Clinical evaluation of the safety and efficacy of lumbar cerebrospinal fluid drainage for the treatment of refractory increased intracranial pressure

Clinical article

JOCHEN TUETTENBERG, M.D.,1 MARCUS CZABANKA, M.D.,2 PETER HORN, M.D.,2 JOHANNES WOITZIK, M.D.,2 MARTIN BARTH, M.D.,2 CLAUDIUS THOMÉ, M.D.,1 PETER VAJKOČZY, M.D.,3 PETER SCHMIEDEK, M.D.,1 AND ELKE MÜENCH, M.D.3
Departments of 1Neurosurgery and 3Anesthesiology and Intensive Care Medicine, University Hospital Mannheim, Faculty of Medicine Mannheim, University of Heidelberg; and 2Department of Neurosurgery, Charité Universitätsmedizin Berlin, Germany

Object. Several approaches have been established for the treatment of intracranial hypertension; however, a considerable number of patients remain unresponsive to even aggressive therapeutic strategies. Lumbar CSF drainage has been contraindicated in the setting of increased intracranial pressure (ICP) because of possible cerebral herniation. The authors of this study investigated the efficacy and safety of controlled lumbar CSF drainage in patients suffering from intracranial hypertension following severe traumatic brain injury (TBI) or aneurysmal subarachnoid hemorrhage (SAH).

Methods. The authors prospectively evaluated 100 patients—45 with TBI and 55 with SAH—having a mean age of 43.7 ± 15.7 years (mean ± SD) and suffering from refractory intracranial hypertension (ICP > 20 mm Hg). Intracranial pressure and cerebral perfusion pressure (CPP) before and after the initiation of lumbar CSF drainage as well as related complications were documented. Patient outcomes were assessed 6 months after injury.

Results. The application of lumbar CSF drainage led to a significant reduction in ICP from 32.7 ± 10.9 to 13.4 ± 5.9 mm Hg (p < 0.05) and an increase in CPP from 70.6 ± 18.2 to 86.2 ± 15.4 mm Hg (p < 0.05). Cerebral herniation with a lethal outcome occurred in 6% of patients. Thirty-six patients had a favorable outcome, 12 were severely disabled, 7 remained in a persistent vegetative state, and 45 died.

Conclusions. Lumbar drainage of CSF led to a significant and clinically relevant reduction in ICP. The risk of cerebral herniation can be minimized by performing lumbar drainage only in cases with discernible basal cisterns. (DOI: 10.3171/2008.10.JNS08293)

Key Words • intracranial hypertension • lumbar cerebrospinal fluid drainage • subarachnoid hemorrhage • traumatic brain injury

Increased ICP and its treatment remain major problems in neurointensive care. Despite a large variety of therapeutic approaches aimed at lowering elevated ICP, the current options are often insufficient. Even in light of significant experimental and clinical research, decreasing ICP to physiological values cannot be achieved in certain patients with TBI or SAH. In this scenario controlled lumbar drainage of CSF may represent a promising and potentially effective therapeutic option.

Lumbar CSF drainage was used in the early 20th century for diagnostic and therapeutic interventions. Until now, however, it has been regarded as a contraindication for the treatment of increased ICP given the risk of transtentorial or tonsillar herniation. Yet, the dogmatic assertion that lumbar drainage is contraindicated in patients with increased ICP is based on historical arguments rather than scientific data. Reports addressing the risk of transtentorial herniation date back to the first half of the 20th century, and most investigations were conducted in patients with intracerebral tumors. Despite absent scientific background for this doctrine and an increasing number of reports supporting lumbar drainage for the treatment of refractory elevated ICP, the prohibition of lumbar CSF drainage in cases of increased ICP, enjoined by Harvey Cushing, has been adhered to rigidly.
Lumbar cerebrospinal fluid drainage for intracranial hypertension

Nevertheless, lumbar CSF drainage was used in the 1990s to lower refractory intracranial hypertension in children. Clinical studies in a small number of patients demonstrated a significant reduction of increased ICP in response to controlled lumbar CSF drainage without any signs of cerebral herniation.\textsuperscript{1,10,19,39} In researching this issue, we have demonstrated a significant reduction in ICP by using controlled lumbar CSF drainage according to defined indications in 23 patients with either TBI or SAH.\textsuperscript{28} Signs of herniation were observed temporarily in 2 patients in that series. To verify our results, in the present study we analyzed the safety of controlled lumbar CSF drainage and its effects on increased ICP in 100 patients with SAH or TBI, including the previously described series of 23 patients.

