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Comparison of Surgical Techniques for Intracranial Arachnoid Cysts: A Volumetric Analysis

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ABSTRACT

AIM: To compare volumetric changes of intracranial arachnoid cysts (IACs) in different surgical techniques.

MATERIAL and METHODS: Sixty-six patients who underwent IAC surgery in our department between 2010 and 2020 were studied retrospectively. Based on the surgical technique, clinical and volumetric changes, postoperative complications, recurrence rates, and length of hospital stay were statistically compared.

RESULTS: Microsurgical fenestration (MF) was performed on 32 (48.5%) patients, endoscopic fenestration (EF) on 17 patients, cystoperitoneal shunt (CPS) on 11 patients, and EF + CPS in six patients. The mean IAC volume change rate was 68.54 mL, and the mean cyst volume change rate was 40.68%. The MF technique produces a significantly greater mean cyst volume change than the EF technique. The mean volume change in sylvian IAC is 4.8 times greater than in posterior fossa IAC, a significant difference. The mean cyst volume change is four times greater in patients with skull deformity than in patients with balance loss, and this difference is statistically significant. In patients with cranial deformity, the mean cyst volume change is 2.6 times greater than in patients with neurological dysfunction. This difference is also statistically significant. The volume of IAC decreased more in patients with postoperative complications, with a significant difference between the postoperative complication and the change in IAC volume.

CONCLUSION: MF can achieve better volumetric reduction in IAC, particularly in patients with sylvian arachnoid cysts. However, more volumetric reduction increases the risk of postoperative complications.

KEYWORDS: Arachnoid cyst, Endoscopy, Fenestration, Microsurgery, Volume

ABBREVIATIONS: CT: Computed tomography, **EF:** Endoscopic fenestration, **IAC:** Intracranial arachnoid cysts, **MF:** Microsurgical fenestration, **MRI:** Magnetic resonance imaging

INTRODUCTION

Intracranial arachnoid cysts (IACs) are benign lesions that originate from the meninges and are continuous with a cisternal arachnoid fold or convexity. It can be congenital or develop later in life (25). The detection of IACs has increased as a result of the increased use of radiological imaging methods. However, the number of people diagnosed with IAC earlier in life has increased. Estimating the epidemiology accurately is difficult because the clinic is mostly asymptomatic. The pediatric incidence was found to be 2.6% in the pediatric population and 1.4% in the adult population, depending on the radiological imaging performed for various indications. Men are more likely to have IACs (2,3).

The clinical course of IACs is unknown. In some cases, it is asymptomatic for the rest of one's life. It may enlarge gradually and become symptomatic in some cases (26). Although extremely uncommon, spontaneous regression has also been reported (26). The clinical symptoms differ depending

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on the patient's age and the location of the IAC. Headache, imbalance, nausea, vomiting, dizziness, weakness, cognitive decline, seizures, focal neurological deficit, vision defect, endocrine disorders, gait disturbance, skull deformities, growth retardation, unclosed anterior fontanel or increased head circumference, speech disorders, hearing loss, and neuropsychological disorders are common symptoms. Headache is the most common presenting complaint (2,3).

IACs are classified into two types based on their location: supratentorial and infratentorial. Infratentorial IACs are found in the posterior fossa in the retrocerebellar, intraventricular, and cerebellopontine angle, whereas supratentorial IACs are found in the sylvian, suprasellar, cerebral convexity, interhemispheric, and intraventricular regions. Quadrigeminal IACs can be supratentorial or infratentorial in nature.

Intracranial arachnoid cyst is commonly diagnosed using computed tomography (CT) and magnetic resonance imaging (MRI). While CT is useful for evaluating bone structure, MRI is typically used for differential diagnosis.

The surgical indication is controversial because IACs are benign lesions that can cause complications and recurrences that require additional surgeries (9). Surgical methods for IACs have advantages and disadvantages (19). The aim of fenestration is to allow cerebrospinal fluid (CSF) circulation between the cyst and the surrounding cisterns or ventricles by opening cyst membranes. The purpose of cystoperitoneal shunt application is to ensure that cyst contents drain into the peritoneal cavity (7). Both methods may be used in conjunction if fenestration or shunt application alone is deemed insufficient for surgical treatment.

This study aims to compare the surgical methods based on cyst volume reduction, postoperative complications, and length of hospital stay and to determine the best technique for cyst volume reduction.

MATERIAL and METHODS

Patient Population

Ethical approval for this retrospective study was obtained from the ethics committee of our institution (Date: 24.12.2020; No:17). The study included 66 patients who were operated on with the diagnosis of IAC in our institution's Department of Neurosurgery between January 2010 and March 2020. Gender, age, cyst location, complaints, examination, surgical technique, and preoperative and postoperative cyst volume based on brain CT scan were recorded during the preoperative period.

