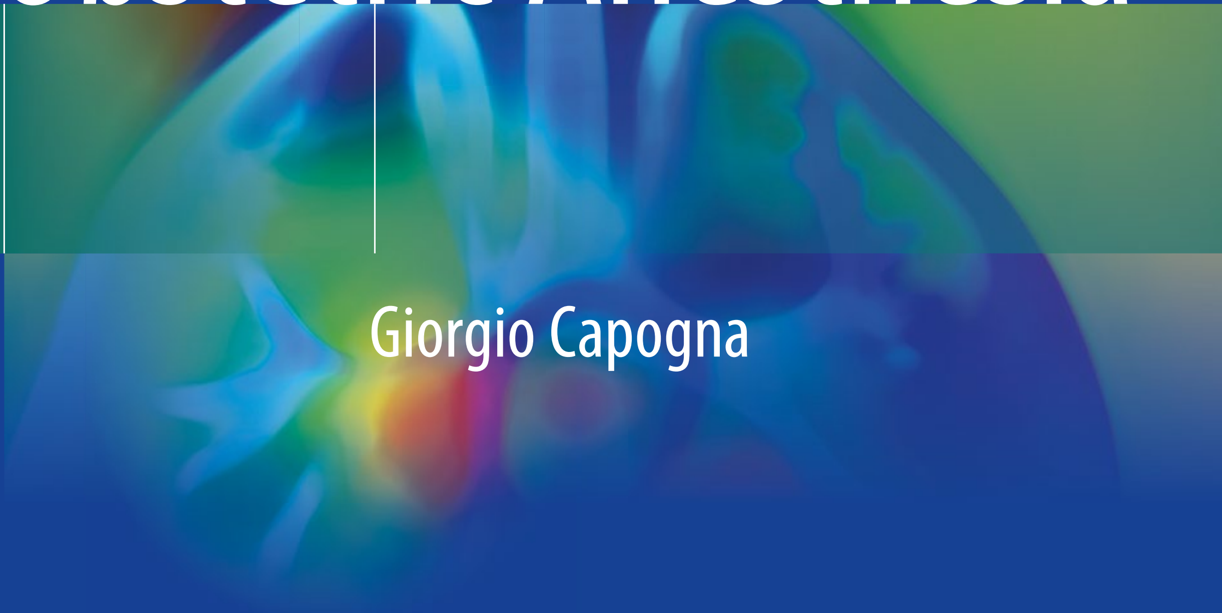
Epidural Technique In Obstetric Anesthesia



Giorgio Capogna

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To Rita and Emanuele

Preface

èpi- [from the Greek. ἐπί “above, in, more”]
pèri- [from the Greek. περί, περι- “around”]
èxtra- [from the Latin. extra “outside”]

The terms “epidural,” “peridural,” and “extradural” are basically synonyms.

To be anatomically precise, peridural should be the most correct term, because it implies that the space is around the dura and therefore it envelops the entire dural sac, while epidural refers to a space that is upon or on the dural sac.

Peridural is most used in countries whose language comes from Latin, extradural is the term currently used in British English-speaking countries, and epidural is currently used in Standard English-speaking countries.

The term “space” is used to indicate the region lying between the dura and the bony walls of the spinal canal. However, the term space is not completely exact, because it is not an empty space, but a place that is filled mainly with fat and with other anatomical structures, and therefore should be called “region” rather than “space.” As we will discuss in the chapter devoted to the anatomy, the most recent anatomical findings support the idea that the epidural region is in part real and in part virtual.

In this text, I will use the most commonly used term: epidural space.

Epidural block is a form of peripheral nerve block accomplished by introducing local anesthetic agents into the epidural space. In this way, the local anesthetic affects the nerve fibers beyond their arachnoid-dural coverings as they lie in the intervertebral foramen, paravertebral space, or sacral canal.

Our masters J. J. Bonica and P. Bromage wrote everything that could be said on the subject, for which I will necessarily refer to their teachings; however, more or less 70 years have passed from their cornerstone publications, and some new things have been discovered, some others have been confirmed with modern methods, and new techniques face the horizon. Clinical practice has also slightly changed. For this reason, I wanted to write this book, to transmit their knowledge and experience to the new generations, adding a little of my updated practical experience.

This book is intended for all colleague anesthetists, but in particular those who want to practice or who already practice analgesia in obstetrics, and therefore it will exclusively describe the lumbar approach to the epidural space which is the one used in obstetrics.

The epidural block has been known universally for a long time; however, its specific teaching is beginning to be lost, as this practice is mainly confined within the scope of obstetric analgesia. For this reason, I hope this book will help my young colleagues to learn and appreciate a fundamental technique for the anesthesiologist and my older colleagues to review their technique to better teach it to future generations.

Rome, Italy Giorgio Capogna

Contents

1

History of Lumbar Epidural Block

Whether Corning in 1884 had obtained true spinal anesthesia in his first human experiment or had merely produced an epidural block remains a debated question. After the introduction of the lumbar puncture by Quincke (1891) only 2 years after Bier's spinal anesthesia (1898), in 1900, Kreis pioneered the use of spinal anesthesia in six parturients for labor pain relief. The very frequent and severe complications related to spinal anesthesia motivated the physicians to investigate other approaches to the spinal cord and nerves, and the most logical was the epidural. Historically, the first approach to the epidural space was that of the caudal, preceding the lumbar, thoracic, and cervical ones. Nine years after the experience with the sacral approach described by Sicard and Chatelin in 1901, Stoeckel introduced the caudal epidural for labor pain relief and until the 1920s, caudal anesthesia was considered the safest route to the epidural space. Sicard and Forestier in 1921 described a technique to reach the lumbar epidural space for neuroradiological purposes and Pagés in the same year sensed that the needle should be stopped in the epidural space to produce a metameric anesthesia. In the early 1930s Dogliotti developed and disseminated the loss of resistance technique and Gutierrez discovered the hanging-drop technique. Graffagnino was the first to use the lumbar approach for labor analgesia while the continuous lumbar technique was introduced by Aburel in 1931, improving the practice of labor pain relief. He also started the systematic investigation of the afferent innervation of the uterus completed by Cleland in 1933 and by Bonica in the 1950s. Finally, Bonica and Bromage (1954) took the practice of epidural anesthesia into the modern era. In their books the epidural block technique is described in an exhaustive way based on their great personal experience and they remain today the major reference for every obstetric anesthesiologist.

1.1 Was the Very First a Spinal or an Epidural Anesthesia?

The beginning of modern local anesthesia may be traced to the late nineteenth century with the availability of the three elements necessary for its administration: a syringe, a needle, and a local anesthetic drug. The year 1885 may be considered the founding year of neuraxial anesthesia with the publication by Corning of the historical article entitled "Spinal anesthesia and local medication of the cord (1885)" [1], followed, only 1 year later, by the first textbook on local anesthesia, *Local Anesthesia in General Medicine and Surgery* (New York, 1886) [2].

James Leonard Corning (1855–1923), a New York neurologist, was born in Connecticut but received his medical education in Germany, graduating from the University of Wurzburg in 1878. The introduction of the hollow needle and the glass syringe by Alexander Wood

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(1817–1884) in 1853 and the clinical demonstration of the local anesthetic properties of cocaine by Karl Koller (1858–1944) in 1884 were the preliminary steps leading to Corning's research that he conducted using hydrochlorate of cocaine on both the peripheral and central nervous systems. He observed that subcutaneous injection of cocaine was associated with both vasoconstriction and local anesthesia and thus hypothesized that injecting cocaine solution into the subcutaneous tissues between two contiguous spinal processes would result in its uptake by veins afferent to the cord. He wrote: "I hoped to produce artificially a temporary condition of things analogous in its physiological consequences to the effects observed in transverse myelitis or after total section of the cord" [1].

At that time the aim of any injection was to deposit the drug as near as possible to the site on which it was desired to act. For example for many years physicians continued to consider morphine effective only if injected close to the painful lesions. In tune with this theory of the time, Corning aimed to deposit the cocaine in close contact with the cord, but at the same time was also searching for a method to avoid the risk of injuring it by puncture.

His first experiment involved injecting 20 minims (1.3 mL) of a 2% cocaine solution into the space between two inferior dorsal vertebrae of a young dog. Within 5 min he noted first incoordination and later weakness and anesthesia of the animal's hind legs which resolved completely in approximately 4 h. The effect did not spread to the forelegs and he attributed this fact "to the lethargy of the circulation at this point."

After this animal experience, he carried out his well-known experiment on man.

He had previously observed that in the lower thoracic region, the vertebral transverse processes lie at the same depth as the laminae which form the posterior boundary of the vertebral canal. He therefore first inserted the needle lateral to the midline until the point of the needle touched the transverse process, and then adjusted a marker located on the shaft of the needle to the skin level. The needle was then reinserted, this time in the midline between the two spines, not quite up to the marker to prevent a too deep an insertion and therefore a possible cord injury (Fig. 1.1).

In a man who suffered "spinal weakness" and "seminal incontinence," he injected 30 minims (2 mL) of 3% cocaine into the T11/12 interspinous space. No effect was noted within 6–8 min and he repeated the injection. Ten minutes later

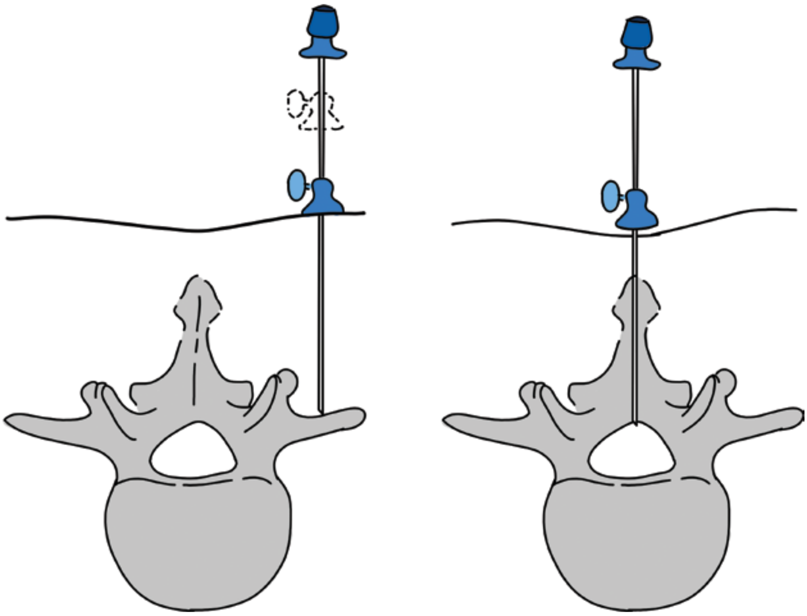


Fig. 1.1 The method Corning used to deposit the drug as near as possible to the desired site

the subject remarked that his legs felt "sleepy" and Corning could demonstrate "greatly impaired" sensitivity to pinprick in the legs, genitalia, and lumbar region which lasted over 15–20 min. No motor weakness or gait disturbance was noted.

Corning did not mention the ligamentum flavum nor the dura mater. In addition he introduced the needle with a charged syringe already attached to the needle, and injected the solution without any previous aspiration, so preventing him from noticing the possible appearance of cerebrospinal fluid in the syringe.

The man made a full recovery but, interestingly, Corning recorded that he complained of headache and vertigo the next morning.

Whether in his first human experiment Corning had obtained, however unknowingly, true spinal anesthesia or merely had produced epidural anesthesia remains a debated question. It seems plausible that Corning's early experimentation resulted in effects more similar to an epidural anesthetic although with signs of some inadvertent dural puncture. Corning's dose of local anesthetic was eight times higher than the doses of the same drug successfully used by Gustav Bier 14 years later for his spinal anesthesia [3]. Yet, the onset of analgesia in Corning's patient was slower and the ultimate sensory level lower. In addition it is certain that Corning's experiment was based on faulty physiological and anatomical premises, since he believed that cocaine injected into the region between two spinous processes would be absorbed by the circulation and transferred to the substance of the cord.

Even in his later experiences, Corning appears to have regarded his intentional intrathecal injections only as a tool to alleviate the existing pain while overlooking its possibilities in surgery.

In his *Pain in its neuropathical relations* (Philadelphia, 1884) [4] under the heading "The irrigation of the cauda equina with medicinal fluids," he wrote: "I became impressed with the desirability of introducing remedies directly into spinal canal with a view to producing still more powerful impressions on the cord, and more especially on its lower segment." He introduced a needle through a small introducer between the L2 and L3 interspace deliberately to perform a lumbar puncture to medicate the cord because of "spinal irritation," but this was 3 years after the technique of lumbar puncture had been described in detail by **Heinrich Irenaeus Quincke** (1842–1922) in 1891 [5].

