

# How much work is required to puncture dura with Tuohy needles?

M. C. Lewis\*, J. P. Lafferty, M. S. Sacks, V. S. Pallares and M. TerRiet

Departments of Anesthesiology, and Biomedical Engineering, Veterans Affairs Medical Center/Jackson Memorial Medical Center, University of Miami, Miami, FL, USA

\*Corresponding author: Anesthesiology Service (139), Veterans Affairs Medical Center, 1201 NW 16th Street, Miami, FL 33125, USA

The effects of needle bevel orientation and cerebrospinal fluid (CSF) pressure on dural displacement and force required to penetrate cadaveric dura were studied using 40 samples. A constant hydrostatic pressure was applied to the subdural surface, either high or low, simulating the sitting and lateral positions. A 17-gauge Tuohy needle was advanced through the dura with the bevel oriented parallel or perpendicular to dural fibres. Travel distance and peak force at which dural penetration occurred were measured under both pressure conditions. The work required to produce dural penetration was calculated. Greater force and work were required to penetrate dura in the perpendicular orientation ( $P < 0.05$ ), regardless of the subdural pressure exerted. Dural displacement was similar under both pressure conditions.

*Br J Anaesth* 2000; **85**: 238–41

**Keywords:** dural leak, dural penetration, dural tenting; epidural needle orientation; position simulation

Accepted for publication: February 15, 2000

Headache occurs in up to 85% of patients following dural puncture with a 17-gauge Tuohy needle,<sup>1</sup> causing significant perioperative morbidity. Some of the differences in the force required for dural penetration with different bevel positions and dural stress may be accounted for in terms of the dura's biomechanical properties.<sup>2</sup> Dural bulging may occur in the sitting position, as cerebrospinal fluid (CSF) pressures are higher,<sup>3</sup> possibly increasing the tendency for puncture, as compared with the lateral or prone positions. Data derived from spinal anaesthesia studies<sup>4</sup> have led to the practice of entering the epidural space with the needle positioned parallel to the fibres,<sup>5</sup> and then rotating the needle to insert the epidural catheter. CSF leakage would be minimized<sup>1</sup> if dural puncture occurred with the needle bevel oriented parallel to the fibre direction. This study was designed to evaluate whether bevel orientation or patient position alters the force necessary to produce dural puncture. In addition, we examined the effect of bevel orientation and patient position on maximal dural tenting before dural penetration. The work (force  $\times$  dural displacement) required to produce dural penetration was calculated for all conditions.

## Methods

Ten posterior lumbar cadaveric dura samples were harvested, trimmed to strips, and then stored in normal

saline at 3°C until use. All samples were obtained from adults.

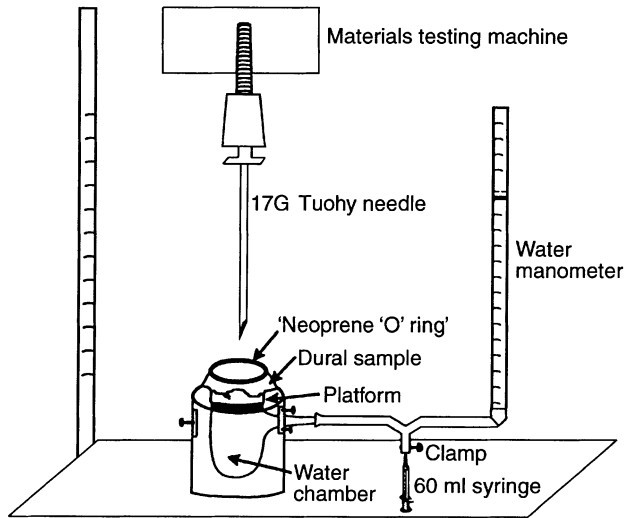
A neoprene-O-ring placed on a metal platform (Fig. 1) was used to hold dura tightly, and pressure was applied to the subdural surface. Two pressures were used: 65 cm H<sub>2</sub>O (which simulates the sitting position) and 5 cm H<sub>2</sub>O (which simulates the supine or lateral position).<sup>1,3</sup> The sitting simulation pressure was slightly greater than that demonstrated *in vivo* in the literature, so that we could see bulging of the dural sample. A water manometer was used to measure these pressures, which were held constant throughout each experiment.

