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Estimation of cerebrospinal fluid pressure via lumbar epidural space by equilibration method

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Abstract: By introducing water into the lumbar epidural space from a vertically held tube under gravity, we measured lumbar epidural pressure (EDP) when the water meniscus no longer declined. In principle, the pressure of either side of dura mater had become equal at this time which is referred to as the equilibrium point. EDP measured in this way was consistently 1–3 mmHg lower than lumbar cerebrospinal fluid pressure (CSFP) not only immediately after the equilibrium point, but also for 5 min after the equilibrium point had been reached. Both EDP and CSFP responded sensitively to the manipulations of CSFP during this period. We suggest that this method may provide a means to continuously monitor CSFP by EDP.

Key words: Cerebrospinal fluid pressure, Dura mater, Epidural space

Introduction

Lumbar epidural pressure (EDP) has been shown to correlate with lumbar cerebrospinal fluid pressure (CSFP) [1–3]. To obtain a measurable EDP, a certain amount of fluid is usually actively injected into the epidural space since there is little substance in the epidural space which can well transmit pressure; then residual EDP is measured. However, residual EDP measured after active injection of water into epidural space should be dependent on the injection speed, the injected volume, and the compliance of the epidural space. Actively injecting fluid into epidural space can sharply increase CSFP, which may cause serious problems in patients with neurological diseases [1,4]. By introducing water into the epidural space under gravity, we developed an equilibration method to make EDP reflect CSFP. This correspondence between EDP and CSFP, which could last for 5 min, may provide a means to continuously estimate CSFP by EDP.

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Materials and methods

Subjects and general procedures

The study was conducted in dogs after the protocol was approved by the Animal Use Committee of University of Tokyo and in humans after obtaining informed consent at preoperative visit. Three mongrel dogs weighing 9–11 kg, 3–5 years of age, were anesthetized with intravenous pentobarbital 25 mg/kg. The dogs breathed spontaneously. A diagram of the design of the measurements is shown in Fig. 1. An epidural puncture was performed with a 17G Tuohy needle at the L2–3 interspace with subjects lying in the left lateral decubitus position. Entry into the epidural space was confirmed by loss of resistance to a water-filled syringe (air was avoided because air in epidural space will affect the measurement of EDP). An 18G catheter was then introduced into epidural space. The external end of the epidural catheter was connected to a vertically held tube (ID 2.5 mm) filled with water as well as to a pressure transducer by a 3-way stopcock. Subarachnoid cannulation was performed at L3–4 as that of epidural space. The outer end of subarachnoid catheter was connected to another pressure transducer. A third 18 G catheter was inserted into the posterior cistern to alter CSFP by injection or withdrawal of fluid. Following these procedures, the dogs were placed in the supine position.

The study in humans involved 6 patients (4 men and 2 women, 20–42 years of age, ASA class I or II) undergoing elective craniotomy for excision of supratentorial neoplasms. All patients were free from cerebrospinal obstruction and disorders of other organs. Before anesthesia was conducted, epidural puncture (G21 spinal

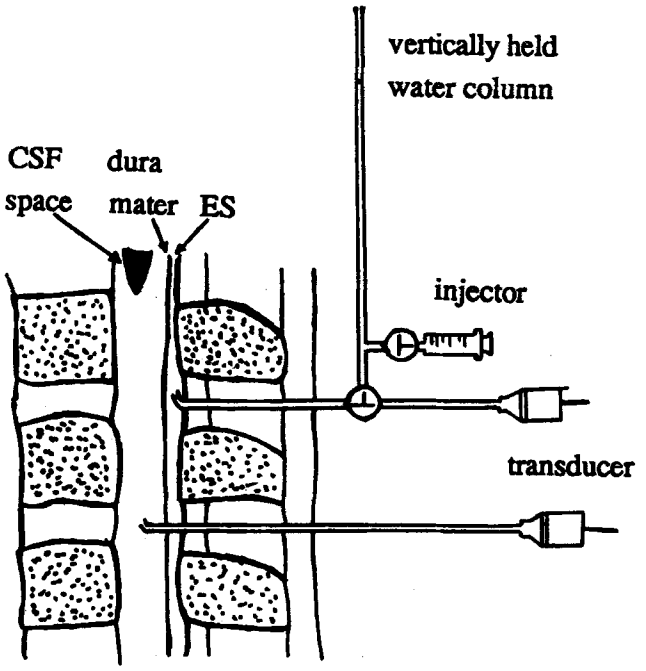


Fig. 1. Diagram of the design of human measurements. *CFS*, subarachnoid space; *ES*, epidural space

needle) and subarachnoid puncture (G23 spinal needle) were performed at the L2–3 and L3–4 interspaces, respectively, with the patients lying in the lateral position. The pressure transducer and the vertically held water tube were connected directly to the epidural needle and another pressure transducer was connected directly to the spinal needle, as in Fig. 1, without placement of the catheter into the epidural or subarachnoid spaces. All EDP and CSFP measurements were conducted before anesthesia.

