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RESEARCH

Cerebrospinal fluid leakage prevention using the anterior transpetrosal approach with versus without postoperative spinal drainage: an institutional cohort study

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Abstract

The efficacy of spinal drain (SD) placement for cerebrospinal fluid (CSF) leakage prevention after the anterior transpetrosal approach (ATPA) remains unclear. Thus, we aimed to assess whether postoperative SD placement improved postoperative CSF leakage after a skull base reconstruction procedure using a small abdominal fat and pericranial flap and clarify whether bed rest with postoperative SD placement increased the length of hospital stay. This retrospective cohort study included 48 patients who underwent primary surgery using ATPA between August 2011 and February 2022. All cases underwent SD placement preoperatively. First, we evaluated the necessity of SD placement for CSF leakage prevention by comparing the postoperative routine continuous SD placement period to a period in which the SD was removed immediately after surgery. Second, the effects of different SD placement durations were evaluated to understand the adverse effects of SD placement requiring bed rest. No patient with or without postoperative continuous SD placement developed CSF leakage. The median postoperative time to first ambulation was 3 days shorter ($P < 0.05$), and the length of hospital stay was 7 days shorter ($P < 0.05$) for patients who underwent SD removal immediately after surgery (2 and 12 days, respectively) than for those who underwent SD removal on postoperative day 1 (5 and 19 days, respectively). This skull base reconstruction technique was effective in preventing CSF leakage in patients undergoing ATPA, and postoperative SD placement was not necessary. Removing the SD immediately after surgery can lead to earlier postoperative ambulation and shorter hospital stay by reducing medical complications and improving functional capacity.

Keywords Anterior transpetrosal approach · Cerebrospinal fluid leakage · Pericranial flap · Spinal drainage

Introduction

Anterior transpetrosal approach (ATPA) is a standard surgical approach for treating petroclival lesions [1–7]. However, 5.2% of patients who undergo ATPA may experience cerebrospinal fluid (CSF) leakage as a complication [11]. Risk factors for postoperative CSF leakage related to ATPA include the presence of air cells in the petrous apex, squamous part of the temporal bone and direct tracts, and difficulty in achieving complete dura closure [31]. There is no existing research on CSF leakage in relation to skull base reconstruction techniques using ATPA.

Postoperative CSF leakage can cause increased healthcare costs and extended hospital stays due to the need for additional treatment [23, 34]. Spinal drain (SD) placement, which requires bed rest, may prevent postoperative CSF leakage after skull base surgery using the ATPA [9, 27, 28]. However, bed rest for ≥ 24 h increases the risk of medical complications and muscle disuse atrophy [24, 35]. Furthermore, resultant short-term muscle disuse atrophy may result in sarcopenia.

SD placement is performed during ATPA for two purposes: reduce intracranial pressure and prevent intraoperative brain contusion by draining CSF and prevent postoperative CSF leakage [8, 9, 22, 25, 37]. SD placement is performed preoperatively in all cases, which has proved useful in avoiding intraoperative brain injury. However, the efficacy of postoperative continuous SD placement in

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preventing postoperative CSF leakage in patients undergoing ATPA remains unknown. This study aimed to determine the effectiveness of postoperative continuous SD placement in preventing postoperative CSF leakage and examine whether postoperative continuous SD placement requiring bed rest increases the risk of medical complications, prolonged bed rest time, and extended hospital stay.

Materials and methods

Study design

This retrospective cohort study was approved by the institutional review board of our hospital (approval number HM21-525), and an opt-out method was used for all potential study participants.

Patient selection

The included patients underwent SD placement under general anesthesia and skull base reconstruction using a small abdominal fat and pericranial flap. All patients received antibiotics and thromboprophylaxis before surgery. Moreover, as a standard institutional practice, patients were administered 1 g cefazolin intravenously twice daily for 24 h postoperatively. Postoperative rehabilitation was initiated 2 days after surgery.

Study phases

This study included patients who underwent primary surgery using ATPA between August 1, 2011, and February 28, 2022. No cases were excluded. All cases underwent SD placement preoperatively. The average length of the follow-up period was 1871.2 ± 1103.9 days in all 48 patients.

This study was conducted in two phases. First, we evaluated the efficacy of postoperative continuous SD placement in CSF leakage prevention. The study period was further divided: first, August 1, 2011, to January 31, 2013 (postoperative continuous SD placement was performed routinely in six patients; the average length of the follow-up period was 3062.3 ± 1457.3 days.); second, February 1, 2013, to December 31, 2018 (27 patients: in 7 patients, SD was removed immediately after surgery prior to the waning of anesthesia, whereas in 20 patients, continuous SD placement after surgery, the average length of the follow-up period was 2202.5 ± 778.8 days.); and third, January 1, 2019, to February 28, 2022 (all 15 patients, the SD was removed immediately after surgery before the waning of anesthesia, the average length of the follow-up period was 798.7 ± 392 days). Furthermore, to avoid selection bias (as the duration of SD placement was decided by surgeons), we stratified patients into two groups—routine drainage and immediate drain removal groups—to investigate the necessity of postoperative continuous SD placement.

In the second phase, all 48 patients underwent preoperative SD placement and were divided between studying whether only 1 day of bed rest following SD placement affects ambulation and muscle disuse: postoperative day (POD) 0 (POD0), POD1, and ≥ POD2 groups, wherein the SD was removed immediately after surgery before the waning of general anesthesia, 1 day postoperatively, and at least 2 days postoperatively, respectively.

CSF leakage was evaluated based on symptoms (postoperative rhinorrhea) and computed tomography (CT) findings (increase or decrease in fluid collection in the antrum, mastoid air cells, and tympanic cavity and presence/absence of pneumocephalus on POD1 and POD7). Subsequently, we evaluated the following parameters in the abovementioned groups.

First, we evaluated intraosseous air cell content (air cells of the petrous apex, direct tracts, and unusual tract on preoperative CT), with or without fluid collection in the mastoid antrum, mastoid air cells, and tympanic cavity on POD1 CT. Direct tract comprises air cells of the petrous apex and/or squamous part of the temporal bone directly connected to the antrum. The unusual tract is composed of air cells of the petrous apex and squamous part of the temporal bone directly connected to the tympanic cavity and attic of the tympanic cavity. Both these tracts were associated with postoperative CSF leakage.