In order to achieve appropriately blunted needles for the experimental situation, 17-gauge Tuohy needles, which had been used previously in one single atraumatic epidural catheter insertion, were collected. Such bluntness simulates changes that occur in the *in vivo* situation due to passage through tissues prior to reaching the dura. Subsequently, each needle was used for eight dural punctures (two punctures in two dural strips, at each of the four simulations), and then discarded.

A materials testing machine (Instron Model 1000 Canton, MA, USA) was used to manipulate the Tuohy needle on all dural samples. This device is capable of advancing the needle at 20 mm min<sup>-1</sup>, while measuring travel distance (i.e. dural tenting), resistance and the peak force required for dural penetration.

Four conditions were tested in each of the dural strips, measuring force and total travel before penetration in each of these simulations.

- (1) Bevel parallel to the longitudinal fibres, supine position simulation.
- (2) Bevel parallel to the longitudinal fibres, sitting position simulation.
- (3) Bevel perpendicular to the longitudinal fibres, supine position simulation.



**Fig 1** The dural sample is mounted on a metal platform, and held in position by a neoprene-O-ring. Constant pressure is applied to the subarachnoid surface using a water manometer. The machine advances the needle and is capable of measuring the total distance travelled and the peak force at the point of dural penetration.

- (4) Bevel perpendicular to the longitudinal fibres, sitting position simulation.

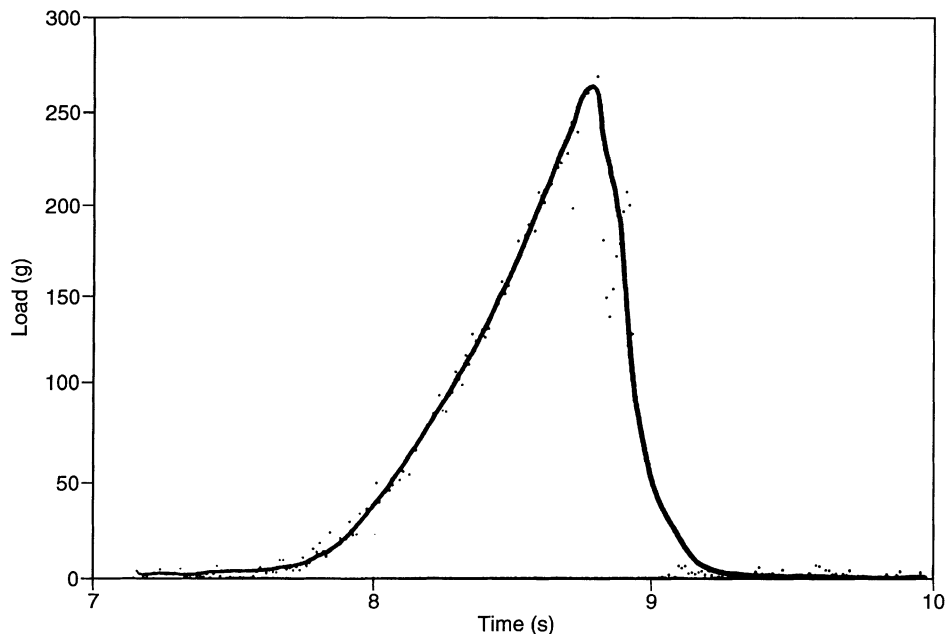
Data were analysed using the pooled *t*-test with  $P < 0.05$  being considered significant.

A total of 10 dural samples was examined, under the four conditions outlined above; the total number was 40 simulations. Samples with artefacts in the tracings, or accidental puncture of the dura before measurement were excluded. Work required for dural penetration in each test was calculated using the data the force needed for dural penetration, and measurement of needle travel distance (work=force×distance).

### Results

A typical tracing obtained from the Instron 1000 is illustrated in Fig. 2. A mean (SEM) of 5.66 (1.21) Newtons (100 g=0.98 N) was required to penetrate the dura with the bevel oriented parallel in the supine simulation and 5.50 (1.33) N in the sitting simulation (NS) (Table 1). When the needle bevel was oriented perpendicularly to dura fibres, a 35% greater force was required in the supine simulation (7.66 (2.47) N). In the sitting simulation, a force of 7.39 (2.06) N was required to pierce the dura. This is 1.89 N more force than was required in the parallel orientation, sitting position (5.50 (1.33) N). The force required for dural penetration with perpendicular orientation in both simulations was significantly greater than that of parallel orientation in equivalent simulations ( $P < 0.05$ ).

