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Salvage endoscopic surgery for skull base osteoradionecrosis in nasopharyngeal carcinoma patients: A prospective, observational, single-arm clinical study*

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Rhinology 61: 1, 61 - 70, 2023

https://doi.org/10.4193/Rhin22.303

***Received for publication:**

July 29, 2022

Accepted: October 5, 2022

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Abstract

Background: Postradiation skull base osteoradionecrosis (ORN) is a severe complication that occurs after radiotherapy in patients with nasopharyngeal carcinoma (NPC) that can severely affect quality of life (QOL) and be life threatening. Only 13.4%–28.6% of patients can be cured by traditional repeated endoscopic debridement. Here, we introduced salvage endoscopic surgery for skull base ORN patients and evaluated its clinical efficacy.

Methods: This was a prospective, observational, single-arm clinical study. Clinical data from 18 skull base ORN patients who underwent radical endoscopic necrectomy followed by reconstruction using a septal pedicled mucosal flap or temporal muscle flap were included in the study. The endpoint was an overall survival (OS) of 2 years. The numeric rating scale (NRS) scores for pain and foul odor were analyzed to determine the efficacy and safety of this surgery.

Results: A total of 21 patients were recruited, 18 of whom completed the study and were analyzed. All surgeries were successfully performed. During the 2-year study, the OS rate of the entire cohort was 75%. The median NRS score for pain decreased from 6.44±2.62 to 0.50 ±0.71, and the NRS score for foul odor decreased from 1.89±1.08 to 1 after surgery.

Conclusions: Salvage endoscopic necrectomy followed by construction using a septal pedicled mucosal flap or temporal muscle flap is a novel, safe, and effective treatment for ORN in patients with NPC.

Clinical trial registration: This study was approved by the independent ethics committee of the Eye, Ear, Nose and Throat Hospital of Fudan University (IEC No. 2019095-1). Written informed consent was obtained from all patients. The study was registered with the Chinese Clinical Trial registry (ChiCTR2000029327).

Key words: nasopharyngeal carcinoma, postradiation, skull base osteoradionecrosis, endoscopy, necrectomy, flap, reconstruction

Introduction

Nasopharyngeal carcinoma (NPC) is a common malignancy in Southeast Asia [1]. Radiotherapy is the main treatment for NPC [2]. However, radiotherapy may cause acute and chronic adverse effects. As a severe adverse event after radiotherapy, postradiation nasopharyngeal necrosis can be observed in NPC patients and is commonly accompanied by a severe headache, foul odor, and epistaxis, which severely affect the patient's quality of life (QOL) [3,4]. According to the literature, necrosis develops via a three-stage process. The severe stage, which is the third step in the process, aligns with the characteristics of skull base osteoradionecrosis (ORN) [5].

The mortality rate among patients with ORN or carotid artery exposure is high. Patients with ORN have an increased risk of

death, ranging from 10.3% to 65.8%. Moreover, the mortality rate has been reported to be 72.7% among patients with carotid artery exposure and only 11.8% among those without exposure [6].

Although repeated endoscopic debridement has been reported as an effective traditional treatment, only 13.4%–28.6% of these patients could be cured [5,6], reflecting the possibility that necrotic tissue cannot be completely removed with or without efficient re-epithelialization of the nasopharyngeal defect [7]. Many researchers have developed reconstruction techniques using different flaps, such as the vastus lateralis muscle free flap [8] and nasoseptal flap [9]. Zou et al. [7] used a posterior pedicle nasal septum and floor mucoperiosteal flap and found that the 2-year overall survival (OS) rate of the patients was improved to 77.9%. Endoscopic necrectomy followed by construction using a flap has been proven to be a safe and effective treatment for postradiation nasopharyngeal necrosis in patients with NPC. Recently, we developed a salvage treatment using endoscopic nasopharyngectomy, which appears to be an effective treatment in the management of patients with advanced recurrent NPC who are in the rT3 or rT4 stage with invasion into the internal carotid artery (ICA), skull base, orbit, infratemporal fossa, dura mater, or cranial nerves, among others. To prevent postoperative complications, such as wound infections caused by extensive exposure of the skull base, a nasal free mucosal flap, septal pedicled mucosal flap, or temporal muscle flap can be used to repair the skull base defect [10].

