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Original Article

Rates of cerebrospinal fluid leak and pseudomeningocele formation after posterior fossa craniotomy versus craniectomy: A systematic review and meta-analysis

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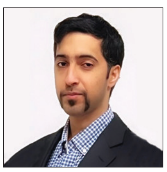

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ABSTRACT

Background: Postoperative cerebrospinal fluid (CSF) leak is a major concern after posterior fossa surgery with significant clinical implications. It has been postulated that replacing the bone flap, performing a craniotomy, would reinforce the surgical closure and decrease rates of CSF leak. This systematic review and meta-analysis compared the rate of CSF leak after posterior fossa craniotomies versus craniectomies.

Methods: Three databases were searched for English studies comparing the primary outcome, rate of CSF leak, after adult posterior fossa craniotomies versus craniectomies. Secondary outcomes included the rate of postoperative pseudomeningocele formation, CSF leak and pseudomeningocele formation, CSF diversion, revision surgery, and infection. Pooled estimates and relative risks for dichotomous outcomes were calculated using Review Manager 5.4, with corresponding 95% confidence intervals (CIs).

Results: A total of 1250 patients (635 craniotomies and 615 craniectomies), from nine studies, were included in the final analysis. Even though rates of CSF leak favored craniotomies, the difference did not reach statistical significance in our pooled analysis (Risk Ratio: 0.71, 95% Confidence Interval: 0.45-1.14, p-value = 0.15, Heterogeneity I-squared = 0%). On the other hand, comparing the rates of pseudomeningocele formation and CSF leak, as a combined outcome, or pseudomeningocele formation only showed a significant difference favoring craniotomies. The quality of evidence in this meta-analysis was graded as having a high risk of bias based on the risk of bias in non-randomized studies - of exposure criteria.

Conclusion: Based on evidence with high risk of bias, rates of postoperative CSF leak and pseudomeningocele formation favored posterior fossa craniotomies over craniectomies. Further research with more robust methodology is required to validate these findings.

Keywords: Cerebrospinal fluid leak, Craniectomy, Cranioplasty, Craniotomy, Posterior cranial fossa, Pseudomeningocele

INTRODUCTION

Posterior fossa surgeries are common and essential in neurosurgery, as they treat a variety of pathologies in a compact space filled with vital anatomy.[8] Given the density of critical structures, several surgical approaches have been developed to safely access different spaces within the posterior fossa.[3] However, a common pitfall to all these different approaches is in how they inflict a gravity-dependent defect in the cranium and scalp. This increases the chances of cerebrospinal fluid (CSF) leak and the formation of pseudomeningocele as gravity facilitates CSF flow through the incision. In fact, posterior fossa surgeries have been shown to be an independent risk factor for CSF leak. A multicenter and prospective study published in 2013 showed a significantly higher risk of CSF leak after infratentorial procedures (23.7%) compared to supratentorial procedures (5.1%).[13] The economic burden of treating patients with postoperative CSF leak is estimated to be 141% greater than that of standard patient care.[9] This risk of CSF leak remains a challenge for neurosurgeons and a significant source of postoperative morbidity. CSF leakage compromises wound healing and is associated with postoperative infection, revision surgery, CSF diversion, and prolonged hospital stay.[19] Factors that influence CSF leak rates in posterior fossa surgery relate to patient comorbidities, surgical indication, surgical approach, closure techniques, and perioperative CSF diversion.[19] Numerous closing strategies have been developed to mitigate this risk such as water-tight primary dural closures, dural substitutes and sealants, and CSF diversion.[1] Recent studies have also shown that performing a craniotomy, where the bone flap is replaced or substituted, decreases the risk of CSF leak when compared to performing a craniectomy where the bone flap is removed without a substitute.[17,20] However, to the best of our knowledge, there has not been a systematic review and meta-analysis to synthesize evidence on the topic. In this article, we perform a systematic review and meta-analysis to evaluate the risk of CSF leak following posterior fossa craniotomy versus craniectomy surgeries.

MATERIALS AND METHODS

Search strategy and study selection

This systematic review and meta-analysis is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis and the Cochrane Handbook for Systematic Reviews of Interventions.[11,14] A detailed electronic literature search was conducted in January 2022 employing Ovid EMBASE, Ovid MEDLINE, and Cochrane Central Register of Controlled Trials. Databases were inspected for English articles linked to keywords and subject headings related to "posterior fossa" and "CSF leak." Supplementary Table 1 details the search terms used in each database. Articles were included if they compared rates of CSF leak after posterior fossa craniotomy versus craniectomy cases in adults. Articles combining CSF leak and pseudomeningocele formation as a single outcome were also included as both conditions share underlying mechanisms and treatment strategies; up to 20% of patients with pseudomeningoceles require surgical intervention.[19] Cranioplasties were included into our umbrella term "craniotomy" as the synthetic material used to replace the bone flap provide comparable structural support.[23] Studies reporting on pediatric populations were excluded as children have a distinct process of healing and should be examined separately.[16] Animal studies, *in vitro* studies, review articles, and correspondences were excluded from the study. Two reviewers evaluated studies for eligibility independently. Disagreements concerning studies' inclusion were resolved by consensus between reviewers and consultation with a third reviewer. This systematic review is registered with PROSPERO (CRD42022324383).

Data collection

Data regarding study characteristics, patient demographics, surgical indications and approaches, closure techniques, postoperative complications, postoperative hospital stay, and all-cause mortality were collected. The primary outcome investigated was the rate of postoperative CSF leak. CSF leak included incisional CSF leak, rhinorrhea, or otorrhea. Secondary outcomes included postoperative rate of CSF leak and pseudomeningocele formation, pseudomeningocele formation only, CSF diversion, revision surgery, superficial wound infection, intracranial abscess, and meningitis. Pseudomeningoceles were included if clinically or radiologically diagnosed. The complete data abstraction table is provided in Supplementary Table 2.