The mean peak travel (dural displacement prior to penetration) was 0.33 cm (Table 2). This did not differ in



**Fig 2** Graph of load (g) (100 g=0.98 N) plotted against time (s). Maximum load is represented by the peak of the graph. Because the tracing is at a speed of 20 mm min<sup>-1</sup> one can calculate the maximum dural displacement by measuring the width of the displacement curve (s) and calculating the distance travelled by the needle in that time. Note the abrupt downward swing of the tracing on dural penetration.

the two patient position simulations or with bevel orientation ( $P>0.05$ ).

The work at maximum load is obtained from measuring the area under the force versus maximum displacement curve. Table 3 summarizes the data for work at maximum load for all conditions. In the parallel orientation, supine simulation, the work at maximum load was 52.83 (20.39) N mm<sup>-1</sup> which did not differ from the sitting simulation. However, this value was greater in the perpendicular orientation at both position simulations ( $P<0.05$ ).

In eight experiments using the parallel orientation, an 'early leak' was noted prior to dural penetration, that is fluid was noted on the epidural surface around the needle tip prior to puncture. This was not seen, however, with the needle oriented in the perpendicular plane.

## Discussion

The product of the force applied to a body and its displacement is termed work, which is represented by the area under the force versus dural displacement curve. Classically, most lumbar dural elastic fibres were thought to run in a longitudinal direction,<sup>2,6</sup> however, recent studies

have questioned this representation.<sup>7</sup> In the classical model, fewer fibres are cut with the parallel as compared with the perpendicular orientation,<sup>8</sup> and less work may be required for dural penetration. Our data show that work was significantly increased in the perpendicular as compared to the parallel orientation ( $P<0.05$ ), indicating that greater force was required to penetrate the dura. The practice of entering the epidural space with the needle oriented parallel to the fibres is challenged by this finding. Puncture size made by a needle with this orientation may be smaller, but less force would be necessary for dural penetration.

The rationale for using the parallel bevel orientation to minimize post-spinal headache came from studies using spinal needles,<sup>4</sup> where the aim is to minimize leakage of CSF and the development of post-spinal headache. In epidural anaesthesia, the aim is to avoid a dural tear and therefore prevent CSF leakage. Our data show that when the needle bevel is orientated parallel to the dural fibre direction less force is required to produce perforation. If an epidural needle is introduced into the peridural space with the longitudinal orientation of the bevel, then it must be rotated 90° before introducing the catheter. Such a manoeuvre may increase further the likelihood of tearing the dura.<sup>9</sup> Therefore, the perpendicular bevel orientation of the Tuohy needle is possibly a technique to avoid such dural tears, and what could be a potentially severe headache from a 17-gauge needle.<sup>1</sup>

Clinical studies have failed to identify an increased risk of dural puncture with the parallel as compared with perpendicular needle bevel orientation.<sup>5</sup> It may be that the differences in penetration between the *in vitro* and *in vivo* condition can be accounted for by the resting tension of the dura. Alternatively, the difference between the clinical situation and our findings may be produced by the experimental method. The needle was advanced on the dural sample at a speed of 20 mm min<sup>-1</sup>. At this slow speed the force required to penetrate the dura may be exaggerated. In addition, the speed of advancement is constant in our experiment. The clinical situation may be marked by variations in the speed of advancement, and the accidental puncture may be related to uncontrolled rapid movement of the needle.

There was no difference in the force producing dural penetrations within needle orientations regardless of the position simulations. We had expected the higher pressure in the sitting position to decrease the force required to puncture the dura. The dura was observed to bulge when pressure was added. Loose lateral fixation of the dura to the bony canal may exaggerate this change *in vivo*, thus the lack of position effect may be related to the experimental method.

The peak travel data suggest that the mechanisms of dural puncture may differ from the presently accepted theory. In our model, when the Tuohy needle was advanced through the centre of the dural sample, it could be displaced 0.35 cm before penetration. Dura is contained within the vertebral

**Table 1** Force (Newtons) required to penetrate the dura. All values are mean (SEM). Greater force was required to penetrate the dura with the needle orientated perpendicular to the fibre direction, in both pressure conditions ( $P<0.05$ ). In both needle orientations there was no difference within the orientation between the sitting and supine conditions

Position orientation	Bevel orientation	
	Parallel	Perpendicular
Supine (N)	5.66 (1.21)	7.66 (2.47)
Sitting	5.50 (1.33)	7.39 (2.06)