Methods

Patient Population

The ethics committee of the Faculty of Medicine Mannheim, University of Heidelberg, Germany, approved the study (No. 0248.3). One hundred neurosurgical patients with severe TBI (45 patients) or aneurysmal SAH (55 patients) were included in our analysis. All patients with ICP > 20 mm Hg were treated according to the guidelines of the American Association of Neurological Surgeons and the Brain Trauma Foundation.\textsuperscript{35} Treatment was conducted following a stepwise design including deep anesthesia, controlled ventilation, moderate hyperventilation, drainage of CSF via an EVD system, and osmotherapy using 20% mannitol in the first stage. Second-step therapeutic escalation was used when treatment with the 20% mannitol did not result in sufficient and permanent normalization of ICP (≤ 20 mm Hg). Hypertonic saline solution (7.5%, 2 ml/kg body weight) was used when the serum level of sodium was < 150 mmol/L and serum osmolarity was < 320 mOsm/L. Barbiturate coma was induced only in patients without signs of systemic inflammation. Unilateral surgical decompression via hemicraniectomy was performed when a unilateral intracranial pathology was present with a minimum of 1 cm of midline shift.

In cases of ongoing ICP elevation, a cranial CT scan was obtained and coagulation parameters were controlled before the use of a lumbar drain. Computed tomography–demonstrated morphological prerequisites for the application of lumbar drainage included open and definable basal cisterns and the exclusion of a cerebral space-occupying lesion amenable to surgical therapy. Requirements for coagulation values were as follows: Quick value > 50%, partial thromboplastin time < 40 seconds, and platelet count > 70,000/μL.

A lumbar CSF drain was placed for the treatment of increased ICP when all evidence-based therapeutic procedures had been tried and failed to lower ICP to physiological values. Increased ICP was defined as refractory if the pressure was > 25 mm Hg for > 10 minutes.

Neuromonitoring Procedures

An EVD (Silverline, Antimikrobieller Ventrikelkatheter, Spiegelberg GmbH & Co. KG) was inserted in all patients for the assessment of ICP. However, if lateral ventricles were not suitable for EVD insertion or a significant midline shift was demonstrated on a CT scan, a parenchymal fiberoptic microprobe (Intracranial Pressure Express, Codman) was placed instead. Cerebral perfusion pressure was calculated based on the following formula: MAP – ICP. In 5 patients a flexible PO\textsubscript{2} microprobe (Licox Oxygen Catheter Microprobe, CCI.5B, GMS) for the assessment of brain tissue PO\textsubscript{2} and a thermal diffusion microprobe (TDP 400, Hemedex, Inc.) for the assessment of rCBF\textsuperscript{37,38} were implanted in the brain parenchyma by using a multicanal implantation bolt placed in front of the coronary suture. A digital data acquisition system was installed for continuous measurement and analysis of ICP, MAP, CPP, brain tissue PO\textsubscript{2}, and rCBF. Parameters were assessed with a sampling rate of 300 Hz and a storage rate of 10 Hz. Lumbar drainage was implemented under continuous control and recording of all monitoring parameters.

Lumbar CSF Drainage

A silicone catheter usually used for peridural anesthesia was inserted into the intradural space at the L4–5 level using a 16-gauge curved tip needle (Tuohy type needle). After careful and gradual aspiration of 5–20 ml of CSF, a sterile collecting pouch (Dispomedica GmbH) was connected to the catheter allowing collection, measurement, and control of the drained fluid. The drainage system was placed at a level 5 cm above the external acoustic meatus (based on the level of the foramen of Monro). Lumbar drainage of CSF was conducted under hemodynamic control and clinical surveillance of brainstem functions (pupil-motor function). Cerebrospinal fluid was drained until an ICP of 10–15 mm Hg was achieved regardless of the drained volume. Further lumbar drainage was performed when ICP increased to > 25 mm Hg for at least 10 minutes and CSF drainage via the EVD did not restore ICP to physiological values. If lumbar drainage did not lead to adequate ICP reduction, second-tier interventions (7.5% hypertonic saline solution) were applied depending on the clinical state (serum sodium level and serum osmolarity) of the patient. Cerebrospinal fluid drainage via the lumbar catheter was stopped when ICP values were < 20 mm Hg for > 12 hours or when complications such as bacterial meningitis or clinical signs of cerebral herniation appeared (that is, one-sided mydriasis without adequate reaction to light).

