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Technical Note

Percutaneous Intraspinal Navigation: Feasibility Study of a New and Minimally Invasive Approach to the Spinal Cord and Brain in Cadavers

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Summary: We describe a percutaneous approach for cerebral surgical access. After lumbar puncture, the spinal subarachnoid space was traversed by using standard angiographic guidewire techniques until the introducer catheters were in the intracranial space. Under fluoroscopic guidance, the intracranial subarachnoid space was navigated, and the ventricular system entered. Subarachnoid placement was confirmed with contrast-enhanced digital angiography. Placement anterior to the brain stem was confirmed in both cadavers during dissection, and spinal navigation without cord damage from the anterior or posterior approach was confirmed in one. Percutaneous intraspinal navigation is a new route of access for cerebrospinal surgery that has many potential applications.

We present a promising technique for cerebral surgery involving percutaneous intraspinal navigation (PIN). It does not require the operator to manipulate the brain by means of craniotomy. The route of access is a standard puncture of the spinal subarachnoid space—in this case, in the lumbar spine—with the application of intravascular techniques for the navigation of the subarachnoid space. This technique should theoretically have fewer problems related to the exposure of the brain to infectious agents, and it offers an opportunity for navigating many structures without brain retraction or removal to achieve access.

Description of the Technique

Initially, attempts to navigate the subarachnoid space were undertaken in two embalmed cadavers. Navigation to the cervicothoracic junction proceeded as expected. However, these attempts were ultimately unsuccessful because of the disappearance of the subarachnoid space at the cervicothoracic junction, as confirmed fluoroscopically after the injection of contrast material. We postulated that the embalming process had eliminated the CSF space and altered tissue compliance, as an explanation for the technical limitation.

Subsequently, two recently deceased, non-embalmed male human cadavers were brought to our research angiography suite (Infinix AX; Toshiba, Inc., Tokyo, Japan) and placed in a prone position. With fluoroscopic guidance, lumbar punctures were performed in each subject at both the L3–L4 and the L4–L5 interspaces by using a standard single-wall puncture angiography needle. A 0.038-inch guidewire was then introduced and directed superiorly (Fig 1). Subsequently, a 5F angiographic dilator was advanced into the subarachnoid space over the guidewire to dilate the tract, and a 5F arterial sheath was placed with its tip directed superiorly. In each cadaver, one sheath was subsequently used for catheterization posterior to the spinal cord, and the other was used for catheterization anterior to the spinal cord.

After sheath placement, angiographic techniques were applied to the subarachnoid space. Specifically, under fluoroscopic guidance, a hydrophilic-coated angle-tipped guidewire was advanced with its tip directed either anteriorly or posteriorly under operator control (Fig 2A). Care was taken to maintain a midline position whenever possible, but it could not always be maintained. The advancement was performed with inflation of the subarachnoid space and infusion of sodium chloride solution into the sheath. The pressure of the infusion was easily controlled by adjusting the height of the flush bag above the patient's spine, although the pressures of the infusion and the subarachnoid space were not specifically monitored for this study.

After the cranial space was entered, catheter manipulations were undertaken to explore the areas possible for catheterization. These are described in the Results section.

After these manipulations, the catheters were left in place for subsequent dissection. The sheaths were cut at the skin with the introducers and microcatheters in place by using standard wire cutters. The stumps of the systems were then oversewn, and the cadavers were returned to the anatomy facility for embalming.

After embalming, cadaver 1 was examined for evidence of spinal cord injury from the catheterization process. Laminectomy was performed throughout the cervical and thoracic spine and extended inferiorly to the point of catheter entry. The opened dura was photographed with the catheters in place. The spinal cord was removed and photographed with the ventral catheter in place. Brain dissections were performed to confirm the locations of the catheters and to examine for unanticipated injury to the brain tissue.

