Postulated Mechanisms for Post Dural Puncture Headache:
Clinical Experience and Review Of Laboratory Models

In the 1950's, the generally accepted theory for the development of post dural puncture headache (PDPH) was leakage of cerebrospinal fluid via the hole in the dura which led to the introduction of smaller sized needles for dural puncture. This has lowered but not eliminated the incidence of PDPH. The literature has virtually as many different statistics on the incidence of PDPH as there are authors. The purpose of this manuscript is to answer the following question: "Why doesn't every patient have PDPH after a dural puncture?" The answer to this question holds the key to eliminating the problem of PDPH. For the first time, it is possible to investigate the reasons for the absence of PDPH. Specifically, the bending of the needle is presented as the major factor why so many patients do not get PDPH. The author's experience with 4465 spinal anesthetics using a 20 gauge sharp beveled needle with the lateral approach and without apparent headache suggested a review to determine whether the angle of puncture is related to the incidence of PDPH. This review will attempt to answer this question by elucidating laboratory work done in this area, citing clinical studies, and including personal observations and experiments.

INTRODUCTION

In 1954, the author administered his first spinal anesthetic. After several unsuccessful attempts at the midline approach, a lateral approach was suggested by the instructor as a technique useful in "difficult" situations. The technique was so easy to perform that since then the author has exclusively used the lateral approach with a 20-gauge Becton Dickinson (B-D) Quincke point needle. Over a period of 20 years, from 1954 to 1973, according to a recounted retrospective survey of the annual reports and records, 4465 spinal anesthetics were performed by the author and by residents under his close supervision utilizing the lateral approach. All were without headache, although this information was retrospectively collected. (This information is provided not as a proof of the author's hypothesis but simply as a comment as to the motivation for this study.) For these cases, spinal anesthesia was used in any procedure which could be performed under spinal anesthesia. The incidence of headache was documented by the mandatory visit (next day) and discharge note of the anesthesia service. All patients were encouraged, where appropriate, to ambulate as early as possible, and not to force fluids. The apparent absence of headache in 4465 consecutive spinal anesthesia cases was the impetus to study the difference between lateral and midline puncture of the dura.

In the midline approach, the spinal needle is introduced in the midline of the interspace in a direction perpendicular to all planes of the back. The author's technique is the lateral approach, in which a 20 gauge sharp beveled B-D needle is introduced about 3 cm lateral to the midline opposite the center of the interspace. The spinal may be done in a sitting or lying position with a relaxed patient positioned by an assistant. The most important landmark is the line between the posterior superior iliac spines. From the chosen interspace (2nd or 3rd lumbar), the index and middle fingers of either hand will slide in a "V" formation from the midline to the right and left, forming a groove with moderate pressure. The skin wheal should be made at the deepest point, in front of the index finger, followed by the piercing with the spinal needle 2 cm deep with the other hand. The bevel should face the skin and be aimed at the midline with about a 25-35 degree angle, with both hands supporting the needle and with both little fingers resting on the patient's back. If the tip of the needle contacts the lamina, it is at the level of the
ligamentum flavum. This can be regarded as a useful landmark. From there, with a short redirection cephalad, the dural puncture can be performed.

LABORATORY STUDIES TO EVALUATE POST DURAL PUNCTURE HEADACHE

Four models were used to study this problem: a human dura model, a lumbar spine model, an artificial dura model, and serial sections of a dural defect.

Human Dura Model

Thirty-six full length human lumbar dura (in normal saline) were obtained from the Pathology Department of Barnes Hospital/Washington University with the permission of the Human Research Committee. The dura thicknesses of five specimens were measured, resulting in an average of 0.61 ± 0.05 mm. (Dittman found thicknesses of 0.5 to 2 mm.) The dura was sealed with a hose clamp (with a 3 mm wide and 5 mm long hole in it) over a 1 cm long and 2 mm wide opening in the middle of a 5 cm long, 3 mm thick, flexible plastic (vinyl) tubing. This tubing, 3 cm in diameter, was closed at both ends with rubber stoppers and connected to a water manometer at one end and a 10 ml syringe at the other. The tubing and syringe were filled with water colored with methylene blue. The entire tube was suspended in a normal saline filled vessel. Pressure in the manometer was set at 200 mm and the dura was ready for a variety of spinal needle punctures (Figures 1, 2, & 3).

The following experiments were performed on the 36 dura specimens with 20, 22, and 25 gauge B-D sharp beveled needles, with a total of 324 punctures:

1. Perpendicular punctures resulted in continuous leakage of fluid, as long as positive pressure existed in the system (Figures 1 and 2). After the pressure went to zero, further re-pressurization of the "dural space" caused more leakage to occur.

