Mechanistic Evaluation of the Dural Puncture Epidural in a Porcine Model

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Abstract

Background
The dural puncture epidural (DPE) technique involves placing a 17G Weiss needle in the epidural space, introducing a 25G Whitacre needle via the Weiss needle to puncture the dural sac, and threading a catheter into the epidural space. All medications are dosed through the epidural catheter.[1] Compared to a conventional epidural (EPL) technique, the DPE has faster onset, greater bilateral and sacral coverage, fewer top-up requests, with no difference in rates of maternal hypotension, fetal bradycardia, high sensory block, or post-dural puncture headache.[1-4] As radiographic evaluation of neuraxial techniques is limited to EPL techniques,[5, 6] we conducted a fluoroscopy and necropsy porcine study to elucidate the mechanism, spread and distribution of EPL, DPE, and combined-spinal epidural (CSE) techniques.

Methods
Following approval by our Animal Care and Use Committee, four 60 kg Yorkshire female pigs were sedated, intubated, and maintained with isoflurane in oxygen. Placed in the left lateral decubitus position, each pig had an attempted EPL, DPE, or CSE technique by a single operator at lumbar, low thoracic, or mid thoracic levels using a loss-of-resistance to air technique and fluoroscopy. Radio-opaque contrast (1 mL) was administered via the EPL catheter at 0, 45, 90, 135, and 180 min. Spread was assessed with fluoroscopy during injections. Dye (1 mL) was administered via the EPL catheter at 3 or 6 hours, the animals euthanized, and necropsy performed to assess dye distribution.

Results
Ten experiments were conducted—consisting of EPL, DPE and CSE techniques, an inadvertent 17G dural puncture and a subcutaneous catheter placement. Fluoroscopic images demonstrated greatest to least segmental spread with CSE > DPE > EPL techniques throughout the 3-hr study period. Dye distribution was distinct to each technique (Table 1): With an EPL, dye was visualized only in the epidural space; DPE dye was visualized in both the epidural and subarachnoid spaces, though less than with a CSE at both 3 and 6 hrs.

Conclusion
Our findings explain the clinical characteristics of the DPE technique: Dural sac puncture allows medication translocation from epidural to subarachnoid spaces for at least 6 hrs. This mechanistic understanding of the DPE, CSE, and EPL techniques offers insight into the procedural elements that ultimately contribute to the ideal neuraxial technique: one that provides rapid onset, reliable spread and quality, and titratable depth and duration, while balancing the risks of less desirable maternal and fetal outcomes.

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Glossary of Abbreviations

DPE – Dural Puncture Epidural
EPL – Conventional Epidural
CSE – Combined-Spinal Epidural

Introduction

Mothers in labor have a wide range of options available to them for analgesia. These options include neuraxial anesthesia and, in the case of cesarean section, general anesthesia. Neuraxial techniques of obstetric anesthesia work by directly exposing spinal nerves to local anesthetics, usually administered through a catheter located in the epidural or, occasionally, spinal space. A novel technique for neuraxial anesthesia, the dural puncture epidural (DPE), was developed at Brigham and Women's Hospital in 2007. In a standard epidural anesthetic, a 17G Weiss needle is introduced into the epidural space and a catheter is threaded. The dural sac and spinal spaces are intentionally avoided. In a DPE, the 17G Weiss needle is introduced into the epidural space and then a 25G Whitacre needle is advanced through the Weiss needle to make an intentional puncture in the dural sac. A catheter is subsequently threaded into the epidural space and local anesthetics are administered through this epidural catheter.[1]

Background

The DPE is an accepted alternative to the traditional epidural in modern practice. This clinical adoption has been supported by evidence showing faster onset of anesthesia, decreased anesthetic asymmetry and improved sacral coverage compared to traditional epidurals[2]. It is suspected that direct translocation of local anesthetic from the epidural space through the intentional dural puncture and into the spinal space in the DPE is responsible for these clinical differences Though this explanation is compelling, it has not been directly observed. In this study, we aim to characterize the presence, magnitude, distribution and timing of translocation of injected agents between the epidural and spinal spaces following a DPE in a porcine model.

It is important to understand the mechanism behind the clinical differences observed in the DPE and epidural techniques. Observed mechanistic differences between the DPE and epidural techniques will lend further support to the clinical evidence supporting the use of DPEs. It is also important to understand whether timing of administration of anesthetic relative to the creation of the dural puncture affects this proposed mechanism. Finally, understanding the distribution of anesthetic along the cephalo-caudal axis in the DPE compared to other techniques may inform safety considerations and the ability to maximize efficacy while preventing unwanted side effects.

