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REVIEW

Ultrasound guidance for difficult lumbar puncture in children: pearls and pitfalls

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Abstract Pediatric lumbar puncture can be challenging or unsuccessful for several reasons. At the same time, the excellent sonographic window into the pediatric spine provides a distinct opportunity for ultrasound-guided lumbar puncture. Minimal cerebrospinal fluid and thecal displacement by subdural or epidural hematomas are common after failed clinical attempts. Ultrasound is useful for determining a safe infraconal level for subarachnoid access. Real-time guidance increases not only the success rate but also the safety of diagnostic lumbar puncture and injections for chemotherapy and myelography. In this article, we discuss clinical and technical factors for ultrasound-guided pediatric lumbar puncture.

Keywords Cerebrospinal fluid · Interventional radiology · Lumbar puncture · Meningitis · Neonate · Subdural hematoma · Ultrasound

Introduction

Lumbar puncture (LP) in children is usually performed at the bedside in hospital wards or in the emergency department. Radiologic assistance is sought in difficult cases, including dry or bloody taps, anatomical variations and surgical hardware. A relative lack of experience with LPs by pediatric trainees, particularly in the infant, may also be contributary to an increased failure rate. Although fluoroscopy has long been the mainstay to assist interventional radiologists to position the spinal needle intrathecally, ultrasound-assisted LPs have been more recently described for surface marking of landmarks by ultrasound (US) prior to puncture [1, 2]. In adults this has been associated with a reduction in the number of attempts and interspaces accessed [2–5]. This technique has also been found to be useful in cases of challenging epidural access [5, 6]. In infants, the spinal canal lends itself to diagnostic evaluation by US because of the sonographic window through incompletely ossified spinous processes. The excellent visualization, lack of ionizing radiation and possibility for real-time guidance make US a useful tool for performing LPs and epidural catheter placement in children [7, 8]. There is, however, limited literature on this subject. In this review, we discuss clinical and technical factors for US-guided pediatric LP. We obtained institutional research ethics board clearance to use the relevant images.

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Failed lumbar puncture in the neonate

Most LPs in neonates are performed in the neonatal intensive care unit or the emergency department, with an assistant holding the baby in a flexed decubitus position. Traumatic or unsuccessful LPs in this group have been documented in the pediatric literature in 30–50% of patients [7, 9]. Difficulty is encountered in the irritable child or in the presence of meningismus, where excessive motion hinders procedural success. Dehydration, sometimes associated with sepsis, can be a factor in unsuccessful LPs in neonates. Some neonatologists recommend intravenous hydration prior to repeating a failed lumbar puncture, although a recent prospective study in neonates and infants found no significant increase in the diameter of the lumbar subarachnoid space with an intravenous fluid bolus prior to LP [10].

Real-time ultrasound-guided neonatal lumbar puncture

Ultrasound is used for the evaluation of spinal dysraphism and tethered cord in infants [11]. The cartilaginous spinous processes allow for excellent visualization of the spinal canal in infants up to 6 months and sometimes up to a year old. As such, ultrasound's utility in performing the procedure in a real-time fashion and its lack of ionizing radiation make it an attractive first-line option for image guidance. The procedure can be performed at bedside or in the interventional radiology suite. We perform LP in the neonate without general anesthesia or sedation, using oral sucrose and local anesthesia, with continuous monitoring. Like in adults, in whom prone or sitting positions are preferred [12], some studies have also considered these positions suitable in infants [13]. In our practice, the child is placed in a left lateral decubitus position with the hips and knees flexed. We do not flex the child's neck because this does not open up the interspinous spaces but rather can obstruct the infant airway [14, 15]. We use an atraumatic Quincke-tip 22-G spinal needle (Becton, Dickinson and Company, Franklin Lakes, NJ).

Before performing an LP, an initial sonogram is extremely useful in evaluating the spinal anatomy and delineating the cause of a failed LP. Normally the posterior dura is seen as a bright echogenic line deep to the more heterogeneous-appearing epidural fat (Fig. 1). The ligamentum flavum is also often seen as an echogenic stripe, superficial to the epidural fat. The nerve roots of the cauda equina can be seen with an undulating motion within the subarachnoid fluid. The position of the conus medullaris can be localized, and a level for access can be determined that is safe and ensures maximum success (Fig. 1). Although failed LPs are often a result of minimal subarachnoid cerebrospinal fluid (CSF) with crowding of the cauda equina (Fig. 1), epidural hematomas from prior attempts are also a frequent cause. In older children and in those with multiple prior LPs, subdural collections are not uncommon.

Ultrasound-guided lumbar puncture techniques and modifications

As mentioned, we perform neonatal LPs without sedation. In this age group, we perform LP most commonly in the sitting position. LP in older infants and young children is performed in the lateral decubitus position, under general anesthesia, whereas for older cooperative children, we prefer light sedation or local anesthesia. For LP in infants we use the 7- to 15-MHz linear-array hockey-stick-shape US transducer (Philips EPIQ7 Ultrasound, Bothell, WA). In the older child, a curvilinear transducer with a small footprint might be required for adequate sonopenetration, and for this we use a 5- to 8-MHz curvilinear transducer (Philips EPIQ7 Ultrasound, Bothell, WA). The transducer is held in the left hand and the needle in the right. Whereas the generous use of sterile ultrasound gel can enhance the sonographic window and is our preference in the calm or anesthetized child, in the moving child it can result in difficulty maintaining a static US image. In this situation we prefer to use normal saline as a coupling agent for scanning, trading some reduction in image clarity for procedural ease. We acquire axial and sagittal images prior to the procedure, which helps determine the best approach. Next we describe the common US techniques to access the intrathecal space for LP in children.