Fig. 1.2 August Karl Gustav Bier (1861–1949) (from Bibliotèque Interuniversitaire de Santé, Paris. Open Licence)

Unfortunately the work of Corning on clinical local analgesia attracted little attention and had no influence on clinical practice, but his investigations on cocainization of the cord antedated Bier's classic and highly influential experiments by 18 years.

In fact it was 14 years after Corning's first publication that **August Karl Gustav Bier** (1861–1949) (Fig. 1.2), a German surgeon, published the first reports of successful spinal anesthesia in surgery: "*Versuche uber Cocainisirung des Ruckenmarks*" (Experiments with cocainization of the spinal cord)

[3]. On August 16, 1898, Bier injected 15 mg of intrathecal cocaine in a 34-year-old worker undergoing resection of a tuberculous ankle joint. His description is remarkable for its similarity to the modern process: he described positioning the patient in the lateral position, infiltrating the skin and subcutaneous tissues with the cocaine solution, and observing the flow of cerebrospinal fluid from a long hollow needle before injection of the anesthetic solution into the dural sac. He went on to perform five more spinal anesthetics in the same month. Complete anesthesia was achieved only in one patient; five patients could still sense touch or pressure, but not pain. Furthermore in four of these patients, Bier reported complications including back and leg pain, vomiting, and headache. Even at this early stage, he had associated the loss of cerebrospinal fluid with headache, and discussed the risks of toxicity. Within the same publication Bier describes the attempts of himself and his assistant, Dr. Otto Hildebrandt, to deliver cocaine spinal anesthetics to one another. Sensation in Dr. Hildebrandt was tested in various ways including a needle pushed down to the femur, burning cigars, avulsion of pubic hairs, and strong blows to the tibia with an iron hammer, none of which resulted in pain. In spite of promising results, complications were recorded including paresthesia in a lower limb and the loss of "much" cerebrospinal fluid. Bier reported that subsequently he experienced a severe headache, associated with dizziness which was relieved completely by lying flat for a total of 9 days [3].

Only 2 years after Bier's spinal anesthesia, in 1900, **Oskar Kreis** (1872–1958), a gynecologist and obstetrician from Basel, pioneered the use of spinal anesthesia in six parturients for labor pain relief. He used cocaine as a local anesthetic, and all but one patient had nausea, vomiting, and severe postpartum headache.

1.2 The First Epidural Approach: The Caudal

The very frequent and severe complications related to spinal anesthesia such as hypotension, nausea, vomiting, postdural puncture headache, and meningeal irritation motivated physicians in Europe and the Americas to investigate other approaches to the spinal cord and nerves, and the most logical being the epidural.

Historically, the first approach to the epidural space was the caudal, preceding the lumbar, thoracic, and cervical approaches.

In 1901, two French physicians, working independently of one another in Paris, **Jean-Athanase Sicard** (1872–1929), neurologist and radiologist, and **Fernard Cathelin** (1873–1945) claimed the birthright of discovering epidural analgesia.

Sicard had released the first publication on epidural injections. In an article entitled "*Les injections mèdicamenteuses extra durales par voie sacro-coccygienne*" (sacro-coccygeal extradural drug injection) [6], on 20 April 1901, he discussed spinal anesthesia with cocaine and commented on the severe headaches, nausea, and vomiting that were produced postoperatively. He then went on to describe his caudal epidural technique in the dog, a human cadaver, and nine patients with pain who had all obtained immediate analgesia. He stated that this technique should replace spinal anesthesia.

One week later, Cathelin presented his work to the Society of Biology in Paris and stressed that he had been working and experimenting with this new method since 5 February 1901. Evidence was given by his chief, Professor Lejars, as to the truth of this statement. His address was entitled "*Une novelle voie d'injection rachidienne. Methode des injections epidurales par le procede du canal sacre. Applications a l'homme*" (A new spinal injection route. Method of epidural injection by the sacral canal method. Applications to man) [7]. He described the caudal injection of cocaine 1% into dogs, and he demonstrated with Indian ink that his injections were limited to the extradural space. In February 1901 he performed caudal block on four patients who were undergoing surgery for hernia repair, but with imperfect results. He stated that further study was needed but he thought that the technique would be useful for surgical operations, to produce analgesia for painful deliveries, inoperable rectal carcinoma, and hemorrhoidal fissures. Controversy ensued, but in the final analysis Sicard relinquished the discovery to the young Cathelin. It subsequently became apparent that Cathelin was worthy of this generous gesture, since he produced 22 publications and notes about this new method. In 1902 he published his thesis on epidural injections and submitted it for the Doctorate in Medicine. This work was obviously the basis for further research. He refuted Corning's priority in using the epidural space and 20 years after the discovery which he had claimed, he described spinal anesthesia as the "poor relation of my method." It must be remembered that cocaine was the only local anesthetic available initially and was sometimes too toxic in the concentrations required to produce analgesia similar to spinal anesthesia.

In the year 1905 the German chemist **Alfred Einhorn** (1856–1917) synthesized procaine, and gave it the trade name of Novocaine, from the Latin nov- (new) and -caine, the common ending for alkaloids used as anesthetic. The new drug was promptly used for caudal anesthesia since it was less toxic, more effective, and more stable than the previously used cocaine.

Walter Stoeckel (1871–1961), professor of gynecology in Marburg, with a special interest in gynecological urology, injected cocaine solutions into the epidural space, through the sacral hiatus. Stoeckel described a series of 141 cases of obstetric caudal epidural analgesia in an article entitled *Uber Sakrale Anasthesie* in 1909 [8]. According to the English translation of this original paper, edited by one of the pioneers of epidural anesthesia, Andrew Doughty [9], he wrote: "In 18 cases there was no noticeable beneficial effect and in a further 12 the relief of pain was minimal. Positive relief was obtained in the remaining 111 cases but to varying degrees. It became apparent that labour pain is not a single entity but is made up of two distinct components which became recognizable by our experience with sacral anaesthesia […] After an effective sacral block the pain of uterine contraction disappears or at least diminishes and becomes quite tolerable […] We have obtained complete relief or reduction to a tolerable degree of the back pain in 72 cases and of both back and hypogastric pain in 39 cases. The considerable degree of relief was evidenced by the behavior of the mothers in whom the pains were no longer accompanied by loud crying and rolling about in bed; the contractions could then only be perceived by abdominal palpation […] Pain sensitivity in the perineum was mostly, but not always, obtunded when tested with a needle. Thus the passage of the head through the vulva was painless in nine cases and only very slightly painful in 16. Three women were delivered by forceps and two had perineal tears sutured quite painlessly. In two other cases, sacral anaesthesia was insufficient for the application of forceps and these patients had to be helped with a few drops of chloroform. In many cases there was a marked relaxation of the pelvic floor musculature. […] In 23 cases the contractions became weaker and less frequent and this depressive effect was especially noticeable if the injection had been given too early in labour; in one case the contractions ceased with the pain and did not return for 4 days. […] However, if labour had been well established, neither the uterine contractions nor the expulsive forces were affected as a general rule."

In the early 1900s through to the 1920s, caudal anesthesia was considered the safest route to the epidural space. Operations utilizing epidural anesthesia were usually limited to the region of the body supplied by the cauda equina. Attempts to push the block higher by using larger volumes of anesthetic or changing the patient's position were not always successful.

However, **Robert Emmett Farr** (1875–1932), surgeon in Minneapolis, was able to produce anesthesia to the level of the nipples injecting volumes up to 120 mL of local anesthetic introduced through the caudal space. In his paper, "*Sacral Anesthesia*," published in 1926 [10], Farr described his cadaveric experiments. Using contrast dye and X-rays, he showed dissemination of contrast from the epidural space via the epidural foramina. He also described the spread of contrast to the level of the cervical vertebrae when volumes greater than 80 ml were introduced through the caudal canal.

Caudal sacral analgesia became popular in obstetric analgesia in the first 20–40 years of the twentieth century. However it had at the very least a discrete failure rate even in the best hands, due to both the variations in the anatomy of the caudal canal and the difficulty, often the impossibility, of identifying the caudal hiatus in the parturient at term. In addition while caudal analgesia was able to produce successful perineal and second-stage analgesia, it could not provide pain relief from uterine contraction unless large doses were used, with the risk of toxicity and a slowing down of the labor process.

1.3 Lumbar Epidural

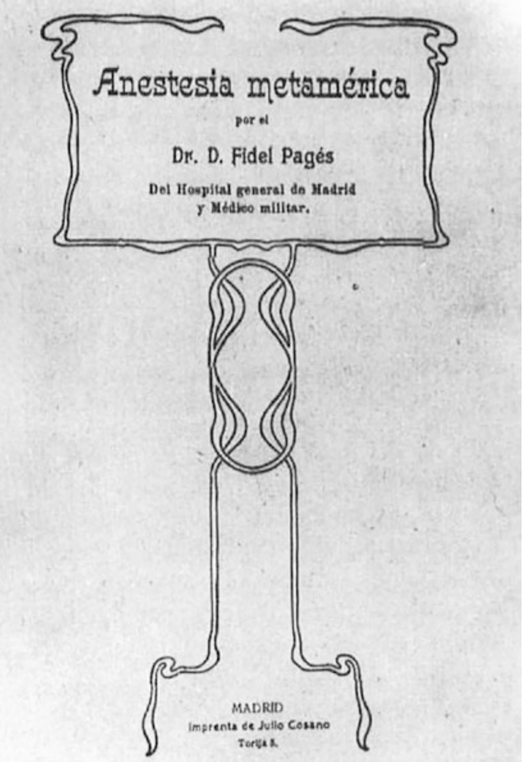
As early as 1921, two French radiologists, **Jean Sicard** (1872–1929) **and Jacques Forestier** (1890–1978), described a "loss of resistance" to syringe injection as a spinal needle was advanced through the lumbar ligaments. They were injecting radiographic contrast (lipiodol) to treat chronic lumbar and sciatic pain while studying spinal canal abnormalities and described this "loss of resistance" as the entry of the needle tip into the epidural space. In the course of this procedure they accidentally injected a few millimeters of lipiodol in the subarachnoid space, producing a myelography with no arachnoideal adverse reaction [11]. However, both were of the opinion that lumbar and thoracic epidural space was not suitable for the diffusion of the injected solutions, due to the presumed presence of tough septa and for the easy diffusion of the liquid itself through the vertebral foramina. In the same year, **Fidel Pagés Miravé** (1886–1923) (Fig. 1.3), a Spanish military surgeon, was the first person to perform epidural anesthesia by the lumbar route.

In his paper *Anestesia Metamérica* (Metameric Anesthesia) which was published in March 1921 simultaneously in the *Revista Espaniola de Cirugia* [12] and in *the Revista de Sanidad Militar* [13], he described his original idea: "*En el mes de noviembre del pasado año, al practicar una raquianestesia, tuve la idea de detener la cánula en pleno conducto raquídeo, antes de atravesar la duramadre, y me propuse bloquear las raíces fuera del espacio meníngeo, y antes de atravesar los agujeros de conjunción, puesto que la punta de la aguja había atravesado el ligamento amarillo correspondiente.*"

Fig. 1.3 Fidel Pagés Miravé (1886–1923) (from Lange JJ et al. (2007) Anaesthesia 49: 429–431, with permission)

This is the English translation of his original description of epidural anesthesia which relied on his feeling for the "snap" as the needle passed through the ligamentum flavum and entered the epidural space: "In November of last year, while I was carrying out spinal anesthesia, I had the idea of detaining the cannula with the spinal canal, before it penetrated the dura mater, and then blocking the roots outside the meningeal space before the needle traversed the corresponding foramina, since the point of the needle had traversed the corresponding yellow ligament. I abandoned the Stovaine that I had prepared, and in a sterilized capsule dissolved three tablets of Suprarenin Novocaine of series A (375 mg of Novocaine) in 25 mL of physiologic serum, and proceeded to inject it immediately through the cannula which was placed between the second and third lumbar vertebrae. Hypoesthesia became accentuated progressively, and within 20 min after injection we decided that it was permissible to start the operation. We carried out radical repair of a right inguinal hernia without the least discomfort to the patient."

After this, he described his experience with this technique in 43 patients (including upper abdominal operations) (Fig. 1.4).



Anestesia metamérica

por el

Dr. D. Fidel Pagés

Del Hospital general de Madrid
y Médico militar.

MADRID
Imprenta de Julio Cosano
Torija 8.

Fig. 1.4 First page of the paper "Anestesia Metamerica" published by Fidel Pagés in 1921 (from Lange JJ et al. (2007) Anaesthesia 49: 429–431, with permission)

Unfortunately his work did not circulate in the scientific world at that time, since he published only in Spanish and he did not present his work at any congress. In addition his premature and unexpected death certainly contributed to the lack of dissemination of his work.

