

# THE EFFECT OF SPINAL NEEDLE DESIGN, SIZE, AND PENETRATION ANGLE ON DURAL PUNCTURE CEREBRAL SPINAL FLUID LOSS

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*Postdural puncture headache (PDPH) is a debilitating side effect of spinal anesthesia, the result of dural puncture and cerebrospinal fluid (CSF) leakage with an incidence of 3% to 75% in patient populations. Despite numerous in vitro and in vivo studies that have identified predictors associated with PDPH, debate continues on the best technique to reduce CSF leak after dural puncture. The purpose of this in vitro study was to evaluate the relationship between spinal needle type (pencil tipped or cutting), needle size (22 or 25 gauge), and dura penetration angle from perpendicular (90° or 30°), with the resulting CSF leak measured after dural puncture. Spinal needle designs continue to be stud-*

*ied and modified to reduce the incidence of PDPH in identified high-risk groups.*

*For the study, 103 cadaver dura samples were punctured with randomly assigned needles at predetermined angles. The relationship between variables was analyzed. Our results found between needle tip designs a 5-fold increase in mean leak (Quincke > Whitacre) and between needle diameters (25 > 22 gauge), a 6-fold greater mean leakage. Puncture angle demonstrated no significant effect.*

**Key words:** Cerebrospinal fluid leak, dural puncture, postdural puncture headache, spinal headache, spinal needle design.

**P**ostdural puncture headache (PDPH) is a side effect of spinal anesthesia caused by needle penetration of the dural sheath, thereby leading to cerebrospinal fluid (CSF) leakage. The effects of PDPH are debilitating to the patient, and, if severe, can outweigh the benefits of spinal anesthesia. The reported incidence of PDPH has a large range, from 1% to 75%.<sup>1</sup> Retrospective demographic reviews of persons experiencing PDPH identify young adults (20-29 years old), females, and patients with a history of PDPH at greatest risk.<sup>1</sup> In addition, studies designed to determine factors that minimize the incidence of PDPH have consistently identified a relationship with needle size (gauge), needle tip design, and bevel orientation to dural fibers.<sup>2-4</sup> From these studies, it is accepted that the incidence of CSF leakage and, therefore, PDPH are reduced by the use of small-diameter, pencil-point needles and with parallel bevel orientation for cutting needles. Some practitioners have postulated that CSF leak is decreased by penetrating the dura with a cutting needle at a 35° angle. This essentially creates a flap in the tissue, producing a 1-way valve occluding flow.<sup>5</sup>

Despite numerous in vitro and in vivo studies that have identified predictors associated with PDPH, a wide range in the reported incidence reflects the variability of the target samples and techniques used. A

multitude of demographic variables along specified strata, including gender, surgical procedures, age, history of PDPH, needle size, and needle design make this an area of continued research.

When reviewing the incidence of PDPH, needle size or gauge is a variable of concern in spinal anesthesia. It is reported that as little as 20 mL of CSF drainage consistently leads to intense intracranial headaches.<sup>6</sup> Logically, it can be assumed that the larger the needle diameter, the greater the risk of CSF leakage. An in vitro study by Holst and colleagues<sup>2</sup> was conducted comparing needle gauges and the amount of CSF loss. They demonstrated a positive correlation in needle diameter and CSF loss. With 22-, 25-, 27-, and 29-gauge Quincke needles, measured losses were 116, 54.6, 31.2, and 16.2 mL, respectively. Results from 24- and 25-gauge Sprotte needles yielded an average fluid loss of 40.3 and 22.5 mL, respectively. With 25-, 26-, and 27-gauge Whitacre needles, average CSF leakage was produced in declining amounts, 25.5, 17.2, and 11.8 mL, respectively. The needle design and size that produced the least CSF leakage was the 26-gauge Atraucan (B. Braun Medical Inc., Bethlehem, Pa), which produced a measured leak of 9.4 mL.<sup>2</sup> Additional in vitro studies involving epidural needles, which have significantly larger diameters than spinal needles, reported similar results with a larger CSF leak

when the dura was punctured with a larger diameter needle.<sup>7</sup> The research consistently concludes that larger diameter needles lead to greater CSF leakage following dural puncture.

