Endoscopic endonasal versus transcranial approaches for trigeminal schwannomas: choosing the optimal surgical corridor based on tumour traits

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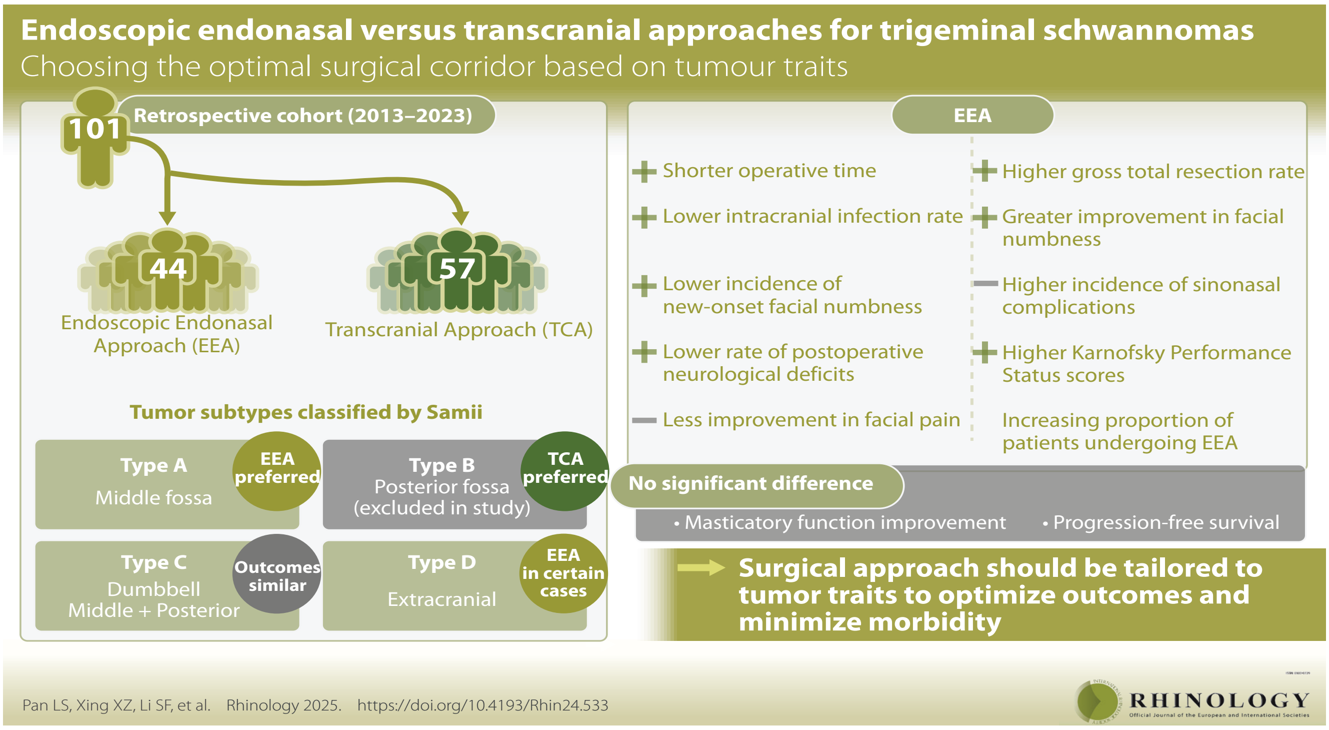

Abstract

Background: Two primary surgical approaches, the transcranial approach (TCA) and the endoscopic endonasal approach (EEA), offer distinct advantages and disadvantages, but studies have yet to compare their outcomes for trigeminal schwannoma (TS) resection systematically. **Methodology**: A retrospective review of TSs between 2013 and 2023 was performed, with clinical characteristics, surgical outcomes, and follow-up data collected and analyzed. The patients were divided into two surgical groups, and tumours within each group were further classified according to the Samii system into middle fossa (type A), dumbbell-shaped involving middle and posterior fossae (type C), and extracranial with intracranial extension (type D), excluding posterior fossa (type B). **Results**: A total of 101 patients (44 via EEA, 57 via TCA) were included. The two groups exhibited comparable baseline characteristics, except for the prevalence of dizziness in the pooled data (types A, C, and D). In pooled data and type A tumours, the EEA was associated with a statistically significant differences in higher gross total resection rate, shorter operative time, lower intracranial infection rate, and greater improvement in facial numbness. EEA was also significantly associated with a lower neurological deficits and higher Karnofsky Performance Scale scores in pooled data. Both approaches resulted in similar outcomes for type C tumours. EEA was advantageous for type D tumours in the infratemporal fossa, pterygopalatine fossa, and medial orbital regions, and no neurological deficits were observed. **Conclusions**: The optimal outcome of the surgical approach and minimization of morbidity for these complicated lesions depend on the meticulous selection of cases.

Key words: Trigeminal schwannoma, skull base surgery, endonasal, endoscopic, craniotomy

Introduction

Trigeminal schwannomas (TSs) originate from Schwann cells and are the most common skull base nonvestibular schwannomas [1]. Nevertheless, they are still relatively rare, accounting for < 0.5% of all intracranial neoplasms [2,3]. TSs can occur anywhere along the nerve, and these tumours grow alone or in combination into the extradural (orbital, pterygopalatine, and infratemporal fossa), interdural (Meckel's cave), or intradural (cerebellopontine angle) regions through different anatomical planes [4-6]. Owing to their intimate involvement with adjacent neurovascular structures, removing these lesions can carry considerable risks of morbidity. However, surgical resection is still the first-line therapy and provides the best chance of oncological cure [7-9]. Traditionally, the transcranial approach (TCA) has been used to remove lesions, but this may require partial brain retraction, which may cause contusions, edema, or venous compromise [6]. In addition, the limited field of view under the microscope cannot reveal the relationship between deep lesions and neurovascular structures well, which may result in approach-related morbidity and residual tumours [10,11]. Recently, the endoscopic endonasal approach (EEA) has emerged as an alternative that avoids the need for brain retraction and allows for close visualization and better illumination by providing a more direct path to the tumour, but it is limited by the TS being located mainly in the posterior cranial fossa [12,13].

