Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

# The Role of Prolonged Bed Rest in Postoperative Cerebrospinal Fluid Leakage After Surgery of Intradural Pathology—A Retrospective Cohort Study

**Sophia Krahwinkel[‡**], Stephanie Schipmann, MD[‡§], Dorothee Spille, MD[‡], Emanuele Maragno, MD[‡], Bilal Al Barim, MD[‡], Nils Warneke, MD[‡], Walter Stummer, MD[‡], Marco Gallus, MD[‡||*], Michael Schwake, MD[‡*]**

[‡]Department of Neurosurgery, University Hospital Muenster, Muenster, Germany; [§]Department of Neurosurgery, University Hospital Bergen, Bergen, Norway; [||]Department of Neurological Surgery, University of California San Francisco, San Francisco, CA, USA

*Marco Gallus and Michael Schwake contributed equally to this work.

**Sophia Krahwinkel is a student with no academic title.

**Correspondence:** Michael Schwake, MD, Department of Neurosurgery, University Hospital Muenster, Albert-Schweitzer-Campus 1, Gebaeude A1, Muenster D-48149, Germany. Email: schwakem@uni-muenster.de

**Received,** November 18, 2022; **Accepted,** January 11, 2023; **Published Online,** March 8, 2023.

© Congress of Neurological Surgeons 2023. All rights reserved.

**BACKGROUND:** Postoperative cerebrospinal fluid leakage (CSFL) is a feared complication after surgery on intradural pathologies and may cause postoperative complications and subsequently higher treatment costs.
**OBJECTIVE:** To assess whether prolonged bed rest may lower the risk of CSFL.
**METHODS:** We performed a retrospective cohort study including patients with intradural pathologies who underwent surgery at our department between 2013 and 2021. Cohorts included patients who completed 3 days of postoperative bed rest and patients who were mobilized earlier. The primary end point was the occurrence of clinically proven CSFL.
**RESULTS:** Four hundred and thirty-three patients were included (female [51.7%], male [48.3%]) with a mean age of 48 years (SD ±20). Bed rest was ordered in 315 cases (72.7%). In 7 cases (N = 7/433, 1.6%), we identified a postoperative CSFL. Four of them (N = 4/118) did not preserve bed rest, showing no significant difference to the bed rest cohort (N = 3/315; *P* = .091). In univariate analysis, laminectomy (N = 4/61; odds ratio [OR] 8.632, 95% CI 1.883-39.573), expansion duraplasty (N = 6/70; OR 33.938, 95% CI 4.019-286.615), and recurrent surgery (N = 5/66; OR 14.959, 95% CI 2.838-78.838) were significant risk factors for developing CSFL. In multivariate analysis, expansion duraplasty was confirmed as independent risk factor (OR 33.937, 95% CI 4.018-286.615, *P* = .001). In addition, patients with CSFL had significant higher risk for meningitis (N = 3/7; 42.8%, *P* = .001).
**CONCLUSION:** Prolonged bed rest did not protect patients from developing CSFL after surgery on intradural pathologies. Avoiding laminectomy, large voids, and minimal invasive approaches may play a role in preventing CSFL. Furthermore, special caution is indicated if expansion duraplasty was done.

**KEY WORDS:** CSFL, Intradural spinal tumors, Mobilization, Postoperative complications, Spinal duraplasty

*Neurosurgery* 93:563–575, 2023 https://doi.org/10.1227/neu.0000000000002448

One of the feared and common complications in spine surgery is postoperative leakage of cerebrospinal fluid (CSFL). It can lead to a prolonged length of hospital stay (LOS) and further complications including infections and additional revision surgery. This is often accompanied by prolonged recovery time, delay of potentially required adjuvant treatment such as irradiation or chemotherapy, and may lead subsequently to higher treatment costs.[1-4] Particularly for the operative treatment of intradural pathologies, opening the dura with subsequent dura closure is unavoidable. Different strategies have been developed to counteract postoperative CSFL. One of these strategies is prolonged postoperative bed rest. The hypothesis is that horizontal position of the patients lowers the intraspinal hydrostatic pressure, thus allowing better healing of the durotomy site avoiding CSFL.[3,5-9] By contrast, prolonged bed rest could be associated with specific risks such as deep venous thrombosis,

**ABBREVIATIONS: CSFL,** cerebrospinal fluid leakage; **LOS,** length of hospital stay; **RR,** relative risk.



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

pulmonary embolism (PE), or ileus because of decreased mobilization.[4-9] Thus, the role of bed rest is still unclear.[9-12] In general, studies showed that early mobilization and discharge of patients after surgery had very positive effects on the patients' outcome. Same effects might apply to patients operated for intradural lesions.[13,14]

The aim of this cohort study was to determine whether prolonged bed rest influences the risk of CSFL, and the secondary outcome was to identify other risk factors for CSFL in patients treated for intradural pathologies.

## METHODS

### Study Design and Setting

This is a retrospective observational cohort study comparing 2 cohorts of patients treated surgically because of intradural pathologies in a single academic neurosurgical department. Reporting is in accordance with Strengthening the Reporting of Observational Studies in Epidemiology guidelines for cohort studies.[15] The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the institutional review board (reference number 2021-714-f-S). Because of the retrospective nature of the study, additional informed consent was not required.

### Participants

All patients who had intradural pathology surgery at our department between 2013 and 2021 were included. We then stratified the patients into 2 cohorts. The first one included patients who were ordered prolonged bed rest for 3 days after surgery, and the second cohort included patients who were mobilized on the first postoperative day (Figure 1). Excluded were traumatic durotomies, extraspinal tumors invading the dura, dysraphic disorders, and cases of unintended durotomy. SW, MG, and MS proofed data for validation.

### Additional Data and Variables

The following possible influencing factors were investigated: age, sex, type of pathology, level of pathology in the spine, type of surgery, preoperative and postoperative neurological status using the McCormick Scale,[16] surgical approach (laminectomy, hemilaminectomy, dorsolateral, and laminoplasty), primary surgery or recurrence, duration of surgery, LOS, type of duraplasty (suture, expansion duraplasty, and utility of adhesives), and other complications (meningitis, thrombotic events, nosocomial infections, etc.).

### Surgical Techniques

For simple closure and in case of a dura expansion with a dura replacement material (in most cases bovine pericardium (Tutopatch, RTI surgical, Tutogen Medical GmbH)) a continuous suture with a 6-0 monofil suture (PROLENE, Ethicon, Johnson and Johnson) was used. After suturing, the watertightness was checked with a Valsalva maneuver followed by further sealing the suture with TachoSil (Takeda GmbH). More rarely, synthetic collagen (DuraGen Saturable, Integra LifeSciences), Gore-Tex (Goremedical), or other adhesives, such as DuraSeal (Intergra) or Tisseel (Baxter), were applied.