Study Protocol

The volume of drained CSF was recorded. Furthermore, ICP and CPP values were recorded directly before and after the application of lumbar drainage. Intracranial pressure and CPP data were noted hourly including all complications related to lumbar drainage (infections and technical complications such as catheter occlusion, bleeding, and alterations in pupil-motor function) until a specific ICP therapy was stopped. The mean values of ICP and CPP for a period 6 hours before and after the initial lumbar drainage were calculated to evaluate how long the...
ICP remained reduced in response to drainage. Additionally, all interventions aimed at reducing ICP as well as body temperature, PaCO₂, serum sodium levels, and serum osmolarity were also recorded before and after lumbar CSF drainage. The neurological state of all patients was evaluated 6 months after injury based on the GOS.23

Cranial CT

Before insertion of a lumbar catheter, a cranial CT scan was obtained to evaluate the underlying pathology of ICP elevation and to assess the status of the basal cisterns. Any subsequent cranial CT was performed according to the clinical indication. An experienced neuroradiologist and neurointensive care physician analyzed in a blinded fashion all CT studies conducted before and directly after the onset of lumbar CSF drainage. All cranial CT scans were evaluated in an anonymous fashion. Factors evaluated included the status of the basal cisterns and the lateral ventricles, the direction and extent of midline shift, and the presence of a unilateral space-occupying lesion. The status of the basal cisterns and lateral ventricles was analyzed semiquantitatively; that is, basal cisterns or lateral ventricles were present, compressed, or absent.

Data Handling and Statistical Analysis

Results in the first 23 patients already have been published.23 To reevaluate and verify the effect of lumbar CSF drainage on refractory elevated ICP, the patient population was increased and the data (including the previously published data) were reanalyzed statistically. Data are presented as the means ± SD, median, and range when calculated for continuous parameters. Absolute and relative frequencies were reported by categorical parameters. Possible effects within a group were tested using the Wilcoxon signed-rank test, whereas differences between groups were analyzed with the Wilcoxon-Mann-Whitney U-test. Spearman correlation coefficients were calculated to describe dependencies between continuous variables. Patient data were tested for normal distributions within parameter and patient groups by using the Kolmogorov-Smirnov test. In cases of normally distributed data a paired t-test was performed, whereas the Wilcoxon rank-sum test was applied for data not normally distributed. The level of significance was set at 5%. Data analysis was performed using an SAS statistical package (version 8.1, SAS Institute, Inc.).

Results

Demographic Data

Between February 1998 and February 2006, 100 patients underwent lumbar drainage to reduce increased ICP. The mean age of the patient population was 43.7 ± 15.7 years (range 12–76 years). The mean GCS score on admission to the intensive care unit was 7 ± 4 points. Severe TBI was diagnosed in 45 patients and SAH in 55 patients. Demographic data are summarized in Table 1 according to subpopulations with TBI and SAH.

After admission 12 patients underwent surgical removal of space-occupying hematomas. Furthermore, 11 patients suffering from severe TBI underwent unilateral decompressive craniectomy for space-occupying unilateral subdural hematomas immediately after admission. In patients with SAH the responsible aneurysm was clipped in 41 patients and coiled in 14. Intracranial pressure was generally assessed (84 patients) using an EVD. Because of massive cerebral edema and absent lateral ventricles on cranial CT, an intraparenchymal fiberoptic microprobe was placed in 16 patients to guarantee ICP measurement.

Specific ICP Therapy

All patients underwent intubation and ventilation. Sedation was achieved via the continuous infusion of fentanyl as well as either midazolam or methohexitol. In the case of methohexitol sedation, bispectral index monitoring was used to surveil sedation with a goal parameter of 40–50. Therapy for elevated ICP also included moderate hyperventilation (PaCO₂, 36.6 ± 3.9, median 36.3) and the maintenance of normothermia (rectal body temperature 37.2 ± 0.8°C, median 37.2°C).

In 84 patients therapy for increased ICP included CSF drainage via an external ventricular catheter. Given that ICP was not always reduced to physiological values under these conditions and that 16 patients did not receive an EVD because of significant cerebral edema and unsuitable lateral ventricles, all patients intermittently received 20% mannitol infusions. After the failure of ICP therapy using CSF drainage via an EVD and mannitol infusion, 63 patients received 7.5% hypertonic saline solution and 6 patients received Tris buffer. In 10 patients a delayed secondary unilateral hemicraniectomy had to be performed.

Lumbar CSF drainage for elevated ICP was applied 119.5 ± 92 hours (median 98 hours) after initial injury. The lumbar CSF catheter remained intradurally for 143.9 ± 105 hours (median 115.5 hours).

Intracranial Pressure and CPP

A drained CSF volume of 5–20 ml resulted in a significant reduction in ICP from 32.7 ± 10.9 (median 30 mm Hg) to 13.4 ± 5.9 mm Hg (median 12 mm Hg; p < 0.05). The mean value of ICP measured during the 6 hours before lumbar drainage was 24.5 ± 4.5 (median 24 mm Hg) compared with 14.7 ± 6.1 mm Hg (median 14 mm Hg; p < 0.05) over the 6 hours after drainage. The mean CPP measured for 6 hours before and after the initiation of lumbar CSF drainage increased significantly from 70.6 ± 18.2 to 86.2 ± 15.4 mm Hg (p < 0.05). Figures 1 and 2 demonstrate the time course of ICP and CPP values before and after the application of lumbar drainage. Values of ICP and CPP are summarized in Table 1 according to the subpopulations with TBI and SAH.

