Clinical recording of pressure on the spinal cord and cauda equina

Part 1: The spinal block infusion test: method and clinical studies

BJÖRN MAGNAES, M.D.
Department of Neurosurgery, Ullevål Hospital, Oslo University Hospital, Oslo, Norway

When an intraspinal expanding lesion causes a spinal block, a segment of the spinal cord or cauda equina will be subjected to general pressure from the surrounding tissue. This spinal block pressure, the spinal equivalent to intracranial pressure, was measured by lumbar infusion of fluid and simultaneous recording of the volume-pressure curve caudal to the block. The point of deviation from or breakthrough of the exponential volume-pressure curve indicated the spinal block pressure. Spinal block pressure of about 500 mm H₂O and more could be determined by this method, and, when it was combined with Queckenstedt’s test, lower pressures could be assessed as well. In the static (thoracic) part of the spine, spinal block pressure up to the level of arterial blood pressure was recorded. In the dynamic part of the spine, however, spinal block pressure could exceed arterial blood pressure due to external compressive forces during extension of the spine.

There was a general tendency for more severe neurological deficits in patients with high spinal block pressure; but the duration of the pressure, additional focal pressure, and spinal cord compared with nerve root compression seemed equally important factors.

The recording has implications for diagnosis, positioning of patients for myelography and surgery, selection of high-risk patients for the most appropriate surgical procedure, and detection of postoperative hematoma. There were no complications associated with the recordings.

KEY WORDS
spinal block pressure • spinal block infusion test • spinal cord compression • cauda equina compression • Queckenstedt test

Clinical Material and Methods
Patient Population

From 1975 to 1981, spinal block pressure was recorded in 108 patients. The precipitating cause of increased pressure in these patients is shown in Table 1. The patients ranged in age from 12 to 78 years, with an average age of 57 years. In 102 patients, the clinical picture and the myelographic findings indicated pressure on the spinal cord or the lumbosacral nerve roots. Six patients with cervical spinal injuries had signs of spinal cord compression, but did not undergo myelography.

All patients had their spinal block pressure recorded before operation or conservative treatment. In 19
Spinal block pressure

TABLE 1
Diagnosis in 108 patients with measurement of spinal block pressure

<table>
<thead>
<tr>
<th>Level of Lesion</th>
<th>Diagnosis</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>cervical</td>
<td>spondylosis</td>
<td>42</td>
</tr>
<tr>
<td>spinal injury</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>thoracic</td>
<td>metastasis to vertebrae</td>
<td>14</td>
</tr>
<tr>
<td>neurinoma</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>meningioma</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>metastasis to epidural space</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>epidural hematoma</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>intramedullary tumor</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>lumbar</td>
<td>spinal stenosis</td>
<td>13</td>
</tr>
<tr>
<td>disc herniation</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

patients with thoracic lesions, the spinal block pressure was also recorded postoperatively, on the 1st postoperative day in 17 patients, and 4 and 6 hours after surgery in the other two patients, who showed operative clinical deterioration. Six patients with cervical spinal injuries had their spinal block pressure recorded two or three times, and at different times after the onset of symptoms (see Results).

Symptoms and Signs

The spinal cord deficits were graded as slight, marked, and subtotal or total paralysis. Slight deficit indicated symptoms and signs such that a reliable clinical diagnosis could be made; these patients could manage most activities of daily life fairly well. A marked deficit was defined as a marked hindrance in activities of daily life. Patients were classified as having subtotal or total paralysis if they were mainly chairbound or bedridden.

Patients with lumbar spinal stenosis had pain as the dominating symptom and minimal neurological deficits. Two patients with lumbar disc herniation had symptoms and signs of cauda equina compression.

Operation

All except three patients with cervical spinal injuries were operated on. Patients with cervical spondylosis had anterior fusion or laminectomy at C3–7, or both. Two patients with cervical injury underwent laminectomy and two an anterior fusion. Patients with extramedullary thoracic lesions had a three-level laminectomy and removal of the tumor or hematoma. Patients with intramedullary tumors had three- to eight-level laminectomies with myelotomy and biopsy. In lumbar spinal stenosis, two- or three-level laminectomies were carried out, and two patients had a lumbar disc herniation removed. In two patients a postoperative hematoma was evacuated.

Spinal Block Infusion Test

Spinal block pressure is measured by infusion of fluid into the lumbar subarachnoid space and simultaneous recording of the exponential volume-pressure curve caudal to the spinal block.1,6 When the fluid pressure of the caudal compartment exceeds spinal block pressure, fluid will begin to flow from the compartment caudal to the block and to the compartment cephalad to the block (Fig. 2). At this pressure, there will be a deviation from or breakthrough of the recorded exponential volume-pressure curve. This point of deviation or breakthrough then indicates the magnitude of the spinal block pressure.