2. Puncturing the dura (at 200 mm CSF pressure) at a 35 degree angle with the bevel facing the dura resulted in total fluid pressure loss similar to the previous experiment. However, as soon as pressure was reapplied to the system by a syringe, the leakage ceased immediately and permanently. Despite any pressure change thereafter, from zero to 570 mm, leakage never reappeared. (Figure 3) (Puncture at an angle caused the colored fluid to escape in a stream at the same angle as the puncture itself. In fact, Thorsen made this same observation in his 1947 manuscript.)

3. Measurement of the minimum necessary angle of the needle to expect prompt closure of the valvular opening was done with gradually decreasing angle (i.e., more perpendicular) of the piercing needle (in 5 degree increments) from 45 degrees. When the needle reached 15, 10, and 5 degrees from perpendicular with needles of 20, 22, and 25 gauge respectively, constant leakage occurred with positive system pressure (even after re-pressurization). The angle of 35 degrees provided valvular closure of the punctured opening in all cases.

4. This model presented the opportunity to investigate the importance of the bevel's cutting position relative to the longitudinal fibers of the dura. Numerous punctures revealed that perpendicular punctures will leak, regardless of bevel rotation and size of the needle.

For all three figures (Figures 1, 2, & 3) the normal saline pool was changed after the initial leakage after puncture (down to 0 mm on the manometer), so that the leakage upon re-pressurization of the dura could be observed.

Lumbar Tissue Model

One complete section of second and third lumbar vertebrae was removed from a cadaver by the Department of Anatomy. Needles of various sizes were inserted perpendicularly to the surface at the
midline into the subarachnoid space. An X-ray examination was then carried out to determine the exact position of the needles as affected by the bevel tip. The X-ray indicates that bevel orientation strongly influences the path traversed by a flexible needle (Figure 4).

Bending of the spinal needle was demonstrated, for the first time, on a cadaver's lumbar section. Twenty-two and 25 gauge needles (later with a 21 gauge introducer) were introduced into the midline. X-ray examination demonstrated that the needles pierced the dura tangentially (Figure 4).

**Artificial Tissue Model**

A one cm thick "dura" made from Getz, Nu-Gel elastic dental impression powder illustrated the characteristics of the three primary modes of needle bevel penetration through the dura (Figure 5), as done by the author.

This model (Figure 5) (for illustration and visualization by the reader) shows the characteristics of dural punctures with sharp beveled needles, emphasizing the differences among the primary modes of perpendicular and tangential punctures of the dura.

Figure 5(A) shows a perpendicular puncture of the dura, where the swinging-door-like valvular flap can remain open by the pressure of spinal fluid which is constantly present and can be reproduced by the physical activity of the patient and by negative epidural relative pressure. Thus, the probability of headache is high. Figure 5(B) shows the puncture at an angle with the bevel of the needle facing the operator. The valvular flap is able to turn into the epidural space. Leakage may be maintained by both subarachnoid positive and epidural negative pressures. In this case, pressure from outside the valve, in form of an epidural saline or blood patch, may help to seal off the opening as the two spaces reach equilibrium. Finally, Figure 5(C) illustrates the puncture of the dura which allows for the least or no leak. The valvular flap made by the bevel facing the dura will be able to close itself by means of increased pressure in the subarachnoid space from cerebrospinal fluid restitution and/or early ambulation, cough, stretching, etc.

**Serial Sections of a Dural Defect**

This particularly important achievement of Thorsen was the result of 12 out of 15 laminectomies performed by him for the histologic study of dural punctures done one to eleven days before the expiration of moribund patients. A total of 5766 histological serial sections were performed on the dural defects and reported by Thorsen's pathologist, Ake Lindgren. One of those sections appears as Figure 6. The cutting of all fibers was explicitly demonstrated, rather than the separation of fibers.

The promotion and use of fine needles began in the 1950's as the result of Moore's theory that needle entry into the dura separated the fibers, when the bevel's face was parallel to the dural fibers. However, since PDPH was still a problem, the "obvious" solution was to use smaller needles to separate the fibers by a lesser amount. Ironically, Moore's conclusions had been contradicted years earlier by Thorsen's serial sections, showing conclusively that dural fibers are cut, not separated.

**CLINICAL CORRELATION AND DURAL MODELS**

The author's experience of 4465 consecutive spinal anesthesias without PDPH was the stimulus to investigate whether the dynamics of the above clinical observation and the millions of "uneventful dural punctures" of this century are identical.