Patients with IAC who had at least one clinical symptom were referred to surgery. Following the exclusion of other pathologies that could cause symptoms, surgical treatment was performed. For the treatment of IACs, four different surgical techniques were used: microsurgical fenestration (MF), endoscopic fenestration (EF), cystoperitoneal shunt (CPS) insertion, and EF plus CPS in the same session (EF + CPS). The patient's most common complaint was recorded as the complaint at admission. Clinical improvement is defined as complete symptom resolution or reduction to the point where it has no effect on daily life.

The postoperative IAC volume was calculated at 1 yr after surgery. It was recorded after the wound healing was complete and the surgical-related complaints had subsided. The patients' IAC volumes were measured before and after surgery. The rate of IAC volume change relative to preoperative volume was recorded. Radiological improvement was defined as a volume change of 10 mL or a volume change rate of 15%. The postoperative complications seen in the first 6 months in the IACs we operated on were considered the short-term postoperative complications. As long-term postoperative complications, we considered revision surgeries due to recurrence or shunt.

Cyst Measurement

IAC volume was measured on axial brain CT scans with a 0.5-mm cross-section using the VITREA Enterprise Imaging Solution (Canon Group USA) program used in our hospital's radiology service, in milliliter (mL) units (Figure 1).

Statistical Analysis

For data analysis, the IBM SPSS Version 25.0 (IBM Corp., Armonk, NY) statistical package program was used. The changes in cyst volume were compared for each surgical method. The cyst location and surgical technique were also used to compare patient complaints and postoperative complications. A p value of less than 0.05 was considered statistically significant.

RESULTS

Demographic Findings

Fifty-five (83.3%) patients were male, and 11 (16.7%) were female. There were 26 (39.4%) patients who were children (younger than 18 years old). While the mean age of the patients in this study was 19.38 ± 1.76 yr (ranged between 0.5 and 67) years, we found that the mean age of pediatric patients was 5.67 ± 0.94 (0.5–16) yr and adult patients were 28.3 ± 1.72 (20–67) yr. The most common complaint was headache, which was mostly seen in sylvian arachnoid cysts (Table I). The arachnoid cyst was found in 44 (66.7%) patients, 10 (15.2%) patients in the posterior fossa, six (9.1%) patients in the convexity, three (4.5%) patients in the suprasellar region, one (1.5%) patient in the interhemispheric area, one (1.5%) patient in the quadrigeminal cistern, and one (1.5%) patient in the intraventricular region. According to the Galassi classification, type II IAC was detected in 12 (18.2%) patients and type III in 32 (48.5%) patients. Because of their location, 22 (33.3%) patients were excluded from the classification.

Surgical Outcomes

As a surgical technique, MF was used in 32 (48.5%) patients (Figure 2), EF in 17 (25.8%) patients, CPS in 11 (16.7%) patients, and EF + CPS in six (9.1%) patients (Figure 3). In the postoperative period, 35 (53.0%) patients had their complaints completely resolved, whereas 30 (45.5%) patients had them significantly reduced. One (1.5%) patient's complaint at

Table I: Preoperative Symptoms of Patients Based on the Cyst Location

Complaints	Sylvian	Posterior fossa	Convexity	Others	Total
Headache	11	7	2	1	21
Fainting	6	1	3	1	11
Neurological dysfunction	7	0	3	1	11
Imbalance	1	5	3	0	9
Cranial deformity	2	1	5	0	8
Other	3	2	0	1	6

