Anesthesiology 2003; 99:1376–82

Dural Tissue Trauma and Cerebrospinal Fluid Leak after Epidural Needle Puncture

Effect of Needle Design, Angle, and Bevel Orientation

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Background: **The effects of epidural needle design, angle, and bevel orientation on cerebrospinal fluid leak after puncture have not been reported. The impact of these factors on leak rate was examined using a dural sac model. Dural trauma was examined using scanning electron microscopy.**

Methods: **Human cadaveric dura, mounted on a cylindrical model, was punctured with epidural needles using a micromanipulator. Tissue was punctured at 15 cm H_2O (left lateral decubitus) system pressure, and leak was measured at 25 cm H_2O (semisitting) pressure. Leak rates and trauma were compared for the following: (1) six different epidural needles at 90°, bevel parallel to the dural long axis; (2) 18-gauge Tuohy and 18-gauge Special Sprotte® epidural needles, 30° *versus* 90°; (3) 18-gauge Tuohy, bevel perpendicular *versus* parallel to the dural long axis.**

Results: **With the 90° puncture, bevel parallel, the greatest leak occurred with a 17-gauge Hustead (516 ± 319 ml/15 min), and the smallest leak occurred with a 20-gauge Tuohy (100 ± 112 ml/15 min; $P = 0.0018$). A 20-gauge Tuohy puncture led to statistically significant reductions in leak (P value range, 0.0001–0.0024) compared with all needles except the Special Sprotte®. With the 30° *versus* 90° angle, 30° punctures with an 18-gauge Tuohy produced nonstatistically significant leak reductions compared with the 18-gauge Tuohy at 90°. The puncture angle made no difference for the Special Sprotte®. Nonsignificant reductions were found for the Special Sprotte® compared with the Tuohy. With the 18-gauge Tuohy bevel orientation, perpendicular orientation produced nonstatistically significant reductions in leak compared with parallel orientation.**

Conclusions: **Cerebrospinal fluid leak after puncture was influenced most by epidural needle gauge. Leak rate was significantly less for the 20-gauge Tuohy needle.**

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POSTDURAL puncture headache (PDPH) is a consequence of cerebrospinal fluid leak,[1–2] occurring after both spinal and epidural placement. However, measures used to prevent headache differ between techniques. By addressing the effect of needle gauge and tip design on leak, spinal needle redesign has greatly reduced the incidence of PDPH after spinal needle puncture.[3–5]

Headache prevention during epidural placement continues to focus on techniques of avoiding puncture rather than reducing cerebrospinal fluid leak. However, the wide variability in unintentional dural puncture rates (0.4–6%) across North America,[6] the high incidence of PDPH after puncture,[7–8] and the severe, refractory nature of some headaches[8–10] suggest that other, potentially additive methods of prevention merit exploration in an effort to further reduce PDPH.

Epidural needle selection and technique of placement represent two obvious and easily modifiable factors likely to impact on cerebrospinal fluid leak and headache. Unfortunately, little research has been done in either area, with most of this information extrapolated from spinal needle studies.[11–16] Given the differences that exist between epidural and spinal needle design, the validity of such assumptions requires investigation. This *in vitro* study examined the effect of epidural needle design, angle of puncture, and bevel orientation on cerebrospinal fluid leak using human cadaveric dura mounted on a physiologically pressurized dural sac model. Dural trauma patterns were examined using scanning electron microscopy.

Materials and Methods

After institutional research ethics approval (University of Toronto, Toronto, Ontario, Canada), fresh human cadaveric spinal cords with intact dural tissue were obtained at autopsy. Before the study, specimens were kept in cooled Ringer's lactate solution. Inclusion crite-

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Received from the Department of Anesthesiology, Women's College Campus, Sunnybrook and Women's College Health Sciences Center, University of Toronto, Toronto, Ontario, Canada. Submitted for publication October 23, 2002. Accepted for publication July 11, 2003. Supported by Physicians Services Incorporated Foundation, Toronto, Ontario, Canada. Presented in part at the meeting of the Society for Obstetric Anesthesia and Perinatology, Hilton Head, South Carolina, May 5, 2002, and the meeting of the Canadian Anesthesiologist's Society, Victoria, British Columbia, Canada, June 25, 2002.