The equipment was the same as for the cerebrospinal fluid (CSF) infusion test in hydrocephalic patients,10 and consisted of a No. 19 spinal needle, a pressure transducer fitted with a disposable fluid chamber, plastic tubing, a 50-ml syringe driven by a constant-rate infusion pump, and a pressure recorder.* After lumbar puncture caudal to the block,

* Pressure transducer manufactured by A/S Nycotron, Drammen, Norway; infusion pump manufactured by Braun, Melsungen, West Germany; and pressure recorder manufactured by Honeywell Ltd., Uddingston, Scotland, or W & W Electronic, Basel, Switzerland.
The spinal block infusion test was performed twice in 20 patients to determine the reproducibility of the test. The test was also performed at two different rates of infusion in seven patients to study the influence of the rate of infusion on the measured spinal block pressure.

**Patient’s Position**

Patients with cervical spondylosis were placed in the lateral body position with the neck in a neutral position, in flexion, and in the extended position similar to that used in the initial phase of metrizamide myelography. Patients with cervical spinal injuries or thoracic lesions were placed in the lateral position, with a normal spinal curvature. Patients with lumbar spinal stenosis were positioned in the lateral body position, with the lumbar spine in the same degree of extension as when standing erect. Patients with lumbar disc herniation were placed in the lateral position, with the lumbar spine in the position most comfortable for the patient.

**Precautions**

The patients were instructed in possible adverse symptoms, which they were requested to report immediately. The neck was kept in the extended position for as short a time as possible. As soon as the point of deviation from or breakthrough of the exponential volume-pressure curve was reached, the fluid pressure was lowered slowly to the base level by withdrawing the fluid.

**Myelography**

Metrizamide was the contrast agent used for mye-
Spinal block pressure

...ography. Two patients with cervical spondylosis had transient clinical deterioration after the myelography procedure. The spinal block pressure was recorded 3 and 5 days later, respectively.

Of the 36 patients with extramedullary thoracic lesions, 23 patients had marked focal lesions; that is, lesions compressing the spinal cord mainly from one side, as opposed to more circumscribed or non-focal lesions, which were found in 13 patients. Focal or circumscribed compression was determined from a visual evaluation of the myelograms, as it was difficult and also beyond the scope of this study to work out exact roentgenological measurements.

Other Measurements

Queckenstedt's test\(^2\) was carried out in the usual way, and arterial blood pressure was recorded by the external cuff method.

Results

Determination of Spinal Block Pressure

When fluid was infused into the lumbar subarachnoid space, an exponential volume-pressure curve was found in 79 patients. In these curves, two points could be distinguished (Fig. 3): 1) a deviation from the exponential curve; and 2) a marked change in the curve from nearly vertical to nearly horizontal, which is referred to as the breakthrough of the curve. In curves with a distinct deviation, this point was taken as indicating spinal block pressure. In the other cases, the start of the breakthrough was taken as indicating spinal block pressure.

When the spinal block pressure was below about 500 mm H\(_2\)O, there was neither a distinct exponential form of the curve nor a point of deviation from or breakthrough of the curve (Fig. 4). Consequently, the spinal block pressure could not be determined below this value.

In six patients with a cervical block, seven patients with a thoracic block, and seven patients with a lumbar block, the test was performed twice, with the spinal curvatures carefully placed in exactly the same position both times (Fig. 5). The results are shown in Fig. 6 left. In seven patients with lumbar spinal stenosis, the block pressure was determined at infusion rates of 1.5 and 5 ml/min. Emphasis was placed on performing the two tests without changing the position of the lumbar spine. The results are shown in Fig. 6 right.

In all 79 patients whose spinal block pressure was measurable by the infusion test, Queckenstedt testing...
and myelography also revealed a block. Of the 29 patients without an exponential infusion curve, 13 patients had a total (no wave) or subtotal (wave barely visible) block on Queckenstedt testing. When the spinal block pressure was too low to be quantified by the infusion test, a total block as judged by the Queckenstedt test was considered as a block pressure of 400 mm H2O, and a subtotal Queckenstedt block as 300 mm H2O in the clinical correlation to follow (see Discussion).

