Frontolateral Approach Applied to Sellar Region Lesions: A Retrospective Study in 79 Patients

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Abstract

Background: Various surgical approaches for the removal of sellar region lesions have previously been described. This study aimed to evaluate the reliability and safety of the frontolateral approach (FLA) to remove sellar region lesions.
Methods: We presented a retrospective study of 79 patients with sellar region lesions who were admitted and operated by the FLA approach from August 2011 to August 2015 in Department of Neurosurgery of Beijing Tian Tan Hospital. We classified FLA into three types, compared the FLA types to the areas of lesion invasion, and analyzed operation bleeding volume, gross total resection (GTR) rate, visual outcome, and mortality.
Results: Seventy-nine patients were followed up from 2.9 to 50.3 months with a mean follow-up of 20.5 months. There were 42 cases of meningiomas, 25 cases of craniopharyngiomas, and 12 cases of pituitary adenomas. The mean follow-up Karnofsky Performance Scale was 90.4. GTR was achieved in 75 patients (94.9%). Two patients (2.5%) had tumor recurrence. No patients died perioperatively or during short-term follow-up. Three patients (3.8%) with craniopharyngioma died 10, 12, and 23 months, respectively, after surgery. The operative bleeding volume of this study was no more than that of the other approaches in the sellar region (P = 0.783). In this study, 35 patients (44.3%) had visual improvement after surgery, 38 patients (48.1%) remained unchanged, and three patients' visual outcome (3.8%) worsened.
Conclusions: FLA was an effective approach in the treatment of sellar region lesions with good preservation of visual function. FLA classification enabled tailored craniotomies for each patient according to the anatomic site of tumor invasion. This study found that FLA had similar outcomes to other surgical approaches of sellar region lesions.

Key words: Craniopharyngioma; Meningioma; Neurosurgery Procedures; Pituitary Neoplasms; Skull Base

Introduction

Sellar region lesions are deeply seated and are in close proximity to neurovascular structures of the anterior skull base, such as the optic nerve, optic chiasm, pituitary stalk, and hypothalamus. Mass effect and compression of these structures can lead to a wide variety of clinical symptoms, including visual defects, polydipsia, polyuria, acromegaly, gigantism, amenorrhea, and galactorrhea.

Resection of sellar region lesions has been a challenge for neurosurgeons for nearly a century. In 1908, Krause[1] first described the treatment of sellar region lesions by using a superior orbital subfrontal approach. Tandler and Ranzi[2] applied the same approach to superior sellar region lesions in 1920. In 1971, Wilson[3] pioneered the concept of limited exposure in cerebral surgery by minimizing any unnecessary surgical interference. Yasargil and Fox[4] further modified the frontal, lateral pterion approach of Dandy by drilling at the sphenoidal ridge in 1975. In 1978, Brock and Dietz[5] reported the first successful treatment of anterior circulation aneurysms via the small frontolateral approach (FLA). Samii[6] used the subfrontal lateral space to resect olfactory groove meningiomas. In 1999, Perneczky *et al*.[7] presented the "Keyhole" concept, and modified "frontolateral approach"

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to "frontolateral keyhole" approach. In 2008, Samii and Gerganov[8] reported the experiences of FLA applied in sellar region lesions and described it as a simple and safe approach. Moreover, Romani *et al*.[9] reported the experiences of using FLA, which was called as a lateral supraorbital approach, in 52 patients with tuberculum meningioma in 2012.

The most frequent microsurgical approaches to remove sellar region lesions are pterional, fronto-orbital and fronto-orbitozygomatic, frontolateral, and bifrontal. FLA has both features and exposure advantages of subfrontal and pterional approach, and many neurosurgeons apply this approach in sellar region lesions. In this article, we retrospectively reviewed the outcomes of 79 patients with sellar region lesions using the FLA.

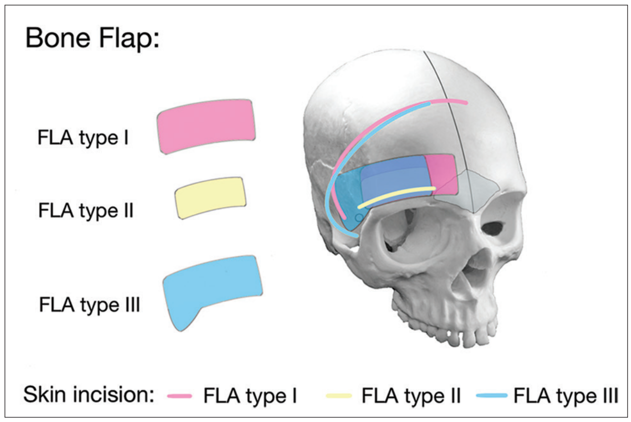

Figure 1: Skin incisions and bone flaps of FLA classified into three types. FLA: Frontolateral approach.

