In Vitro Investigation


**Background:** Factors contributing to subarachnoid catheter passage after epidural placement are not well understood. This study explored mechanisms that might explain its occurrence.

**Methods:** Human cadaveric dura was mounted on a model and pressurized to physiologic levels. In a standardized fashion, a 20-gauge Portex® three-port, closed end (nonflexible) tip catheter was passed through an epidural needle mounted on a micromanipulator at a 90° angle, attempting to penetrate dura with the catheter. Attempts then followed with a 19-gauge Arrow Flex Tip Plus® single-port catheter. Subarachnoid catheter passage was compared in (1) intact dura, (2) clinically occult gauge Whitacre® spinal needle punctures after combined spinal–epidural (CSE) technique. The study explored mechanisms that might explain its occurrence. Although it is well known that catheter penetration may occur, factors contributing to its occurrence are less well understood.

UNRECOGNIZED subarachnoid catheter passage is an uncommon but potentially hazardous complication of epidural placement.1 Although it is well known that catheter penetration may occur, factors contributing to its occurrence are less well understood.

This study explored mechanisms that might explain unintentional catheter passage using fresh human cadaveric dura mounted on a physiologically pressurized dural sac model, an epidural needle (mounted on a micromanipulator), and two different types of epidural catheters. The mechanisms examined relate to catheter passage: (1) in intact dura, (2) in the presence of clinically occult versus obvious epidural needle punctures, and (3) after a single 25-gauge Whitacre® spinal needle (Becton Dickinson and Co., Franklin Lakes, NJ) puncture as part of a combined spinal–epidural (CSE) technique. The study did not attempt to examine the mechanism of subdural catheter placement or catheter movement after epidural placement.2,3

**Materials and Methods**

After institutional research ethics approval, 10 fresh human cadaveric spinal cords with intact dura were obtained at autopsy. Cadaveric characteristics (age, sex, cause of death) and tissue age (from the time of death to the start of experimentation) are reported in table 1. Before study, specimens were maintained in lactated Ringer’s solution at 20°C. Inclusion criteria were consent for autopsy and medical research; age greater than 18 yr; absence of known or suspected infections such as meningitis, human immunodeficiency virus, hepatitis, or Creutzfeldt-Jakob disease; and absence of spinal cord trauma or spinal cord malignancy.

Dura was dissected from the lumbar dural sac from L1–L2 to L4–L5 and cut into approximately 2-cm square pieces. Normal appearing dural specimens were mounted, in order of harvest (cephalad to caudad), over a 1-cm aperture in a cylindrical human dural sac model, preserving the anatomical orientation of the tissue (fig. 1A). A wet seal was achieved using a customized gasket and hose clamps. The OD of the model (2.4 cm) closely approximated the ID of the adult human vertebral canal (dural sac) at L3–L4 and L4–L5 measured in five cadavers before study onset.
The model was pressurized to physiologic levels (fig. 1b) with artificial cerebrospinal fluid (CSF; 147 mM Na, 2.88 mM K, 127 mM Cl, 1.0 mM phosphate, 1.15 mM Ca, 1.10 mM Mg, 1.10 mM SO₄, 23.19 mM HCO₃, 5410 mg/l glucose, 300 mOsm/kg [calculated]) prepared by the hospital pharmacy. Protein was not present in the solution. Pressures were measured using a standard in-line CSF manometer. Methylene blue dye (3 ml) was added to each 3-l bag of CSF to improve visualization of fluid levels.

