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Lumbar Puncture of the Newborn

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Abstract

Heinrich Irenäus Quincke was the first person in medical history to perform lumbar puncture (LP). Indications of lumbar puncture include suspected meningitis, suspected subarachnoid hemorrhage, administration of chemotherapeutic agents, instillation of contrast media for imaging of the spinal cord, and the evaluation of various neurologic conditions including normal pressure hydrocephalus and Guillain-Barré syndrome, and the treatment of idiopathic intracranial hypertension. Contraindications of lumbar puncture include findings of increased intracranial pressure, bleeding diathesis, cardiopulmonary instability, soft tissue infection at the puncture site, shock, respiratory insufficiency, and suspected meningococcal septicemia with extensive or spreading purpura. Altered mental status, focal neurologic signs, papilledema, focal seizure, and risk for brain abscess are indications for cranial imaging before performing LP. Lack of local anesthetic use and advancement of the spinal needle with the stylet in place were most prominent risk factors for a traumatic LP. Ultrasound may minimize the number of LP attempts and decrease patient and parent anxiety by easily identifying an insertion site. Infection, spinal hematoma, epidermoid tumor, and cerebral herniation are the main complications of LP. When LP is traumatic, the wisest approach is to assume the patient is having meningitis and start empirical therapy.

Keywords: infants, neonate, newborns, lumbar puncture, spinal tap, meningitis

Core tips

It seems that Heinrich Irenäus Quincke was the first person in medical history to use lumbar puncture for therapeutic, and subsequently, diagnostic purposes.

Empirical antibiotic therapy for suspected meningitis, which should ideally succeed lumbar puncture, should be started immediately if lumbar puncture is to be delayed.

Lumbar puncture should always be performed as soon as the infant becomes clinically stable and can tolerate the procedure even if it has not been possible to be performed at the first suspicion of meningitis.

Lumbar puncture can be performed safely in patients with thrombocytopenia less than $10,000/\mu\text{L}$, if they receive transfusion to a peripheral platelet count greater than $50,000/\mu\text{L}$, and in patients with coagulopathy after appropriate correction of factor deficiency.

Physicians may have to treat suspected meningitis being deprived of cerebrospinal fluid (CSF) analysis guidance, since getting parental consent for lumbar puncture may be problematic.

During lumbar puncture, airway and resuscitation equipment should be immediately at hand.

Lumbar puncture in children younger than 12 months must be performed below the L2-L3 interspace.

The presence of a family member was found to be associated with neither an increased risk of traumatic or unobtainable lumbar puncture nor more attempts at the procedure.

The “ideal” angle for lumbar puncture as determined with ultrasonography was 50° in infants in both the lateral recumbent and sitting positions.

When lumbar puncture is traumatic, the wisest approach is to assume the patient as having meningitis and start empirical therapy.

1. Introduction

Lumbar puncture (LP) may be considered one of the most well-known diagnostic procedures in the field of pediatric infectious diseases. It is an essential procedure for analyzing cerebrospinal fluid (CSF) in the evaluation for meningitis, sepsis, fever, or subarachnoid hemorrhage (SAH) in neonates.

2. History

Our knowledge of meninges dates back to ancient Egypt, where it was described in Ebers papyrus around 1500 BC. Hippocrates (and his physician contemporaries) must have been aware of the presence of CSF, since he is known to have referred to hydrocephalus as “water in the head.”

Despite, apparently, a long time has passed since the discovery of CSF, its usual collection technique, called lumbar puncture, has a relatively short history—about only a century long. The answer to the question of who has performed the first lumbar puncture is still a little matter of debate today:

- In 1885, North-American neurologist Leonard Corning (1855–1923) published two articles, in which he described the application of “local medication” cocaine for local anesthesia to

the spinal cord in thoracic D1–D2 interspace, most probably in the epidural space not removing any CSF.

- Heinrich Irenäus Quincke (1842–1922), a German professor of internal medicine in Kiel, presented his first communication on LP in the “X. Kongress der Gesellschaft für inneren Medizin” (X. Congress of the Society of Internal Medicine) in Wiesbaden, Germany on April 8, 1891. In his first procedure of its kind, Quincke used a hollow needle with stiletto, which very closely resembles the LP needles that are routinely used today. He entered the subarachnoid space at the L3–L4 intervertebral level and drained CSF with the purpose of relieving headache, suffered by children with hydrocephalus. Quincke coined the term “Lumbalpunktion” (LP) in his subsequent paper on this field.
- According to English physician Walter Essex Wynter’s (1860–1945) article published in the *Lancet* on May 2, 1891, he made a skin incision at the second lumbar vertebra, and then made a big opening up to the dura mater, in addition to which laminectomy was often required. Next, he introduced a trochar and took CSF out for decreasing CSF pressure. Wynter used the term “paracentesis” for his procedure.

It is clearly seen that all three investigators have done the procedure for therapeutic, not diagnostic purposes, which is the main difference from today’s LP. It is also obvious that Corning’s performance involves a site (thoracic) and an intermeningeal space (epidural) that is very distinct from LP.