Methods

Data collection

One hundred and seven patients with sellar region lesions were operated by FLA in Department of Neurosurgery of Beijing Tian Tan Hospital from August 2011 to August 2015. Twenty-eight patients were lost to follow-up and a total of 79 patients were included in this study. All cases were analyzed retrospectively. Pre- and post-operative clinical conditions were expressed using the Karnofsky Performance Scale (KPS). Visual acuity and visual fields were tested by a neuro-ophthalmologist before and after surgery. Both the Goldmann and Octopus perimetry systems were used for visual field testing. Operative bleeding volume was collected from the operation records.

Radiography data

Seventy-nine patients underwent magnetic resonance imaging (MRI) before and after surgery. Forty-two patients underwent an additional computed tomography (CT) or magnetic resonance angiography because of the close relation between the lesion and major vessels including the internal carotid artery (ICA), anterior cerebral artery (ACA), middle cerebral artery (MCA), anterior communicating artery (AcomA) or cavernous sinus. The diameter of the lesion and affected structures was recorded from preoperative MRI while the extent of lesion resection was measured by comparing pre- and post-operative MRI and the surgical records. All patients underwent CT within 1 day after surgery.

Classification of the frontolateral approach

Patients were operated in a supine position with the head rotated to the contralateral side at an angle of 30°–45°. FLA was classified into three types based on the anatomic location of lesion invasion [Figure 1].

- Type I (frontal extended FLA): A Type I FLA was performed for lesions that invaded the olfactory groove, sphenoidal platinum, and the third ventricle. The upper side of the skin incision was behind the hairline 2–3 cm across the frontal middle line, while the lower side of the skin incision was 1 cm anterior to the ear screen on the upper rim of the zygomatic arch. The temporal muscle was stripped from its bony insertion and retracted laterally. A bur hole was subsequently drilled on the key point (frontozygomatic process). A bone flap measuring 4 cm × 5 cm was created with the inner edge 0.5–1.0 cm from the middle line and the outer edge 1 cm outside the supratemporal line. The opened frontal sinus was sealed, and the supraorbital nerve was preserved as possible.
- Type II (standard FLA): A Type II FLA was performed for lesions that invaded the anterior clinoid process, cavernous sinus, and the third ventricle. Mannitol 0.5 g/kg was delivered intravenously for over 20 min before incision. A skin incision was made at the upper edge of the eyebrow lateral to the supraorbital nerve and extending 3–5 mm beyond the lateral edge of the eyebrow. Following skin incision, the frontal muscle was incised and the temporal muscle was stripped from its bony insertion and retracted laterally. A burr hole was subsequently drilled on the key point (frontozygomatic process). A bone flap with a width of approximately 2.0–3.0 cm and a height of approximately 1.5–2.0 cm was created. The frontal sinus was not opened and the supraorbital nerve was preserved as possible. The inner edge of the supraorbital rim was then drilled to improve intracranial visualization and facilitate the introduction of instruments.
- Type III (temporal extended FLA): A Type III FLA was performed for lesions that invaded the greater wing of the sphenoid bone, sphenoidal ridge, anterior clinoid process, cavernous sinus, and the third ventricle. The upper side of the skin incision was behind the hairline 1–2 cm from the frontal middle line while the lower side of the skin incision was 1 cm anterior to the ear screen on the upper rim of zygomatic arch. The temporal muscle was stripped from its bony insertion and retracted laterally. Two bur holes were drilled on the key point (frontozygomatic process) and the pterion point. A bone flap measuring 4 cm × 5 cm was created with the inner edge on the supraorbital foramen and the outer edge 1 cm outside the sphenoidal ridge. The bone of the sphenoidal ridge was drilled off. The frontal sinus was not opened and the supraorbital nerve was preserved as possible.

After the bone flap was performed, the dura was opened in a C-shaped, semilunar fashion with its base toward the supraorbital rim, followed by opening of the Sylvian fissure and the carotid cisterns for cerebrospinal fluid (CSF) drainage.

Follow-up data

Short-term follow-up data were available for patients at 6 months and 1 year after surgery and included a clinical examination and MRI scan. The patients who underwent surgery <6 months received follow-up by telephone. Long-term follow-up was performed every 1–2 years thereafter and data were collected either through outpatient records or through home visits.