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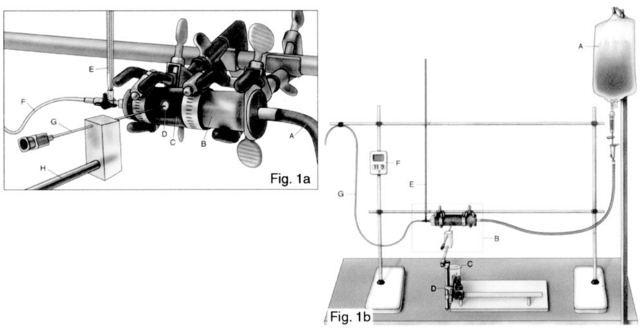

Fig. 1. (*a*) Dural sac model: artificial cerebrospinal fluid inflow (*A*), dural sac model (*B*), customized gasket (*C*), human dura (*D*), standard manometer (*E*), outflow (*F*), epidural needle mounted on a micromanipulator (*G*), micromanipulator (*H*). (*b*) Experimental setup: 3-l bag of artificial cerebrospinal fluid (*A*), syringe model (*B*), beaker (*C*), micromanipulator (*D*), lumbar puncture (*E*), digital timer (*F*), variable outflow (*G*).

ria were consent for autopsy and medical research; age older than 18 yr; absence of known or suspected infections such as meningitis, HIV, 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. Specimens were mounted, in order of harvest (cephalad to caudal), over a 1-cm aperture in a cylindrical human dural sac model, preserving the anatomic 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 the study onset.

The model was pressurized to physiologic levels (fig. 1B) with artificial cerebrospinal fluid (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 SO_4, 23.19 mM HCO_3, 5,410 mg/L glucose; 300 mOsm/kg) prepared by the hospital pharmacy. Pressures were measured using a standard in-line manometer. Three milliliters methylene blue dye was added to each 3-l bag of fluid to allow visualization of fluid levels.

Epidural needles were coded and selected for use according to predetermined randomization tables made for each part of the study. Use of a micromanipulator enabled precise needle angulation and bevel orientation during dural puncture as well as controlled advancement. Needles were advanced by means of a hand screw at the highest rate possible. Each needle was used to puncture a specimen of dura obtained from the same cadaver. Each dural specimen was punctured only once. The model was pressurized to 15 ± 1 cm H_2O pressure (left lateral decubitus position) during puncture. *Dural puncture* was defined by free flow of artificial cerebrospinal fluid through the needle hub. After puncture, the needle was withdrawn, and the syringe model was rotated (puncture site downward) without disconnection of the system to allow for collection of fluid. Pressure was increased to 25 ± 1 cm H_2O for fluid collection, simulating semisitting position pressure.[3] Fluid was collected in preweighed, dry beakers for four 15-min periods for each puncture. Each 15-min collection was timed using a digital timer and weighed using a standard electronic pan balance sensitive to 0.1 g. Volumes were obtained from weights using a cerebrospinal fluid density of 1.0. Dural specimens were then mounted on paraffin and fixed with universal fixative, and scanning electron microscopy was performed. The trauma patterns produced by each needle type were photographed. The dura used in part 1 was derived from 10 cadavers. The dura used for parts 2 and 3 was derived from a second set of 10 cadavers.

Part 1: Effect of Epidural Needle Design on Cerebrospinal Fluid Leak and Dural Trauma

Punctures were made using the following six epidural needles at an angle of 90°, bevel parallel (where applicable) to the dural long axis: 17-gauge Hustead (a modified Tuohy with a shorter, blunter tip; Portex/SIMMS, Keene, NH); 17-gauge Tuohy (Ballard Medical Products, Draper, UT); 18-gauge Tuohy-Schliff Perifix (B. Braun, Bethlehem, PA); 18-gauge Special Sprotte® (Pajunk, Geisingen, Germany); 18-gauge Crawford (Becton-Dickinson, Rutherford, NJ); and a 20-gauge Tuohy (Portex/SIMMS). Needle specifications are found in table 1.

Part 2: Effect of Angle of Puncture on Cerebrospinal Fluid Leak and Dural Trauma

The effect of needle angulation and tip design was studied using 18-gauge Tuohy and 18-gauge Special Sprotte® epidural needles. Punctures were performed at 90° and 30° angles to the dural sac in the horizontal plane using a fresh specimen for each puncture. Measurements were repeated for each needle and angle using a separate specimen from the same cadaver. The bevel of the Tuohy needle was oriented parallel to the dural long axis for all of these punctures.

Table 1. Epidural Needles Examined

Needle	Gauge	Manufacturer	OD,* mm
Hustead	17	Portex/SIMMS, Keene, NH	1.46–1.48
Tuohy	17	Ballard Medical Products, Draper, UT	1.49–1.52
Tuohy-Schliff Perifix	18	B. Braun, Bethlehem, PA	1.29–1.31
Special Sprotte®	18	Pajunk, Geisingen, Germany	1.2
Crawford	18	Becton-Dickinson, Rutherford, NJ	1.2
Tuohy	20	Portex/SIMMS, Keene, NH	0.90–0.91

* Information supplied by the manufacturers.

