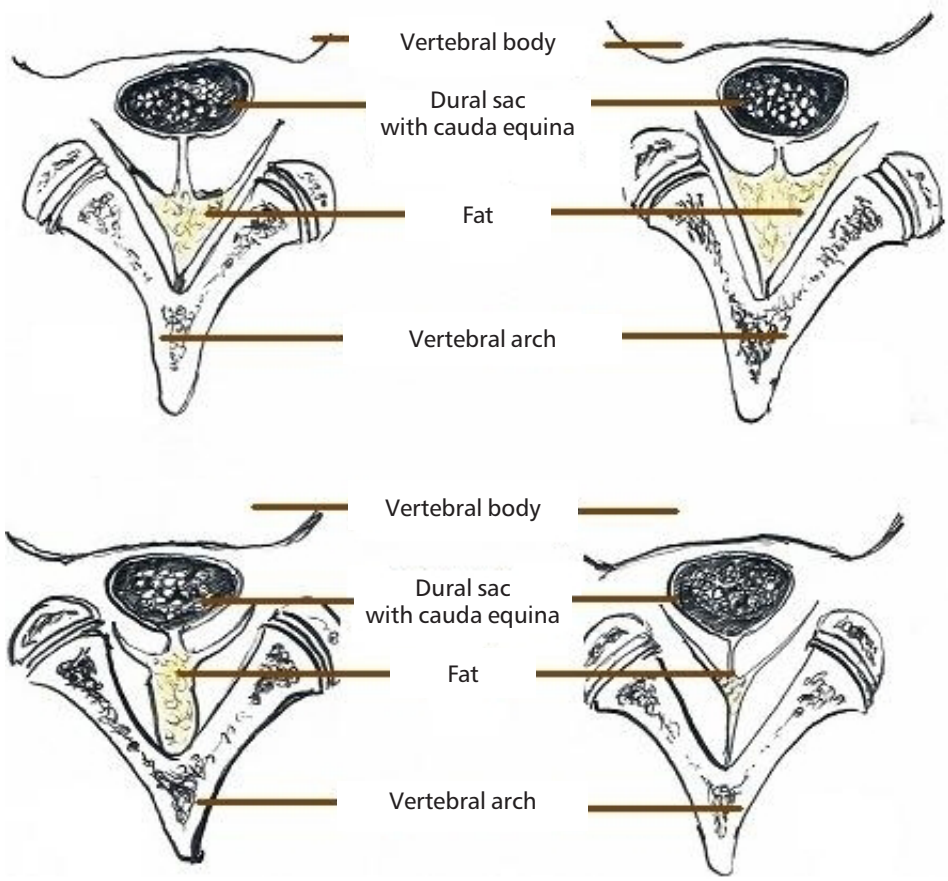

Figure 5. Fat distribution in epidural space. Specific patterns of anatomic configuration seen on CT-epidurography. 40 patients were examinated. 7 showed pattern A, 2 showed pattern B, 18 showed pattern C and 13 showed pattern D. After [14]