Statistical analysis

All descriptive and statistical analyses were performed using IBM SPSS software version 22.0 (IBM Corporation, New York, USA) and NCSS version 10 (Copyright© 1983–2016, NCSS, LLC, Utah, USA, All Rights Reserved). The FLA type and anatomic region of tumor invasion were compared by cross-tabulation through a Pearson's Chi-squared test, and age, operative bleeding volume, and tumor size were compared using Student's *t*-test. Age, operative bleeding volume, and tumor size were shown as mean ± standard deviation (SD). A $P < 0.05$ was considered statistically significant.

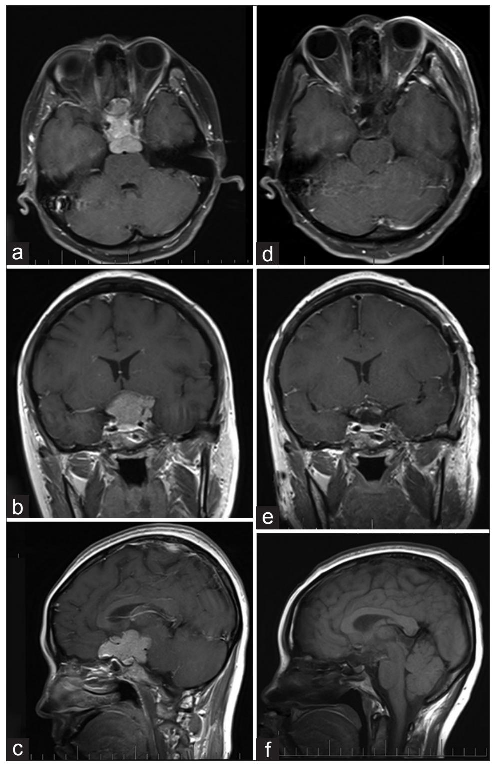

Figure 2: Tuberculum sellae meningiomas pre- and post-operative magnetic resonance imaging. (a-c) MRI with contrast before operation; (d-f) MRI with contrast after operation.

Results

Seventy-nine patients were included in this study (29 males, 50 females), with the mean age of 44.9 ± 11.7 years. Unilateral visual acuity defect was found in 16 patients, and bilateral visual acuity defect was in 35 patients. Forty-three patients had visual field defect. There were 42 cases of meningiomas, 25 craniopharyngiomas, and 12 pituitary adenomas [Figures 2–4]. Gross total resection (GTR) was achieved in 75 patients (94.9%) and STR in four patients (5.1%).

Operation

Surgical approach and characteristics of tumors

Twenty patients had undergone FLA Type I, the mean operative bleeding volume was 360.0 ± 303.8 ml: eight patients had tumor size ≤3 cm and 12 patients had tumor size >3 cm. Tumors invaded the greater wing of the sphenoid bone in one case, anterior clinoidal process in one case, olfactory groove or sphenoidal platinum in ten cases, cavernous sinus in two cases, and the third ventricle in eight cases. There were 11 cases of meningioma, four cases of craniopharyngioma, and five cases of pituitary adenomas. GTR was achieved in 19 patients. One patient with pituitary adenoma received subtotal resection (STR) because of tumor invasion of the cavernous sinus.

Twenty-six patients had undergone FLA Type II, the mean operative bleeding volume was 292.9 ± 217.1 ml: 16 patients had tumor size ≤3 cm and ten patients had tumor size >3 cm. Tumors invaded the greater wing of sphenoid bone in one case, anterior clinoidal process in ten cases, olfactory groove or sphenoidal platinum in eight cases, cavernous sinus in three cases, and the third ventricle in three cases. There were 13 cases of meningioma, ten cases of craniopharyngioma, and three cases of pituitary adenoma. GTR was achieved in 25 patients. One meningioma patient received STR because of the tumor invasion of the cavernous sinus.

Thirty-three patients had undergone FLA Type III, the mean operative bleeding volume was 475.0 ± 148.1 ml: 16 patients had tumor size ≤3 cm and 17 patients had tumor size >3 cm. Tumor invaded the greater wing of sphenoid bone in 12 cases, anterior clinoidal process in ten cases, cavernous sinus in 14 cases, and the third ventricle in ten cases. About 18 cases were meningioma, 11 cases were craniopharyngioma, and four cases were pituitary adenoma. GTR was achieved in 31 patients. Two patients received STR: one meningioma patient with tumor invasion of the cavernous sinus and anterior clinoidal process and one pituitary adenoma patient with tumor invasion of the cavernous sinus.