However, whether this technique would be an effective treatment for ORN remains unclear. Thus, in the present study, we aimed to investigate and evaluate the clinical efficacy of salvage treatment using endoscopic necrectomy and reconstruction of skull base defects using septal pedicled mucosal flaps or temporal muscle flaps to treat ORN lesions in NPC patients.

Methods

Patient selection and eligibility criteria

This was a prospective, observational, single-arm clinical study. From January 2020 to January 2022, skull base ORN patients who underwent radical endoscopic necrectomy followed by reconstruction using a septal pedicled mucosal flap or temporal muscle flap at the Eye, Ear, Nose and Throat Hospital of Fudan University were selected for enrollment. The selection criteria were as follows: 1) a definitive history of radiotherapy; 2) diagnosis of skull base ORN based on clinical symptoms, imaging examinations, and preoperative biopsy; and 3) surgical resection of skull base ORN after our evaluation to completely remove necrotic tissue by endoscopic necrectomy.

The exclusion criteria for this study were as follows: 1) broad ORN of the skull base beyond the resectable region (e.g., necrosis causing extensive damage to the intracranial structures, especially important blood vessels and nerves; necrosis destroying the intracranial structures with obvious radiation-induced brain edema after previous radiotherapy and unresectable cervical lymph node metastasis), which would make removal difficult and risky; 2) pathologically confirmed local recurrence with or without distant metastases before surgery; and 3) physical conditions unsuitable for surgery, such as heart failure.

The elimination criteria for this study were as follows: 1) tumor recurrence or distant metastases in the follow-up period; 2) serious complications after surgery affecting the patient's ability to continue treatment; 3) changes in the patient's physical condition rendering the patient unsuitable for continuing the original planned treatment or a request for the patient to stop treatment; or 4) missing data affecting the analysis of the curative effects.

This study was approved by the independent ethics committee of the Eye, Ear, Nose and Throat Hospital of Fudan University (IEC No. 2019095-1). Written informed consent was obtained from all patients. The study was registered with the Chinese Clinical Trial registry (ChiCTR2000029327).

Surgical procedure

The decision to perform endoscopic surgery was based on the location and severity of ORN, taking into account the patient's preferences and consultations with both radiation oncologists and surgeons. The endoscopic surgery was performed using 0- and 45-degree endoscopes (Matrix P Spectar, XION GmbH, Berlin, Germany). If lesions involved the sphenoid sinus, the bilateral sphenoid sinuses were opened, and the septum was removed. The posterior end of the nasal septum was removed, and the base of the sphenoid sinus was trimmed to outline the sphenoid sinus and nasopharynx (Figure 1A). To remove the necrosis invading the base of the middle cranial fossa and infratemporal fossa, using a modified Caldwell-Luc approach, we penetrated through the anterior wall of the ipsilateral maxillary sinus into the infratemporal fossa. The base of the middle cranial fossa was needed to create a better surgical space and to complete the surgical procedure (Figure 1B). The external pterygoid plate was abraded, and the foramen ovale and the main trunk of the mandibular nerve were exposed toward the back. The lingual and inferior alveolar nerves on the posteromedial side of the external pterygoid muscle were located, and the middle meningeal artery and sphenoid spine were exposed posteriorly (Figure 1C, D, E).

The skull base bone can be divided into cancellous and cortical bone. When necrosis invades the cortex of the skull base, surgeons can judge the extent of necrotic invasion by examining the endoscopic visual field and grinding the invaded bone to the normal boundary using a drill (Figure 1D). The extent of satisfactory debridement was determined during the operation by removing the necrotic soft tissue and muscle tissue and grinding the necrotic bone until bleeding was observed, indicating