Cerebral Perfusion and Brain Tissue Oxygenation

In 5 patients, 31 lumbar drainage maneuvers were conducted under continuous monitoring of ICP and brain tissue PO₂, and 15 maneuvers were conducted under additional monitoring with rCBF. Analysis of continuously obtained data revealed a significant decrease in ICP from 27.8 ± 6.1 (median 27 mm Hg) to 14.6 ± 4.2 mm Hg (median 16 mm Hg; p < 0.05), a significant increase in
Lumbar cerebrospinal fluid drainage for intracranial hypertension

rCBF from 19.9 ± 7 (median 18 ml/100 g/min) to 22.5 ± 9 ml/100 g/min (median 21 ml/100 g/min; p < 0.05), and a significant improvement in brain tissue PO$_2$ from 19.1 ± 7 (median 16 mm Hg) to 22.5 ± 10 mm Hg (median 21 mm Hg; p < 0.05). Figure 3 graphically illustrates the continuously measured data.

Cranial CT Scans

A cranial CT scan was obtained in all patients 13.6 ± 17.8 hours (median 6.8 hours) before and 90.2 ± 103.5 hours (median 64 hours) after the application of lumbar CSF drainage. Computed tomography studies demonstrated well-defined lateral ventricles in 7 patients, compressed ventricles in 70 patients, and no lateral ventricles in 23 patients. Before lumbar drainage, basal cisterns were present in 98 patients and were partially compressed in 2. Furthermore, 12 patients demonstrated a midline shift due to a unilateral space-occupying lesion.

Cranial CT studies obtained after lumbar drainage revealed lateral ventricles in 13 patients and compressed ventricles in 69. In 18 patients the lateral ventricles and basal cisterns were absent, and 21 patients displayed a midline shift. Analysis of CT scans obtained before lumbar drainage displayed no interrelation between the status of lateral ventricles and basal cisterns or a midline shift, and clinical outcome or the appearance of clinical signs of cerebral herniation. However, there was a statistically significant correlation between the status of basal cisterns after lumbar drainage and patient outcome. Patients without basal cisterns after the initiation of lumbar CSF drainage were characterized by a significantly reduced rate of neurological recovery and an increased mortality rate (p < 0.05).

Patient Complications

In 14 patients the lumbar drainage system had to be replaced because of an occluded lumbar catheter after the drainage of blood-tinged CSF. In 2 patients uncontrolled CSF draining occurred after disconnecting the drainage system. A temporary unilateral mydriasis without reaction to light developed in 1 of these patients as a sign of cerebral herniation; the patient survived without neurological deficit. Meningitis occurred in 7 patients (7%). All of these patients had an external ventricular catheter and a lumbar drainage system at the same time; therefore, the cause of CSF infection could not be conclusively attributed to either the ventricular or lumbar catheter.

Clinical signs of cerebral herniation with temporary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TBI</th>
<th>Median</th>
<th>SAH</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (yrs)</td>
<td>37.6 ± 18.1</td>
<td>35</td>
<td>48.4 ± 11.8†</td>
<td>49</td>
</tr>
<tr>
<td>GCS score</td>
<td>6.4 ± 3</td>
<td>6</td>
<td>7.5 ± 3</td>
<td>5</td>
</tr>
<tr>
<td>ICU stay (days)</td>
<td>22.1 ± 11.9</td>
<td>20</td>
<td>23.5 ± 18.4</td>
<td>19</td>
</tr>
<tr>
<td>start of LD after insult (days)</td>
<td>4.4 ± 4.3</td>
<td>3.2</td>
<td>5.4 ± 3.4†</td>
<td>4.6</td>
</tr>
<tr>
<td>PaCO$_2$ (mm Hg)</td>
<td>37 ± 3.3</td>
<td>36.7</td>
<td>36.7 ± 4.3</td>
<td>35.6</td>
</tr>
<tr>
<td>body temperature (°C)</td>
<td>37.1 ± 0.7</td>
<td>37.4</td>
<td>37.2 ± 0.8</td>
<td>37.3</td>
</tr>
<tr>
<td>serum sodium (mmol/L)</td>
<td>146.6 ± 7.1</td>
<td>146</td>
<td>150.3 ± 7.6</td>
<td>150</td>
</tr>
<tr>
<td>serum osmolality (mOsm/L)</td>
<td>312.6 ± 22.6</td>
<td>311</td>
<td>318.5 ± 19.5</td>
<td>317</td>
</tr>
<tr>
<td>ICP (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>directly before LD</td>
<td>31.2 ± 10.4</td>
<td>28</td>
<td>33.9 ± 11.3</td>
<td>33</td>
</tr>
<tr>
<td>directly after LD</td>
<td>12.9 ± 5.6</td>
<td>12</td>
<td>13.8 ± 6.2</td>
<td>12</td>
</tr>
<tr>
<td>6 hrs before LD</td>
<td>24 ± 4</td>
<td>23.5</td>
<td>24.8 ± 5.3</td>
<td>24</td>
</tr>
<tr>
<td>6 hrs after LD</td>
<td>14.3 ± 5.2</td>
<td>14</td>
<td>15 ± 6.7</td>
<td>14</td>
</tr>
<tr>
<td>CPP (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>directly before LD</td>
<td>64.3 ± 16.5</td>
<td>65</td>
<td>75.5 ± 18.1</td>
<td>76</td>
</tr>
<tr>
<td>directly after LD</td>
<td>80 ± 9.2</td>
<td>79</td>
<td>91.1 ± 17.5</td>
<td>88</td>
</tr>
<tr>
<td>6 hrs before LD</td>
<td>71.1 ± 10.2</td>
<td>71</td>
<td>83.3 ± 13.9</td>
<td>80</td>
</tr>
<tr>
<td>6 hrs after LD</td>
<td>79 ± 8.3</td>
<td>78.5</td>
<td>89.8 ± 14.7</td>
<td>89.5</td>
</tr>
</tbody>
</table>