The FLA type and region of tumor invasion were compared through cross-tabulation by Pearson's Chi-squared test. In the first analysis, five regions (greater wing of the sphenoid bone, anterior clinoidal process, olfactory groove or sphenoidal platinum, cavernous sinus, and third ventricle) were compared to FLA type. A *P* value, $P_1 = 0.000$, was achieved but five cells (33.3%) have expected count <5 wherein the minimum expected count was 3.11 (Chi-square value: 28.980). In the second analysis, the greater wing

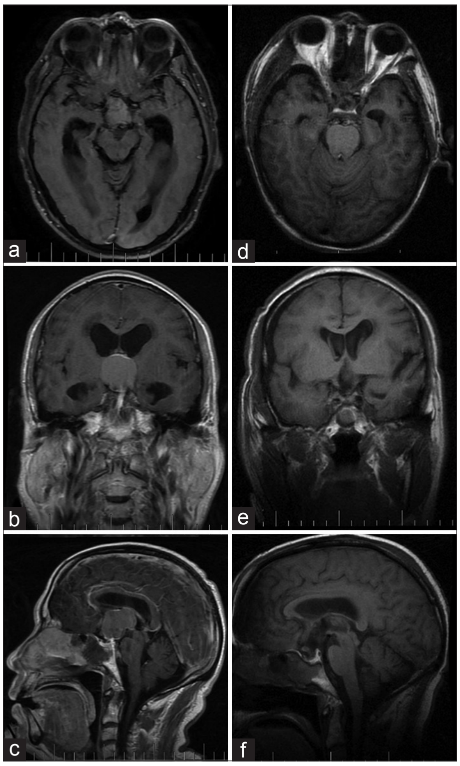

Figure 3: Craniopharyngioma pre- and post-operative magnetic resonance imaging. (a-c) MRI with contrast before operation; (d-f) MRI with contrast after operation.

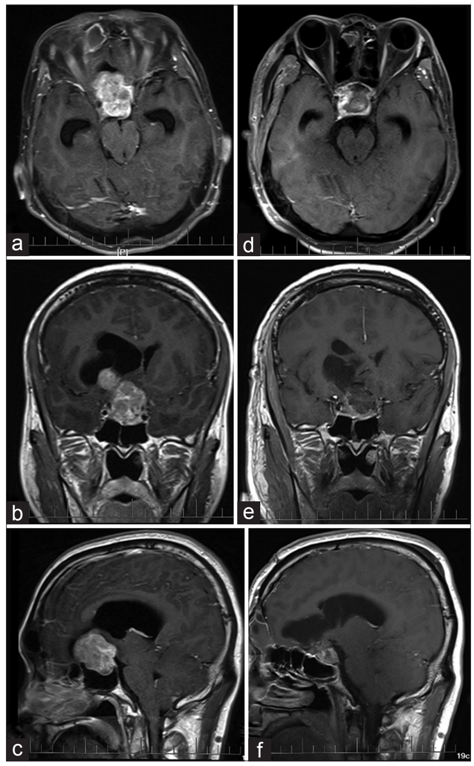

Figure 4: Pituitary adenoma pre- and post-operative magnetic resonance imaging. (a-c) MRI with contrast before operation; (d-f) MRI with contrast after operation.

of the sphenoid bone and anterior clinoidal process were merged as one region for analysis. The resulting of four regions was compared to FLA type. A *P* value, $P_2 = 0.002$, was achieved and two cells (16.7%) have expected counts <5 wherein the minimum expected count was 4.44 (Chi-square value: 21.352). The result showed FLA Types I, II, and III had significant differences in the regions of tumor invasion.

Operative bleeding volume

In the study by Zhang *et al.*[10] (as control group), the average operative bleeding volume of thirty patients was 375.0 ml. The mean operative bleeding volume in this group was 389.9 ± 289.9 ml [Table 1]. There were no significant differences for gender, age, tumor size, and patient numbers achieved GTR between our study and Zhang *et al.*'s study (all $P > 0.05$). The operative bleeding volume of this study was no more than that of Zhang *et al.*'s study ($P = 0.783$).

Table 1: Demographic characteristics and operative bleeding volumes of patients in this study and Zhang *et al*'s study

Items	Patients in this study (*n* = 79)	Patients in Zhang *et al.*'s study (*n* = 30)	Statistical values	*P*
Gender (male/female), *n*	29/50	16/14	2.479*	0.115
Age (years), mean ± SD	44.9 ± 11.7	41.9 ± 9.3	1.260†	0.210
Tumor size (cm), mean ± SD	3.32 ± 1.26	3.50 ± 0.75	–0.733†	0.465
Patients achieved GTR, *n*	75	28	0.107*	0.743
Operative bleeding volume (ml), mean ± SD	389.9 ± 289.9	375.0 ± 92.6	0.276†	0.783

*Chi-square values; †*t* values. SD: Standard deviation; GTR: Gross total resection.