Use of a micromanipulator enabled precise epidural needle angulation, bevel orientation, and controlled advancement. A 17-gauge Hustead needle (modified Tuohy needle with a shorter, blunter tip; Portex/SIMMS, Keene, NH) was used to facilitate catheter passage in parts 1 and 3 of the study. A 17-gauge Tuohy needle (Ballard Medical Products, Draper, UT) was used for part 2. Two cathe-

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**Table 1. Cadaveric Characteristics**

<table>
<thead>
<tr>
<th>Cadaver No./Sex</th>
<th>Age, yr</th>
<th>Cause of Death</th>
<th>Time from Death to Start of Experiment, h</th>
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<tr>
<td>1/F</td>
<td>93</td>
<td>Sepsis</td>
<td>60</td>
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<tr>
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<td>71</td>
<td>Myocardial infarction</td>
<td>48</td>
</tr>
<tr>
<td>3/F</td>
<td>71</td>
<td>Liver transplant</td>
<td>48</td>
</tr>
<tr>
<td>4/M</td>
<td>78</td>
<td>Postoperative bowel ischemia</td>
<td>19</td>
</tr>
<tr>
<td>5/F</td>
<td>25</td>
<td>Heart-lung transplant</td>
<td>60</td>
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<td>Lung cancer</td>
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<td>64</td>
<td>Myocardial infarction-pulmonary embolus</td>
<td>24</td>
</tr>
<tr>
<td>8/M</td>
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<td>Lung disease</td>
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<td>Liver disease-alcoholism</td>
<td>32</td>
</tr>
<tr>
<td>10/M</td>
<td>19</td>
<td>Acute lymphocytic leukemia</td>
<td>47</td>
</tr>
</tbody>
</table>

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**Fig. 1.** (a) Dural sac model: (A) artificial cerebrospinal fluid, (B) syringe model, (C) customized gasket, (D) dura, (E) standard lumbar puncture manometer, (F) cerebrospinal fluid outflow, (G) 17-gauge Hustead epidural needle mounted on a micromanipulator, (H) micromanipulator arm, (I) epidural catheter. (b) Experimental setup: (A) 3-l bag of artificial cerebrospinal fluid stained with methylene blue, (B) dural sac model, (C) collection beaker, (D) micromanipulator, (E) standard lumbar puncture manometer, (F) cerebrospinal fluid outflow.
Catheters were examined in each study part: (1) a 20-gauge Portex® three-port, closed end nylon (nonflexible) catheter (OD, 1.0287 mm; Portex/SIMMS) and (2) a 19-gauge Arrow FlexTip Plus® single-port epidural catheter (OD, 1.0668–1.11506 mm; Arrow International, Inc., Reading, PA). Attempts at catheter passage and punctures were performed under standardized conditions. In each phase of the investigation, five attempts at passage of the Portex catheter were always followed by five attempts with an Arrow catheter, the order of catheter choice used commonly in our institution when faced with difficult catheter insertion. The number of attempts used to pass catheters represented the maximum number thought clinically relevant in this setting. Each catheter was passed through the epidural needle to the needle tip and advanced from the hub until the catheter either passed through the dura or could not be passed further. In the case of the Arrow catheter, the feeding guide supplied by the manufacturer was used for all attempts. Catheter passage was defined by visible catheter penetration through the dura and aspiration of CSF. Study methods were divided into the following three distinct parts according to the question addressed.

**Part 1: Examination of Epidural Catheter Passage through Intact Human Dura**

After pressurizing the model to 15 cm H2O pressure (left lateral decubitus position pressure), a 17-gauge Hustead needle (bevel parallel, 90° to the dural long axis) was advanced to the point of marked dural tenting (without leak) using a micromanipulator. A 20-gauge Portex catheter was passed five times through the needle, each time attempting to penetrate the tissue. Using the same specimen under the same conditions, five attempts were then made to pass a 19-gauge Arrow catheter. After these attempts, the needle was withdrawn and rotated in the micromanipulator holding device to make the bevel face cephalad and then readvanced to the point of dural tenting without leak. The experiment was then repeated for each catheter. When this was completed, the needle was again withdrawn, bevel rotated hole caudad, readvanced to the point of dural tenting, and the experiment was repeated once more using each catheter. This sequence of testing yielded 30 attempts at catheter passage per specimen at 15 cm H2O pressure.