Spinal needle tip design is also of interest when studied in relation to the incidence of PDPH. Vallejo and colleagues<sup>4</sup> conducted a study comparing 5 spinal needles and their associated incidence of PDPH in 965 women. The study demonstrated a 9% incidence of PDPH in 172 patients receiving a spinal anesthetic with a cutting tip Quincke needle. Comparatively, the incidence of PDPH with 3 pencil-point needles, Sprotte (211 patients), Gertie-Marx (201 patients), and Whitacre (201 patients) was 2.8%, 4%, and 3.1% incidence, respectively. The Atraucan needle incorporates elements of the cutting and pencil-tipped designs but is classified as a cutting tip. In 180 patients, only 5% had PDPH. The study demonstrated that the Atraucan needle had a lower incidence of PDPH than the other cutting-tip needle (Quincke). The population recruited for this study was limited to women receiving spinal anesthesia at parturition.

A comparison by Pan et al<sup>3</sup> of Atraucan and Whitacre needles produced similar incidences of PDPH: Atraucan, 3.9%; and Whitacre, 4%. An important variation in the study results was the duration of headaches experienced in both groups. The study by Pan et al<sup>3</sup> showed similar headache duration. In contrast, Holst et al<sup>2</sup> reported that Atraucan needle groups experienced headache symptoms for 5 days, which, on average, was 10 days shorter than the Whitacre patient groups (15 days). As previously mentioned, the in vitro study conducted by Holst et al<sup>2</sup> examined CSF leakage through dura punctured by 4 needle types. Their study showed a 2- to 3-fold greater loss of CSF for the cutting (Quincke) tips than for pencil points (Whitacre and Sprotte). The Atraucan needle showed the least CSF loss compared with all other needle types. Overall, these studies suggest the cutting-type needle produces a higher incidence of CSF leak and PDPH.

The approach angle is a third variable frequently studied in relation to the incidence of PDPH. A retrospective analysis of 4,465 spinal anesthetics by Hatfalvi<sup>5</sup> using a lateral approach resulted in a zero incidence of PDPH. From this result, he hypothesized that the more acute angle of dural puncture created a flap in the tissue that self-sealed the hole, lowering the amount of CSF leak. He subsequently performed an in vitro study using cadaver dura and compared dural leak after 90° and 35° puncture angles using 20-, 22-, and 25-gauge cutting needles. In the study, 324 punc-

**Table 1. Experiment cerebrospinal fluid\***

<b>Solute</b>	<b>Final concentration mixed (mmol/L)†</b>
Sodium	147
Potassium	2.88
Chloride	1.0
Phosphate	1.0
Calcium	1.15
Magnesium	1.10
Sulfate	1.10
Bicarbonate	23.19
Glucose (mg/L)	5,410

\* Each component was added in its appropriate amount per liter of distilled water to reach the desired molar concentration. The final concentration closely approximated physiologic cerebrospinal fluid molarity.

† Unless otherwise indicated.

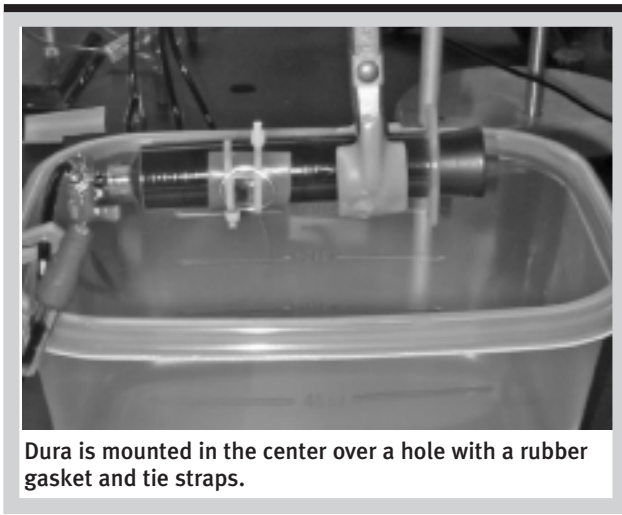
tures were performed, and a visual qualitative analysis demonstrated that punctures at an angle of 35° consistently resulted in flap closure, whereas the 90° puncture created a continuous leak.<sup>5</sup>