Table 2. Effect of Epidural Needle Design on CSF Leak (90° Punctures, Bevel Parallel), Cadaver n = 10

Epidural Needles	17-Gauge Hustead	17-Gauge Tuohy	18-Gauge Tuohy	20-Gauge Tuohy	18-Gauge Special Sprotte®	18-Gauge Crawford
17-Gauge Hustead	516 ± 319	0.3668	0.2922	0.0018*	0.2078	0.1326
17-Gauge Tuohy		405 ± 209	0.8312	0.0024*	0.6468	0.4312
18-Gauge Tuohy			420 ± 191	0.0003*	0.4324	0.2707
20-Gauge Tuohy				100 ± 112	0.0162	0.0001*
18-Gauge Special Sprotte®					360 ± 208	0.9698
18-Gauge Crawford						356 ± 121

Part 1 results are presented in the form of a *P* value matrix. Mean ± SD cerebrospinal fluid (CSF) leak rates are found on the diagonal for each needle in ml/15-min interval. The table may be read in the following way: Mean ± SD leak for the 17-g Hustead = 516 ± 319 (17-g Hustead [row] *vs.* 17-g Hustead [column]). Mean ± SD leak rate for the 17-g Tuohy (row) *vs.* 17-g Tuohy (column) = 405 ± 209. *P* value for differences in leak for the 17-g Hustead (row) *vs.* 17-g Tuohy (column) = 0.3668. *P* value required to reach statistical significance, corrected for multiple testing = 0.003.

* Statistically significant *P* values.

Part 3: Effect of Epidural Needle Bevel Orientation on Cerebrospinal Fluid Leak and Dural Trauma

An 18-gauge Tuohy needle was used to puncture specimens at a 90° angle with the bevel oriented perpendicular or parallel to the dural long axis.

Tissue Selection

Dural tissue texture appeared uniformly normal (opaque) in most cadavers. In one cadaver, the dura was found to be uniformly translucent throughout. Specimens from these cadavers were punctured as assigned, and cerebrospinal fluid leak rates were included in the main analysis.

In several cases, the dura was nonuniform in texture. This was noted as patchy translucency interspersed within grossly normal dura in the same cadaver. When this was found, tissue was handled in the following way: (1) the dura was dissected into approximately 2-cm square specimens in accordance with the standard study protocol; (2) both the translucent specimen and the next adjacent grossly normal-appearing specimen were punctured using the assigned needle and conditions. Only leak rates from grossly normal-appearing specimens were included in the main analysis, with puncture of the translucent dura done for comparative purposes only. This method of dealing with gross nonuniformity of tissue within the same cadaver was initiated with the first recognition of gross tissue nonuniformity and was applied consistently throughout the study.

Nonleaking Tissue after Puncture

When dural puncture was achieved but complete absence of leak was found after withdrawal of the needle, the result was noted but not included in the final analysis because this was thought to represent a separate phenomenon. The puncture was repeated using the next 2-cm square specimen in the sequence and the same needle. The leak rate from the second (leaking) specimen was entered into the analysis. Nonleaking puncture sites were examined with use of scanning electron microscopy.

Statistical Analysis

Cerebrospinal fluid leak rates were assessed for part 1 using two-factor repeated measures analysis of variance (RMANOVA) for needle (six levels) and time (four levels); for part 2 using three-factor RMANOVA for needle (two levels), angle (two levels), and time (four levels); and for part 3 using two-factor RMANOVA for bevel orientation (two levels) and time (four levels). A *P* value of less than 0.05 was considered statistically significant. Secondary analyses of part 1 and 2 results using RMANOVA were corrected for multiple testing and required *P* values of less than 0.003 and less than 0.008, respectively, to reach statistical significance. The statistician responsible for the analysis was Dr. J. P. Szalai, Associate Professor, Director of Research Design and Biostatistics, Sunnybrook and Women's College Health Sciences Center.

Results

Information relating to cadaver sex, age, cause of death, and tissue age at the start of the experiment is available on the ANESTHESIOLOGY Web site at http://www.anesthesiology.org. The mean age of the tissue from the time of death to the start of each experimental phase was (mean ± SD) 43 ± 17 h for part 1, 38.1 ± 19 h for part 2, and 33 ± 18 h for part 3. Differences in tissue age between parts 2 and 3 reflect the smaller number of cadavers used in part 2 (n = 7) compared to part 3 (n = 10).