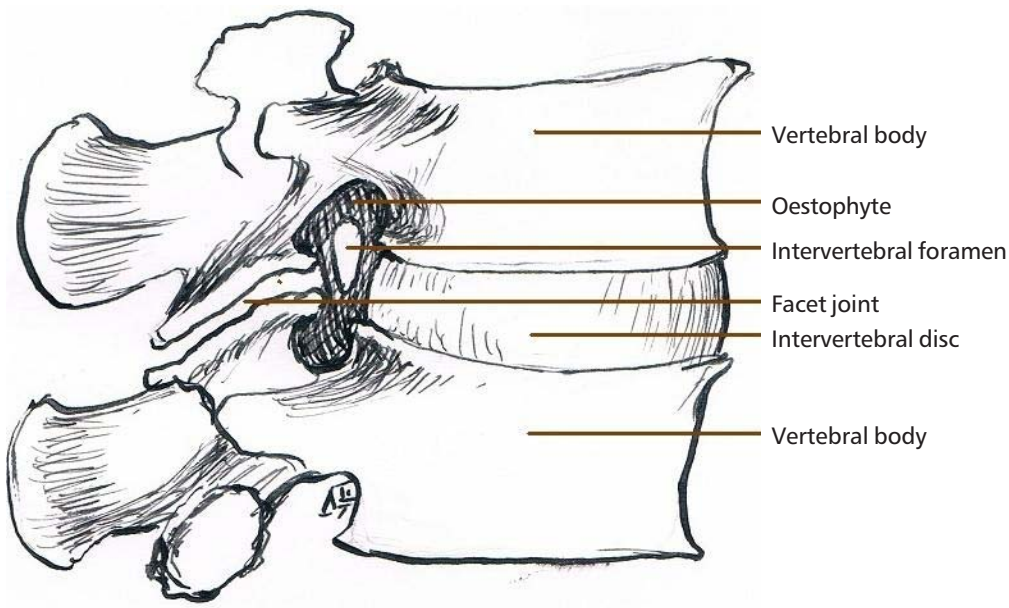

Figure 6. Degeneration of the vertebral column with osteophyte formation leads to sealing up intervertebral foramen

