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Anatomical and physiological factors for a lower incidence of post-dural puncture headache during thoracic spinal anesthesia. Narrative review

Abstract

Post-dural puncture headache (PDPH) is a side effect of the first spinal anesthesia and can also occur after an accidental dural puncture during epidural anesthesia. The risk of PDPH can be influenced by the size, shape, and orientation of the spinal needles, as well as the patient's posture. Leakage of cerebrospinal fluid (CSF) through the dura mater opening leads to traction on pain-sensitive structures, causing PDPH. There are various proposed mechanisms explaining how headaches are brought on by CSF hypotension. Spinal CSF dynamics are sensitive to varying respiratory performances. Since the beginning of the last century, subarachnoid blocks can be performed at any of the thoracic and lumbar spinal levels. Thoracic spinal anesthesia has been extensively studied in the 21st century, as have several new indications for spinal anesthesia. Thoracic spinal anesthesia (TSA) has been extensively studied in the 21st century, as have several new indications for spinal anesthesia. Several published articles on TSA demonstrate its safety, with a lack of neurological complications, particularly PDPH. Several mechanisms have been implicated in the lower incidence of thoracic puncture compared to lumbar puncture. This article shows several mechanisms for this lower incidence, and the low incidence after TSA compared with lumbar spinal anesthesia (LSA).

Keywords: Thoracic spinal anesthesia, post-dural puncture headache, cerebrospinal fluid.

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Key Points

- PDPH is much less frequent after TSA compared with lumbar spinal anesthesia.
- Reported incidence is less than 1% with fine-gauge needles in lumbar puncture.
- Smaller CSF volume in the thoracic region causes less CSF leakage.
- More perpendicular dural fibers in the thoracic region compared to the lumbar region cause less splitting of fibers.
- CSF pressure is lower at the thoracic level, especially if the patient is in the supine position, reducing the force of CSF leak.

Meaning

- Thoracic spinal anesthesia has a very low PDPH risk because of the anatomical and physiological characteristics of the thoracic subarachnoid space.
- The incidence of PDPH after TSA is 11.5 times lower than after LSA.

Introduction

Postdural puncture headache (PDPH) can occur because of diagnostic lumbar puncture, spinal anaesthesia, and accidental dural puncture during epidural anesthesia. Four studies on thoracic epidural anesthesia showed that in 1,071 patients,[1] 4,185 patients,[2] 1,240 patients[3] and 113 patients[4] there were 50 (0.75%) accidental perforations of the spinal dura mater with a large gauge needle, no neurological sequelae and no PDPH. The fact that there was no neurological injury led us to question whether there was anatomical protection or divine protection. And indeed, a magnetic resonance imaging (MRI) study in adult patients,[5,6], and in children aged 0 to 13 years,[7] showed a space between the spinal cord and the dura mater with protection for the needle tip.

Regarding the absence of neurological spinal cord injury, both studies demonstrated anatomical protection. However, since none of the four studies post accidental puncture during epidural anesthesia reported PDPH, this prompted us to investigate this fact. Whether an accidental perfusion of the thoracic region with a large-bore needle does not result in this complication?

After MRI studies, I began my studies to perform TSA in 300 patients, comparing Quincke and Whitacre needles. Paresthesias occurred in 20/300 (6.6%) of patients, with no statistical difference between the needle tip designs.[7] All paresthesias were transient, and no neurological complications were observed in all patients during this study, and there were no reports of PDPH. From 2010 to 2025, eight studies on TSA have been conducted by me and my research group, with a total of 3,791 patients, and 4 (0.1%) headaches have been reported, all light (grade 1/3) easily treated with clinical methods and without the need to use a blood patch. All these articles will be included when the incidence of PDPH during TSA is addressed, and a survey of all published TSA. After more than 15 years of experience with TSA, I have found that the incidence of PDPH is significantly lower when the puncture is performed at the thoracic level compared to the lumbar region. Two articles were recently written addressing TSA with its indications, safety, anatomy and approach to the subarachnoid space in the thoracic region.[8,9] Thus, this study aimed to determine whether there are any anatomical, physiological, and cerebrospinal fluid (CSF) related explanations.