Current studies and literature tend to promote the belief that a lower incidence of PDPH is associated with pencil-tipped needle designs, smaller needle diameters, and parallel bevel orientation. Spinal needle designs continue to be studied and modified to reduce the incidence of PDPH in identified high-risk groups. Despite this, there remains debate among practitioners regarding the optimal needle tip design, gauge, and approach angle when performing dural puncture for spinal anesthesia. Our research looks to answer the question: Do needle tip design, size, and approach angle have significant roles in the amount of CSF leak following dural puncture? We predict there will be a reduction in CSF leak with a smaller diameter, pencil-tipped needle and with introduction of cutting needles at a 35° angle to the sagittal dural plane.

## Materials and methods

Approval for the study was granted by the investigational review board. Our study was an in vitro, quasi-experimental, randomized, quantitative design to explore the effect of needle tip design (cutting or pencil) on the amount of CSF leakage following puncture of human cadaver dura at 2 angles of entry (30° and 90°). Four commonly used needle types were compared: 22-gauge Quincke, 25-gauge Quincke, 22-gauge Whitacre, and 25-gauge Whitacre. The Quincke

**Figure 1.** A 20-mL BD syringe (Becton, Dickinson and Company, Franklin Lakes, NJ), stopper at one end and connected to the fluid system with a stopcock at the other end



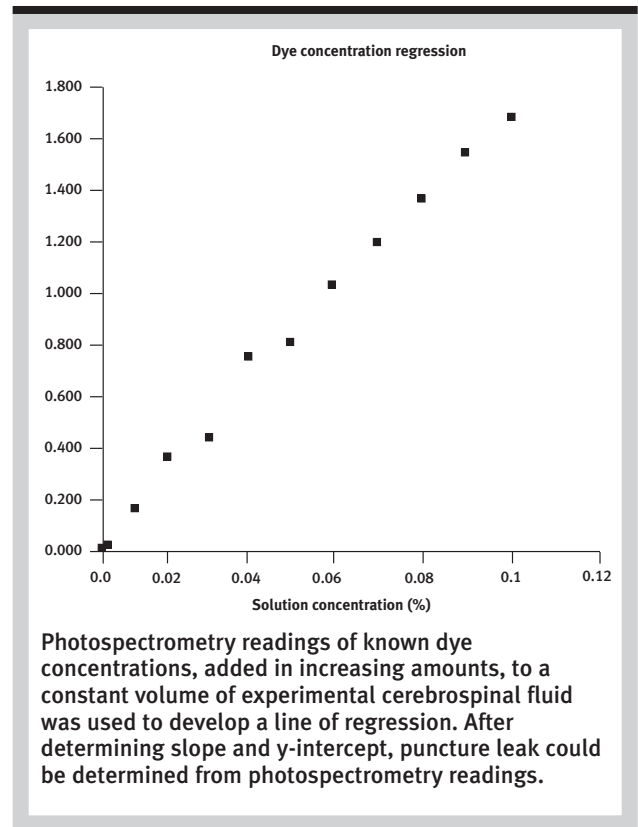
Dura is mounted in the center over a hole with a rubber gasket and tie straps.

needle is described as having a cutting bevel tip. The Whitacre needle has a pencil-point tip that is designed to separate the dural fibers, rather than cut. Full-thickness dura used for experimentation was harvested from 6 cadavers at levels T1 to S1. Demographics, including the age and gender of the donor, cause of death, and comorbidities, were recorded.