Transverse inter-laminar approach

In most neonates and in younger children with adequate sonopenetration of the spinal canal, we use the transverse interlaminar approach. A midline out-of-plane technique, scanning off the echo-bright needle tip, can be employed in straightforward cases with adequate cerebrospinal fluid and a distended thecal sac (Fig. 2). Most cases that require image guidance, however, have minimal cerebrospinal fluid within a collapsed thecal sac. Scanning in the interspinous space also limits the space available for needle insertion in the midline. We therefore prefer the transverse in-plane inter-laminar method (Fig. 2) for most cases. This also allows real-time targeting of pockets or thin strips of cerebrospinal fluid. The required angle of entry can be accommodated by sliding the transducer laterally from the midline away from the side of entry while angling toward the needle, which is advanced at approximately 45° and enters the spinal canal at the 1 to 2 o'clock position. Needle and probe positions for the transverse out-of-plane and in-plane approaches are shown in Fig. 2. Although the patient position on the left side means that access is usually through the right side, a left interlaminar approach, although more technically challenging, can be performed, if required, by positioning the transducer to the right of the midline with the right hand and advancing the spinal needle with the left hand. As an alternative, the child can be positioned in the sitting-flexed position [14], as discussed later.

Sagittal paramedian approach

This approach is useful in older infants and young children in whom the spinous processes are ossified and do not permit a clear window. After determining the midline using axial scanning (Appendix 1), a midline sagittal scan is performed by rotating the transducer 90° over the

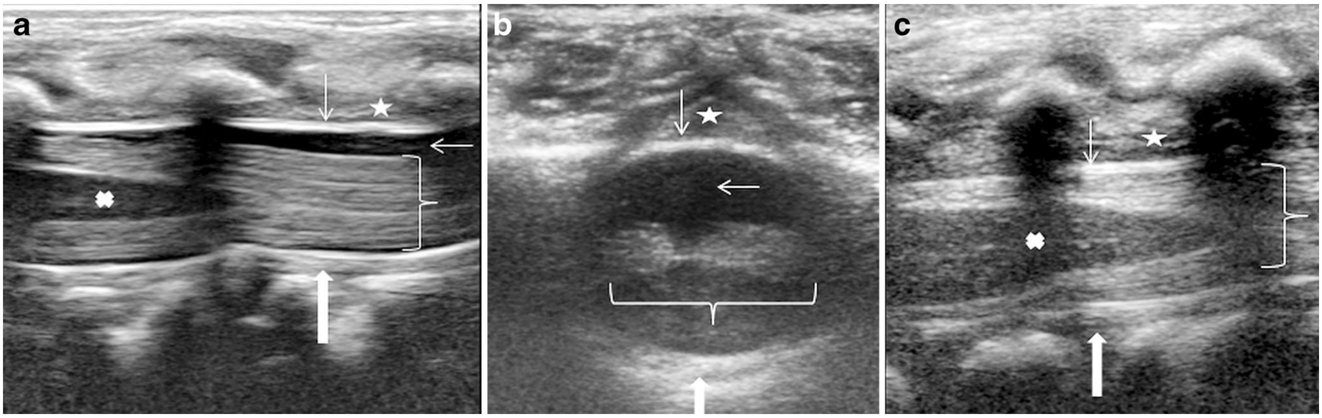

Fig. 1 Normal sonographic anatomy of the lumbar spinal canal in an infant. **a** Sagittal midline view of the lumbar spine in a 14-day-old boy shows the conus medullaris (*x*), cauda equina (*bracket*) within the subarachnoid cerebrospinal fluid (*horizontal arrow*), posterior dura-arachnoid (*vertical thin arrow*), epidural space (*star*), and anterior complex (*vertical thick arrow*) comprising the anterior dura, anterior epidural space, posterior longitudinal ligament and posterior edge of the vertebral body. **b** Axial section selected for lumbar puncture, at the level marked by the vertical arrows in (**a**), shows the same structures in cross-section. Note the nerve roots (*bracket*) lying in left and right bundles. **c** Sagittal midline view in a different boy, age 10 days, (structures marked as in **a**), shows crowded nerve roots of the cauda equina within a poorly distended thecal sac caused by minimal cerebrospinal fluid

spinous process. The transducer is then slid laterally, whence the ipsilateral laminae or facet joints are seen. At this stage, the transducer is angled toward the midline to visualize the inter-laminar space. Often the posterior dura can be identified as a