Independently of Pagés, an Italian surgeon, Achille Mario Dogliotti who did not previously know about Pagés' work described epidural anesthesia through the lumbar route in 1931. A controversy as to who was the first to discover lumbar epidural anesthesia consequently arose. Dogliotti, as president of the International College of Surgeons, attended numerous conferences and published in the English language, facilitating the diffusion of his technique. Dogliotti learnt later of the work of Pagés and acknowledged him as the first to develop and describe the lumbar epidural approach [14].

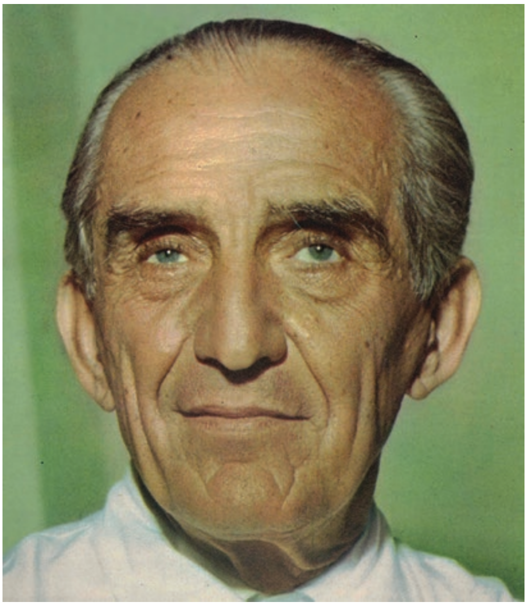


Fig. 1.5 Achille Mario Dogliotti (1897–1966)

However, whereas Pagés used a tactile approach to identify the epidural space, Dogliotti was the first to identify it by using the loss of resistance technique.

Achille Mario Dogliotti (1897–1966) (Fig. 1.5), professor of surgery in Modena, Catania, and Turin, was an innovator of Italian surgery, having developed one of the first heart-lung machines. He was also a pioneer in the X-ray techniques of the biliary tract and responsible for the organization of the first blood bank in Italy. He may be considered the "father" of modern epidural anesthesia since he first described the modern loss of resistance technique that overcame the main obstacle to the advancement of lumbar and thoracic epidural anesthesia due to the inability to reproducibly identify the epidural space at those levels.

We can consider the "birth certificate" of lumbar epidural anesthesia the lecture Dogliotti gave on April 18, 1931, at the meeting of the Società Piemontese di Chirurgia (Piemontese Society of Surgery) which was entitled "*Un promettente metodo di anestesia tronculare in studio: la rachianestesia peridurale segmentaria*" (A study on a promising method of troncular anesthesia: segmental peridural rachianesthesia) [15].

As he explained during his lecture at the XIth Annual Congress of Anesthesiologists, in

New York City in October 1932 [16], Dogliotti was looking for an alternative to spinal anesthesia, since “inconveniences always complained about in spinal anesthesia, besides the decrease of blood pressure, are nausea and vomiting during the operation (about 30% of the cases), and postoperative headaches (about 10–20%)” and defined his epidural approach as “a regional anesthesia covering a large region which permits the obtaining for the upper and lower abdomen, for the extremities and for the thorax what the Cathelin epidural sacral anesthesia obtains for the perineum and pelvis.”

After having recognized the relative difficulty of the lumbar epidural technique encountered in the past, Dogliotti explained how he had made it simple and reliable: “The technique has been made easy and simple by introducing the needle, connected with a syringe filled with physiological solution, slowly and exercising at the same time as the needle penetrates the yellow ligaments a constant and considerable pressure on the piston. While the needle is penetrating the yellow ligaments, a strong resistance to the injection of the liquid is felt. As soon as the needle pierces the ligaments and arrives in the peridural space, all resistance is at once removed and the liquid enters with every facility separating the dura mater from the peridural adipose tissue. The needle is thus in place and after having ascertained that there is no flow of either blood or cerebro-spinal fluid, the next procedure is the injection of the anesthetic which will diffuse itself in the peridural space” (Fig. 1.6).

Dogliotti’s method of identification of the epidural space was a very important innovation that launched this valuable technique in the modern practice of anesthesiology. The previously described methods, such as that described by Pagés, were primarily tactile methods of identifying the epidural space, noting the “feel” of the needle tip as it passed through the ligamentum flavum, and this limited these techniques to the manually clever. Instead Dogliotti’s technique was reproducible and easily learned. Dogliotti’s Anesthesia Textbook was published in 1935 [17], was translated into English in 1939 [18], and contained an extensive and detailed chapter on epidural analgesia which also included all his exhaustive studies performed on this matter. Textbooks by American authors several years later contained only a short description of the technique, treating it as a novelty practiced only by those with special expertise.

Initial acceptance of epidural analgesia was therefore slow to develop in North America, although it gained early and wide acceptance in Europe and South America.

In the 1930s, **Alberto Guiterrez** (1892–1945) (Fig. 1.7), professor of surgery in Buenos Aires, used the epidural anesthesia technique from Pagés and Dogliotti and applied it for thousands of different operations. Concerned about general anesthesia accidents, Gutierrez turned to other alternatives. He first used spinal anesthesia, and then epidural anesthesia in an approach called at that time the “direct method” (loss of resistance). Occasionally, he used what was indicated as the

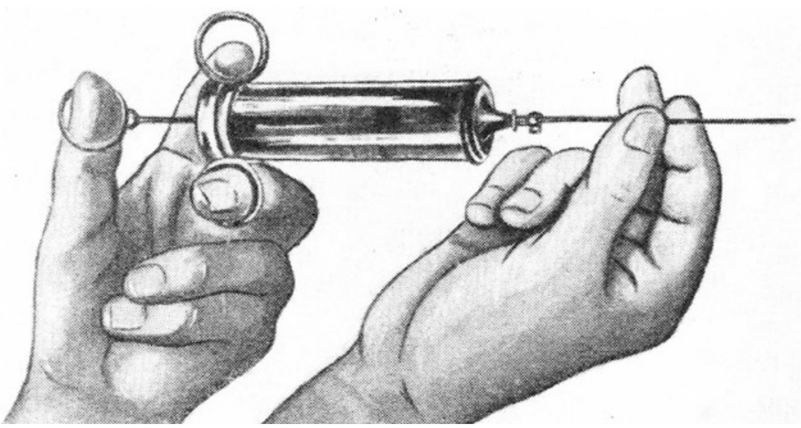


Fig. 1.6 Original Dogliotti’s description of his loss of resistance technique: the syringe is held in one hand, the thumb of which applies a continued and uniform pressure to the piston (from [16] with permission)

Fig. 1.7 Alberto Gutierrez (1892–1945) (from [19] with permission)

"indirect method," in which the needle was intentionally introduced into the dural sac, and then gradually withdrawn a few millimeters until the cerebrospinal fluid stopped dripping, assuming that at that moment, the bevel was as in the epidural space. Antonio Aldrete [19] describes the history of the Gutierrez discovery as follows: "One day in February 1933, Alberto Gutierrez was searching for the epidural space by use of the loss- of-resistance method with fluid. Apparently, while introducing the tip of the needle through the interspinous ligament and approaching the ligamentum flavum, he felt undue resistance, so he disconnected the syringe and noted that a drop of the fluid was left hanging from the hub. He did not reattach the syringe but continued to advance the needle, without touching the drop. As he continued to insert the needle very slowly, he suddenly noticed that the drop disappeared. He then reconnected the syringe and aspirated without obtaining fluid." After fractionated doses of 1% procaine without feeling resistance up to 15 mm, he was able to perform a painless saphenectomy. This observation was reported in an informal way in the periodical *el Dia Medico* on March 27, 1933 [20], and followed by a formal paper in the *Revista de Cirugia* [21]. Gutierrez reported that sometimes the drop did not hang, but rather a meniscus of fluid could be observed within the hub, in which case the needle must be advanced very slowly and injected only when the fluid could no longer be seen.

In 1938 Gutierrez published in his book *Extradural Anesthesia* [22] the updated experience of everyone he knew that was practicing epidural anesthesia, including Dogliotti who, at the time, had performed over 4000 cases.

Of interest were his attempts to find out about the negative pressure in the epidural space.

Gutierrez's way of using the negative epidural pressure as a marker of finding the epidural space by placing a drop of saline on the hub of the advancing needle became known as the sign of the hanging drop.

In 1936 **Charles Odom** (1909–1988), director of surgical services at the Charity Hospital of New Orleans, substituted a capillary tube for the hanging drop as follows [23]: "I cut a small glass adapter commonly used to connect a rubber infusion hose to an infusion needle, in half and connected it to the spinal needle after it had been engaged in the interspinous ligament. The ground glass tip of the adapter made the connection air-tight. The lumen of the adapter was then filled with sterile solution. This small glass cylinder with the enclosed fluid made a very delicate indicator. The smaller the bore of the cylinder the more delicate it becomes. This indicator is very easily sterilized and is far less cumbersome to use than the spinal manometers or U tubes used in some of the European clinics." Odom performed a large number of surgeries with this technique including two cesarean sections in women with tuberculosis.

Odom suggested that the epidural space is a potential space in the erect posture and that it only comes into existence when the spine is flexed and the two layers of the dura mater separate. As the anterior wall of the vertebral column does not flex as much as the posterior wall, a space is created between them and as this space is formed from no space at all, a vacuum will be created. This vacuum will slowly dissipate owing to an influx of venous blood until atmospheric pressure is achieved.

In the same hospital **Peter Graffagnino**, a gynecologist, “attempted to add to the anesthetic armamentarium of the obstetrician another procedure, epidural anesthesia, which we have thus far administered to 76 patients” with this publication of February 1939 [24], in which he became the first to report the use of lumbar epidural block for labor analgesia, performed according to Odom’s technique. In his conclusions he stated: “The anesthetic can be administered to all patients in the childbearing age. All major operative obstetrical procedures can be performed under this form of anesthesia safely and with the conscious cooperation of the patient.”

The era of epidural indicators had started, and a number of visual and mechanical devices were developed to help the physician to identify the epidural space.

Massey Dawkins (1905–1975), consultant anesthetist at the University College, London, pioneer of epidurals, the first to administer it in the UK in 1942, in 1963 wrote an extensive review of the main devices in use at that time [25] (Figs. 1.8 and 1.9): “(1) In the Iklè syringe the pressure of the thumb is replaced by a spring which drives the piston forward as soon as the epidural space is entered. (2) In 1935 Macintosh modified this spring loading on the piston by applying spring pressure to a blunt trocar inside the epidural needle. This trocar will not normally pierce the dura. While the needle is traversing the interspinous ligaments, the distal end of the trocar projects from the hub of the needle. When the point of the needle enters the space, a hidden spring in the hub of the needle drives the trocar forward and the distal end of the trocar disappears into the hub. This is an excellent device as the weight of the needle is unaltered and there are two wings protruding on either side of the hub which make for ease in handling … No data concerning the efficiency of this device have been recorded in the literature. (3) A simpler device, also introduced by Macintosh, consists of a balloon distended by air which is plugged into the hub of the needle … Directly the advancing needle enters the space, the balloon will deflate. It is advisable to use a fresh balloon for each case in order to avoid leaks. Although the balloon is widely used, no details of its efficiency have been published, but enquiries among colleagues who use it have established that in 506 cases there was a dural puncture rate of 6.7%. (4) In 1956 Zelenka suggested that the tactile and visual techniques could be combined in one device. He took a U shaped manometer containing bubbles of air in sterile water and fitted a tap at the distal end into which a distended balloon could be plugged. When the needle was in the interspinous ligament the device was attached and the tap opened. Now as soon as the space was entered the meniscus received an impulse of positive pressure from behind which helped to overcome the 19% failure rate of the visual technique alone. There are however no recorded details of the efficiency of this device. (5) In 1958 the above device was simplified by Brooks who took an Odom’s indicator, heated the distal end, sealed it and then blew a small bulb in it. If a bubble of air in saline is placed in the capillary tube and the indicator is plugged into the hub of the epidural needle and the bulb is then heated, the air within it expands and provides a positive pressure behind the meniscus. This exceedingly simple device works well in practice and in my own experience converts a success rate with Odom’s indicator alone of 73% to one of 90%.”

1.4 Continuous Lumbar Epidural

Clinicians realized that to provide continuous anesthesia for long-lasting surgical procedures, there had to be a way to repeatedly inject local anesthetics.

As with the epidural single-shot technique, the continuous method also used this technique first starting from the caudal and spinal route, the lumbar approach only being considered a few years later on.