Although some authors mention the names of Corning and Wynter, it seems that Quincke was the first person in medical history to use LP for therapeutic, and subsequently, diagnostic purposes. Putting the common point of therapeutic use apart, during the time of publication, characteristics of puncture and nomenclature used were compared; we, in agreement with authors like Frederiks and Koehler, favor Quincke as the discoverer of LP. Besides, we believe that he deserves this title for being the first investigator to apply LP for diagnostic purposes thereafter [1, 2].

3. Indications

- The main indication for LP in newborn period is suspected central nervous system (CNS) infection. LP is an indispensable and emergent tool in the diagnosis of neonatal meningitis and should ideally precede the initiation of empirical antimicrobial therapy. If LP should be delayed or cannot be performed for any reason, such as deteriorating clinical status of the patient or transferring the patient to another health institution, empirical antibiotic therapy should be started immediately, since minutes count in the diagnosis and early commencement of therapy [3].

Clinical findings of neonatal meningitis are similar to those of neonatal sepsis with or without meningitis. Thus, it is not possible to predict with physical findings alone whether the infant has sepsis, meningitis, or both. Although signs of sepsis and meningitis intertwine in the newborn period, some neonatologist deem it unnecessary to perform LP on neonates evaluated for sepsis, especially those with early neonatal sepsis [4, 5], because the antibiotics for

both conditions would be the same. However, it should be kept in mind that blood cultures are negative in one-third of neonates with meningitis who are very-low-birth-weight and born over 34 weeks of gestation [6]. Thus, in case of LP is not performed, a significant portion of neonates with meningitis would not get a correct diagnosis and would not be observed for the likely complications of meningitis. For that reason, the author is in favor of the opinion that LP should always be performed as soon as the infant becomes clinically stable and can tolerate the procedure even if it has not been possible to be performed at the first suspicion of meningitis. CSF inflammation lasts for a considerably long duration of days, which would allow the clinician to diagnose or exclude the diagnosis of meningitis although CSF cultures may become negative within hours.

- Suspected subarachnoid hemorrhage (SAH) is another emergent indication for LP. Computed tomography (CT) should be performed for all children suspected of having SAH. There are times when SAH is not detectable on a CT scan and LP becomes the sole method of diagnosing this condition [7].
- Other indications for LP include the administration of chemotherapeutic agents, instillation of contrast media for imaging of the spinal cord, and the evaluation of various neurologic conditions including normal pressure hydrocephalus and Guillain-Barré syndrome. Among therapeutic uses of LP, removal of CSF in the treatment of idiopathic intracranial hypertension (pseudotumor cerebri) is noteworthy [8].

4. Contraindications

A contraindication to LP can be absolute or relative. In all situations, the clinician should use her/his clinical judgment by taking into account the relative risk of performing LP.

- Increased intracranial pressure (ICP): Increased intracranial pressure (ICP) is an absolute contraindication. Children with elevated ICP are at risk for cerebral herniation during LP. Therefore, cranial CT of all patients with clinical suspicion of increased ICP is essential for the physician's decision to perform LP, including those at risk because of brain abscess [8].
- Bleeding diathesis: Our knowledge regarding the safety of performing LP in patients with thrombocytopenia or coagulation factor deficiency is limited. The safety of LP in thrombocytopenia was investigated in 5223 LPs performed on 958 children with acute lymphoblastic leukemia in a retrospective study. Of these LPs, 912 were done at platelet counts of 11,000–20,000/ μ L, and 29 were performed at platelet counts of 10,000/ μ L or less. Serious complications of LP were not observed, regardless of platelet count. The authors concluded that prophylactic platelet transfusion was not necessary in children with platelet counts higher than 10,000/ μ L with a little caution that no conclusion can be made for children with platelet counts of 10,000/ μ L or less, due to the small number of patients in the study [9].

Because of the risk of subdural or epidural hematoma formation, many experts are against performing LP in patients with coagulation defects who are bleeding, severely thrombocytopenic (i.e., with platelet counts <50,000/ μ L), receiving anticoagulant therapy or an international

normalized ratio of 1.4 or higher, without correcting the underlying abnormalities [8, 10]. However, LP can be performed safely in patients with thrombocytopenia less than 10,000/ μ L, if they receive transfusion to a peripheral platelet count greater than 50,000/ μ L, and in patients with coagulopathy after appropriate correction of factor deficiency [9, 11].

- Cardiopulmonary instability: The position of the newborn during LP may result in cardiopulmonary compromise. This issue will be addressed further in detail elsewhere in the text.
- Soft tissue infection at the puncture site
- Shock
- Respiratory insufficiency
- Suspected meningococcal septicemia with extensive or spreading purpura [10]

Conditions listed below are conditions in which imaging is needed before LP to exclude brain shift, swelling, or space occupying lesion [10]:

- Moderate to severe impairment of consciousness [Glasgow coma scale (GCS) < 13 or 9 according to some experts] or fall in GCS of >2
- Focal neurological signs (including unequal, dilated, or poorly responsive pupils)
- Abnormal posture or posturing
- Papilledema
- After seizures until stabilized
- Relative bradycardia with hypertension
- Abnormal “doll’s eye” movements
- Immunocompromise

Consequently, LP is sometimes contraindicated simply because the patient is too ill to safely undergo the procedure.