Part 1: Epidural Needle Design, Cerebrospinal Fluid Leak, and Dural Tissue Trauma after 90° Puncture

Dural specimens from 10 different cadavers were examined. Two-factor RMANOVA (needle, time) showed highly significant needle ($P = 0.0004$) and time ($P = 0.0007$) main effects with no evidence of a needle by time interaction ($P = 0.7665$). The leak rates obtained for six different epidural needles after 90° puncture are shown in table 2. The greatest leak was found with the

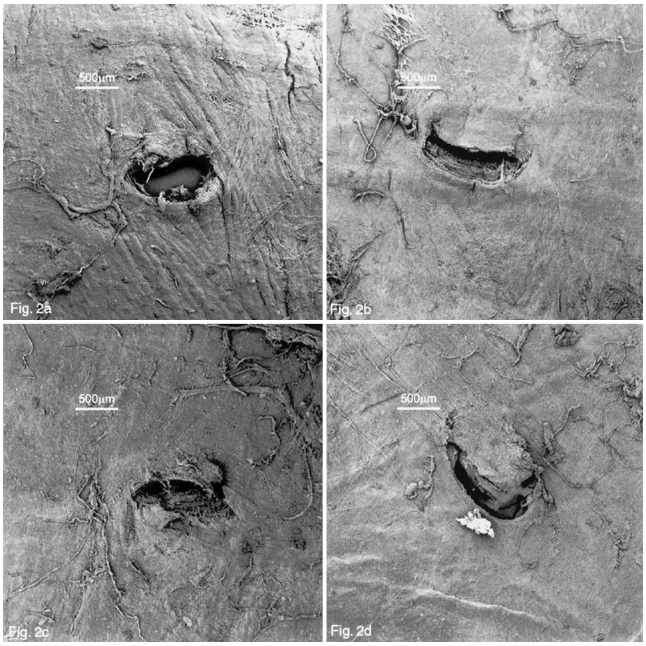

Fig. 2. Scanning electron microscopic images of (*a*) a 17-gauge Hustead epidural needle puncture (bevel parallel, 90° angle), (*b*) a 17-gauge Tuohy epidural needle puncture (bevel parallel, 90° angle), (*c*) an 18-gauge Special Sprotte® epidural needle puncture (90° angle), and (*d*) an 18-gauge Crawford epidural needle puncture (bevel parallel, 90° angle).

17-gauge Hustead needle, and the least leak was found with the 20-gauge Tuohy. Subanalysis using RMANOVA showed that 20-gauge Tuohy puncture produced large, statistically significant reductions in leak rate ($P = 0.0001$–0.0024) compared with all of the needles studied except the Special Sprotte® ($P < 0.003$ required to reach statistical significance, adjusted for multiple testing). Cerebrospinal fluid leak was found to decrease over time for all needle types. The magnitude of this decrease ranged from 3 to 14 ml/h. These reductions reached statistical significance only when compared between the first 15-min interval and at 1 h. Dural trauma patterns for the 17-gauge Hustead, 17-gauge Tuohy, 18-gauge Special Sprotte®, and 18-gauge Crawford needles after 90° puncture are shown in figures 2A–D. Additional figures showing trauma patterns for 18-gauge Tuohy and 20-gauge Tuohy needles are available on the ANESTHESIOLOGY Web site.

Part 2: Effect of 30° versus *90° Angle, 18-Gauge Tuohy, and 18-Gauge Special Sprotte® Needles*

Dural specimens from seven different cadavers were examined. Three-factor RMANOVA (needle, angle, time) showed a nonsignificant effect for needle type ($P = 0.0634$), no effect for puncture angle ($P = 0.4019$), and a significant time effect ($P = 0.0159$). The magnitude of the differences in leak and the consistency of the direction of the reductions led to subanalysis using RMANOVA for the purposes of hypothesis-generation only. The results are presented in table 3. None of the comparisons reached statistical significance ($P < 0.008$ required, corrected for multiple testing). Figures demonstrating the variability in dural trauma found after standardized puncture of dural specimens from the same cadaver using the same needle are available on the ANESTHESIOLOGY Web site. Photographs are provided for both 18-gauge Tuohy and 18-gauge Special Sprotte® needles after 30° punctures.