Data analysis

Rates of CSF leak and related complications after posterior fossa craniotomy versus craniectomy surgeries were pooled using Review Manager (version 5.4.1, Cochrane Collaboration) by the inverse variance method and random effects analysis model. The pooled results of the eight dichotomous outcomes were presented as risk ratio (RR) with a corresponding 95% confidence interval (CI). The statistical significance was defined as $P < 0.05$. Quality of evidence was assessed using the Risk of Bias In Non-randomized Studies - of Exposure (ROBINS-E).[4] Evidence was ranked as being of very high risk, high risk, some concern over, or low risk of bias.

RESULTS

This systematic review identified 2264 studies, with 198 of those representing duplicate publications. Of the remaining articles, 2044 studies were excluded after title and abstract screening. Full-text review of the resulting 22 articles excluded another 13 studies. The remaining nine full-text retrospective studies[6,7,10,12,15,17,20-22] were included in the meta-analysis [Figure 1]. Please refer to Supplementary Table 2 for detailed description of individual studies including study characteristics, patient demographics, operative details, postoperative outcomes, and references. The analyses included 635 patients who underwent posterior fossa craniotomies and 615 patients who underwent posterior fossa craniectomies [Table 1].

In the craniotomy group, the average age based on five studies was 52.1 years. Six studies reported patient gender of which 54% were female. Five studies detailed the indication for surgery: vestibular schwannoma 33.5%, trigeminal neuralgia 30%, chiari malformation 19%, metastasis 15%, meningioma 0.5%, and other 2%. Eight articles mentioned the surgical procedure: retrosigmoid 64%, translabrynthine 23%, and suboccipital 13% craniotomies. Only two papers documented on surgical urgency; all surgeries were performed on elective bases [Table 1]. The craniotomy technique was listed in eight articles: bone flap replacement 68%, resorbable plate 24%, bone flap + methyl-methacrylate 7%, and metallic mesh 1%. On the other hand, 52% of patients in the craniectomy group were females, and the average age was 50.7 years. Indications for surgery included vestibular schwannoma 51%, metastasis 18%, trigeminal neuralgia 17%, chiari malformation 12%, meningioma 1%, and other 1%. The approaches used were translabrynthine 51%, retrosigmoid 31%, and suboccipital craniectomies 18%. All surgeries were performed on elective bases [Table 1].

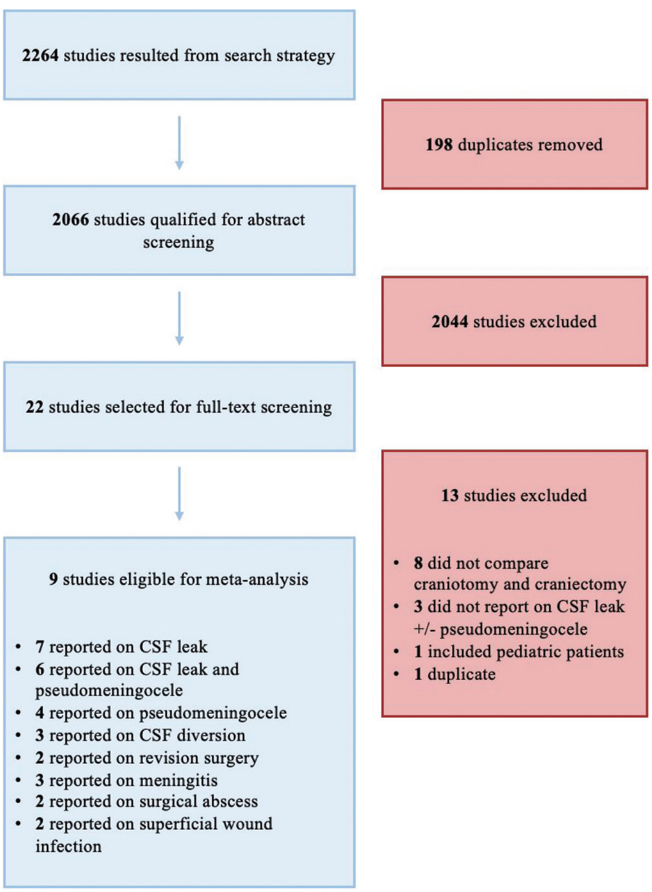

Figure 1: Flowchart of study selection. [CSF = cerebrospinal fluid].

Seven studies reported on CSF leak with a total of 85 events over 1002 cases. CSF leak occurred after 28 of 484 craniotomies (5.79%) and 57 of 518 craniectomies (11.00%). Even though CSF leak was almost twice as common after craniectomies, there was no statistical difference in the pooled analysis (Risk Ratio (RR): 0.71, 95% Confidence Interval (CI) 0.45-1.14, p-value (P) = 0.15, Heterogeneity I-squared (I^2) = 0%) [Figure 2]. Four studies described pseudomeningocele formation with a total of 75 events over 552 surgeries. It occurred after 25 of 338 craniotomies (7.40%) and 50 of 214 craniectomies (23.36%). Pooled analysis showed a significant increase in rates of pseudomeningocele formation after craniectomy surgeries (RR: 0.42, 95 % CI 0.26–0.69, $P = 0.0005$, $I^2 = 0\%$) [Figure 2]. In addition, when CSF leak and pseudomeningocele formation were combined into a single outcome, pooled analysis showed a significant difference favoring craniotomies as well (RR: 0.55, 95 % CI 0.32–0.94, $P = 0.03$, $I^2 = 59\%$). This combined outcome was detailed in six papers with a total of 144 occurrences over 816 cases. This outcome occurred after 62 of 489 craniotomies (12.68%) and 82 of 327 craniectomies (25.08%) [Figure 2].