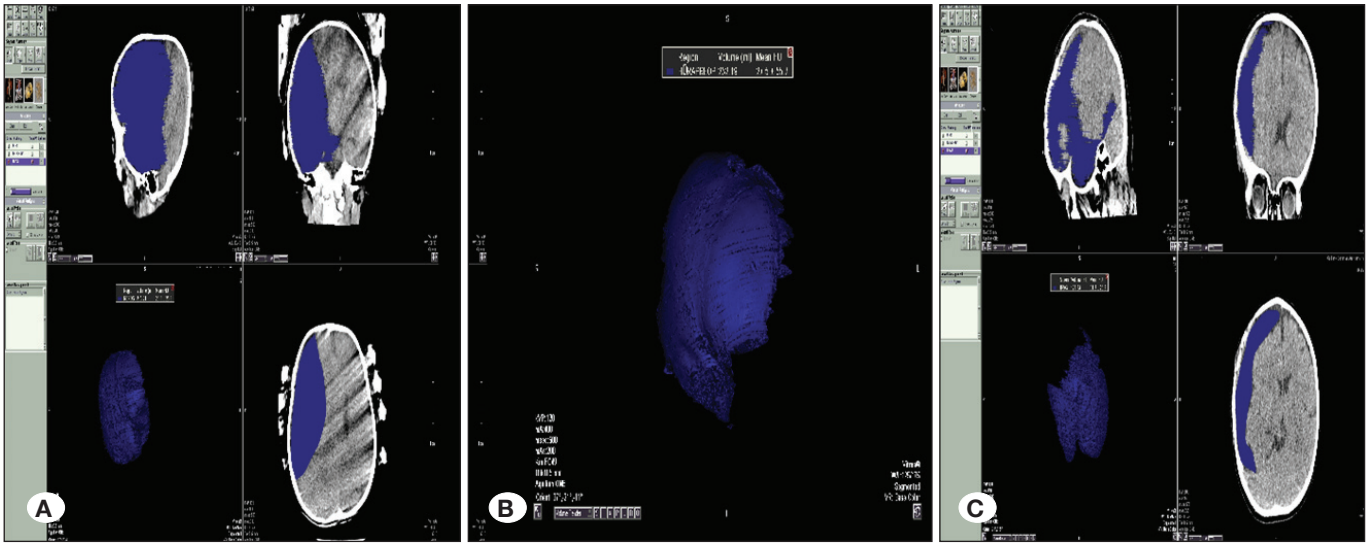

Figure 1: 3D volume measurement of intracranial arachnoid cysts is shown. **A)** Right sylvian-localized IAC 3 axis volume measurement, **B)** right sylvian-located IAC 3D modeling, and **C)** right sylvian-located IAC 3 axis volume measurement and modeling are shown.

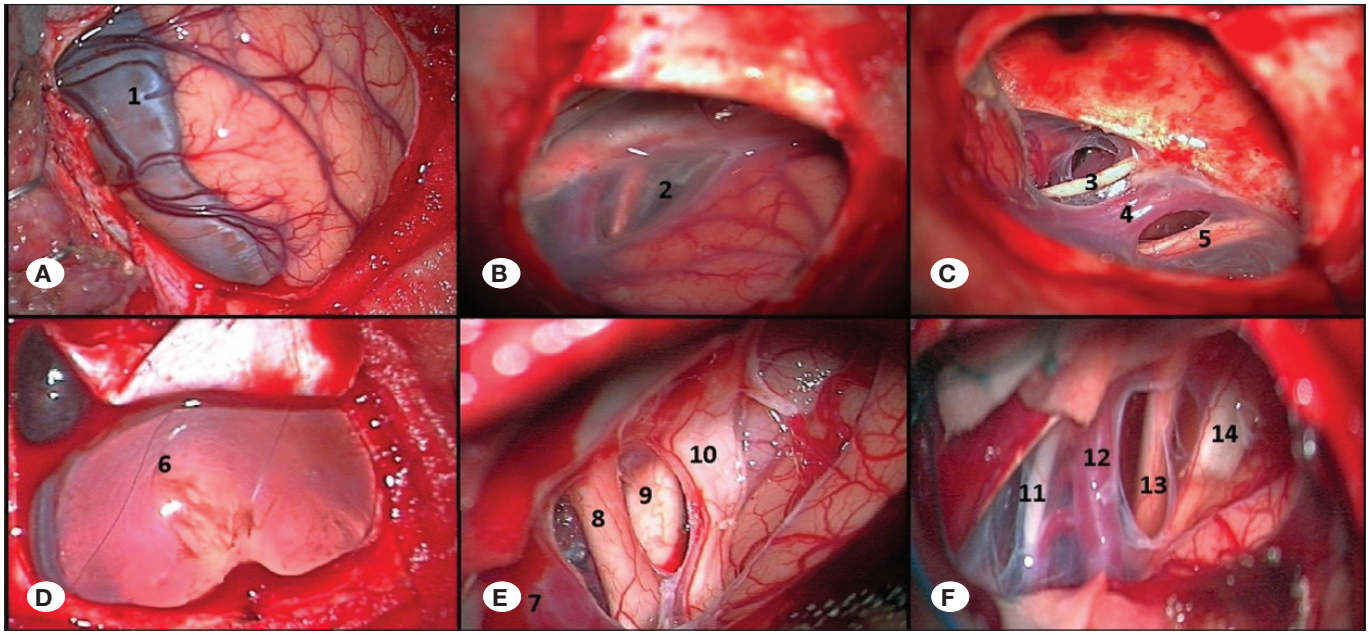

Figure 2: Intraoperative microscopic images of IAC treated with MF technique are shown. **A)** Outer membrane (1) of the left sylvian-located IAC after the opening of the A dura; **B)** inner membrane (2) of the right sylvian IAC; **C)** after fenestration of IAC, III cranial nerve (3), ICA (4), and II cranial nerve (5); **D)** outer membrane (6) of the left sylvian IAC; **E)** after fenestration, ICA (7), left II.cranial nerve (8), right II.cranial nerve (9), and left I.cranial nerve (10); **F)** after fenestration, left III cranial nerve (11), left ICA (12), left II cranial nerve (13), and left I cranial nerve (14) are shown.

admission did not change. The mean follow-up period was 78.12 ± 4.07 (12–144) months. The mean volume change was 68.54 ± 10.67 (0.39–624.96) mL, and the mean volume change rate was 40.68 ± 2.29% (1.37–91.82) (Figures 4 and 5).