* ICU = intensive care unit; LD = lumbar CSF drainage.
† p < 0.05.
unilateral mydriasis without reaction to light occurred in 12 patients. In 3 of these patients cerebral injury was devastating and lumbar drainage was applied as ultima ratio therapy given that no further treatment options were available. Four of the patients who had demonstrated temporary unilateral mydriasis survived. Among these 4 patients, 2 displayed no neurological deficit. One patient survived with a neurological handicap, and 1 patient survived in a vegetative state. One patient died of severe pulmonary embolism and 1 patient of extensive cerebral infarction. Another 3 patients died during the time course of the study because of the refractory intracranial hypertension. The complication rate of cerebral herniation with a lethal outcome was 6%. There was no correlation between the occurrence of a unilateral mydriasis and the status of basal cisterns or the presence of a midline shift on CT.

Neurological Recovery

Thirty-six patients (36%) had a favorable outcome (good recovery or moderate disability), 12 (12%) were severely disabled and therefore permanently unable to work, 7 (7%) were in a persistent vegetative state, and 45 (45%) died. The frequency with which a particular therapy was applied in patients was correlated with neurological recovery. After the application of lumbar CSF drainage, treatments specifically directed at ICP (sedation, osmotherapy, ventricular drainage, and barbiturate coma) could be stopped in 43 patients. This patient population had a mean GOS score of $3.4 \pm 1.6$ (median score 4). In 57 patients specific ICP therapy (osmotherapy and barbiturate coma) had to be continued despite the application of lumbar CSF drainage. Among this patient population the mean GOS score was $2.2 \pm 1.7$ (median score 1). How often specific ICP treatments were applied before and after the initiation of lumbar CSF drainage is presented in Fig. 4. There was no change in the use of hyperventilation before (PaCO$_2$ 36.6 ± 3.9 mm Hg) and after (PaCO$_2$ 35.9 ± 5.7 mm Hg) lumbar CSF drainage. Statistical analysis revealed a significant correlation between patient age and outcome in that as patients become older the mortality rate increases and the rate of neurological recovery decreases. As demonstrated in Fig. 5 more patients in the SAH group died (58%) than in the TBI group (29%). According to the correlation between age and outcome, patients with SAH were significantly older than those with TBI (Table 1). The cause of death in patients with SAH was multiple cerebral infarctions due to severe vasospasm, finally leading to massive cerebral edema with refractory intracranial hypertension. In patients with extensive cerebral infarctions with a very poor prognosis, minimal therapy was initiated.

Discussion

Our aim in this study was to determine if lumbar CSF drainage 1) reduces increased ICP and 2) is accompanied by a significant risk of cerebral herniation as a potentially dangerous complication, thus excluding further investigations into this therapeutic option. In the literature cerebral herniation has been postulated to be a frequent and lethal complication of lumbar CSF drainage in cases of intracranial hypertension; therefore, lumbar drainage has been regarded as a major contraindication during intracranial hypertension.6 Note, however, that the investigations underlying this dogma were conducted during a time period in which technical and medical possibilities were significantly inferior to modern standards. Furthermore, studies demonstrating cerebral herniation after lumbar drainage were performed in patients suffering from cerebral tumors.9,10,13,34 In the 1990s the first report on the successful and safe application of lumbar CSF drainage in 5 children with refractory intracranial hypertension was published.1 Additional reports followed, demonstrating positive results in reducing ICP in children through the use of lumbar CSF drainage. Cerebral herniation did not occur in any of the treated children in response to lumbar CSF drainage.10,21,39 Considering that refractory intracranial hypertension remains a major problem in severely brain-injured patients, we decided to reevaluate the efficacy and

---

Fig. 1. Bar graph demonstrating ICP values in 100 patients directly before (dark bar) and after (light bar) the initiation of lumbar drainage (LD) and averaged ICP values 6 hours before (dark bar) and after (light bar) lumbar drainage was started.