5. Parental consent

Since patients without appropriate decisional capacity cannot give their informed consent and written informed consent of the caregiver is required before the procedure, in many institutions including ours, it is customary for physicians to talk to parents for providing informed permission for an intervention like LP on their child. A straightforward explanation of the urgency and essentialness of the procedure, as well as the details of the procedure itself, maybe with the help of comparison with usual venipuncture (author’s practice), is usually reassuring and should routinely be provided. Sometimes parents refuse to give assent and physicians are forced to initiate and continue CNS infection treatment totally blindfolded—that is without

being able to include or exclude the diagnosis, grow the etiologic organism, and confirm the treatment success. Although LP is a relatively safe process, results from studies show that the most frequent concern that lay behind a dissent is that LP would cause a complication [12, 13]. In a single-center study carried out in Turkey, the most feared complication was paralysis (60%) followed by sterility (22%) [14].

6. Imaging

The decision to carry out imaging before LP should be done on a case-by-case basis. Children with the following conditions may have increased intracranial pressure (ICP) and, because of the assumption is that CT scan of the head can more or less reliably predict who will and who will not experience brain herniation after lumbar puncture, are advised to have a CT scan performed before LP [15]:

- Altered mental status
- Focal neurologic signs
- Papilledema
- Focal seizure
- Risk for brain abscess (immunocompromise or congenital heart disease with a right-to-left shunt)

It should be noted that a normal CT scan does not fully exclude the presence of elevated ICP or the possibility that elevated ICP will not develop thereafter. It is also known from adult studies that even those not undergoing LP because of a mass effect on head CTs may experience brain herniation [16]. Thus, although imaging for this purpose has been questioned by some specialists of this field, we agree with the recommendation that LP can be considered within 6 hours of a normal CT scan and no other contraindications [8, 17].

7. Preparation

Once the informed consent is obtained and imaging is performed if necessary, it is time for:

- providing oxygen saturation, respirations, and heart rate (HR) monitoring for critically-ill children during the procedure;
- “rehearsing” the position that infants will assume and getting help from a health care personnel who can hold the infant in sitting position if she/he is in respiratory distress (since in this position LP may be tolerated better) [18];
- getting help from a radiologist for patients with spinal abnormalities, such as spina bifida or severe scoliosis, to perform the procedure under ultrasonographic guidance [19]; and

- identification of infants who may require sedation or topical transdermal anesthesia for the procedure.

Materials needed for a smooth LP may be listed as follows [8]:

- Lidocaine 1% without epinephrine and topical anesthetic cream, such as liposomal lidocaine or eutectic mixture of lidocaine 2.5% and prilocaine 2.5%
- Sterile 3 mL syringe with 25-gauge needle for lidocaine injection
- Four sterile collecting tubes
- Sterile gloves
- Sterile drapes
- Povidone-iodine solution
- Sterile sponges for preparing puncture site
- Manometer (typically used in patients older than two years of age)
- 22-gauge and 1.5 inches (3.75 cm) long styletted spinal needle [7]
- Resuscitation equipment

8. Anatomy

CSF circulates in the space between the pia mater and the arachnoid mater, called subarachnoid space that surrounds the brain, spinal cord, ventricles, aqueductus cerebri (Sylvius), and central canal of the spinal cord. After the formation of most of its volume in the choroid plexuses of the lateral ventricles, CSF passes through the foramina of Luschka and Magendie into the subarachnoid space, which is around the spinal column and over the cerebrum. The CSF is primarily absorbed by the arachnoid villi found next to the sagittal sinus and then drains into the venous circulation [7, 20, 21]. In full-term infants, the volume of total CSF is about 40 mL, a quarter of which is in the ventricles, and the remainder in the subarachnoid space. CSF serves as a cushion between bony structures and the brain, together with the spinal cord. Since brain has no lymphatics, CSF also has an important role of carrying chemical byproducts of metabolism out of the brain to the venous circulation [7].

In order to avoid an accidental nervous injury, LP should be performed distal to the spinal cord, at the level of the cauda equina. In older children, LP can be performed from the L2-L3 interspace to the L5-S1 interspace, because these interspaces are below the termination of the spinal cord [8]. At birth, the inferior end of the spinal cord is opposite to the body of the third lumbar vertebra (L3); therefore, LP in children younger than 12 months must be performed below the L2-L3 interspace. As the child's spinal cord grows, the vertebral column grows more rapidly. An imaginary line that connects the two posterior-superior iliac crests intersects the spine at approximately the fourth lumbar vertebra. This landmark helps to locate the L3-L4

and L4-L5 interspaces [8]. Anatomic structures pierced during median LP in order are skin, subcutaneous fat, supraspinal ligament, interspinal ligament, ligamentum flavum, dura mater, and arachnoid mater [7].