In the thoracic region (the static part of the spine), spinal block pressure was recorded up to, but never above, the level of mean arterial blood pressure (MABP). A spinal block pressure close to MABP was recorded in eight patients having subtotal or total paralysis and anesthesia. In the lumbar spine (the dynamic part of the spine), spinal block pressure was measured above the level of the MABP. The highest block pressure, 2300 mm H2O, was recorded in the lumbar spine in the erect position, and was about 900 mm H2O (65 mm Hg) above MABP. In one case of cervical spondylosis, a block pressure up to 1450 mm H2O was recorded during extension of the neck, which was close to MABP in that patient.

Complications and Adverse Effects

The test did not lead to neurological deterioration in any of the patients. Two patients with lumbar spinal stenosis and a very high block pressure in the erect position felt considerable pain in the legs during the infusion. The symptoms in these four patients disappeared immediately on bending forward, which released the pressure on the cauda equina.

Eleven patients with cervical spondylosis had provocation of pain in the arms during extension of the neck. There were no further symptoms during the infusion test. Patients with thoracic lesions did not feel any kind of discomfort during the test. Two patients with epidural metastasis had improved sensory perception, and one of them also had slightly improved motor function after the recording. The spinal block pressure in these two patients was 850 and 900 mm H2O, respectively.

Clinical Correlation

Cervical Spondylosis. In cases of cervical spondylosis, the pressure on the spinal cord regularly increased when the neck moved from flexion to extension. The spinal block pressure in flexion, neutral position, and in extension of the neck is correlated with the degree of neurological deficits in Fig. 8. There is a tendency toward increasing neurological deficits with increasing spinal block pressure, especially when measured in the neutral position.

Cervical Injuries. There were six patients with cervical injuries. The first patient had a C5–6 fracture with anterior dislocation and complete paralysis from the moment of the injury. Five hours after the accident the spinal block pressure was 1250 mm H2O, which corresponded approximately to MABP (Fig. 9). After skeletal traction with a 6 kg weight and reduction of the dislocation, the pressure on the spinal cord was normal, but there was no return of function.

The second patient had sustained an extension injury causing paralysis. There was no fracture-dislocation. Four hours after the injury the spinal block pressure was not measurable. The symptoms in these four patients disappeared immediately on bending forward, which released the pressure on the cauda equina.

Eleven patients with cervical spondylosis had provocation of pain in the arms during extension of the neck. There were no further symptoms during the infusion test. Patients with thoracic lesions did not feel any kind of discomfort during the test. Two patients with epidural metastasis had improved sensory perception, and one of them also had slightly improved motor function after the recording. The spinal block pressure in these two patients was 850 and 900 mm H2O, respectively.
Spinal block pressure

Fig. 9. Spinal block pressure in a patient with cervical fracture-dislocation. Skeletal traction reduced the pressure on the spinal cord from 1250 mm H2O to normal. CSF = cerebrospinal fluid; Q = Queckenstedt.

pressure was 1300 mm H2O, which was about the same as the MABP. Decompressive laminectomy was carried out without return of function.

The third patient with flexion-compression fracture of C-6 had severe paresis in the arms and legs. Two hours after the injury, the spinal block pressure was 800 mm H2O. After skeletal traction with partial realignment of the spine, the spinal block pressure was 400 mm H2O. Immediately after admission, treatment with dexamethasone and mannitol was started. The 3rd day after injury the spinal block pressure was normal. There was gradual clinical improvement, and finally the patient could walk without aid.

The fourth patient had a hyperextension injury and, initially, total paralysis of the arms and legs. On admission 1 hour after the accident, the patient had recovered some function in the legs. The spinal block pressure was 750 mm H2O. Treatment with dexamethasone and mannitol was started. The clinical picture, which was that of a central medullary cord syndrome, improved gradually. The 6th day after the injury, the spinal block pressure was normal. Three weeks after the injury the patient was able to walk, and the bladder function was almost normal. There was moderate residual deficit in the hands and fingers.

The fifth patient had flexion injury with bilateral facet fracture at C5–6, anterior dislocation of 3 mm, and marked paresis in the arms and legs. Four hours after the accident, the spinal block pressure was 750 mm H2O. Skeletal traction with spinal realignment reduced the spinal block pressure to 300 mm H2O. Treatment with dexamethasone and mannitol was started. Over the next 2 days, there was slight clinical improvement, but on the 3rd day the patient deteriorated. Spinal block pressure was 650 mm H2O. A decompressive laminectomy was carried out, followed by improvement. An anterior fusion was performed later. The patient had slight residual deficit in the arms and legs.