**Table 2** Travel (cm) at maximum load prior to dural puncture. This value represents dural displacement. All values are mean (SEM). No significant difference

Position simulation	Bevel orientation	
	Parallel	Perpendicular
Supine (cm)	0.34 (0.16)	0.31 (0.14)
Sitting	0.32 (0.10)	0.31 (0.11)

**Table 3** Work (N mm<sup>-1</sup>) at maximum load. All values are mean (SEM). This value is greater ( $P<0.05$ ) for the perpendicular orientation compared to the parallel, both in the supine and the sitting simulation. There is no significant difference within the needle orientation groups for different position simulations

Position simulation	Bevel orientation	
	Parallel	Perpendicular
Supine (N mm <sup>-1</sup> )	52.8 (20.4)	119.3 (65.0)
Sitting	54.6 (25.2)	100.7 (62.5)

canal. The antero-posterior (A-P) diameter is 1.3 cm, whereas the widest transverse diameter between the intervertebral foramina is 2.2 cm.<sup>10</sup> At the L2 level, the intervertebral foramina are posterior to a frontal plane passing through the midpoint of the A-P diameter. This means that the dura is not tethered at the posterior aspect of the vertebral canal, but at its midpoint just 0.6–0.7 cm from the anterior wall of the canal. If our dural samples are displaced 0.35 cm, the average lumbar dura at its widest point (2.2 cm) would probably ‘tent’ more than this. By applying proportionality it may be assumed that dura can be displaced 0.77 cm *in vivo*. Because the dura is tethered only 0.6 mm from the anterior canal wall, it would be impaled prior to being stretched maximally. This is supported by the work of Holloway and Telford,<sup>11</sup> who found that following identification of the epidural space, the needle was advanced 1–1.5 cm prior to obtaining CSF flow in 75% of patients. This would place the needle tip at the anterior limit of the vertebral canal.

In eight experiments with the needle oriented parallel to the fibres, an ‘early leak’ was noted (i.e. water was noted on the epidural surface prior to actual dural penetration). This may be due to the needle separating the fibres, allowing for some fluid leakage prior to the formation of an actual tract.

In conclusion, our data indicate that more work is required to puncture the dura with the bevel oriented perpendicular to the longitudinal axis. This supports our contention that it may be safer to enter the epidural space with a perpendicularly oriented needle. An ‘early leak’ phenomenon was observed with the needle oriented parallel to the fibres. The clinical significance of this observation and whether it plays a role in the development of postdural

headache in the absence of an observable penetration requires further study.

## References

- 1 Brownbridge P. The management of headache following accidental dural puncture in obstetric patients. *Anaesth Intens Care* 1983; **11**: 4–11
- 2 Patin DJ, Eckstein EC, Harum K, Pallares VS. Anatomy and biomedical properties of human lumbar dura matter. *Anesth Analg* 1993; **76**: 5535–40
- 3 Kunkle CE, Ray BS, Wolff H. Experimental studies of headache. Analysis of headache associated with changes in intracranial pressure. *Arch Neurol Psychiatr* 1943; **49**: 323–58
- 4 Mihic DN. Postspinal headache and the relationship of needle bevel to longitudinal dural fibers. *Reg Anesth* 1985; **10**: 76–81
- 5 Norris MC, Leighton B, DeSimone CA. Needle bevel direction and headache after inadvertent dural puncture. *Anesthesiology* 1989; **70**: 729–31
- 6 Fink BR, Walker S. Orientation of fibers in human dorsal dural matter in relationship to lumbar puncture. *Anesth Analg* 1989; **69**: 768–72
- 7 Dittmann M, Reina MA, Lopez Garcia A. New results in visualization of the dura mater spinalis by scanning electron microscopy. *Anaesthesist* 1998; **47**: 409–413
- 8 Haupt W, Stofft E. Elasticity and tensile strength of human dural matter. *Verhandl Anat Gesellsch* 1978; **72**: 139–44
- 9 Meiklejohn BH. The effect of rotation of an epidural needle. *Anaesthesia* 1987; **42**: 1180–2
- 10 Eisentein S. Measurement of the lumbar canal in two racial groups. *Clin Orthop* 1976; **115**: 42
- 11 Holloway TE, Telford RJ. Observations on deliberate dural puncture with a Tuohy needle: depth measurements. *Anaesthesia* 1991; **46**: 722–4