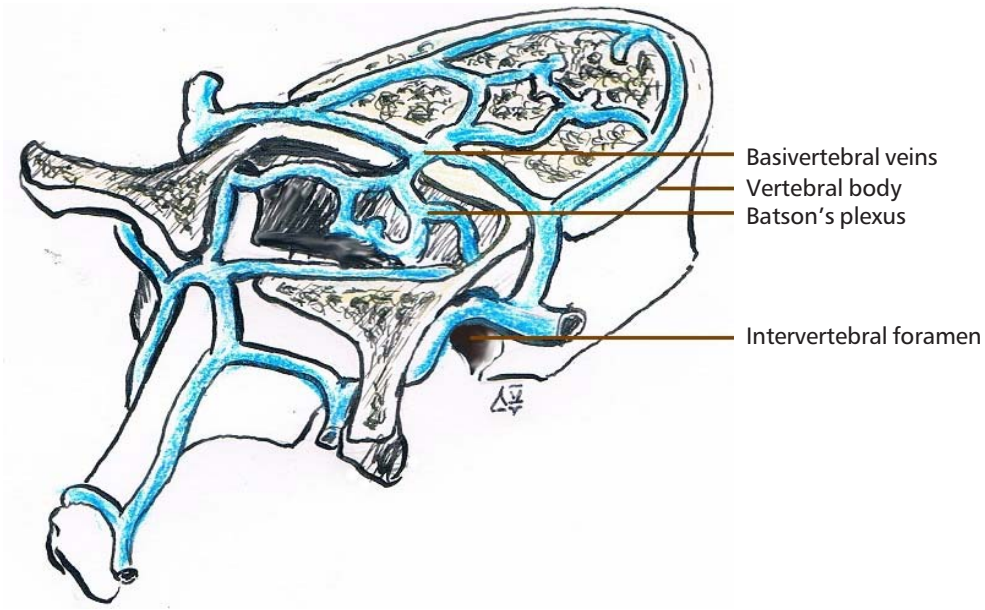

Figure 7. Scheme of Batson's plexus

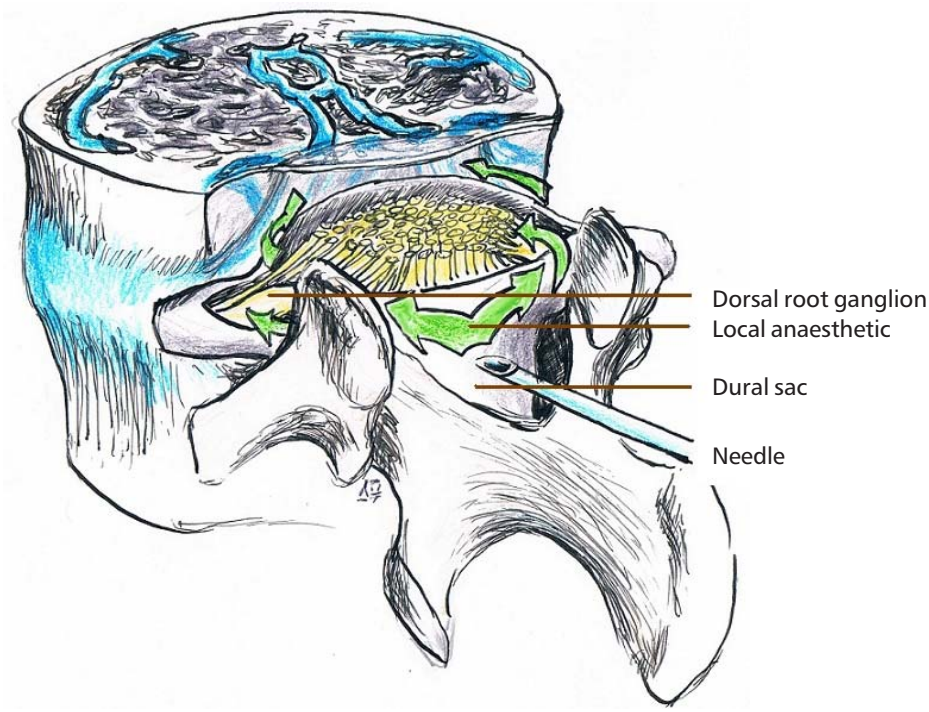

Figure 8. Epidurally deposited drug (arrows) spreading laterally from the midline. After [18]

the canals of the nerve roots and contain the spinal nerve, radicular vessels, veins linking intra-vertebral and extra-vertebral venous plexuses, along with a small amount fat. An important fact is that these windows are not closed. They contain a kind of opercula consisting of fibrous connective tissue. Local anesthetic may efflux through the spaces of these opercula into the perivertebral space. In the elderly, degeneration of the vertebral column with osteophytes formation may lead to sealing up these foramina resulting in an upward spread of the neuronal blockade.

Because of the lack of continuity in the vertebral canal walls, the pressure in epidural space is the same as in the abdominal cavity. Any increase of pressure in the abdominal cavity leads to an increase of pressure in the epidural space [15]. There is no data that this change is mediated by the venous plexus. The intervertebral venous plexus, referred to as Batson's plexus, becomes enlarged during pregnancy. Batson's plexus has some unique properties. For instance, it has no valves, allowing for the appearance of Steal syndrome when fistula with radicular artery occurs. This condition may lead to ischemia and even stroke of the medulla.

Anterior epidural space. The posterior longitudinal ligament remains close to the anterior surface of the dural sac. They come in contact via the peridural membrane with each other closely at the level of the intervertebral discs, especially in the lumbar levels. Anteriorly to the posterior longitudinal ligament one may find Batson's plexus where blood flow is usually continuous. This venous area is the starting point for the basi-vertebral veins which penetrate the corpuses of vertebrae. The close relationship of the posterior longitudinal ligament with the dural sac seals the anterior epidural space in the level of each intervertebral disc leading to the horizontal orientation of venous vessels [16]. The importat fact is that epidural veins are restricted to the anterior and lateral epidural space [17, 18].

Attachment of the posterior longitudinal ligament to the vertebral discs places venous vessels anteriorly to the roots of the spinal nerves which are orientated: the vein — fibrous patch — nervous roots. Anaesthetic administered into the epidural space is first delivered to roots and not into the veins [19].