The need for postoperative CSF diversion was recorded in three articles with a total of 31 diversions after 342 surgeries. CSF diversion was required after 8 of 119 craniotomies (6.72%) and 23 of 223 craniectomies (10.31%). There was no significant difference between the two groups in the pooled analysis (RR: 0.78, 95 % CI 0.36–0.1.68, $P = 0.53$, $I^2 = 0\%$)

Table 1: Baseline characteristics of patients, surgical indications, and procedures.

	Craniotomy (*n*=635) (%)	Craniectomy (*n*=615) (%)
Age (years) [5 studies]	52.1	50.7
Gender [6 studies]	*n*=220	*n*=380
Female	54	52
Male	46	48
Urgency (2 studies)	*n*=129	*n*=132
Elective	100	100
Emergency	0	0
Indication (5 studies)	*n*=215	*n*=303
Meningioma	0.5	1
Vestibular schwannoma	33.5	51
Metastasis	15	18
Chiari malformation	19	12
Trigeminal neuralgia	30	17
Other	2	1
Approach (9 studies)	*n*=564	*n*=525
Suboccipital	13	18
Retrosigmoid	64	31
Translabyrinthine	23	51

n = sample size

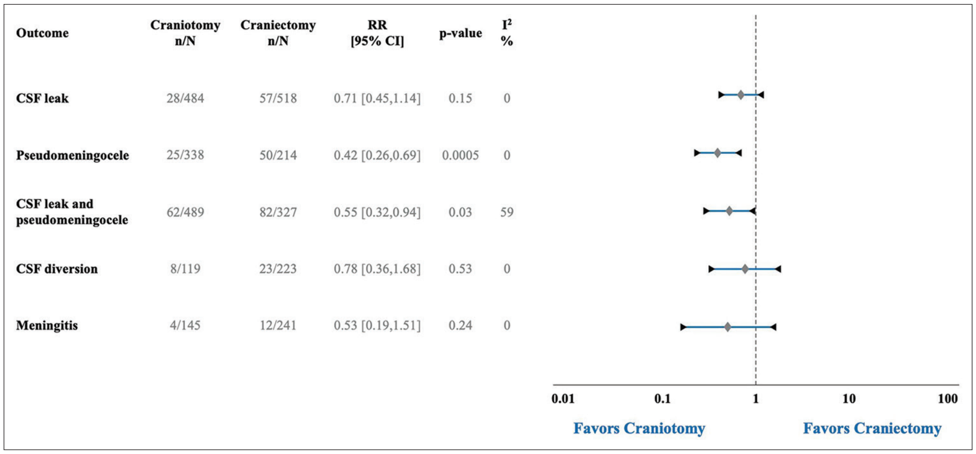

Figure 2: Pooled analysis of risk rations of measured outcomes. [CSF = cerebrospinal fluid, RR = risk ration, n/N = event count/ sample size, CI = confidence interval, I^2 = heterogeneity I-squared].

[Figure 2]. Similarly, the rate of postoperative meningitis was not statistically different between the craniotomy and craniectomy groups (RR: 0.53, 95 % CI 0.19–0.1.51, $P = 0.24$, $I^2 = 0\%$) [Figure 2]. Meningitis developed after 16 of 386 cases listed in three articles. It occurred in four of 145 craniotomies (2.76%) and 12 of 241 craniectomies (4.98%). Please refer to Supplementary Figures 1.1-1.5 for individual forest plots. Other secondary outcomes such as rates of revision surgery, superficial wound infection and abscess were excluded from the meta-analysis due to insufficient reported data. One patient in the craniotomy group (0.9%) versus five patients in the craniectomy group (2.7%) required revision surgery. Superficial wound infections occurred after two craniotomies (2.78%) and five craniectomies (8.1%). There were no cases of intracranial abscesses in either group.

The quality of evidence in this meta-analysis was graded using the ROBINS-E criteria. Three studies were graded as having some concerns for bias, five were graded as having a high risk of bias, and one had a very high risk of bias [Figure 3].

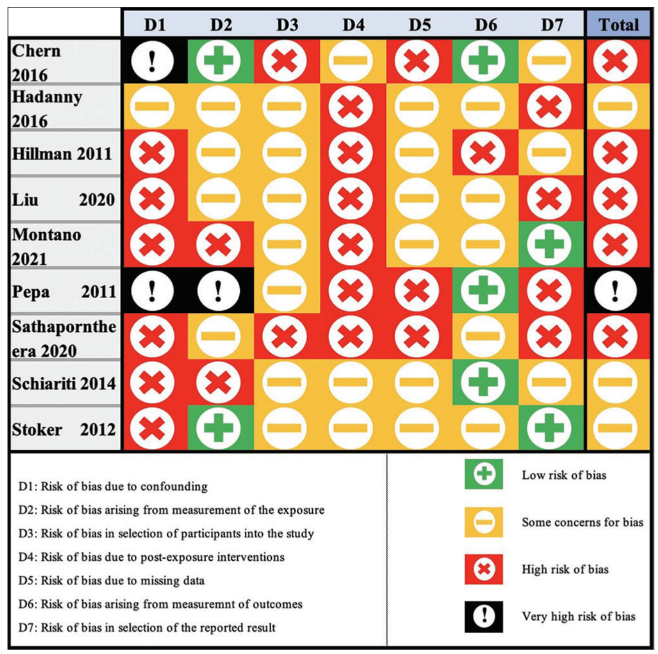

Figure 3: Quality of evidence based on the risk of bias in non-randomized studies - of exposure criteria.