Part 3: Effect of Bevel Orientation on Cerebrospinal Fluid Leak for the 18-Gauge Tuohy Needle

Dural specimens from 10 different cadavers were punctured with an 18-gauge Tuohy needle with the bevel oriented parallel *versus* perpendicular to the dural long axis. RMANOVA of leak rates per 15-min interval showed nonstatistically significant reductions in leak (mean ± SD) with perpendicular *versus* parallel punctures, respectively (367 ± 119 *vs.* 485 ± 216; $P = 0.12$). Statistically significant reductions in leak rate were found over time, regardless of the needle bevel orientation at the time of puncture ($P = 0.0010$). Perpendicular 18-gauge Tuohy bevel orientation was often associated with a more prominent flap in the dura on scanning electron microscopy (fig. 3) compared with punctures with the needle bevel parallel (fig. 2B). Additional figures illustrating the spectrum of trauma found after perpendicular puncture with an 18-gauge Tuohy needle are available on the ANESTHESIOLOGY Web site.

Additional Observations: Nonleaking and Slowly Leaking Puncture Sites

Seven specimens were found to produce no cerebrospinal fluid leak after needle withdrawal despite free

Table 3. Effect of Angle of Puncture on CSF Leak (Tuohy Bevel Parallel), Cadaver n = 7

Needle Type and Angle	18-g Tuohy, 90°	18-g Tuohy, 30°	18-g Special Sprotte®, 90°	18-g Special Sprotte®, 30°
18-g Tuohy, 90°	485 ± 215	0.31	0.02	0.047
18-g Tuohy, 30°		401 ± 135	0.92	0.51
18-g Special Sprotte®, 90°			401 ± 208	0.96
18-g Special Sprotte®, 30°				408 ± 205

The results of part 2 are presented as a *P* value matrix. Mean ± SD cerebrospinal fluid (CSF) leak rates are represented on the diagonal for each needle in ml/15-min interval. The table may be read in the following way: Mean ± leak rate for the 18-g Tuohy at 90° = 485 ± 215 (18-g Tuohy, 90° [row] *vs.* 18-g Tuohy, 90° [column]). Mean ± SD leak rate for the 18-g Tuohy at 30° = 401 ± 135 (18-g Tuohy, 30° [row] *vs*. 18-g Tuohy, 90° [column]). *P* value for differences in leak between the 18-g Tuohy at 90° (row) *vs.* 18-g Tuohy at 30° (column) = 0.31. *P* value required to reach statistical significance, corrected for multiple testing is < 0.008. None of the contrasts reached statistical significance.

Fig. 3. Scanning electron microscopic image of a dural puncture made by an 18-gauge Tuohy-Schliff Perifix epidural needle with the bevel perpendicular to the dural long axis (90° angle).

flow of fluid from the needle hub at the time of puncture. Incremental increases in pressure (up to 45 cm H_2O) failed to produce any leak from puncture sites in these specimens. This was observed for the following needles: 17-gauge Tuohy (one time); 18-gauge Tuohy (one time) and 18-gauge Crawford (two times) after 90° punctures; and the Special Sprotte® (three times) after 30° punctures. Scanning electron microscopy of nonleaking samples showed plugs of debris in the puncture site. An example is shown in figure 4A. Examination of the debris within the puncture site at higher levels of magnification (figs. 4B and C) and comparison with nondisrupted dural tissue outside the puncture site on the same specimen (fig. 4D) suggests that the hole was plugged with dural tissue fragments.

Several comparative punctures, using the same needle and dura from the same cadaver, were found to demonstrate markedly different cerebrospinal fluid leak rates. Partial plugging of the puncture sites was found in these cases on scanning electron microscopy. This was observed for both 18-gauge Tuohy and 18-gauge Special Sprotte® needles at 90° and 30°. Scanning electron microscopy of one slowly leaking puncture site (Special Sprotte® epidural needle) shows a partial dural tissue plug extending from the edge of the puncture site into the hole as well as debris (fig. 5).

Dural Tissue Variability

Several punctures were performed to compare leak rates between grossly translucent- and normal-appearing dura obtained from the same cadavers. When subjected to a standardized puncture, translucent specimens of dura exhibited as much as a 50% greater leak rate compared with normal-appearing specimens from the same cadaver. Leak rates after standardized puncture of specimens derived from a single cadaver with diffusely transparent dura also exhibited much higher leak rates (> 50%) than those found in grossly normal-appearing specimens from other cadavers.