### Surgical Approach

Depending on the location of the intradural lesion, different surgical approaches were performed. The most common approach was unilateral hemilaminectomy. Laminoplasty was usually performed when intramedullary lesions were addressed. In this context, previously removed laminae were refixed at the end of the procedure. Furthermore, laminectomies were performed less frequently. For pathologies located ventral to the spinal cord, unidorsolateral approaches were performed including hemilaminectomy via partial transversectomy. In one case in this study, a corpectomy was performed.

Furthermore, in all procedures, subfacial drains (Redon, B.Braun SE) without suction were placed and removed on the first postoperative day. The fascia was closed watertight, followed by multilayer suture of the skin.

### Statistics

Statistical analysis was conducted using IBM SPSS Statistics 24.0 software (IBM Corp) as reported previously.[17] For parametric variables, we used the two-tailed Student $t$ tests, and for nonparametric, the two-tailed Mann–Whitney $U$ tests. To compare binary categorical variables, we used Fisher's exact test, and the $\chi^2$ test was conducted in the case of multiple categorical variables. Missing data may have been excluded in the single calculation.

Relative risk (RR) for development of CSFL in both cohorts, including 95% CI, was calculated. Furthermore, univariate odds ratios (ORs) for the development of CSFL were calculated, also including 95% CI. Multivariate analyses were performed by binary logistic regression. A probability value less than $P < .05$ was considered statistically significant.

## RESULTS

A total of 433 patients with intradural pathologies were included into the analysis (see Table 1 for further patients' characteristics). Bed rest was ordered in 315 cases and the remaining 118 were mobilized on the first postoperative day. In total, we identified 7 cases of CSFL (N = 7/433, 1.6%), of which 6 (6/7, 85.6%) required surgical revision, whereas 1 patient was treated conservatively with placement of a lumbar drain.

In the bed rest cohort, CSFL occurred in 1% of the patients (N = 3/315) in comparison with 3.4% in the no bed rest cohort (N = 4/118), showing no significant association or increased risk for the development of a CSFL ($P$ = .091; RR 0.281; 95% CI 0.064-1.237). Bed rest was more frequently ordered after procedures on pathologies below thoracic vertebral body 6 (D-6) and lumbar spine ($P$ < .001). On the other hand, most CSFL cases were above D-6 (N = 5/185, 2.7%, compared with N = 2/248, 0.8%); however, this was not statistically significant ($P$ = .143) (Table 2).

### Risk Factors for Development of CSFL

In univariate analysis, we observed that CSFL was more frequent when patients underwent a recurrent surgery on the same spinal level compared with a primary surgery (N = 5/66, 7.6% vs N = 2/367, 0.5%, $P$ < .001; OR 14.959, 95% CI 2.838-78.838)



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

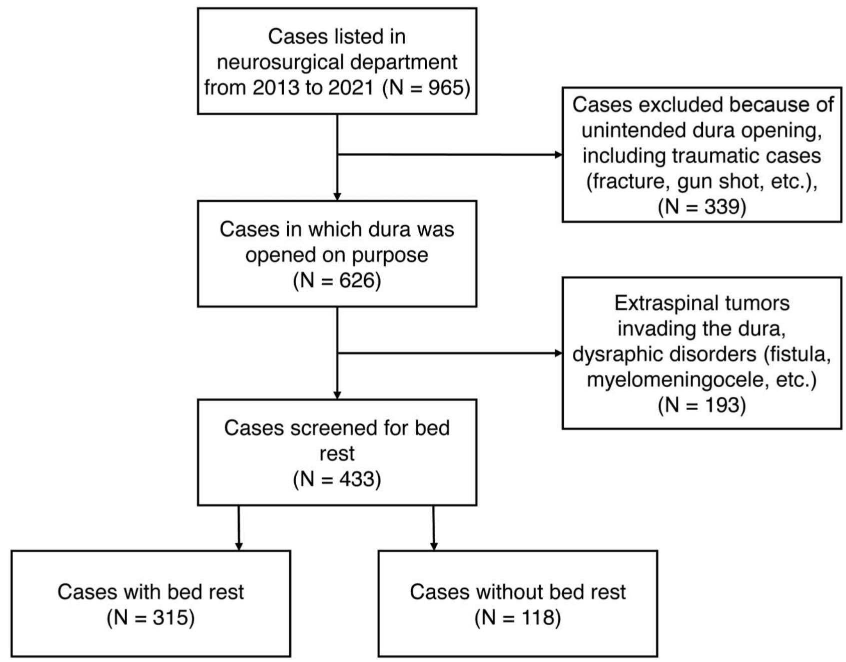


**FIGURE 1.** *Flowchart of patients included to the study.*

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

(Table 3). Furthermore, expansion duraplasty was associated with an increased risk for CSFL compared with simple suture (N = 6/70, 8.6% vs N = 1/363, 0.3%, $P < .001$; OR 33.938, 95% CI 4.019-286.615). Also, laminectomy was associated with an increased prevalence of CSFL compared with unilateral access and laminoplasty together (N = 4/61, 6.6%, N = 3/372, $P = .01$; OR 8.632, 95% CI 1.883-39.573). To further confirm our results, we performed a binary logistic regression analysis including all above-mentioned risk factors and found that expansion duraplasty was the only independent risk factor (OR 33.937, 95% CI 4.018-285.615, $P = .001$).

### Complications Associated With Prolonged Bed Rest and CSFL

Regarding complications, we found that the patients in the bed rest cohort did not have an increased risk for complications (N = 48/315, 15% vs 16/118, 13.5%, $P = .850$), especially not an increased rate of thrombosis or pulmonary embolism (N = 4/315, 1.3% vs 2/118, 1.7%, $P = .666$). By contrast, patients with CSFL had significantly more often complications (N = 4/7, 57.1% vs N = 60/426. 14%, $P = .011$), especially postoperative meningitis (N = 3/7 vs 1/426, $P < .001$). Not surprisingly, CSFL lead to longer LOS (22.43 days ± 7.42 in comparison to 7.97 days ± 7.08; $P = .005$). By contrast, LOS in bed rest cohort was only slightly, but not significantly longer (8.24 days ± 6.67 in comparison with 7.85 days ± 7.43; $P = .959$). Table 4 includes all patients with CSFL. Figures 2 and 3 demonstrate case examples.

## DISCUSSION

Postoperative CSFL after durotomy for surgery on intradural pathologies is a well-known risk and associated with infectious complications, prolonged lengths of stay, increased health care costs, and the risk for early reoperation.[3-6] The aim of our study was to evaluate the effect of postoperative early mobilization on the development of CSFL. We documented an overall prevalence of CSFL of 1.6%, compared with other studies, which found rates ranging from 2% to 34%.[1,4,6,18] In summary, we demonstrated that early postoperative mobilization after durotomy was not associated with a significantly increased risk of CSFL. Taking this into consideration, we cannot support a general recommendation for prolonged postoperative bed rest after durotomy for surgery on intradural pathologies. These findings support previous results that bed rest does not play a significant role in preventing CSFL.[5,6,9,11,12] Beyond that, our data did not show an association between early mobilization and the occurrence of other postoperative adverse events.