The observation of the mechanism of the DPE is best performed in an animal model. Fluoroscopic visualization of an administered contrast agent is not feasible in humans. An animal model also affords the ability to perform a necropsy, which may coordinate imaging with anatomic findings. Previous studies[3,7] have described the porcine model as a reasonable proxy for the study of epidural anesthetic mechanics, and have demonstrated epidural (L2-3, L3-4) and spinal (L4-5) needle placement with 17G and 22G needles, respectively, in juvenile anesthetized pigs (20-25 kg)[8].

Student Role

My role in this study has been multifaceted and comprehensive. Before the study began, I created the necessary data collection forms and compiled the necessary materials at the study site. I also developed the necropsy dissection protocol.

I participated in each of the four days of experiments. In preparing the animals for the experiment, I delivered a temporary intramuscular anesthetic consisting of telazole and xylazine. Once the animal was sedated, I transported them to the preparatory room alongside the animal imaging suite where the experiments took place. I intubated the pigs, connected them to the anesthesia machine and prepared their back for the DPE to be performed. Once the animals were prepared, I transported the animals into the imaging suite and positioned them in the left lateral decubitus position on the C-arm table. I placed central lines in the internal jugular veins of the animals to ensure sufficient venous access throughout the experiments. I palpated anatomic landmarks and labeled the sites where the neuraxial techniques would be performed. I operated the C-arm to confirm these anatomic landmarks.

Once the animals were properly positioned, landmarked, labelled and venous access was ensured, I assisted with each of the DPE techniques. I guided or confirmed our techniques using the C-arm. Once the location of the catheter was confirmed, I operated the C-arm to record all injections of the radio-opaque contrast. After all of the images were taken, I administered a 1cc bolus of colored dye into the epidural catheters in preparation for necropsy of the animals. I assisted with the administration of the euthanasia cocktail. I assisted in confirming death of the animals. Once death was confirmed, I repositioned the animals in anticipation for necropsy. I led the dissection of each animal and subsequent photo-documentation.

After the experiments were complete, I developed the database that connected each image to its specific step in the experiment. I reformatted and coded each of the 200+ images to reflect each step in the experiment in a way that would be descriptive but prevent bias from the reviewing neuroradiologists.

I am currently working on constructing the manuscript for our work to be published soon.

Methods

This study was approved by the BWH Institutional Animal Care and Use Committee. Four 60 kg Yorkshire female pigs were sedated, intubated, and maintained with isoflurane in oxygen. The animals were placed in the left lateral decubitus position and the spinous processes were identified and marked at three levels (lumbar, L3-4; thoracic, T10-11; and mid-thoracic, T5-6). Each pig had an attempted EPL, DPE, or CSE technique by a single operator at lumbar, low thoracic, or mid thoracic levels using a loss-of-resistance to air technique with a 17G 90 mm Touhy needle (Braun Medical inc, Bethlehem PA, USA) and a 25G, 112 mm Whitacre needle (Arrow) as needed. After the 112 mm Whitacre needle was placed, 15 minutes were given to allow for spontaneous return of CSF to confirm successful DPE/CSE. If CSF did not return, the technique was considered an EPL. Radio-opaque contrast (1 mL) was administered via the EPL catheter at 0, 45, 90, 135, and 180 minutes following technique confirmation. Images were taken and recorded using a GE OEC 9800 fluoroscopic C-arm to determine cephalo-caudal spread and

epidural-spinal translocation. Following completion of the contrast studies, dye (1 mL) was administered via the EPL catheter at 3 or 6 hrs. The animals were euthanized, and necropsy performed to assess dye distribution. Images were presented for review to neuroradiologists who were blinded to the technique of each experiment.

Results

Ten experiments were conducted, consisting of 5 EPL, 2 DPE and 1 CSE technique as well as an inadvertent 17G dural puncture and subcutaneous catheter placement. Fluoroscopic images demonstrated greatest to least cephalo-caudal spread with CSE > DPE > EPL techniques throughout the 3-hr study period. Dye injection and subsequent necropsy was completed on four of the five study animals. Dye distribution was distinct to each technique (Table 1). With an EPL, dye was visualized only in the epidural space. With a DPE, dye was visualized in both the epidural and spinal spaces, though less than with a CSE at both three and six hours.

The fluoroscopic images are still under review by our neuroradiology collaborators. However, their preliminary impressions of the images are positive and suggest a distinct difference in appearance between each of the techniques. This report will be updated once the review of all of the images is complete.

Discussion, Limitations, Conclusions, and Suggestions for Future Work

In this study, we characterized the presence, magnitude and distribution and timing of translocation of injected agents between the epidural and spinal spaces following a DPE in a porcine model. The dye and necropsy experiments demonstrate that injected agents do translocate from the epidural to subarachnoid spaces following a DPE. These experiments also demonstrated that there is a difference in cephalo-caudal spread between the CSE, DPE and EPL techniques (CSE > DPE > EPL). Preliminary review of the imaging experiments demonstrates a distinct difference in fluoroscopically visualized contrast translocation between these techniques as well. Further review of the images will allow for comment on whether the magnitude of this translocation is altered by time elapsed following the dural puncture. Overall, these results support the hypothesis that the clinical differences demonstrated by the DPE relative to the EPL are due to translocation of local anesthetic from the epidural to subarachnoid spaces.