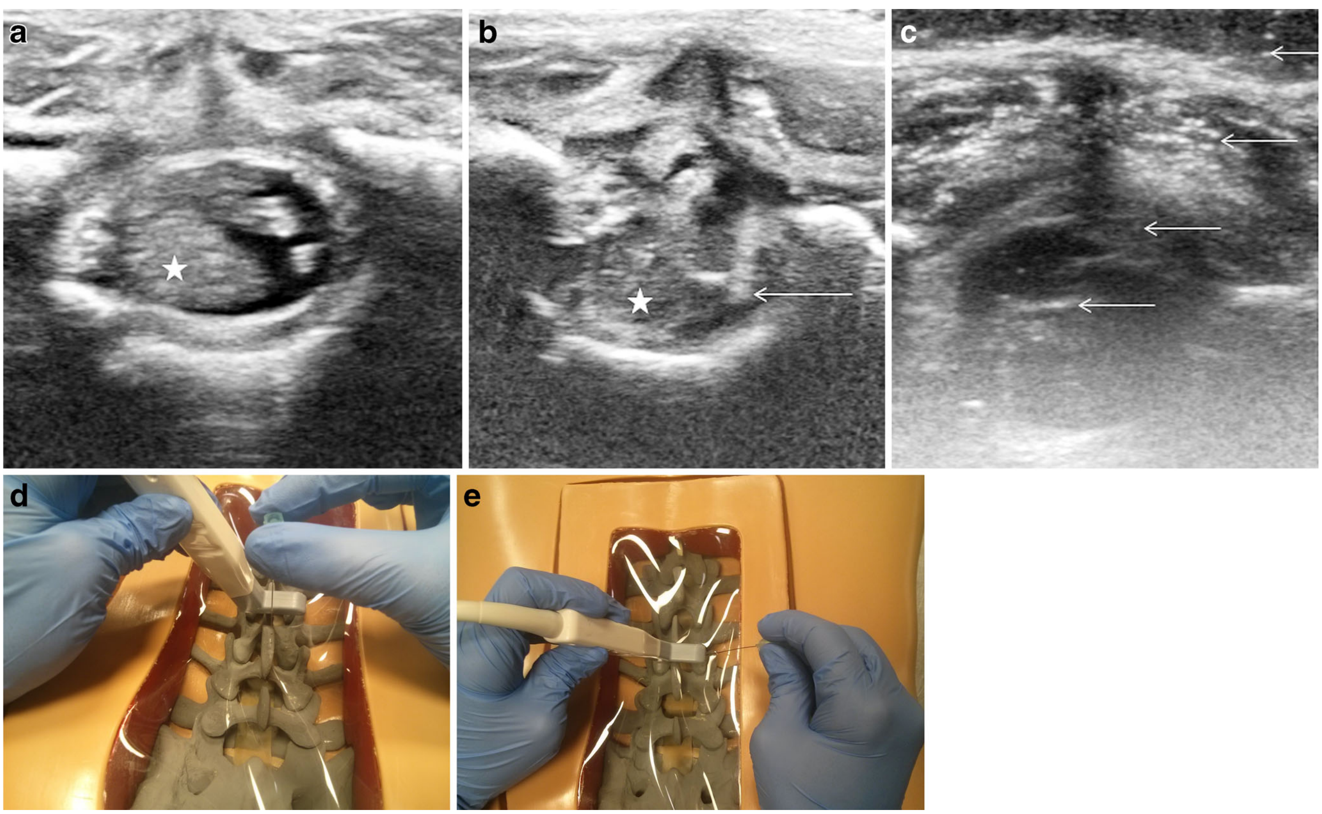

Fig. 2 Transverse inter-laminar approach to US-guided lumbar puncture in infants. **a** Axial US section at the third–fourth lumbar interspace in a 28-day-old girl shows an adequately distended thecal sac, the nerve roots (*star*) displaced toward the girl's dependent decubitus. **b** Out-of-plane access technique in a 2-month-old boy shows the needle tip (*arrow*) entering the subarachnoid space. Nerve roots (*star*) are avoided. **c** In-plane access technique in a 4-month-old girl shows the needle path from the skin, entering the thecal sac at approximately 45° at the 1–2 o'clock position. **d** Needle and probe position on a spine mannequin (Vertebroplasty trunk; Sawbones, Vashon Island, WA) shows the transverse out-of-plane approach to lumbar puncture. **e** Needle and probe position on a spine mannequin represent the transverse in-plane approach to lumbar puncture

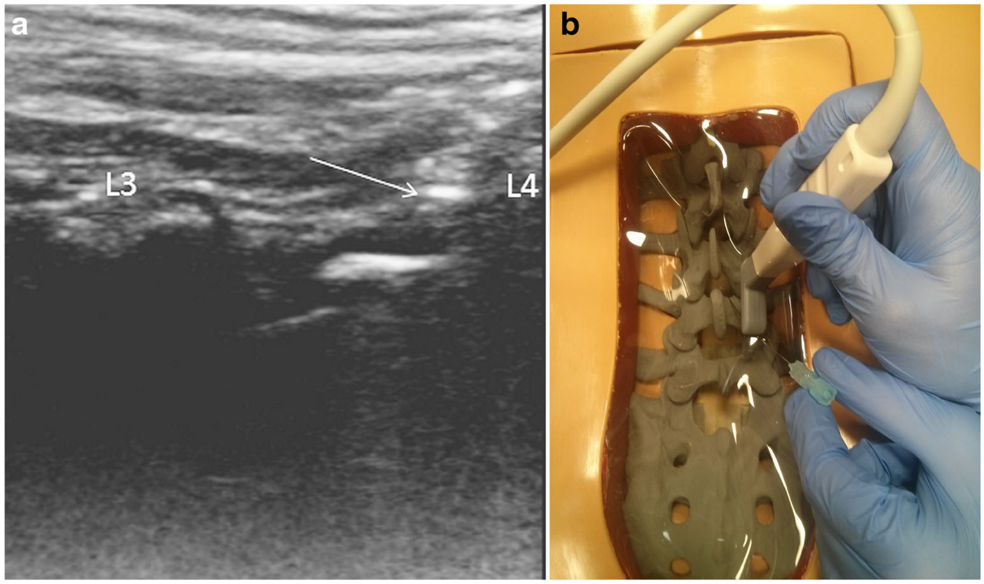

Fig. 3 Sagittal paramedian approach to US-guided lumbar puncture. a. Parasagittal oblique US image in a 5-year-old boy shows the laminae of L3 and L4, with the posterior dura seen as a bright echogenic stripe deep to the interlaminar space. The tip of the spinal needle can be seen as an echogenic dot (*arrow*) entering the skin at the L4 level, targeting the posterior dura at the L3–L4 interspace. **b** Needle and probe position on a spine mannequin represent the parasagittal oblique approach to lumbar puncture. Note that skin entry for this approach is at the next lower level