### Duraplasty as a Risk Factor for the Development of Postoperative CSFL

As a second aim of this study, we evaluated other possible risk factors for developing CSFL. In this context we demonstrated that when direct closure of the dura was not indicated or not possible, the risk of CSFL was significantly higher. Although CSFL was found only in 0.3% (N = 1/363) of patients where a simple



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

**TABLE 1. Baseline Patients' Characteristics**

| Variable | Bed rest (N = 315) 72.75% | No bed rest (N = 118) 27.25% | *P* value |
|---|---|---|---|
| Sex (N, %) | | | .450 |
| Female | 159 (50.5%) | 65 (55.1%) | |
| Male | 156 (49.5%) | 53 (44.9%) | |
| Age (y, mean ± SD) | 48.02 (20.78) | 49.44 (18.47) | .097 |
| Preoperative McCormick Scale | | | .051 |
| 1 | 118 (37.5%) | 29 (24.6%) | |
| 2 | 113 (35.9%) | 58 (49.2%) | |
| 3 | 47 (14.9%) | 20 (16.9%) | |
| 4 | 26 (8.3%) | 6 (5.1%) | |
| 5 | 11 (3.5%) | 4 (3.4%) | |
| No data | x | 1 (0.8%) | |
| Preoperative binary McCormick Scale | | | .902 |
| Favorable (score 1-2) | 231 (73.4%) | 87 (73.8%) | |
| Nonfavorable (score 3-5) | 84 (26.6%) | 30 (26.2%) | |
| No data | x | 1 | |
| Recurrent surgery on same level | | | .176 |
| Yes | 53 (16.8%) | 13 (11.0%) | |
| No (=primary surgery) | 262 (83.2%) | 105 (89.0%) | |
| Intramedullary/extramedullary | | | .106 |
| Intramedullary | 90 (28.6%) | 46 (39.0%) | |
| Extramedullary | 150 (47.6%) | 46 (39.0%) | |
| No tumor | 75 (23.8%) | 26 (22.0%) | |
| Tumor/no tumor | | | .898 |
| Tumor | 240 (76.2%) | 92 (78.0%) | |
| No tumor | 75 (23.8%) | 26 (22.0%) | |
| Pathology (N) | 315 | 118 | |
| Tumor | 240 | 92 | |
| Intramedullary | 90 | 46 | |
| Cavernoma | 5 | 2 | |
| Ependymoma | 36 | 13 | |
| Astrocytoma | 12 | 4 | |
| Glioblastoma | 4 | 6 | |
| Hemangioblastoma | 13 | 13 | |

**TABLE 1. Continued.**

| Variable | Bed rest (N = 315) 72.75% | No bed rest (N = 118) 27.25% | *P* value |
|---|---|---|---|
| Others | 20 | 8 | |
| Lipoma | 4 | x | |
| Lymphoma | x | 1 | |
| Melanocytic tumor | 3 | 1 | |
| Metastases | 11 | 5 | |
| Ganglioglioma | 1 | x | |
| Sarcoma | 1 | x | |
| Unclear tumor | x | 1 | |
| Extramedullary | 150 | 46 | |
| Meningioma | 48 | 28 | |
| Schwannoma | 56 | 17 | |
| Ependymoma | 22 | x | |
| Others | 24 | 1 | |
| Melanocytic tumor | 2 | x | |
| Neurofibroma | 1 | x | |
| Nerve sheath tumor | 6 | x | |
| Angiolipoma | 1 | x | |
| Chordoma | 1 | x | |
| Metastases | 9 | x | |
| Diffused midline glioma | 2 | x | |
| Paraganglioma | 1 | x | |
| Sarcoma | 1 | x | |
| Unclear tumor | x | 1 | |
| Other pathology | 75 | 26 | |
| Cysts | 26 | 5 | |
| Arachnoidal cyst | 8 | 4 | |
| Other cysts | 18 | 1 | |
| Arachnopathy | 2 | x | |
| Arteriovenous fistula | 2 | 6 | |
| CSF leakage | 4 | 2 | |
| Spontaneous CSF loss syndrome | 1 | x | |
| Reactive modified CNS tissue | 5 | 3 | |
| Tethered cord | 15 | 3 | |



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

**TABLE 1. Continued.**

| Variable | Bed rest (N = 315) 72.75% | No bed rest (N = 118) 27.25% | *P* value |
|---|---|---|---|
| Syringomyelia | 4 | x | |
| Disk herniation/transdural approach | 3 | 3 | |
| Inflammation | 2 | 1 | |
| Bleeding | 7 | x | |
| Cord herniation | 3 | 1 | |
| Meningeosis | 1 | x | |
| Hirayama syndrome | x | 1 | |
| Histiocytosis | x | 1 | |
| Surgical approach (N, %) | | | .26 |
| Dorsolateral | 15 (4.8%) | 12 (10.2%) | |
| Extended interlaminar fenestration | 8 (2.5%) | 3 (2.5%) | |
| Hemilaminectomy | 185 (58.7%) | 66 (55.9%) | |
| Laminectomy | 46 (14.6%) | 14 (11.9%) | |
| Laminoplasty | 51 (16.2%) | 19 (16.1%) | |
| Laminotomy | 10 (3.2%) | 2 (1.7%) | |
| Laminectomy and corpectomy | x | 2 (1.6%) | |
| Level of extension | | | <.001 |
| Cervical | 19 (6.0%) | 73 (61.9%) | |
| Cervicothoracic | 9 (2.9%) | 6 (5.1%) | |
| Thoracic | 135 (42.9%) | 30 (25.4%) | |
| Thoracolumbar | 14 (4.4%) | x | |
| Lumbar | 120 (38.1%) | 7 (5.9%) | |
| Lumbosacral | 7 (2.2%) | 1 (0.8%) | |
| Sacral | 11 (3.5%) | 1 (0.8%) | |
| Level above/below thoracic vertebral body 6 | | | <.001 |
| Occiput—thoracic vertebral body 6 | 85 (27.0%) | 100 (84.7%) | |
| Thoracic vertebral body 7—sacrum | 230 (73.0%) | 18 (15.3%) | |

durotomy and suture was performed, it was found in 8.6% of the cases after expansion duraplasty (N = 6/70; OR 33.938, 95% CI 4.019-286.615, *P* < .001).