Eugen Bogdan Aburel (1899–1975) (Fig. 1.10), Romanian professor in obstetrics and

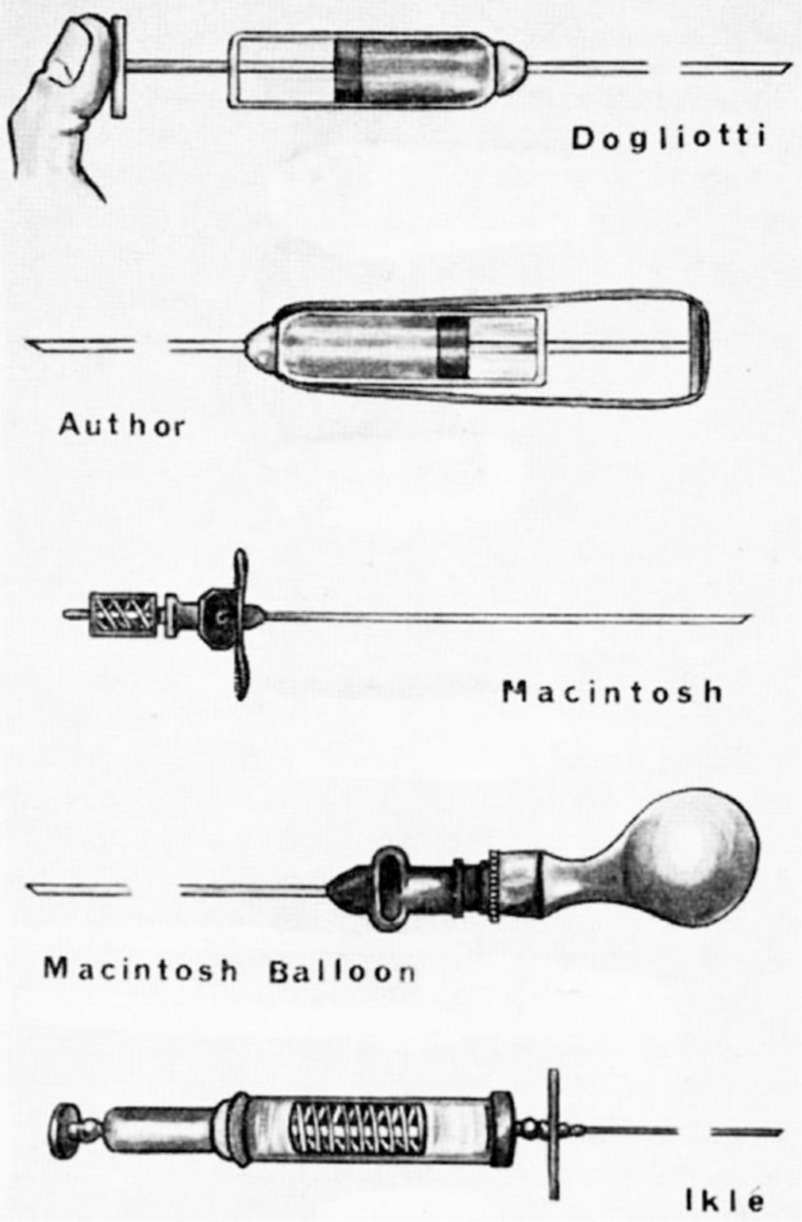


Fig. 1.8 Various types of epidural indicators (1935–1958) (from [25] with permission)

gynecology, and a pioneer in obstetric analgesia, in 1931 presented his technique of "*anesthèsie locale continue (prolonguèe) en obstètrique*" (continuous local anesthesia in obstetrics) [26]. His technique for insertion of the catheter through the needle withdrawing the needle over it and positioning the catheter is very similar to what is in use today. Curelaru [27] describes Aburel's description of his technique as follows: "Firstly, introduce the needle at the selected level (epidural, lumbo-aortic): inject 30 mL of cinchocaine (Percaine) 0.5%; introduce through the needle a soft catheter (similar to ureteric catheters); remove the needle with the catheter left in situ: finally, apply a dressing above the catheter. If repeated injections are required, they could be performed with a fine needle through the catheter left in situ … Through … the needle-catheter approach, it becomes possible to obtain prolonged local anaesthesia in obstetrics.

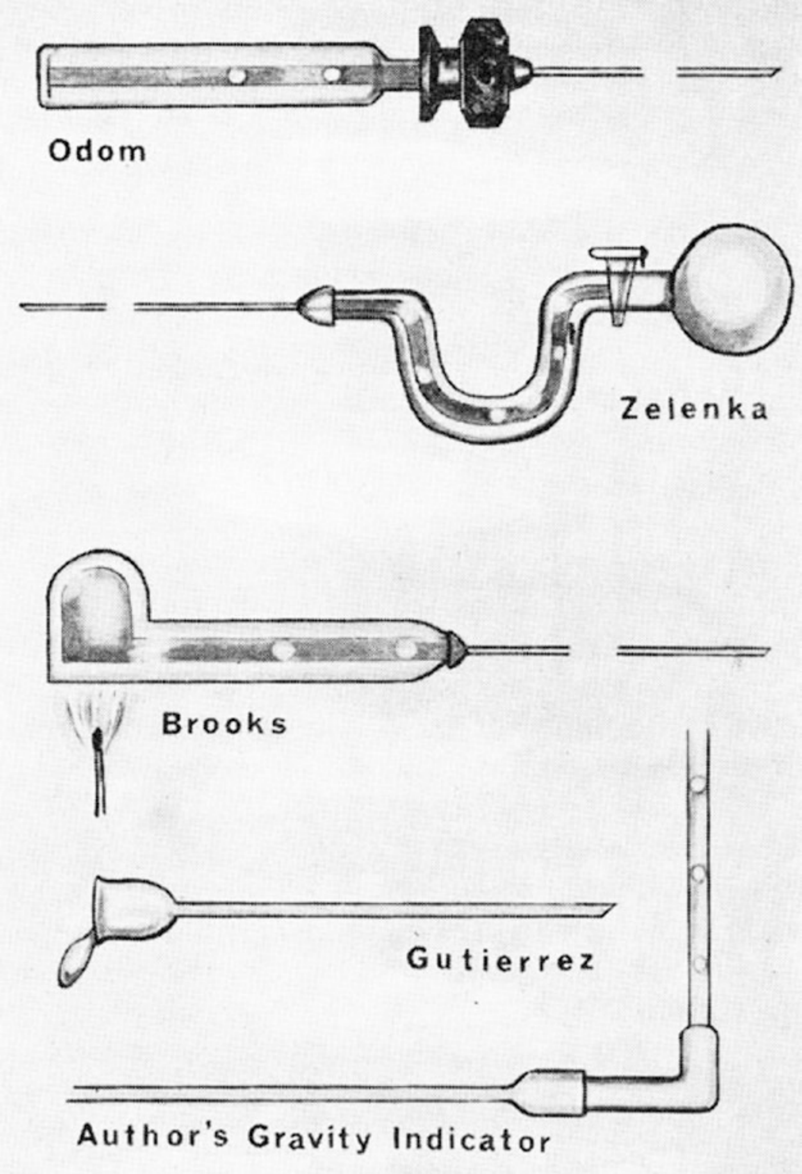


Fig. 1.9 Various types of epidural indicators (1935–1958) (from [25] with permission)

This approach should no longer be considered experimental but as an everyday procedure." The catheter used by Aburel was made of flexible silk and resembled a ureteric catheter. Aburel also began a systematic investigation of the afferent innervation of the uterus by meticulous anatomical dissection and sharp clinical observation in parallel with the analogue researches (1927–1933) of Cleland on this subject in the USA. However, since his publications were written in French [28, 29], they went unnoticed by overseas colleagues.

John Cleland (1898–1980), from the University of Oregon, used paravertebral block and low caudal analgesia to "present experimental proof via visceromotor reflexes of the location of these paths in the dog, to correlate these findings in man, to explain the error of conclusions hitherto accepted, and to demonstrate that the pain of uterine contraction may be abolished without affecting the contractions by paravertebral block of only two adjacent nerves" [30]. Cleland concluded in his paper of 1933 [30] that the sensory afferents from the uterus and cervix that transmit

Fig. 1.10 Eugen Bogdan Aburel (1899–1975) (from [26] with permission)

pain during the first stage of labor enter the spinal cord T11 and T12 and that the second stage of labor is primarily somatic in nature and it is transmitted through the sacral nerves.

William Lemmon (1896–1974) published preliminarily in 1940 [31] and more extensively in 1944 [32] the description of a 17G or 18G nickel-silver alloy malleable needle (Fig. 1.11). The needle was placed in the subarachnoid space, was bent at the skin surface, and was attached to rubber tubing through which local anesthetic solution was injected when required. The patient lay on a mattress and table that had a hole placed so as to accommodate the protruding needle (Fig. 1.12).

Robert Hingson (1913–1996), Chief of Anesthesia of the Marine Hospital at Staten Island, USA, after trying malleable needles inserted caudally, used continuous epidural anesthesia by the caudal route, injecting local anesthetics through ureteral catheters. With his Chief Obstetrician colleague, **Waldo Edwards** (1905–1981), they decided to combine the advantages of continuous spinal analgesia with the safety, simplicity, and effectiveness of sacral epidural block. Securing the hub of the malleable needle to rigid rubber tubing, the analgesic agent could be introduced with the patient in her hospital room, uninterrupted during transfer to the delivery site, and easily maneuvered for preparation, delivery, and, if necessary, episiotomy. Of course the needle was left in the caudal canal and the patient labored in the decubitus position. In their paper published in JAMA in 1942 [33] they wrote: “since that time we have managed the entire course of six hundred labors and deliveries with this method without restoring to any other form of anesthesia. We believe that continuous caudal analgesia has opened a new medical horizon to the profession comparable to that developed … with continuous spinal anesthesia … We would emphasize that with our method the drug producing the analgesia is continuously bathing the nerve trunks of the sacral and lumbar plexuses within the peridural space. Consequently the patient is still able to move the lower extremities throughout labor, and uterine contractions continue without impediment.”

Edward B. Tuohy (1908–1959), in the 1940s, was aware of the early clinical work by Pagés and Dogliotti on epidural blocks, but he was particularly interested in continuous spinal anesthesia [34]. He replaced the sharp previously used needle with a needle that had been designed by **Ralph L. Huber** (1890–1953), a Seattle dentist. Huber’s needle had a directional tip, which allowed the direction of the catheter as it exited the needle tip.

Although Huber intended this needle for intravenous and tissue injections, Tuohy recognized that the directional point might facilitate the placement of spinal catheters. In addition, he added a stylet hoping to further decrease the risk of skin plugging.

But it was **Pio Manuel Martinez Curbelo** (1905–1962), not Tuohy, who realized how the directional needle might facilitate the placement of epidural catheters and who may be considered the initiator of continuous lumbar epidural anesthesia. Curbelo visited Tuohy at the Mayo Clinic in November 1946. He observed Tuohy using his

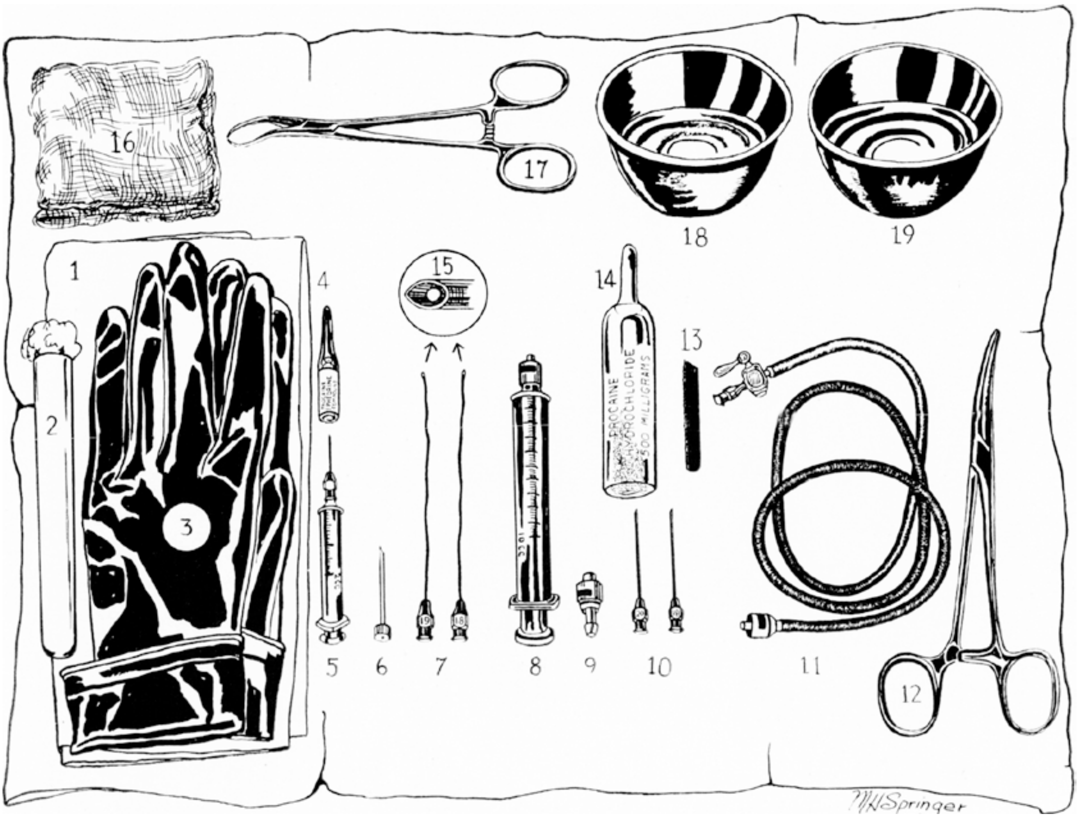


Fig. 1.11 Tray for continuous spinal anesthesia (1944) (from [32] with permission)