Results

In each case, the wire was advanced relatively easily through the thoracic and cervical spine. In some areas, the catheter was advanced readily without guidewire placement. Once it was at the foramen magnum,

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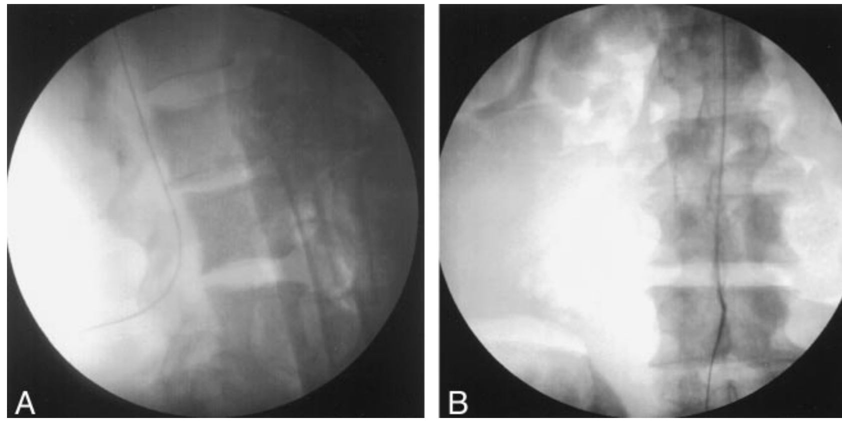

Fig 1. Radiographic images in cadaver 1 obtained with fluoroscopic guidance.

A, Lateral view of the lumbar spine shows the guidewire entering the spinal canal and ascending it.

B, Anteroposterior view shows the guidewire ascending in the canal from the lumbar entry point.

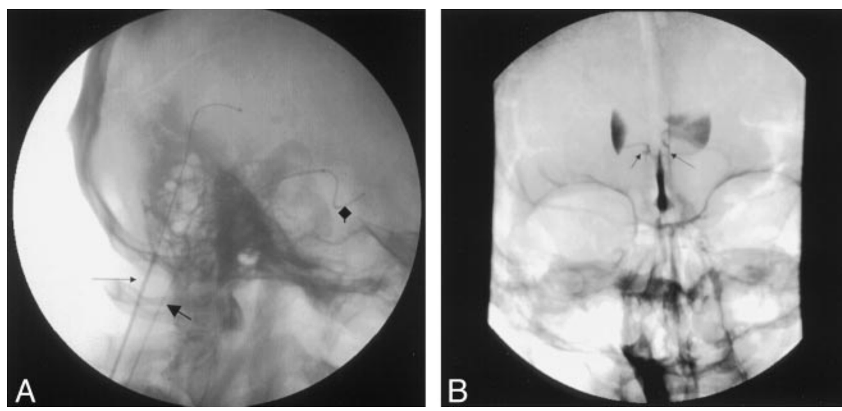

Fig 2. Placement of the guidewire under fluoroscopic guidance.

A, Lateral view in cadaver 1 shows the dorsal catheter (*small arrow*) posterior to the spinal cord and the ventral catheter (*large arrow*) anterior to the spinal cord. *Diamond* shows the tip of the ventral catheter in the sylvian fissure.

B, In cadaver 2, contrast material fills the third ventricle and spills through the foramina of Munro (*arrows*) into the lateral ventricles.

attempts were made to enter the fourth ventricle with the posterior catheters. We observed that navigation of the retrocerebellar space in the posterior fossa occurred relatively easily. On some occasions, we circumnavigated the posterior fossa to a position anterior to the pons. Also, advancement behind the cerebellum to the level of the tentorium was feasible. In cadaver 1, the posterior fossa catheter ultimately traversed the cerebellum during an attempt at fluoroscopically directed catheterization of the fourth ventricle. In cadaver 2, this ventricle was successfully catheterized and injected with contrast material.

Tough membranes were encountered at the foramen magnum posteriorly and at the upper pontine level anteriorly, and the use of stiffer wires was required.

Because we had only fluoroscopic guidance, determining the location of the fourth ventricle was difficult. Blind passes with the catheter to where the fourth ventricle should be resulted in successful catheterization of the fourth ventricle in cadaver 2. The placement was confirmed with contrast-material filling of the fourth ventricle, retrograde flow into the aqueduct of Sylvius, flow into the third ventricle, and subsequent flow into the frontal horns of the lateral ventricles bilaterally via the foramina of Munro (Fig 2B).