Furthermore, we were able to show that a dura closure via a continuous watertight suture with a monofil 6-0 suture followed by sealing with TachoSil, as practiced in our institution, is an efficient method to prevent leakage, which is consistent with previous observations from the literature. Lee et al[5] reported a very low prevalence of CSFL when using monofilament sutures compared with silk. Several other studies confirm that a watertight suture is elementary.[1,19-21] Additional sealing with TachoSil or DuraSeal could also have a positive effect on the results.[8,22-24] Ebel et al[20] underlined the advantages of TachoSil, demonstrated the superiority of thin monofil 6-0 sutures to thicker sutures, and concluded that the combination of sutures with TachoSil or DuraSeal was able to counteract much higher pressures than other alternatives.

Typically, expansion duraplasty is performed in 2 situations. First, in cases where the surgeon intends to enlarge the intradural space, and second, when the dura is damaged by an infiltrating tumor. In the past, surgeons had to use autologous transplants[25,26]; nowadays, xenogeneic or artificial plastics are increasingly used, mainly to save time[20] and to improve the tightness of the duraplasty.[27,28] In our department, bovine pericardium (Tutopatch) was primarily used. In other studies, it has been shown that this material is associated with very good tightness. For example, Lee et al[29] demonstrated that bovine pericardium achieved significantly better tightness rates than porcine pericardium or artificial equivalents. Similar results were published regarding synthetic materials such as collagen matrix (DuraGen).[20,30,31]

## The Role of Surgical Approach for Developing CSFL

As we further compared the different surgical approaches, we found out that the prevalence of CSFL after laminectomies was higher than after unilateral approaches and laminoplasty (OR 8.632, 95% CI 1.883-39.573; *P* = .009). These data concur with a previous review and meta-analysis, which demonstrated that laminoplasty is superior to laminectomy in preventing CSFL.[32] The hypothesis is that reinsertion of the vertebral arches creates a barrier and fills the void in paraspinal tissue, thereby supporting the healing of the durotomy.[33] Indeed, we did not identify any case of CSFL after laminoplasty (N = 0/70, 0%, in comparison with 4/64 in case of laminectomy; *P* = .046). Moreover, large dead space in the paraspinal tissue after resection of large tumors was found in 4 (N = 4/7, 57%) CSFL cases in this study. When reviewing the reasons for revision surgeries and their outcome, we noticed that decreasing the dead space by filling it with adipose tissue or mobilizing muscle tissue is very efficient.

One further alternative to avoid a large void in the paraspinal tissue is performing the surgery via more minimal invasive approaches including only unilateral hemilaminectomy,[34,35] which may make the surgery technically more challenging for the surgeon. However, the minimal damage to the paraspinal muscles and smaller void in the vertebral lamina may lead at the same time to a lower rate of CSFL as shown in this study (N = 3/273, 0.7% in comparison with 4/62, 6.45% in case of laminectomy; *P* = .024). These results are analogous to the results after laminoplasty (*P* = 1).



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

**TABLE 2. Perioperative Data and Outcome**

| Variable | Bed rest (N = 315) 72.75% | No bed rest (N = 118) 27.25% | *P* value |
|---|---|---|---|
| Length of hospital stay (LOS), (d, mean ± SD) | 8.34 (6.67) | 7.85 (7.43) | .959 |
| Duration of surgery (min, mean ± SD) | 240.92 (103.68) | 262.97 (112.89) | .852 |
| CSFL | | | .091 |
| Yes | 3 (1.0%) | 4 (3.4%) | |
| No | 312 (99.0%) | 114 (96.6%) | RR 0.281, 95% CI 0.064-1.237 |
| Dura closure | | | .434 |
| Suture | 267 (84.8%) | 95 (80.5%) | |
| Expansion duraplasty | 47 (14.9%) | 23 (19.5%) | |
| No suture (Only patching with TachoSil) | 1 (0.3%) | x | |
| Additional patching | | | .700 |
| Duraseal | 2 (0.6%) | 3 (2.5%) | |
| TachoSil | 228 (72.4%) | 84 (71.2%) | |
| Muscle patch | 1 (0.3%) | 1 (0.8%) | |
| Tisseel | 2 (0.6%) | 2 (1.7%) | |
| TachoSil combinations | 58 (17.8%) | 16 (13.6%) | |
| TachoSil and Duraseal | 18 | 4 | |
| TachoSil and Tisseel | 25 | 5 | |
| TachoSil and Floseal | 4 | 2 | |
| TachoSil and Gelitta | 10 | 4 | |
| TachoSil and Tabotamp | 1 | 1 | |
| Muscle patch in combination | 10 (3.2%) | 4 (4.2%) | |
| At least 3 patches and/or Tisseel | 7 (2.2%) | 3 (3.1%) | |
| No data | 7 (2.2%) | 5 (4.3%) | |
| Postoperative complications | | | .865 |
| No complications | 265 (84.1%) | 99 (83.9%) | |
| Urinary tract infection | 8 (2.5%) | 1 (0.8%) | |
| Neurological deterioration | 14 (4.4%) | 6 (5.1%) | |
| PE/deep vein thrombosis | 4 (1.3%) | 2 (1.7%) | |
| Infection[a] | 10 (3.2%) | 3 (2.5%) | |
| Bleeding | 5 (1.6%) | 1 (0.8%) | |
| Meningitis | 2 (0.6%) | 2 (1.7%) | |
| Death | 5 (0.6%) | 1 (0.8%) | |
| No data | 2 (0.6%) | 3 (2.5%) | |



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

**TABLE 2. Continued.**

| Variable | Bed rest (N = 315) 72.75% | No bed rest (N = 118) 27.25% | *P* value |
|---|---|---|---|
| Postoperative McCormick Scale | | | .023 |
| 1 | 139 (44.1%) | 38 (32.2%) | |
| 2 | 100 (31.7%) | 57 (48.3%) | |
| 3 | 46 (14.6%) | 11 (9.3%) | |
| 4 | 24 (7.6%) | 9 (7.6%) | |
| 5 | 6 (1.9%) | 2 (1.7) | |
| No data | X | 1 (0.8%) | |
| Postoperative binary McCormick Scale | | | .301 |
| Favorable (score 1-2) | 239 (75.9%) | 95 (81.2%) | |
| Nonfavorable (score 3-5) | 76 (24.1%) | 22 (18.8%) | |

CSFL, cerebrospinal fluid leakage; LOS, length of hospital stay; PE, pulmonary embolism; RR, relative risk.
[a]Infections include pneumonia, unclear fever, and postoperative fever periods because of a bacterial or viral infection.