Even though both have advantages and are advocates, there is no distinct consensus regarding the superiority of one approach over the other. To address this issue, the most straightforward strategy would entail conducting a comparative analysis of surgical outcomes between the two approaches. However, no study has systematically compared the outcomes of different surgical approaches for TSs. Therefore, in this study, we evaluated the outcomes of the TCA and EEA to provide more compelling evidence regarding the optimal approach for individual patients. To our knowledge, the present study is the first original study to systematically compare the therapeutic outcomes of EEA versus TCA for TS resection.

Materials and methods

Patients who were treated with only the EEA or open TCA between 2013 and 2023 were reviewed. We retrospectively analyzed these patients' clinical data, surgical videos, radiological images and follow-up records. All cases were histologically confirmed as TSs with a minimum follow-up of 6 months. This study excluded patients who had undergone surgical treatment or radiotherapy, in addition to patients with multifocal TS and neurofibromatosis. Type B TSs were also excluded because EEA is not applicable to the posterior fossa, making it impossible to compare the results of the surgical approach in this type. The data were collected at three time points: before surgery and one day and 6 months after surgery. The criteria for intracranial infection refer to the recommendations of the Neurosurgery Branch of the Chinese Medical Association, including etiological and clinical diagnosis [14]. The clinical diagnostic criteria must meet the infection indicators of cerebrospinal fluid (CSF) examination, clinical manifestations, imaging examinations and blood tests. The study was approved by the Nanchang University Institutional Review Board.

Radiological investigation

The patients were separated into 2 surgical groups (EEA and TCA) and then arranged into 3 subtypes depending on their radiological characteristics. Tumours were classified following the method outlined by Samii et al. into 4 types: Type A, predominantly in the middle fossa; Type B, predominantly in the posterior fossa; Type C, a dumbbell-shaped tumour in the middle and posterior fossa; and Type D, an extracranial tumour with intracranial extension [15]. The maximum diameter on the axial image was recorded as the tumour size. The consistency of the tumour was classified as solid, cystic, or mixed. Two reviewers assessed the images in a blinded manner. A third party was responsible for making the final decision in the case of conflicting results. MRI was conducted on all patients both before and after surgery. Postoperative imaging and an intraoperative view were used to ascertain the extent of resection (EOR). Gross total resection (GTR), subtotal resection (STR), and partial resection (PR) indicated complete tumor resection, 90%–99% resection, and less than 90% resection, respectively.

Surgical approaches

According to the tumour location, we have previously described four endoscopic endonasal subapproaches to remove TSs, namely, endoscopic endonasal trans-Meckel's cave (type A and type C without a "waist" sign), transclival (type C with a "waist" sign), trans-lamina papyracea (type D: medial orbital region) and trans-prelacrimal recess approaches (type D: pterygopalatine and infratemporal fossa) [12]. Only the trans-prelacrimal recess approach used the nasolacrimal duct-inferior turbinate flap for reconstruction; all other approaches used the nasoseptal flap. Open transcranial surgical approaches were chosen based on tumour classification. Type A tumours are removed through the intra/extradural subtemporal and Kawase approaches [3,7,16]. Type C tumours are extirpated via the zygomatic middle fossa approach and the subtemporal, extradural-intradural approach with anterior petrosectomy [7,16]. The frontotemporal orbitozygomatic subtemporal approach, frontotemporal epidural approach, and infratemporal fossa approach were carried out for type D tumours based on tumour location [8,17]. A combination of multiple surgical approaches may be needed according to the case's specific circumstances. Lumbar drainage is selectively used postoperatively if persistent CSF leakage is encountered or exhibit symptoms suggestive of intracranial infection.

Table 1. Clinical and tumor characteristics in 101 patients with 3 subtypes of trigeminal schwannomas.

Characteristic	Type A			Type C			Type D			Pooled data		
	EEA n=26	TCA n=26	P	EEA n=7	TCA n=24	P	EEA n=11	TCA n=7	P	EEA n=44	TCA n=57	P
Age, yrs (mean ± SD)	45.3 ± 10.5	49.5 ± 10.3	0.148	50.9 ± 7.9	49.4 ± 10.2	0.733	47.4 ± 8.7	50.7 ± 6.3	0.393	46.7 ± 9.7	49.6 ± 9.7	0.136
Female	18(69.2)	15(57.7)	0.388	1(14.3)	14(58.3)	0.083	3(27.3)	5(71.4)	0.145	22(50)	34(59.6)	0.333
Facial numbness	12(46.2)	16(61.5)	0.266	4(57.1)	12(50)	1.000	8(72.7)	3(42.9)	0.332	24(54.5)	31(54.4)	0.987
Facial pain	8(30.8)	6(23.1)	0.532	2(28.6)	2(8.3)	0.212	0(0)	0(0)	-	10(22.7)	8(14)	0.258
Headache	13(50)	10(38.5)	0.402	2(28.6)	12(50)	0.412	3(27.3)	4(57.1)	0.332	18(40.9)	26(45.6)	0.636
Dizziness	4(15.4)	7(26.9)	0.308	0(0)	8(33.3)	0.146	1(9.1)	2(28.6)	0.528	5(11.4)	17(29.8)	**0.026**
Hearing impairment	3(11.5)	4(15.4)	1.000	1(14.3)	2(8.3)	0.550	0(0)	0(0)	-	4(9.1)	6(10.5)	1.000
Mastication weakness	4(15.4)	0(0)	0.110	0(0)	2(8.3)	1.000	1(9.1)	0(0)	1.000	5(11.4)	2(3.5)	0.235
Reduced vision	4(15.4)	5(19.2)	1.000	0(0)	2(8.3)	1.000	1(9.1)	0(0)	1.000	5(11.4)	7(12.3)	0.888
Diplopia	5(19.2)	3(11.5)	0.703	1(14.3)	2(8.3)	0.550	0(0)	0(0)	-	6(13.6)	5(8.8)	0.526
LCN involvement	0(0)	0(0)	-	2(28.6)	5(20.8)	0.642	0(0)	2(28.6)	0.137	2(4.5)	7(12.3)	0.292
Gait disturbance	0(0)	2(7.7)	0.490	1(14.3)	2(8.3)	0.550	0(0)	0(0)	-	1(2.3)	4(7)	0.384
Asymptomatic	1(3.8)	2(7.7)	1.000	1(14.3)	2(8.3)	0.550	1(9.1)	0(0)	1.000	3(6.8)	4(7)	1.000
Consistency			0.372			0.225			0.627			
Cystic	6(23.1)	2(7.7)	0.248	2(28.6)	1(4.2)	0.120	0(0)	0(0)	-	8(18.2)	3(5.3)	0.054
Solid	11(42.3)	14(53.8)	0.405	2(28.6)	12(50)	0.412	8(72.7)	4(57.1)	0.627	21(47.7)	30(52.6)	0.625
Mixed	9(34.6)	10(38.5)	0.773	3(42.9)	11(45.8)	1.000	3(27.3)	3(42.9)	0.627	15(34.1)	24(42.1)	0.412
Tumor size, mm (mean ± SD)	32.2 ± 12.7	29.9 ± 13.0	0.534	44.9 ± 9.3	45.0 ± 7.4	0.957	41 ± 11.8	55 ± 19.8	0.077	36.4 ± 12.9	39.4 ± 15.0	0.296