Postoperative complications were subdural hygroma in six (9.1%) patients, subgaleal collection in four (6.1%) patients, subdural hematoma in three (4.5%) patients, wound healing problem in three (4.5%) patients, meningitis in one (1.5%) patient, and subdural empyema in one (1.5%) patient (Table II). Due to postoperative complications, all patients with subdural hematoma, wound problems, and subdural empyema and two patients with subdural hygroma were operated on. Six (9.1%) patients required revision surgery due to fibrosis in the fenestration area, and five (7.6%) patients had shunt dysfunction. CPS was implanted in five patients who had MF or EF as their first surgical procedure and required revision. CPS was also implanted in four patients who had previously

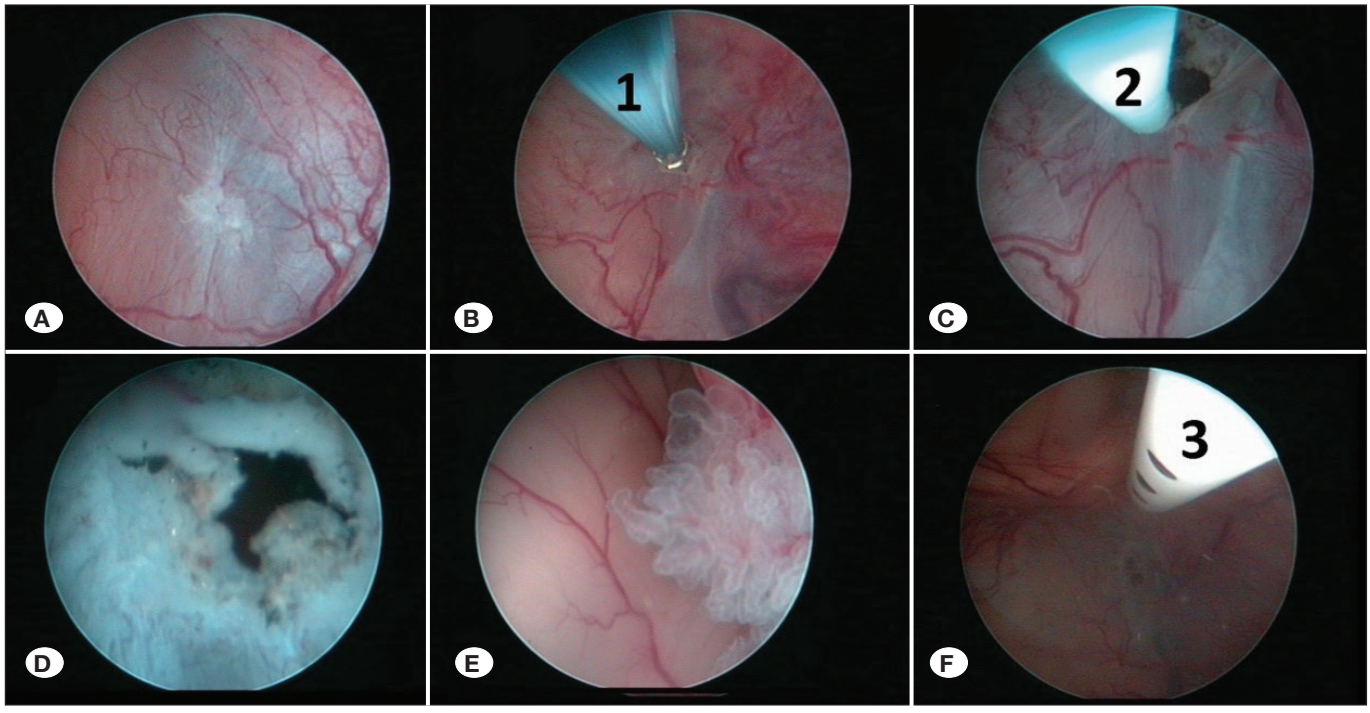

Figure 3: Intraoperative endoscopic images of IAC treated with EF + CPS technique are shown. **A)** Superior membrane of the third ventricular IAC; **B)** opening of the membrane with endoscopic monopolar cautery (1); **C)** enlarging the fenestration with Fogarty catheter (2); **D)** IAC with the superior membrane fenestrated by the ventricle; **E)** choroid plexus inside the ventricle; **F)** shunt placement (3) is shown with the endoscope.