In both cadavers, catheterization of the subarachnoid space anterior to the pons with the introducer catheter occurred easily. For catheterization of the interpeduncular cistern and above, a 3F microcatheter was used in most cases; in some cases, a 4F catheter was used as a guide catheter. Once it was in the suprasellar cistern in cadaver 1, catheterization of the sylvian fissure was observed and confirmed when contrast material was injected and seen to flow dependently within the fissure (Fig 3). The catheter was left in that position, and the cadaver was embalmed.

In cadaver 2, catheterization of the suprasellar cistern was followed by experimentation regarding placement of the catheter. First, a catheter was placed in the frontal fossa. The catheter was advanced along the orbital roof and observed to curve superiorly, with its tip ultimately anterior to the frontal lobe and deep to the frontal sinus. The catheter was then withdrawn to the location on the orbital roof, and this placement was confirmed with an injection of contrast material (Fig 4). Next, the a catheter was placed in the contralateral floor of the middle cranial fossa, and this position was confirmed with a contrast agent injection.

The posterior fossa catheter was then advanced and seen to be in the fourth ventricle, as described previously. After the injection of contrast medium, some opacification of the third ventricle was seen. This opacification was used as a roadmap for the anteriorly placed catheter, and a catheter was successfully placed in the third ventricle by means of direct puncture of its floor. This was confirmed with a contrast agent injection. This subject was then sent for embalming.

In cadaver 1, after full spinal laminectomy from the upper cervical area to the area of puncture in the

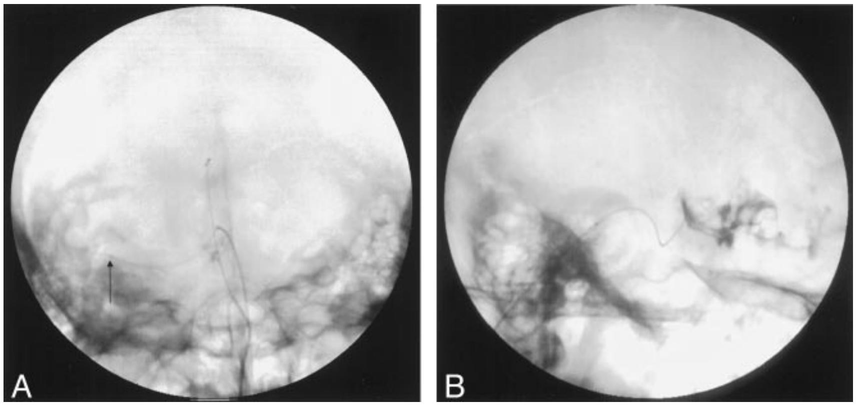

FIG 3. Images in cadaver 1.
A, Anteroposterior view shows the tip of the microcatheter in the sylvian fissure (*arrow*). The other (dorsal) catheter was traversing the cerebellum at the time this image is obtained.
B, Lateral digital subtraction angiogram obtained during the injection of contrast material through the catheter in the sylvian fissure. The subject is prone. Note the flow of contrast material over the gyri and sulci in the sylvian fissure as it falls away from the catheter tip.

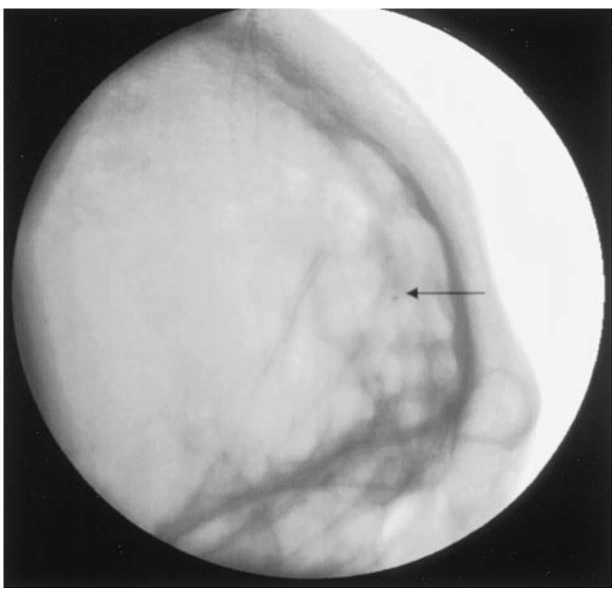

FIG 4. Lateral view in cadaver 2 shows the tip of the microcatheter anterior to the frontal lobe (*arrow*) along the inner table of the skull. The catheter passed along the orbital roof and turned superiorly, following the contour of the calvaria.