Second, we evaluated the association of medical complications with or without postoperative continuous SD placement. Medical complications were defined based on radiographic, culture, prescription, and hospital stay findings. We recorded the presence/absence of medical complications, including pulmonary, gastrointestinal, urinary complications, and deep venous thrombosis.

Patients receiving laxatives were diagnosed with constipation. The presence of deep venous thrombosis on ultrasonography was documented. Patients who required Foley catheter reinsertion and/or medication prescription for urinary disorders were considered to have a urinary complication. Urinary tract infection was defined as a positive urine culture and the administration of antibiotics to the concerned patients. Pulmonary complications were defined as new and worsening oxygen requirements and/or chest radiography showing signs of pneumonia. Finally, we evaluated whether postoperative continuous SD placement requiring bed rest prolonged the time to first ambulation and length of hospital stay. Time to first ambulation was defined as the time for a patient to begin walking independently after surgery. Length of hospital stay was defined as the duration until discharge after surgery. All patients were discharged after suture removal.

Statistical analysis

All quantified data except age are expressed as median values (25th percentile value, 75th percentile value). Age is expressed as mean ± standard deviation. Comparisons between the two stratified and three classified groups were performed using the Mann–Whitney *U* and the Kruskal–Wallis tests, respectively. Thereafter, the Dunnett test was performed to perform multiple comparisons. All statistical analyses were performed using GraphPad Prism (GraphPad Software Inc, San Diego, CA, USA), and *P*-values < 0.05 were considered to indicate statistical significance.

Skull base reconstruction technique

This skull base reconstruction technique is indicated for evacuating petroclival meningioma, which has attachments from the clivus and petrous apex to the tentorium cerebelli (Fig. 1a). For tumor evacuation, Kawase's triangle was drilled, the middle cranial fossa dura was cut, and the tentorium cerebelli and posterior fossa dura were removed. Furthermore, air cells of the petrous apex and squamous part of the temporal bone were opened (Fig. 1b). In the first step, an oxidized cellulose sheet for hemostasis was placed on the defected posterior fossa dura to prevent abdominal fat from dropping into the posterior fossa space. Next, the

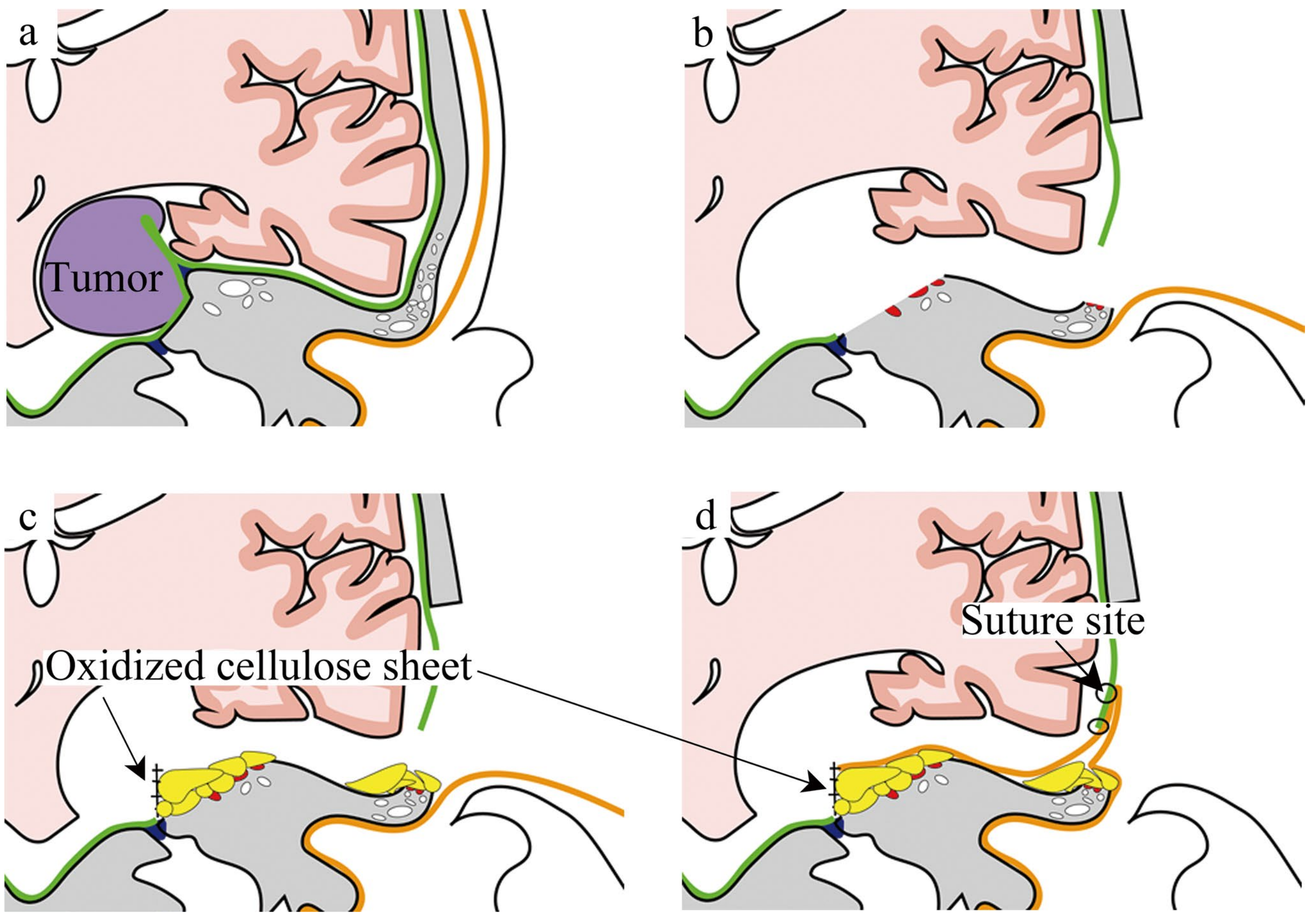

Fig. 1 Schematic of the dura closure method using anterior transpetrosal approach (ATPA). This schema is a coronal section of a petrous apex lesion. The green line indicates the dura. The orange line indicates the superficial temporal fascia and pericranium membrane. **a** The tumor is located in the petroclival region and extends to the supratentorium over the cerebrum tentorium. **b** The tumor was removed using the ATPA. The petrous apex bone (Kawase's triangle) was drilled out, the middle cranial fossa dura was cut, and the posterior fossa dura and cerebrum tentorium were cut and/or removed. The air cells of the petrous apex and squamous part of the temporal bone were opened (red air cell). **c** The oxidized cellulose sheet for hemostasis was positioned on the defect in the posterior fossa dura to prevent migration of the abdominal fat into the posterior fossa space. Next, we plugged the small abdominal fat into the opened air cells in the petrous apex and the squamous part of the temporal bone. Furthermore, we placed the small abdominal fat graft on the opened air cells of the petrous apex and squamous part of the temporal bone. **d** The pericranial flap was laid on the petrous apex defect, and the middle cranial fossa dura was sutured