Fig. 2. Bar graph revealing CPP values in 100 patients directly before (dark bar) and after (light bar) the initiation of lumbar drainage (LD) and averaged CPP values 6 hours before (dark bar) and after (light bar) lumbar drainage was started.
Lumbar cerebrospinal fluid drainage for intracranial hypertension

safety of lumbar CSF drainage by using improved and refined medical and technical standards.

Effectiveness of Lumbar CSF Drainage

As demonstrated in our results lumbar CSF drainage leads to a significant and lasting reduction in ICP and an increase in CPP. Furthermore, monitoring brain tissue PO$_2$ and rCBF revealed significant improvement in both of these parameters following lumbar CSF drainage. The mean ICP of 32.7 ± 10.9 mm Hg before applying lumbar CSF drainage and after exhausting specific evidence-based ICP therapies underlines the necessity for and importance of additional ICP therapies in patients, as intracranial hypertension represents a key factor in clinical outcome and disease prognosis.$^4,6,23,24$

Complications and Outcome

Cerebral herniation occurred in 12 patients (12%) after lumbar CSF drainage. However, temporarily occurring clinical signs of herniation did not lead to significantly reduced rates of neurological recovery or mortality. In the present study 6 patients died of significant intracranial hypertension leading to cerebral herniation. Three of these patients temporarily demonstrated clinical signs of cerebral herniation in the period before inclusion in the study. At the time of enrollment, however, signs of herniation were not present. Although an unfavorable clinical outcome in these cases was conceivable even before performing lumbar CSF drainage, patients were enrolled into the study according to the inclusion criteria.

Patients with SAH had a significantly increased mortality rate compared with patients with TBI. Subgroup analysis demonstrated no difference in the initial GCS score between these 2 subpopulations. There was also no significant difference between the 2 groups regarding the degree of intracranial hypertension (based on ICP measurement) before lumbar CSF drainage. The status of the basal cisterns or lateral ventricles according to cranial CT was comparable. Furthermore, there was no difference in the degree of ICP reduction after lumbar CSF drainage. A potential explanation for this result may be the increased age of patients with SAH. There was a significant correlation between age and neurological recovery in the entire study population. The close correlation between age and clinical outcome in patients with SAH and those with TBI has been described in various studies.$^{11,14,15,17,25,27,33}$ However, differences in outcome may also be explained by differences in the underlying pathophysiological mechanisms responsible for the development of intracranial hypertension. Note that intracranial hypertension develops in patients with SAH at a significantly later time point than in those with TBI. Moreover, it develops in patients with TBI as a result of the initial trauma, which often makes immediate therapy for ICP mandatory. In contrast, patients suffering from SAH incur refractory intracranial hypertension as a result of cerebral ischemia due to cerebral vasospasm several days after the initial bleeding. However, the development of cerebral vasospasm with

![Fig. 3. Box plots showing the effect of lumbar CSF drainage on ICP (31 patients), brain tissue PO$_2$ (31 patients), and rCBF (15 patients). Measurements revealed a significant decrease in ICP and rCBF and a significant improvement in brain tissue PO$_2$.](image)

![Fig. 4. Bar graph illustrating specific ICP therapies before and after the initiation of lumbar CSF drainage in 100 patients.](image)
According to the GOS score.

Our data confirmed a statistical correlation between ab-
cranial CT

According to the recommendations of Levy et al.,21 and Willemse and Egerle-Peerdeeman,39 lumbar CSF drainage should be undertaken only in patients demonstrating open and well-defined basal cisterns on cranial CT to minimize the danger of cerebral herniation. These recommendations were based on retrospective data in 16 children with open basal cisterns before the application of lumbar CSF drainage.21 Because there was no sign of cerebral herniation in all 16 children, the authors postulated a direct correlation between the status of basal cisterns and the danger of cerebral herniation. Data from our study cannot answer the question of whether there is a direct relation between the status of basal cisterns and the danger of cerebral herniation as only 2 patients underwent lumbar CSF drainage despite partially compressed basal cisterns on CT. Neither of these patients showed any signs of cerebral herniation. The evaluation of cranial CT scans did not provide diagnostic criteria that might predict cerebral herniation or a worse neurological outcome. Even in the case of unilateral space-occupying lesions with midline shift the incidence of cerebral herniation was unchanged. Studies have shown a direct correlation between the status of basal cisterns after TBI and patient outcome. In the case of absent basal cisterns the mortality rate increases to 68% compared with a rate of 22% among patients with normal basal cisterns on CT.40 Accordingly, our data confirmed a statistical correlation between absent basal cisterns on CT scans after performing lumbar CSF drainage and a worse clinical outcome.