Anatomy of the thoracic intervertebral space

The spinal canal is narrower than the cervical and lumbar regions, leaving less epidural and subarachnoid space volume. The spinal cord in the thoracic region occupies a larger proportion of the spinal canal, resulting in less free space between the spinal cord and the dura mater. Studied lesions of the human dural sac produced by different spinal needles and different bevel orientations. The dura mater has a thickness of around 400 µm, and it is formed by randomly distributed fibers, arranged around 80 concentric layers, known as dural laminas, while the arachnoid layer has a thickness of around 40 µm.[10,11] The interlaminar spaces in the thoracic spine are narrow and more difficult to access with a needle due to the overlapping vertebral lamina, and the spinous processes of the thoracic vertebrae point downward.[12] Intrathecal injections at mid-thoracic levels may have a minimum safe distance before the spinal needle contacts the spinal cord tissue.[13] The spinal dura mater is a key component of the thoracic dura, and its anatomy plays a significant role in its function. The spinal dura mater is a tough fibrous membrane that protects and encloses the spinal cord. Understanding the biomechanics of the thorax is crucial, as it affects how the thoracic dura functions and can impact the closure of holes.[14]

Physiology of the thoracic intervertebral space

A smaller number of nerve roots are covered by an anesthetic within the subarachnoid space in TSA, providing anesthesia in the necessary surgical field dermatomes. Further, since there is less of a block of lower extremities, a larger portion of the body does not experience venous dilation, which may compensate for adverse effects on blood pressure intraoperatively.[15]

CSF formation and volume

CSF is essential for the mechanical and homeostatic protection of the central nervous system and the spinal column. CSF is produced primarily in the choroid plexus at a rate of approximately 0.35 mL/min and reabsorbed through the arachnoid villa, and a smaller part is formed by secretion of the ependyma and passage of interstitial fluid from the central nervous system (CNS) to the subarachnoid space.[16] The total volume in adults is around 150 mL, with 20-30 mL in the ventricles, 80-100 mL in the cranial subarachnoid space, and 25-30 mL in the spinal subarachnoid space, with lumbar pressure of 5-15 cm H_2O in the horizontal position and 40-50 cm H_2O in the vertical position.[16] PDPH is due to the loss of CSF through a persistent leak in the meninges.[1]7 It has been shown experimentally that the loss of approximately 10% of total CSF volume predictably results in the development of typical PDPH symptoms, which resolve promptly with reconstitution of this deficit.

The influence of body position on CSF circulation

CSF plays an important role in providing structural and homeostatic support to the central nervous system.[18] Evaluating 30 healthy volunteers in the upright and supine sitting positions with 0.6 T multiposition MRI (Fonar, New York, USA), CSF flow and spinal cord pulsation were visualized and quantified at the mid-axial level of C2 with contrast, showed that in upright posture, heart rate increased by 10%, and peak diastolic CSF flow decreased by 43% compared to the supine posture.[19] The body position has significant effects on CSF flow in and out of the cranium, with more CSF oscillating in the supine compared to the upright position.[19]

CSF in the thoracic and lumbar subarachnoid space

CSF is present throughout the subarachnoid space, surrounding the spinal cord and brain. However, the distribution of CSF and the relationship between the spinal cord, nerve roots, and meninges vary between the thoracic and lumbar regions. In the thoracic region, the CSF volume is smaller, because the subarachnoid space is narrower around the spinal cord in this region, and the spinal cord occupies a greater proportion of the spinal canal, with less free space between the spinal cord and the dura mater.[20] In the lumbar region, the volume of CSF is greater, and the spinal cord has already ended, with only the cauda equina existing, and the spinal canal is relatively wider, and the subarachnoid space contains a large amount of free CSF around the nerve roots.[20]

CSF volume in the thoracic space compared with the lumbar space

CSF circulation consists of two components, a net flow and a pulsatile flow. The pulsatile driving forces include cardiac vascular pulsation, respiration and muscular contraction. MR myelography (MRM) is an effective tool for detecting CSF leak in the spine in patients with spinal CSF leak syndrome.[21] The thoracic region has a smaller subarachnoid space than the lumbar region, providing important space for the dispersion of intrathecal medications. Because it has a smaller CSF reservoir, it provides less loss, resulting in a lower incidence of PDPH. Furthermore, the spinal cord and roots are heavily surrounded by CSF and meninges, with less free mobility than the lumbar cauda equina. The smaller CSF volume in the thoracic region provides faster drug dissemination (short latency) and more restricted dispersion of local anesthetics injected into the subarachnoid space.