In addition, minimal invasive spine surgery has further advantages such as less pain and shorter recovery time.[13,14,36] Former studies already demonstrated comparable rates of tumor resection in unilateral approaches in comparison with full laminectomy.[35,37,38]

### Other Risk Factors for the Occurrence of Postoperative CSFL

One more risk factor was the performance of recurrent surgery in the same level. These findings are in accordance with those of Jesse et al[6] who discussed the presence of scar tissue and the resulting impaired healing of the durotomy as possible associated risk factors for the occurrence of CSFL. However, several studies could not verify this.[2,4,11,34,39]

In comparison with other studies, we could not find any association between the development of CSFL and underlying pathology—tumor vs nontumor—and localization level of the durotomy in the spine.[4,6,39] Furthermore, Jesse et al reported a higher incidence of CSFL when the approach was in the cervicothoracic junction, explained by the higher movements in that area[6]; however, none of the patients in this study operated for pathology in this region developed a CSFL.

Because of the different nature of intended and accidental dura opening, both conditions are difficult to compare. However, our results do indicate that watertight closure of the dural tear and less invasive surgical approaches may also have advantages in treating nonintended dural tears.[40]

### Complications Associated With the Occurrence of CSFL

In this study, we could also demonstrate that the presence of CSFL may lead to further complications. The overall complication rate was higher than in patients without CSFL, especially the rate of meningitis. One explanation is that open communication between subarachnoid and extradural spaces may promote germs entering the subdural space causing meningitis.[3,4,41] The increased rate of postoperative complications and the need for revision surgery led to significant longer LOS and probably overall recovery.

### Limitations

The retrospective nature of the study and the fact that the patients were not randomized limit the conclusions that can be drawn from the data. As mentioned earlier, there were significantly more patients with pathologies in the lower part of the thoracic spine below D-6 and lumbar spine in the bed rest group. When postulating that the intraspinal hydrostatic pressure is higher because of gravity, bed rest still can seem to be reasonable for preventing CSFL in patients with lower-level pathology.

However, of all patients diagnosed with CSFL, only 1 patient with a giant ependymoma, who had to be revised twice, had a pathology below D-6. All other CSFL occurred in the upper spinal levels above D-6 (N = 5/7, 71.4%). Previous studies also did not demonstrate a higher rate of CSFL in the lumbar spine,[1,2,4,5,18,39,42] questioning the hypothesis that elevated hydrostatic pressure in the lower spinal segment is a risk factor for CSFL.

## CONCLUSION

Early postoperative mobilization after durotomy is not associated with an increased risk of CSFL. Moreover, the technique of dura closure and the surgical approach seem to play a much bigger role. Closure of the durotomy with a watertight continuous monofil 6.0 suture including sealants and avoiding large voids in



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

**TABLE 3. Patients' Characteristics With CSFL in Comparison With Patients Without**

| Variable | CSFL (N = 7) 1.62% | No CSFL (N = 426) 98.38% | *P* value |
|---|---|---|---|
| Sex (N, %) | | | .451 |
| Female | 5 (71.4%) | 207 (48.6%) | |
| Male | 2 (28.6%) | 219 (51.4%) | |
| Age (y, mean ± SD) | 37.69 (±17.81) | 48.58 (±20.14) | .094 |
| Intramedullary/ extramedullary | | | .265 |
| Intramedullary | 2 (28.6%) | 135 (31.7%) | |
| Extramedullary | 5 (71.4%) | 193 (45.3%) | |
| No tumor | 0 | 98 (23.0%) | |
| Tumor | | | 1.000 |
| Yes | 7 (100%) | 328 (77.0%) | OR: 1.793 CI 95%: .213-15.070 |
| No | 0 (0%) | 98 (23.0%) | |
| Level of extension | | | .403 |
| Cervical | 4 (57.1%) | 88 (20.7%) | |
| Cervicothoracic | 0 | 15 (3.5%) | |
| Thoracic | 1 (14.3%) | 164 (38.5%) | |
| Thoracolumbar | 0 | 14 (3.3%) | |
| Lumbar | 0 | 125 (29.3%) | |
| Lumbosacral | 2 (28.6%) | 8 (1.9%) | |
| Sacral | 0 | 12 (2.8%) | |
| Level above/below thoracic vertebral body 6 | | | .143 |
| Above thoracic vertebral body 6 | 5 (71.4%) | 180 (42.3%) | OR: 3.417 CI 95%: 0.655-17.809 |
| Below thoracic vertebral body 6 | 2 (28.6%) | 246 (57.7%) | |
| Bed rest | | | .091 |
| Yes | 3 (42.9%) | 312 (73.2%) | OR: 0.274 CI 95%: 0.060-1.243 |
| No | 4 (57.1%) | 114 (26.8%) | |
| Cases with pathology above below thoracic vertebral body 6 | | | .377 |
| Bed rest | 1 (20%) | 84 (46.6%) | |
| Early mobilization | 4 (80%) | 96 (53.3%) | |
| Cases with pathology below thoracic vertebral body 6 | | | >.999 |
| Bed rest | 2 (0.8%) | 0 (0%) | |
| Early mobilization | 228 (99.99%) | 18 (100%) | |
| Only case with early mobilization | | | >.999 |
| Above thoracic vertebral body 6 | 4 (100 %) | 96 (81.4%) | |
| Below thoracic vertebral body 6 | 0 (0%) | 18 (15.8%) | |
| Preoperative McCormick Scale | | | .028 |
| 1 | 0 | 147 (34.5%) | |
| 2 | 7 (100%) | 164 (38.5%) | |
| 3 | 0 | 67 (15.7%) | |
| 4 | 0 | 32 (7.5%) | |
| 5 | 0 | 15 (3.5%) | |
| No data | 0 | 1 (0.2%) | |
| Preoperative McCormick Scale (binary) | | | .197 |
| Favorable (score 1-2) | 7 (100%) | 311 (73.0%) | |
| Nonfavorable (score 3-5) | 0 (0%) | 114 (26.7%) | |
| Recurrent surgery on same level | | | .001 |
| Yes | 5 (71.4%) | 61 (14.3%) | OR: 0.067 CI 95%: 0.013-0.352 |
| No (=primary surgery) | 2 (28.6%) | 365 (85.7%) | |
| Approach | | | .071 |
| Dorsolateral | 0 (0%) | 27 (100%) | |