The use of computed tomography allows us to know that the endings of catheters introduced by median approach in the lumbar level during epidural anaesthesia are placed most often laterally to the dural sac. Even if the end of the catheter passes through the intervertebral foramen into the para-vertebral space, local anaesthetic injected into the epidural space penetrates sufficiently as far as the other side of the epidural space. There is much variation in the spread of drugs in the epidural space. Injected drugs may circulate in the dural sac equally, spread in an asymmetrical manner, not penetrate to the anterior part, penetrate anteriorly or posteriorly to the sympathetic chain, or even end up in the para-vertebral muscles through the route of injection. Leakage of fluid through intervertebral foramina is rather variable. It is possible to create a deposition of anaesthesia in the adipose tissue. The success of epidural anaesthesia, despite highly variable distribution of the drugs, proves the excellent absorptive capabilities of the epidural space. To compensate for this problem one can administer larger amounts of anaesthetic. When local anaesthetic is injected via needle and not through a catheter the deposition of drug is much more median. It improves the chances for adequate anaesthesia.

Intrathecal space

The volume of cerebrospinal fluid (CSF) is a very important factor in drug distribution and blockade spreading [20]. Magnetic resonance imaging (MRI) has proven the huge inter-space diversity in the volume of CSF. From the level of the intervertebral disc between the 11^{th} and 12^{th} thoracic vertebrae to the end of the dorsal sac the mean volume of CSF is 50ml, however it can range between 28 and 81 ml [21, 22]. The volume of CSF is influenced by some factors such as obesity or increase of intra-abdominal pressure. These factors may decrease the CSF volume. Vertical oscillations are coordinated with the pulse of the intracranial vessels. From a clinical point of view it is important to note that the dural sac is easily compressed by an increase of intra-abdominal pressure (for instance during cough, obesity, pregnancy). This pressure is transmitted via the intervertebral foramina. Sudden transient elevations in pressure as in Valsalva manouver or cough, evoke cranial distribution of the CSF and as such higher blockade penetration. In chronic increased epidural space pressure (eg. during pregnancy, obesity), the CSF volume is decreased but vertical oscillations of CSF are present. Consequently, this causes an increase in anaesthetic dissolution and causes increased vertical spreading of injected drug during spinal analgesia.

Spinal analgesia

The posterior sub-arachnoid space is divided by membranous septa into many compartments with small spaces. Membranous septa extend in the median plane from the median fissure to the arachnoid lying in the front of this fissure. Studies carried out on cadavers prove that this structure can be found in almost all people in the cervical and thoracic levels and 28% of people at the lumbar