9. Procedure

9.1. Before the procedure

Most of the time, LP is a relatively simple procedure, although it can sometimes prove challenging even for the most experienced physician. The potential for complications during and following LP makes it necessary that it be performed in an area with proper resuscitation equipment. Although not technically complex, LP is not a procedure that may be taken lightly, and it should only be performed by or under the supervision of a knowledgeable and experienced health professional.

HR, respiratory action, and oxygen saturation should be monitored closely during the procedure in neonates. Airway and resuscitation equipment should be immediately at hand. If the indication for the LP is elective, or by any other reason LP is not going to be done urgently, 4% lidocaine cream (effective after about 30 minutes) or eutectic mixture of lidocaine and prilocaine (effective after about 45–60 minutes) may be applied over the puncture site to lessen the pain [22, 23]. Due to the shorter time it takes for the onset of its effect, 4% lidocaine cream may be the preferred agent for this purpose.

9.2. Positioning of the newborn

According to a popular saying in pediatric circles in Turkey, “the person who performs the LP is the one who holds the infant.” This saying emphasizes the challenging task of achieving and maintaining a proper patient position for the performer of LP. The patient is placed on the examining table. The goals of positioning are to stabilize the infant, to stretch the ligamenta flava and to increase the interlaminar spaces. The most common positions used for the pediatric LP are the lateral recumbent and sitting positions (**Figures 1** and **2**). For the lateral recumbent position, the patient is laid on her/his side near the edge of the bed. For a right-handed performer, the patient’s head should face left because of ergonomics of the right upper extremity of the performer. The patient’s neck is flexed and the knees are drawn up to the chest by the assistant by placing one arm under the child’s knees and the other arm around the posterior aspect of the neck. The assistant should ensure that the spinal column is in no rotation by keeping the shoulders and hips perpendicular to the bed.

In the sitting position, the assistant holds the patient in the position with an arm and a leg in each hand while supporting the head to prevent from dropping, that is, excess flexion of the neck.

Choosing among the lateral recumbent and sitting positions with the neck or hip flexed or neutral, has not been standardized and is at the physician’s disposal, and most neonatologists prefer placing the infant in lateral recumbent position [24]. The positions are important because they may be superior over one another in avoiding a traumatic tap (peripheral blood staining the CSF specimen) and to get sufficient amount of cerebrospinal fluid, which should

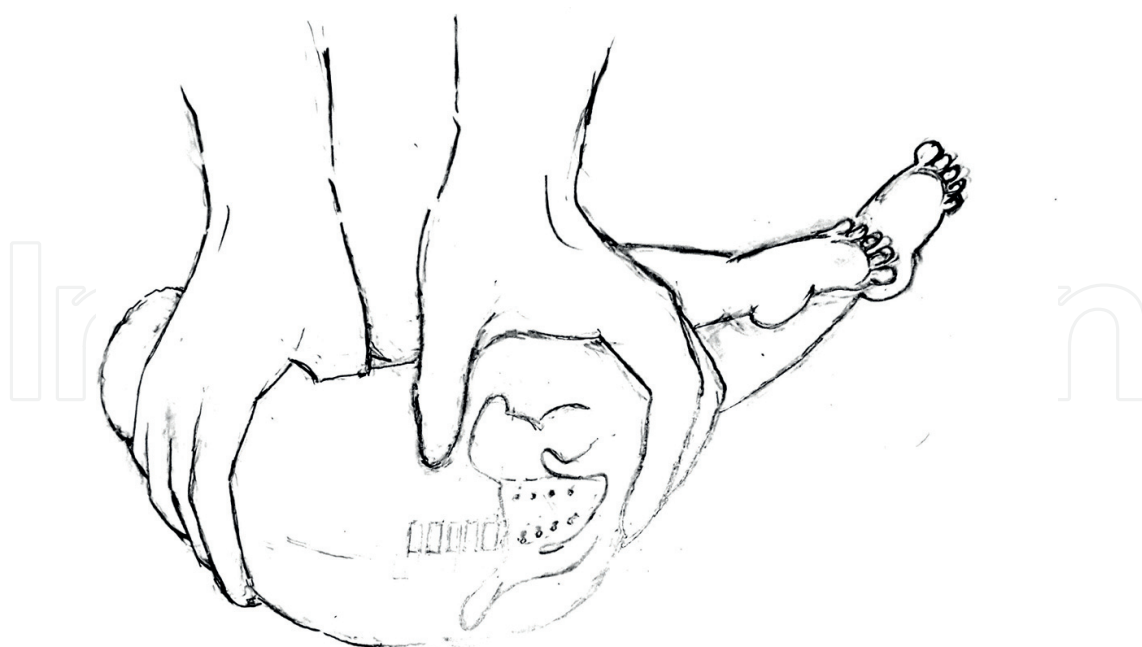


Figure 1. Lateral recumbent position (by Ziver Öncel).