DISCUSSION

In this systematic review and meta-analysis, data were pooled from nine retrospective studies comparing the rates of CSF leak or pseudomeningocele formation after posterior fossa craniotomies versus craniectomies. In terms of our primary outcome, the postoperative rate of CSF leak did not differ significantly between the two groups despite the craniectomy group having almost double the incidence of CSF leak (5.79% vs. 11.00%). On the other hand, pooled data demonstrated a statistically lower incidence of postoperative CSF leak and pseudomeningocele formation, as a combined outcome, or pseudomeningocele formation alone after craniotomy surgeries. The difference in significance between the rates of CSF leak and combined outcome, CSF leak and pseudomeningocele formation, is likely attributed to the larger proportion of cases with postoperative pseudomeningocele formation (13.59%) than CSF leak (8.48%). This could potentially skew the result towards favoring craniotomies given their significantly lower occurrence of pseudomeningocele formation. In addition, only two studies were included in the combined outcome but not in the CSF leak comparison;[17,21] one of which favored craniectomies[21] causing substantial heterogeneity ($I^2 = 59\%$). Thus, it is difficult to attribute this difference in significance to the incorporation of articles that did not differentiate between postoperative CSF leak and pseudomeningocele, which was the rationale behind including the combined outcome. Overall, we hope that the results of these analyses, favoring craniotomy, will serve as a motivation to promote further studies investigating the impact of craniotomies on adult posterior fossa surgery.

Unfortunately, there was a lack of sufficient data to adequately compare complications related to CSF leak and pseudomeningocele formation such as postoperative infections and interventions. Only the postoperative rate of meningitis (16 events) and need of CSF diversion (31 events) were included in the meta-analysis with no significant difference between the surgical groups in either outcome. Further prospective studies are required to further investigate the occurrence and impact of CSF leak and pseudomeningocele formation after posterior fossa surgeries.

There are multiple limitations to this systematic review and meta-analysis. The first limitation is pertaining to the low quality of evidence with high risk of bias based on the ROBINS-E criteria. This is heavily influenced by the retrospective nature of included studies. As previously mentioned, paucity of data also precluded extensive and comprehensive analyses on the impact of craniotomies on posterior fossa CSF leak, pseudomeningocele formation, and related complications. Furthermore, various confounding factors and heterogeneity between studies may have influenced the outcomes of this analysis; factors such as patient demographics, pathology, surgical procedure, closure technique, and other concurrent therapies such as steroids and radiation.[1,2,5,10,13,18,21,22] Heterogeneity in closure techniques is particularly concerning, as variability in closing the dura, fascia, and muscle might substantially influence outcomes after craniotomy or craniectomy. As an example, the paper by Schiariti *et al*.[21] utilized two alternative dural sealing techniques, one of which significantly reduced rates of CSF leak after craniectomy but not craniotomy. The use of a different dural sealant likely influenced the results in favor of craniectomies.[21] Even though no statistical significance was reached, this article was the only study favoring craniectomies in the CSF leak and pseudomeningocele formation comparison [Supplementary Figure 1.2].

CONCLUSION

This systematic review and meta-analysis is the first to compare the postoperative rate of CSF leak and pseudomeningocele formation after posterior fossa craniotomies versus craniectomies. The results of this study favored craniotomies over craniectomies in terms of CSF leak (P = 0.15, non-significant) and pseudomeningocele formation ($P < 0.05$, significant). Given these findings, and in the absence of evidence implicating posterior fossa craniotomies with higher surgical risks, neurosurgeons should consider performing craniotomies for posterior fossa surgeries. Further prospective studies are required to determine and validate the implications of posterior fossa craniotomy in reducing the risk of postoperative CSF leak and pseudomeningocele formation.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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SUPPLEMENTARY TABLES

Supplementary Table 1: Search terms utilized in each of the included databases.