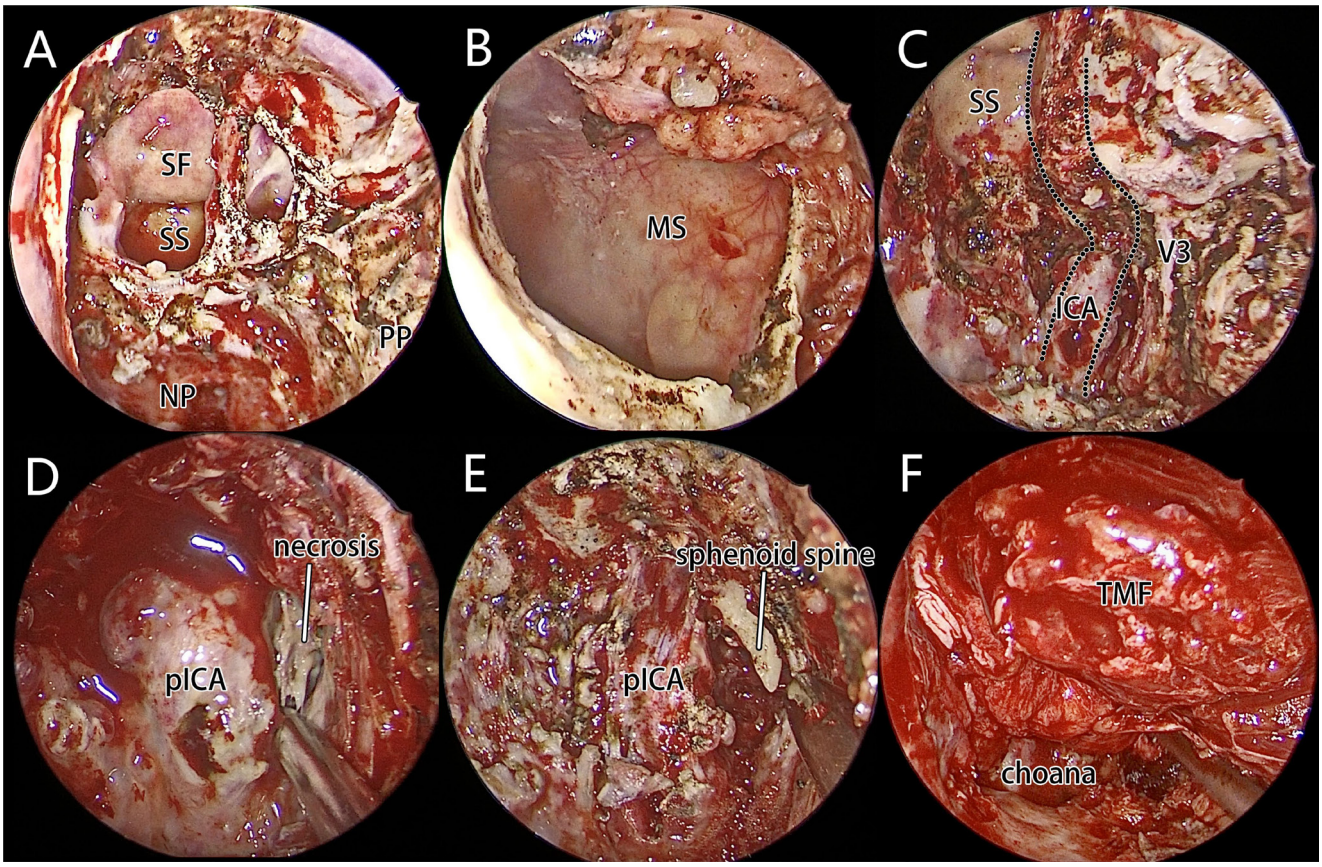

Figure 1. Intraoperative endoscopic endonasal images showing the main structures of the surgical field. (A)(B)(C) The sphenoid sinus was trimmed to outline the sphenoid sinus and nasopharynx. (D)(E) Necrosis was removed by grinding the invaded bone to the normal boundary. (F) A temporal muscle flap was used to repair the skull base defect. ICA: internal carotid artery; pICA: parapharyngeal ICA segment; MS: maxillary sinus; NP: nasopharynx; PP: pterygoid process; SF: sellar floor; SS: sphenoid sinus; TMF: temporal muscle flap.

that normal tissues and bone had been reached. Additionally, it is recommended that surgeons perform a basic evaluation of the necrotic areas and surrounding anatomical structures by computed tomography (CT) and magnetic resonance imaging (MRI) before the operation; surgeons should also assess the effect of the operation according to the results of CT and MRI on the first day after the operation.