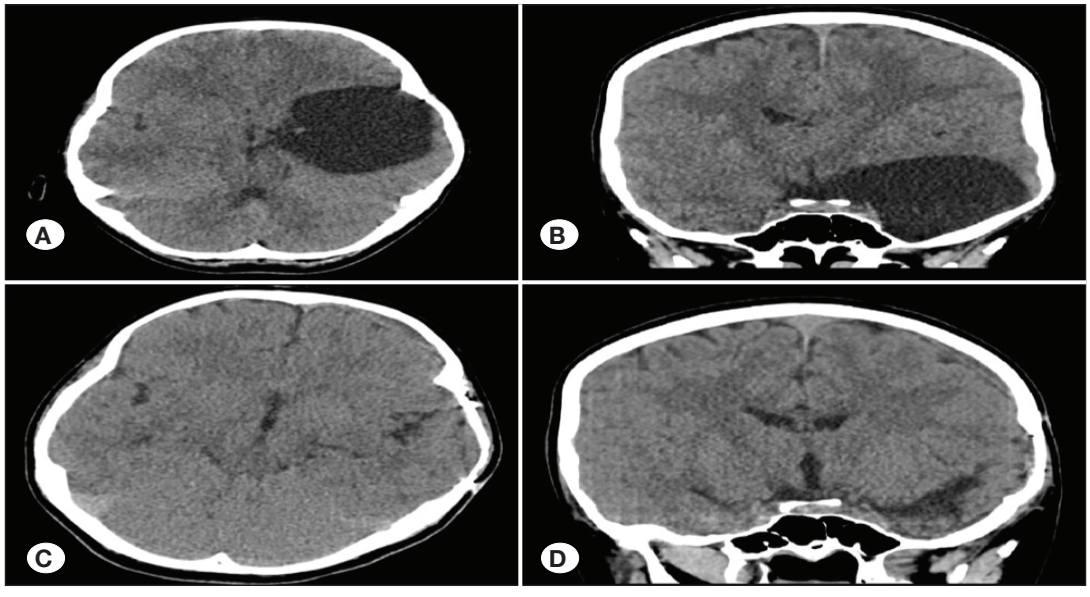

Figure 4: A 25-year-old patient diagnosed with left sylvian IAC was operated with MF technique.
A, B) Preoperative axial and coronal brain CT scan.
C, D) Postoperative axial and coronal brain CT scan.

received CPS. Only one patient underwent EF + CPS, and this patient did not require any revision surgery. The interval between the two procedures in patients who underwent revision surgery was 13.18 ± 3.27 months (ranged between 1 and 34 months).

There is no statistically significant difference between the patient's age group and the rate of IAC volume change and volume reduction ($p>0.05$). There is also no statistically significant difference between patient gender and IAC volume change and volume reduction rate ($p>0.05$).

The differences between surgical techniques and cyst volume changes were statistically significant ($p=0.004$). The mean cyst volume change in MF patients is approximately 2.7 times greater than in EF patients, and the difference between the groups is statistically significant ($p=0.004$). The EF + CPS technique has a 2.9-fold higher mean cyst volume change than the EF technique. However, this difference is not statistically significant ($p=0.072$). There was no statistically significant difference between the other groups ($p>0.05$). There is no statistically significant difference in the rates of IAC volume reduction rates observed in different surgical techniques ($p>0.05$, Table III).

Age and cyst volume change have a negative and significant relationship (correlation coefficient = –0.254, $p=0.039$ and $p<0.05$). There is no significant relationship between age and the rate of decrease in IAC volume ($p>0.05$).

The relationship between cyst location and volume change is statistically significant ($p<0.0001$). The mean volume change of IACs in the sylvian region is 4.8 times greater than that of IACs in the posterior fossa. The difference is statistically significant ($p<0.0001$). There was no statistically significant difference between the other groups ($p>0.05$). There is no statistically significant relationship between IAC location and IAC volume reduction rate ($p>0.05$, Table IV).

There is a statistically significant difference between preoperative complaints and cyst volume change ($p=0.005$). The mean cyst volume change in patients with skull deformity is four times that of patients with balance loss, and this difference is statistically significant ($p=0.004$). The mean

Table II: Distribution of Complications Based on the Cyst Location

Complications	Sylvian	Posterior fossa	Convexity	Others	Total
Subdural hygroma	3	0	3	0	6
Subgaleal collection	2	0	1	1	4
Subdural haematoma	2	0	1	0	3
Wound dehiscence	1	0	1	1	3
Meningitis	1	0	0	0	1
Subdural empyema	0	0	1	0	1