EEA: endoscopic endonasal approach; TCA: transcranial approach; SD: standard deviation; LCN: lower cranial nerves. Values are shown as number (%) or median (interquartile range) unless indicated otherwise. Boldface type indicates statistical significance ($P < 0.05$).

Evaluation of trigeminal nerve function improvement and postoperative performance status

The Barrow Neurological Institute (BNI) facial numbness score was used to assess the degree of facial numbness, with a score ranging from 1 (no numbness) to 4 (severe numbness) (18). Masticatory muscle weakness was divided into 4 levels: none (1 point), mild (2 points), moderate (3 points), and severe (4 points). To assess the degree of facial pain, we used the Changhai Pain Scale, which provides a more prompt and accurate assessment to better interpret pain levels [19]. Facial numbness scores, masticatory muscle weakness scores, and facial pain scores were used to assess the degree of the corresponding symptoms before and one day and six months after surgery. The postoperative performance status of the patients was evaluated via the Karnofsky Performance Scale (KPS) [20]. Patient performance was divided into good (≥ 90) and poor (≤ 80) according to the KPS score.

Statistical analysis

Data analysis was conducted via SPSS (version 26.0) and GraphPad Prism (version 10.1.26). The chi-square test or Fisher's exact test was used to compare independent categorical variables. Student's t test or the Mann-Whitney U test was used to compare continuous variables. Normal and skewed data distributions are presented as the means ± standard deviations (SDs) and medians (interquartile ranges, IQRs), respectively. Friedman's ANOVA was used to evaluate the effect of the surgery across the three time points (before and one day and 6 months after surgery), with post hoc Bonferroni correction for pairwise comparisons. Survival curves generated via the Kaplan-Meier method were used to depict the progression-free survival (PFS) of the patients. The log-rank test was used to compare tumour progression time between surgical groups. $P < 0.05$ was considered statistically significant.

Results

A total of 101 patients (44 treated via EEA and 57 via TCA) met all the inclusion criteria. Among them, 52 patients were type A (26 treated via the EEA and 26 via the TCA), 31 with type C (7 treated via the EEA and 24 via the TCA), and 18 with type D (11 treated

Table 2. Surgical outcomes and complications in 101 patients with 3 subtypes of trigeminal schwannomas.

Characteristic	Type A			Type C			Type D			Pooled data		
	EEA n=26	TCA n=26	P	EEA n=7	TCA n=24	P	EEA n=11	TCA n=7	P	EEA n=44	TCA n=57	P
EOR			**0.023**			1.000			0.137			**0.004**
GTR	26(100)	20(76.9)	**0.023**	6(85.7)	18(75)	1.000	11(100)	5(71.4)	0.137	43(97.7)	43(75.4)	**0.002**
STR	0(0)	6(23.1)	**0.023**	1(14.3)	5(20.8)	1.000	0(0)	0(0)	-	1(2.3)	11(19.3)	**0.009**
PR	0(0)	0(0)	-	0(0)	1(4.2)	1.000	0(0)	2(28.6)	0.137	0(0)	3(5.3)	0.255
CSF leakage	0(0)	2(7.7)	0.490	1(14.3)	2(8.3)	0.550	0(0)	2(28.6)	0.137	1(2.3)	6(10.5)	0.134
Intracranial infection	0(0)	6(23.1)	**0.023**	2(28.6)	7(29.2)	1.000	0(0)	0(0)	-	2(4.5)	13(22.8)	**0.010**
Etiological diagnosis	0(0)	0(0)	-	1(14.3)	2(8.3)	0.550	0(0)	0(0)	-	1(2.3)	2(3.5)	1.000
Clinical diagnosis	0(0)	6(23.1)	**0.023**	1(14.3)	5(20.8)	1.000	0(0)	0(0)	-	1(2.3)	11(19.2)	**0.009**
Sinonasal complications	4(15.4)	0(0)	0.110	1(14.3)	0(0)	0.226	1(9.1)	0(0)	1.000	6(13.6)	0(0)	**0.006**
Hyposmia	3(11.5)	0(0)	0.235	1(14.3)	0(0)	0.226	0(0)	0(0)	-	4(9.1)	0(0)	**0.033**
Crusting	3(11.5)	0(0)	0.235	0(0)	0(0)	-	1(9.1)	0(0)	1.000	4(9.1)	0(0)	**0.033**
Septal perforation	2(7.7)	0(0)	0.490	0(0)	0(0)	-	0(0)	0(0)	-	2(4.5)	0(0)	0.187
ICA injury	1(3.8)	0(0)	1.000	0(0)	0(0)	-	0(0)	0(0)	-	1(2.3)	0(0)	0.436
Operation time, mins	160(71)	245(43)	**< 0.001**	250(35)	240(83)	0.538	200(100)	220(10)	0.272	175(105)	230(60)	**< 0.001**
Estimated blood loss, ml	300(313)	550(400)	0.061	600(100)	600(350)	0.500	1000 (500)	1000 (800)	0.445	500(475)	600(355)	0.273
Length of stay, days	11(4)	11(7)	0.978	14(7)	15(8)	0.406	10(3)	10(14)	0.676	11.5(5)	12(9)	0.262
Improve												
Facial numbness	9/12(75)	5/16 (31.3)	**0.022**	2/4(50)	2/12 (16.7)	0.245	7/8(87.5)	1/3(33.3)	0.152	18/24 (75)	8/31 (25.8)	**< 0.001**
Facial pain	6/8(75)	6/6(100)	0.473	1/2(50)	2/2(100)	1.000	0(0)	0(0)	-	7/10 (70)	8/8 (100)	0.216
Mastication weakness	2/4(50)	0(0)	-	0(0)	2/2(100)	-	1/1(100)	0(0)	-	3/5(60)	2/2(100)	1.000
Headache	11/13 (84.6)	10/10 (100)	0.486	2/2(100)	11/12 (91.7)	1.000	3/3(100)	4/4(100)	-	16/18 (88.9)	25/26 (96.2)	0.558
Dizziness	4/4(100)	5/7(71.4)	0.491	0(0)	6/8(75)	-	1/1(100)	0/2(0)	0.333	5/5 (100)	11/17 (64.7)	0.266
Hearing impairment	2/3(66.7)	4/4(100)	0.429	0/1(0)	2/2(100)	0.333	0(0)	0(0)	-	2/4(50)	6/6 (100)	0.133
Reduced vision	2/4(50.0)	2/5(40.0)	1.000	0(0)	2/2(100)	-	1/1(100)	0(0)	-	3/5(60.0)	4/7(57.1)	1.000
Diplopia	5/5(100)	2/3(66.7)	0.375	0/1(0)	2/2(100)	0.333	0(0)	0(0)	-	5/6(83.3)	4/5(80)	1.000
LCN syptom	0(0)	0(0)	-	2/2(100)	5/5(100)	-	0(0)	2/2(100)	-	2/2(100)	7/7(100)	-
Gait disturbance	0(0)	2/2(100)	-	1/1(100)	2/2(100)	-	0(0)	0(0)	-	1/1(100)	4/4(100)	-