The last patient with cervical injuries had a flexion-rotation injury with a unilateral facet fracture at C5–6 and a marked Brown-Séquard syndrome. Three hours after the injury, the spinal block pressure was 400 mm H2O. He was treated with skeletal traction, dexamethasone, and mannitol. The day after the injury, Queckenstedt’s test was normal. The patient improved gradually from the time of admission. After 1 week, an anterior decompression and fusion was carried out, and the patient eventually made a good recovery.

Thoracic Lesions. In patients with thoracic lesions, a high spinal block pressure was regularly associated with marked neurological deficits. Those with a block pressure close to MABP all had subtotal or total paralysis and anesthesia. In some cases, patients with marked focal lesions had severe neurological deficits at lower levels of spinal block pressure. The results from the patients with extramedullary lesions and those with intramedullary tumors are shown in Figs. 10 and 11.

Lumbar Spinal Stenosis. Of the 13 patients with lumbar spinal stenosis, 11 had a measurable block pressure ranging from 400 to 2300 mm H2O while in the erect position. A more detailed report of patients with lumbar spinal stenosis is given in Part 2 of this study.7 The 13 patients are mentioned briefly here because of the methodology.

Lumbar Disc Herniation. Two patients had herniation of the L-4 disc, with compression of the cauda equina. The spinal block pressure was 750 and 1050 mm H2O at 11 and 8 hours, respectively, after the onset of pain. After operation, both patients regained strength in the legs and control of bladder and bowel function.

Postoperative Spinal Block Pressure

Two patients with thoracic lesions had postoperative neurological deterioration. One of them had metastasis to the epidural space and a preoperative block pressure of 700 mm H2O. Six hours after the operation, when she had deteriorated, the block pressure was 1200 mm H2O. The other patient had a meningioma and a preoperative block pressure of 400 mm H2O. Four hours after the operation, when she had deteriorated, the block pressure was 1100 mm H2O. Reoperation and evacuation of a hematoma was followed by clinical improvement in both patients. The block pressure in these two patients was about 30 mm Hg below MABP.
FIG. 10. Relationship between neurological deficits and spinal block pressure in 36 patients with extramedullary compression in the thoracic region.

An example of the relative importance of focal pressure and surrounding pressure is shown in Fig. 12. These recordings are from a patient with a meningioma. The preoperative block pressure was slightly pathological. Removal of the tumor eliminated the focal pressure on the spinal cord which led to immediate clinical improvement in spite of a postoperative block pressure of about 800 mm H$_2$O, probably due to a postoperative hematoma.

**Discussion**

**Validity and Limitations of Spinal Block Infusion Test**

In previous studies, cervical and lumbar metrizamide myelography and Queckenstedt's test have shown progressive narrowing of the subarachnoid space with increasing frequency of block phenomena when moving from flexion to extension of the spine.$^{2,5,9,13,14}$ The spinal block infusion test regularly followed the same pattern, with increasing block pressure toward extension. Furthermore, the general tendency was for patients with high spinal block pressure to have more severe neurological deficits. These results, therefore, showed the validity of the test in assessing the general pressure surrounding a segment of the spinal cord or cauda equina, and its clinical relevance.

However, the test has several limitations. The reproducibility of the test and the influence of the rate of infusion on the block pressure showed that the test is by no means as exact as the recording of intracranial pressure. The rates of infusion were chosen while considering the patient's safety and practical applicability: 1) the time of infusion should be short, with a high pressure on the spinal cord lasting no more than about 1 minute; and 2) both infusion and pressure recording should be performed through one No. 19 needle. The rates of infusion which were chosen for the different block levels fulfilled these requirements well. This study does not solve the problem of which rates give the most correct value of the spinal block pressure; however, standardizing the infusion rates assures that the values are at least comparable from patient to patient. One must also expect that the length of the spinal block, which could not be evaluated in this study, will influence the values recorded.$^2$

The spinal block infusion test must therefore be regarded as a semiquantitative test.

A block pressure below about 500 mm H$_2$O could not be determined by this method. In this low-pressure area, however, a block could be verified by Queckenstedt's test. Cerebrospinal fluid pressure during Queckenstedt's test increases to about 400 mm H$_2$O.$^5$ A total Queckenstedt block then most likely means that the spinal block pressure is about 400 mm H$_2$O or higher, which seems to correspond fairly well with the present recordings. A Queckenstedt block without a clear exponential infusion curve is, therefore, considered as 400 mm H$_2$O. A subtotal Queckenstedt block in the same way means that the pressure is between normal and 400 mm H$_2$O, and is given as 300 mm H$_2$O.