When experimentation was completed at 15 cm H2O pressure, each specimen was subjected to a higher system pressure of 25 cm H2O, and all steps were repeated as above, yielding an additional 30 attempts at catheter passage per specimen.

**Part 2: The Role of Epidural Needle Damage in Facilitating Catheter Passage**

The first part of this experiment was performed to determine whether it was possible to produce clinically occult dural punctures with an epidural needle. We defined an *occult* puncture as one with CSF leakage around the epidural needle tip after attempted puncture but no evidence of leakage from the needle hub. Clinically obvious punctures were defined as those with CSF leakage from the needle hub.

Using fresh dural specimens mounted on the model and a system pressure of 15 cm H2O, a 17-gauge Tuohy epidural needle was repeatedly advanced into the dura to the point of marked dural tenting. This was done with the needle positioned 90° to the dura, bevel parallel to the dural long axis. The needle was readvanced until evidence of a dural perforation (*i.e.*, CSF leak) was found. Penetration usually occurred within four attempts. The resulting punctures were studied to examine the probability of catheter passage.

In specimens with occult punctures, attempts at catheter passage were made without changing the position of the epidural needle after puncture. A 20-gauge Portex catheter was advanced through the epidural needle into the dura five times, attempting to penetrate it. Five attempts were then made to pass a 19-gauge Arrow catheter. If the Portex catheter was found to pass through the occult puncture site before completion of five attempts, further attempts at Portex catheter passage were abandoned, and attempts with the Arrow catheter commenced. To mimic clinical practice more closely, no efforts were made to facilitate catheter penetration by manipulation of the needle or catheter toward punctures.

In specimens with clinically obvious punctures, the epidural needle was withdrawn to the point where CSF leakage from the hub just stopped before attempts at catheter passage. Epidural needle position was otherwise not altered. This was done to mimic the risk of catheter passage after recognized dural puncture at the same level. Up to five attempts were made to pass the Portex through the puncture site, followed by up to five attempts with the Arrow. If the Portex passed through a puncture site before five attempts were made, further attempts were abandoned, and attempts with the Arrow commenced.

**Part 3: Catheter Passage after Uncomplicated Combined Spinal–Epidural Placement**

Using fresh specimens, the model was pressurized to 15 cm H2O, and an uncomplicated CSE was performed. A 25-gauge Whitacre needle, advanced through a 17-gauge Hustead epidural needle mounted on a micromanipulator at a 90° angle, was used to produce a single dural puncture. The Portex catheter was passed through the epidural needle five times followed by five attempts with the Arrow to examine catheter penetration through a spinal needle puncture. Catheters were advanced through the epidural needle in three bevel orientations: bevel parallel, bevel cephalad, and bevel caudal. No contact was made with the dura during rotation of the
epidural needle. The position of the epidural needle was not otherwise altered after spinal needle puncture. No attempt was made to actively manipulate catheters to facilitate catheter passage. A total of 15 attempts at passage were made per catheter for each specimen.

**Statistical Analysis**

The results for parts 1, 2, and 3 are presented using descriptive statistics. Binomial proportions are reported with 95% confidence intervals [CIs] using equations recommended by J. L. Fleiss when \( P \) is near zero or near unity. The Fisher exact test was used where appropriate, with a two-tailed \( P \) value of less than 0.05 considered significant. The consultant statistician for the study was J. P. Szalai, Ph.D. (Director Research Design and Biostatistics, Sunnybrook and Women’s College Health Sciences Center, University of Toronto, Canada).

**Results**

Tissue ages from the time of death to the start of experimentation were as follows (mean ± SD): part 1, 38.5 ± 16 h (10 specimens from 10 cadavers); part 2, 40 ± 18 h (10 specimens from 6 cadavers); part 3, 42 ± 19 h (6 specimens from 6 cadavers).