EEA: endoscopic endonasal approach; TCA: transcranial approach; EOR: extent of resection; GTR: gross-total resection; STR: subtotal resection; PR: partial resection; CSF: cerebrospinal fluid; ICA: internal carotid artery; LCN: lower cranial nerves. Values are shown as number (%) or median (interquartile range) unless indicated otherwise. Boldface type indicates statistical significance (P < 0.05).

via the EEA and 7 via the TCA). To characterize temporal trends, we created a year-by-year breakdown of EEA versus TCA patients from 2013 to 2023 (Figure 1). A historical review of surgical trends revealed a dramatic shift in surgical approaches. The

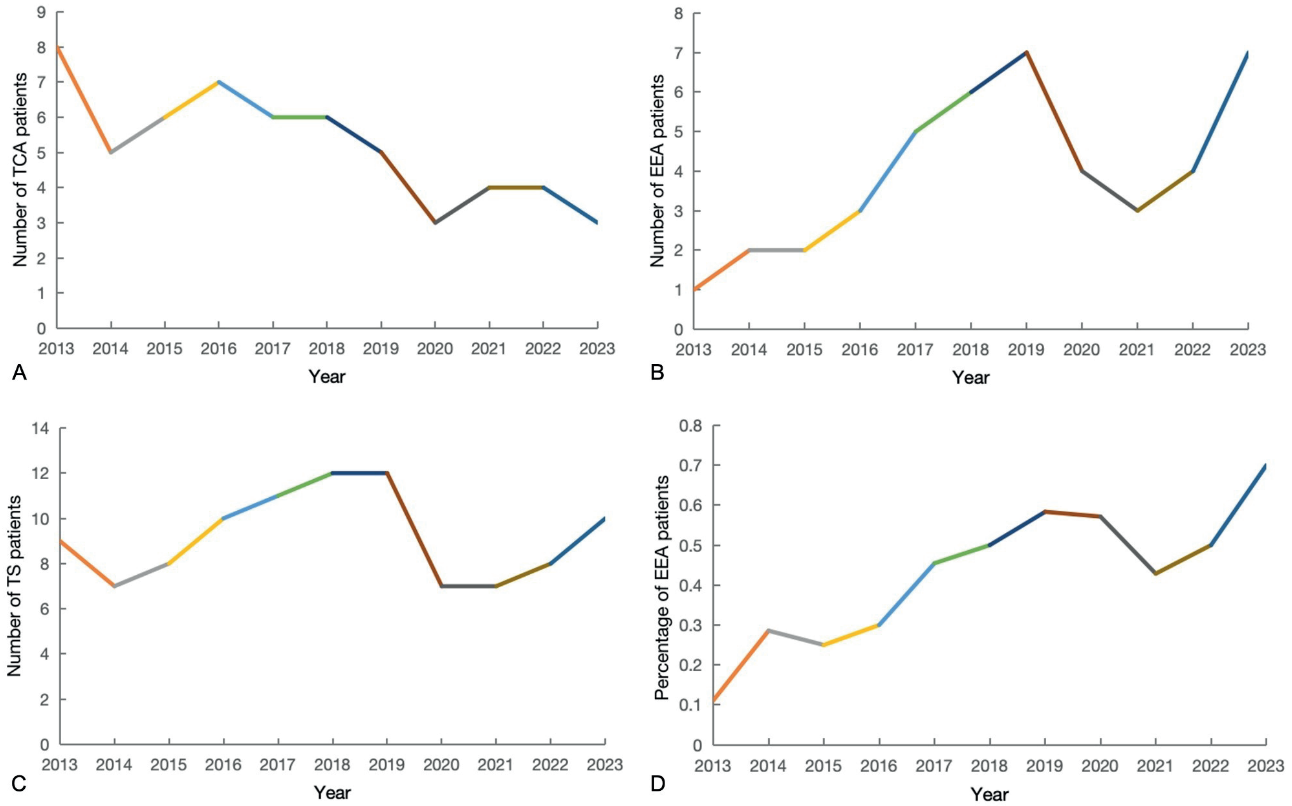

Figure 1. Trends in TCA patients (A), EEA patients (B), total TS patients (C), and the proportion of EEA patients in the overall number of cases (D) for patients undergoing EEA for TS resection from 2013 to 2023. Affected by coronavirus disease 2019 in 2020 and 2021. TCA: transcranial approach; EEA: endoscopic endonasal approach; TS: trigeminal schwannoma.

number of patients treated with the EEA consistently increased, whereas the number of patients treated with the TCA declined. Additionally, the total number of TS patients has remained stable each year, but the proportion of EEA patients has been increasing.

Patient and tumour characteristics

The characteristics of 101 patients with the 3 subtypes of TSs are tabulated in Table 1. There were no significant differences in sex (female 50% for EEA vs. 59.6% for TCA, P = 0.333) or age (mean 46.7 ± 9.7 years for EEA vs. 49.6 ± 9.7 years for TCA, P = 0.136) between the two groups. Facial numbness was the most common symptom in both groups, followed by headache. The two groups exhibited comparable baseline characteristics, except for the prevalence of dizziness (11.4% vs. 29.8%, P = 0.026) in the pooled data (types A, C, and D).

