Percutaneous intraspinal navigation for access to the subarachnoid space: use of another natural conduit for neurosurgical procedures

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Object. The purpose of this paper was to demonstrate the usefulness of various fiberoptic endoscopes for percutaneous intraspinal navigation of the spinal canal, posterior fossa, and ventricular system.

Methods. Fresh, unembalmed cadavers were used, in which lumbar punctures were made for access to the subarachnoid space (in the case of larger [3.8- and 5-mm-diameter] endoscopes, small laminotomies were performed). Static and video images of pertinent structures were acquired for comparison among devices. Endoscopes were compared for their maneuverability, durability, field of view, and image quality. Seven sizes and types of endoscopes were considered.

Overall, the devices offering a tip deflecting mechanism were superior in maneuverability. Endoscopes in which a charged couple display chip was used at the tip of the scope for image acquisition offered improved image quality and field of view. Larger scopes, although more durable, were more rigid and may be limited in application. Multiple images from multiple devices are presented.

Conclusions. Percutaneous intraspinal navigation offers a promising neurosurgical approach to the spinal canal, the posterior fossa, and the ventricular system. Concerns regarding safety, management of complications, and the lack of adjunctive tools for intervention through the endoscopes or for use under fluoroscopic guidance represent areas that warrant further investigation and development.

KEY WORDS • percutaneous intraspinal navigation • endoscopy

Percutaneous intraspinal navigation refers to use of the subarachnoid space for navigation of the central nervous system from the spine to the intracranial compartments. We have described our experience with this technique in a canine model for creation of spinal cord injury with angioplasty balloons. We have also described navigation in human cadavers in which fluoroscopic guidance from a lumbar puncture into the cerebral subarachnoid space and the ventricular system is used, with magnetic resonance guidance to demonstrate the relationships between the apparatus and the cerebral structures during navigation, and with fiberoptic endoscopy to provide direct visualization of neural structures through catheters inserted with the aid of fluoroscopic guidance, or with more sophisticated, maneuverable endoscopes such as commercially available pediatric bronchoscopes (unpublished data; presentations at the 2004 and 2005 American Society of Neuroradiology annual meetings). Additionally, experimental fourth ventricular catheterization and third ventricular fenestration have been described in other cadaver studies. In this paper we discuss technical considerations and concerns regarding implementation of these techniques with currently available technology, based on our experience with 20 fresh human cadavers.

MATERIALS AND METHODS

Twenty fresh human cadavers (unselected as to age or sex) were acquired through the Willed Body Program at The University of Texas Southwestern Medical School. Each cadaver underwent fluoroscopically guided lumbar puncture at various levels by using either an arterial micro-puncture needle (luminal diameter 0.018 in) or a standard arterial puncture needle (luminal diameter 0.038 in). After needle placement in the subarachnoid space, a guidewire was introduced. Arterial dilation catheters were placed over the wire to dilate a tract through the soft tissues and dura mater to permit introduction of an arterial sheath. The sheath size was selected to accommodate the catheter or endoscopic system that was to be introduced. In some cadavers, navigation was performed using only a catheter/guide wire system with either fluoroscopic or magnetic resonance guidance. In approximately 10 cadavers, endoscopy was performed.
In the case of endoscopes measuring more than 3 mm in diameter (one measured 3.8 mm and another measured 5 mm, both provided by Olympus Optical Co., Tokyo, Japan) small laminotomies were made because the bone did not permit simple percutaneous introduction. Endoscopes in which optical fibers are used to transmit images to a digital acquisition device are called “fiberscopes,” and endoscopes in which a charged couple display chip on the tip of the scope is used for direct digital acquisition are labeled “videoscopes.”

Following introduction of a sheath through the lumbar region, a room-temperature saline flush was connected to the side port of the sheath, both for lubrication purposes and to use the hydraulic pressure for gentle inflation of the subarachnoid space. The pressure was regulated by raising or lowering the pole holding the intravenous saline drip.

Endoscope structure dictated the means of introduction. In the case of the simple fiberoptic scope (1-mm diameter; Olympus Optical Co.), the scope could not be advanced without a conduit. Also, it had no tip deflection capability and therefore could not be independently maneuvered. Thus, an angiographic introducer catheter with a slight curve on its tip (2-mm outer diameter) was used. The catheter was advanced over a soft, hydrophilic, 0.035-in angiographic guidewire (Glidewire; Boston Scientific Corp., Natick, MA) into the sheath. Under fluoroscopic guidance, the guidewire and catheter were advanced into the spinal subarachnoid space and could be easily advanced either anterior or posterior to the spinal cord to the level of the foramen magnum. In the anterior space, advancement into the preoptic cistern, cerebellopontine angle, and interpeduncular cistern was achieved. The intermammillary space was identified and puncture of the floor of the third ventricle was accomplished using the endoscope as the puncturing apparatus. The endoscope was advanced into the third ventricle, where the choroid plexus was identified, and the catheter was advanced over the fiberoptic scope as though the scope was a guidewire. The foramen of Monro was identified and the endoscope and catheter were advanced into the frontal horn of the lateral ventricle. Contrast material was injected and ventriculography was performed to confirm placement. The catheter and scope were then withdrawn and the spinal cord was visualized along its length during withdrawal. No injuries to the spinal cord or brain structures were observed during the procedure, although this device’s field of view was severely limited (Fig. 1).