**Part 1: Examination of Epidural Catheter Passage through Intact Human Dura**

No evidence of catheter penetration of intact dura was found in 10 dural specimens derived from 10 different cadavers despite 300 attempts per catheter: Portex, 0 of 300 attempts (0.0000; 95% CI: 0.0000, 0.0158); Arrow, 0 of 300 attempts (0.0000; 95% CI: 0.0000, 0.0158).

**Part 2: The Role of Epidural Needle Damage in Facilitating Catheter Passage**

Ten fresh specimens were obtained from six different cadavers. Clinically occult punctures were demonstrated in three specimens derived from two cadavers. The remaining seven specimens had clinically obvious punctures. In the three specimens with clinically occult epidural needle punctures, the 20-gauge Portex (nonflexible tip) catheter penetrated 1 of 3 specimens in 1 of 14 attempts with a distinct “pop” felt as the catheter passed through the dura and into the model (0.0714; 95% CI: 0.0021, 0.3583). CSF was easily aspirated through the catheter. The 19-gauge Arrow (flexible-tip catheter) did not pass through any of the three specimens (0 of 15 attempts, 0.0000; 95% CI: 0.0000, 0.2535). Differences in the rates of passage between catheter types did not reach statistical significance (\( P = 0.48 \)).

In clinically obvious epidural needle punctures, the 20-gauge Portex (nonflexible tip) catheter passed in 6 of 33 attempts (0.1818, 95% CI: 0.0760, 0.3608), and the 19-gauge Arrow (flexible tip) catheter passed in 1 of 35 attempts (0.0286; 95% CI: 0.0012, 0.1662). Differences in the rates of passage approached but did not reach statistical significance between the two catheters (\( P = 0.051 \)).

**Part 3: Catheter Passage after Uncomplicated Combined Spinal–Epidural Placement**

Neither catheter passed through a single 25-gauge Whitacre spinal needle puncture after 90 attempts per catheter using 6 specimens derived from 6 different cadavers: Portex, 0 of 90 attempts (0.0000; 95% CI: 0.0000, 0.0510); Arrow, 0 of 90 attempts (0.0000; 95% CI: 0.0000, 0.0510).

**Additional Observations**

Throughout the study, it was observed that catheter stiffness, the distance of the Huber point from the puncture site, and the degree of dural trauma resulting from needle puncture played a role in the likelihood of catheter passage. In the case of occult punctures, the needle tip was maintained against the dura (i.e., not moved) after CSF leak was noted to mimic conditions of passage after unrecognized dural injury in clinical practice. In this setting, both catheters usually exited the epidural needle tip, impacting close to the puncture site. Catheter passage through occult punctures seemed to be prevented by the relatively smaller dural hole and the resistance of the remaining dura at the site.

It should be noted that in the single case where 20-gauge Portex passage occurred through an occult puncture, that subsequent attempts to pass the 19-gauge Arrow (flexible tip) catheter through the same puncture site were unsuccessful. Because both catheters were passed with the epidural needle tip maintained against the dura after occult puncture, it is likely that failure of the Arrow catheter to pass was related to the flexible nature of the tip (permitting less force to be applied) as well as the somewhat larger OD of this catheter.

In the case of obvious dural punctures, the epidural needle was withdrawn just to the point where CSF leakage from the needle hub stopped before attempts at catheter passage. The tendency of the curved epidural needle tip to deflect both catheters away from puncture sites increased as the distance between the epidural needle tip and the puncture site increased. The relative degree of deflection was greater for the flexible-tip Arrow catheter (fig. 2a) than for the nonflexible-tip Portex catheter (fig. 2b).

**Discussion**

Dural tissue, formed by meshed layers of collagen and elastin fibers, has high tensile strength under pressure, making it fairly resistant to puncture.\(^5,6\) When dura is breached, however, the arachnoid membrane, which
forms the watertight barrier to CSF on the dural undersurface, offers little further resistance to penetration. This study examined subarachnoid catheter passage during epidural placement using cadaveric dura mounted on a pressurized dural sac model. Our ability to achieve a "watertight" seal with the dural specimens mounted on our model suggests that the arachnoid membrane, easily visualized on the undersurface of specimens at the time of dissection, was maintained intact.