Surgical outcomes

The surgical outcomes are summarized in Table 2. The pooled EOR (P = 0.004), intracranial infection (4.5% for EEA vs. 22.8% for TCA, P = 0.010), operative time (median 175 minutes for EEA vs. 230 minutes for TCA, P < 0.001) and improvement rate of preoperative facial numbness (75% for EEA vs. 25.8% for TCA, P < 0.001) were significantly different between the surgical groups. Interestingly, all these differences were caused primarily by type A tumours. Specifically, for type A tumours, the EEA resulted in significantly better outcomes, with higher rates of improvement in preoperative facial numbness (75% vs. 31.3%, P = 0.022) and GTR (100% vs. 76.9%, P = 0.023). Additionally, the EEA group had shorter operative times (median 160 minutes for EEA vs. 245 minutes for TCA, P < 0.001) and a lower incidence of intracranial infection (0% vs. 23.1%, P = 0.023). The pooled data on sinonasal complications (13.6% vs. 0%, P = 0.006), including olfactory dysfunction (9.1% vs. 0%, P = 0.033), crusting (9.1% vs. 0%, P = 0.033) and septal perforation (4.5% vs. 0%, P = 0.187), showed statistically significant differences. Other surgical outcomes were similar for any of the tumour types between the 2 surgical groups (Table 2).

Follow-up outcomes

The median follow-up time was 53 months (IQR 38 months) in the EEA cohort and 58 months (IQR 70 months) in the TCA cohort (P = 0.079). Overall, the morbidity of permanent postoperative neurological deficits was 18.2% in the EEA group and 36.8% in the TCA group (P = 0.040). No significant differences were observed in tumour recurrence and death during follow-up. The

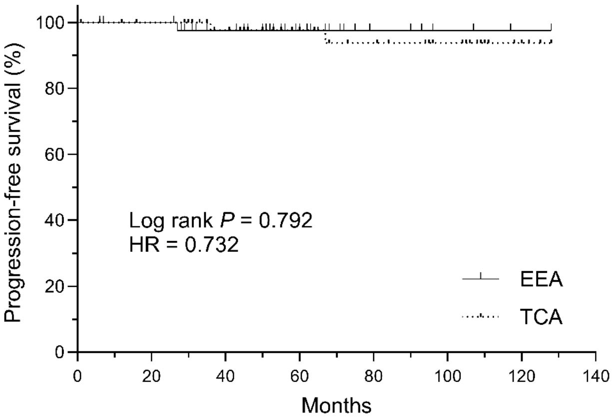

Figure 2. Kaplan-Meier curves comparing progress-free survival for trigeminal schwannoma patients undergoing endoscopic endonasal versus transcranial approach. HR: hazard ratio; EEA: endoscopic endonasal approach; TCA: transcranial approach.

recurrent patient subsequently received CyberKnife radiosurgery. Additionally, Kaplan-Meier curves were constructed for PFS for both surgical groups of patients. No significant difference in the PFS curves of patients was observed between the surgical groups (log rank test, P = 0.792) (Figure 2).

At the last follow-up, the TCA group had a significantly greater incidence of facial numbness (10% vs. 38.5%, P = 0.029) among those with new postoperative symptoms. The difference in postoperative reduced vision did not reach significance between the two surgical cohorts, despite the greater proportion of deteriorated visual acuity (0% vs. 8.5%, P = 0.087) observed in the TCA group. The KPS score was significantly greater in the EEA group (score ≥ 90: 90.9% vs. 75.9%, P = 0.041). Other results were similar between the two groups (Table 3).

Trigeminal nerve function score

Compared with the preoperative measurements, the degree of numbness in the EEA group was significantly lower on the first day and six months after surgery. However, there was no significant difference in the numbness score between the first day and six months after surgery in the EEA group. We also discovered no significant differences in the numbness scores among the TCA groups at the three time points (Table 4).

The pain levels in TCA patients were significantly improved on the first day and six months after surgery compared with those before surgery. However, no significant difference in pain intensity was observed on the first day or six months after surgery in the TCA group. Furthermore, we noticed no significant differences in pain severity among the EEA groups at the three intervals (Table 5).

Unlike facial numbness and pain, the masticatory muscle weakness score was not significantly different at any of the three time points in the EEA or TCA groups (Table 6).

Discussion

With the development and broad application of endoscopy at the skull base, an increasing number of surgeons have gradually advocated minimally invasive endoscopic techniques. we found an overall stable trend from 2013 to 2023 in the number of patients treated for TS but a corresponding increase in the proportion of EEA patients (Figure 1). Over the past eleven years, the EEA has become the treatment of choice for an increasing number of TS patients.

The GTR rate was significantly higher in the EEA than in the TCA group, in parallel with a significantly shorter EEA operative time. The literature reports that the improvement rate of preoperative facial numbness with TCA is 11%-40% [2,7,10,11,21-23], whereas the improvement rate with EEA is 43%-75% [9,12,24,25]. In this study, the improvement rate of facial numbness in EEA was higher than that in TCA. These favorable results are mainly related to the ventral approach, which allows direct access to the lesion and provides close visualization and better illumination.

A literature review of TSs reveals a paucity of discussion on approach-related intracranial infections [21,22,26]. This study paid special attention to the incidence of intracranial infections after endoscopic endonasal and transcranial surgery. Considering that the mortality rate of intracranial infection in postneurosurgical patients is as high as 12% to 33% [27-29], and EEA is a clean-contaminated procedure. Therefore, identifying high-risk patients at an early stage and providing timely intervention are highly important. The bacteriological examination of CSF is the gold standard for diagnosing intracranial infection after surgery. However, when the bacteriological examination results are negative, it is still necessary to attach great importance to the patient's clinical manifestations, imaging examinations, blood tests, and infection indicators indicated in CSF examinations and finally make a comprehensive diagnosis. Accordingly, the Neurosurgery Branch of the Chinese Medical Association has formulated diagnostic criteria for intracranial infection, including etiological and clinical diagnoses [14]. This comprehensive diagnostic strategy helps identify high-risk patients early and provides them with more precise and rapid treatment. As a result, the incidence of intracranial infection among surgical patients is relatively high (EEA 4.5%, TCA 22.8%) in our study compared with the published literature (EEA 0%-2.6%, TCA 0%-13.3%) [2,7-12,15,21,25,26,30-32]. This is not a discrepancy in surgical techniques but a distinction in treatment philosophy. In fact, according to the bacteriological examination criteria, the intracranial infection rates in the EEA (2.3%) and TCA (3.5%) groups are comparable to those in the literature.