bright echogenic stripe deep to the interlaminar space and can be targeted with the needle entering the plane of the transducer, angled cranially from the subjacent vertebral level (Fig. 3).

Collapsed or compressed thecal sac

Minimal cerebrospinal fluid, or CSF displaced by epidural hematomas or fluid (Fig. 4), does not preclude obtaining a diagnostic sample. Sonographic determination of CSF pockets enables targeted sampling with the spinal needle (Fig. 4). Color Doppler can help to confirm large epidural veins, which can be mistaken for pockets of CSF (Fig. 4). In these cases we usually prefer the transverse in-plane orientation of the US probe (see Ultrasound-guided lumbar puncture techniques and modifications section) for accurate and safe needle positioning. A singular challenge encountered in the neonate is the elasticity of the arachnoid membrane, which can often be seen to buckle, rather than "give" to the needle tip, even after dural penetration (Fig. 5). This is more pronounced when the thecal sac is collapsed, resulting in poor distention with CSF. This is likely the reason for several seemingly dry CSF clinical taps in the neonate. Even a fluoroscopic appearance of appropriate needle position would be misleading because the arachnoid layer would have only been pushed forward and not actually traversed. In these cases real-time US can help in performing a controlled stab through the meninges rather than gradually advancing, without traumatizing the anterior epidural space or, even worse, the intervertebral disc (Fig. 5). This problem can also be overcome to some extent by using the early stylet-removal technique [16,

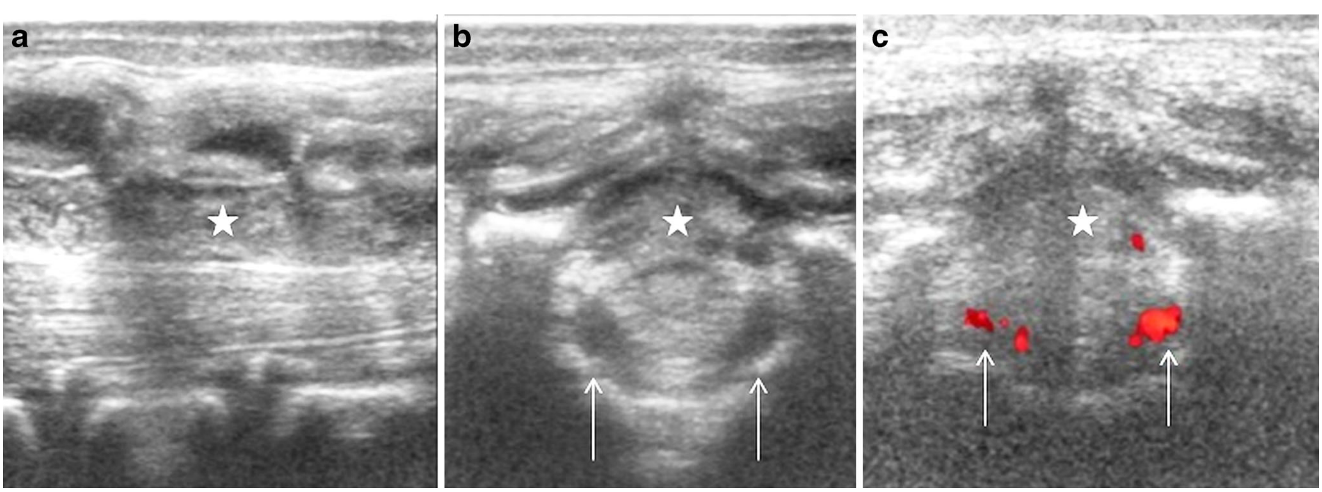

Fig. 4 Epidural hematoma in a 20-day-old girl after prior failed lumbar punctures in the neonatal intensive care unit. **a** Sagittal midline US image shows an echogenic hematoma (*star*). **b** Axial section at the L3–L4 level shows prominent epidural veins (*arrows*) on either side of the cauda equina. **c** This is confirmed with color Doppler flow (*arrows*), which is conspicuous because of compression from the hematoma