Follow-up

Seventy-nine patients were followed up from 2.9 to 50.3 months with a median follow-up of 20.5 months. Among the 79 patients, 64 patients (81.0%) had a normal life (KPS: 90–100), 12 (15.2%) had moderate disabilities (KPS: 60–80), and 3 (3.8%) were dead (KPS: 0). The median follow-up KPS was 90.4. Shallow postoperative forehead wrinkles were present in two cases that underwent FLA Type II. One case undergoing FLA Type II had transient CSF leakage immediately after operation because of a large frontal sinus, which was subsequently resolved after 10 days of continuous lumbar drainage. One patient with pituitary adenoma, who underwent FLA Type I, suffered a skin infection caused by an obstructive frontal sinus mucocele 38 months after surgery. One patient with meningioma who received FLA Type III had temporalis atrophy. Four patients with craniopharyngioma (1 in FLA Type II and 3 in FLA Type III) had polydipsia and polyuria, which resolved 7 months after surgery in one patient, and remained in three patients at follow-ups of 21, 26, and 27 months after surgery, respectively. One meningioma patient undergoing FLA Type III had an episode of epilepsy 20 months after surgery. One patient undergoing FLA Type II lost olfactory function on the operative side, which did not recover 20 months after surgery.

Tumor recurrences were found in two patients: one patient with tuberculum sellae meningioma recurred 34 months after surgery and underwent the operation again; and another patient with craniopharyngioma recurred 20 months after surgery and received radiation therapy. The other two patients received radiotherapy after surgery, and no recurrence was found during follow-up.

No patient died perioperatively or during short-term follow-up (<6 months). Three patients (3.8%) with craniopharyngioma died from severe hypopituitarism 10, 12, and 23 months after surgery, respectively.

In this study, 35 patients (44.3%) had visual improvement after surgery, 38 patients (48.1%) remained unchanged, and three patients' visual outcome (3.8%) worsened.

Discussion

In this study, FLAs were performed on sellar region lesions. According to the different anatomic region of tumor invasion, we classified FLA into three types. FLA Types I, II, and III had significant differences in tumor invaded areas. We were able to tailor the procedure to each patient according to the specific anatomic location of tumor invasion. FLA was more powerful in tran-orbital-cranial lesions and more flexible combined with other approaches. In the research of Maier *et al.*[11] and Adawi and Abdelbaky,[12] the FLA were also suitable for tumors of the posterior orbit. Yamada *et al*.[13] also reported the combination of an orbitozygomatic approach and Le Fort I osteotomy under frontolateral craniotomy in the treatment of a large juvenile nasopharyngeal angiofibroma in an 8-year-old boy. In the report of Gerganov *et al*.,[14] they focused on the feasibility and efficacy of microsurgical resection of extensive craniopharyngiomas using an FLA. Metwali *et al*.[15] introduced the surgical technique of medial optic nerve mobilization for better inspection and preservation of the pituitary stalk via an FLA.

The median operative bleeding volume of this study showed no more than the subfrontal approach. Only one patient in this study had the operative bleeding volume of 2000 ml. The meningioma of this patient was larger than 3 cm (6.5 cm in diameter) and invaded the anterior clinoid process and the bottom of the third ventricle. Ipsilateral ACA and AcomA were encased. The FLA Type III was applied in this patient, with the intent to gain more exposure of the Sylvian fissure. However, bleeding from the AcomA was difficult to coagulate because of the poor exposure from the cerebral longitudinal fissure.

Among the 79 patients, the median follow-up KPS was 90.4. Forehead wrinkles were shallow postoperatively in two patients who received FLA Type II, and the superior orbital nerve was bruised during the formation of the bone flap from the high-speed milling tool in the early stage of this group. From prior studies, CSF leakage ranged from 4% to 33%.[16-21] In this study, only one patient with FLA Type II had transient CSF leakage after operation because of a large frontal sinus, which was resolved after 10 days of continuous lumbar drainage.

One patient with pituitary adenoma in the FLA Type I group suffered skin infection caused by an obstructive frontal sinus mucocele 38 months after surgery. In FLA Type, I or Type II with large frontal sinuses, the treatment of the opened frontal sinus was difficult. In this study, we tried the following methods to decrease the CSF leakage and infection rate: first, the hard dura was sutured in a water-tight manner; second, the mucosa of the frontal sinus had to be completely removed and the smashed temporalis muscle was used to fill the sinus cavity; finally, a galea aponeurotica-pericranium flap with an intact blood supply was used to seal the opening of the sinus cavity.