In contrast to conventional wisdom, the EEA group experienced a significant reduction in intracranial infection rate (4.5% vs. 22.8%, P = 0.010), while the incidence of CSF leakage was numerically lower in the EEA group (2.3% vs. 10.5%), with no statistically significant difference (P = 0.134). These results may

Table 3. New permanent symptoms after surgery and long-term follow-up outcomes in 101 patients with 3 subtypes of trigeminal schwannomas.

Characteristic	Type A			Type C			Type D			Pooled data		
	EEA n=26	TCA n=26	P	EEA n=7	TCA n=24	P	EEA n=11	TCA n=7	P	EEA n=44	TCA n=57	P
Facial numbness	2/14 (14.3)	3/10 (30.0)	0.615	0/3(0)	5/12 (41.7)	0.505	0/3(0)	2/4(50.0)	0.429	2/20 (10.0)	10/26 (38.5)	**0.029**
Facial pain	1/18 (5.6)	2/20 (10)	1.000	0/5(0)	0/22(0)	-	0/11(0)	0/7(0)	-	1/34 (2.9)	2/49 (4.1)	1.000
Mastication weakness	2/22 (9.1)	2/26(7.7)	1.000	0/7(0)	5/22 (22.7)	0.296	0/10(0)	2/7(28.6)	0.154	2/39 (5.1)	9/55 (16.4)	0.115
Headache	0/13(0)	3/16 (18.8)	0.232	0/5(0)	0/12(0)	-	0/8(0)	0/3(0)	-	0/26(0)	3/31(9.7)	0.242
Dizziness	0/22(0)	0/19(0)	-	0/7(0)	0/16(0)	-	0/10(0)	2/5(40)	0.095	0/39(0)	2/40(5)	0.494
Reduced vision	0/22(0)	2/21(9.5)	0.233	0/7(0)	2/22 (9.1)	1.000	0/10(0)	0/7(0)	-	0/39(0)	4/50(8)	0.128
Diplopia	2/21(9.5)	0/23(0)	0.222	0/6(0)	2/22 (9.1)	1.000	0/11(0)	0/7(0)	-	2/38(5.3)	2/52(3.8)	1.000
Dry eye	3/26 (11.5)	3/26 (11.5)	1.000	1/7(14.3)	0/22(0)	0.241	0/11(0)	0/7(0)	-	4/44(9.1)	3/55(5.5)	0.697
LCN involvement	0/26(0)	0/26(0)	-	0/5(0)	2/19 (10.5)	1.000	0/11(0)	0/5(0)	-	0/42(0)	2/50(4)	0.498
Neurological deficits	7/26 (26.9)	8/26 (30.8)	0.760	1/7(14.3)	10/24 (41.7)	0.372	0/11(0)	3/7(42.9)	**0.043**	8/44 (18.2)	21/57 (36.8)	**0.040**
Recurrence	0/26(0)	0/26(0)	-	0/7(0)	1/24(4.2)	1.000	0/11(0)	0/7(0)	-	0/44(0)	1/57(1.8)	1.000
Deaths during follow-up	0/26(0)	0/26(0)	-	0/7(0)	1/24(4.2)	1.000	1/11(9.1)	0/7(0)	1.000	1/44(2.3)	1/57(1.8)	1.000
Follow-up, months	52(28)	50.5(68)	0.332	71(50)	62(63)	0.872	60(33)	55(70)	0.860	53(38)	58(70)	0.079
KPS score (≥90)	24/26 (92.3)	20/26 (76.9)	0.248	7/7(100)	18/24 (75))	0.293	9/11 (81.8)	5/7(71.4)	1.000	40/44 (90.9)	43/57 (75.4)	**0.044**

EEA: endoscopic endonasal approach; TCA: transcranial approach; LCN: lower cranial nerves; KPS: Karnofsky Performance Scale. Values are shown as number (%) or median (interquartile range) unless indicated otherwise. Boldface type indicates statistical significance ($P < 0.05$).

be related to the TCA requiring additional resection of excess skull bone to better expose the tumour and shorten the contact distance [33]. Furthermore, TCA requires a more extensive exposure area and longer operative time, and some procedures are performed via a subdural approach, which increases the risk of CSF leakage and intracranial infection. In contrast, EEA is performed mainly via an epidural approach, which can effectively reduce the occurrence of CSF leakage and intracranial infection through mature and personalized reconstruction protocols.12 In our study, all patients with intracranial infection fully recovered after medication treatment with or without lumbar drainage. The rate of postoperative CSF leakage (EEA 2.3%, TCA 10.5%) is comparable to that reported in previous studies (EEA 0–2.6%, TCA 0–16.7%) [4,7–10,12,15,21,23,25,26,30,32,34,35], and all patients achieved resolution with conservative management or lumbar drainage. There were no significant differences in the recurrence rate, mortality, or follow-up time between the two surgical groups. Notably, the recurrence occurred in non-GTR patient in the TCA group. The EOR substantially impacts the recurrence/progression of tumours postoperatively [6,31]. A recent meta-analysis revealed that the recurrence rate at the last follow-up after GTR was only 1.9%, whereas the progression rate after non-GTR was 26.2%, which was a statistically significant difference [36]. Although stereotactic radiosurgery has been widely utilized as an adjuvant therapy or salvage tool for residual tumours, GTR still presents the most effective long-term control [36]. Nevertheless, minimizing neurological deficits continues to be a simultaneous goal. In this context, the EEA can reduce postoperative neurological morbidity by providing a shorter working distance, a more direct field of view, and a surgical corridor parallel to the tumour axis. These advantages were validated by lower neurological deficits and higher KPS score in the EEA group.

For the first time, we introduced a quantitative scoring tool for TS to describe improvements in trigeminal nerve function more objectively and precisely. The study revealed that the EEA group had significantly greater improvement in preoperative facial numbness (Table 4). TCA significantly improved preoperative facial pain (Table 5), whereas improvement in preoperative

Table 4. Multiple comparisons of facial numbness score.