The experimental CSF (CSFe) was mixed to approximate physiologic osmolality and solute content of human CSF (Table 1). The calculated total osmolality of 300 mOsm/kg was consistent with human CSF.<sup>7</sup> Following a pilot study designed to test the spectrometer sensitivity, toluidine blue dye was added to the CSFe and mixed to a final concentration of 1%.

The dura sample puncture chamber consisted of a 20-mL BD syringe (Bectin, Dickinson, and Company, Franklin Lakes, NJ) with a rubber stopper at the barrel end and a stopcock connected to the CSFe at the other end (Figure 1). A total of 9 identical test stations were established to run samples simultaneously. The 20-mL syringe was chosen for its size, which closely matches that of the spinal canal, an outer diameter of 2.4 cm.<sup>7</sup> A bath of 300 mL of clear CSFe was used for dura leak collection and measurement. Total puncture leak was measured by the difference created when the dyed syringe chamber CSFe leaked into the clear collection bath. The amount of leakage was then calculated by measuring the concentration of toluidine blue dye in the collection bath. A photospectrometry reading from the collection bath was plotted against a previously computed line of regression, which was

**Figure 2.** Slope and y-intercept line of regression



determined by adding known concentrations of dye to a clear bath solution and then calculating its slope (m) and y-intercept (b) (Figure 2). By using the formula for slope ( $y = mx + b$ ), a linear regression with slope ( $m = 2.996$ ) and y-intercept ( $b = 0.114$ ) allowed us to use our spectrometry readings (x) to determine the amount of leak (y). Following each 60-minute leak period, a sample of the bath fluid was collected and measured in the spectrometer. The amount of leak was calculated and adjusted for time (leak adjusted = time actual x leak actual/60 minutes).

Selection of the body dura source and needle used for puncture were determined using a random number generator assigning the 2 variables in pairs. Samples of the dura, 2 x 2 cm, were dissected from the caudal to cephalad aspect with each sample of the dural sheath. Each dura specimen was mounted and punctured only once. The dura was mounted on the outer surface of the 20-mL syringe barrel, covering a drilled hole and secured by a fenestrated rubber gasket with tie straps (see Figure 2). The hole in the plastic tubing permitted passage of the needle through the dura and allowed the dyed CSFe to leak through the dural puncture into the collection bath. Attention to dural fiber orientation was noted at the time of harvest and mounted longitudinally on the apparatus,

cephalad to the CSF source, caudad to the rubber stopper end. Because the entire sample population could not be mounted and tested in a single run of testing, unmounted dura remained stored in a preservative solution and refrigerated.

Leak testing was performed once the dura was mounted to the sample chamber, filled with dyed CSFe solution, and brought to a test pressure of 10 to 15 mm Hg. The entire apparatus was plunged into the collection bath 5 minutes before puncture and observed for visible leaks. Failed leak tests were identified by discoloration of the CSFe collection bath. Should the sample fail a 5-minute prepuncture leak test, the sample and needle-dura pairing were discarded and the next pairing used. The penetration angle was changed after each 10 samples, beginning with the 90° angle. Orientation of the beveled edge of the cutting Quincke needles were parallel with the longitudinal axis of the dural fibers throughout the experiment. The effect of cutting the dura longitudinally on CSFe leak was not a variable for consideration in this study and was, therefore, not controlled. Data collection for each specimen included the following: needle code, dura code, approach angle, presence of leak, puncture leak time, bath dye concentration, calculated leak, and leak adjusted for time.

Dural puncture was performed, after a negative leak was ensured, with the assigned needle at the predetermined angle. Immediately following puncture, the entire apparatus was rotated downward 90° and plunged 2 cm into a bath of clear CSFe and allowed to leak for at least 60 minutes unless gross leakage was evident. Identified gross leakages were stopped after 30 to 45 minutes and corrected for time as described. The entire system of dyed CSFe was maintained at a measured pressure range of 10 to 15 mm Hg during leak test and puncture measure, thus simulating the CSF pressure generated in the lateral recumbent position.<sup>2</sup> System pressure was measured continuously using a strain-gauge pressure transducer (CardioPac, Datex-Omeda, Madison, Wis). A standard transducer was zeroed at the level of the testing chambers with upper and lower alarm limits set in a central venous pressure monitoring mode (Figure 3).