In FLA Type III, the incision and retraction of the temporalis muscle were still larger than those in Types I and II. One patient with meningioma receiving FLA Type III had temporalis atrophy in the early stage. The overdose coagulation with mono-polar or bipolar on temporalis muscle and the decreased blood supply were the main reasons for temporalis atrophy.

Three patients (3.8%) with craniopharyngioma remained polydipsic and polyuric at follow-up, which was similar to the results of Shi *et al*.'s study.[22] In Shi *et al*.'s study, two patients out of 110 craniopharyngioma cases (1.8%) still presented with polydipsia and polyuria 2 years after surgery. The incidences of postoperative epilepsy after tuberculum sellae meningiomas (TSM) surgery in the literature ranges from 2% to 11%.[16,19,23] In this study, only one patient with meningioma had a single episode of epilepsy at 20 months after surgery, the incidence rate was 1.3%, which was lower than previously reported.

Tumor recurrence was found in two patients with one tuberculum sellae meningioma and one craniopharyngioma, respectively. In previous literature,[24-29] the recurrence rate of craniopharyngiomas was from 9.3% to 41%, while the recurrence rate in this study was only 4.0% (1/25). The recurrence rates of meningioma previously reported were from 0 to 20% and it was 2.4% (1/42) in this study.[30-34]

In the literatures,[29-33,35] the mortality of craniopharyngioma was reported from 0 to 16.7%. In this study, the mortality of craniopharyngioma was 12% (3/25), and all three patients died from severe hypopituitarism during follow-up. All of them were living in other provinces outside of Beijing, and their situations were changing rapidly. If they were received hormone replacement therapy in time, their prognosis might be better.

The visual deterioration rate in this study was significantly lower than previously reported, and this might be attributed to good exposure of the optic nerve, anterior clinoidal process, and carotid artery of the FLA. In the report of

Chokyu *et al.*,[36] 29 (90.6%) of 32 patients showed improved visual outcomes after TSM operations. However, the visual improvement rate in this study was 44.3% (35/79), the reasons might be due to the different timing of operation and tumor size.

The GTR rate and visual deterioration rate varied from 71% to 100% and 0% to 20%, respectively, in previous literature, and in this study, GTR was achieved in 75 patients (94.9%) and visual deterioration rate was 3.8%. The mortality was 3.8% in this study, similar to previously reported.[37-44] Because of potential differences in patient age, tumor size, and different pathological component distribution of each report, we could not confirm FLA was better, which need further study in the future to confirm it. However, at least FLA was comparable with other approaches of sellar region lesions.

In conclusion, we found that FLA was a safe and effective approach for the treatment of sellar region lesions with good preservation of visual function. We were able to tailor the procedure to each patient according to the specific anatomic location of tumor invasion. This study found that FLA had similar outcome to other surgical approaches of sellar region lesions.

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Conflicts of interest

There are no conflicts of interest.