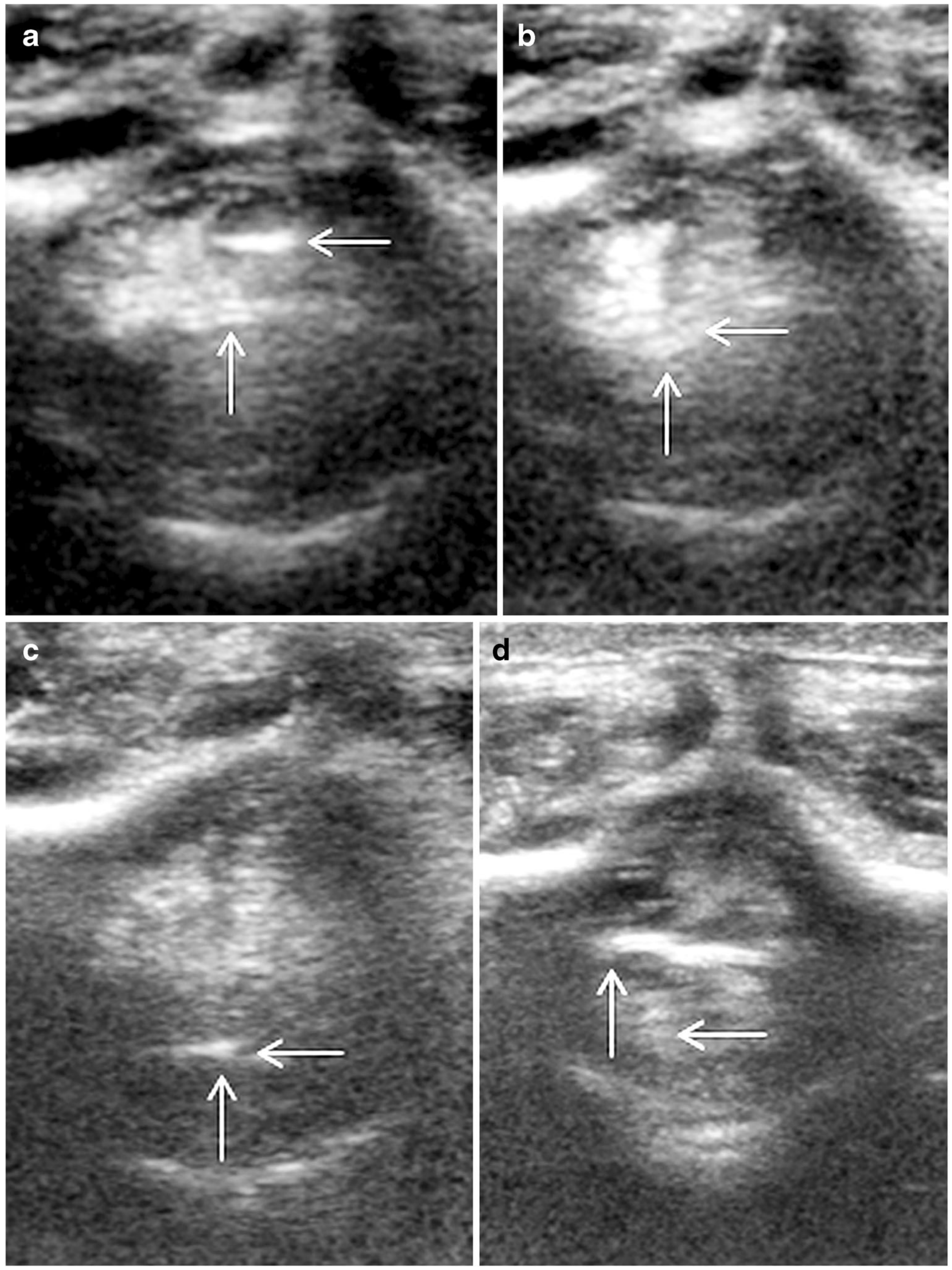

Fig. 5 Ultrasound-guided controlled dural-arachnoid puncture on axial US images in a 4-day-old boy with two failed clinical lumbar puncture attempts. **a** Needle tip (*horizontal arrows* in **a**–**d**) within a small subdural hematoma. The arachnoid membrane (*vertical arrows* in **a**–**d**) can be seen as a faint echogenic line displaced anteriorly by the hematoma. **b** Needle tip against the arachnoid membrane. **c** Note the anterior displacement of the arachnoid membrane with attempts to advance the needle tip. **d** A controlled jab is used to advance the needle past the elastic arachnoid membrane, which returns to its previous position after the needle tip is advanced into the subarachnoid space. The impression of increasing subdural blood during this process is caused by redistribution, as evidenced by the arachnoid membrane's return to its previous size after the subarachnoid space is accessed

17], ensuring stylet removal only after the epidermis and dermis are crossed. Smaller-gauge (24 G or 25 G) atraumatic needles can also penetrate the arachnoid membrane more successfully, with the caveat of poorer CSF drainage when fluid is minimal.

Subdural and epidural hematomas and collections

The relative elasticity — and possibly poorer adherence — of the arachnoid to the dura in children vs. adults can result in stripping of the arachnoid from the (relatively more rigid) dura during needle advancement, even when the dural pop is felt. This can result in a dry clinical tap because the needle tip is in the subdural space, not the subarachnoid space. Venous blood and CSF can subsequently accumulate in this subdural space. Subdural hematomas are characteristically echogenic and lenticular, compressing the subarachnoid space to varying degrees, displacing CSF from the lumbar subarachnoid space if large (Fig. 5 & 6). In the neonate they are self-limiting for the most part, and our practice is to attempt to access the subarachnoid space without traversing the largest part of the hematoma, or, if it is extensive with minimal stripe-like CSF space (Fig. 6), to defer the LP for 2–