Influence of respiration and heart rate on CSF

Respiration-induced pressure changes represent a powerful driving force behind CSF dynamics. Eighteen subjects without known illness using contrast flow MRI, comparing forced thoracic versus abdominal breathing, showed that spinal CSF dynamics are sensitive to varying respiratory performances.[22] Concluding that forced inspiration and expiration therefore lead to upward and downward CSF flow in the spinal canal. CSF has been thought to mainly follow cardiac-related oscillations as suggested by electrocardiogram-synchronized cine flow MRI.[23] Through a mathematical model, it is suggested that the interaction between thoracic pressure and the cardiovascular system,

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particularly the central veins, has a greater influence on CSF pressure.[24]

Different characteristics of lumbar puncture and thoracic puncture

Several characteristics differ when performing a lumbar puncture, recommended by most anesthesiologists, compared to a thoracic puncture, which has seen significant development in the 21st century, as illustrated by two fundamental articles.[8,9] The most important characteristics are: CSF volume, CSF pressure, epidural space, dura mater fibers, influence on respiration and heart on CSF (Table 1).

Table 1 Comparison between lumbar puncture and thoracic puncture

Characteristics	Lumbar Spinal Anesthesia	Thoracic Spinal Anesthesia
CSF volume	Greater amount in subarachnoid space	Less amount in thoracic space
CSF pressure	Higher in a sitting position	Lower reducing leakage
Epidural space	Wider, less positive pressure	Narrower, more positive pressure
Dura mater fibers	Less resistant hole open longer	More resistant hole closes faster
Technique and needles	Fine (25G, 26G, 27G, 29G)	Fine (25G, 26G, 27G,29G)
Incidence of PDPH	Higher with thick needle	Very low, rarely reported

Incidence of PDPH after lumbar spinal anesthesia

Performed between the lumbar vertebrae (L2-L3, L3-L4, L4-L5), this is below the termination of the spinal cord (which ends around L1-L2 in adults), in the cauda equina region. PDPH is occasionally an inevitable side effect of neuraxial anesthesia, which can happen after spinal anesthesia or if an accidental dural puncture happens during epidural anesthesia. However, PDPH is more frequently caused by dural puncture during epidural anesthesia than by spinal anesthesia because spinal anesthesia uses small needles, in non-obstetric patients.[25] PDPH is believed to be due to reduced brain pressure caused by CSF leakage. A decline in CSF pressure leads to traction on pain-sensitive parietal dura and intracranial structures, thereby causing subsequent headache in patients. When a pencil-point spinal needle is used, the risk of PDPH is reduced.[26] The risk of PDPH can be influenced by the size, shape, and orientation of the spinal needles, as well as the patient's posture.[27] The difference between the incidence of PDPH after LSA in non-obstetric patients in the different studies can be explained by the needle gauge and design, patient age, body mass index, history of chronic headache, puncture technique, direction of needle bevel and number of punctures.

Incidence of PDPH after thoracic spinal anesthesia

Performed between the thoracic vertebrae (e.g., T2-T11), at this level, the spinal cord is present and occupies most of the spinal canal. Patients are typically positioned either in the lateral recumbent or upright sitting posture. Spontaneous intracranial hypotension typically presents with a positional headache caused by downward displacement of the brain due to reduced buoyant support. It has long been accepted that PDPH results from a disruption of normal CSF homeostasis. CSF leakage from the dura, which leads to traction on pain-sensitive structures, is the cause of PDPH. The association between needle size and type of needle with the incidence of PDPH was described. However, despite a great deal of research and observational data, the pathophysiology of PDPH remains incompletely understood. In an article defining the role of thoracic spinal anesthesia in the 21st century, the authors do not address the incidence of PDPH after thoracic puncture.[8] In another article evaluating the state of the art of Jonnesco's TSA to date, PDPH after thoracic puncture was not addressed.[9] Performing a search in the various TSA publications to verify the incidence of PDPH in these publications correlating with the needles used (Table 2).