Similar to previous in vitro work with older epidural catheters, our results suggest that even after multiple attempts at catheter passage, penetration of intact, normal-appearing dura is unlikely with either a 20-gauge Portex (nonflexible tip) catheter or a larger 19-gauge Arrow (flexible tip) catheter. Overall, the results suggest that needle-related dural trauma must be present for catheter passage to occur. Our observations suggest that catheter passage with the needle sited at the same level as the puncture depends on the nature of the trauma, the properties of the catheter, and the distance between the epidural needle tip and the dural puncture. The role that dural puncture morphology plays in facilitating catheter passage was not examined in this study.

The results show that penetration with either of the catheters studied is unlikely after a single puncture with a 25-gauge Whitacre spinal needle as part of an uncomplicated CSE technique. This is consistent with previous work in cadavers using epiduroscopy. The authors in that study noted that passage was possible only if the catheter was actively directed toward an area containing five holes made by a 25-gauge spinal needle. We examined catheter passage without active manipulation of catheters toward dural punctures throughout the study to mimic clinical conditions more closely.

Unrecognized dural trauma with the epidural needle seems to be the most likely explanation for the phenomenon of catheter passage. We found that it was possible to produce clinically occult punctures with an epidural needle after repeated advancement of the needle into the dura to the point of maximal tenting while attempting to avoid overt puncture. The occult punctures produced were small, full-thickness dural tears produced by the leading edge of the needle and defined by leakage of CSF at the needle tip/dural interface without leakage from the hub. We found that it was possible to pass the Portex catheter in one of three occult punctures produced by the epidural needle with a distinct "pop" being felt as the catheter passed through the remaining resistance of the dura at the occult puncture site. Occult dural injury is also a likely explanation for the occurrence of post-dural puncture headache in patients without recognized punctures at the time of epidural placement. The propensity of epidural needles to produce this phenomenon likely varies by needle tip design and the length and sharpness of the advancing needle edge.

It is common practice to site epidurals at another

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Fig. 2. (a) Deflection of a 19-gauge Arrow Flex Tip Plus® epidural catheter on passage through an epidural needle after dural puncture. The needle was withdrawn to the point where cerebrospinal fluid leak stopped before attempts at catheter passage. Note the degree of deflection of the catheter tip away from the dural puncture site. (A) Tuohy epidural needle, (B) Arrow catheter, (C) dura, (D) puncture site, (E) artificial cerebrospinal fluid. (b) Deflection of a 20-gauge Portex® three-port closed end (nonflexible tip) catheter exiting the Huber tip of an epidural needle after dural puncture. The needle was withdrawn to the point where cerebrospinal fluid leak stopped before attempts at catheter passage. (A) Tuohy epidural needle, (B) Portex catheter, (C) dura, (D) puncture site, (E) artificial cerebrospinal fluid. Note the smaller degree of deflection of the Portex (nonflexible) catheter tip away from the dural puncture site compared with the flexible-tip Arrow catheter (a).
anatomical level after recognized epidural needle puncture. Although subarachnoid catheter placement is clearly possible even if the needle is resisted at another level,\(^{10}\) the risk of catheter passage if sited at the same anatomical level is not clear. The findings suggest that the risk of direct catheter passage at the same level as the puncture may be lessened by using a flexible-tip catheter after withdrawing the needle to the point where leakage stops at the needle hub. The rates of catheter passage found in this study were lower (18\% Portex, 3\% Arrow) than those found during epiduroscopy in a nonpressurized cadaveric model after epidural needle puncture (45\%).\(^9\) The higher rates in the latter study may partly reflect deliberate manipulation of catheters toward the puncture site and the amount of force applied. Both the impact of epidural needle withdrawal on the success rate of epidural catheter placement and the effect of catheter type (flexible vs. nonflexible) on subarachnoid passage require further clinical study.