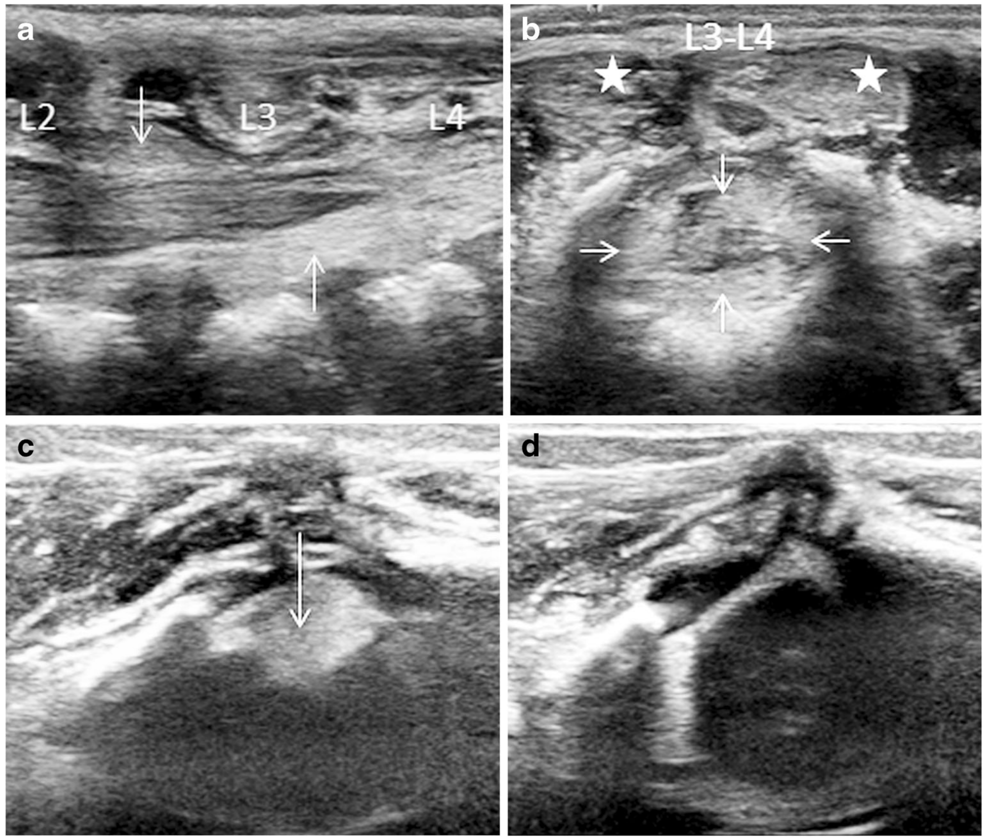

Fig. 6 Subdural and epidural hematomas. **a** Sagittal and (**b**) axial US scans of the lumbar spine in a 2-day-old girl with bloody taps in the intensive care unit show a large circumferential subdural hematoma (*arrows*). Paraspinal muscle hematomas are also seen (*stars*). In the absence of anticoagulation therapy, this should raise suspicion for coagulation disorders. **c**, **d** Axial US scans of the lumbar spine in a 10-day-old girl show a small focal epidural hematoma (*arrow*) at the (**c**) L2–L3 level but no significant hematoma at the (**d**) L3–L4 level, which was thus targeted for cerebrospinal fluid sampling under sonographic guidance

3 days and repeat a diagnostic sonogram prior to another LP to confirm resolution. In the case of smaller, more focal hematomas, US can be used to select a suitable level free from hematoma and inferior to the conus medullaris (Fig. 6). We have found that large compressive subdural collections in older children, usually in the setting of multiple chemotherapy sessions, take longer to resolve. We perform an MRI at least 2–3 weeks after an attempted LP to assess resolution before proceeding with further LPs.

Epidural hematomas resulting from needle injury of the very prominent epidural venous plexus [18] are more common than subdural collections, and can similarly displace the dura and make access challenging (Fig. 7). The differentiation of whether the collection is epidural or subdural is difficult by US, especially when the collection is large and compressive. At times, however, US can show large epidural veins coursing within the collection. MRI can more definitively characterize the location of the fluid as epidural or subdural. Indeed, we have seen both subdural and epidural collections on MRI after lumbar punctures. We have observed a needle positioned within a large subdural collection resulting in the appearance of free-flowing CSF. This can, however, result in inaccurate diagnostic test results, especially if the collection is multi-loculated or compartmentalized from the subarachnoid space (Fig. 7). In the population of children getting multiple lumbar punctures for intrathecal chemotherapy, either with clinical or fluoroscopic guidance, this can result in suboptimal therapy. In this regard, we have found real-time US to be very useful in guiding the needle past posterior collections and into the subarachnoid space (Fig. 7).

Ultrasound for intrathecal injection for myelography in infants

Lumbar puncture for CT myelography is performed in infants for assessing for birth-related nerve root injury. Although traditionally performed under fluoroscopy, LPs and contrast injection can be performed under real-time US guidance (Fig. 8). The contrast injection can be visualized as a stream of echogenicity, with progressive distension of the thecal sac (Fig. 8). The CT scout image can confirm adequacy of intrathecal filling at the cervical level (Fig. 8), the radiation dose of the scout image being negligible in comparison to the radiation dose of the CT images, and this avoids the need to irradiate the pelvis with fluoroscopy. Similarly, intrathecal injections for chemotherapy for acute lymphoblastic leukemia can be performed under direct sonographic visualization.