Table 2 Incidence of PDPH in various articles published on TSA.[15,28-44]

Ref	Patients	Needle	PDPH
15	20	Q=20	0
28	300	W=150 / Q=150	0
29	70	W=70	0
30	636	W=315 / Q=321	0
31	200	W=98 / Q=102	0
32	296	W=153 / Q=143	4
33	200	W=NR / Q=NR	0
34	1406	W=697 / Q=709	0
35	505	W=NR / Q=NR	0
36	674	W=332 / Q=341	0
37	40	Q=40	0
38	28	Q=28	0
39	2102	Q=2102	0
40	39	Q=39	0
41	78	Q=78	0
42	30	NR	0
43	60	Q=60	0
44	50	Q=50	1
Total	**6734**		**5 (0.07%)**

REF, References; W, Whitacre; Q, Quincke; NR, Not Reported.

Difference in incidence of PDPH lumbar and thoracic puncture

Start this topic with a question: Is there a difference in incidence of PDPH lumbar puncture and thoracic puncture for spinal anesthesia? The short answer is that there is a significant and well-established difference in the incidence of PDPH between lumbar and thoracic punctures. Since its inception by Bier,[45] lumbar puncture has been considered the standard approach for spinal anesthesia and carries a well-known risk of PDPH. Thoracic puncture, pioneered by Jonnesco[46] for spinal anesthesia, is extremely rare, used more in the 21st century and by a few authors, but with increasing use, making direct comparison in clinical practice difficult. PDPH is one of the complications following the first spinal anesthesia described by Bier and performed on his assistant and during accidental dural puncture. Several modifiable risk factors contribute to the development of headache after lumbar puncture, including needle size, needle design, direction of the bevel, and number of lumbar puncture attempts. In 5050 non-obstetric patients used 25G, 26G, 27G or 29G Quincke needles; 26G Atraucan or 27G Whitacre without introducer, the incidence was 0.8%.[25] Regarding the caliber and tip design, the result was 25G Quincke 3%, 26G Quincke 1.4%, 27G Quincke 0.7%, 26G Atraucan 0.4%, 27G Whitacre 0.4% and 29G Quincke 0.3% (Table 3).[25] The association between the gauge and type of needle tip with the incidence of PDPH was described with different types of needles, being greater with thicker needles (22G, 23G and 25G) and lower with thinner needles (26G, 27G and 29G) with the different types of Whitacre and Quincke tip.[25]

Table 3 Incidence of PDPH in an article published on LSA.[25]

Caliber	Needle	Patients	PDPH	Incidence
25G	Quincke	324	10	3%
26G	Quincke	138	2	1.4%
26G	Atraucan	220	1	0.4%
27G	Quincke	3234	23	0.7%
27G	Whitacre	210	1	0.4%
29G	Quincke	924	3	0.3%
Total		**5050**	**40**	**0.8%**

Use of the tip design of fine-gauge needles in thoracic puncture

In the thoracic dura, fibers are denser and more compact, creating a tighter, less compliant sheath. When a spinal needle penetrates the thoracic dura, the longitudinal orientation makes the puncture track more likely to close, reducing CSF leakage compared to a lumber puncture. However, when thoracic puncture was used to perform TSA, it was shown in 6,734 patients from various publications punctured with Whitacre or Quincke needles that the incidence was only 0.07% (Table II). Several explanations were shown in this article. Direction of the spinal needle is seen to be that mid or lower thoracic punctures need a steep angle for penetration of the structures, and an angle of 45 degrees is often recommended.[4] This angulation gives a less direct communication between the epidural and the dural rent leading to less PDPH.

Orientation of dura mater fibers in the thoracic and lumbar regions

The dura mater is of similar embryological origin to the fascial organ. It contains several fibroblasts which make the dura mater a flexible structure (Figure 1). The dura mater is the outermost layer of the meninges and plays a crucial role in protecting the spinal cord. The dura mater in the thoracic spine has a very organized fiber orientation, which is relevant to why PDPH is less common after thoracic puncture than after lumbar puncture. The collagen and elastic fibers in the thoracic dura run predominantly in a longitudinal (craniocaudal) direction, parallel to the spinal axis.[47] These fibers are arranged in lamellae (layers), with most oriented longitudinally, but with some interlacing oblique and transverse fibers providing tensile strength.[47]

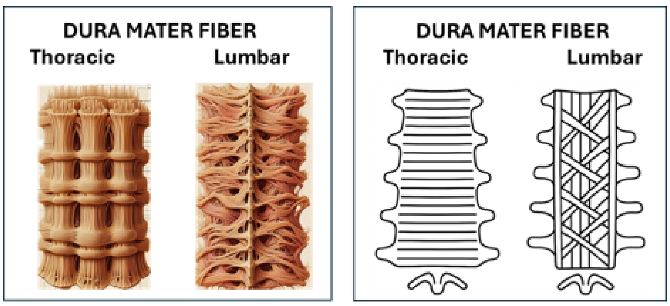

Figure 1 Fibers of the dura mater in the thoracic region and lumbar region and copilot design.