**Tangential Puncture Crucial to Headache Prevention**
The above laboratory studies suggest that a tangential puncture, with the bevel facing the dura, is the most critical factor in the avoidance of PDPH. The importance of this bevel position manifests itself after the needle is withdrawn, and the healing process begins to take place. At first there will be an uncontrollable cerebrospinal fluid escape, until pressure equilibrium is established between the two compartments, i.e., epidural and subarachnoid spaces. This phenomenon is repeatedly reproducible on the human dura model due to the fact that fluid will flow from a high pressure area as long as positive pressure exists and an escape route is open. The unequivocal flow of CSF after every dural puncture is a definite impediment to wound healing. However, after a momentary equilibrium, the puncture style shown in Figure 5C will close from CSF restitution, ambulation, etc., and will not re-open, thus preventing headache.

One interesting aspect of this physiologic concept is that it explains why, in spite of the use of larger needles particularly in the first half of this century, 100% PDPH was not encountered or reported in the literature. The closing force on the valvular opening is directly proportional to the area of the valvular flap (by Force = Pressure x Area). Thus, large-needle users actually had the benefit of greater force to close the valvular opening.

**Needle Bending**

The inevitable bending of needles, including the Whitaker pencil-point type, due to tissue resistance has been demonstrated. The degree of bending is influenced significantly by the flexibility of the needle, distance from the skin to the dura, and the density of the tissues in between. Thus, the angle of entry into the subarachnoid space will be increased or decreased, piercing the dura more or less tangentially depending on these factors. In order to appreciate the importance of needle deviation during puncture through different depth and density of tissue, a simple yet very illustrative experiment may be done by the reader. Two objects with extremely high and low density are suggested for puncture, each with a set of 20, and 26 gauge sharp beveled needles. The first object is a 6-8 cm raw potato with both ends cut flat, representing a very dense tissue with high resistance. The second object is a ripe tomato or a 6-8 cm section of banana. This comparison will demonstrate a convincing difference in deflection due to high and low density tissue. (Figure 7)

It is evident that the most important reason that the majority of dural punctures are not complicated with headaches is the inevitable bending and deflection of most customary spinal needles, which causes even midline approaches to puncture the dura somewhat tangentially. Since the needle always bends away from the direction the bevel face is pointing, the bevel will thus be facing the dura upon entry. However, the incident angle may or may not be near the "optimal angle" of 35 degrees found by the author and mentioned earlier (thus the variance in PDPH rates among different groups).

**Age, Gender, and Pregnancy Effects on Tissue Resistance**

Applying anatomic, physiologic and physical factors, the wide discrepancy of PDPH incidence with midline approach by gender, age, and pregnancy, can be explained as follows:

1. In children and women, the distance between the skin and dura is short. Needle bending effect is diminished, and needle entry is more nearly perpendicular. Thus, there is an increased incidence of headaches.

2. Also in women and children, their softer tissues will contribute to diminished needle bending and more perpendicular punctures, with a resulting increased incidence of headaches.

3. During pregnancy, the softness of tissues is accentuated, and the highest incidence of headache occurs.
4. Decreased incidence of headache in the elderly population is due to physiologic factors (aging, dehydration, arthritis, etc.) which contribute to increased tissue density and needle resistance. This results in more needle bending, a more tangential puncture, and thus a lower incidence of headache.

**CLINICAL WORK ON POST-DURAL PUNCTURE HEADACHE**

A small group of investigators7-12 studied "off the midline" approaches.

The most encouraging single finding was in the monograph of Tourtellotte, et al.13: "Thorsen also suggested that a tangential entry of the needle through the dura healed more quickly than a vertical one. This observation should be tested critically." This quotation of Tourtellotte, a neurologist, was published in 1964, 17 years after Thorsen's monograph.2 Thorsen wrote in 1947, "When the direction of puncture was as tangential as possible, leakage often failed to appear completely in spite of considerable pressure." Unfortunately, Thorsen himself expressed his opinion as, "An extreme tangential puncture for valvular closure of the punctured hole is, for anatomic reasons, unfeasible. Accordingly, fine puncture needles were recommended instead at an early date."2

Figure 6, showing the serial sections of a dural defect, was published by Thorsen in 1947, and is the most important and conclusive demonstration of the definite cutting of dural fibers with spinal needles.

It is very important to emphasize that the fiber-separating theory may be in error, as demonstrated in Figure 6. The angle of puncture is the dominant factor in PDPH. Furthermore, the size of conventional needles has nothing to do with the frequency of PDPH. Its control is a clear, simple, and remarkable physiologic phenomenon. Dural punctures cause uncontrollable CSF loss, until pressure equilibrium develops between the positive subarachnoid and negative epidural compartments. In the case of the inward-opening valvular defect (Figure 5C), healing occurs with increased pressure on the valvular flap due to reproduced CSF and/or ambulation, cough, stress, etc. In the case of the outward-opening valvular defect (Figure 5B), healing occurs with the plugging of the extroverted valve by the "tamponage" of previously leaked CSF. The role of CSF in terms of its replacement capacity14 is extremely important (500 ml per 24 hr, or more) in providing the closing force on the valvular opening of tangential dural puncture. It is interesting to note that Brocker's observation of 195815 was rediscovered by others,16,17 and cited a decreased incidence of PDPH when the patient remained in a prone position for 2-4 hours after dural puncture. This phenomenon correlates with this author's study, i.e., that persistent CSF escape after a probable perpendicular puncture will stop and the forthcoming pressure equilibrium will constitute the most important prerequisite for "wound-healing". Actually, a dural defect closure is very similar to a vein or artery puncture where mild pressure of a split second or a couple of minutes, respectively, secures healing, in spite of the bevel piercing in the "wrong" position (Figure 5B). Enlarging the valvular opening by using a large needle will increase the CSF pressure on the valve surface and close the valve forcefully (Figure 5C). Of course, the larger needle will deviate less and allow greater control and more accurate placement of the puncture.