Endoscopes used included a 1-mm rigid fiberoptic endoscope (Olympus Optical Co.); a No. 7 French straight scope containing a 1-mm rigid fiberoptic imaging apparatus and a working lumen (Myeloscope; Aesculap, Tuttingen, Germany); and a 2.5-mm scope with a tip-deflecting steering apparatus, a 1-mm fiberoptic imaging apparatus, and a working lumen (Storz and Co., Tuttingen, Germany). Also, various models of tip-deflecting scopes, each with a working lumen, were provided by Olympus Optical Co. for the trial in cadavers, and included a 2.8-mm fiberscope, a 2.8-mm videoscope marketed as a pediatric bronchoscope, a 3.8-mm videoscope, and a prototype 5-mm videoscope. Selected images from these studies are included in this report.

Endoscopes were evaluated based on maneuverability, durability, field of view, and image quality. Subjective grades of 1 (poor) to 3 (good) were assigned to each scope for each parameter.

**RESULTS**

Navigation of the subarachnoid space was achieved with each endoscope. With the 1-mm fiberscope, navigation involved placement of a catheter with the aid of fluoroscopic guidance, followed by introduction of the endoscope. In all other scopes, a working lumen was present in the device and a guidewire was introduced via that port, and naviga-

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Fig. 1. A: Cranial nerve with adjacent vessel seen through a 1-mm straight fiberscope introduced via an angiographic catheter. Identification of anatomical structures is significantly limited because of the small field of view and difficulty visualizing relationships to adjacent structures. B: View within the third ventricle with a 1-mm straight fiberscope, looking through the foramen of Monro and showing the choroid plexus (C).
tion was achieved using both direct visualization and fluoroscopy. With each scope, the spinal cord, part or all of the distal vertebral and basilar arteries, brainstem, multiple cranial nerves, and the third and lateral ventricles (via third ventricular fenestration) were visualized. Selected images of these structures viewed with different scopes are shown (Figs. 1–6).

Results of the grading of the scopes are shown in Table 1. Overall, the 1-mm fiberscope was judged inadequate on all criteria. Each of the tip-deflecting scopes measuring 2.5 mm and larger demonstrated adequate maneuverability, field of view, and image quality. Nevertheless, the larger (3.8- and 5-mm) videoscopes were superior in both the field of view and image quality, although the larger size also caused the scopes to be stiffer.

**DISCUSSION**

Many advances in neurosurgery have been greeted with understandable skepticism about the safety of the technique and the surgeon’s ability to manage intraprocedural difficulties. Unquestionably, concerns about the safety of navigation in the subarachnoid space, both in terms of the effect on adjacent neural structures and in terms of the potential for vascular injury still have to be addressed in patients. Nevertheless, the advantages of a minimally invasive approach, visualization of the subarachnoid space without surgical distortion due to retraction, potential for access without cranial nerve injuries, and the potential for the use of the technique not only for therapeutic but also for diagnostic purposes warrant further exploration.

Direct access to the spinal cord under combined visual and fluoroscopic guidance may enable percutaneous ap-
proaches to syringomyelia, traumatic injury, or implantation of materials for radiation therapy. As reported by Horowitz, et al.,\textsuperscript{1} third ventricular fenestration via this route may enable treatment of noncommunicating hydrocephalus without violation of the corpus callosum to drain the third ventricle. Many vascular structures and cranial nerves in the posterior fossa are accessible without craniotomy.

Identification of animal models in which to perform this procedure is difficult in light of the sizes of the available scopes. No available primate species is amenable. Larger canine models may have some applicability, and our preliminary data obtained from angioplasty balloons inflated adjacent to the spinal cord indicate that spinal canal occlusion less than 30\% is tolerated without spinal cord injury.\textsuperscript{3} In a human whose circular canal has a diameter of 1 cm, this would imply tolerance of an endoscope that is 5.4 mm in diameter. Although this size would likely be unacceptably stiff and its introduction potentially traumatic, even though the degree of spinal cord compression might be tolerated, this information indicates that at sizes less than 3 mm in diameter, currently available endoscopes are potentially viable in size.

TABLE 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fiberscopes 1-mm</th>
<th>2.3-mm†</th>
<th>2.5 &amp; 2.8-mm</th>
<th>2.8-, 3.8-, &amp; 5-mm</th>
</tr>
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<tr>
<td>steerability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>durability</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3 (2.8-mm)</td>
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<tr>
<td>field of view</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>image quality</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
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</table>

* Overall, seven endoscopes were tested; both the 2.5- and the 2.8-mm fiberscopes as well as all of the videoscopes had tip-deflecting mechanisms, which contributed significantly to steerability. The myeloscope had a lumen that permitted guidewire introduction, but did not have tip deflection. Scores: 1 = poor; 2 = intermediate; 3 = good.
† Myeloscope.

CONCLUSIONS

Percutaneous intraspinal navigation represents a promising and potentially revolutionary neurosurgical approach to the spinal canal, the posterior fossa, and the ventricular system. Significant concerns regarding safety, management of complications, and the lack of adjunctive tools for intervention through the endoscopes or for use under fluoroscopic guidance represent areas that warrant further investigation and development.
References


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