recently developed needle to allow for the insertion of ureteral catheters intrathecally and noted that by injecting small, fractionated doses of local anesthetics repeatedly, long-term analgesia could be achieved. On January 1947, at the Hospital Municipal de la Havana, he inserted a catheter into the lumbar epidural space in a 40-year-old woman about to have a laparotomy for removal of a giant ovarian cyst. He found the epidural space by the "loss of resistance" method, then passed a ureteral catheter through the needle, and then injected 1% procaine, followed by a supplemental dose 40 min later. He announced his success in a meeting of the Surgical Society of La Habana [35]. Alderete [36] reports his description made at the joint IARS and ICA International Congress in New York in September 1947: "The guide is introduced up to one cm from the tip of the catheter, which is inserted into the needle 9.5 cm, then placing the index finger of the left hand at the entry point of the needle into the skin and holding its hub with the left thumb and middle fingers, the catheter is advanced with the right hand one more cm and the guide was removed one cm at a time, alternating this move with the advancing of the catheter, the same distance, until 12.5 cm indicating that the catheter is 3 cm in the epidural space. Slowly, the guide is removed and the 23 gauge needle, connected to a syringe is adapted to the catheter … A wide strip of sterile adhesive tape is applied over the entire length of catheter fixing it to the skin of the back making it accessible for ulterior supplementary doses; thereafter, the patient is placed in the supine position."

Curbelo used the "Pages-Dogliotti method of the loss of resistance" to identify the epidural space utilizing the 2 cc syringe containing 1.5 cc of normal saline. Occasionally he lubricated the outside wall of the needle with sterile Vaseline and advanced it millimeter by millimeter. In addition, he was known to place a drop of chloroform on the plunger of the syringe to obtain optimal seal while allowing free movement. Interestingly he recommended to always "feel the three open-

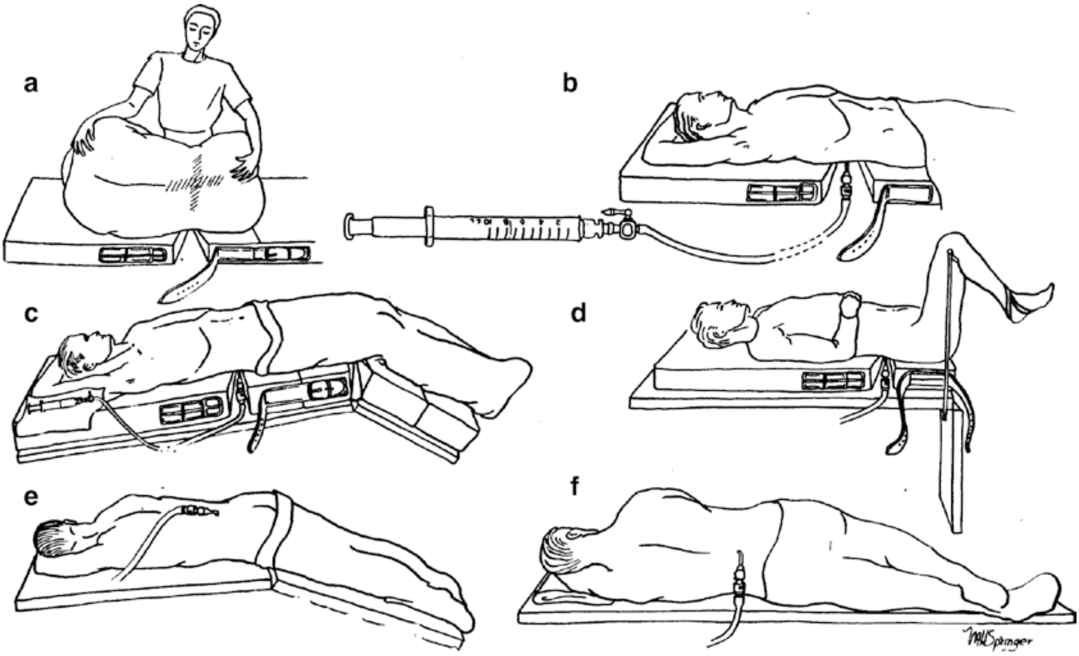


Fig. 1.12 Special mattress for continuous spinal anesthesia (1944) (from [32] with permission). (**a**) position of patient on special mattress for spinal puncture. (**b**) patient lying on back, with opening in mattress for adjusting needle. (**c**) patient in position for operation, showing syringe in sterile towel. Syringe and towel are fastened to mattress by towel clip. Strap on side of mattress is buckled during operation. (**d**) patient in perineal position. Lower half of mattress is detached. (**e**) patient in prone position for operations on back, anal region or posterior surface of extremities. (**f**) patient in Sim's position. Needle is bent at skin and fastened with adhesive. No special mattress is needed for the last two positions

ing steps, when the needle approached it, when it contacted it and finally when it penetrated" the ligamentum flavum, perceiving then a sudden disappearance of the resistance.

Charles Flowers (1920–1999) of the J Hopkins University in Baltimore was convinced that the work of Dogliotti evidenced that the lumbar peridural space could be used for the relief of obstetric pain. He published in August 1949 "Continuous peridural anesthesia and analgesia for labor, delivery and cesarean section" [37]. In this paper Flowers described his lumbar epidural loss of resistance technique using air, as follows: "When the dense ligamentum flavum has been entered, one pauses and tests the ease with which two cubic centimeters of air can be introduced into the ligament with a small syringe. When an attempt is made to inject air into the ligamentum flavum, the plunger of the syringe rebounds quickly. However, when air is injected into the peridural space, the plunger of the syringe literally falls into place. As the needle is advanced through the ligamentum flavum, frequent minute air tests are made with a small syringe to determine when the area of negative pressure in the peridural space is entered. Often this entrance is evident by the release of resistance that is felt when the blunt 16-gage Tuohy needle passes through the dense ligamentum flavum and enters the peridural space. When the Tuohy needle has been properly placed and there is no aspiration of spinal fluid, a plastic tube is introduced through the needle into the peridural space. The tubing is passed cephalad to the twelfth thoracic interspace for patients in early labor or about to undergo cesarean section. It is introduced caudal ward to the fourth lumbar space for patients in well-established labor."

In this paper Flowers reported 37 cases of cesarean section and 72 cases of labor analgesia conducted under continuous lumbar anesthesia and interestingly he noted that "whether peridural anesthesia is used for labor or cesarean section, one must always realize that the exact dose and time interval depends upon the somatic level of each patient."

1.5 Modern Epidural Analgesia

In the 1950s, **Philip Raikes Bromage** (1920–2013) (Fig. 1.13) took the practice of epidural anesthesia into the modern era. Born and educated in London, he became professor in anesthesia in Canada, the USA, and Saudi Arabia.

He published two major single-author textbooks on epidural anesthesia: *Spinal Epidural Analgesia* (1954) [38] and *Epidural Analgesia* (1978) [39]. The latter text covered all aspects of epidural anesthesia at the time of publication and it remains the reference book and a very valuable resource even today. It promoted safety and scientific basis for the practice of regional anesthesia. It played a pivotal role in the widespread acceptance and utilization of epidural analgesia for surgery, obstetrics, and pain management.

But the birth of modern obstetric analgesia can easily be traced back to **John Joseph Bonica** (1917–1994) (Fig. 1.14), an Italian-American physician, the father of the field of pain control, who devoted his career to the study of pain, establishing it as a multidisciplinary field. He created residency programs, chaired departments, wrote standard texts in the field, and had his work published in numerous languages. Among his huge number of publications, his masterpiece is *The Management of Pain* published for the first time in 1953 [40] and followed by numerous editions. His paper "*Peridural Block: analysis of 3637 cases and review*," published in 1957 [41], is still today one of the most beautiful, in-depth, exhaustive descriptions of the epidural technique in all its practical aspects.

Bonica traced the path for a rational, reproducible, and effective approach for the abolition of pain in labor and delivery. He used a series of nerve blocks of various nociceptive pathways, including paracervical, segmental epidural, caudal, and trans-sacral blocks, to further refine the knowledge—due to Cleland's previous work—of the nerve pathways that transmit labor pain to the central nervous system. He demonstrated that the upper part of the cervix and lower uterine segment are supplied by afferents that accompany the sympathetic nerve through the uterine and cervical plexus; the inferior, middle, and superior hypogastric plexuses; and the aortic plexuses.

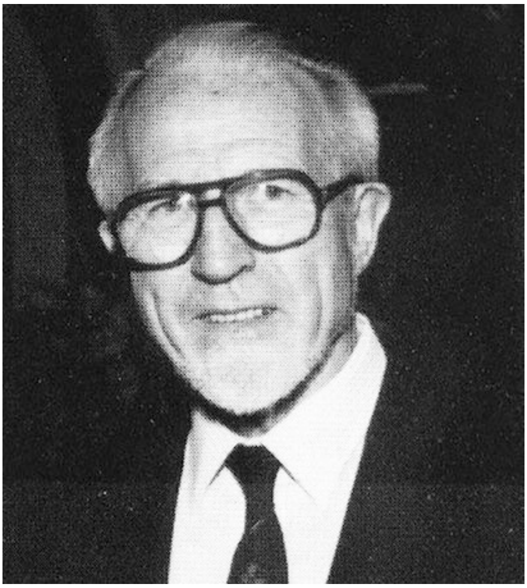


Fig. 1.13 Philip Raikes Bromage (1920–2013) (from Douglas (2013) IJOA 22:272, with permission)

Fig. 1.14 John Joseph Bonica (1917–1994)

In his *Principles and Practice of Obstetric Analgesia and Anesthesia* (1967 and 1995) [42, 43] the epidural block technique, as it may be used for labor analgesia, is described in a thorough and exhaustive way in accordance with his great personal experience and remains today the major reference for every obstetric anesthesiologist.

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Anatomy of the Lumbar Epidural Region

2

Vertebral lumbar column anatomy and its attachments must be well known in order to have a mental picture of the course the needle should take during lumbar puncture.

The ligamentum flavum is one of the most important structures involved in epidural anesthesia. Its identification is essential to the loss of resistance technique (LORT) which relies on the distinctive resistance to needle advancement and fluid injection elicited by the ligamentum flavum. The very first small resistance encountered when the epidural needle is advanced in the lumbar region with a median approach is due to the density of the supraspinous ligament, followed by the feeling of no resistance when the needle is eventually advanced through the loose interspinous ligament. The knowledge of these two ligaments is therefore also crucial to performing the epidural technique.

The anatomy of the intervertebral foramen is important to understand the diffusion of the local anesthetic solutions in the epidural space, since it represents the doorway between the spinal canal and the periphery. Epidural fat distribution and epidural vein locations complete the essential basic background necessary to successfully carry out every epidural technique. The microscopic architecture of different tissue layers can help to better understand the mechanism of technical failures and complications.

2.1 Vertebral Column

The vertebral column is a curved linkage of individual bones or vertebrae. Its function is to support the trunk, to protect the spinal cord and nerves, and to provide attachments for the muscles.

A continuous series of vertebral foramina runs through the articulated vertebrae posterior to their bodies and constitutes the vertebral canal, inside which there is the dural sac containing the spinal cord and nerve roots, their coverings, and vasculature. A series of paired lateral intervertebral foramina permits communication between the lumen of the vertebral canal and the paravertebral soft tissues and accesses the passage of the spinal nerves and their associate vessels between adjacent vertebrae.

The adult vertebral column consists of 33 vertebral segments, each (except the first two cervical) separated from its neighbor by a fibrocartilaginous intervertebral disc. The usual number of the vertebrae is 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal for a total length of approximately 70 (male)–60 (female) cm. The fact that the vertebrae are separate units gives flexibility to the vertebral column. The joint between the bodies of two vertebrae is fibrocartilaginous, the union between the arches is ligamentous, and the joint between the articular processes is synovial in type.