abdominal fat was plugged into the opened air cells of the petrous apex and squamous part of the temporal bone, if possible. This abdominal fat was applied using thrombin and fibrin solutions of exogenous fibrin glue (Fig. 1c). Finally, a pericranial flap was laid on the defected petrous apex and sutured on the middle cranial fossa dura. The space between the subarachnoid space and intraosseous air cells was completely separated to prevent CSF leakage into the nasal cavity via the Eustachian tube. Moreover, the space between the subarachnoid and epidural spaces was separated to prevent CSF leakage into the epidural subcutaneous space (Fig. 1d).

Results

Operative example (Video 1)

A 54-year-old woman presented with trigeminal neuralgia. Brain magnetic resonance imaging showed a mass centered at the left Meckel's cave and progressing into the tentorium cerebelli, petrous apex, and clivus (Fig. 2a, b). Preoperative CT showed well-developed petrous apex air cells (Fig. 2c). Postoperative CT showed pneumocephalus and slight fluid collection in the mastoid air cells but no abdominal fat migration into the posterior fossa (Fig. 2d). Seven-day postoperative CT showed decreased pneumocephalus volume and no increase in fluid collection in the mastoid air cells (Fig. 2e). Postoperative patient course was good; trigeminal neuralgia improved without rhinorrhea occurrence.

Study findings

This study included 48 patients (men: 13, mean age: 52.9 ± 14.1 years) who underwent primary surgery using ATPA between August 1, 2011, and February 28, 2022. The 48 patients included 41, 3, 2, 1, and 1 patient with meningioma, trigeminal schwannoma, epidermoid, trigeminal cavernous angioma, and pontine cavernous angioma, respectively. No patient developed CSF leakage, postoperative meningitis, or wound infection. Moreover, there was no brain retraction-related contusion in the

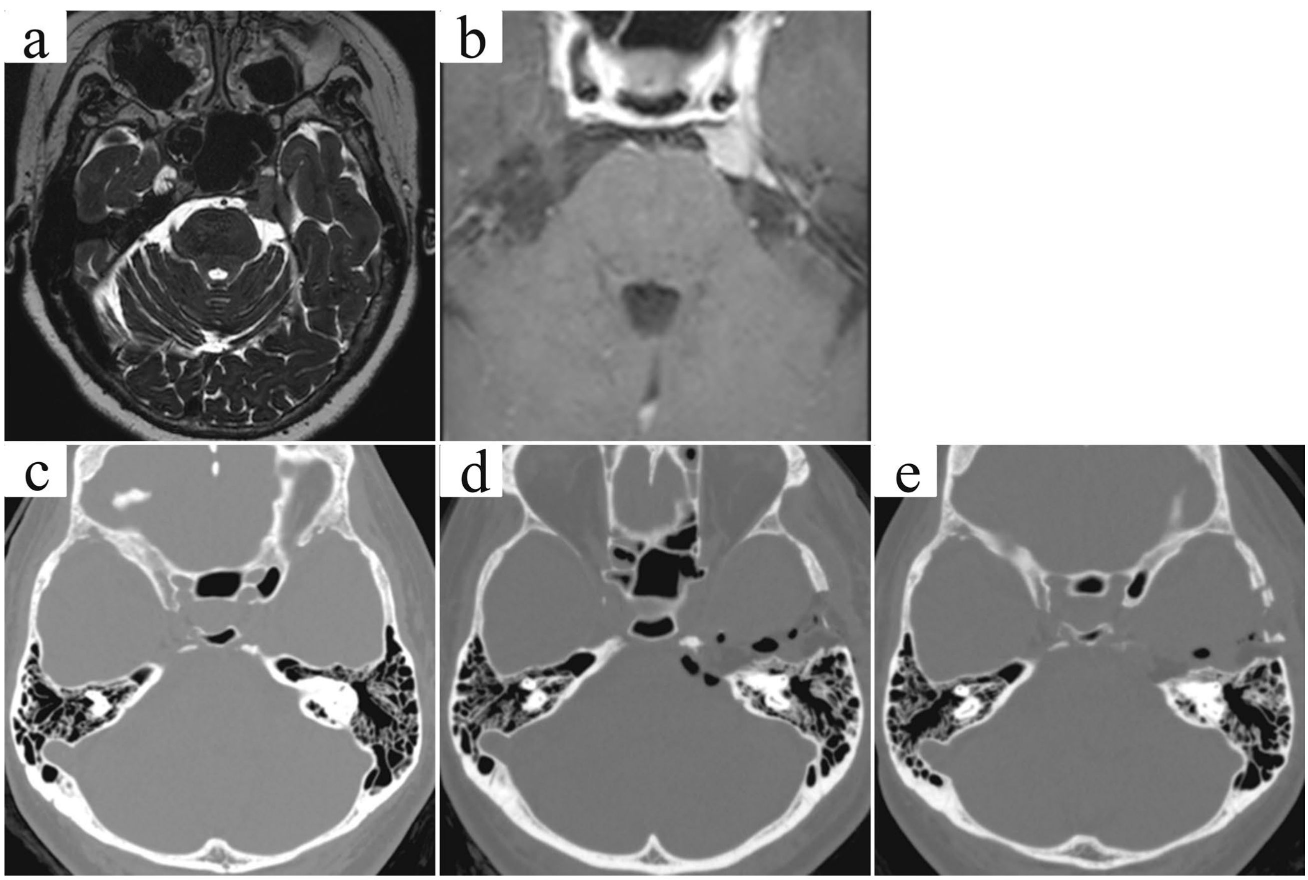

Fig. 2 Illustrative case. Left petroapex menigioma. **a** Preoperative MRI CISS image. **b** Preoperative enhanced T1-MRI. **c** Preoperative CT bone image. Petrous apex air cells are well developed. **d** Postoperative day (POD) 1 CT bone image. Pneumocephalus of the posterior fossa is present. Abdominal fat has not migrated into the posterior fossa. **e** POD7 CT bone image. The pneumocephalus of the posterior fossa is not present anymore. The fluid collection in the mastoid air cells did not increase compared with that observed in the POD1 CT bone image. MRI, magnetic resonance imaging; CISS, constructive interference in steady state; CT, computed tomography

lower aspect of the temporal lobe. No patient showed abdominal fat migration into the posterior fossa. All patients had stable, independent gait before discharge.