Measurement of EDP and CSFP

We take the dura mater as a membrane which can transmit pressures between epidural space and subarachnoid space. To measure EDP, the water meniscus in the vertically held tube was raised by injection of water into this tube when this tube was connected to a transducer and disconnected from epidural space by means of a 3-way stopcock. The height of water meniscus should be higher than the anticipated CSFP (in this study, it was set at 30 to 40 cm in subjects with normal CSFP and 70 to 80 cm in those with high CSFP). The vertical water column was then connected both to epidural space and to the transducer. Because of the pressure gradient between the epidural and subarachnoid spaces, water meniscus would decline as water entered the epidural space. As the height of the water column became equal to CSFP, the water meniscus stabilized. At this time point, the pressure in the epidural space should be equal to CSFP because the water column was connected with the epidural space. We refer to this time point as the "equilibrium point." Dura mater can be thought of as the equilibration membrane between the epidural and subarachnoid spaces.

Both in dogs and in humans, as soon as the equilibrium point was achieved, we disconnected the vertically held tube from the system by a 3-way stopcock. The EDP and CSFP were simultaneously measured by the pressure transducers immediately after the equilibrium point was reached. In dogs, we also measured EDP and CSFP continuously for 5 min thereafter to evaluate the possibility of continuously monitoring CSFP by EDP.

Pressures were referenced at the level of the midaxillary line in dogs lying in the supine position and at the level of the spinal cord line in humans lying in the lateral position.

Data analysis

Data were presented as the mean ± SD. Statistics were applied using linear regression, and significance was accepted at a $P < 0.05$.

Results

Water-falling into the epidural space followed an exponential curve (Fig. 2). The equilibrium point was achieved usually at 3–4 min after the start of water-falling. Immediately after the equilibrium point was reached, EDP was consistently 1–3 mmHg lower than CSFP both in dogs and humans (Table 1). EDP correlated well with CSFP both in dogs and humans (Fig. 3). The manipulations of CSFP, including injecting normal saline into the posterior cistern and pressing both sides of the neck (in dogs) and asking patients to cough (in humans), caused simultaneous increases in EDP and CSFP (Fig. 4).

EDP and CSFP were continuously measured for 5 min after the equilibrium point in dogs. During this period, EDP was consistently parallel to CSFP (Fig. 5). Both EDP and CSFP responded sensitively to the manipulations of CSFP.

Water-falling into the epidural space from the vertically held tube under gravity induced a slight and transient increase in CSFP (Fig. 2). Peak increase in CSFP was 2.2 ± 0.4 mmHg in dogs with normal CSFP and 3.6 ± 0.8 mmHg in dogs with high CSFP. Peak increase in CSFP from water-falling appeared after about 20 s. CSFP then decreased slowly and returned to the baseline value in 5–10 min. In humans, we did not record response of CSFP to water-falling into epidural space. Either during water-falling into the epidural space or after the equilibrium point, none of the pa-