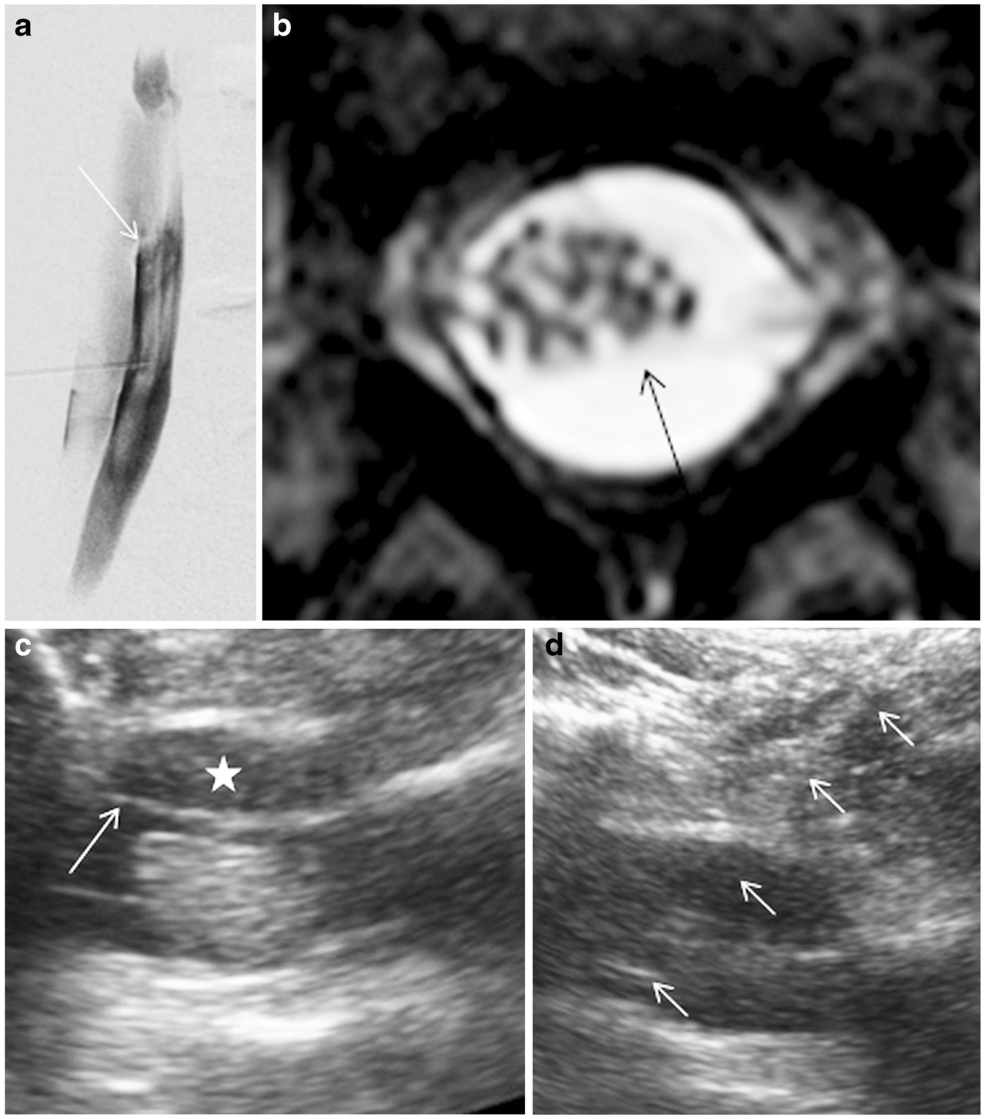

Fig. 7 Multiple lumbar punctures for intrathecal chemotherapy in a 4-year-old boy. **a** Myelography performed as a result of reduced cerebrospinal fluid flow after fluoroscopically guided lumbar puncture shows a large arachnoid tear (*arrow*) at the L2–L3 level with a sizeable posterior subdural collection. **b** Axial T2-W FIESTA (fast imaging employing steady-state acquisition) MR image at the L3–L4 level shows a loculated subdural fluid displacing the cauda anterolaterally. *Arrow* shows the anteriorly displaced arachnoid membrane. **c** Axial US image at the same level shows the posterior subdural collection (*star*) and arachnoid membrane (*arrow*). **d** The subarachnoid space is targeted using the transverse inter-laminar in-plane technique. *Arrows* delineate the needle trajectory

Neonatal ultrasound-guided lumbar puncture in the sitting position

Neonatal LPs are often performed in the sitting position — this has been shown to maximally widen the lumbar interspinous distance [12]. This position also allows for ease of probe manipulation when using US guidance. The awake neonate is often most comfortable being held over the shoulder, a position that mimics the sitting position and allows the US operator easy access. Although there is literature to suggest that there is no difference in the diameter of the thecal sac between the sitting and lying positions [19], we think the sitting position favors thecal distension and increased hydrostatic CSF pressure for effective needle penetration, especially in the presence of small hematomas. In our experience, however, this is not adequate for large compressive hematomas, and we prefer to defer these as previously discussed.