It is worth mentioning that, as an additional advantage of lateral approach with the bevel facing the subarachnoid structures, the likelihood of nerve injuries is diminished.

On the basis of the clinical observation of tangential puncture and in vitro investigations, a new concept and direction is indicated in the elimination of PDPH. Considering the excellent investigation by Ready et. al.,18 illuminating the importance of dural puncture angle, with attention to and inclusion of discussed physiologic factors, the resolution of the century-old problem of PDPH is a reality.

The work of Vandam and Dripps19 is an impressive sample to analyze the past and foresee the possible future of PDPH. Considering this new concept of needle bending (and therefore type of puncture made) as the decisive factor in the occurrence of PDPH, the differing incidence rates in age, sex, and
pregnancy groups represent precisely the physiological factors of every patient in terms of tissue density and depth.

While the cumbersome, time consuming spinal anesthesia with the Greene20 26 gauge needle caused a significant decrease of PDPH (without eliminating it), it did help to promote the development of epidural analgesia (as a substitute for spinal) and eventually "epidural blood patch".

Later Frumin21 with his nearly invisible 32 gauge special B-D needle boldly and heroically tried, albeit unsuccessfully, to eliminate PDPH. This failure was a warning to us to change direction away from finer needles in defeating PDPH.

CONCLUSION

The demographic differences in PDPH incidence rates are well known. Obstetric patients have one of the highest rates of PDPH; elderly patients have nearly the lowest. However, no explanation of these differences has been previously published. The importance of needle entry angle has been shown by Ready et al.18 and others. Yet, this idea of the degree of needle bending as a factor of PDPH incidence has not been previously suggested. Since the density and depth of the material through which the beveled needle travels determines the degree of bending, even midline punctures can and will enter the dura somewhat as though they were done with a lateral approach with the bevel facing the dura. However, since finer beveled needles cannot be controlled as well as large needles in terms of dura entry point (or even dural entry itself), and since there is growing anecdotal and less-than-fully-controlled-study evidence of successful use of lateral approach with large beveled needles in obstetric patients, it seemed reasonable to re-examine the use of larger beveled needles with the lateral approach for the general population. To avoid the need for many practitioners to learn the lateral approach, the author is currently investigating the use of large gauge, slightly bent, beveled needles to allow the same dura entry angle as a lateral approach, but instead with a midline approach.

The inevitable bending of needles, the importance of spinal fluid leakage under pressure, and the tangential puncture of the dura without PDPH (resembling the dynamics and healing process of veins arteries) are points for serious evaluation and research.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Noel N. Grean for her inspiration and support, and Dr. Jonathan S. Jahr for his extensive editing of this manuscript. The initial support of Dr. A. Roos and Dr. Glenn Weygandt for this investigation has been very much appreciated, as well as the continued support of Dr. Susan Krechel. The generous contributions of time and effort by Peter, Catherine, and Emil Hatfalvi in preparing and editing this manuscript are gratefully acknowledged.

REFERENCES


Figure 1.
Minor leakage after perpendicular puncture with 25 gauge needle.
Figure 2.

Significant leakage after perpendicular puncture with 20 gauge needle.
Figure 3.
No leakage after lateral puncture with 20 gauge needle, bevel down.
Figure 4.
Deviation of 22 and 25 gauge needles, with bevels facing each other.

Figure 5.
(A) Perpendicular puncture. Valve can open in either direction depending on pressure differential.
(B) Bevel away from dura. Valve can be kept open (outward from dura) by CSF pressure.
(C) Bevel facing the dura. Ideal puncture for closure. Headache is avoidable.
Serial sections from the margins and the central part of a dural defect.

(Courtesy of Acta Chir Scand)
Figure 7(a).
Deviation difference: 20 gauge Quincke needles through potato (left) and banana (right)
(bevel facing left).

Figure 7(b).
Deviation difference: 26 gauge Quincke needles through potato (left) and banana (right)
(bevel facing left)