Evaluations based on the time of surgery

Duration of postoperative continuous SD placement ranged from 2 to 4 days (median 3 days) in the routine drainage group with six patients (Table 1). The immediate drain removal group had 15 patients, i.e., 21 patients in both groups. There was no significant between-group difference in preoperative intraosseous air cell contents, postoperative fluid collection in the intraosseous air cells on POD1, and occurrence of medical complications. The time to first ambulation was 5 and 2 days ($P = 0.0024$), and postoperative lengths of hospital stay were 18 and 12 days ($P = 0.028$) (Fig. 3) in the routine drainage and immediate drain removal groups, respectively.

Evaluations based on the duration of postoperative SD placement

The POD0, POD1, and ≥ POD2 groups included 13, 19, and 16 patients, respectively (Table 2). There was no significant difference among them in preoperative intraosseous air cell contents, postoperative fluid collection in intraosseous air cells on POD1, and occurrence of medical complications. There was no significant difference in the occurrence of medical complications.

In the POD0, POD1, and ≥ POD2 groups, the time to first ambulation was 2, 5, and 5 days ($P = 0.0012$), and postoperative length of hospital stay was 12, 19, and 21.5 days ($P = 0.0037$), respectively. There were significant differences in the time to the first ambulation between the POD0 and POD1 groups ($P < 0.05$) and between the POD0 and ≥ POD2 groups ($P < 0.01$). Furthermore, there were significant differences in length of hospital stay between the POD0 and POD1 groups ($P < 0.05$) and between the POD0 and ≥ POD2 groups ($P < 0.01$) (Fig. 4).

Discussion

Our study findings were in line with our hypothesis that the absence of postoperative continuous SD placement does not increase the incidence of postoperative CSF leakage and contributed to reduced postoperative time to first ambulation and length of hospital stay. Preventive postoperative continuous SD placement is not required for these patients.

Necessity of postoperative SD placement

The efficacy of SD placement after skull base surgery in CSF leakage prevention has been reported in patients who underwent craniotomy[9, 12] and endonasal surgery [17, 32, 38].

Table 1 Intergroup comparison between routine drainage and drain removal immediately after surgery

		Routine drainage	Immediate drain removal	Total	*P*-value
Period		2011/8–2013/1	2019/1–2022/2		
Number of cases		6	15	21	
Duration of drainage (days)		3 [3]	0		
Postoperative drainage		Yes	No		
Average age (years)		57.6 ± 7.1	50.9 ± 12.3	52.9 ± 11.4	0.29
Female sex		4 (66.7)	12 (80)	16 (76.1)	0.56
Postoperative CSF leakage		0	0	0	
Intraosseous air cells	Petrous apex air cells	1 (16.7)	8 (53.3)	9 (42.9)	0.15
	Direct tract	2 (33.3)	2 (13.3)	4 (19)	0.33
	Unusual tract	1 (16.7)	7 (46.7)	8 (38)	0.28
Fluid collection in 1 POD CT	Mastoid antrum	1 (16.7)	1 (6.7)	2 (9.5)	0.54
	Mastoid air cells	6 (100)	11 (73.3)	17 (81)	0.19
	Tympanic cavity	1 (16.7)	1 (6.7)	2 (9.5)	0.54
Complications	Total	1 (16.7)	2 (13.3)	3 (14.3)	0.90
	Constipation	1	1	2	
	Urinary tract infection	0	1	1	
Days after surgery	Time to first ambulation	5 [5, 6]	2 [2, 3]	3 [2, 5]	0.0024
	Length of hospital stay	18 [15, 21.75]	12 [11, 13.5]	13 [11, 17]	0.028

Values represent the number of female patients (%) unless stated otherwise

Quantified data of time to first ambulation and length of hospital stay are expressed as median values [25% tile value, 75% tile value]