Database	Search category 1	Search category 2
EMBASE 1974-present	**CSF Leak**	**Posterior fossa**
	Subject headings Exp wound dehiscence/or exp liquorrhea/	**Subject headings** Exp posterior fossa/or exp rhombencephalon/ or exp brain stem/or exp cisterna magna/or exp cerebellectomy/or exp fourth ventricle/or exp foramen magnum/or exp brain stem neoplasms/or exp cerebellar tumor/or exp cerebellopotine angle tumor/ or exp posterior cranial fossa tumor/
	Keywords ([[Pseudo-meningocele or liquorrhea or Pseudomeningocele or [CSF adj4 leak] or [Cerebrospinal adj4 leak] or [Cerebrospinalfluid adj4 leak] or [Incision* adj4 leak] or [Wound adj4 leak)] or [CSF adj10 Dehiscence] or [Cerebrospinal adj10 Dehiscence] or [Cerebrospinalfluid adj10 Dehiscence] or CSF] adj10 Discharge] or [Cerebrospinal adj10 Discharge] or [Cerebrospinalfluid adj10 Discharge]).af.	**Keywords** (Post* fossa or [Post* adj2 fossa] or Posteriorfossa or Postfossa or Rhombencephalon or Brain-stem or brainstem or Cisterna-Magn* or CisternaMagn* or Cerebell* or Fourthventric* or Fourth-ventric* or Foramen-magn* or Foramenmagn* or Infratent* or Infra-tent* or Myelencephalon or Metencephalon or Medulla* or Pontine or Pons or Supracerebell* or Craniocervic*OR Crani*-cervic* or Sub-occipit* or Suboccipit* or Telovel* or Transvermia*).af
Medline	**CSF Leak**	**Posterior fossa**
1946-present	**Subject headings** Exp surgical wound dehiscence/or exp cerebrospinal fluid leak/	**Subject headings** Exp cranial fossa, posterior/or exp brainstem/or cisterna magna/or exp fourth ventricle/or exp foramen magnum/or exp infratentorial neoplasms/
	Keywords ([[Pseudo-meningocele or Pseudomeningocele or [CSF adj4 leak] or [Cerebrospinal adj4 leak] or [Cerebrospinalfluid adj4 leak] or [Incision* adj4 leak] or [Wound adj4 leak] or [CSF adj10 Dehiscence] or [Cerebrospinal adj10 Dehiscence] or [Cerebrospinalfluid adj10 Dehiscence] or CSF] adj10 Discharge] or [Cerebrospinal adj10 Discharge] or [Cerebrospinalfluid adj10 Discharge]).af.	**Keywords** (Post* fossa or (Post* adj2 fossa) or Posteriorfossa or Postfossa or Rhombencephalon or Brain-stem or brainstem or Cisterna-Magn* or CisternaMagn* or Cerebell* or Fourthventric* or Fourth-ventric* or Foramen-magn* or Foramenmagn* or Infratent* or Infra-tent* or Myelencephalon or Metencephalon or Medulla* or Pontine or Pons or Supracerebell* or Craniocervic*OR Crani*-cervic* or Sub-occipit* or Suboccipit* or Telovel* or Transvermia*).af.
CENTRAL	**CSF Leak**	**Posterior fossa**
(Cochrane Central Register of Controlled Trials)	**Subject headings** Surgical wound dehiscence, Cerebrospinal fluid leak	**Subject headings** Cranial fossa, Posterior, Brain stem, Fourth ventricle, Infratentorial Neoplasms, Cisterna Magna, Foramen magnum
	Keywords Pseudo-meningocele, Pseudomeningocele, CSF leak, Cerebrospinal leak, Cerebrospinalfluid leak, Incision* leak, Wound leak, CSF Dehiscence, Cerebrospinal Dehiscence, Cerebrospinalfluid Dehiscence, CSF Discharge, Cerebrospinal Discharge, Cerebrospinalfluid Discharge	**Keywords** Post* fossa, Post* Adj2 fossa, Posteriorfossa, Postfossa, Rhombencephalon, Brain-stem, Cisterna-Magn*, CisternaMagn* Cerebell*, Fourthventric*, Fourth-ventric*, Foramen-magn*, Foramenmagn*, Infratent*, Infra-tent*, Myelencephalon, Metencephalon, Medulla*, Medulla-oblangata, Pontine, Pons, Supracerebell*, Craniocervic*, Cranio-cervic*, Sub-occipit*, Suboccipit*, Telovelar; Transvermia*

CSF = cerebrospinal fluid, * = unlimited truncation, Exp = explode, adj4 = defined adjacency , af = all searchable fields

Supplementary Table 2: Data abstraction table of the nine included articles.

Title	First author (Last name)	Year	Design	Country	Hospital centre	Total patients	Total craniotomy patients	Total craniectomy patients
Factors associated with csf leak after retrosig approach for cpa surgery	Montano	2021	Retrospective	Italy	Universitario Agostino Gemelli	103	80	23
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	Liu	2020	Retrospective	China	Tangdu Hospital	78	40	38
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	Pepa	2011	Retrospective	Italy	Catholic University of Rome	34	14	20
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	Hadanny	2016	Retrospective	Isreal	Tel Aviv Medical centre	88	34	54
Resorbable plate cranioplasty after the translabyrinthine approach	Hillman	2011	Retrospective craniectomy control cohort before 2005 with Prospective intervention craniotomy group	USA	University of Utah	220	71	149
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	Chern	2016	Retrospective	USA	Vanderbilt University Medical Center,	180	61	119
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	Sathaporntheera	2020	Retrospective case-control	Thailand	Ramathibodi Hospital, Mahidol University	286	206	80
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	Schiariti	2014	Retrospective	Italy	Fondazione Istituto Neurologico Besta	161	71	90
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	Stoker	2012	Retrospective	USA	Vanderbilt University Medical Center,	100	58	42

Title	Sex				Mean age		Comorbidities		Hydrocephalus		Urgency (elective or emergency)		Pathology/ Diagnosis		Surgical approach		Reconstruction/ Closure	
	Craniotomy		Craniectomy		Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy
	Male	Female	Male	Female														
Factors associated with csf leak after retrosig approach for cpa surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	80 retrosig	23 retrosig	NA	NA
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	18	22	18	20	41.5±10.8	40.9±9.8	NA	NA	7	8	NA	NA	40 chiari malformation type 1	38 chiari malformation type 1	40 suboccipital	38 suboccipital	40 Dura-Guard with primary closure and bone flap	38 Dura-Guard with primary closure
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	6	8	12	8	54.43±13.06	51.27±13.00	NA	NA	NA	NA	NA	NA	Vestibular schwannoma 4, V nerve decompression 6, Glossopharyngeal neuralgia 1 , Epidermoidcyst 2, Hemifacial spasm 1	Vestibular schwannoma 7, V nerve decompression 9 , Epidermoidcyst 1 , Hemifacial spasm 2, Arachnoid cyst 1	14 retrosigmoid	20 retrosigmoid	Fibrin glue 14, bone flap 14, primary closure 14	Fibrin glue 20, primary closure 20
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	20	14	23	31	57.8±10.5	60.7±11.6	Mean KPS 82.3±12.3	Mean KPS 80.0±13.6	9	11	NA	NA	Posterior fossa malignancies, lung 20, breast 6, colon 2, others 4	Posterior fossa malignancies, lung 14, breast 16, colon 10, others 14	34 suboccipital	54 suboccipital	Dural graft 34	Dural graft 54
Resorbable plate cranioplasty after the translabyrinthine approach	34	37	68	81	Average age 51.0 years, median of 53.5 years.	Average age 49.8 years, median of 50 years.	Average tumor size was 2 cm in width, diabetes (2/71, 3%) , hypertension (13/71, 18%)	Average tumor size was 2.2 cm in width, diabetes mellitus (1/149, 0.7%), hypertension (40/149, 26.8%).	NA	NA	NA	NA	CPA meningioma 1, vestibular shcwannoma 70	CPA meningioma 2, vestibular shcwannoma 147	71 translabyrinthine	149 translabyrinthine	Fat+Resorbable plate cranioplasty 71	Fat only 149
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	23	38	60	59	55.6	50.9	Median BMI 20, former or current smoker 8, diabetic 4	Median BMI 35, former or current smoker 14, diabetic 16	NA	NA	NA	NA	NA	NA	61 translabyrinthine CPA tumor surgery	119 translabyrinthine CPA tumor surgery	Fat+Resorbable plate cranioplasty 61	fat only 119

(Contd...)