lumbar spine, the posterior dura was incised and reflected. The dorsal introducer catheter was seen lying superficial to the spinal cord without apparent spinal cord violation or laceration. This catheter was then removed, and the spinal cord was resected by cutting the nerve roots bilaterally and lifting it out; the ventral catheter was retained with the spinal cord. It was observed to traverse anterolaterally, weaving anterior and posterior to different nerve roots. Again, no spinal cord violation or laceration was apparent.

In cadaver 1, a neurosurgeon (R.E.R.) performed a dissection to reproduce an expanded surgical approach to the sylvian fissure and the basilar apex. Exposure by using an operating microscope revealed the microcatheter anterior to the midbrain, between the clivus and midbrain. It was followed inferiorly as it migrated to the right side of the basis pontis. No violation of cerebral structures by the catheter was observed. The catheter traversed laterally in a sulcus in the left sylvian fissure. Removal of the temporal lobe revealed that the catheter was in the sylvian fissure, near branches of the middle cerebral artery (Fig 5). The posterior fossa catheter was observed to enter the cerebellum and was not pursued with detailed dissection.

Dissections in cadaver 2 revealed that the third ventricular catheter was in place within the third ventricle, as suggested on the radiographs. The catheter was seen passing anterior to the brain stem along the clivus, without penetrating the brain stem. Also, the basilar artery was seen separate from the catheter. The point of penetration of the ventricle was essentially vertical in the midline from the interpeduncular cistern (Fig 6). The catheter in the fourth ventricle was not dissected.

Discussion

Some authors have described experimental data from endoscopy in the subarachnoid space. To our knowledge, translumbar approaches to the subarachnoid space with visualization or access to the intracranial contents have been described only recently and only in cadavers so far. One group from Sweden (1) used a relatively large (4-mm) bronchoscope to travel the length of the subarachnoid space either ventrally or dorsally to eventually visualize the contents of the posterior fossa, as well as to gain access to the ventricular system. These studies were performed in cadavers and involved dissection to the lumbar space and introduction of the bronchoscope from that location, with only endoscopic guidance. In light of the size of the instrument used, applications in the clinical setting could not be advocated, and navigation into more remote cerebral structures with that instrumentation would be fraught with risk.

Eguchi et al (2) used a smaller endoscope in cadavers to access only the subarachnoid space around the spinal cord and posterior fossa. No attempt was made to access either the ventricles or the supratentorial cisterns. The endoscopes used also had no directional capability. Uchiyama et al (3) used a myeloscope that was sufficiently small (0.5–2 mm) to safely access the spinal subarachnoid space without injuring the spinal cord in a group of patients. None of these groups attempted more directed navigation by using catheters and guidewires or other means to more precisely and distally control the placement of the device or the insertion of other instruments.

Fig 5. Image from the dissection in cadaver 1 shows the view into the sylvian fissure from an extensive frontotemporal craniotomy. The temporal lobe was removed. The catheter (*black arrow*) is seen in the sylvian fissure. Also seen are the middle cerebral artery (*MCA*), posterior cerebral artery (*PCA*), superior cerebellar artery (*white arrow*), internal carotid artery (*ICA*), and third cranial nerve (*3*).

Fig 6. View in cadaver 2 was obtained after the sagittal removal of the right hemisphere in the plane of the third ventricle. Image shows the course of the microcatheter (*white arrow*) that penetrates the floor of the ventricle. The dorsum sella (*white square*) and third cranial nerve (*black arrow*) are also shown. The brain stem and basilar artery are reflected posteriorly, and the course of the catheter in the subarachnoid space is shown.