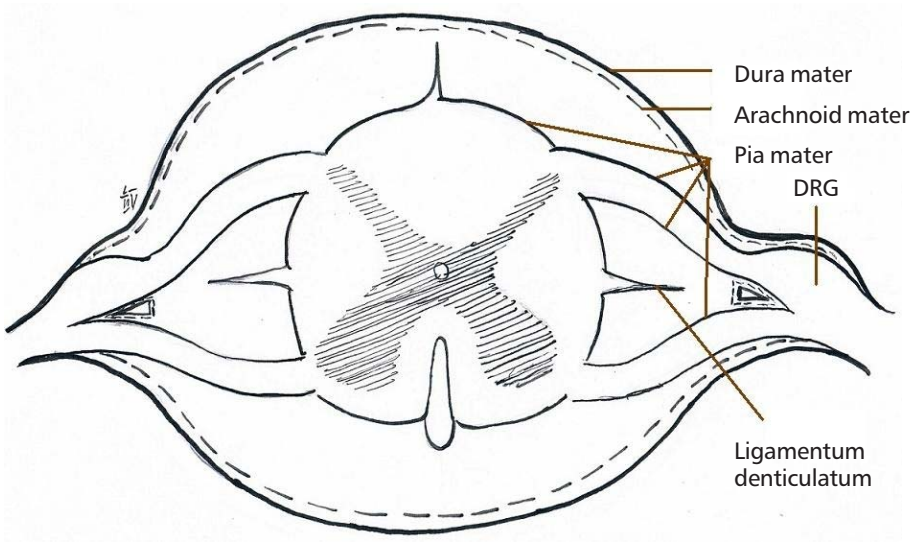

Figure 9. The spinal cord and meninges in transverse section

level. Additionally, from the cuff of every dorsal root of the spinal nerves arise septa connecting the posterior septum to the arachnoid, forming the cul-de-sac structure. Cyst-like spaces create saccular enlargements of posterior septa along the whole length of the subarachnoid space. This forms saccular dilations of the posterior median septum along the whole course of the posterior subarachnoid space. As a matter of fact, these are recesses which communicate with posteriori subarachnoid septum.

After radiological examination with contrast, the unequal distribution of CSF in 45–84% of the population has been observed.

The spinal nerve roots

The spinal nerve roots emerge from the dorsal sac encircled by tubular enlargements of arachnoid, subarachnoid space, and CSF, continuing to the proximal part of DRG. At the lateral ends of these neural root cuffs, the subarachnoid space ends in a cul-de-sac manner, flexing to the back of the cuff along the roots. At this junction, cuffs made from dura mater reach the villi of the arachnoid matter, usually not visible with a naked eye.

In the course of time arachnoid matter may swell and become filled with CSF. It projects into the epidural space through the dural sac and makes

Figure 10. Cul-de-sac as endings of subarachnoid space near dorsal root ganglion (DRG)

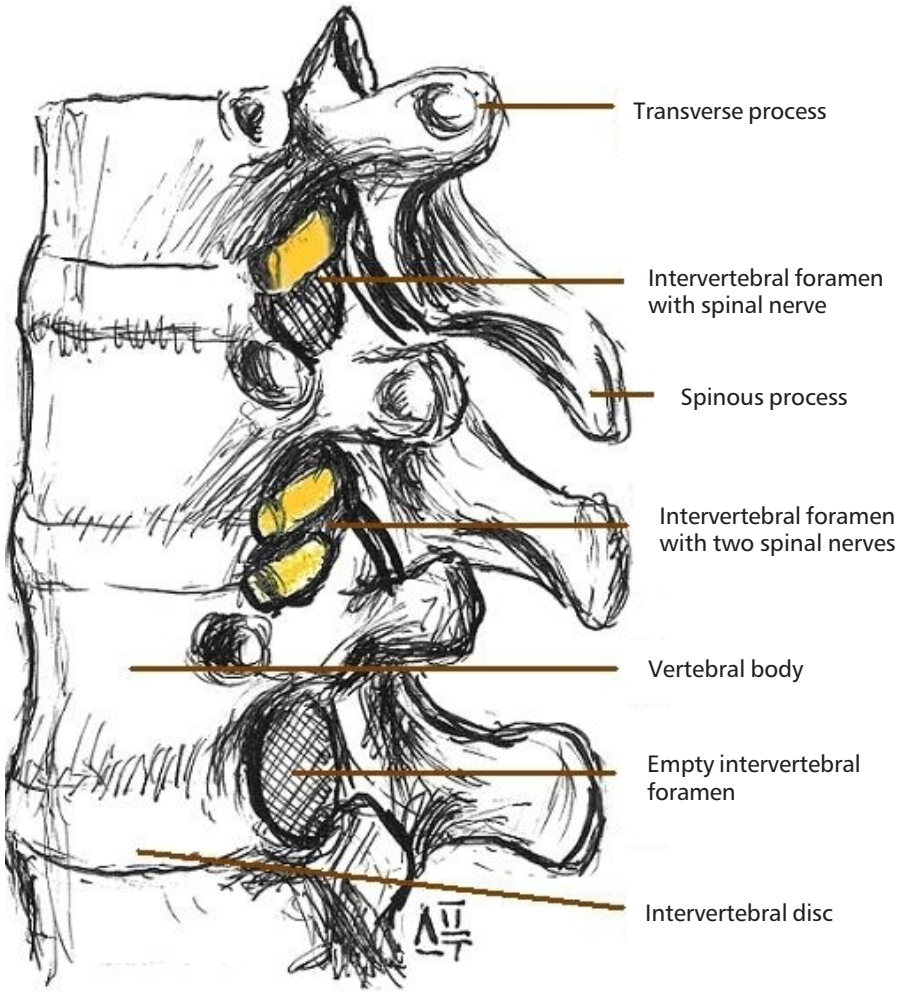

Figure 11. The possibility of common passage of two consecutive spinal nerves through a single intervertebral foramen with company of empty next one