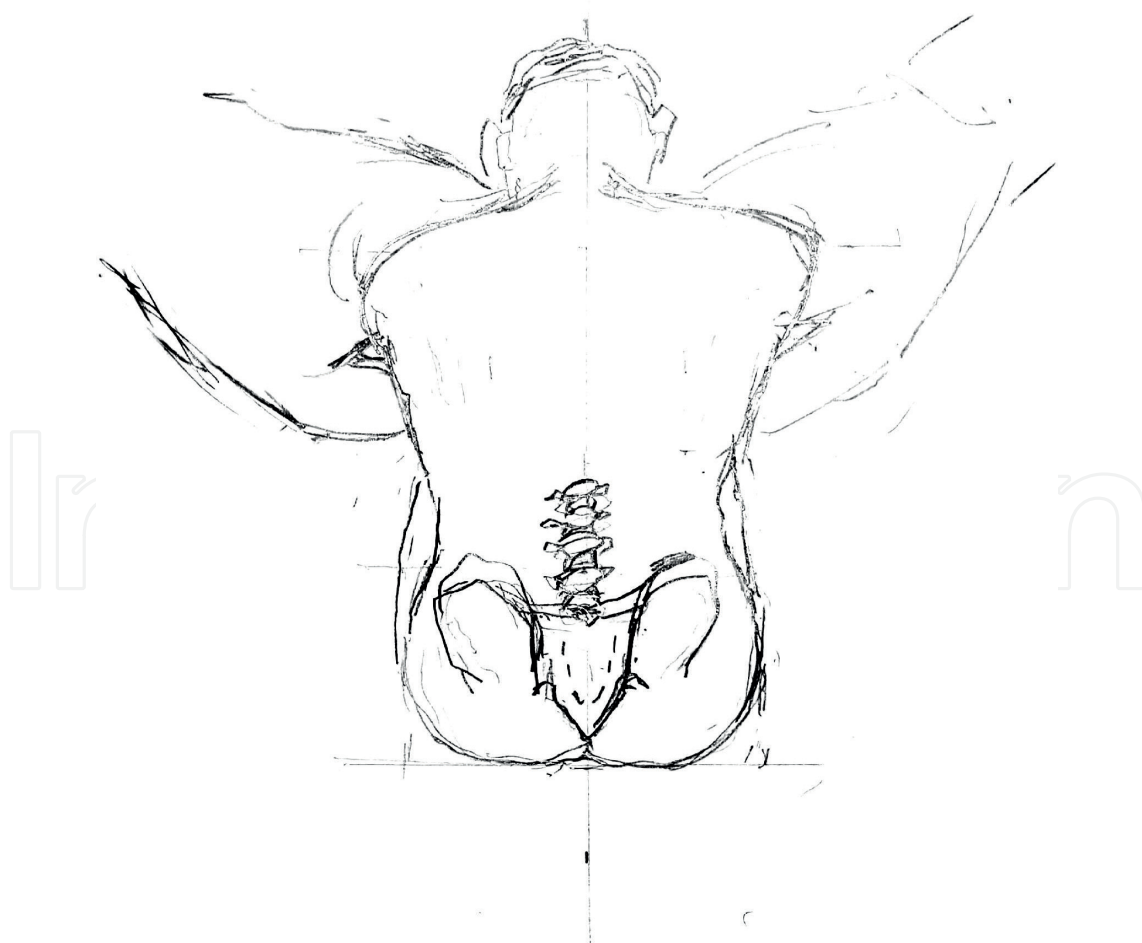


Figure 2. Sitting position (by Ziver Öncel).

be feasible in a still infant with the widest interspinous space (the space between the spinous processes of two adjacent vertebrae) possible. Change of position does not alter subarachnoid space width, thus does not have a role in lumbar puncture success via this mechanism [25]. Safety, as well as the ease of the LP is a very important issue in the neonatal period especially considering the vulnerability of infants hospitalized in neonatal intensive care units. In adults, studies have uniformly showed that the maximal interspinous distance can be obtained with maximal hip flexion [26, 27].

We have shown in our study, in which the infants enrolled were placed in two lateral recumbent and two upright positions (lateral recumbent without flexing the hips, lateral recumbent with maximal hip flexion, sitting without flexing the hips and sitting with maximal hip flexion), that having the patient sit with maximal hip flexion provided the largest interspinous space for the grand majority of the infants, and that the lateral recumbent position without flexing the hips has resulted in the narrowest interspinous space. Although providing significantly larger interspinous spaces, sitting positions with/without flexion have resulted in significant increases in HR with respect to lateral recumbent position without flexion. Similarly, we observed statistically significant drops in oxygen saturations between lateral recumbent and sitting with flexion, lateral recumbent with flexion and sitting without flexion, and lateral recumbent with flexion and sitting with flexion positions. No adverse hypoxic events occurred during the procedure in the entire study [28]. In adults, the position providing the significantly greatest interspinous space was obtained with the so-called “sitting, feet supported position” in which the patient touches her/his ankles while sitting [27]. This position resembles sitting with maximal hip flexion position in newborns. In a survey, most (82%) pediatric emergency attending physicians were found to opt for the lateral decubitus position [29]. Gleason et al. found that although PO_2 decreased and the HR increased with each position for LP, the decrease was significantly greater in the recumbent position with maximal hip flexion [30]. Cadigan et al. also found that recumbent with maximal hip flexion position provided wider interspinous spaces than did the recumbent without flexing the hips in healthy newborns in their well-child visits [24]. HR and oxygen saturation differed significantly with positioning of the infants in our study; however, this did not result in any apparent changes in clinical status. Although there were few infants weighing less than 1500 g in our study population, our results have shown that sitting-flexed position was a safe alternative to traditional-flexed recumbent position [28].