Discussion

Of all the measures used to prevent PDPH after spinal needle puncture, needle modification has proved most effective. Understanding the effects of needle design on cerebrospinal fluid leak and headache and clinical acceptance of modified needles has led to a dramatic reduction in PDPH, from 20% to 1–2% or less.[5,17] On average, the risk of PDPH after deliberate puncture during spinal anesthesia is now similar to the overall risk of PDPH after epidural placement.[17] However, important differences remain in the character of PDPH produced—in the nature of the headache, its responsiveness to therapy, and possibly in the potential for long-term sequelae.[9,10,18]

Although it is best to avoid dural puncture during epidural placement, reducing dural damage when it does occur is likely to reduce PDPH development and severity. Unfortunately, little direct information is available to describe the effects of epidural needle design or tech-

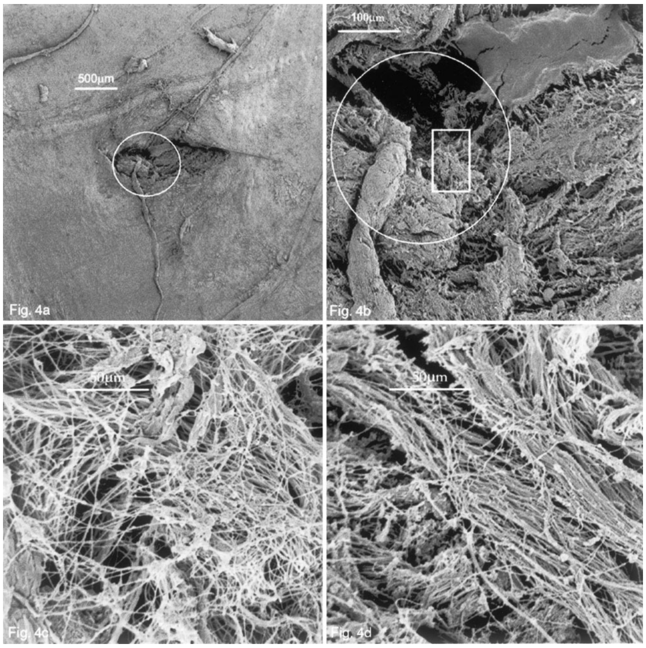

Fig. 4. Scanning electron microscopic images of a nonleaking dural puncture site after obvious puncture with a 17-gauge Tuohy needle (90° angle, bevel parallel). Three images, taken at ×25 (*a*), ×200 (*b*), and ×5,000 (*c*) magnification are used to examine debris in the area of the puncture site. Comparison with nondisrupted dura on the outer edge of the same specimen suggests that the debris within the puncture site consists of dural tissue fragments (*d*).

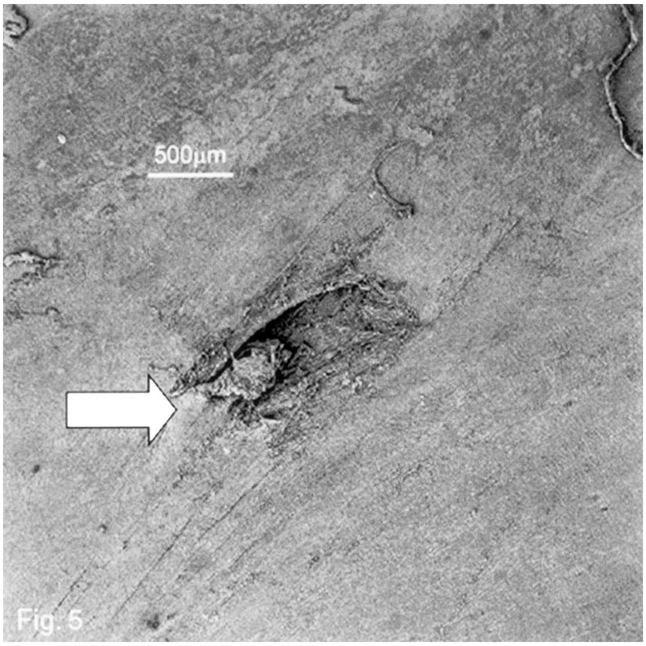

Fig. 5. Scanning electron microscopic image of a specimen found to leak slowly after standardized puncture with an 18-gauge Special Sprotte® epidural needle at 30°. A piece of dura (*arrow*) extends as a partial plug from the wall of the puncture site into the lumen, which is also filled with debris.

nique of insertion on cerebrospinal fluid leak or PDPH. This study examined the effects of epidural needle design, angle, and bevel orientation on cerebrospinal fluid leak and dural trauma after puncture.

As with spinal needle studies, the results of the current study suggest that epidural needle gauge is the most important predictor of cerebrospinal fluid leak.[3,5] The findings show that leak is greatest with the 17-gauge Hustead and least with the 20-gauge Tuohy needle (table 2). Although it is not possible to comment on PDPH in this study, existing clinical work suggests that accidental punctures with 20-gauge Tuohy needles (notably at mixed anatomic levels using only loss of resistance to normal saline) are associated with large reductions in the incidence of PDPH compared to rates found with larger epidural needles.[7,8,19]

The variable impact of epidural needle tip design on dural trauma and cerebrospinal fluid leak is interesting. The slightly smaller-diameter 17-gauge Hustead needle (a modified Tuohy needle with a shorter, blunter tip) produced "punched-out" ovoid dural holes and greater leak rates than the slightly greater-diameter 17-gauge Tuohy needle (table 1). The latter was found to produce crescentic punctures on scanning electron microscopy, although occasional punched-out holes were also seen with this needle. Differences in leak rates between these two needles did not achieve statistical significance (table 2).