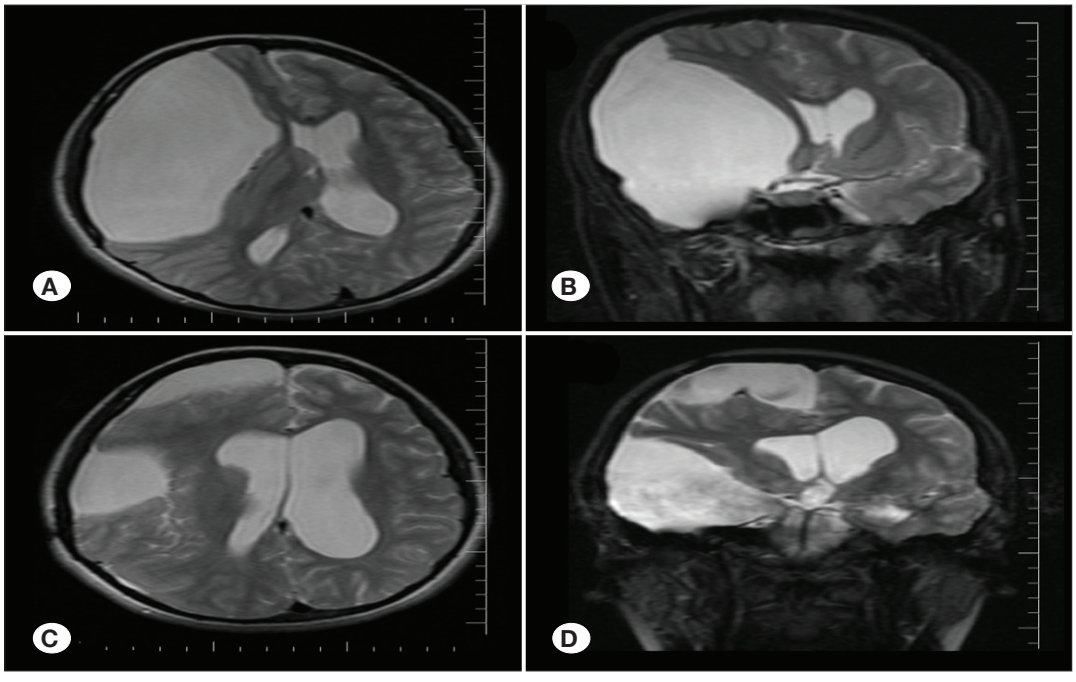

Figure 5: A 2-year-old patient with right parietal convexity IAC was operated with MF technique.
A, B) Preoperative axial and coronal T2 MRI.
C, D) Postoperative axial and coronal T2 MRI.

Table III: Cyst Volume Change and Cyst Volume Reduction Rate According to Surgical Technique

Surgical Technique	Cyst Volume Change (ml)	Cyst Volume Reduction Rate (%)
MF (n=32)	84.75 ± 18.87* (11.65-624.96)	42.08 ± 3.07 (15.21-87.60)
EF (n=17)	31.40 ± 6.74* (0.39-119.83)	37.70 ± 4.80 (1.37–91.82)
CPS (n=11)	65.20 ± 19.05 (8.53-188.06)	35.38 ± 4.97 (10.87-67.52)
EF+ CPS (n=6)	93.47 ± 39.87 (24.45-288.06)	51.38 ± 10.01 (17.82-78.45)
p	**0.004**	0.504

Data are expressed as mean ± SH (minimum-maximum value). Kruskal-Wallis H test. post-hoc Bonferroni correction. ***:** *p<0.05*
***CPS:** Cystoperitoneal shunt, **EF:** Endoscopic fenestration, **EF+ CPS:** Endoscopic fenestration with cystoperitoneal shunt, **MF:** Microsurgical fenestration.*

Table IV: Cyst Volume Change and Cyst Volume Reduction Rate According to Cyst Location

Cyst Location	Cyst Volume Change (ml)	Cyst Volume Reduction Rate (%)
Sylvian (n=44)	88.74 ± 15.02*** (8.53-624.96)	40.15 ± 2.77 (10.87–91.82)
Posterior fossa (n=10)	18.35 ± 3.18*** (0.39-35.36)	31.25 ± 4.39 (1.37–52.67)
Cerebral convexity (n=6)	35.41 ± 8.96 (11.65-70.00)	53.64 ± 7.52 (35.27-82.43)
Other (n=6)	37.22 ± 9.60 (15–80.80)	47.37 ± 8.94 (17.82-71.52)
p	**<0.0001**	0.119

Data are expressed as mean ± SH (minimum-maximum value).
Kruskal-Wallis H test. post-hoc Bonferroni correction. ***:** *p<0.0001.*

cyst volume change in patients with cranial deformity is 2.6 times higher than in patients with neurological dysfunction. This difference is also statistically significant (p=0.037). Other differences between groups were not statistically significant (p>0.05). There is no statistically significant relationship between preoperative complaints and IAC volume reduction rate (p>0.05, Table V).