There were several limitations to this study. Most obviously, having incomplete evaluation of the imaging weakens the conclusions that can be drawn from that portion of the study. This will soon be remedied by an update following the completion of the review of images. Additionally, the two successfully confirmed DPE techniques were fewer than the four that we had anticipated. To our knowledge, we are the first to perform the DPE technique in a porcine model. This technique challenging, as identification of a DPE requires flow of CSF from the spinal space through the 22G needle used to puncture the dural sac. Our techniques were difficult to confirm given that these animals have less CSF within the subarachnoid space than humans, raising the possibility of false negatives. Finally, the spread of agents along the cephalo-caudal axis of the epidural space in Yorkshire pigs is known to differ from humans and therefore these cephalo-caudal spread patterns may differ from what would be observed in humans.

This study brings forward several interesting questions which can be investigated with future work. In this study, dye was injected into the epidural space at three and six hours following dural puncture, both of which showed evidence of dye translocation. It would be interesting to continue increasing this time interval in an effort to identify whether there is an elapsed time at which translocation discontinues.

Acknowledgements

My participation in this study was one of the best parts of my medical school experience, and I owe that to the thoughtful, inclusive and supportive attitudes of Dr. Tsen and Dr. Taha. My ability to mentor, teach and inspire other learners within the field of anesthesia will benefit tremendously from watching them so masterfully perform those skills for me.

References

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Tables and Figures

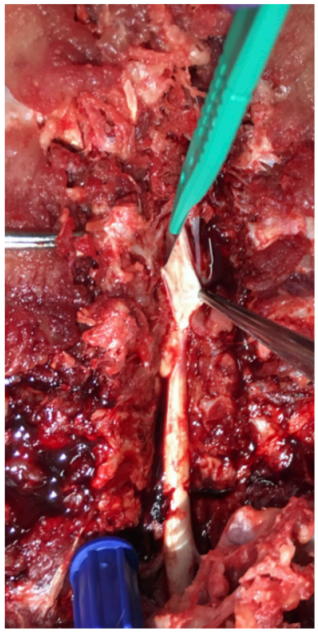
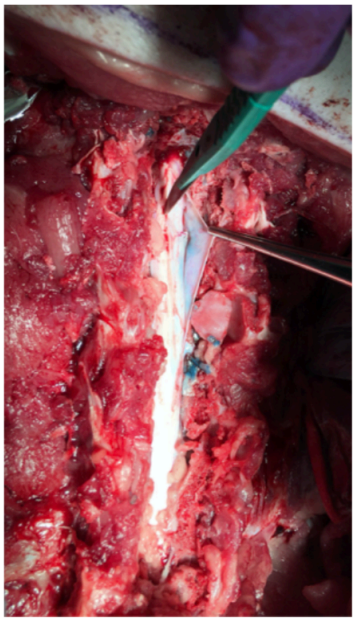
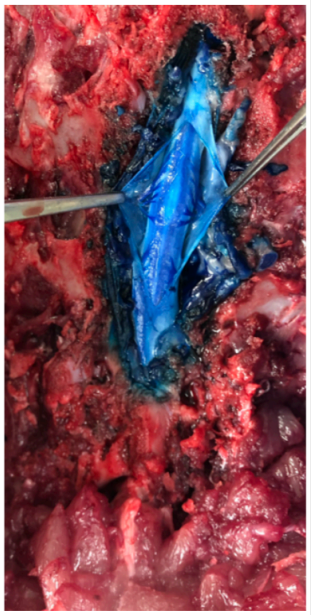
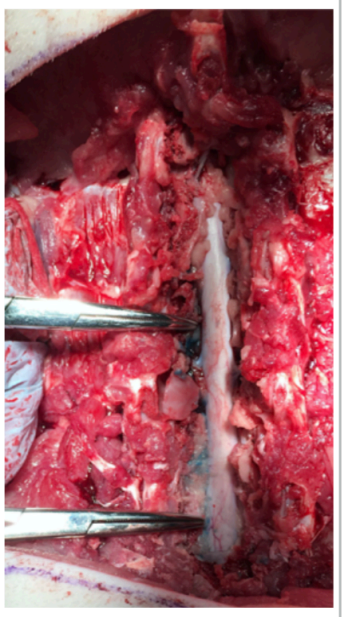
	EPL	DPE	CSE	Inadvertent Dural Puncture
Necropsy				
Dye Epidural	+	+	+	+
Dye Intrathecal	-	+	++	++

Table 1. Necropsy dye distribution, spread, and magnitude for epidural (EPL), dural puncture epidural (DPE), combined spinal epidural (CSE), and inadvertent dural puncture epidural techniques.