Why is thinner dura less prone to tearing?

The dura mater is the tough outermost membrane covering the brain and spinal cord, and its thickness can vary depending on the region of the spine.[48,49] Thinner dura is generally less prone to tearing due to its greater elasticity, reduced resistance to penetration, lower internal stresses, and potentially faster healing capabilities.[48,49]

a) Greater elasticity: Thinner dura has more elasticity, flexing and deforming under stress instead of tearing outright, which absorbs mechanical forces and lowers the risk of tearing.

b) Less tissue to traverse: Thinner dura requires less force for penetration, reducing the likelihood of inadvertent tearing.

c) Less resistance to needle insertion: Thinner dura offers less resistance to spinal needle insertion, reducing frictional forces and the risk of tearing.

d) Lower structural stress: Thinner structures experience lower internal stresses, decreasing the risk of tears due to mechanical strain.

Conclusion

CSF hydrodynamics is quite complicated and multiple physical and physiological factors can influence its change. Studies have shown that there is a decrease in CSF exchange in the upright posture. The thoracic region has a smaller subarachnoid space than the lumbar region, providing important space for the dispersion of intrathecal medications. Because it has a smaller CSF reservoir, it provides less loss, resulting in a lower incidence of PDPH. Furthermore, the spinal cord and roots are heavily surrounded by CSF and meninges, with less free mobility than the lumbar cauda equina. The smaller CSF volume in the thoracic region provides faster drug dissemination (short latency) and more restricted dispersion of local anesthetics injected into the subarachnoid space. Modifications in surgical practices have led to a lower incidence of PDPH, reflecting a shift in how thoracic spinal anesthesia is performed. These factors contribute to the reduced likelihood of experiencing PDPH during thoracic spinal anesthesia.

Finally, the lower incidence of PDPH after TSA is explained anatomically and physiologically: the thoracic subarachnoid space is narrower and contains a smaller volume of CSF, resulting in less loss. Similarly, CSF pressure is lower in this region compared to the lumbar region. And the needle's path to the subarachnoid space is typically more oblique, acting as a "valve flap."

In conclusion, a new indication for performing TSA is a significantly lower incidence of PDPH during thoracic puncture of 0.07% compared with the incidence of 0.8% during lumbar puncture, representing **11.5** times lower.

References

1. Scherer R, Schmutzler M, Giebler R, et al. Complications related to thoracic epidural analgesia: a prospective study in 1071 surgical patients. *Acta Anaesthesiol Scand.* 1993;37:370–374.

2. Giebler RM, Scherer RU, Jurgen P. Incidence of neurologic complications related to thoracic epidural catheterization. *Anesthesiology.* 1997;86:55–63.

3. Leão DG. Thoracic epidural: retrospective study in 1240 cases. *Rev Bras Anestesiol.* 1997;47:138–147.

4. Bessa PRN, Costa VV, Arci ECP, et al. Thoracic epidural block performed safely in anesthetized patients: a study of a series of cases. *Rev Bras Anestesiol.* 2008;58:354–362.

5. Imbelloni LE, Quirici MB, Ferraz Filho JR, et al. The anatomy of the thoracic spinal canal investigated with magnetic resonance imaging. *Anesth Analg.* 2010;110(5):1494–1495.

6. Chandra R, Misra G, Pokharia P. Study of thoracic spinal canal in Indian

population with 3.0 tesla magnetic resonance imaging: exploring the safety profile of thoracic spinal anesthesia. *J Anesth Clin Res.* 2024;15:1148.