9.3. Landmarks

Once the patient is positioned, the most upper points of the posterior superior iliac crests are palpated. The line imaginarily drawn between these two points intersects the midline just above the fourth lumbar vertebra. The interspaces between L3-L4 and L4-L5 can then be located. Unlike children outside infancy, for whom the L2-L3 interspace may also be used, L3-L4 or L4-L5 interspace should be used for LP of neonates due to anatomical positioning explained above [7].

9.4. Puncture

The puncture site should be cleansed with povidone-iodine solution, which can be removed with alcohol. Sterile drapes with a hole in the center to allow for a fine exposure are placed on

the procedure site. The projection of interspace on the skin may be marked by depressing a fingernail on the skin so that the puncture site can be relocated.

If not previously anesthetized with one of the topical agents mentioned above, the skin and subcutaneous tissues are infiltrated with 1% lidocaine. Local anesthesia for LP is encouraged in neonates, because it has been shown to decrease the pain response to LPs without altering their success rate [31].

Two approaches are possible for inserting the spinal needle: in the median approach, the needle is inserted through the supraspinal ligament exactly in the midline. In the lateral approach, the needle is inserted lateral to the ligament. Unlike older patients, supraspinal and interspinal ligaments are rarely calcified in children, which renders a lateral approach unnecessary; therefore the median approach is most commonly used. With both approaches, the needle may be held in one hand or with both hands. It is better if the bevel of the spinal needle is positioned horizontally in the lateral recumbent position and vertically in the sitting position, because in this way, the fibers of the dura mater, which run longitudinally down the spinal cord, are pierced parallelly, the amount of CSF leakage is minimized, and likelihood of post-LP headache is decreased [7]. The needle is then advanced cephalad toward the umbilicus or slightly caudad according to the patient's position of lateral recumbency or sitting, respectively. In the study by Brucoleri et al., the "ideal" angle for LP as determined by ultrasonography was 50° in infants in both the lateral recumbent and sitting positions [32]. In the lateral approach, the needle should be inserted lateral to the upper border of the spinous process of L3 or L4. It should then be directed slightly medial and slightly upward (cephalad) to avoid contact with the supraspinal ligament.

It is normal that some resistance is felt during the advancement of the needle. When the ligamentum flavum is penetrated, this resistance may be lost a bit, especially in older children. There is a second resistance change when the dura is pierced. This second loss of resistance is often referred to as a "pop," which may not be evident in infants. Inserting the needle too far may result in a traumatic LP. The most effective way to avoid this problem is by inserting the needle slowly and methodically, in increments of a few millimeters at a time, and frequently checking for return of CSF. For infants under 3 months of age, the appropriate distance of insertion is approximately 1.0–1.5 cm [33]. Various studies have been carried out to determine the proper depth of needle insertion for LP. Of these studies, numerous different formulae have been developed. Taking the studies of Craig et al., Shenkman et al., Arthurs et al., and Oulego-Erraz et al., whose formulae are applicable to neonates, as examples, the ideal distances of insertion were found to be

- $[0.03 \times \text{height (cm)}] \text{ cm}$,
- $[13.19 + 0.0026 \times \text{weight (g)} - 0.12 \times \text{post-conceptual age in weeks}] \text{ mm}$,
- $[2 \times \text{weight (kg)} + 7] \text{ mm}$, and
- $[2.5 \times \text{weight (kg)} + 6] \text{ mm}$, respectively [34–37].

The spinal needle should be supported with fingers during fluid collection in order to prevent dural tugging, a potential source of local pain and post-LP CSF leakage.

If no CSF is coming after the needle has been inserted into an appropriate depth, rotating the needle 90° may be of help. If this is not effective, the stylet is replaced and the needle is advanced slightly. In some cases, withdrawing the needle incrementally will result in CSF flow when the procedure is initially unsuccessful. If spinal fluid is not obtained despite such maneuvers, the procedure should be attempted again by removing the spinal needle with the stylet in place till it arrives just under the skin and redirecting it. The needle can also be withdrawn entirely and a new needle used at a different insertion site. CSF may come very slowly in dehydrated infants when LP is performed using the lateral recumbent position. Getting the patient to a sitting position may increase flow in this situation.