Care should be taken to avoid not only direct neural tissue injury but also vascular injury, both arterial and venous. The cranial and spinal nerves must be passed. With the advancements in soft guidewires and microcatheters in recent years, routine navigation of the intracranial vasculature is now possible, when it was considered not possible only 20 years ago. Retraction of the spinal cord, cranial nerves, vessels, and brain tissue are now routine during traditional neurosurgical procedures. Therefore, we do not know if our fear of navigating the subarachnoid space is well founded.

In making comparisons with traditional surgery, we have considered many different applications of PIN. Some of these applications should share the end results that can be achieved with the use of burr holes or craniotomy: ventricular catheterization, brain biopsy with image-guided direction of the catheter, depth-electrode implantation, possible electrocorticography or brain stem signal-intensity recording, implantation of radioactive beads in brain tumors, and thermal or cryothermal ablation, among others. The cranial nerves and vertebrobasilar vascular complex lie near the path through which the catheter enters the posterior fossa, and devices that will permit catheter-based interventions in this anatomy may be developed. The catheters in our subjects passed in the region of the pituitary and pituitary stalk, as well as in the circle of Willis.

Other applications are not easily compared with conventional neurosurgery. Examples of these include subarachnoid clot lavage in cases of subarachnoid hemorrhage; this is currently performed most often in an open setting at the time of aneurysm clip placement (4) and was recently reported with cisternal catheter placement via lumbar puncture (5). This procedure could be performed in association with coil placement of an aneurysm, decreasing the lavage advantage of open clip placement. Also, we should explore the use of hypothermic lavage to induce cerebral hypothermia. The possibility of infusing fluid at the catheter tip and withdrawing it via the sheath or another catheter is intriguing. Manipulation of the pressure in the subarachnoid space is enabled in PIN, and the therapeutic implications of that manipulation are not understood. Treatment of hydrocephalus via third ventricular fenestration from below is a possibility. Further experimentation with all of these applications is warranted.

An attractive feature of PIN is potential amenability to MR guidance. Subarachnoid navigation has many advantages compared with vascular navigation for MR guidance. First, the spinal canal is a midline, straight structure that is routinely seen in its entirety on sagittal MR images, whereas the vasculature is tortuous. Furthermore, the ability to perform surgical procedures in the brain from a lumbar puncture approach enables surgery in which the surgeon is truly remote from the operative field. Hence, extensive modification of conventional MR technology should be unnecessary. The percutaneous approach without an open surgical wound should limit the need for many infection-prevention steps required in the operating room environment. Also, because CSF is not flowing the way blood is flowing, different and simpler imaging parameters likely come into play. PIN has the theoretical potential to usher in true neurointerventional MR imaging in ways currently impeded by the logistics of traditional neurosurgery in an MR imaging setting. Furthermore, because the calvarium is not violated, brain structures are not distorted by the surgical procedure in the way that craniotomy and brain retraction do. Moreover, the development of catheters in sizes that avoid excessive indentation of neural structures will enhance PIN.

We recognize that bleeding is a concern. Intracranial vessels are sometimes perforated during microcatheter manipulation, most frequently without significant sequelae. Hence, some degree of bleeding in the subarachnoid space is tolerated. The outer diameter of most microcatheters is on the order of 1 mm. In comparison to the size of catheters routinely used for ventriculostomy, the size of these catheters is small. The effect of brain penetration by guidewires or microcatheters has not been established in structured studies. Also, the technique itself may enable subarachnoid lavage, offering a means for intraoperative management of bleeding beyond the obvious potential for cauterization, if appropriate tools are developed. This possibility clearly represents an area for device development. Endoscopic visualization should be helpful in identifying emerging challenges. We believe that combinations of imaging mechanisms represent the most likely eventual means of implementation of this technique.

Conclusion

In two human cadavers, we successfully demonstrated the ability to navigate the intracranial subarachnoid space and enter the ventricular system by way of a lumbar puncture. We believe that this technique has many potential applications, some of which may represent improvements on current approaches and some of which may enable new treatments. The potential of the technique warrants further investigation.

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