Supplementary Table 2: *(Continued)*.

Title	Sex				Mean age		Comorbidities		Hydrocephalus		Urgency (elective or emergency)		Pathology/ Diagnosis		Surgical approach		Reconstruction/ Closure	
	Craniotomy		Craniectomy		Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy
	Male	Female	Male	Female														
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	206 retrosigmoid	80 retrosigmoid	Autologous bone flap	No bone flap
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	71 elctives	90 elctives	NA	NA	NA	NA	53 TPD, 18 DuraSeal	62 TPD, 28 DuraSeal
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	58 electives	42 elctives	58 trigeminal neurlgia	42 trigeminal neurlgia	58 Retrosigmoid	42 Retrosigmoid	36 Methylmethacrylate/ bone flap+synthetic analogue, 14 bone flap, 8 mesh	42 Nothing

Title	Operative time		CSF leak + pseudomeningocele		CSF leak (incisional, rhinorrhea, ottorhea)		Total pseudomeningecele		Asymptomatic pseudomeningecele		Symptoatic pseudomeningecele		Timing of CSF leak/pseudomeningocele		Need for csf diversion	
	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy
Factors associated with csf leak after retrosig approach for cpa surgery	NA	NA	9	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	NA	NA	0	3	0	2	0	1	NA	NA	NA	NA	NA	NA	0	0
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	NA	NA	NA	NA	0	5	NA	NA	NA	NA	NA	NA	NA	NA	0	5
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	NA	NA	8	34	1	2	Total 7, Short term Pseudomeningocele 6, long term Pseudomeningocele 1	Total 32, Short term Pseudomeningocele 21, long term Pseudomeningocele 11	NA	NA	NA	NA	NA	NA	1	2
Resorbable plate cranioplasty after the translabyrinthine approach	Average 5.1 h	Average 6.3 h	NA	NA	(9/71, 12.7%).	20 (13.4%)	NA	NA	NA	NA	NA	NA	NA	NA	7 (9.9%)	16 (10.7%)
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	NA	NA	NA	NA	1 CSF leak	14 CSF leak	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	NA	NA	25	12	10 (71.43%) wound, 9 (75%) rhinorrhea/ otorrhea	4 (28.57%) wound, 3 (25%) rhinorrhea/ otorrhea	15 (65.22%)	8 (34.78%)	NA	NA	NA	NA	NA	NA	NA	NA
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	NA	NA	10	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	NA	NA	10	19	7	10	3	9	NA	NA	NA	NA	NA	NA	11 lumbar drains	NA
Factors associated with csf leak after retrosig approach for cpa surgery	NA	NA	9	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	NA	NA	0	3	0	2	0	1	NA	NA	NA	NA	NA	NA	0	0
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	NA	NA	NA	NA	0	5	NA	NA	NA	NA	NA	NA	NA	NA	0	5

(Contd...)

Supplementary Table 2: *(Continued).*

Title	Operative time		CSF leak + pseudomeningocele		CSF leak (incisional, rhinorrhea, ottorhea)		Total pseudomeningecele		Asymptomatic pseudomeningecele		Symptoatic pseudomeningecele		Timing of CSF leak/pseudomeningocele		Need for csf diversion	
	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	NA	NA	8	34	1	2	Total 7, Short term Pseudomeningocele 6, long term Pseudomeningocele 1	Total 32, Short term Pseudomeningocele 21, long term Pseudomeningocele 11	NA	NA	na	NA	NA	NA	1	2
Resorbable plate cranioplasty after the translabyrinthine approach	Average 5.1 h	Average 6.3 h	NA	NA	(9/71, 12.7%).	20 (13.4%)	NA	NA	NA	NA	na	NA	NA	NA	7 (9.9%)	16 (10.7%)
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	NA	NA	NA	NA	1 CSF leak	14 CSF leak	NA	NA	NA	NA	na	NA	NA	NA	NA	NA
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	NA	NA	25	12	10 (71.43%) wound, 9 (75%) rhinorrhea/otorrhea	4 (28.57%) wound, 3 (25%) rhinorrhea/otorrhea	15 (65.22%)	8 (34.78%)	NA	NA	NA	NA	NA	NA	NA	NA
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	NA	NA	10	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	NA	NA	10	19	7	10	3	9	NA	NA	NA	NA	NA	NA	11 lumbar drains	NA

Title	Type of csf diversion		Need for revision surgery for CSF leak/pseudomeningocele		Type of revision surgery for CSF leak/pseudomeningocele		Wound dehiscence without CSF leak		Superficial wound infection		Post-operative abscess		Meningitis		Infection treatment (surgically/conservatively)	
	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy
Factors associated with csf leak after retrosig approach for cpa surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	NA	NA	0	1	NA	NA	NA	NA	0	0	0	0	1 (aseptic)	4 (aseptic)	0	0
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	0	Lumbar drain 5	0	0	0	0	NA	NA	0	1	0	0	0	0	0	Conservative/abx 1
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	EVD 1	EVD 2	NA	NA	NA	NA	0	6	NA	NA	NA	NA	3	7	NA	NA
Resorbable plate cranioplasty after the translabyrinthine approach	Lumbar drain 7	Lumbar drain 16	1	4	NA	NA	2 pts needed suture reinforcement	4 pts needed suture reinforcement	0	0	0	0	0	1	0	1 pt had csf negative meningitis treated with IV Abx
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	NA	NA	NA	NA	NA	NA	NA	NA	2	4	NA	NA	NA	NA	NA	NA
Factors associated with csf leak after retrosig approach for cpa surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

(Contd...)