As in any investigation, this in vitro study has limitations, including the relatively small number of cadavers used and absence of an epidural space in the model. We chose to examine only one sequence of catheter passage (Portex followed by Arrow) because randomizing the order would be unlikely to have demonstrated a difference (even if one existed) given the small number of specimens available. Although this approach does not control for the effects of previous attempts with the Portex on the likelihood of Arrow passage, it did permit description of the likelihood of catheter passage in three experimental scenarios (intact tissue, occult puncture, obvious puncture) using one clinically relevant order of passage.

Our observations suggest that the order of catheter passage examined in this study (Portex followed by Arrow) was likely to be the most important of the two possible sequences. We base this on observations made related to the nature of the catheters, their propensity to impact on the edge of the dural puncture site, and the overall rates of passage observed. The stiffer (nonflexible tip) Portex catheter seemed to permit more force (subjective assessment) to be exerted on the dura at the point of impact than the flexible tip of the Arrow catheter. Further, the degree of deflection of catheter tips away from punctures by the curved Huber point was found to be somewhat greater for the more flexible Arrow compared with the stiffer Portex catheter at any given distance of the epidural needle from the dura except when the needle tip was juxtaposed to the dura. These observations suggest a mechanism by which flexible-tip catheters might help to reduce the risk of catheter passage in the presence of known dural damage with the epidural needle. It is also noteworthy that the overall rates of Arrow passage were low to nonexistent throughout the study despite previous attempts at passage with the Portex. The odds of passage of the nonflexible-tip Portex through an overt puncture was 7.5 times that of the flexible-tip Arrow catheter (\(P = 0.05\)).

Features of the model and study design that increase the clinical relevance of the findings include (1) the human lumbar spine dimensions of the dural sac model, (2) in vivo orientation of dural tissue specimens, (3) use of physiologic CSF pressures at the time of attempted catheter passage and during dural punctures, (4) observed dural tenting, (5) use of conditions mimicking those in clinical practice (i.e., no attempt to actively direct catheters into puncture sites), and (6) findings consistent with earlier work related to catheter passage in intact dura and after spinal needle punctures during CSE anesthesia.

In summary, the findings of this study suggest that subarachnoid catheter passage is unlikely in the presence of intact dura or after an uncomplicated combined spinal epidural with a 25-gauge Whitacre needle. Unintentional subarachnoid catheter passage suggests the presence of dural damage with the epidural needle.

The authors thank: (1) Anna Marie Mosculak, B.A., P.A. (Department of Pathology), Frank Brommecker, B.Sc.Plspin, Michael Ritchie B.Sc.Plspin, and staff (Pharmacy Department), Michael Wong, L.B.I.P.P. (Audio Visual Department), Wedladia Hannah, M.D., F.R.C.P.C. (Chief, Department of Pathology), and Lee Cyn Ang, M.D., F.R.C.P.C. (Neuropathologist, Department of Pathology), all from the Women’s College Campus, Sunnybrook and Women’s College Health Sciences Center, Toronto, Canada; (2) Jack Butany, M.D., F.R.C.P.C. (Chief, Department of Pathology Toronto Hospital, Toronto, Canada); (3) William Halliday, M.D., F.R.C.P.C. (Chief, Department of Neuropathology, Toronto Western Hospital, Toronto, Canada), and (4) Valerie Oxorn, M.Sc.B.M.C. (Medical Illustrator, Toronto, Canada). The authors also thank Joanne Douglas, M.D., F.R.C.P.C. (Visiting Professor in Obstetric Anesthesia, Department of Anesthesia, Women’s College Campus of Sunnybrook and Women’s College Health Sciences Center), and Stephen Halpern, M.D., F.R.C.P.C. (Associate Professor, Department of Anesthesia, Women’s College Campus of Sunnybrook and Women’s College Health Sciences Center), for reviewing the manuscript and for their helpful comments and suggestions.

References

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