**TABLE 3. Continued.**



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

**TABLE 3. Continued.**

| Variable | CSFL (N = 7) 1.62% | No CSFL (N = 426) 98.38% | *P* value |
|---|---|---|---|
| Hemilaminectomy | 2 (0.7%) | 271 (99.3%) | |
| Laminectomy | 4 (6.6%) | 57 (93.3%) | |
| Laminoplasty | 0 (0%) | 70 (100%) | |
| Laminectomy and corpectomy | 1 (50%) | 1 (50%) | |
| Approach (binary) | | | .009 |
| Laminectomy (AND corpectomy) | 4 (57.14%) | 57(13.38%) | OR: 8.632 CI 95%: 1.883-39.573 |
| Laminoplasty and unilateral | 3 (42.86%) | 369 (86.62%) | |
| Dura closure | | | <.001 |
| Suture with TachoSil | 1 (14.3%) | 361 (84.7%) | OR: 33.938 CI 95%: 4.018-286.615 |
| Expansion duraplasty | 6 (85.7%) | 64 (15.0%) | |
| No suture | 0 | 1 (0.2%) | |
| Additional patching | | | .093 |
| Duraseal | 0 | 5 (1.2%) | |
| TachoSil | 3 (42.9%) | 309 (72.5%) | |
| Muscle patch | 0 | 2 (0.5%) | |
| Tisseel | 0 | 4 (0.9%) | |
| TachoSil combinations | 2 (28.6%) | 72 (16.9%) | |
| TachoSil and Duraseal | 2 (28.6%) | 20 (4.7%) | |
| TachoSil and Tisseel | 0 | 30 (7.0%) | |
| TachoSil and Floseal | 0 | 6 (1.4%) | |
| TachoSil and Gelitta | 0 | 14 (3.3%) | |
| TachoSil and Tabotamp | 0 | 2 (0.5%) | |
| Muscle patch in combination | 1 (14.3%) | 13 (3.1%) | |
| At least 3 patches and/or Tisseel | 1 (14.3%) | 9 (2.1%) | |
| No data | x | 5 (1.2%) | |

**TABLE 3. Continued.**

| Variable | CSFL (N = 7) 1.62% | No CSFL (N = 426) 98.38% | *P* value |
|---|---|---|---|
| Duration of surgery (min, mean ± SD) | 343.29 (114.74) | 5 (1.2%) | .486 |
| LOS, (d, mean ± SD) | 22.43 (7.42) | 7.97 (7.08) | .005 |
| Postoperative McCormick Scale | | | .106 |
| 1 | 1 (14.3%) | 176 (41.3%) | |
| 2 | 6 (85.7%) | 151 (35.4%) | |
| 3 | 0 | 57 (13.4%) | |
| 4 | 0 | 33 (7.7%) | |
| 5 | 0 | 8 (1.9%) | |
| No data | 0 | 1 (0.2%) | |
| Postoperative binary McCormick Scale | | | .358 |
| Favorable (score 1-2) | 7 (100%) | 327 (76.7%) | |
| Nonfavorable (score 3-5) | 0 | 98 (23.2%) | |
| No data | 0 | 1 (0.2%) | |
| Postoperative complications | | | <.001 |
| No | 3 (42.9%) | 361 (84.7%) | |
| Meningitis | 3 (42.9%) | 1 (0.2%) | |
| PE | 1 (14.3%) | 5 (1.2%) | |
| Other | 0 | 54 (12.7%) | |
| No data | 0 | 5 (1.2%) | |
| Postoperative complication | | | .011 |
| No | 3 (42.9%) | 361 (84.7%) | |
| Any | 4 (57.1%) | 60 (14.1%) | |
| No data | 0 | 5 (1.2%) | |
| Meningitis | | | <.001 |
| Yes | 3 (42.9%) | 1 (0.2%) | |
| No | 4 (57.1%) | 420 (98.6%) | |
| No data | 0 | 5 (1.2%) | |

CSFL, cerebrospinal fluid leakage; LOS, length of hospital stay; OR, odds ratio; PE, pulmonary embolism.



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023



**TABLE 4. Data of Patients With CSFL**

| Patient | Sex | Age (years) | Pathology | Level | Preoperative neurological status (McCormick) | Postoperative neurological status (McCormick) | Approach | Dura closure | Primary surgery | Postoperative complication | Bed rest | Revision technique |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F | 29 | Ependymoma | L-1 to S-2 | 2 | 2 | Laminectomy | Expansion duraplasty | Yes | Meningitis | Yes | First revision, revision of duraplasty with collagen substitute (Duragen), TachoSil, and autologous fat tissue |
| 2 | M | 48 | Hemangioblastoma | C-1 | 2 | 2 | Laminectomy | Expansion duraplasty | No | PE | No | Duroplasty with xenograft (Tutopatch), TachoSil, and fat tissue |
| 3 | F | 53 | Bronchogenic cyst | C-5-6 | 2 | 2 | Hemilaminectomy | Expansion duraplasty | No | No | Yes | Duroplasty with xenograft (Tutopatch) and TachoSil |
| 4 | F | 27 | Schwannoma | C-2-5 | 2 | 2 | Laminectomy and corpectomy | Expansion duraplasty | No | Meningitis | No | Duroplasty with xenograft (Tutopatch), TachoSil, and fat tissue to fill the void |
| 5 | M | 50 | Schwannoma | D-4-5 | 2 | 1 | Hemilaminectomy | Simple suture | Yes | No | No | Release of the spinal cord, watertight suture, and TachoSil |
| 6 | F | 28 | Meningioma | C-2-3 | 2 | 2 | Hemilaminectomy | Expansion duraplasty | No | Meningitis | No | Conservative treatment with lumbar drain |
| 7 | F | 29 | Ependymoma | L-1 to S-2 | 2 | 2 | Laminectomy | Expansion duraplasty | No | No | Yes | Second revision, revision of duraplasty with collagen substitute (Duragen), TachoSil, and autologous fat tissue. In addition, laminoplasty with titanium mesh. |

CSFL, cerebrospinal fluid leakage; F, female; M, male; PE, pulmonary embolism.



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

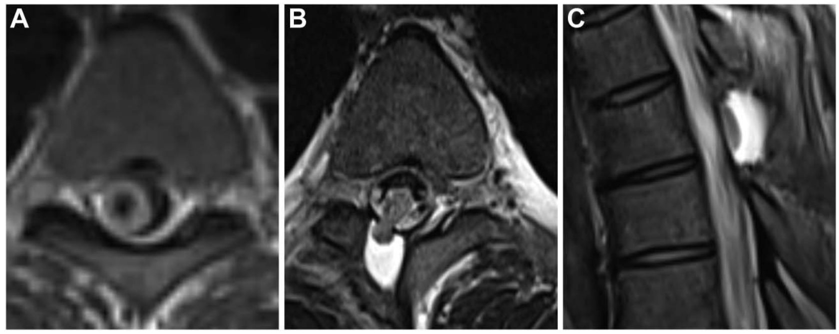


**FIGURE 2.** *Example case of a patient (number 5 in Table 4) with a schwannoma at the level of thoracic vertebral body 4 to 5.* **A**, *Preoperative T1 axial slide with gadolinium. The tumor was resected via right-sided hemilaminectomy, dura was closed with continuous monofil 6-0 suture, and then sealed with TachoSil. The patient recovered and had postoperative McCormick score of 1.* **B** *and* **C**, *First follow-up imaging 3 months after surgery demonstrated a small cerebrospinal fluid leakage with a herniated cord out of the durotomy site; the patient underwent a revision surgery.*