In contrast, 18-gauge Special Sprotte® and 18-gauge Crawford needles, needles of equivalent OD with markedly different tip designs, produced leaks of similar magnitude (table 2) despite very different trauma patterns (figs. 2C and D). The large crescentic flap produced by the Crawford needle may be a reason for the low leak rate obtained with this needle.

Similar to spinal needle studies, cerebrospinal fluid leak was found to be less with a noncutting-tip epidural needle (Special Sprotte®) than with a cutting needle (Tuohy) of the same gauge.[11,13,14] The angle of puncture reduced leak only for the cutting-tip needle. Reductions did not reach statistical significance in either case (table 3).

Bevel orientation at the time of puncture has demonstrated inconsistent effects on cerebrospinal fluid leak and PDPH in spinal needle studies.[11,15,16] Results with an 18-gauge Tuohy epidural needle showed larger mean leak rates after parallel puncture compared with perpendicular puncture, but these differences did not reach statistical significance. The individual data points consistently suggest similar or greater leak rates after parallel (rather than perpendicular) puncture. The larger, crescentic flap found with perpendicular punctures may help to explain the differences in leak rate related to bevel orientation. These results are not in accordance with those of a clinical study reporting a greater incidence of PDPH and epidural blood patch after perpendicular (*vs.* parallel) punctures in parturients.[20] It should be noted that our study examined the effect of bevel orientation on cerebrospinal fluid leak for the 18-gauge Tuohy needle only. These findings may vary between needle types. Further study is warranted.

Spinal needle studies have reported that cerebrospinal fluid leak decreases over time and may stop completely, a phenomenon attributed to viscoelastic properties of the dura and hole retraction.[11,12,14,21] In all parts of this study, statistically significant decreases in leak rate were found over the first hour after puncture. However, in no instance was there complete cessation of leak related to this phenomenon.

A second phenomenon was found when cerebrospinal fluid leak was either completely absent after needle withdrawal or markedly lower than comparative punctures performed under standardized conditions. Scanning electron microscopy of these specimens showed complete or partial plugging of the puncture sites with what seems to be dural tissue fragments. This finding affords a plausible mechanism for the observed absence of PDPH development in 20–30% of patients after recognized epidural needle puncture.

Little attention has been given to the role of dural structure on cerebrospinal fluid leak after puncture. The observation that grossly transparent tissue leaks at a greater rate than grossly normal-appearing dura suggests that differences in dural stroma may also predispose some patients to greater leak and presumably PDPH.

This *in vitro* investigation has limitations, including the relatively small number of cadavers used (n = 20) and the absence of an epidural space in the model. No attempt was made to examine the propensity of the needles themselves to pierce dura, a factor that probably varies between needle types. The absence of protein in the artificial cerebrospinal fluid used may have influenced absolute leak rate measurements, although relative leak rates are probably comparable. Minor differences in the rate of needle advancement at the time of puncture might have had some impact on dural trauma patterns and leak, although overall, these were performed in a uniform fashion.

Other elements of the model design suggest that it demonstrates face and content validity. These include (1) the human lumbar spine dimensions of the model used, (2) the preservation of *in vivo* orientation of dural tissue specimens, (3) use of physiologic cerebrospinal fluid pressures at the time of puncture and during leak measurement, (4) observed dural tenting during puncture, and (5) findings consistent with earlier work related to spinal needle gauge and tip design.

The results suggest that use of a 20-gauge Tuohy needle significantly reduces cerebrospinal fluid leak rate compared with larger epidural needles. The feasibility of using such small needles for continuous epidural analgesia or anesthesia in adults and the impact on PDPH awaits further study.