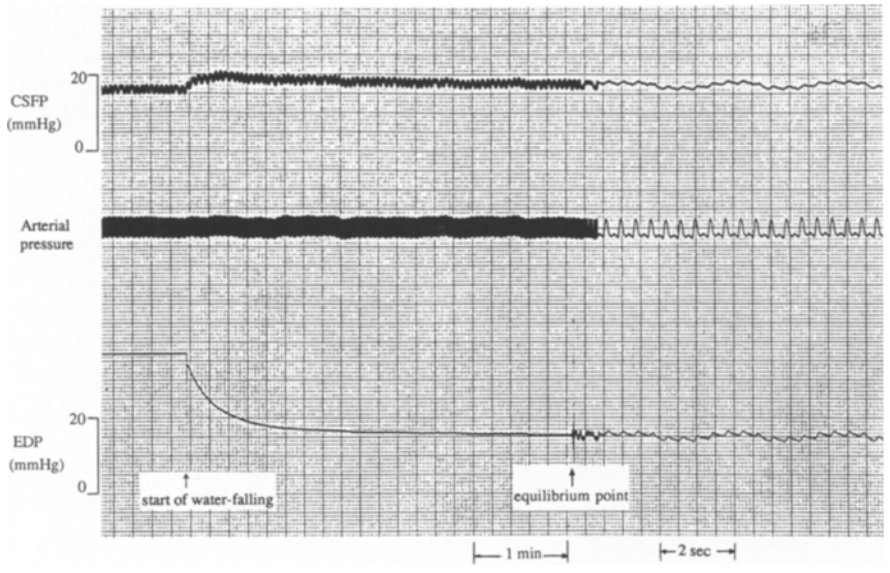


Fig. 2. Water-falling into the lumbar epidural space, which followed an exponential curve, caused a transient and slight increase in cerebrospinal fluid pressure (*CSFP*). When water no longer entered the epidural space (*equilibrium point*), we disconnected the vertical water column from epidural space. Lumbar epidural pressure (*EDP*) was consistent with CSFP immediately after the equilibrium point

Table 1. Lumbar cerebrospinal fluid pressure (CSFP) and lumbar epidural pressure (EDP) immediately after the equilibrium point

	Time of measurement	CSFP (mmHg)	EDP (mmHg)	CSFP-EDP
Dogs with normal CSFP	51	11.5 ± 3.8	9.2 ± 3.8	2.3 ± 0.6
Dogs with high CSFP	20	31.6 ± 10.7	29.6 ± 10.7	1.4 ± 0.6
Humans	26	15.1 ± 5.1	14.4 ± 4.9	0.8 ± 0.7

Mean ± SD.

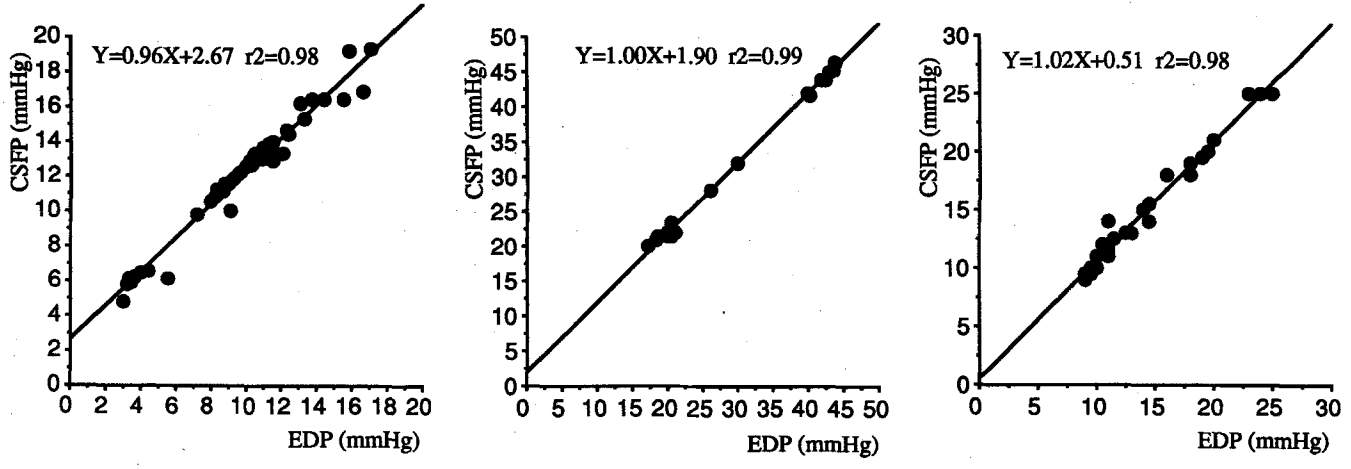


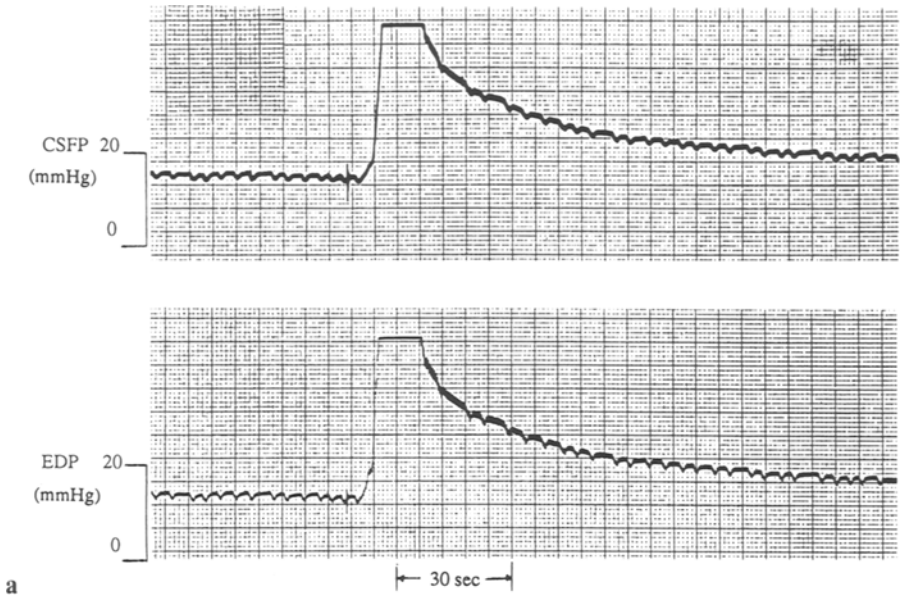
Fig. 3. Relationship between CSFP and lumbar EDP immediately after the equilibrium point in dogs with normal CSFP (*left panel*), in dogs with high CSFP (*middle panel*) and in humans (*rights panel*)