7. Imbelloni LE, Cardoso BB, Torres CC, et al. The anatomy of the thoracic spinal canal investigated with magnetic resonance imaging in children aged 0 to 13 years. *J Cancer Prev Curr Res*. 2023;14(1):15–22.
8. J le Roux JJ, Wakabayashi K, Jooma Z. Defining the role of thoracic spinal anaesthesia in the 21st century: a narrative review. *Br J Anaesth.* 2023;130(1):e56–e65.
9. Imbelloni LE, Chandra R. The state of the art of thoracic spinal anesthesia: from Jonnesco in the early 20th century to the present day. *J Anesth Crit Care Open Acces.* 2025;17(2):40–47.
10. Dittmann M, Reina MA, López García A. New results in the visualization of the spinal dura mater with scanning electron microscopy. *Anaesthesist.* 1998;47(5):409–413.
11. Reina MA, Prats–Galino A, Sola RG, et al. Structure of the arachnoid layer of the human spinal meninges: a barrier that regulates dural sac permeability. *Rev Esp Anestesiol Reanim*. 2010;57(8):486–492.
12. Chin KJ, Karmakar MK, Peng P. Ultrasonography of the adult thoracic and lumbar spine for central neuraxial blockade. *Anesthesiology.* 2011;114(6):1459–1485.
13. Imbelloni LE, Chandra R, Rivoli AL, et al. Safety in spinal anesthesia: from asepsis and antisepsis to total recovery from block. *J Sur Anesth Res.* 2025;6(6):1–10.
14. Lee DG. Biomechanics of the thorax: research evidence and clinical expertise. *J Man Manip Ther.* 2015;23(3):128–138.
15. Elakany MH, Abdelhamid SA. Segmental thoracic spinal has advantages over general anesthesia for breast cancer surgery. *Anesth Essays Res.* 2013;7(3):390–395.
16. Sakka L, Coll G, Chazal J. Anatomy and physiology of cerebrospinal fluid. *Eur Ann Otorhinolaryngol Head Neck Dis.* 2011;128(6):309–316.
17. Skipor J, Thierry J. The choroid plexus–cerebrospinal fluid system: undervaluated pathway of neuroendocrine signaling into the brain. *Acta Neurobiol Exp (Wars).* 2008;68(3):414–428.
18. Spector R, Snodgrass SR, Johanson CE. A balanced view of the cerebrospinal fluid composition and functions: focus on adult humans. *Exp Neurol.* 2015;273:57–68.
19. Muccio M, Chu D, Minkoff L, et al. Upright versus supine MRI: effects of body position on craniocervical CSF flow. *Fluids Barriers CNS.* 2021;18:61.
20. Strbačko M, Rados M, Jurjevic I, et al. Body position influence on cerebrospinal fluid volume redistribution inside the cranial and spinal CSF compartments. *Front Hum Neurosci.* 2025;18:1463740.
21. Yoo HM, Kim SJ, Choi CG, et al. Detection of CSF leak in spinal CSF leak syndrome using MR myelography: correlation with radioisotope cisternography. *AJNR Am J Neuroradiol.* 2008;29:649–654.
22. Aktas G, Kollmeier JM, Joseph AA, et al. Spinal CSF flow in response to forced thoracic and abdominal respiration. *Fluids Barriers CNS.* 2019;16:10.
23. Greitz D, Franck A, Nordell B. On the pulsatile nature of intracranial and spinal CSF circulation demonstrated by MR imaging. *Acta Radiol.* 1993;34:321–328.
24. Munster DW, Lewandowski BE, Nelson ES, et al. Modeling the impact of thoracic pressure on intracranial pressure. *NPJ Microgravity.* 2024;10:46.
25. Imbelloni LE, Sobral MGC, Carneiro ANG. Postdural puncture headache and spinal needle design: experience in 5050 cases. *Rev Bras Anestesiol.* 2001;51:43–52.
26. Kwak KH. Postdural puncture headache. *Korean J Anesthesiol.* 2017;70:136–143.
27. Barati–Boldaji R, Shojaei–Zarghani S, Mehrabi M, et al. Post–dural puncture headache prevention and treatment with aminophylline or theophylline: a systematic review and meta–analysis. *Anesth Pain Med (Seoul).* 2023;18:177–189.
28. Imbelloni LE, Pitombo PF, Ganem EM. The incidence of paresthesia and neurologic complications after lower spinal thoracic puncture with cut needle compared to pencil point needle: study in 300 patients. *J Anesth Clin Res.* 2010;1:106.