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In adults, the vertebral column has four curvatures that change the cross-sectional profile of the trunk. The cervical curve is a lordosis (convex forward) and is the less marked. The thoracic curve is a kyphosis (convex dorsally) that extends from the second to the 11th–12th thoracic vertebrae; the lumbar curve is also a lordosis and has a greater magnitude in females and in pregnancy, and extends from the 12th thoracic to the lumbosacral angle. The pelvic curve is concave anteroinferiorly and involves the sacrum and the coccygeal vertebrae.

2.2 Lumbar Vertebra

The lumbar vertebra anatomy and its attachments should be well known in order to have a mental picture of the course the needle should take during lumbar puncture.

A typical vertebra is made up of a body, which bears weight and forms the base for the arch, composed of pedicles and laminae, which surround and protect the cord laterally and posteriorly (Fig. 2.1). There are seven projections from these vertebral arches. There are three processes, two transverse and one spinous, for the attachment of muscles and ligaments, and four articular processes, two upper and two lower, to articulate with processes of the arches of the two neighboring vertebrae.

The five lumbar vertebrae are distinguished by their large size and absence of costal facets and transverse foramina. Their body is kidney shaped, wider transversally and deeper in front. The flat articular surface of the vertebral body is covered with hyaline cartilage which is very firmly united to the fibrocartilaginous intervertebral disc, this union being reinforced by anterior and posterior longitudinal ligamentous bands, which run the whole length of the vertebral column.

The pedicles are short and together with articular processes constitute the boundaries of the intervertebral foramen. The spinous process is almost horizontal, quadrangular, and thickened along its posterior and inferior borders. The trans-

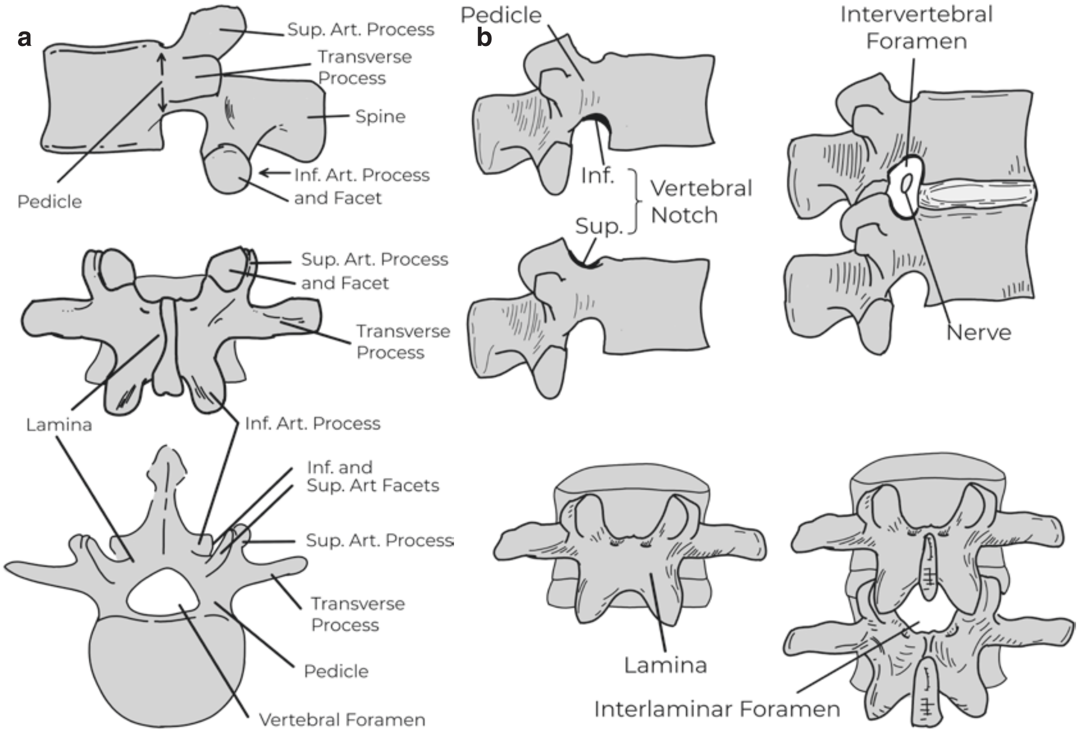


Fig. 2.1 (**a**, **b**) Anatomy of lumbar vertebra

verse processes are thin and long. The articular facets are reciprocally concave (superior) and convex (inferior) which allow flexion, extension, lateral bending, and some degree of rotation.

The interlaminar foramen is small and triangular in shape when the vertebral column is extended. The base is formed of the upper border of the laminae of the lower vertebra, and the sides of the medial aspects of the inferior articular processes of the vertebra above. During flexion the inferior articular process slides upwards and the interlaminar foramen enlarges and becomes diamond shaped, since the medial borders of the upper articular processes of the vertebra below now form the lower lateral boundaries of the aperture (Fig. 2.2). The interlaminar foramen is closed by the ligamenta flava.

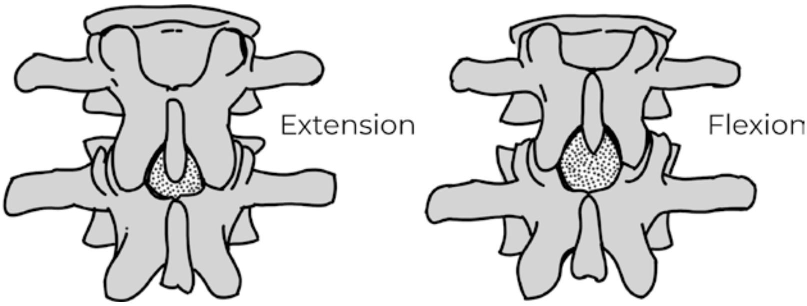
2.3 Ligamentum Flavum

The ligamentum flavum is an important structure involved in epidural anesthesia. Its identification is essential to the loss of resistance technique (LORT) which relies on the distinctive resistance to needle advancement and fluid injection elicited by the ligamentum flavum.

It is rectangular/trapezoidal in shape, and is 13–20 mm high and 12–22 mm wide, and its thickness may vary from 3 to 5 mm [1] (Fig. 2.3).

The ligamentum flavum embryologically consists of a left and a right portion which usually fuse in the midline in the adult. The degree of midline fusion varies between individuals and across vertebral heights and midline gaps are more frequent in the cervical and high thoracic

Fig. 2.2 Dimension and shape of the interlaminar foramen when the vertebral column is extended or flexed



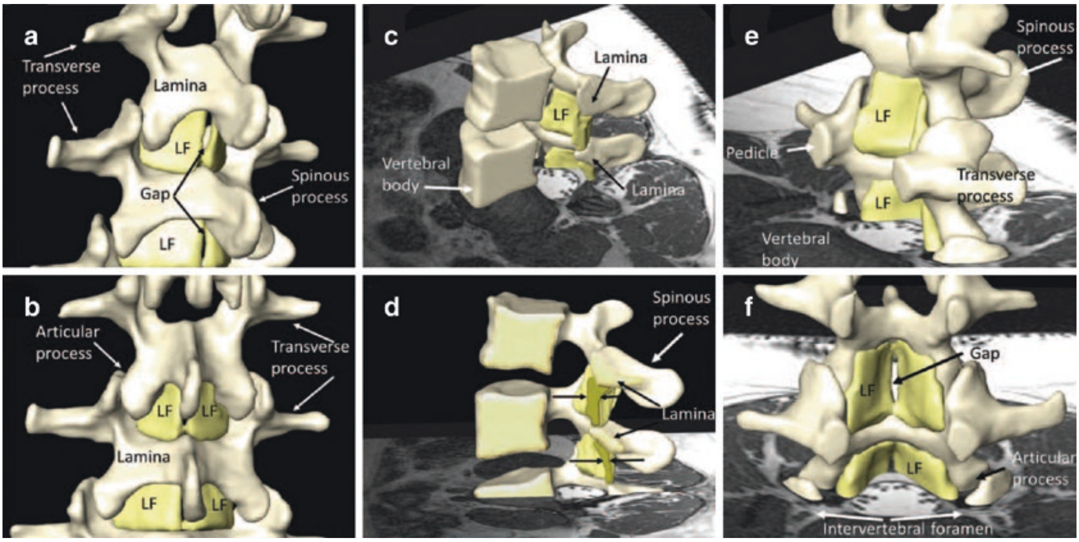


Fig. 2.3 3D reconstruction of human lumbar ligamentum flavum (LF). (**a**) Posterior-lateral view; (**b**) posterior view; (**c**, **d**) lateral view (sagittal section); (**e**) anterior lateral view; (**f**) anterior view (from [3] with permission)

regions. However ligamentum flavum midline gaps may also be present in approximately 20% of cases in the lumbar region too, especially between the L1 and L2 level [2] (Fig. 2.4).

Ligamenta flava connect laminae of adjacent vertebrae in the vertebral canal. They run from the anterior and inferior aspects of one lamina to the posterior and superior aspects of the lamina below. It laterally extends as far as the interlaminar foramen where it blends with the capsule of the articular processes. Here small foramina give passage to veins. Posteriorly they are bordered by the spinous muscles (multifidus) and in the midline the two ligamenta flava meet to become continuous with the deep fibers of the interspinous ligament. Anteriorly they are bordered by a mixture of fatty or loose connective tissue ("epidural space"). The upper border of the ligamenta flava of the same intervertebral space joins medially in an angle of more than 90° opening upwards. The internal surfaces form an angle of less than 90° opening towards the epidural space and a vertex merging with the interspinous ligament.

The topographical relationship of the ligamenta flava with the spinous, transverse, and articular processes and dural sac has recently been reviewed by using postmortem samples and magnetic resonance imaging in living humans [3]. In a 3D reconstruction, the ligamenta flava span from the external facet of the superior border of the caudal vertebrae to the inner facet of the inferior border of the cranial vertebrae. The inferior and lateral portion of the ligamentum makes contact with the paravertebral muscles. The medial border reaches the spinous process and the lateral border extends towards the intervertebral foramen and merges with the joint capsule of the articular facets. At the most lateral parts of the epidural space, where there is no epidural fat, the ligamenta flava directly contact the dural sac (Fig. 2.5a, b).

The predominant tissue is yellow elastic tissue ("flavus" is Latin for "yellow"), whose almost perpendicular fibers descend from the lower anterior surface of one lamina to the posterior surface and upper margin of the lamina below. This

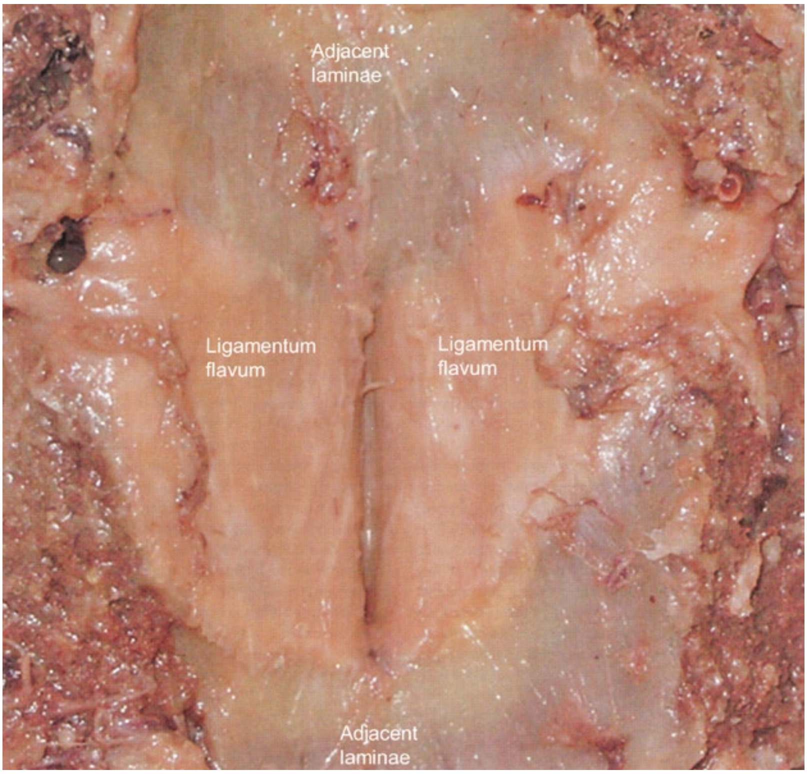


Fig. 2.4 Anatomy of the paired ligamentum flavum spanning out between adjacent laminae (from Reina et al. (2015) Atlas of functional anatomy for regional anesthesia and pain medicine. Springer, with permission)