We categorized transnasal endoscopic nasopharyngectomy (TEN) into four types: type I, with resection of the nasopharynx and sinuses; type II, with lateral extension to the parapharyngeal space; type III, with lateral extension to the floor of the middle cranial fossa and the infratemporal fossa and superior extension to the orbital apex and the cavernous sinus back to the prevertebral region; and type IV, with additional resection of the involved ICA following the type III procedure [11].

If necrosis invaded the ICA, a balloon occlusion test (BOT) of the ICA was performed prior to the surgical procedure. If the BOT was negative, surgery was performed immediately to resolve the ICA occlusion, and the lesion was removed during surgery (Figure 2). The parapharyngeal, petrosal, foramen, and clival segments of the ICA were exposed, and the related ICA was resected, in accordance with the extent of invasion. If the BOT was positive, bypass surgery between the external carotid artery and middle cerebral artery was performed prior to necrosis resection, which was performed two weeks later. To prevent postoperative complications, such as wound infections caused by extensive exposure of the skull base, a septal pedicled mucosal flap or temporal muscle flap was used to repair the skull base defect (Figure 1F).

Evaluation of the treatment efficacy

The primary endpoint of this study was an OS of 2 years, and a follow-up time less than 2 years was regarded as the last follow-up time. Locoregional recurrence in this study was defined as tumor recurrence identified in the skull base ORN lesion with positive pathology at the time of surgery or if the skull base ORN lesion had negative pathology at the time of surgery, but the patient developed recurrence during follow-up examinations. Patients with recurrence were excluded from this study.

The observed OS was taken as the endpoint, and headache syndrome changes and foul odor were also considered. The numeric rating scale (NRS) scores for QOL, pain and foul odor were