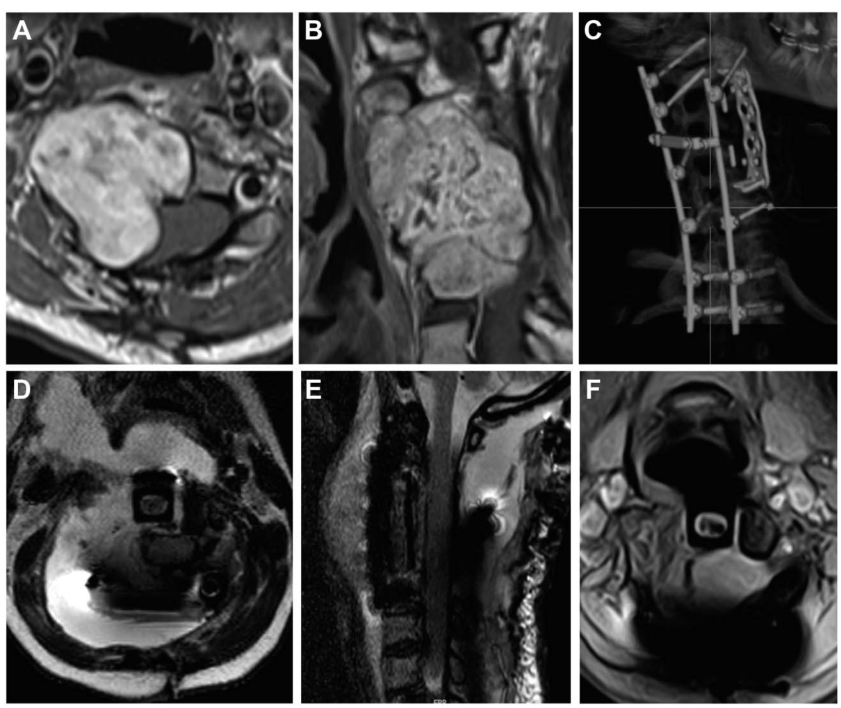


**FIGURE 3.** *Example case of a patient (number 4 in Table 4) with recurrent large cervical schwannoma extending from cervical vertebral body 2 to 5.* **A** *and* **B**, *Tumor resection was performed in the dorsoventral approach including laminectomy, dorsal fusion, and corpectomy. Because of tumor infiltration of the dura, duraplasty with bovine pericardium (Tutopatch) had to be performed and subsequently sealed with TachoSil.* **C**, *3-D reconstruction of postoperative computed tomography. During postoperative course, the patient developed dysphagia and fever.* **D** *and* **E**, *Postoperative images demonstrating a huge cerebrospinal fluid leakage and elevated leucocytes in cerebrospinal fluid, indicating meningitis. Initially lumbar drain was inserted, and calculated antibiotic treatment was started.* **F**, *In the following revision surgery—also from a dorsoventral approach—the void left after tumor resection was filled with autologous adipose tissue.*



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023

the paraspinal tissue seem to be most efficient in preventing CSFL after surgery on intradural pathologies. Further prospective studies should be performed to confirm these results, especially for durotomies in the caudal spinal segments.

## Funding

This study did not receive any funding or financial support.

## Disclosures

Michael Schwake reports consultant activities for Medac (Wedel. Germany) and MagForce AG (Berlin, Germany) and financial support from Silony Medical (Leinfelden-Echterdingen, Germany) and Spineart (Frankfurt, Germany) and grants from Stryker (Duisburg, Germany) and Johnson and Johnson (Norderstedt, Germany). Stephanie Schipmann reports consultant activities for NxDevelopment (Kentucky, USA). Marco Gallus receives funding from the German Research Foundation (Bonn, Germany). The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