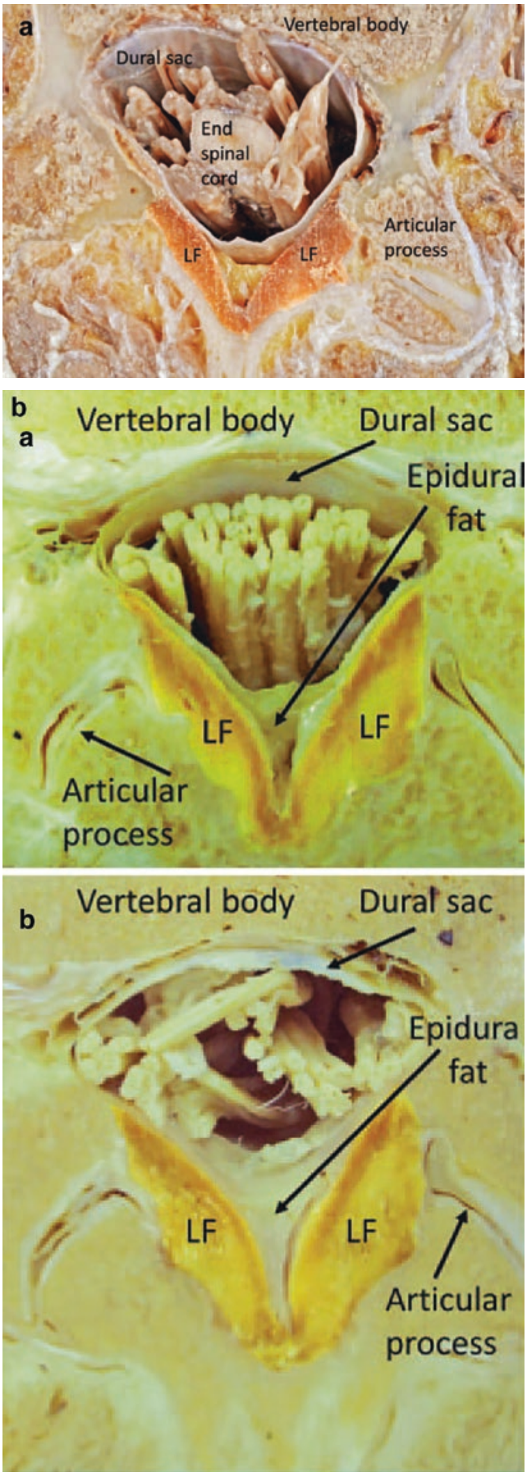


Fig. 2.5 (**a**) Transverse section of human lumbar spine at L1 vertebral level. *LF* ligamentum flavum (from [3] with permission). (**B**) Transverse section of human lumbar spine at L3 vertebral level (**a**, **b**). *LF* ligamentum flavum (from [3] with permission)

high content of elastic and elaunin fibers and the favorable proportion of elastic to collagen fibers (2:1) give this ligament elastic properties [4, 5].

The ligaments are thickest and strongest in the lumbar region since their role is to arrest separation of the laminae in spinal flexion, preventing abrupt limitation, and also to assist restoration to an erect posture after flexion, protecting the discs from injury. When the spine is flexed the ligamentum flavum is stretched and stores mechanical energy, which is regained upon extension of the spinal column. Fine free fiber nerve endings innervate the outermost layer of this ligament, most likely related to positional control.

The thickness of the ligamentum may vary with vertebral level, body mass index, disc herniation, and age [6]. In addition it is not uniform even within the single intervertebral space, and most likely its thickness may also decrease if the back is well flexed and the ligament very stretched. Finally the method of assessment of its thickness (cadaveric studies, magnetic resonance, computed tomography, or ultrasound studies in living subjects) may also affect the precise measurement [7].

2.4 Interspinous and Supraspinous Ligaments

The very first small resistance encountered when the epidural needle is advanced in the lumbar region with a median approach is due to the density of the supraspinous ligament, followed by the feeling of no resistance when the needle is eventually advanced through the loose interspinous ligament.

Interspinous ligaments are thin, almost membranous and connect adjoining spines, since their attachments extend from the root to the apex of each. They meet the ligamenta flava in front and the supraspinous ligament behind. These ligaments are thick and quadrilateral at lumbar levels. Their ventral part may be regarded as a posterior extension of the ligamentum flavum and contains a few elastic fibers. The middle part is the main component and is purely collagenous. The dorsal part is also collagenous and its fibers continue with the supraspinous ligament and the medial tendons of the multifidus muscle.

The supraspinous ligament is commonly described as a strong fibrous cord which connects the tips of the spinous process from C7 to the sacrum, and it is thicker and broader at lumbar levels (Fig. 2.6).

However, there is evidence to support the definition of supraspinous and interspinous ligaments as structures formed of a combination of muscle tendons and aponeuroses along the length of the thoracic and lumbar spine, with regional differ-

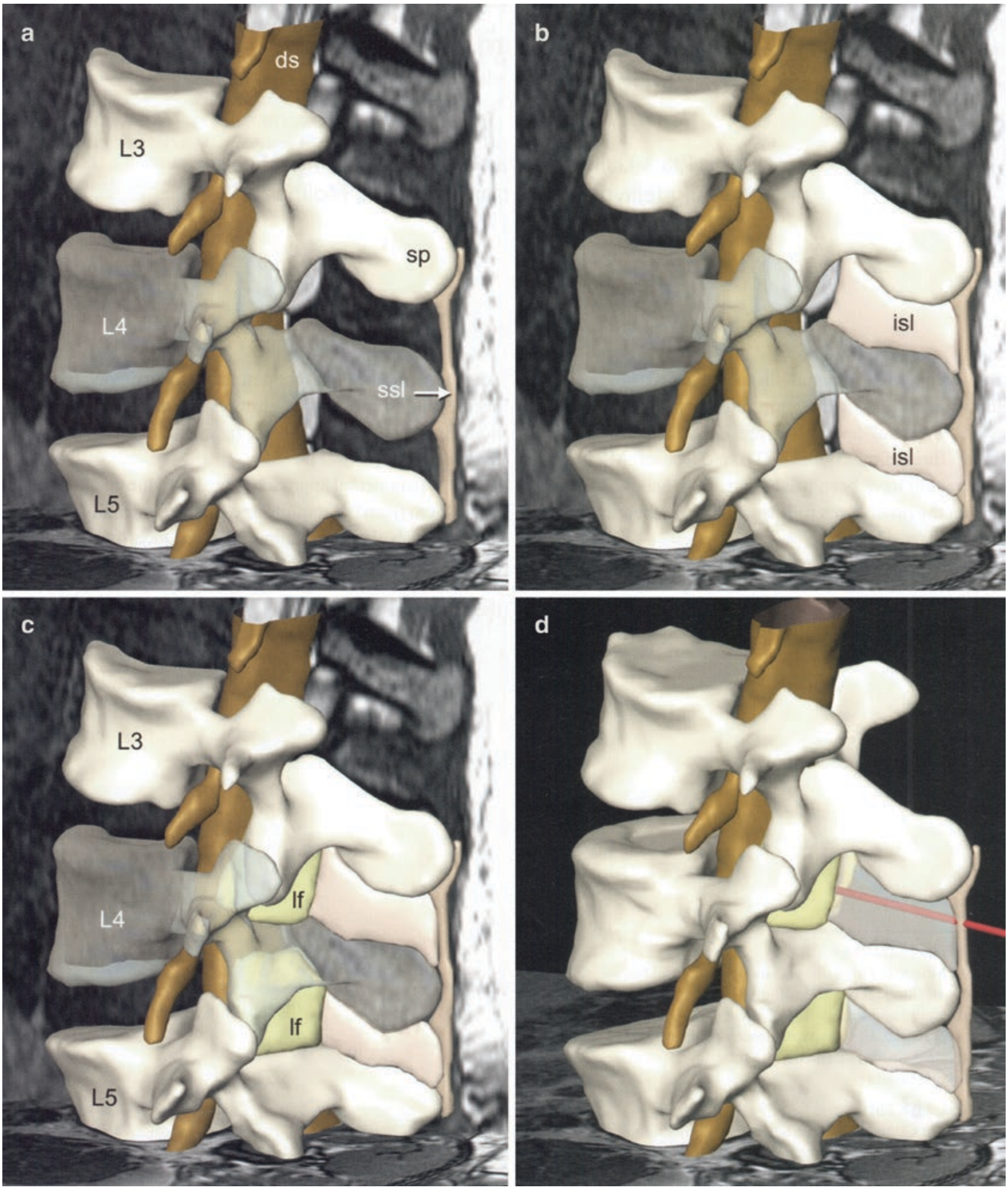


Fig. 2.6 Posterior ligaments of interest in lumbar epidural block. Supraspinous ligament (ssl), spinous process (sp), interspinous ligament (isl), ligamentum flavum (lf), dural sac (ds). 3D models built from axial (**a**–**d**) and sagittal (**a**–**c**) T2-weighted reference images (from Reina et al. (2015) Atlas of functional anatomy for regional anesthesia and pain medicine. Springer, with permission)

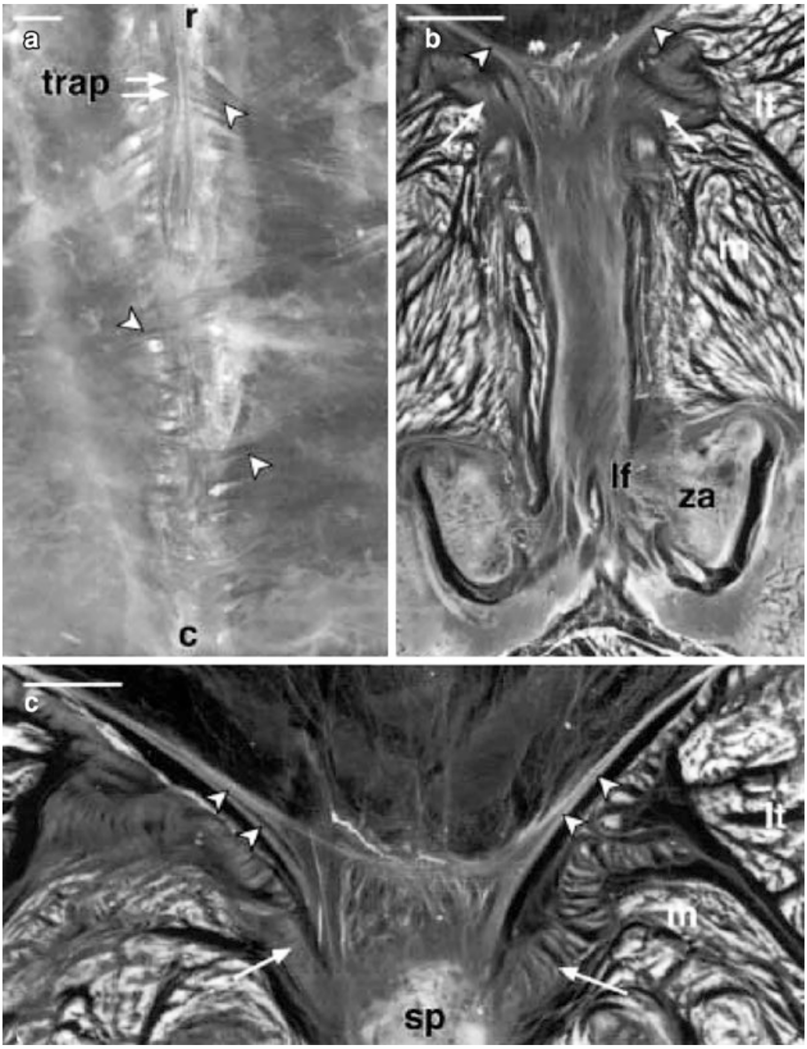


Fig. 2.7 (**a**) Formation of the lumbar supraspinous ligament by trapezius (trap-double arrows) and the posterior layer of thoracolumbar fascia (single arrowheads) orientated in the rostral (r) to caudal (c) direction. (**b**) Horizontal slice at L3 level. Formation of the supraspinous ligament by the posterior layer of the thoracolumbar fascia. Longissimus thoracis (lt) and multifidus (m) attached to the spinous process (sp) laterally. (**c**) Horizontal slice at L1–L2 level. The contribution of the posterior layer of the thoracolumbar fascia, multifidus, and longissimus thoracis to the interspinous ligament. The interspinous ligament merges with the ligamentum flavum (lf) and capsule of the zygapophyseal joint (za) (bar scales = 4 mm) (from [8] with permission)

ences in their connective structure [8] (Figs. 2.7 and 2.8).

The midline attachments of the posterior layer of the thoracolumbar fascia and the longissimus thoracis with the contribution of the fascia of the muscle multifidus form the main dense connective tissue component of both the supraspinous and interspinous ligaments at the lumbar level.

While in the thoracic area no interspinous ligament is detectable, at lumbar level, where the posterior layer of the thoracolumbar fascia joins the other tendinous insertion, the interspinous ligament becomes recognizable as a separate anatomical entity.