If bony resistance is felt when the needle is not yet advanced into deep tissues, then puncture over the spinous process is likely, and the needle should be withdrawn till it is just below the skin and redirected through the interspace. If bony resistance is felt when it went deeper, then the likely cause is inadequate spinal flexion. Directing the needle more cephalad and improving the position usually overcomes this problem [7].

9.5. Traumatic LP

Traumatic or unsuccessful LP a neonates is a probability in 30–50% of the time [38]. A traumatic LP may stem from improper technique. Causes include inserting the needle too far into an epidural venous plexus or through the subarachnoid space into or adjacent to the vertebral body. Nigrovic et al. found that lack of local anesthetic use and advancement of the spinal needle with the stylet in place were most prominent risk factors for a traumatic LP [39]. In the study of Glatstein et al., its incidence was independent of physician experience, sedation use or time of procedure [40]. It is also surprising for the author of these lines that the presence of a family member was not found to be associated with an increased risk of traumatic or unobtainable lumbar puncture, nor was it associated with more attempts at the procedure [41]. If blood is seen during fluid collection but the spinal needle is in proper position, the CSF often clears and the specimen does not clot. If the bloody CSF does not clear and clots form when it is collected in the test tube, then the needle should be removed and LP attempted at a different interspace with a new needle [7]. Ultrasound may minimize the number of LP attempts and decrease patient and parent anxiety by easily identifying an insertion site. It may also be useful to determine the reason for failure and the likelihood of success on continued attempts [19].

9.6. Measurements and tests

Measurement of CSF opening pressure is recommended during any LP when possible. The infant's struggling may be an obstacle for accurate measurement of opening pressure. The measurement is most reliable in a calm patient in the lateral recumbent position. As soon as the flow of CSF stabilizes and show pressure pulses with respiration, heartbeat, and jugular occlusion, the pressure manometer is immediately attached to the needle hub via a three-way stopcock. The pressure is measured at the highest level CSF reaches. Normal CSF pressure is 5–20 cm H₂O in a child with neck and legs extended and 10–28 cm H₂O with neck and legs flexed [7]. However, since an adult study reached totally opposite results, it is also possible that CSF pressure does not meaningfully decrease when the lower extremities are brought to extension from flexion in newborns. Kaiser et al. found the normal range of 0–7.6 cm H₂O for

newborns [42]. Of note, an estimation on CSF pressure can be made by counting the drops of CSF in a certain time. For 22-gauge, 1.5-inch needles recommended for use in the newborn period of life, the counting periods for which the number of drops counted equals the CSF pressure (in cm H₂O) are 21 and 20 seconds for body temperatures of <40 and ≥40°C, respectively [43].

The CSF is collected in test tubes. Approximately, 1 mL per tube is required for routine studies. The first tube specimen should be sent for Gram stain and bacterial culture, the second for quantitative glucose and protein, and the third for cell count and differential. Additional tubes may be used for viral culture, fungal culture, bacterial antigens, cell pathology, or special chemistries, if needed. After CSF collection, closing pressure may be measured as previously described. The spinal needle is removed with the stylet in place. The puncture area should be cleansed and a sterile dressing applied. It is important to remember removing the dressing after a reasonable time so that it does not become a source of infection.

10. Complications

LP is frequently associated with the minor complications of localized back pain without neurologic abnormalities, transient paresthesia during the procedure, and post-LP headache, all of which a newborn may fail to express in some way.

Permanent peripheral nerve damage is rare, because the spinal needle does not pierce the nerve, instead, it may move or stretch it [7].

Major complications after LP include LP-induced meningitis, epidural or subdural hematoma, acquired epidermoid tumor, damage to adjacent structures (disk herniation, retroperitoneal abscess, spinal cord hematoma), and cerebral herniation. Fortunately, these complications are quite rare. As previously mentioned, in the young infant, the lateral recumbent position for LP can cause respiratory obstruction, hypoxemia, and cardiovascular instability.

- **Infection:** LP through an area of cellulitis predictably causes meningitis. For this reason, cellulitis overlying the LP site constitutes an absolute contraindication to this procedure. An association has also been detected between performing LP in children with bacteremia and the occurrence of meningitis [44]; but in a subsequent analysis, this association was not confirmed [45]. In the absence of soft tissue infection at the puncture site, the risk of causing meningitis, epidural abscess, or osteomyelitis is rare enough to be clinically insignificant [46].
- **Spinal hematoma:** Subdural or epidural hematoma following LP has been reported with all forms of bleeding diathesis. Signs and symptoms of spinal cord compression, which develops hours to days after the procedure, include sensory deficits, paralysis, and incontinence. In most cases, LP is difficult and yields bloody fluid. In these patients, platelet counts are low or falling, and platelet transfusion has not been provided before LP [7, 47].
- **Epidermoid tumor:** Acquired epidermal spinal cord tumors can arise 1.5–23 years after LP due to implantation of epidermal material into the spinal canal during LP. The tumor manifests itself as gait disturbance, pain, and neurologic dysfunction. Experimental and

clinical evidence strongly suggests that these tumors can be avoided if a spinal needle with a tight fitting stylet is used [7, 48].