There is a statistically significant difference between postoperative complications and IAC volume change (p=0.02). Patients with postoperative complications had a greater decrease in IAC volume. However, no statistically significant difference exists between postoperative complications and IAC volume reduction rate (p>0.05).

There is a statistically significant difference between IAC location and surgical technique (p<0.05). The MF technique was used four times more than the EF technique and 2.5 times more than the CPS technique at the sylvian location. In sellar locations, EF and EF + CPS techniques were preferred, EF in interhemispheric and quadrigeminal IACs, and EF + CPS techniques in intraventricular IACs. In hemispheric IACs, MF and EF techniques were mostly preferred, with the MF technique being used five times more than the EF technique. The EF technique was used 3.5 times more than the MF technique and seven times more than the CPS technique in posterior fossa IACs (Table VI).

Postoperative complications occurred in 66.7% of patients undergoing EF + CPS and 31.2% of patients undergoing MF technique. This rate decreased to 17.6% in EF patients and 9.1% in CPS patients. However, there is no statistically significant relationship between postoperative complications and surgical techniques (p>0.05).

DISCUSSION

The treatment of IACs, particularly the indication for surgery and surgical technique, is still debatable among neurosurgeons. It is important to determine the precise and correct surgical indication for a patient with IAC. There are also various surgical options for these patients, each with its own advantage and disadvantage. One option is to enlarge the cyst walls with CSF regions, whereas another is to divert cyst fluid to other body spaces (abdomen and pleura) using shunt systems. According to the surgical instruments used, fenestra-

Table V: Cyst Volume Change and Cyst Volume Reduction Rate According to Preoperative Complaints

Preoperative Complaints	Cyst Volume Change (ml)	Cyst Volume Reduction Rate (%)
Headache (n=21)	90.94 ± 29.66 (15.00- 624.96)	40.24 ± 4.15 (15.21-87.60)
Cranial deformity (n=8)	115.42 ± 15.68*ǂ (26.44-158.28)	45.37 ± 7.80 (17.82-91.82)
Imbalance (n=9)	28.93 ± 6.48ǂ (9.28-74.59)	41.17 ± 4.56 (26.21-71.52)
Fainting (n=11)	42.90 ± 8.21 (8.53-103.67)	31.14 ± 3.63 (10.87-56.06)
Neurological dysfunction (n=11)	45.27 ± 13.70* (0.39-169.00)	41.44 ± 7.29 (1.37-82.43)
Other (n=6)	76.71 ± 24.81 (24.11-188.06)	51.36 ± 6.43 (28.48-67.52)
p	**0.005**	0.207

Data are expressed as mean ± SH (minimum-maximum value).
*Kruskal-Wallis H test, post-hoc Bonferroni correction, ***:** p<0.05, **ǂ:** p<0.01.*

Table VI: The Relationship Between Cyst Location and Surgical Technique

Surgical Technique	Sylvian	Sellar	Cerebral Convexity	Posterior Fossa	Interhemispheric	Quadrigeminal	Intraventricular	p
MF	25 (56.8%)	-	5 (83.3%)	2 (20.0%)	-	-	-	**0.000**
EF	6 (13.6%)	1 (33.3%)	1 (16.7%)	7 (70.0%)	1 (100%)	1 (100%)	-	
CPS	10 (22.7%)	-	-	1 (10.0%)	-	-	-	
EF+ CPS	3 (6.8%)	2 (66.7%)	-	-	-	-	1 (100%)	

*Data are expressed as number and ratio (%). Pearson Chi-Square test. **CPS:** Cystoperitoneal shunt, **EF:** Endoscopic fenestration, **EF+ CPS:** Endoscopic fenestration with cystoperitoneal shunt, **MF:** Microsurgical fenestration.*

tion techniques are now classified as microsurgical and endoscopic.

Complications are possible with surgical treatment of IACs, and some patients require multiple surgeries to manage complications. Therefore, strict criteria for surgical indication should be established (13). Most studies recommend surgical treatment for symptomatic IACs (7,11). Although these cysts are mostly asymptomatic, surgical treatment is recommended in some studies for radiologically large IACs even if the patient is asymptomatic (8,12). Another option for asymptomatic large IACs is follow-up. Common non-specific symptoms of IACs, such as headache and dizziness, were evaluated to rule out other intracranial lesions that could be causing these symptoms. Clinical and radiological manifestations of increased ICP and hydrocephalus may be observed in IACs, particularly when the cyst enlarges or bleeds. The most common sign of increased ICP is papilledema.