CSF cerebrospinal fluid, *POD* postoperative day, *CT* computed tomography

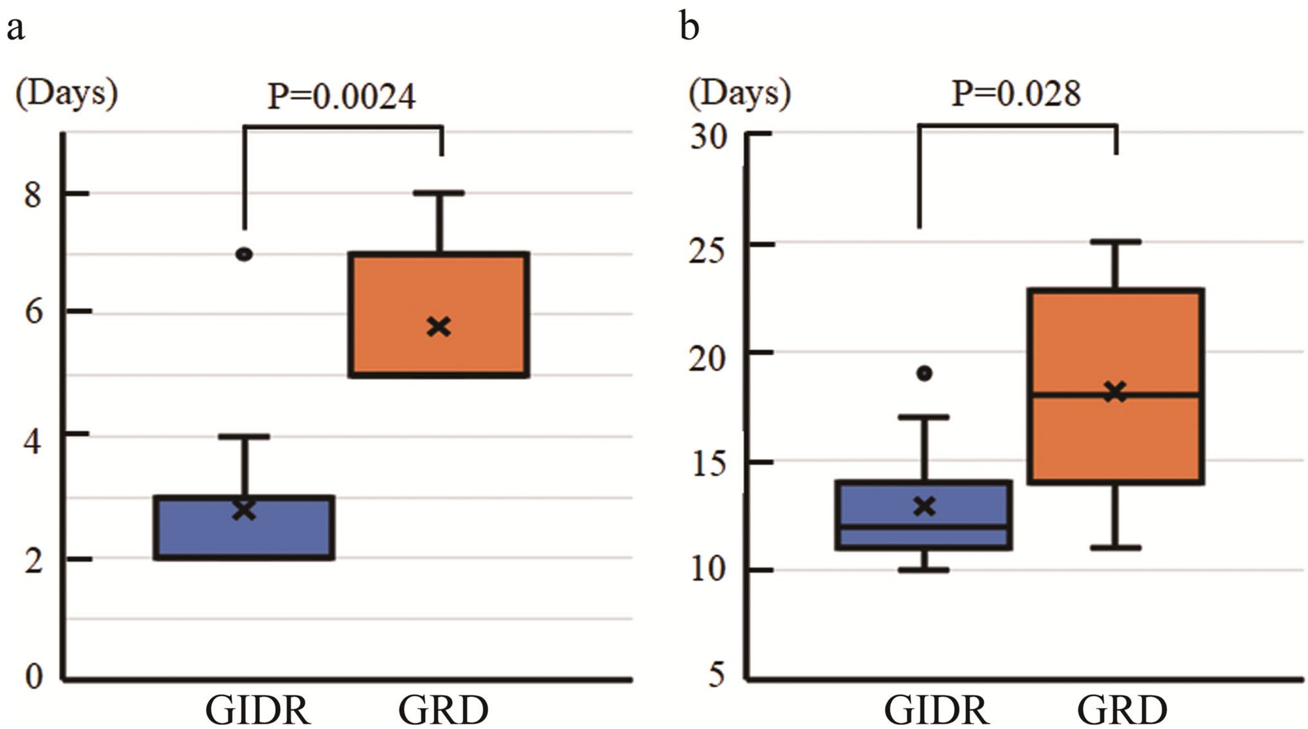

Fig. 3 Graphs comparing the two groups. **a** Duration until "time to the first ambulation." **b** Length of hospital stay. GIDR, group of immediate drain removal; GRD, group of routine drainage

Table 2 Comparison of the postoperative duration of SD placement

Time of drain removal		0 POD	1 POD	≥ 2 POD	Total	*P*-value
Number of cases		13	19	16	48	
Average age (years)		53 ± 10.9	53.1 ± 13.5	52.6 ± 17.5	52.9 ± 14	0.84
Female sex		10 (76.9)	16 (84.2)	9 (56.3)	35 (73)	0.21
Postoperative CSF leakage		0	0	0	0	
Intraosseous air cells	Petrous apex air cells	7 (54)	6 (31.6)	6 (37.5)	19 (39.6)	0.45
	Direct tract	2 (15.4)	3 (15.8)	6 (37.5)	11 (22.9)	0.24
	Unusual tract	5 (38.5)	5 (26.3)	1 (6.3)	11 (22.9)	0.04
Fluid collection in 1 POD CT	Mastoid antrum	1 (7.7)	1 (5.3)	3 (18.8)	5 (10.4)	0.4
	Mastoid air cells	10 (76.9)	13 (68.4)	13 (81.3)	36 (75)	0.68
	Tympanic cavity	1 (7.7)	0	3 (18.8)	4 (8.3)	0.14
Complications	Total (cases)	1 (7.7)	6 (31.6)	4 (25)	11 (22.9)	0.29
	Constipation	1	4	1		
	Dysuria		1			
	Urinary tract infection		1			
	Both constipation and urinary tract infection			3		
Days after surgery	Time to first ambulation	2 [2, 3]	5 [3, 6]	5 [4.5, 6.5]	4 [2, 6]	0.0012
	Length of hospital stay	12 [11, 14]	19 [12, 28.5]	21.5 [15, 25.3]	17.5 [12, 25]	0.0037

Values represent the number of female patients (%) unless stated otherwise

Quantified data of time to first ambulation and length of hospital stay are expressed as median values [25% tile value, 75% tile value]

CSF cerebrospinal fluid, *POD* postoperative day, *CT* computed tomography, *SD* spinal drain

In the ≥ POD2 group, four patients developed medical complications, three of whom had both constipation and urinary tract infections, whereas one patient had only constipation

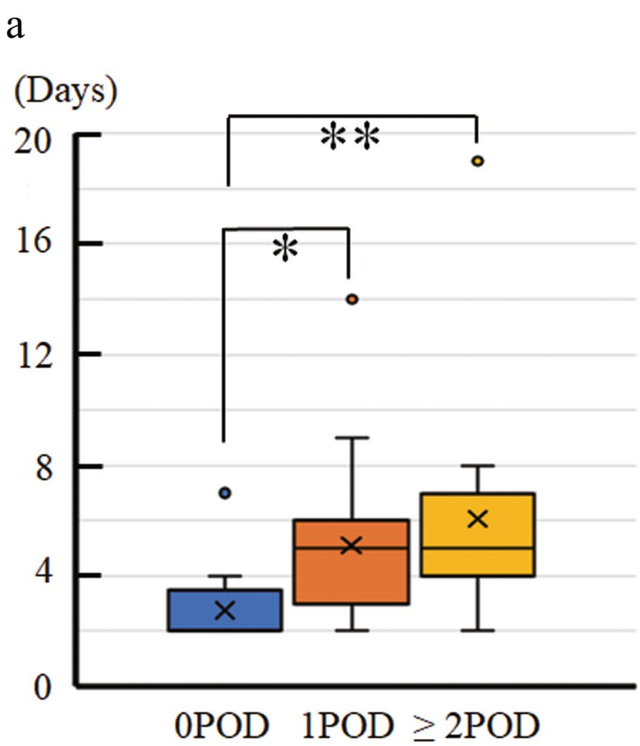

Fig. 4 Graphs comparing the two groups in terms of the postoperative duration of SD placement. **a** Duration until "time to first ambulation" (*$P<0.05$, **$P<0.01$). **b** Length of hospital stay (*$P<0.05$, **$P<0.01$). POD, postoperative day

However, postoperative continuous SD placement to prevent CSF leakage is not required in all skull base surgeries.