29. Imbelloni LE, Sant'Anna R, Fornasari M. Laparoscopic cholecystectomy under spinal anesthesia: comparative study between conventional–dose and low–dose hyperbaric bupivacaine. *Local Reg Anesth.* 2011;4:1–6.
30. Imbelloni LE, Grigorio R, Fialho JC, et al. Thoracic spinal anesthesia with low doses of local anesthetic decreases latency time, motor block and cardiovascular changes: study in 636 patients. *J Anesth Clin Res.* 2012;S11:001.
31. Imbelloni LE, Gouveia MA. A comparison of thoracic spinal anesthesia with low–dose isobaric and low–dose hyperbaric bupivacaine for orthopedic surgery: a randomized controlled trial. *Anesth Essays Res.* 2014;8:26–31.
32. Imbelloni LE. Spinal anesthesia for laparoscopic cholecystectomy: thoracic vs lumbar technique. *Saudi J Anaesth.* 2014;8:477–483.
33. Imbelloni LE, Fornasari M, Fialho JC, et al. Laparoscopic cholecystectomy under thoracic spinal anesthesia: comparative study between two different hyperbaric bupivacaine doses. *World J Pharm Pharm Sci.* 2019;8(7):212–223.
34. Imbelloni LE, Fornasari M, Sant'Anna R. Thoracic spinal anesthesia is safe and without neurological sequelae: study with 1406 patients. *Int J Anesth Anesthesiol.* 2022;9(2):148.
35. Imbelloni LE, Fornasari M, Sant'Anna R. Laparoscopic cholecystectomy under lower thoracic spinal anesthesia: a retrospective study with 505 patients. *J Sur Anesth Res.* 2022;3(4):1–6.
36. Imbelloni LE, Ventura TB, Lacerda S, et al. Lower thoracic spinal anesthesia for orthopedic surgery of lower limbs: retrospective study with 674 patients. *World J Pharm Pharm Sci.* 2022;11(12):71–84.
37. Deshpande N, Agarwal K, Hatgaonkar R. Efficacy of thoracic segmental spinal anesthesia along with unilateral erector spinae block in patients undergoing unilateral modified radical mastectomy and axillary dissection: a multicentric study. *Asian J Pharm Clin Res.* 2023;16(6):158–163.
38. Paliwal N, Maurya N, Suthar OP. Segmental thoracic spinal anesthesia versus general anesthesia for breast cancer surgery: a prospective randomized controlled open–label trial. *J Anaesthesiol Clin Pharmacol.* 2022;38:560–565.
39. Chandra R, Misra G, Datta G. Thoracic spinal anesthesia for laparoscopic cholecystectomy: an observational feasibility study. *Cureus.* 2023;15(3):e36617.
40. Chandra R, Pullano C, Misra G, et al. Double needle technique: a novel approach of anaesthesia for thoracolumbar spine fractures. *Austin J Anesth Analg.* 2023;11(2):1116.
41. Chandra R, Misra G, Langoo SA. A prospective observational study on the effectiveness of segmental spinal anesthesia in patients posted for modified radical mastectomies. *Ann Case Report.* 2023;8:1349.
42. Sultana A, Shuvra R, Hoque F, et al. Efficacy of segmental thoracic spinal anaesthesia in laparoscopic cholecystectomy. *Sch J App Med Sci.* 2024;12(2):145–150.
43. Verma AK, Kumar N, Srinivas C, et al. Comparison of effectiveness and safety of segmental thoracic spinal anesthesia using isobaric levobupivacaine 0.5% vs hyperbaric levobupivacaine 0.5% in laparoscopic cholecystectomy: a randomized controlled trial. *Cureus.* 2024;16(12):e76060.
44. Singhal G, Mathur BL, Mathur AK. Efficacy and safety of segmental spinal anaesthesia in laparoscopic cholecystectomy: a prospective study.

Indian J Clin Anaesth. 2023;10(1):3–10.

45. Bier A. Versuche **über** Cocainisierung des Rückenmarkes. *Dtsch Z Chir.* 1898;51(3–4):361–369.
46. Jonnesco T. General spinal analgesia. *Br Med J.* 1909;2:1396–1401.
47. **Ünal** M, Sezgin AB. Dura mater: anatomy and clinical implication. *J Behav Brain Sci.* 2021;11:239–247.
48. Reina MA, López A, De Andrés JA. Thickness variation of the dural sac. *Rev Esp Anestesiol Reanim.* 1999;46:344–349.
49. Reina MA, López A, Dittmann M, et al. Structural analysis of the thickness of the human dura mater with scanning electron microscopy. *Rev Esp*