## Results

A total of 117 dura samples were mounted for puncture, of which 14 were excluded for a positive leak test, lack of suitable dura tissue, or gross contamination of the collection bath after dural puncture (Table 2). This left 103 successful punctures available for data analysis. Random assignment distribution is reported in Tables 3 and 4 for needle and dura. The

**Figure 3. System pressure is ensured with continuous monitoring to maintain 10-15 mm Hg.**



**Table 2. Number of samples and reason for exclusion from data group**

N	Reason for exclusion
10	Failed 5-minute leak test
3	Numbered pairs discarded because of unacceptable tissue
1	Dye splashed into a collection bath following puncture

mean age of the cadavers from which dura was harvested was 80 years. Gender distribution was 4 women and 2 men (Table 5). When leak was compared between needle types, cutting vs pencil tipped, we found a significant difference in the mean  $\pm$  SD rate of leak between the Quincke ( $2.191 \pm 6.146$  mL/h) and Whitacre ( $0.409 \pm 0.348$  mL/h) needles (Table 6). Needle size produced a significant difference only between the 22-gauge Quincke and 25-gauge Whitacre (Table 7) when paired comparisons were performed ( $P = .038$ ). Measured differences between the remaining pairs were not significant for CSFe leak. Surprisingly, needle approach angle was not significant in our results ( $P = .445$ ) (Table 8). The leak did not differ between dural samples.

## Discussion

The data support our hypothesis that a smaller diameter and pencil-tipped needle reduce CSF leakage with dural puncture. This strengthens the current arguments supporting the use of a pencil-tipped needle design over a cutting design and when choosing a needle such as a Quincke, using the smallest diameter

**Table 3. Distribution of dura samples used from each cadaver as determined by the random number generator**

		Frequency	Percentage	Valid percentage	Cumulative percentage
Valid	Body 1	22	21.4	21.4	21.4
	Body 2	26	25.2	25.2	46.6
	Body 3	16	15.5	15.5	62.1
	Body 4	11	10.7	10.7	72.8
	Body 5	11	10.7	10.7	83.5
	Body 6	17	16.5	16.5	100.0
	Total	103	100.0	100.0	

**Table 4. Distribution of needle types used for dura puncture as determined by the random number generator**

		Frequency	Percentage	Valid percentage	Cumulative percentage
Valid	25-gauge Quincke	19	18.4	18.4	18.4
	25-gauge Whitacre	27	26.2	26.2	44.7
	22-gauge Quincke	30	29.1	29.1	73.8
	22-gauge Whitacre	27	26.2	26.2	100.0
	Total	103	100.0	100.0	

**Table 5. Demographic data for dura sample donors by gender, age, and cause of death**

Gender	Age	Cause of death
M	85	Intracranial bleeding
F	82	Cardiac arrest
F	93	Sepsis
M	91	CHF, diabetes
F	59	Carcinoma, CHF
F	70	MI, sepsis

CHF indicates congestive heart failure; and MI, myocardial infarction.

**Table 6. Leak needle type**

Needle design	Mean	N	SD
Quincke	2.19133	49	6.146439
Whitacre	0.40889	54	0.348466
Total	1.25684	103	4.317578

The mean leak is reported in milliliters and corrected for time to represent a 60-minute interval. N equals the number of dura punctures for each of the needle types. The SD is reported in milliliters.

**Table 7. Corrected leak times (needle type)**

Needle type	Mean	N	SD
25-gauge Quincke	0.47905	19	0.914051
25-gauge Whitacre	0.25793	27	0.080449
22-gauge Quincke	3.27577	30	7.672956
22-gauge Whitacre	0.55985	27	0.440139
Total	1.25684	103	4.317578

The mean leak is reported in milliliters and corrected for time to represent a 60-minute interval. N equals the number of dura punctures for each of the needle types. The SD is reported in milliliters.