Pathophysiological Mechanisms

The pathophysiological mechanism responsible for reducing ICP through lumbar CSF drainage remains unclear. In healthy patients, compliance of the intracranial cavity depends mainly on CSF flow in the subarachnoid space.2,3 There are no data addressing CSF flow and dynamics in patients with intracranial hypertension. Lumbar CSF drainage may reduce ICP by decreasing CSF volume according to the Monro-Kellie doctrine. However, in consideration of the long-lasting effect of CSF drainage, we hypothesize that a reduction in lumbar pressure via CSF drainage may lead to a reduction in the craniocaudal flow resistance of CSF and thus improve cranio-caudal CSF oscillations. With this mechanism cerebral venous outflow may be improved, followed by a decrease in ICP.

Study Limitations

Several limitations of our study must be mentioned. First, we were unable to demonstrate that lumbar CSF drainage improves clinical outcome. However, the primary goal of our study was to challenge the old but well-established paradigm stating that lumbar drainage is contraindicated in patients with increased ICP, which is based on historical arguments rather than scientific data. We determined patient outcome in order to demonstrate that lumbar CSF drainage does not “automatically” lead to cerebral herniation and death, as is usually proclaimed. Cerebral herniation after lumbar CSF drainage occurred in 12 patients (12%); however, temporary clinical signs of cerebral herniation did not lead to lower rates of neurological recovery or a higher mortality rate. A thorough statistical analysis of all cases showing clinical signs of cerebral herniation revealed a complication rate with a lethal outcome of 6%. The overall mortality rate in our study was 45% (including patients with SAH and those with TBI), which is in accordance with the reported rate of 47% in patients with an increased ICP > 20 mm Hg as compared with a rate of 17% in those with an average ICP of < 20 mm Hg.4

According to the Monro-Kellie doctrine, compliance of the intracranial cavity depends mainly on CSF flow in the subarachnoid space.2,3 There are no data addressing CSF flow and dynamics in patients with intracranial hypertension. Lumbar CSF drainage may reduce ICP by decreasing CSF volume according to the Monro-Kellie doctrine. However, in consideration of the long-lasting effect of CSF drainage, we hypothesize that a reduction in lumbar pressure via CSF drainage may lead to a reduction in the craniocaudal flow resistance of CSF and thus improve cranio-caudal CSF oscillations. With this mechanism cerebral venous outflow may be improved, followed by a decrease in ICP.

Several limitations of our study must be mentioned. First, we were unable to demonstrate that lumbar CSF drainage improves clinical outcome. However, the primary goal of our study was to challenge the old but well-established paradigm stating that lumbar drainage is contraindicated in patients with increased ICP, which is based on historical arguments rather than scientific data. We determined patient outcome in order to demonstrate that lumbar CSF drainage does not “automatically” lead to cerebral herniation and death, as is usually proclaimed. Cerebral herniation after lumbar CSF drainage occurred in 12 patients (12%); however, temporary clinical signs of cerebral herniation did not lead to lower rates of neurological recovery or a higher mortality rate. A thorough statistical analysis of all cases showing clinical signs of cerebral herniation revealed a complication rate with a lethal outcome of 6%. The overall mortality rate in our study was 45% (including patients with SAH and those with TBI), which is in accordance with the reported rate of 47% in patients with an increased ICP > 20 mm Hg as compared with a rate of 17% in those with an average ICP of < 20 mm Hg.4

Cranial CT

According to the recommendations of Levy et al.21 and Willemse and Egerle-Peerdeeman,39 lumbar CSF drainage should be undertaken only in patients demonstrating open and well-defined basal cisterns on cranial CT to minimize the danger of cerebral herniation. These recommendations were based on retrospective data in 16 children with open basal cisterns before the application of lumbar CSF drainage.21 Because there was no sign of cerebral herniation in all 16 children, the authors postulated a direct correlation between the status of basal cisterns and the danger of cerebral herniation. Data from our study cannot answer the question of whether there is a direct relation between the status of basal cisterns and the danger of cerebral herniation as only 2 patients underwent lumbar CSF drainage despite partially compressed basal cisterns on CT. Neither of these patients showed any signs of cerebral herniation. The evaluation of cranial CT scans did not provide diagnostic criteria that might predict cerebral herniation or a worse neurological outcome. Even in the case of unilateral space-occupying lesions with midline shift the incidence of cerebral herniation was unchanged. Studies have shown a direct correlation between the status of basal cisterns after TBI and patient outcome. In the case of absent basal cisterns the mortality rate increases to 68% compared with a rate of 22% among patients with normal basal cisterns on CT.40 Accordingly, our data confirmed a statistical correlation between absent basal cisterns on CT scans after performing lumbar CSF drainage and a worse clinical outcome.