## REFERENCES

1. Sellin JN, Kolcun JPG, Levi AD. Cerebrospinal fluid leak and symptomatic pseudomeningocele after intradural spine surgery. *World Neurosurg.* 2018;120: e497-502.
2. Hoover JM, Clarke MJ, Wetjen NM, Mandrekar J, Puffer RC, Krauss WE. Complications necessitating a return to the operating room following intradural spine surgery. *World Neurosurg.* 2012;78(3-4):344-347.
3. Barber SM, Fridley JS, Konakondla S, et al. Cerebrospinal fluid leaks after spine tumor resection: avoidance, recognition and management. *Ann Transl Med.* 2019; 7(10):217.
4. Liu V, Gillis C, Cochrane D, Singhal A, Steinbok P. CSF complications following intradural spinal surgeries in children. *Childs Nerv Syst.* 2014;30(2): 299-305.
5. Lee S, Cho DC, Kim KT, Lee YS, Rhim SC, Park JH. Reliability of early ambulation after intradural spine surgery: risk factors and a preventive method for cerebrospinal fluid leak related complications. *J Korean Neurosurg Soc.* 2021;64(5): 799-807.
6. Jesse CM, Schermann H, Goldberg J, et al. Risk factors for postoperative cerebrospinal fluid leakage after intradural spine surgery. *World Neurosurg.* 2022;164: e1190-1199.
7. Menon SK, Onyia CU. A short review on a complication of lumbar spine surgery: CSF leak. *Clin Neurol Neurosurg.* 2015;139:248-251. doi: 10.1016/j.clineuro.2015.10.013.
8. Dafford EE, Anderson PA. Comparison of dural repair techniques. *Spine J.* 2015; 15(5):1099-1105.
9. Radcliff KE, Sidhu GDS, Kepler CK, et al. Complications of flat bed rest after incidental durotomy. *Clin Spine Surg.* 2016;29(7):281-284.
10. Hodges SD, Humphreys SC, Eck JC, Covington LA. Management of incidental durotomy without mandatory bed rest. A retrospective review of 20 cases. *Spine (Phila Pa. 1976).* 1999;24(19):2062-2064.
11. Lenschow M, Perrech M, Telentschak S, et al. Cerebrospinal fluid leaks following intradural spinal surgery-Risk factors and clinical management. *Front Surg.* 2022;9: 959533. Published 2022 Sep 20. doi: 10.3389/fsurg.2022.959533.
12. Low JCM, von Niederhäusern B, Rutherford SA, King AT. Pilot study of perioperative accidental durotomy: does the period of postoperative bed rest reduce the incidence of complication? *Br J Neurosurg.* 2013;27(6):800-802.
13. Dietz N, Sharma M, Adams S, et al. Enhanced recovery after surgery (ERAS) for spine surgery: a systematic review. *World Neurosurg.* 2019;130:415-426.
14. Debono B, Wainwright TW, Wang MY, et al. Consensus statement for perioperative care in lumbar spinal fusion: enhanced Recovery after Surgery (ERAS®) Society recommendations. *Spine J.* 2021;21(5):729-752.
15. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet.* 2007; 370(9596):1453-1457.
16. Guirado VMP, Taricco MA, Nobre MRC, et al. Quality of life in adult intradural primary spinal tumors: 36-Item Short Form Health Survey correlation with McCormick and Aminoff-Logue scales. *J Neurosurg Spine.* 2013;19(6): 721-735.
17. Schwake M, Maragno E, Gallus M, et al. Minimally invasive facetectomy and fusion for resection of extensive dumbbell tumors in the lumbar spine. *Medicina (Kaunas).* 2022;58(11):1613.
18. Koechlin NO, Burkhardt JK, Scherer M, et al. Cerebrospinal fluid leaks after planned intradural spine surgery: a single-center analysis of 91 cases. *J Neurol Surg A Cent Eur Neurosurg.* 2013;74(4):216-221.
19. Kinaci A, van Thoor S, Redegeld S, Tooren M, van Doormaal TPC. Ex vivo evaluation of a multilayered sealant patch for watertight dural closure: cranial and spinal models. *J Mater Sci Mater Med.* 2021;32(8):85.
20. Ebel F, Wanderer S, Jesse CM, et al. A standardized model for in vitro testing of sutures and patches for watertight dural closure. *J Neurosurg.* 2022;136(5): 1485-1494.
21. Espiritu MT, Rhyne A, Darden BV. Dural tears in spine surgery. *J Am Acad Orthop Surg.* 2010;18(9):537-545.
22. Wright NM, Park J, Tew JM, et al. Spinal sealant system provides better intraoperative watertight closure than standard of care during spinal surgery: a prospective, multicenter, randomized controlled study. *Spine (Phila Pa. 1976).* 2015; 40(8):505-513.
23. Lewis KM, Sweet J, Wilson ST, Rousselle S, Gulle H, Baumgartner B. Safety and efficacy of a novel, self-adhering dural substitute in a canine supratentorial durotomy model. *Neurosurgery.* 2018;82(3):397-406.
24. Chauvet D, Tran V, Mutlu G, George B, Allain JM. Study of dural suture watertightness: an in vitro comparison of different sealants. *Acta Neurochir (Wien).* 2011;153(12):2465-2472.
25. Lam FC, Kasper E. Augmented autologous pericranium duraplasty in 100 posterior fossa surgeries—a retrospective case series. *Neurosurgery.* 2012;71(2 suppl operative).
26. Sabatino G, Della Pepa GM, Bianchi F, et al. Autologous dural substitutes: a prospective study. *Clin Neurol Neurosurg.* 2014;116:20-23. doi: 10.1016/j.clineuro.2013.11.010.
27. Neulen A, Gutenberg A, Takács I, et al. Evaluation of efficacy and biocompatibility of a novel semisynthetic collagen matrix as a dural onlay graft in a large animal model. *Acta Neurochir (Wien).* 2011;153(11):2241-2250.
28. Filippi R, Derdilopoulos A, Heimann A, Krummenauer F, Perneczky A, Kempski O. Tightness of duraplasty in rabbits: a comparative study. *Neurosurgery.* 2000; 46(6):1470-1477.
29. Lee CK, Mokhtari T, Connolly ID, et al. Comparison of porcine and bovine collagen dural substitutes in posterior fossa decompression for chiari I malformation in adults. *World Neurosurg.* 2017;108:33-40.
30. Moskowitz SI, Liu J, Krishnaney AA. Postoperative complications associated with dural substitutes in suboccipital craniotomies. *Neurosurgery* 2009;64(3 suppl): ONS28-ONS34.
31. Preul MC, Campbell PK, Bichard WD, Spetzler RF. Application of a hydrogel sealant improves watertight closures of duraplasty onlay grafts in a canine craniotomy model. *J Neurosurg.* 2007;107(3):642-650.
32. Sun S, Li Y, Wang X, et al. Safety and efficacy of laminoplasty versus laminectomy in the treatment of spinal cord tumors: a systematic review and meta-analysis. *World Neurosurg.* 2019;125:136-145.
33. Lee S, Jung SK, Kim HB, Roh SW, Jeon SR, Park JH. Postoperative nonpathological fever following posterior cervical fusion surgery: is laminoplasty a better preventive method than laminectomy? *J Korean Neurosurg Soc.* 2020;63(4): 487-494.
34. Wong AP, Shih P, Smith TR, et al. Comparison of symptomatic cerebral spinal fluid leak between patients undergoing minimally invasive versus open lumbar foraminotomy, discectomy, or laminectomy. *World Neurosurg.* 2014;81(3-4): 634-640.
35. Formo M, Halvorsen CM, Dahlberg D, et al. Minimally invasive microsurgical resection of primary, intradural spinal tumors is feasible and safe: a consecutive series of 83 patients. *Neurosurgery.* 2018;82(3):365-371.



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.

36. Mummaneni PV, Shaffrey CI, Lenke LG, et al. The minimally invasive spinal deformity surgery algorithm: a reproducible rational framework for decision making in minimally invasive spinal deformity surgery. *Neurosurg Focus.* 2014; 36(5):E6.
37. Boström A, Bürgel U, Reinacher P, et al. A less invasive surgical concept for the resection of spinal meningiomas. *Acta Neurochir (Wien).* 2008;150(6):551-556; discussion 556.
38. Schwake M, Adeli A, Sporns P, et al. Spinal meningiomas - Risks and potential of an increasing age at the time of surgery. *J Clin Neurosci.* 2018;57:86-92. doi: 10.1016/j.jocn.2018.08.030.
39. Eser MT, Hanalioglu S, Cetiner MZ, et al. Identification of risk factors for postoperative cerebrospinal fluid leakage and comparison of two alternative dural augmentation techniques in posterior fossa and spinal surgeries. *Turk Neurosurg.* 2019;29(3):377-385.
40. Sin AH, Caldito G, Smith D, Rashidi M, Willis B, Nanda A. Predictive factors for dural tear and cerebrospinal fluid leakage in patients undergoing lumbar surgery. *J Neurosurg Spine.* 2006;5(3):224-227.
41. Jenkinson MD, Simpson C, Nicholas RS, Miles J, Findlay GFG, Pigott TJD. Outcome predictors and complications in the management of intradural spinal tumours. *Eur Spine J.* 2006;15(2):203-210.
42. Jesse CM, Alvarez Abut P, Wermelinger J, Raabe A, Schär RT, Seidel K. Functional outcome in spinal meningioma surgery and use of intraoperative neurophysiological monitoring. *Cancers (Basel).* 2022;14(16):3989.

Downloaded from http://journals.lww.com/neurosurgery by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8K2+Ya6H515kE= on 08/30/2023



© Congress of Neurological Surgeons 2023. Unauthorized reproduction of this article is prohibited.