The authors thank Susan Cromwell, P.A., and Anna Marie Moscoluk, B.A., P.A. (Pathology Assistants, Department of Pathology); Shan Balasubramanian, R.R.T. (Department of Anesthesia); Frank Brommecker, B.Sc.Phm., Michael Ritchie, B.Sc.Phm., and staff (Pharmacy Department); Michael Wong, L.B.I.P.P. (Audio Visual Department); Weddad 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 Women's College Campus, Sunnybrook and Women's College Health Sciences Center, Toronto, Ontario, Canada; Jack Butany, M.D., F.R.C.P.C. (Chief, Department of Pathology, Toronto Hospital, Toronto, Ontario, Canada); William Halliday, M.D., F.R.C.P.C. (Chief, Department of Neuropathology, Toronto Western Hospital, Toronto, Ontario, Canada); and Aina Tilups, B.Sc., R.T. (Electron Microscopy Laboratory, Hospital for Sick Children, Toronto, Ontario, Canada). The authors also thank Stephen Halpern, M.D., F.R.C.P.C. (Women's College Campus, Sunnybrook and Women's College Health Sciences Centre, Toronto, Ontario, Canada); and Joanne Douglas, M.D., F.R.C.P.C. (British Columbia Women's Hospital, University of British Columbia, British Columbia, Canada) for reviewing the manuscript and for their helpful comments and suggestions.

References

1. Kunkle EC, Ray BS, Wolff HG: Experimental studies on headache: Analysis of the headache associated with changes in intracranial pressure. Arch Neurol and Psychiat (Chicago) 1943; 49:323–58
2. Fay T: A new test for the diagnosis of certain headaches: The cephalalgiogram. Diseases of the Nervous System 1940(Oct. 8):312–5
3. Holst D, Mollman M, Ebel C, Hausman R, Wendt M: In vitro investigation of cerebrospinal fluid leakage after dural puncture with various spinal needles. Anesth Analg 1998; 87:1331–5
4. Hopkinson JM, Samaan AK, Russel IF, Birks RJ, Patrick MR: A comparative multicentre trial of spinal needles for caesarean section. Anaesthesia 1997; 52:1005–11
5. Halpern S, Preston R: Postdural puncture headache and spinal needle design: Meta-analyses. Anesthesiology 1994; 81:1376–83
6. Berger CW, Crosby ET, Grodecki W: North American survey of the management of dural puncture occurring during labour epidural analgesia. Can J Anaesth 1998; 45:110–4
7. Stride PC, Cooper GM: Dural taps revisited: A 20 year survey from Birmingham Maternity Hospital. Anaesthesia 1993; 48:247–55
8. Banks S, Paech M, Gurrin L: An audit of epidural blood patch after accidental dural puncture with a Tuohy needle in obstetric patients. Int J Obstet Anesth 2001; 10:172–6
9. Reynolds F: Dural puncture and headache, Regional Analgesia in Obstetrics: A Millennium Update. Edited by Reynolds F. London, Springer-Verlag, 2000, pp 307–19
10. MacArthur C, Lewis M, Knox EG: Accidental dural puncture in obstetric patients and long term symptoms. BMJ 1993; 306:883–5
11. Cruickshank RH, Hopkinson JM: Fluid flow through dural puncture sites: An in vitro comparison of needle point types. Anaesthesia 1989; 44:415–8
12. Dittmann M, Schafer HG, Ulrich J, Bond-Taylor W: Anatomical re-evaluation of lumbar dura mater with regard to postspinal headache: Effect of dural puncture. Anaesthesia 1988; 43:635–7
13. Ready LB, Cuplin S, Haschke RH, Nessly M: Spinal needle determinants of rate of transdural fluid leak. Anesth Analg 1989; 69:457–60
14. Hatfalvi BI: Postulated mechanisms for postdural puncture headache and review of laboratory models. Reg Anesth 1995; 20:329–36
15. Ansaloni L, Balzani C, Falaschi F, Paze E: Post-spinal headache after dural puncture with perpendicular or horizontal needle bevel direction: A randomized controlled trial in an African rural hospital. Trop Doct 2000; 30:167–9
16. Mihic DN: Postspinal headache and relationship of needle bevel to longitudinal dural fibers. Reg Anesth 1985; 10:76–81
17. Rasmussen BS, Blom L, Hansen P, Mikkelsen SS: Postspinal headache in young and elderly patients: Two randomized, double-blind studies that compared 20- and 25-gauge spinal needles. Anaesthesia 1989; 44:571–3
18. Lambert DH, Hurley RJ, Hertwig L, Datta S: Role of needle gauge and tip configuration in the production of lumbar puncture headache. Reg Anesth 1997; 22:66–72
19. Aida S, Taga K, Yamakura T, Endoh H, Shimoji K: Headache after attempted epidural block: The role of intrathecal air. Anesthesiology 1998; 88:76–81
20. Norris MC, Leighton BL, DeSimone CA: Needle bevel direction and headache after inadvertent dural puncture. Anesthesiology 1989; 70:729–31
21. Patin DJ, Eckstein EC, Harum K, Pallares VS: Anatomic and biomechanical properties of human lumbar dura mater. Anesth Analg 1993; 76:535–40