Pathophysiological Mechanisms

The pathophysiological mechanism responsible for reducing ICP through lumbar CSF drainage remains unclear. In healthy patients, compliance of the intracranial cavity depends mainly on CSF flow in the subarachnoid space.2,3 There are no data addressing CSF flow and dynamics in patients with intracranial hypertension. Lumbar CSF drainage may reduce ICP by decreasing CSF volume according to the Monro-Kellie doctrine. However, in consideration of the long-lasting effect of CSF drainage, we hypothesize that a reduction in lumbar pressure via CSF drainage may lead to a reduction in the craniocaudal flow resistance of CSF and thus improve cranio-caudal CSF oscillations. With this mechanism cerebral venous outflow may be improved, followed by a decrease in ICP.
that a randomized controlled trial must be performed to assess the effect of lumbar CSF drainage on outcome. Nonetheless, before such a trial could be initiated, one first had to demonstrate that lumbar CSF drainage does not inevitably increase the mortality rate among patients with intracranial hypertension.

Second, the selection of our patient population was based on the fact that patients suffering from either SAH or TBI constitute the majority of patients on a neurosurgical intensive care unit who develop pathologically increased ICP values. Refractory intracranial hypertension represents a major problem in both of these patient populations. In patients with TBI, intracranial hypertension develops as a result of the initial trauma, which often makes immediate therapy for ICP mandatory. Patients suffering from SAH instead usually have refractory intracranial hypertension as a result of cerebral ischemia caused by the development of cerebral vasospasm several days after the initial bleeding. Although the underlying pathology differs significantly for these 2 diseases, cerebral ischemia contributes to the spread of secondary damage to the brain in both. For this reason, the treatment of increased ICP currently is identical in both disease groups. Established guidelines\(^4\) (American Association of Neurological Surgeons) for the treatment of head injuries have therefore been applied in treating intracranial hypertension in patients with SAH. Thus, lumbar CSF drainage seems justified as a therapeutic option in both patient populations.

It is generally agreed that clinical trials in patients with TBI or SAH targeting clinical outcome are difficult to design and perform.\(^30\) A study with clinical outcome as the primary end point requires the consideration of several design issues. Since 1985 more than 20 multicenter clinical trials have been conducted in head-injured patients to determine the effect of new therapeutic approaches. Except for 1, all of these trials have failed to demonstrate a convincing benefit in patients with TBI.\(^22\) Only in the so-called CRASH study, focused on the effect of steroids in patients with TBI, were authors able to detect a 2\% difference in outcome between treatment and control groups.\(^8\) That study was terminated after the recruitment of more than 10,000 patients. To conduct a trial in patients with TBI or SAH to detect the effect of a 5–10\% mortality reduction, \(\sim\) 1000 patients would need to be randomized;\(^22\) therefore, a network of investigators is essential to conduct such a trial.

**Conclusions**

Lumbar drainage of CSF in patients with intracranial hypertension leads to a significant and clinically relevant reduction in ICP. The risk of cerebral herniation in the context of lumbar CSF drainage, which has been postulated in the literature for over a century, cannot be ruled out by our data. Nonetheless, our study does provide important information indicating that the risk of cerebral herniation has been overestimated for a long time. A mortality rate of 6\% and a 3\% rate of patients demonstrating a direct relation between lumbar CSF drainage and cerebral herniation do not justify withholding this effective therapeutic option from those suffering from refractory intracranial hypertension after SAH or TBI. Considering a 47\% mortality rate in patients with TBI whose ICP was > 20 mm Hg and in view of the serious side effects from non–evidence-based second-tier therapies (that is, barbiturate coma and decompressive hemiecraniectomy), lumbar CSF drainage seems justified in treating intracranial hypertension in patients with SAH or TBI. However, it remains unclear whether lumbar CSF drainage improves clinical outcome by reducing ICP or worsens clinical outcome because of complications such as cerebral herniation. A randomized controlled clinical trial must be conducted to answer this question in the future.

**Disclaimer**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Acknowledgments**

The authors thank Tom Bruckner for statistical support and the staff of the intensive care unit for their help.

**References**


---

Manuscript submitted April 14, 2008.
Accepted October 17, 2008.

Please include this information when citing this paper: published online February 27, 2009; DOI: 10.3171/2008.10.JNS08293.

Address correspondence to: J. Tuettenberg, M.D., Department of Neurosurgery, University Hospital Mannheim, Theodor-Kutzer-Ufer 1-3, D-68167 Mannheim, Germany. email: jochen.tuettenberg@nch.ma.uni-heidelberg.de.