**Table 8. Corrected leak times (needle puncture angle)**

Needle puncture angle	Mean	N	SD
90°	1.35661	56	4.163191
30°	1.13798	47	4.537144
Total	1.25684	103	4.317578

The mean leak is reported in milliliters and corrected for time to represent a 60-minute interval. N equals the number of dura punctures for each of the needle types. The SD is reported in milliliters.

available. The third variable in our hypothesis, an approach angle of 30° vs 90° yielded no significant difference. Due to the limited sample size, this result cannot challenge or support previously reported research noting the self-sealing hole postulation.<sup>5</sup> Of note, 3% of the measured leaks were sufficiently great, more than 20 mL/h, to potentiate a PDPH.

Improvements to strengthen the study include increasing the sample size and restricting the reuse of needles. Our sample size was limited by a lack of available dura; some dura was no longer suitable for testing near the end of our study due to tissue deterioration. The small sample groups and the advanced mean age were additional limiting factors. Given a greater amount of tissue with a wider range in age, we believe our data would have supported our hypotheses. The reuse of needles did not likely impact our study significantly because the needles were used solely for puncture of the dura. We did not have to traverse layers of tissue normally encountered for spinal anesthesia, which might alter the needle tip. We considered the possible impact on dura puncture when striking bone before successful subarachnoid entry, but decided this subject warrants study on its own.

Another limitation was the use of cadaver dura, which probably varies physiologically from living tissue. Reports that an inflammatory response may contribute to less leakage with the pencil-tipped needle cannot be evaluated in the in vitro setting.<sup>8</sup> It is difficult to extrapolate data found using cadaver dura that has been processed with embalming fluids to the experience of PDPH in the clinical setting.

## Conclusion

The use of a smaller diameter and pencil-tipped needle will cause less CSF leakage through human dura. It is accepted that this CSF leakage is the contributing cause of the PDPH associated with spinal anesthesia. This study was unique because it measured dye concentration change between fluid compartments after dural puncture. This method gave greater accuracy in leakage measurement by not being subject to the difficulties encountered when trying to weigh or physically measure small fluid leaks from dural punctures.

Given the congruence of our study findings with those in other published results, we suggest future study of practitioner technique and needle preference associated with variables such as patient population and institution practice and the outcomes of these decisions related to incidence of PDPH.

## REFERENCES

1. Davignon K, Dennehy K. Update on postdural puncture headache. *Int Anesthesiol Clin*. 2002;40:89-102.
2. Holst D, Mollmann M, Ebel C, Hausman R, Wendt M. In vitro investigation of cerebrospinal fluid leakage after dural puncture with various spinal needles. *Anesth Analg*. 1998;87:1331-1335.
3. Pan P, Fragneto R, Moore C, Ross V. Incidence of postdural puncture headache and backache, and success rate of dural puncture: comparison of two spinal needle designs. *South Med J*. 2004;97:359-363.
4. Vallejo M, Mandell G, Sabo D, Ramanathan S. Postdural puncture headache: a randomized comparison of five spinal needles in obstetric patients. *Anesth Analg*. 2000;91:916-920.
5. Hatfalvi BI. Postulated mechanisms for post dural puncture headache. *Reg Anesth*. 1995;20:329-336.
6. Guyton A, Hall J. *Textbook of Medical Physiology*. 10th ed. Philadelphia, Pa: WB Saunders Co; 2000:561.
7. Angle P, Kronberg J, Thompson D, et al. Dural tissue trauma and cerebrospinal fluid leak after epidural needle puncture. *Anesthesiology*. 2003;99:1376-1382.
8. Reina MA, de Leon-Casasola OA, Lopez A, De Andres J, Martin S, Mora M. An in vitro study of dural lesions produced by 25-gauge Quincke and Whitacre needles evaluated by scanning electron microscopy. *Reg Anesth Pain Med*. 2000;25:393-403.

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