Groups	Time point 1	Time point 2	Median difference (Before - After)	P
EEA (n = 24)	Before surgery	One day after surgery	1	**0.001**
		Six months after surgery	1	**0.001**
	One day after surgery	Six months after surgery	0	1.000
TCA (n = 31)	Before surgery	One day after surgery	0	> 0.050
		Six months after surgery	0	> 0.050
	One day after surgery	Six months after surgery	0	> 0.050

EEA: endoscopic endonasal approach; TCA: transcranial approach. Boldface type indicates statistical significance (P < 0.05).

Table 5. Multiple comparisons of facial pain score.

Groups	Time point 1	Time point 2	Median difference (Before - After)	P
EEA (n = 10)	Before surgery	One day after surgery	2	0.133
		Six months after surgery	2	0.133
	One day after surgery	Six months after surgery	0	1.000
TCA (n = 8)	Before surgery	One day after surgery	2	**0.008**
		Six months after surgery	2	**0.008**
	One day after surgery	Six months after surgery	0	1.000

EEA: endoscopic endonasal approach; TCA: transcranial approach.

Table 6. Multiple comparisons of masticatory muscle weakness score. Boldface type indicates statistical significance (P < 0.05).

Groups	Time point 1	Time point 2	Median difference (Before - After)	P
EEA (n = 5)	Before surgery	One day after surgery	1	> 0.050
		Six months after surgery	1	> 0.050
	One day after surgery	Six months after surgery	0	> 0.050
TCA (n = 2)	Before surgery	One day after surgery	1	> 0.050
		Six months after surgery	1	> 0.050
	One day after surgery	Six months after surgery	0	> 0.050

EEA: endoscopic endonasal approach; TCA: transcranial approach. Boldface type indicates statistical significance (P < 0.05).

masticatory muscle weakness was not significantly different between the two surgical groups (Table 6). Given the limited number of patients with preoperative facial pain and masticatory muscle weakness, the results should be interpreted cautiously. Although the TCA group had greater improvement in facial pain, the overall incidence of facial numbness and permanent neurological deficits was significantly lower in the EEA group, which may explain why the KPS score was significantly greater in the EEA group. The overall morbidity of permanent neurological deficits in the TCA group was 36.8%, which was comparable to the data reported in previous studies [2,3,7,21,26,32,34,37].

Surgical approaches based on TS classification

Type A

Type A tumours are predominantly located in the middle cranial fossa, and the EEA can offer direct visualization and initial dissection of Meckel's cave, thus enhancing the likelihood of achieving total removal while preserving the integrity of the remaining fibers of the trigeminal nerve. In contrast, the TCA sometimes has a blind spot in revealing the relationship between deep tumours and neurovascular structures, which may lead to inadequate tumour excision or unwarranted transection of nerves/vessels [4,24]. This can be verified by the significantly higher

GTR rate and improvement rate of facial numbness in type A patients after endonasal surgery. Moreover, the operative time was significantly shorter in the EEA group, which further indicated that the EEA had advantages in the treatment of middle cranial fossa tumours. Considering the comparability of postoperative complications, it is reasonable to believe that the EEA is more suitable than the TCA for type A TSs.

Type B

Type B tumours are located mainly in the posterior fossa and are removed via craniotomy. Given the complex anatomical trajectory of the sixth cranial nerve and the long distance from the EEA to the posterior fossa, type B TSs are undoubtedly the best indication for the TCA, with satisfactory results (9,10,16,38). Resection of posterior fossa tumours represents a limitation of endoscopic approaches relative to retrosigmoid or transpetrosal approaches.

Type C

Type C tumours with notable components in both the middle and posterior fossae are described as having a distinctive dumbbell-shaped morphology. Surgical removal of dumbbell-shaped tumours, whether via the TCA or EEA, is highly challenging (13,15,37). Statistical analysis revealed no significant differences between the surgical groups in terms of preoperative characteristics, surgical outcomes, or follow-up outcomes. Satisfactory results can be achieved for dumbbell-shaped tumours when a tailored EEA is employed (13). Considering that the TCA system faces many approach-related morbidities such as brain retraction, cerebral edema, and temporal muscle atrophy, the EEA can be a feasible alternative to the TCA system (2,3,10).

Type D

Type D tumours are primarily extracranial and are the rarest of all TS types. Tumours can arise in the orbit, pterygopalatine fossa (PPF), or infratemporal fossa (ITF) and traditionally require an extensive approach. With the advancement of endoscopic technology, the EEA enables direct and minimally invasive access to some type D tumours. Compared with craniotomy, EEA involves the creation of a natural surgical corridor to reach the PPF and ITF and does not require an extensive incision, resulting in less trauma and better cosmetic effects (11,12,24). Notably, no complications occurred following endoscopic surgery for extracranial tumours in this study, which is consistent with the findings of Zhang et al. (11). As a result, the morbidity of permanent neurological deficits in the EEA group for type D tumours was significantly lower than that in the TCA group. Given the resulting better postoperative neurological function and long-term outcomes, the EEA could be preferable when approaching tumours of the PPF, ITF, and medial orbital.

Limitations

The results reported herein should be considering several limitations. First, the retrospective nature of the analysis carries inherent limitations in our study and will inevitably introduce selection bias. However, this limitation is standard in most of the literature on this topic. Second, the small sample sizes for certain subtypes, particularly type D tumours, reduce the statistical power of the comparisons between surgical approaches. Third, this study lacked detailed assessment of quality-of-life. Finally, the follow-up period, though over 50 months on average, may be insufficient to fully assess long-term outcomes such as recurrence.

Conclusion

This study revealed that the optimal surgical approach for treating TSs depends largely on the tumour location. The EEA offers significant advantages for type A and certain type D tumours. However, the TCA remains the superior choice for type B tumours because of the limitations of the EEA in accessing posterior fossa lesions. Type C tumours show no clear advantage when one approach is used over the other. These findings highlight the importance of tailoring the surgical approach to the anatomical characteristics of the tumour. This study aids in refining decision-making for skull base surgeons by providing evidence-based recommendations for choosing the optimal surgical corridor.