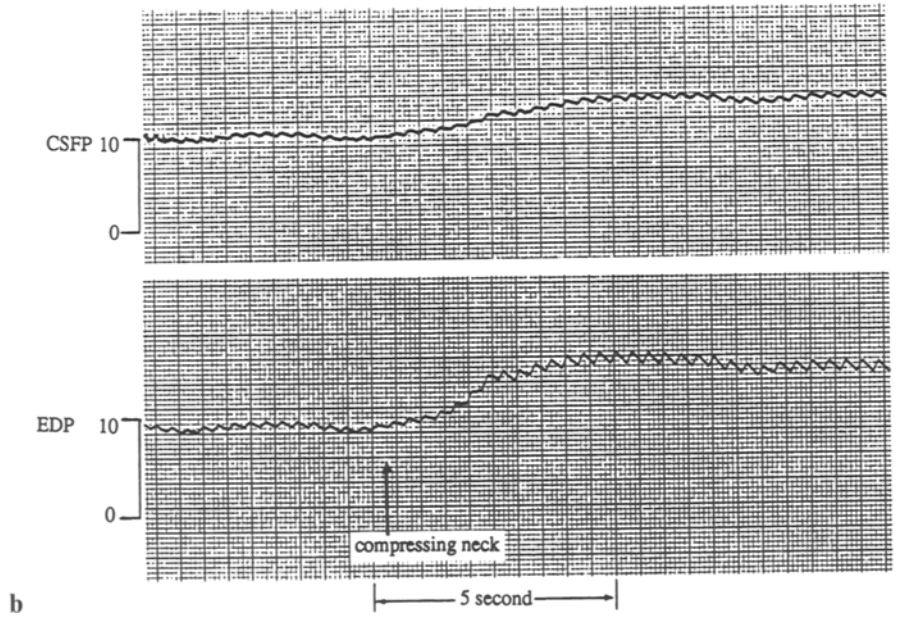
tients complained of discomfort, and there was no complication attributable to the measurements of EDP or CSFP.

Discussion

By introducing water into the epidural space from a vertically held tube in which the height of water was set higher than anticipated CSFP, we found that EDP was consistently 1–3 mmHg lower than CSFP, not only immediately after the equilibrium point, but also for 5 min after the equilibrium point. EDP measured during this period responded sensitively to the manipulations of CSFP.

Lumbar CSFP is usually measured by means of a mini-transducer placed on the surface of the dura mater in the lumbar epidural space or by a catheter directly introduced into subarachnoid space [5]. Placement of a





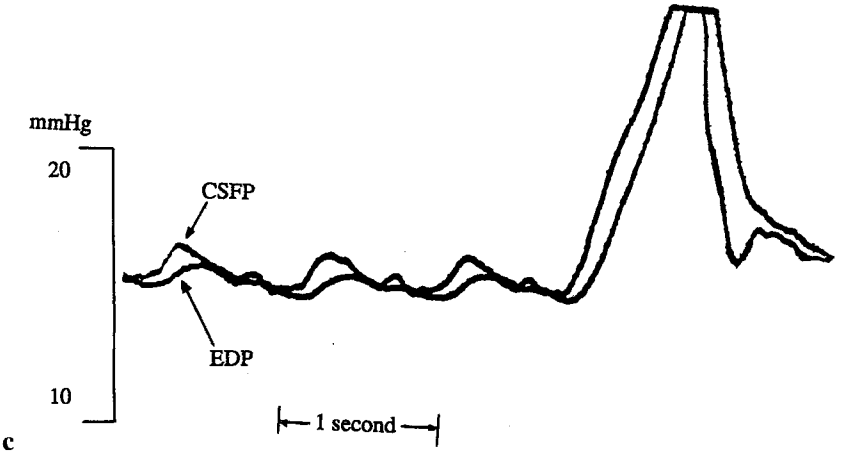


Fig. 4. Simultaneous and sensitive responses of lumbar EDP and CSFP to the injection of normal saline into the posterior cistern **a** and compression of the neck **b** in dogs and cough in humans **c**