A study reported the necessity of SD placement for patients with spontaneous CSF leakage exhibiting high intracranial pressure [20]. Furthermore, a meta-analysis highlighted that SD placement is necessary to prevent postoperative CSF leakage in patients undergoing endonasal skull base surgery with a dura defect sized > 1 cm^2 and high-flow CSF leak [38]. In patients who underwent ATPA, it was unclear whether intracranial pressure was high or low; however, the dura defect size was > 1 cm^2 with a high-flow CSF leak postoperatively. Since none of the patients in the present study experienced CSF leakage, it may be reasonable to consider that plugging the abdominal fat into opened air cells is a useful way of managing high-flow CSF leak and laying a pericranial flap from the defect in the posterior fossa dura to the cut middle cranial fossa is effective in managing dural defects with areas > 1 cm^2. In the translabyrinthine approach, plugging by direct abdominal fat strip insertion is more effective than using fascia lata in CSF leakage prevention [15]. In ATPA, the abdominal fat strip is oversized; since the opened air cells of the petrous apex are deep, it is difficult to insert the fat strip into the opened air cells under direct vision. Using small abdominal fat is beneficial because of its plasticity, as it can be plugged into opened air cells without disturbing the visibility of the deep operative field. Although the size of the abdominal fat used depends on the size of the opened air cells, we used ≤ 1-cm-diameter fat. Instead of creating dura and tentorium cerebelli defects, the flap provides clear divisions of the subdural and epidural spaces.

Although free abdominal fat is avascular, no patient in this study developed an infection of the free abdominal fat and vascularized pericranial flap because the abdominal fat was harvested just before use and was sufficiently rinsed with saline.

Challenges with postoperative bed rest after SD placement

SD placement requiring bed rest reportedly lasts mostly between 4 and 5 days without exceeding 1 week [8, 9]. However, reports revealed that the average length of hospital stay was shorter in patients with bed rest ≤ 24 h than in those with bed rest > 24 h [26, 35]. In the present study, the postoperative time to first ambulation and length of hospital stay were 3 and 6 days longer, respectively, in the routine drainage group than in the immediate drain removal group, although the median duration of SD placement was 3 days. The median postoperative time to first ambulation and length of hospital stay were 3 and 7 days longer in the POD1 group than in the POD0 group, although SD was placed only 1 day longer.

Medical complications

Verma et al. examined 361 patients who underwent spinal surgery and reported a significant increase in the occurrence of wound complications, ileus, urinary retention, urinary tract infections, pulmonary complications, and altered mental status in patients who had flat bed rest for > 24 h owing to incidental durotomy compared with those who had bed rest for ≤ 24 h. Moreover, the mean length of hospital stay for patients with bed rest for ≤ 24 h and those with bed rest for > 24 h was 4.47 ± 3.64 and 7.24 ± 4.23 days, respectively [35]. Studies have reported that bed rest for > 24 h prolongs hospital stay with [24, 35] or without medical complications [16].

In our study, one (16.7%) and two (13.3%) patients developed medical complications in the routine drainage and immediate drain removal groups, respectively. One (1/13, 7.7%), six (6/19, 31.6%), and four (4/16, 25%) patients developed medical complications in the POD0, POD1, and ≥ POD2 groups, respectively, which was not statistically significant. All patients with constipation were treated using aperients, whereas those with urinary tract infections were treated using oral antibiotics; patients with dysuria did not require urinary catheter replacement. These medical complications are under grade 2 of the Common Terminology Criteria for Adverse Events. Three patients had both constipation and urinary tract infections in the ≥ POD2 group. The presence of medical complications seemed to prolong the length of hospital stay.

Low functional capacity

Dirks et al. reported that 1-week bed rest led to muscle atrophy even in healthy young men (mean age: 23 ± 1 years) [14], although a 1-day bed rest can maintain muscle volume [13]. A study of skeletal muscle homeostasis revealed that signaling pathways associated with muscle atrophy are activated in the initial phase of muscle disuse, which consequently leads to a rapid initial atrophy response within 1–4 days [30]. Furthermore, short-term (5 days) hospitalization without bed rest reduces functional capacity in terms of upper limb muscle strength, spinal and trunk mobility, respiratory function, and submaximal exercise tolerance [29]. The mean age in our study was higher (52.9 ± 14.1 years) than that previously reported. Patients with impaired functional capacity need more time to recover than healthy young men. Previous and current study findings suggest that early postoperative ambulation is useful in preventing the development of muscle atrophy, disuse, and sarcopenia in the future.

Suitability of craniotomy or endoscopic endonasal surgery for petroclival lesion treatment

The technical advancement of the endoscopic endonasal approach (EEA) makes it more effective for treating hard and tough skull base lesions. Studies have reported the use of the EEA in the cadaveric anatomical study of petroclival lesions [10, 18, 19, 21, 33]. However, the surgical approach to petroclival lesions cannot be generalized for every patient. Extradural lesions, including bone lesions, are more suitably operated using EEA. However, subdural lesions, such as petroclival meningioma, require the removal of the attachment between the dura and tentorium cerebelli to prevent recurrence; hence, a transpetrosal approach, including ATPA, is more suitable. In a meta-analysis of the efficacy of postoperative SD placement for CSF leakage prevention in patients undergoing endoscopic endonasal skull base surgery, the rates of CSF leakage were 8.2% and 21.2% with and without SD placement, respectively [38]. These results suggest that ATPA is the best operative approach for subdural petroclival lesions, in addition to its efficacy in CSF leakage prevention.

Limitations

Our study is limited by its retrospective design and single-center nature. However, we separately analyzed data based on the time of surgery and duration of postoperative SD placement to exclude selection bias, as SD placement was performed at the discretion of surgeons. Both analyses produced similar results. In this retrospective study, some phases cannot be excluded entirely from selection bias, even though the study was performed carefully. This may lay the groundwork for further prospective research initiatives.

Conclusions

CSF leakage prevention does not depend on postoperative continuous SD placement, and the incidence of CSF leakage was low in patients who underwent the ATPA using small abdominal fat and pericranial flap. Postoperative continuous SD placement requiring bed rest prolonged the length of hospital stay. In ATPA, we recommend SD removal immediately after surgery to avoid postoperative medical complications and low functional capacity.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10143-023-02045-w.

Author contribution All authors contributed to the study concept and design. Material preparation, data collection, and analysis were performed by Kazuhide Adachi, Mituhiro Hasegawa, and Yuichi Hirose. The first draft of the manuscript was written by Kazuhide Adachi, and all authors commented on the early versions of the manuscript. All authors read and approved the final manuscript.