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Conflict of interest

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Authors' contributions

LSP and SZX had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: TH, XW, LSP, SZX, ZCY, SHX, PW. Acquisition, analysis, or interpretation of data: SFL, JW, CMX, FO, YCW, JYZ, HD, LMX, BT. Drafting of the manuscript: LSP, SZX, XW, TH, JW, SHX, PW. Critical revision of the manuscript for important intellectual content: TH, XW, BT, SZX, ZCY. Statistical analysis: SZX, JW, CMX; Obtained funding: XW; Administrative, technical, or material support: SFL, YCW, FO, LMX, HD, JYZ; Supervision: TH, XW.

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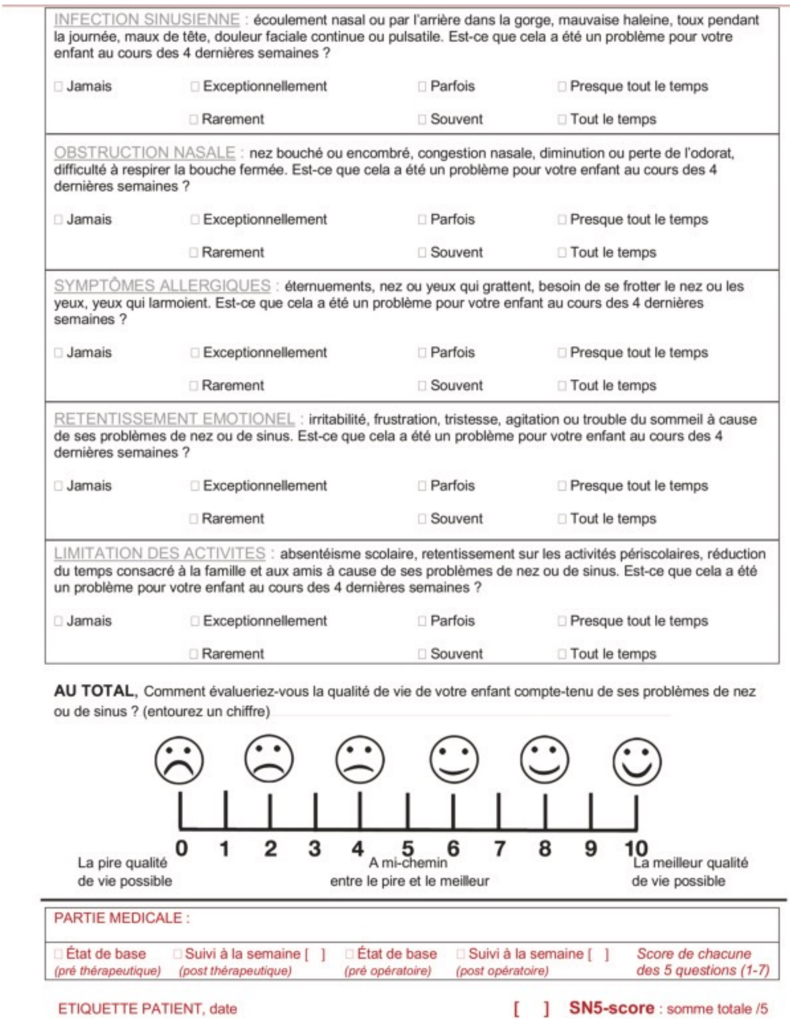
SUPPLEMENTARY MATERIAL

Appendix


INFECTION SINUSIENNE : écoulement nasal ou par l'arrière dans la gorge, mauvaise haleine, toux pendant la journée, maux de tête, douleur faciale continue ou pulsatile. Est-ce que cela a été un problème pour votre enfant au cours des 4 dernières semaines ?

☐ Jamais ☐ Exceptionnellement ☐ Parfois ☐ Presque tout le temps
☐ Rarement ☐ Souvent ☐ Tout le temps

OBSTRUCTION NASALE : nez bouché ou encombré, congestion nasale, diminution ou perte de l'odorat, difficulté à respirer la bouche fermée. Est-ce que cela a été un problème pour votre enfant au cours des 4 dernières semaines ?

☐ Jamais ☐ Exceptionnellement ☐ Parfois ☐ Presque tout le temps
☐ Rarement ☐ Souvent ☐ Tout le temps

SYMPTÔMES ALLERGIQUES : éternuements, nez ou yeux qui grattent, besoin de se frotter le nez ou les yeux, yeux qui larmoient. Est-ce que cela a été un problème pour votre enfant au cours des 4 dernières semaines ?

☐ Jamais ☐ Exceptionnellement ☐ Parfois ☐ Presque tout le temps
☐ Rarement ☐ Souvent ☐ Tout le temps

RETENTISSEMENT EMOTIONEL : irritabilité, frustration, tristesse, agitation ou trouble du sommeil à cause de ses problèmes de nez ou de sinus. Est-ce que cela a été un problème pour votre enfant au cours des 4 dernières semaines ?

☐ Jamais ☐ Exceptionnellement ☐ Parfois ☐ Presque tout le temps
☐ Rarement ☐ Souvent ☐ Tout le temps

LIMITATION DES ACTIVITES : absentéisme scolaire, retentissement sur les activités périscolaires, réduction du temps consacré à la famille et aux amis à cause de ses problèmes de nez ou de sinus. Est-ce que cela a été un problème pour votre enfant au cours des 4 dernières semaines ?

☐ Jamais ☐ Exceptionnellement ☐ Parfois ☐ Presque tout le temps
☐ Rarement ☐ Souvent ☐ Tout le temps

AU TOTAL, Comment évalueriez-vous la qualité de vie de votre enfant compte-tenu de ses problèmes de nez ou de sinus ? (entourez un chiffre)

0 1 2 3 4 5 6 7 8 9 10

La pire qualité de vie possible — A mi-chemin entre le pire et le meilleur — La meilleur qualité de vie possible

PARTIE MEDICALE :

☐ État de base (pré thérapeutique) ☐ Suivi à la semaine [ ] (post thérapeutique) ☐ État de base (pré opératoire) ☐ Suivi à la semaine [ ] (post opératoire) *Score de chacune des 5 questions (1-7)*

ETIQUETTE PATIENT, date [ ] **SN5-score** : somme totale /5

Stéphane Gargula, Romain Luscan, David Drummond, Françoise Denoyelle, Vincent Couloigner, Nicolas Leboulanger, François Simon. « French Translation and Validation of the Sinus and Nasal Quality of Life Survey (SN-5) in Children ». International Journal of Pediatric Otorhinolaryngology 145: 110706. https://doi.org/10.1016/j.ijporl.2021.110706.