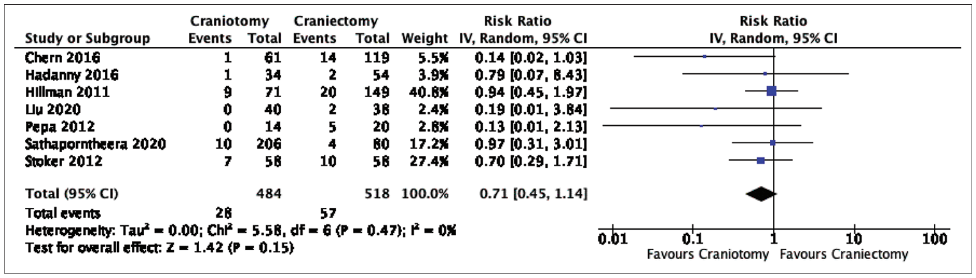
Supplementary Table 2: *(Continued).*

Title	Type of csf diversion		Need for revision surgery for CSF leak/pseudomeningocele		Type of revision surgery for CSF leak/pseudomeningocele		Wound dehiscence without CSF leak		Superficial wound infection		Post-operative abscess		Meningitis		Infection treatment (surgically/conservatively)	
	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	na	na	0	1	NA	NA	NA	NA	0	0	0	0	1 (aseptic)	4 (aseptic)	0	0
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	0	Lumbar drain 5	0	0	0	0	NA	NA	0	1	0	0	0	0	0	Conservative/ abx 1
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	EVD 1	EVD 2	NA	NA	NA	NA	0	6	NA	NA	NA	NA	3	7	NA	NA
Resorbable plate cranioplasty after the translabyrinthine approach	Lumbar drain 7	Lumbar drain 16	1	4	NA	NA	2 pts needed suture reinforcement	4 pts needed suture reinforcement	0	0	0	0	0	1	0	1 pt had csf negative meningitis treated with IV Abx
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	NA	NA	NA	NA	NA	NA	NA	NA	2	4	NA	NA	NA	NA	NA	NA

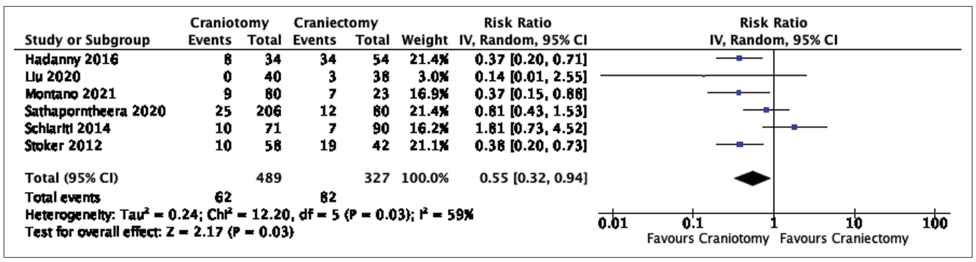
Title	Post-op Hydrocephalus		All - cause mortality		Hospital Stay (days)		References
	Craniotomy	Craniectomy	Craniotomy	Craniectomy	Craniotomy	Craniectomy	
Factors associated with csf leak after retrosig approach for cpa surgery	NA	NA	NA	NA	NA	NA	Montano N, Signorelli F, Giordano M,D'Onofrio FG, Izzo A, D'Ercole M, *et al*. Factors associated with cerebrospinal fluid leak after a retrosigmoid approach for cerebellopontine angle surgery. *Surg Neurol Int*. 2021;12:258. doi:10.25259/SNI_42_2021
Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia	NA	NA	NA	NA	NA	NA	Liu B, Wang Y, Liu S, Zhang Y, Lu D, Chen L, *et al*. Tonsillectomy with modified reconstruction of the cisterna magna with and without craniectomy for the treatment of adult Chiari malformation type I with syringomyelia. *Acta Neurochir (Wien)*. 2020;162(7):1585-1595. doi:10.1007/s00701-019-04177-9
Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers	NA	NA	NA	NA	NA	NA	Della Pepa GM, Montano N, Lucantoni C, Alexandre AM, Papacci F, Meglio M. Craniotomy repair with the retrosigmoid approach: the impact on quality of life of meticulous reconstruction of anatomical layers. *Acta Neurochir (Wien)*. 2011;153(11):2255-2258. doi:10.1007/s00701-011-1113-3
Craniectomy versus craniotomy for posterior fossa metastases, complication profile	1	2	2	0	4	4.5	Hadanny A, Rozovski U, Nossek E, Shapira Y, Strauss I, Kanner AA, *et al*. Craniectomy Versus Craniotomy for Posterior Fossa Metastases: Complication Profile. *World Neurosurg*. 2016;89:193-198. doi:10.1016/j.wneu.2016.01.076
Resorbable plate cranioplasty after the translabyrinthine approach	NA	NA	NA	NA	3.8	5.7	Hillman TA and Shelton C. Resorbable Plate Cranioplasty After the Translabyrinthine Approach. *Otology & Neurotology*. 2011;32(7):1171-1174. doi:10.1097/MAO.0b013e318229d301
Cost analysis of cerebrospinal fluid leaks and cerebrospinal fluid leak prevention in patients undergoing cerebellopontine angle surgery	NA	NA	NA	NA	NA	NA	Chern A, Hunter JB, Bennett ML. Cost Analysis of Cerebrospinal Fluid Leaks and Cerebrospinal Fluid Leak Prevention in Patients Undergoing Cerebellopontine Angle Surgery. *Otology & Neurotology*. 2017;38(1):147-151. doi:10.1097/MAO.0000000000001252
Risk factors associated with CSF leakage and complications after retrosigmoid surgery	NA	NA	NA	NA	NA	NA	Sathaporntheera P, Saetia K. Risk factors associated with CSF leakage and complications after retrosigmoid surgery. *Interdisciplinary Neurosurgery*. 2020;22:100865. doi:10.1016/j.inat.2020.100865
Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel	NA	NA	NA	NA	NA	NA	Schiariti M, Acerbi F, Broggi M, Tringali G, Raggi A, Broggi G, *et al*. Two alternative dural sealing techniques in posterior fossa surgery: (Polylactide-co-glycolide) self-adhesive resorbable membrane versus polyethylene glycol hydrogel. *Surg Neurol Int*. 2014;5(1):171. doi:10.4103/2152-7806.146154
Decreased rate of CSF leakage associated with complete reconstruction of suboccipital cranial defects	NA	NA	NA	NA	NA	NA	Stoker M, Forbes J, Hanif R, Cooper C, Nian H, Konrad PE, *et al*. Decreased Rate of CSF Leakage Associated with Complete Reconstruction of Suboccipital Cranial Defects. *J Neurol Surg B Skull Base*. 2012;73(04):281-286. doi:10.1055/s-0032-1312709