Data availability All data generated or analyzed during the study are included in this published article.

Declarations

Ethics approval This retrospective cohort study was approved by the institutional review board of Fujita Health University Hospital (approval number HM21-525).

Consent to participate An opt-out method was used for all potential study participants. Written informed consent is not required in opt-out approach as all participants are included in the study unless they express their desire to be excluded.

Consent for publication The participants have all consented to submitting their case report for journal publication.

Competing interests The authors declare no competing interests.

References

1. Adachi K, Hasegawa M, Hayakawa M, Tateyama S, Hirose Y (2019) Susceptibility-weighted imaging of deep venous congestion in petroclival meningioma. World Neurosurg 122:e20–e31. https://doi.org/10.1016/j.wneu.2018.08.218
2. Adachi K, Hasegawa M, Hirose Y (2017) Evaluation of venous drainage patterns for skull base meningioma surgery. Neurol Med Chir (Tokyo) 57:505–512. https://doi.org/10.2176/nmc.ra.2016-0336
3. Adachi K, Hasegawa M, Hirose Y (2021) Prediction of trigeminal nerve position based on the main feeding artery in petroclival meningioma. Neurosurg Rev 44:1173–1181. https://doi.org/10.1007/s10143-020-01313-3
4. Adachi K, Hasegawa M, Tateyama S, Kawazoe Y, Hirose Y (2018) Surgical strategy for and anatomic locations of petroapex and petroclival meningiomas based on evaluation of the feeding artery. World Neurosurg 116:e611–e623. https://doi.org/10.1016/j.wneu.2018.05.052
5. Adachi K, Hayakawa M, Ishihara K, Ganaha T, Nagahisa S, Hasegawa M, Hirose Y (2016) Study of changing intracranial venous drainage patterns in petroclival meningioma. World Neurosurg 92:339–348. https://doi.org/10.1016/j.wneu.2016.05.019
6. Adachi K, Kawase T, Yoshida K, Yazaki T, Onozuka S (2009) ABC Surgical Risk Scale for skull base meningioma: a new scoring system for predicting the extent of tumor removal and neurological outcome. Clinical article. J Neurosurg 111:1053–1061. https://doi.org/10.3171/2007.11.17446
7. Adachi K, Murayama K, Hayakawa M, Hasegawa M, Muto J, Nishiyama Y, Ohba S, Hirose Y (2021) Objective and quantitative evaluation of angiographic vascularity in meningioma: parameters of dynamic susceptibility contrast-perfusion-weighted imaging as clinical indicators of preoperative embolization. Neurosurg Rev 44:2629–2638. https://doi.org/10.1007/s10143-020-01431-y
8. Allen KP, Isaacson B, Purcell P, Kutz JW Jr, Roland PS (2011) Lumbar subarachnoid drainage in cerebrospinal fluid leaks after lateral skull base surgery. Otol Neurotol 32:1522–1524. https://doi.org/10.1097/MAO.0b013e318232e387
9. Bien AG, Bowdino B, Moore G, Leibrock L (2007) Utilization of preoperative cerebrospinal fluid drain in skull base surgery. Skull Base 17:133–139. https://doi.org/10.1055/s-2007-970562
10. Borghei-Razavi H, Truong HQ, Fernandes Cabral DT, Sun X, Celtikci E, Wang E, Snyderman C, Gardner PA, Fernandez-Miranda JC (2019) Endoscopic endonasal petrosectomy: anatomical investigation, limitations, and surgical relevance. Oper Neurosurg (Hagerstown) 16:557–570. https://doi.org/10.1093/ons/opy195
11. Coucke B, Van Gerven L, De Vleeschouwer S, Van Calenbergh F, van Loon J, Theys T (2021) The incidence of postoperative cerebrospinal fluid leakage after elective cranial surgery: a systematic review. Neurosurg Rev. https://doi.org/10.1007/s10143-021-01641-y
12. Dalle Ore CL, Magill ST, Rodriguez Rubio R, Shahin MN, Aghi MK, Theodosopoulos PV, Villanueva-Meyer JE, Kersten RC, Idowu OO, Vagefi MR, McDermott MW (2020) Hyperostosing sphenoid wing meningiomas: surgical outcomes and strategy for bone resection and multidisciplinary orbital reconstruction. J Neurosurg 134:711–720. https://doi.org/10.3171/2019.12.JNS192543
13. Dirks ML, Stephens FB, Jackman SR, Galera Gordo J, Machin DJ, Pulsford RM, van Loon LJC, Wall BT (2018) A single day of bed rest, irrespective of energy balance, does not affect skeletal muscle gene expression or insulin sensitivity. Exp Physiol 103:860–875. https://doi.org/10.1113/EP086961
14. Dirks ML, Wall BT, van de Valk B, Holloway TM, Holloway GP, Chabowski A, Goossens GH, van Loon LJ (2016) One week of bed rest leads to substantial muscle atrophy and induces whole-body insulin resistance in the absence of skeletal muscle lipid accumulation. Diabetes 65:2862–2875. https://doi.org/10.2337/db15-1661
15. Falcioni M, Sanna M (2001) Cerebrospinal fluid leak after acoustic surgery. J Neurosurg 95:373–374. https://doi.org/10.3171/jns.2001.95.2.0373
16. Farshad M, Aichmair A, Wanivenhaus F, Betz M, Spirig J, Bauer DE (2020) No benefit of early versus late ambulation after incidental durotomy in lumbar spine surgery: a randomized controlled trial. Eur Spine J 29:141–146. https://doi.org/10.1007/s00586-019-06144-5
17. Forbes JA, Ordonez-Rubiano EG, Tomasiewicz HC, Banu MA, Younus I, Dobri GA, Phillips CD, Kacker A, Cisse B, Anand VK, Schwartz TH (2018) Endonasal endoscopic transsphenoidal resection of intrinsic third ventricular craniopharyngioma: surgical results. J Neurosurg 131:1152–1162. https://doi.org/10.3171/2018.5.JNS18198
18. Freeman JL, Sampath R, Quattlebaum SC, Casey MA, Folzenlogen ZA, Ramakrishnan VR, Youssef AS (2018) Expanding the endoscopic transpterygoid corridor to the petroclival region: anatomical study and volumetric comparative analysis. J Neurosurg 128:1855–1864. https://doi.org/10.3171/2017.1.JNS161788
19. Hasanbelliu A, Andaluz N, Di Somma A, Keller JT, Zimmer LA, Samy RN, Pensak ML, Zuccarello M (2020) Extended anterior petrosectomy through the transcranial middle fossa approach and extended endoscopic transsphenoidal-transclival approach: qualitative and quantitative anatomic analysis. World Neurosurg 138:e405–e412. https://doi.org/10.1016/j.wneu.2020.02.127
20. Kreatsoulas DC, Shah VS, Otto BA, Carrau RL, Prevedello DM, Hardesty DA (2020) Surgical outcomes of the endonasal endoscopic approach within a standardized management protocol for repair of spontaneous cerebrospinal fluid rhinorrhea. J Neurosurg 134:780–786. https://doi.org/10.3171/2019.12.JNS192891
21. Muto J, Prevedello DM, Ditzel Filho LF, Tang IP, Oyama K, Kerr EE, Otto BA, Kawase T, Yoshida K, Carrau RL (2016) Comparative analysis of the anterior transpetrosal approach with the