- **Cerebral herniation:** This is the most feared complication of LP which may lead to sudden death. Patients with an intracranial space occupying lesions, such as abscess, hematoma, and tumor are at greatest risk. Elevated intracranial pressure manifested as focal neurologic signs seems to cause herniation much more (40%) than does elevated intracranial pressure presenting with either papilledema or abnormal manometric findings alone (5 and 1.2%, respectively) [7, 49, 50]. Risk of herniation in a newborn with an open fontanel and no focal neurologic findings is much lower. In most patients, assessment of the safety of performing LP can be made based on clinical basis. Patients who have a history of focal neurologic symptoms (e.g., focal seizures, unilateral motor paralysis), focal neurologic findings on physical examination, signs of impending herniation (posturing, Glasgow Coma Score less than 8, bilateral dilated pupils, respiratory abnormalities, abnormal tone, absent Doll eye reflex), or papilledema should not undergo LP until imaging establishes that the procedure can be safely performed [7] If meningitis or other CNS infections cannot be ruled out, the patient should receive appropriate antibiotic therapy prior to the imaging study.

11. Interpretation of CSF findings

Lumbar puncture is an indispensable diagnostic tool in neonatal meningitis. Direct microscopy should be performed as soon as possible, because if performed later, the erythrocytes and leukocytes likely undergo cellular lysis and escape detection. Gram- and Giemsa-stained smears of CSF should also be examined. CSF should be cultured, and if needed, sent for polymerase chain reaction. LP should ideally precede the initiation of antimicrobial therapy, but if delayed for any reason, empirical antibiotic therapy should be started immediately.

Interpretation of CSF findings is challenging in neonates, because glucose, and protein concentrations, and cell count are higher due to the high permeability of the blood-brain barrier [51] (Table 1).

Many experts accept 20–30/ μ L as the cutoff value for pleocytosis. Low CSF glucose, elevated CSF protein, and pleocytosis may indicate either bacterial or viral (especially herpes simplex virus) meningitis. One of these parameters being in the normal range cannot be accepted as

Age	Erythrocytes (μ L/L)	Leukocytes (μ L/L)	Protein (mg/dL)	Glucose (mg/dL)
Preterm— < 7 d	30 (0–333)	9 (0–30)	100 (50–290) (mostly <200)	54 (27–99)
Preterm— > 7 d	30	12 (2–70)	90 (50–260) (mostly <150)	54 (27–99)
Term— < 7 d	9 (0–50)	5 (0–21)	60 (30–250)	54 (27–99)
Term— > 7 d	<10	3 (0–10)	50 (20–80)	54 (27–99)

d: day(s).

Table 1. Means and normal ranges of cerebrospinal parameters in neonates [51].

evidence against the presence of meningitis. In order to exclude meningitis, all three parameters should be normal; nevertheless, CSF findings may be completely normal in the very early course of neonatal meningitis. The most prudent approach would be to repeat LP after 24–72 hours in such borderline cases: if the infant had meningitis, pleocytosis and other abnormalities consistent with meningitis would be detected in CSF obtained in this second LP [52]. Ample number of erythrocytes in CSF may be interpreted as a clue to herpes simplex virus meningitis if the physician is sure that the LP was not traumatic. Pleocytosis is more marked in bacterial and Gram-negative meningitides than in viral and Gram-positive meningitides [6].

CSF protein concentrations higher than 100 mg/dL in term infants and 150 mg/dL in preterm neonates is consistent with bacterial meningitis and parameningeal infections, such as brain abscess, congenital infections, and intracranial hemorrhage [52]. Nigrovic et al. and Hines et al. found that CSF protein concentrations increased by approximately 1.1 and 2 mg/dL, respectively, for every 1000 CSF red blood cells [53, 54].

Glucose concentrations below 30 mg/dL in term newborns and 20 mg/dL in preterm infants are consistent with bacterial meningitis. Unlike in older children, CSF glucose to serum glucose ratio is not a reliable indicator of meningitis in the first 28 days of life, because newborns often receive intravenous glucose infusions and serum glucose concentrations can rise abruptly with stress [52]. In case of a bloody tap, assessing the CSF leucocyte count by correcting it with respect to that of the peripheral blood is not recommended in that it decreases the sensitivity and provides only a slight increase in specificity. When LP is traumatic, the wisest approach is to assume the patient is having meningitis and start empirical therapy [55]. Although no statistically significant difference in LP success rate was found between the lateral and sitting positions in infants in a randomized controlled trial, we, in order to lessen the chances of dealing with a difficult LP, favor sitting position with the legs flexed for it provides the widest interspinous spaces and is sufficiently safe [18, 28, 56].

12. Conclusion

Lumbar puncture of the newborn is not a smaller equivalent of the procedure performed in adults, even older children, as evidenced by its specific challenges of success and interpretation.

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