Wide variation in fiber direction in the connective tissue architecture within both the interspinous and supraspinous ligaments can be explained together with their biomechanical function to limit flexion. The multiple directions of connective tissue fibers within the ligaments indicate that they are capable of transmitting loads in more than one direction.

Since they both originate from the same connective tissues (thoracolumbar fascia, longissimus thoracis, and multifidus fascia) it may be considered difficult, at the lumbar level, to consider the supraspinous and interspinous ligaments as a separate entity. The average depth of

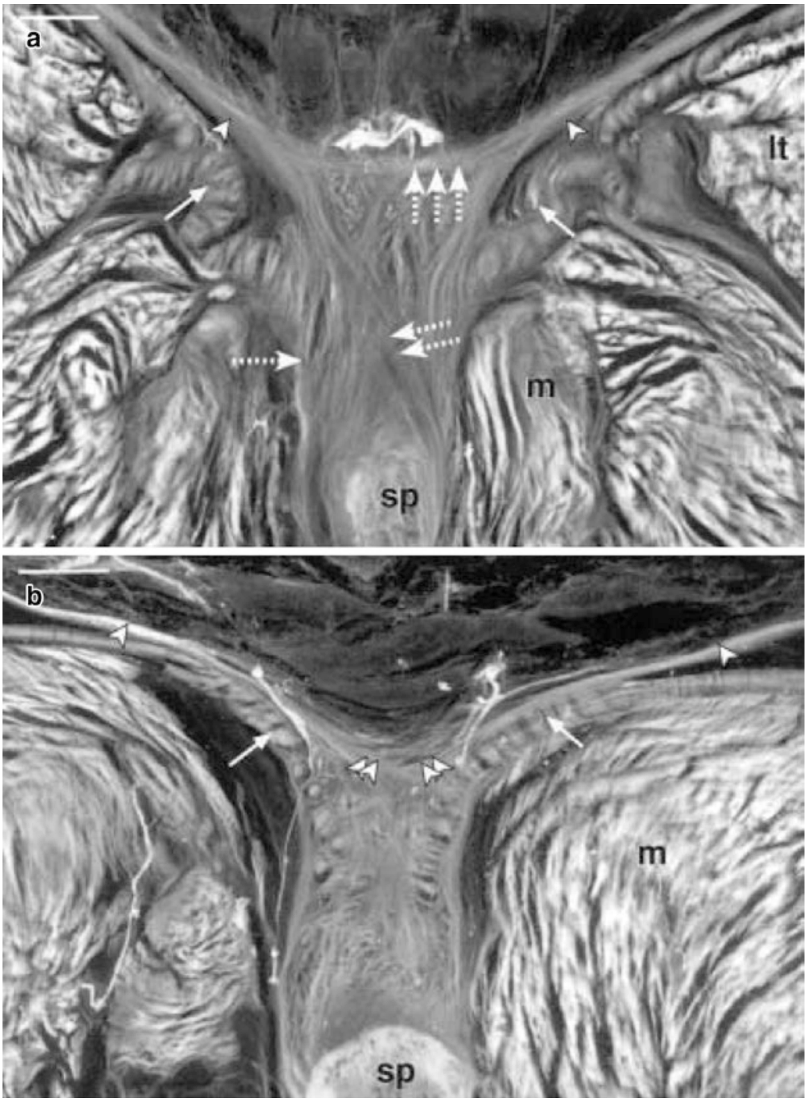


Fig. 2.8 (**a**) Horizontal slice at L3 level. Connective tissue fiber orientation within the supraspinous ligament and attachments to the spinous process (sp). Anteriorly (single-dashed arrow), obliquely (double-dashed arrows), and horizontally (triple-dashed arrows) directed fibers are evident. The posterior layer of the thoracolumbar fascia (single arrowheads) and shared attachment (single arrow) from longissimus thoracis (lt) and multifidus (m). (**b**) Horizontal slice at L5 level. Decussation of connective tissue fibers (double arrowheads) from the posterior layer of the thoracolumbar fascia is visible superficial to the erector spinae aponeuroses. Multifidus merges with the interspinous ligament to attach onto the spinous process (bar scales = 4 mm) (from [8] with permission)

the supraspinous-interspinous complex ranges, in the young female, between 24 and 30 mm [9].

2.5 Muscles

In the case of the epidural paramedian approach technique, the needle avoids the supraspinous and interspinous ligaments, and reaches the ligamentum flavum penetrating the paraspinous muscles: erector spinae and multifidus.

The erector spinae (sacrospinalis) lies on either side of the vertebral column. It forms a large musculotendinous mass which varies in size and composition at different levels. At the lumbar and sacral levels it narrows and becomes tendinous as it approaches its attachments. In the upper lumbar region it expands to form three columns (iliocostalis, longissimus, and spinalis). It arises from the anterior surface of a large aponeurosis which is attached to the median and lateral sacral crest and the spines of the lumbar and the

11th and 12th thoracic vertebrae with their supraspinous ligaments. This muscle has numerous functions, such as back extension, lateral back flexion, and rotation.

The multifidus muscle is a multipennate muscle and is the most medial paraspinal muscle lying lateral to the spinous process [10]. Its fibers are continuous with the erector spinae and its aponeurosis contributes to the formation of the interspinous and supraspinous ligaments (Fig. 2.8). Its function is to stabilize the lumbar spine in the transverse plane.

2.6 Intervertebral Foramen and Its Ligaments

Knowledge of the anatomy of the intervertebral foramen is important to understand the diffusion of the local anesthetic solutions in the epidural space, since it represents the doorway between the spinal canal and the periphery. The boundaries of this foramen consist of two movable joints, the ventral intervertebral joint and the dorsal zygapophysial joint, and it is essentially a large osseous hole though which structures pass. The intervertebral foramen transmits the spinal nerves, spinal arteries and veins, recurrent meningeal nerves, and lymphatics. The intervertebral foramen has ligaments crossing its openings and their morphology may vary from L1 to L5. They serve a protective and organizational role for the neurovascular structures of the foramen [11, 12]. They may be designated into internal, intraforaminal, and external ligaments and their arrangement causes the intervertebral foramen to be partitioned into smaller compartments for the passage of the spinal artery, for the ventral ramus of the spinal nerve, for the recurrent meningeal nerve and the segmental artery, and for the passage of the dorsal ramus of the spinal nerve and its accompanying vessels, and a compartment for the veins (Fig. 2.9).

Epidural fat surrounds each nerve root throughout their course to the intervertebral fora-

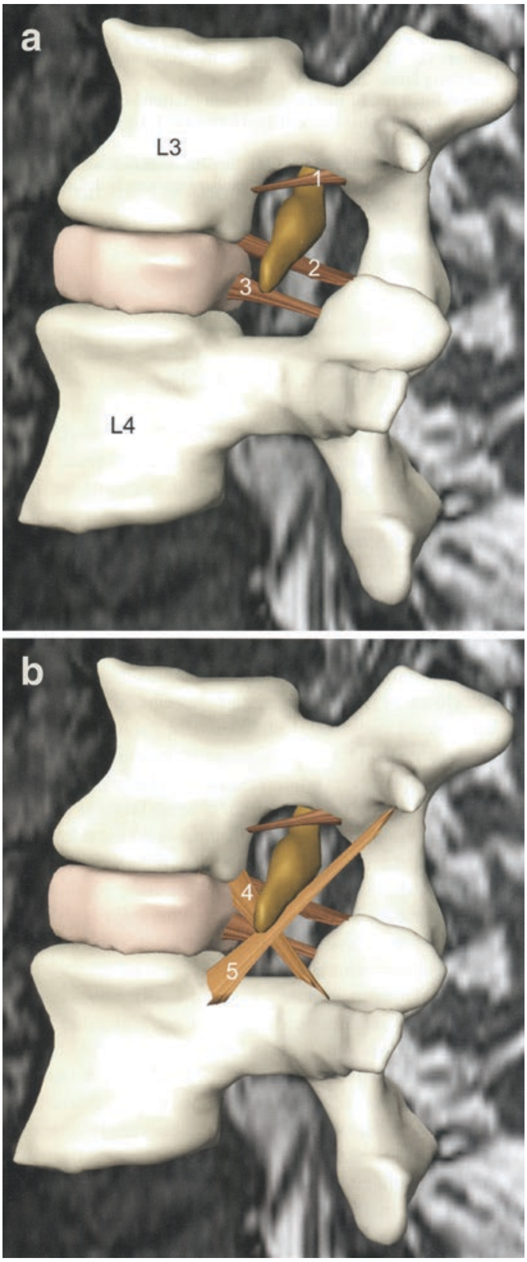


Fig. 2.9 The main transforaminal ligaments (a group of collagen condensations that compartmentalize the intervertebral foramen). (**a**) Deep and middle layers: (1) oblique superior, (2) mid-transforaminal, and (3) oblique inferior. (**b**) Superficial layers: (4) superior corporo-transverse and (5) inferior corporo-transverse (from Reina et al. (2015) Atlas of functional anatomy for regional anesthesia and pain medicine. Springer, with permission)

men. The nerve roots, once located in the intervertebral foramen, commonly combine to form the spinal nerve. Just prior to the formation of the spinal nerve a small enlargement of the dorsal root is noted. This enlargement is called the dorsal root ganglion (DRG) which contains the cell bodies of sensory neurons. At lumbar level the DRG is located within the anatomic boundaries of the intervertebral foramen, usually directly beneath the foramen.

2.7 Epidural Space

Immediately outside the epidural mater there is the epidural space which extends from the foramen magnum to the sacral hiatus. The epidural space is in part real, filled with adipose tissue, nerve roots, veins, arteries, and lymphatics, and in part virtual, with the dural sac resting on the vertebral bodies, pedicles, laminae, and ligamentum flavum [13, 14].

2.7.1 Epidural Fat

Epidural fat is the main component of the epidural space, contributes to its shape, has a metameric and a discontinuous topography, and is mainly located in the posterior and in the lateral region, around the nerve cuffs (Fig. 2.10). Nerve cuffs are lateral prolongations of the dura mater, arachnoid lamina, and pia mater that enclose nerve roots in their way across the epidural space towards the intervertebral foramen, and the dorsal root ganglion, located within the intervertebral foramen.

Epidural fat is relatively metabolically inactive and it is not a simple space-filling tissue. Fascicles of connective tissue are less numerous and thinner than in subcutaneous fat with

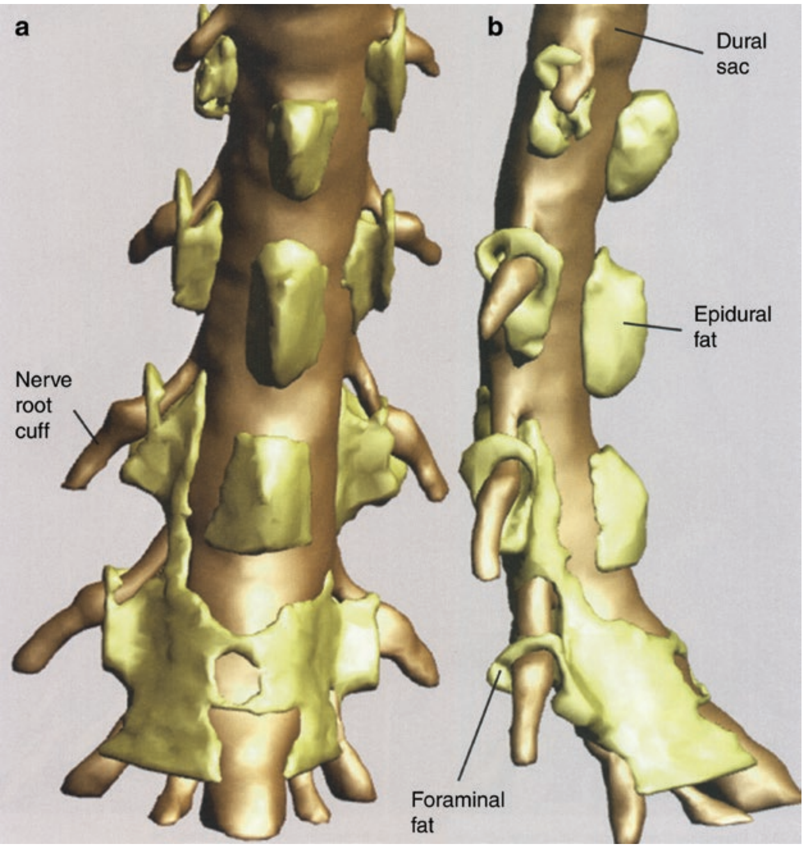


Fig. 2.10 3D reconstruction of human epidural fat. Posterior (**a**) and lateral (**b**) view (from Reina et al. (2015) Atlas of functional anatomy for regional anesthesia and pain medicine. Springer, with permission)