CSF: Cerebrospinal fluid, USA = United States of America, NA = data not available, TPD = Tissue Patch Dural, + = and, h = hours, EVD = external ventricular drain, pts = patients

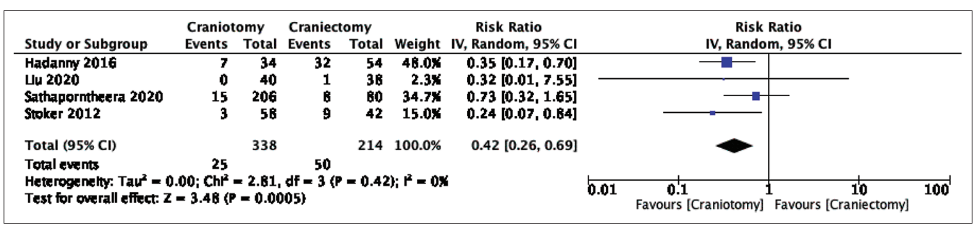
SUPPLEMENTARY FIGURES



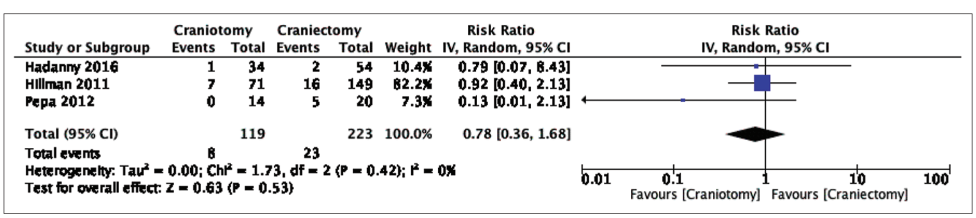
Supplementary Figure 1.1: Forest plot of cerebrospinal fluid leak comparison. [IV = inverse variance, CI = confidence interval, Tau^2 = Tau-square between-study variance, Chi^2 = Chi-square statistic, df = degrees of freedom, P = p-value, I^2 = heterogeneity I-squared, Z = Z-test].



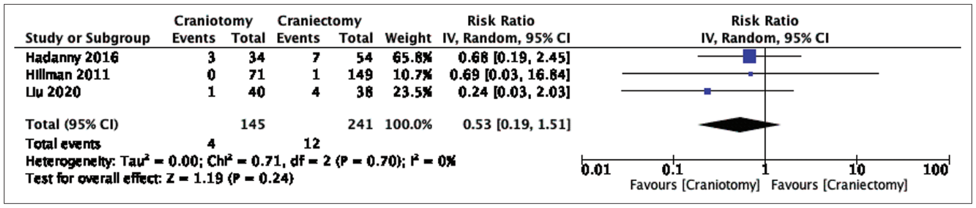
Supplementary Figure 1.2: Forest plot of cerebrospinal fluid leak and pseudomeningocele formation comparison. [IV = inverse variance, CI = confidence interval, Tau^2 = Tau-square between-study variance, Chi^2 = Chi-square statistic, df = degrees of freedom, P = p-value, I^2 = heterogeneity I-squared, Z = Z-test].



Supplementary Figure 1.3: Forest plot of pseudomeningocele formation comparison. [IV = inverse variance, CI = confidence interval, Tau^2 = Tau-square between-study variance, Chi^2 = Chi-square statistic, df = degrees of freedom, P = p-value, I^2 = heterogeneity I-squared, Z = Z-test].



Supplementary Figure 1.4: Forest plot of need for cerebrospinal fluid diversion comparison. [IV = inverse variance, CI = confidence interval, Tau^2 = Tau-square between-study variance, Chi^2 = Chi-square statistic, df = degrees of freedom, P = p-value, I^2 = heterogeneity I-squared, Z = Z-test].



Supplementary Figure 1.5: Forest plot of meningitis comparison. [IV = inverse variance, CI = confidence interval, Tau^2 = Tau-square between-study variance, Chi^2 = Chi-square statistic, df = degrees of freedom, P = p-value, I^2 = heterogeneity I-squared, Z = Z-test].