granulations similar to those in the venous dural sinuses. While their role is still unclear, they may play a role as specific traps for CSF. Arachnoid expansion along the roots, especially where the arachnoid comes into contact with the dural sac, induces pocket-like areas filled with CSF where exchange of its components is diminished [21, 22]. The degree to which sub-arachnoidal structures influence the distributions of drugs injected during spinal analgesia is still unknown. Membranes of the subarachnoid space reduce side-to-side distribution of drugs which may lead to an asymmetrical block.

The area of subarachnoid space enclosed by the arachnoid in the form of a border encircling the nerve roots may "incarcerate" a high dose of administered drug (eg. local anesthetic). This may lead to a higher concentration of local anesthetics in these regions while fibers lying centrally may not come into contact with the local anesthetic at all.

To date, the only mechanism that has been shown experimentally to explain drug movement between epidural space and the CSF/spinal cord is simple diffusion trough the spinal meninges [23–25]. Dura mater is the most permeable of the spinal meninges [23–25]. In fact, it is a very thin arachnoid matter that accounts for greather than 90% of the resistance to drug diffusion through the spinal meninges. Even if the dura mater is much thicker than the arachnoid mater, it is composed primarilly of collagen fibers and the molecular distances between the individual fibres is large enough that it presents very little resistance to drug movement. The arachnoid mater, on the other hand, is composed of overlapping tiers of flat-

tened epithelial-like cells that are connected to one another by frequent tight junctions and occluding junctions. This cellular architecture accounts for the high resistance to drug movement through the arachnoid mater. This low permeability of the arachnoid mater explains the fact that CSF is contained in the subarachnoid space and not the subdural space.

Spinal nerve roots

Spinal nerve roots are the target for anesthestics during epidural or spinal anaesthesia. Their size may determine the degree of anaesthesia penetration and thus influence the anaesthetic efficacy. The anterior nerve roots are half the length of the posterior nerve roots. The 1st sacral (S1) nerve roots are generally accepted to have the greatest diameter, but this may vary and include the 3rd lumbar or 2nd sacral. The posterior roots vary at the level of the 5th spinal nerve from 2.33 to 7.71 mm^2. A single spinal nerve's root is composed of several fascicles (up to 5) with each fascicle composed of root fibres. The fascicles are separated by arachnoid extensions. Along the whole length of the dural sac, the anastomoses between consecutive/neighbouring roots may be found.

Anterior and posterior roots pierce the dural sac at a specific level and go out from the vertebral canal through a common intra-vertebral foramen. In 14% of people we observe common passage of two neighbouring/consecutive spinal nerves through a single intervertebral foramen. It is usually accompanied by a wide previous or next intervertebral foramen [26–28]. This should be kept in mind while performing invasive techniques such as thermo- or neurolysis of spinal nerves.

The large diameter of the L5 and S1 roots may lead to poor anaesthesia in the area around the region of the ankles. The diversity of size and localisation of spinal nerve roots may lead to diverse anaesthetic effects.

The small diameter of the anterior sacral roots is a risk factor in their damage by local anaesthetic administration. The high degree of spinal nerve diversity segmentation, as well as many sensory impulse divergencies, results in the poor correlation between dermatome area and individual segmental innervation.

Injection of local anaesthetic into the epidural space leads to an upward spreading of the anaesthetic blockade in combined spinal-epidural anaesthesia.

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