The size of an IAC is important, and various methods are used to evaluate its size in IACs. The first method is to measure the diameter of the IAC at its widest point (18). Choi et al. (8) measured the diameter of the IAC in 75 patients who had the largest IAC diameter. They defined a preoperative reduction in cyst diameter of more than 25% as a decrease, an enlargement of more than 25% as an increase, and a change in IAC volume of less than 25% as no change. Another method is to divide the sum of the largest diameters measured in all three axes (axial, sagittal, and coronal) by half (14). The volume of the cyst is calculated using a three-dimensional model of the cyst created in this method (16,33).

In the treatment of IACs, different surgical techniques, such as MF, EF, and CPS, can be used (6,7,10,11,20,35). The best and most effective surgical procedure among these options has yet to be determined (9,27,38,39). Each has its own advantages and disadvantages (4,19,22). In our series, we used MF, EF, CPS, and EF + CPS techniques.

The improvement of clinical and radiological symptoms is considered in determining the surgical technique's effectiveness (9,15,19,28). Clinical improvement was defined

in most studies as the improvement or regression of at least one symptom (15,28). Despite the use of different surgical techniques, clinical improvement was reported in all studies (1,7,19,31). Radiological regression and cyst size reduction are accepted as signs of radiological improvement. There are different radiological recovery parameters in the literature, such as a reduction of 10 cm^3 in cyst volume or a volume change of 10%, 15%, or 50% (5,16,21,33). Although cyst size decreases with every surgical technique, it has been most commonly reported after CPS placement (14,19). Studies have not found a relationship between cyst size reduction and clinical improvement in patients (17,23,28). In our series, regardless of surgical method, complete recovery or significant reduction of clinical symptoms was mostly observed. Neurological examination confirmed clinical recovery. One patient's clinical symptoms and neurological examination did not change. There was no increase in clinical symptoms in any of the patients. In our study, except for two patients, the change in IAC volume and rate resulted in radiological improvement. One of these two patients had to have revision surgery. Although the EF + CPS method achieved the highest volume reduction and volume change ratio, it was not statistically significant. Although the MF and CPS methods reduced volume more than the EF method, the volume change rates were similar. The amount of volume reduction was greatest in IACs located in the sylvian region and least in IACs located in the posterior fossa. Other locations experienced similar volume changes. There was no correlation found between radiological recovery and clinical improvement.

Short-term postoperative complications include CSF leakage and related subgaleal collection, meningitis, subdural hygroma, subdural hematoma, intraparenchymal hematoma, focal neurological deficit, cranial nerve paralysis, and wound problems (7,19,30). These complications are more common in the MF technique (19,24,28,30). Long-term postoperative complications include cyst recurrence/regrowth, shunt infection, dysfunction, and failure (9,19,29). These complications are more common in the CPS technique than in others (19,28). In our study, we found more short-term postoperative complications after MF than in other methods, but less revision surgery was required.

Hall et al. examined 82 patients who had undergone MF, EF, or CPS and compared radiological results in 62 patients. In terms of clinical improvement, cyst volume change, and postoperative complications, there was no statistically significant difference between surgical methods. In symptomatic patients, there was no correlation between IAC volume reduction and symptom relief (17). Tamimi et al. studied 20 patients who received MF treatment. They found no correlation between the rate of volume reduction and clinical symptom improvement (36). Wang et al. evaluated 63 patients who had MF, EF, or CPS and found a significant relationship between cyst volume change and cyst location after surgery (37). Pitsika and Sgrous reported that the cyst volume remained stable after the fastest decrease in cyst volume was observed between 3 and 6 months postoperatively in four patients operated with the EF method (32). Rabiei et al. studied 27 pediatric patients who had MF or EF. They stated that the amount of cyst volume change was not associated with clinical improvement, and they emphasized the importance of surgical indication due to the high complication and recurrent surgery rate (34). In a meta-analysis study for sylvian-located IACs who had undergone MF, EF, or CPS surgery, Chen et al. defined efficacy parameters as symptom resolution rate and cyst volume reduction and safety parameters as short-term and long-term complications. In terms of clinical symptom improvement rate, there was no statistically significant difference between surgical techniques. CPS surgery had the highest rate of cyst reduction. In both short-term and long-term complications, EF has been found to be the safest method (7).

CONCLUSION

The primary goals of IAC surgery are to improve clinical symptoms and reduce cyst volume. The first surgical option should be cyst fenestration after measuring the change in cyst size with three-dimensional modeling software. MF can achieve better volumetric reduction, especially in patients with sylvian arachnoid cysts. However, more volumetric reduction increases the risk of postoperative complications.

AUTHORSHIP CONTRIBUTION

Study conception and design: ŞK
Data collection: ŞK, AD
Analysis and interpretation of results: ŞK, SK
Draft manuscript preparation: ŞK, SYS
Critical revision of the article: ŞK, OT
All authors (ŞK, AD, SK, SYS, OT) reviewed the results and approved the final version of the manuscript.

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