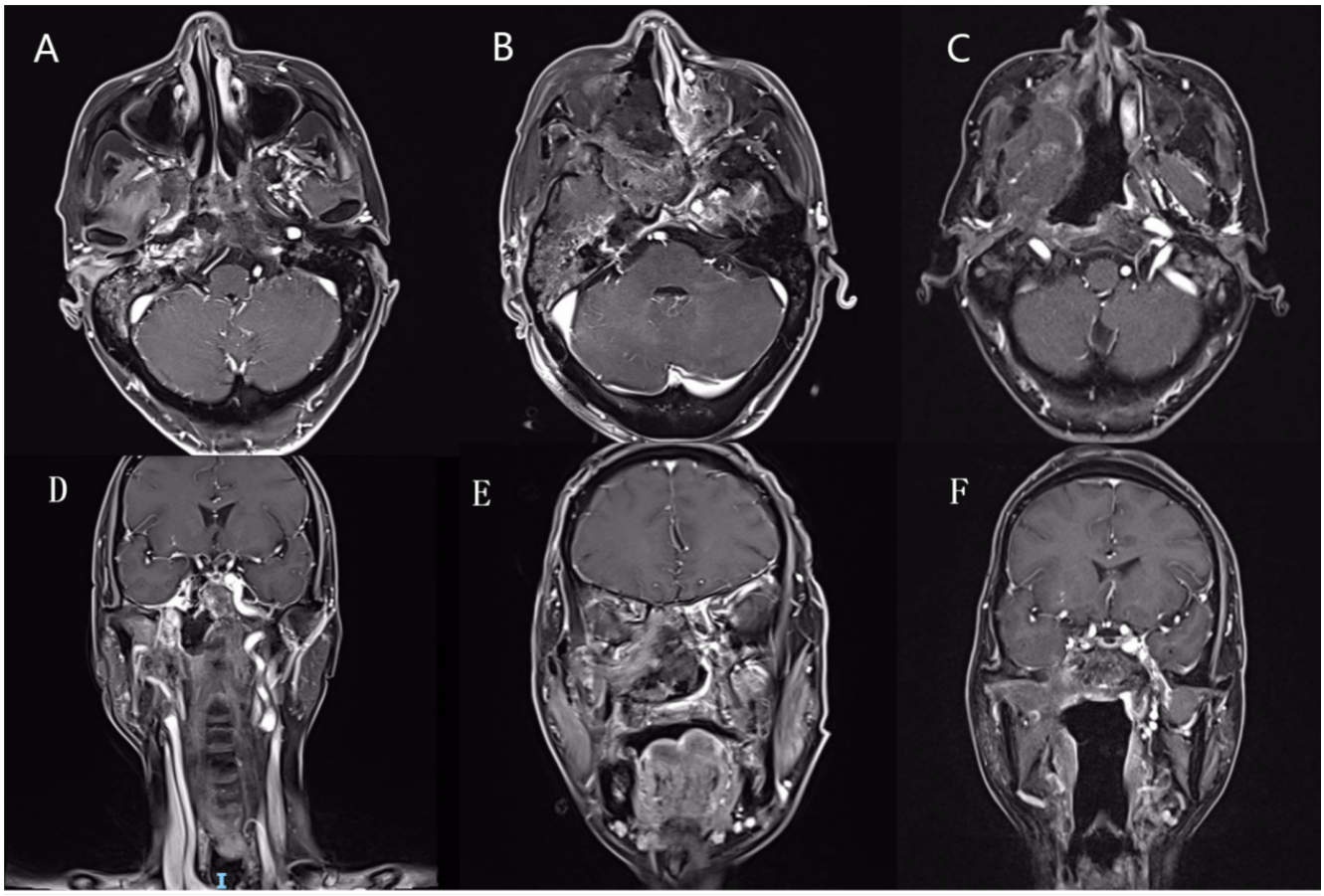

Figure 2. Enhanced magnetic resonance imaging (MRI) before and after surgery. (A) Horizontal and (D) coronal MRI showing the necrosis partially invading the right ICA. (B)(E) One day after surgery, the right ICA was embolized, and part of it was resected. A temporal muscle flap was used to repair the skull base defect, and the nasal cavity was packed. (C)(F) One year after surgery.

used to evaluate the headache levels before and within 3, 6, and 9 months after surgery. The patients were asked to rate their level of headache on a scale from 0 to 10, with 0 being none and 10 being unbearable, and foul odor on a scale from 0 to 3, with 0 being none and 3 being unbearable. QOL was scored on a scale from 0 to 7, with 0 being unbearable and 7 being normal. OS was calculated from the date of surgery until the date of last follow-up (January 1, 2022).

Follow-up

All patients were followed-up to assess the surgical outcomes, disease status, and performance status at the first month and every 3 months in the first 1 year after the operation, every 6 months in the second year, and annually thereafter. The follow-up examinations included complete physical examinations, MRI (MAGNETOM Video, Siemens, Berlin, Germany) and CT (SOMATOM Sensation 10; Siemens, Berlin, Germany) examinations of the head and neck, and syndrome and QOL evaluations.

Statistical analysis

For all cohorts, categorical data are described as numbers and percentages, and continuous data are presented as medians. Categorical data were analyzed using the chi-square test or chi-square test with continuity correction. The Wilcoxon rank-sum test was conducted for ranked data. The OS curves were plotted using the Kaplan–Meier method, and the significance of the differences among patients regarding the prognostic factors was analyzed using log-rank tests. A Cox regression model was used to perform multivariate survival analyses. The predicted values of the parameters were determined by receiver operating characteristic (ROC) curve analysis. All analyses were performed using SPSS software (version 16.0, SPSS, Chicago, IL, USA), and a two-tailed P value less than 0.05 was considered statistically significant.

Results

Patient characteristics

Between January 2020 and January 2022, 21 patients diagnosed with skull base ORN were assessed for eligibility, of whom 3 patients were excluded (Figure 3). The remaining 18 eligible patients completed the trial. A summary of the patients' details is presented in Table 1. There were 13 males and 5 females enrolled in our study, with a median age of 57 years, ranging from 34 to 72 years. In the present study, the normal range of BMI was

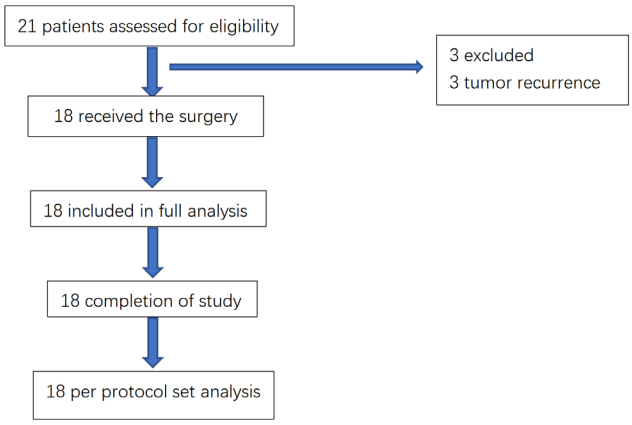

Figure 3. Trial profile.