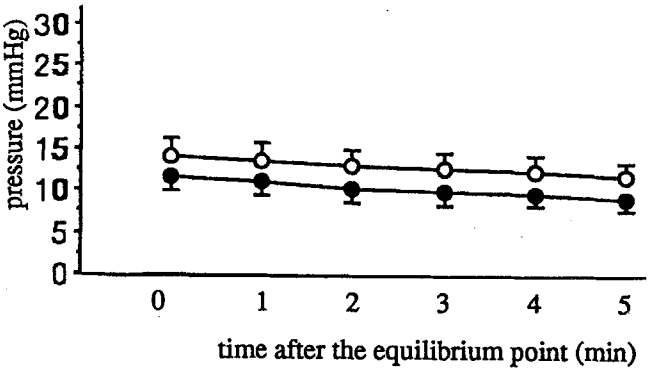


Fig. 5 Lumbar EDP and CSFP during 5 min after the equilibrium point. Declines of both pressures were the result of the increase in CSFP before the equilibrium point caused by water-falling into the epidural space. *Open circles*, CSFP; *closed circles*, EDP

catheter into the subarachnoid space for the measurement of CSFP may cause problems such as tonsillar herniation in patients with intracranial hypertension and intracranial infection in patients in whom monitoring of CSFP is performed for a long period of time. The value of CSFP obtained by a mini-transducer placed in the epidural space will be affected by the contact condition of the dura mater with the surface of the transducer. Residual EDP after active injection of fluid into the epidural space, as measured by Usubiaga et al. [1] and Asano and Kosaka [2,3], was not consistent with CSFP, although a good correlation between both pressures was obtained. Moreover, actively injecting fluid into the epidural space may sharply increase CSFP, especially in those who have intracranial hypertension and low intracranial compliance [1,4]. In our study, because water-falling into the epidural space was driven by gravity, the driving pressure which was equal to the water height in the vertically held tube was only 30–80 cmH_2O. The amount of water entering the epidural space was less than 1 ml. As a result, the mean peak increase in CSFP resulted from water-falling into epidural space, was only 2.1–3.6 mmHg. This increase in CSFP was temporary because CSFP returned to the baseline within 5–10 min. Therefore, we may speculate that our method influence the fluid mechanics of epidural space and subarachnoid space slightly and temporarily.

The consistency of the difference between EDP and CSFP and good response of EDP to the manipulations of CSFP for 5 min after equilibrium point, suggests that estimation of CSFP may be accomplished by continuously monitoring EDP. In some cases such as those of post-cardiopulmonary resuscitation and Reye's syndrome in whom CSFP monitoring is helpful while cerebrospinal fluid sampling is not necessary, CSFP can be estimated by a catheter placed in the lumbar epidural space. This method can also be used to study the effects of anesthesia or surgical procedures on CSFP.

The consistent differences between EDP and CSFP immediately after the equilibrium point can be easily explained by the Newton's Third Law. An EDP 1–3 mmHg lower than CSFP may be due to the elasticity of the dura mater. EDP measured after the equilibrium point should gradually become lower than CSFP as water in the epidural space is gradually absorbed. However, the consistent differences between EDP and CSFP lasted for as long as 5 min after the equilibrium point in our study. We attribute this to the movement of dura mater and the relatively slow absorption of water in the epidural space. At the equilibrium point, dura mater will project slightly toward subarachnoid space, which is evidenced by the increase in CSFP when water falls into epidural space (Fig. 2). After the water column is disconnected from the epidural space, the dura mater will move back toward the epidural space as water is slowly absorbed and the pressure in the epidural space declines. These factors may cause the difference between EDP and CSFP to remain constant for a certain time. Although we did not record EDP and CSFP for a long time, we believe that this pattern should continue well beyond 5 min.

When our technique is used clinically, attention should be paid to the following points:

1. EDP measured by this technique reflects CSFP, not intracranial pressure (ICP). Although Kinuta et al. [6] have shown that the mean CSFP was the same as the mean ICP in the dog, it is necessary to further examine the difference in EDP measured by this technique and ICP measured by conventional clinical methods.
2. By this method, one can only measure the pressure. If it is necessary to sample or withdraw cerebrospinal fluid, our method is not valid.
3. Although water-falling into the epidural space resulted in only a slight and transient increase in CSFP, special attention should be paid in those patients who have intracranial hypertension and low intracranial compliance.

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