**Safety of Spinal Block Infusion Test**

The gradually increasing fluid pressure on the spinal cord and nerve roots was well tolerated, and no complications occurred. Extension of the neck usually lasted no more than 3 minutes, and high fluid pressure usually no more than 1 minute. To obtain a good safety margin, it is important to keep these periods of high tissue and fluid pressure as short as possible. It is noteworthy that some clinical improvement oc-
Spinal block pressure

FIG. 11. Relationship between neurological deficits and spinal block pressure in nine patients with intramedullary tumors.

occurred in two patients following the test. It is well known that the opposite may occur, that is, clinical deterioration may follow reduction of the fluid pressure below a block after lumbar puncture.

Forces Behind Spinal Block Pressure

Arterial Blood Pressure. In the static part of the spine, the upper level of block pressure corresponded approximately to MABP, and consequently the perfusion pressure was about zero. These patients had complete and irreversible loss of function. The clinical condition and upper pressure level thus corresponded to brain death from elevated intracranial pressure.

External Compressive Forces. In the dynamic part of the spine, the block pressure could exceed MABP during extension of the spine. The highest block pressure, 2800 mm H2O, was recorded in the walking position in a patient with lumbar spinal stenosis (see Part 2 of this study'). The compression due to fracture-dislocation and disc herniation results from the same group of nonvascular external decompressive forces.

Mechanical Pressure and Neurological Deficits

The general tendency for the severity of neurological deficits to increase with increasing spinal block pressure has already been discussed. Other very important factors are described below.

Focal Pressure. The closest correlation between the clinical status and the block pressure was found in patients with circumscribed compression, such as in cases of epidural metastasis, cervical spondylisis, and extradural hematomas. Marked focal expansions could, however, cause severe neurological deficits even at a lower block pressure. Clinical neurosurgical experience has revealed that focal pressure is a very important pathogenic factor.

Duration of Compression. Many patients with cervical spondylisis had a high block pressure on extension of the neck, and in several patients the pressure approached MABP. These patients most likely had assumed this position several times a day, when looking upward, without feeling adverse symptoms, and the extended position during the infusion test lasted about 3 minutes and did not cause complications. The extension of the neck in the initial phase of metrizamide myelography usually lasts longer than 3 minutes, and resulted in transient deterioration in two patients. Our study showed that all patients with a high constant block pressure in the thoracic region had severe neurological deficits. This illustrates the importance of the duration of compression.

Cord versus Root Compression. Patients with lumbar spinal stenosis had higher average block pressure but far less permanent neurological deficits compared with patients with myelopathy due to cervical spondylisis. Two factors may explain this difference: 1) nerve roots are less vulnerable than the spinal cord; and 2) compression of the cauda equina causes pain, and consequently the patients assume a stooped position with less pressure on the nerve roots. Patients with cervical spondylisis felt discomfort in the extended position only if it caused pain in the neck and arms (which is a sign of root and not cord compression). The cauda equina, therefore, seemed better protected than the spinal cord against the high block pressure on extension of the spine. Thus, elderly people may develop a protective lumbar kyphosis and, to be able to look ahead, a harmful compensating cervical hyperlordosis.
Clinical Implications

Cervical Spondylosis. During metrizamide myelography, care should be taken not to extend the neck more than absolutely necessary, and the duration of the extended position should be kept at an absolute minimum.

In a previous study, we found that manometric block phenomena were preoperative factors related to postoperative improvement of the myelopathy. The spinal block infusion test now allows a better grading of the mechanical pressure on the spinal cord that may further improve our prediction of the outcome of surgery.

Safety is a major problem in surgery for cervical spondylosis, as a certain percentage of the patients have additional neurological deficits after the operation. The spinal cord may be injured not only during the surgical procedure, but also during endotracheal intubation and the operative positioning of the patient. The risk is of course greatest in patients who have myelopathy and a high block pressure. For several years we have used Queckenstedt's test to select high-risk patients for laminectomy under local anesthesia, and we have now included the spinal block infusion test in this evaluation.

Postoperative Hematoma. Postoperative hematoma with spinal block seems to be more frequent than we realize, because only those hematomas leading to postoperative deterioration are usually recognized. Other patients may also have clinically significant hematomas. In patients with minimal or no preoperative function it is not possible in the postoperative phase to distinguish clinically between an irreversibly injured cord and a postoperative hematoma with significant compression of the spinal cord. Even patients with better preoperative function may not reach their potential postoperative functional level for the same reasons. The spinal block infusion test may be helpful in such patients.

References