References

1. Krause F. Surgery of the brain and spinal cord. 1st ed. Berlin: Urban & Schwarzenberg; 1908.
2. Tandler J, Ranzi E. Surgical anatomy and operation technology of the central nervous system. 1st ed. Berlin: Springer; 1920.
3. Wilson DH. Limited exposure in cerebral surgery. Technical note. J Neurosurg 1971;34:102-6. doi: 10.3171/jns.1971.34.1.0102.
4. Yasargil MG, Fox JL. The microsurgical approach to intracranial aneurysms. Surg Neurol 1975;3:7-14.
5. Brock M, Dietz H. The small frontolateral approach for the microsurgical treatment of intracranial aneurysms. Neurochirurgia (Stuttg) 1978;21:185-91. doi: 10.1055/s-0028-1090343.
6. Samii M. In: Surgery of the Skull Base: Meningiomas. 1st ed. Berlin: Springer; 1992.
7. Perneczky A, MI-FW, van Lindert E, Fries G. Keyhole Concept in Neurosurgery. 1st ed. Stuttgart: Thieme Medical Publishers; 1999.
8. Samii M, Gerganov VM. Surgery of extra-axial tumors of the cerebral base. Neurosurgery 2008;62 6 Suppl 3:1153-66. doi: 10.1227/01.neu.0000333782.
9. Romani R, Laakso A, Kangasniemi M, Niemelä M, Hernesniemi J. Lateral supraorbital approach applied to tuberculum sellae meningiomas: Experience with 52 consecutive patients. Neurosurgery 2012;70:1504-18. doi: 10.1227/NEU.0b013e31824a36e8.
10. Zhang M, Qi W, Zhang W, Wang L, Wang R. Surgical experience with supraorbital frontolateral Keyhole approach for tumors of the anterior skull base and sellae region (in Chinese). Bull Med Res 2004;12:6-8.
11. Maier W, Ridder GJ, Kaminsky J, Grosu AL. Therapy of posterior orbital tumors. Ophthalmologe 2011;108:531-9. doi: 10.1007/s00347-010-2192-x.
12. Adawi MM, Abdelbaky AM. Validity of the lateral supraorbital approach as a minimally invasive corridor for orbital lesions. World Neurosurg 2015;84:766-71. doi: 10.1016/j.wneu.2015.04.058.
13. Yamada M, Tsunoda A, Hagino K, Aoyagi M, Kawano Y, Yano T, *et al.* Surgical management of large juvenile nasopharyngeal angiofibroma invading the infratemporal fossa with intracranial extradural parasellar involvement in an 8-year-old boy. Auris Nasus Larynx 2012;39:341-4. doi: 10.1016/j.anl.2011.07.017.
14. Gerganov V, Metwali H, Samii A, Fahlbusch R, Samii M. Microsurgical resection of extensive craniopharyngiomas using a frontolateral approach: Operative technique and outcome. J Neurosurg 2014;120:559-70. doi: 10.3171/2013.9.JNS122133.
15. Metwali H, Gerganov V, Fahlbusch R. Optic nerve mobilization to enhance the exposure of the pituitary stalk during craniopharyngioma resection: Early experience. J Neurosurg 2015;18:1-6. doi: 10.3171/2015.6.jns141847.
16. Schick U, Hassler W. Surgical management of tuberculum sellae meningiomas: Involvement of the optic canal and visual outcome. J Neurol Neurosurg Psychiatry 2005;76:977-83. doi: 10.1136/jnnp.2004.039974.
17. Nakamura M, Roser F, Struck M, Vorkapic P, Samii M. Tuberculum sellae meningiomas: Clinical outcome considering different surgical approaches. Neurosurgery 2006;59:1019-28. doi: 10.1227/01.NEU.0000245600.92322.06.
18. Jennett B, Bond M. Assessment of outcome after severe brain damage. Lancet 1975;1:480-4. doi: 10.1016/S0140-6736(75)92830-5.
19. Symon L, Rosenstein J. Surgical management of suprasellar meningioma. Part 1: The influence of tumor size, duration of symptoms, and microsurgery on surgical outcome in 101 consecutive cases. J Neurosurg 1984;61:633-41. doi: 10.3171/jns.1984.61.4.0633.
20. Arai H, Sato K, Okuda, Miyajima M, Hishii M, Nakanishi H, *et al.* Transcranial transsphenoidal approach for tuberculum sellae meningiomas. Acta Neurochir (Wien) 2000;142:751-6. doi: 10.1007/s007010070089.
21. Terasaka S, Asaoka K, Kobayashi H, Yamaguchi S. Anterior interhemispheric approach for tuberculum sellae meningioma. Neurosurgery 2011;68 1 Suppl:84-8. doi: 10.1227/NEU.0b013e31820781e1.
22. Shi XE, Wang Z. Experience in surgical treatment of 110 patients with craniopharyngiomas (in Chinese). Chin J Surg 2001;39:608-10.
23. Solero CL, Giombini S, Morello G. Suprasellar and olfactory meningiomas. Report on a series of 153 personal cases. Acta Neurochir (Wien) 1983;67:181-94. doi: 10.1007/BF01401420.
24. De Vile CJ, Grant DB, Kendall BE, Neville BG, Stanhope R, Watkins KE, *et al.* Management of childhood craniopharyngioma: Can the morbidity of radical surgery be predicted? J Neurosurg 1996;85:73-81. doi: 10.3171/jns.1996.85.1.0073.
25. Hofmann BM, Höllig A, Strauss C, Buslei R, Buchfelder M, Fahlbusch R. Results after treatment of craniopharyngiomas: Further experiences with 73 patients since 1997. J Neurosurg 2012;116:373-84. doi: 10.3171/2011.6.JNS081451.
26. Maira G, Anile C, Albanese A, Cabezas D, Pardi F, Vignati A. The role of transsphenoidal surgery in the treatment of craniopharyngiomas. J Neurosurg 2004;100:445-51. doi: 10.3171/jns.2004.100.3.0445.
27. Thompson D, Phipps K, Hayward R. Craniopharyngioma in childhood: Our evidence-based approach to management. Childs Nerv Syst 2005;21:660-8. doi: 10.1007/s00381-005-1210-9.
28. Zhang YQ, Ma ZY, Wu ZB, Luo SQ, Wang ZC. Radical resection of 202 pediatric craniopharyngiomas with special reference to the surgical approaches and hypothalamic protection. Pediatr Neurosurg 2008;44:435-43. doi: 10.1159/000172965.
29. Lee EJ, Cho YH, Hong SH, Kim JH, Kim CJ. Is the complete resection of craniopharyngiomas in adults feasible considering both the oncologic and functional outcomes? J Korean Neurosurg Soc 2015;58:432-41. doi: 10.3340/jkns.2015.58.5.432.
30. Pamir MN, Ozduman K, Belirgen M, Kilic T, Ozek MM. Outcome determinants of pterional surgery for tuberculum sellae meningiomas. Acta Neurochir (Wien) 2005;147:1121-30. doi: 10.1007/s00701-005-0625-0.
31. Mathiesen T, Kihlström L. Visual outcome of tuberculum sellae meningiomas after extradural optic nerve decompression. Neurosurgery 2006;59:570-6. doi: 10.1227/01.NEU.0000228683.79123.F9.
32. Yasargil MG. Microneurosurgery. Stuttgart, Germany: Thieme Verlag; 1996.