Older children

Although in older infants and young children the spinous processes are ossified, there is often an adequate window using either a sagittal paramedian oblique or sagittal midline approach. We prefer to use a 5- to 8-MHz curvilinear-array transducer, which allows sonographic penetration into the spinal canal. The conus medullaris can often be visualized in thin children, even up to the age of 10 years [20]. In older or obese children the parasagittal oblique window is ideal for scanning the inter-laminar spaces. As an alternative, or when the acoustic window is poor, the same land-marking technique can be used as in adults. Our land-marking technique is described in Appendix 1. In our practice, we prefer to use fluoroscopic guidance in children older than 5 years, in children younger than 5 years when there is a poor sono-window past the posterior dura, when opening pressure has to be measured (to

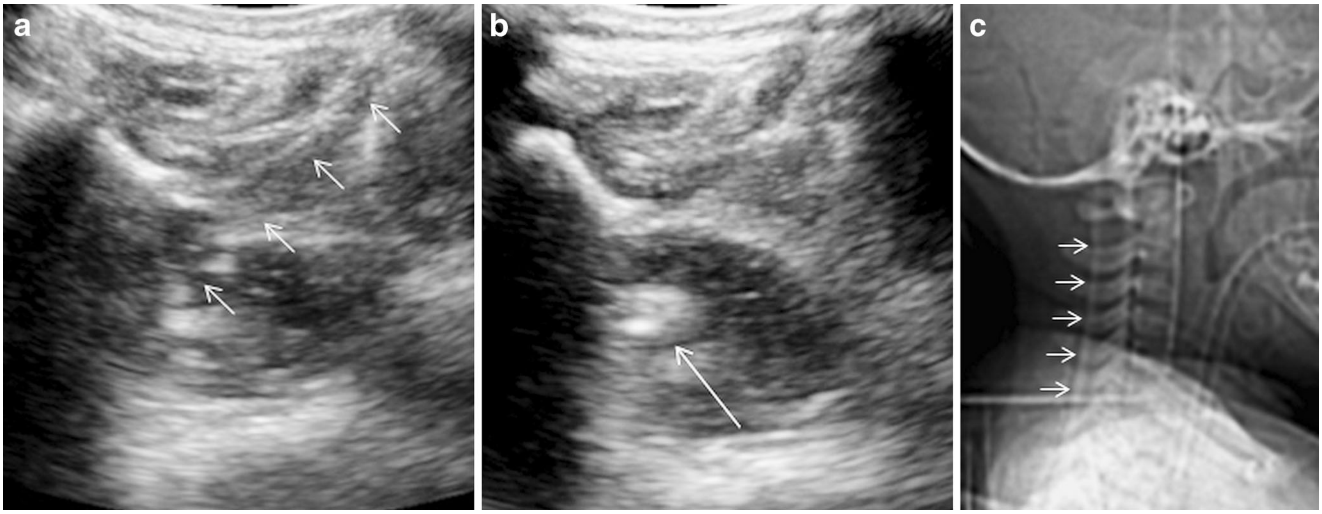

Fig. 8 Ultrasound-guided intrathecal injection for CT myelography in a 9-month-old boy. **a** Axial US image at the L3–L4 level shows the spinal needle (*arrows*) within the subarachnoid space. **b** Contrast injection is seen as an echogenic stream (*arrow*) from the needle tip. Note the interval distention of the thecal sac from the injection. **c** Scout image from subsequent CT confirms contrast agent filling the cervical subarachnoid space (*arrows*)

maintain midline access into the spinal canal) and in the presence of surgical hardware.

Ultrasound for epidural catheter placement in children

Epidural catheter placements are largely performed by anesthetists using the loss-of-resistance technique. In this technique, a syringe with 2–5 ml of air is gradually advanced into the interspinous space, with manual pressure maintained on the syringe plunger. Entry into the epidural space is identified by a sudden loss to the counter-resistance felt on the plunger up to the ligamentum flavum. Ultrasound can be used for land-marking the site and angle of entry, for measuring the distance to the epidural space in challenging cases, for thoracic epidural access, and for real-time guidance in caudal epidural access [11, 21]. However we prefer a combination of fluoroscopy and the loss-of-resistance technique to prevent inadvertent dural transgression and to obtain a contrast epidurogram if necessary.

Conclusion

The sonographic window to the lumbar spine in infants provides a distinct opportunity for performing lumbar punctures in this population. The advantages, including absence of ionizing radiation, identifying causes of a dry clinical tap, and targeted sampling of CSF pockets make this an attractive choice in terms of safety and procedural success. Whereas the land-marking technique of US-assisted lumbar puncture can be performed in older children, similar to adults, in most infants and younger children one can perform a true real-time US-guided procedure. We have discussed technical nuances and procedural tips that result in reduced radiation burden and improved success rates for difficult lumbar punctures in children.

Compliance with ethical standards

Conflicts of interest None

Appendix 1 Land-marking technique for lumbar puncture using ultrasound

- Patient is positioned in left lateral decubitus, flexed at hip and knee.
- Sagittal ultrasound image is obtained to identify upper sacral margin (S1).
- Ultrasound probe is moved cephalad to identify L3 and L4 vertebral body levels, which are marked by horizontal lines on the skin on either side of the probe.
- Axial ultrasound scanning is performed to identify the midline (spinous process) at the L3 and L4 levels, and is marked by vertical lines on the skin to transect the previously marked horizontal lines.
- Axial scanning is performed on the midline (vertical line) in the interspinous space (between the two horizontal lines) with gradual cephalad angulation of the transducer to obtain a clear view of the ligamentum flavum–posterior dura echogenicity. This transducer angle is eyeballed to determine the angle of needle entry.
- Measurement of skin-to-posterior-dura distance is obtained in the last axial image.
- Skin preparation and sterile draping are conducted.

- The spinal needle is introduced into the L3–L4 interspace on the previously marked vertical line, along the predetermined angle.

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