endoscopic endonasal approach to the petroclival region. J Neurosurg 125:1171–1186. https://doi.org/10.3171/2015.8.JNS15302
22. Panigrahi M, Venkateswaraprasanna G (2006) Transpetrosal approach. J Neurosurg 105:336–337. https://doi.org/10.3171/jns.2006.105.2.336. (author reply 337-338)
23. Piek J, Weber C, Kundt G, Tronnier V, Spuck S, Hirdes C, Kehler U, Ditges C (2012) Pharmacoeconomical consequences of postoperative CSF leaks after intracranial surgery–a prospective analysis. J Neurol Surg A Cent Eur Neurosurg 73:25–28. https://doi.org/10.1055/s-0032-1304501
24. Radcliff KE, Sidhu GD, Kepler CK, Gruskay J, Anderson DG, Hilibrand A, Albert TJ, Vaccaro AR (2016) Complications of flat bed rest after incidental durotomy. Clin Spine Surg 29:281–284. https://doi.org/10.1097/BSD.0b013e31827d7ad8
25. Rao RM, Shrivastava A, Nair S (2020) Anterior transpetrosal approach for petroclival meningioma: operative nuances. Neurol India 68:20–25. https://doi.org/10.4103/0028-3886.279689
26. Robson CH, Paranathala MP, Dobson G, Ly F, Brown DP, O'Reilly G (2018) Early mobilisation does not increase the complication rate from unintended lumbar durotomy. Br J Neurosurg 37:460–465. https://doi.org/10.1080/02688697.2018.1508641
27. Scheithauer S, Burgel U, Bickenbach J, Hafner H, Haase G, Waitschies B, Reinges MH, Lemmen SW (2010) External ventricular and lumbar drainage-associated meningoventriculitis: prospective analysis of time-dependent infection rates and risk factor analysis. Infection 38:205–209. https://doi.org/10.1007/s15010-010-0006-3
28. Seifert V, Raabe A, Zimmermann M (2003) Conservative (labyrinth-preserving) transpetrosal approach to the clivus and petroclival region–indications, complications, results and lessons learned. Acta Neurochir (Wien) 145:631–642. https://doi.org/10.1007/s00701-003-0086-2. (discussion 642)
29. Suesada MM, Martins MA, Carvalho CR (2007) Effect of short-term hospitalization on functional capacity in patients not restricted to bed. Am J Phys Med Rehabil 86:455–462. https://doi.org/10.1097/PHM.0b013e31805b7566
30. Suetta C (2017) Plasticity and function of human skeletal muscle in relation to disuse and rehabilitation: Influence of ageing and surgery. Dan Med J 64:1–28
31. Tamura R, Tomio R, Mohammad F, Toda M, Yoshida K (2018) Analysis of various tracts of mastoid air cells related to CSF leak after the anterior transpetrosal approach. J Neurosurg 130:360–367. https://doi.org/10.3171/2017.9.JNS171622
32. Tan J, Song R, Huan R, Huang N, Chen J (2020) Intraoperative lumbar drainage can prevent cerebrospinal fluid leakage during transsphenoidal surgery for pituitary adenomas: a systematic review and meta-analysis. BMC Neurol 20:303. https://doi.org/10.1186/s12883-020-01877-z
33. Topczewski TE, Di Somma A, Pineda J, Ferres A, Torales J, Reyes L, Morillas R, Solari D, Cavallo LM, Cappabianca P, Ensenat J, Prats-Galino A (2020) Endoscopic endonasal and transorbital routes to the petrous apex: anatomic comparative study of two pathways. Acta Neurochir (Wien) 162:2097–2109. https://doi.org/10.1007/s00701-020-04451-1
34. van Lieshout C, Slot EMH, Kinaci A, Kollen MH, Hoving EW, Frederix GWJ, van Doormaal TPC (2021) Cerebrospinal fluid leakage costs after craniotomy and health economic assessment of incidence reduction from a hospital perspective in the Netherlands. BMJ Open 11:e052553. https://doi.org/10.1136/bmjopen-2021-052553
35. Verma K, Freelin AH, Atkinson KA, Graham RS, Broaddus WC (2022) Early mobilization versus bed rest for incidental durotomy: an institutional cohort study. J Neurosurg Spine 37:460–465. https://doi.org/10.3171/2022.1.SPINE211208
36. Wall BT, Dirks ML, van Loon LJ (2013) Skeletal muscle atrophy during short-term disuse: implications for age-related sarcopenia. Ageing Res Rev 12:898–906. https://doi.org/10.1016/j.arr.2013.07.003
37. Yoshida K, Kawase T (1999) Trigeminal neurinomas extending into multiple fossae: surgical methods and review of the literature. J Neurosurg 91:202–211. https://doi.org/10.3171/jns.1999.91.2.0202
38. Zwagerman NT, Wang EW, Shin SS, Chang YF, Fernandez-Miranda JC, Snyderman CH, Gardner PA (2018) Does lumbar drainage reduce postoperative cerebrospinal fluid leak after endoscopic endonasal skull base surgery? A prospective, randomized controlled trial. J Neurosurg 131:1172–1178. https://doi.org/10.3171/2018.4.JNS172447