33. Sade B, Lee JH. High incidence of optic canal involvement in tuberculum sellae meningiomas: Rationale for aggressive skull base approach. Surg Neurol 2009;72:118-23. doi: 10.1016/j.surneu.2008.08.007.
34. Nozaki K, Kikuta K, Takagi Y, Mineharu Y, Takahashi JA, Hashimoto N. Effect of early optic canal unroofing on the outcome of visual functions in surgery for meningiomas of the tuberculum sellae and planum sphenoidale. Neurosurgery 2008;62:839-44. doi: 10.1227/01.neu.0000318169.75095.cb.
35. Yasargil MG, Curcic M, Kis M, Siegenthaler G, Teddy PJ, Roth P. Total removal of craniopharyngiomas. Approaches and long-term results in 144 patients. J Neurosurg 1990;73:3-11. doi: 10.3171/jns.1990.73.1.0003.
36. Chokyu I, Goto T, Ishibashi K, Nagata T, Ohata K. Bilateral subfrontal approach for tuberculum sellae meningiomas in long-term postoperative visual outcome. J Neurosurg 2011;115:802-10. doi: 10.3171/2011.5.JNS101812.
37. Goel A, Muzumdar D, Desai KI. Tuberculum sellae meningioma: A report on management on the basis of a surgical experience with 70 patients. Neurosurgery 2002;51:1358-63. doi: 10.1097/00006123-200212000-00005.
38. Jallo GI, Benjamin V. Tuberculum sellae meningiomas: Microsurgical anatomy and surgical technique. Neurosurgery 2002;51:1432-39. doi: 10.1097/00006123-200212000-00013.
39. Bassiouni H, Asgari S, Stolke D. Tuberculum sellae meningiomas: Functional outcome in a consecutive series treated microsurgically. Surg Neurol 2006;66:37-44. doi: 10.1016/j.surneu.2005.11.059.
40. Otani N, Muroi C, Yano H, Khan N, Pangalu A, Yonekawa Y. Surgical management of tuberculum sellae meningioma: Role of selective extradural anterior clinoidectomy. Br J Neurosurg 2006;20:129-38. doi: 10.1080/02688690600776747.
41. Park CK, Jung HW, Yang SY, Seol HJ, Paek SH, Kim DG. Surgically treated tuberculum sellae and diaphragm sellae meningiomas: The importance of short-term visual outcome. Neurosurgery 2006;59:238-43. doi: 10.1227/01.NEU.0000223341.08402.C5.
42. Jia W, Liu L, Jiang Z, Guo E, He X, Zong Z, *et al*. Tuberculum sellar operation by frontolateral approach (32 cases report) (in Chinese). Chin J Neurosurg 2010;5:448-50. doi: 10.3760/cma.j.issn.1001-2346.2010.05.023.
43. Fahlbusch R, Schott W. Pterional surgery of meningiomas of the tuberculum sellae and planum sphenoidale: Surgical results with special consideration of ophthalmological and endocrinological outcomes. J Neurosurg 2002;96:235-43. doi: 10.3171/jns.2002.96.2.0235.
44. Czirják S, Szeifert GT. Surgical experience with frontolateral keyhole craniotomy through a superciliary skin incision. Neurosurgery 2001;48:145-9. doi: 10.1097/00006123-200101000-00025.