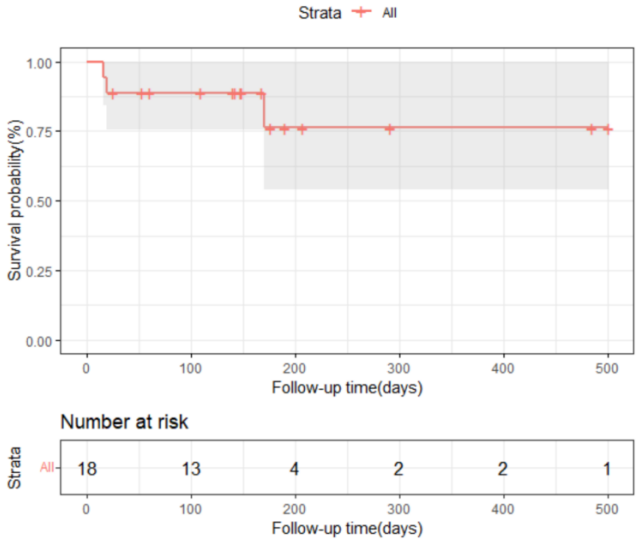

Figure 4. Kaplan–Meier curve of the overall survival (OS) of osteoradionecrosis (ORN) patients. During the 2-year study, the OS rate of the entire cohort was 75%.

Table 1. Characteristics of patients with ORN.

Characteristics	Total=18	%
Sex		
male	13	72.2
female	5	27.8
Age (years)		
≥50	14	77.8
<50	4	22.2
BMI (kg/m^2)		
18.5-24.9	11	61.1
<18.5	5	27.8
>24.9	2	11.1
Use of pedicled flap		
yes	16	88.9
no	2	11.1
Invasion of the ICA		
no invasion	7	38.9
invasion	5	27.8
invasion but ICA was embolized	6	33.3
Surgery type		
I	4	22.2
II	3	16.7
III	3	16.7
IV	8	44.4

ORN: osteordionecrosis; ICA: internal carotid artery.

set at 18.5-24.9 kg/m^2; 2, 11, and 5 patients had a high, normal, and low BMI, respectively. Two patients underwent endoscopic debridement, and 16 patients underwent reconstruction using pedicled flaps, including 4 patients treated with pedicled septal mucosal flaps and 12 patients treated with temporal muscle flaps. All flaps survived. Preoperative necrotic invasion into the ICA was observed in 11 patients (61.1%), including 6 patients with ICA embolization and 5 patients without ICA embolization. Moreover, in 7 patients, necrosis did not invade the ICA (38.9%). Furthermore, the procedure was categorized as type I, type II, type III, and type IV in 4, 3, 3, and 8 patients, respectively.

The follow-up period ranged from 2 weeks to 16 months, with a median of 3.68 months. During the 2-year study, the OS rate of the entire cohort was 75% (Figure 4). According to Table 2, only intraoperative blood transfusion was significantly associated with survival (Figure 5). No patient had a stroke as an outcome of any of the procedures. Three patients died, and all of them received an intraoperative blood transfusion. Two of them died in the first month because of hemorrhage, and the hemorrhage causing death was not related to the ICA. Another patient died in the sixth month because of multiple organ failure, and none of them underwent embolization. Age, weight, BMI, surgery type, whether a temporal muscle flap was used, and whether part of the ICA was resected were not significantly associated with survival (Figure 5).

Treatment efficacy

The median NRS score for pain decreased from 6.44±2.62 to 0.50 ±0.71 (P<0.001) after surgery, the NRS score for foul odor decreased from 1.89±1.08 to 1 (P=0.045), and the QOL score improved from 3.61±1.54 to 4.50±0.71 (P=0.045) (Table 3). These results show that the surgery relieved the symptoms and improved the QOL of patients.

No clinical characteristics were found to be an independent risk factor for survival on univariate logistic regression analysis (Table 4). This result is probably because the number of patients was too small. Because of the small sample size, the correlations

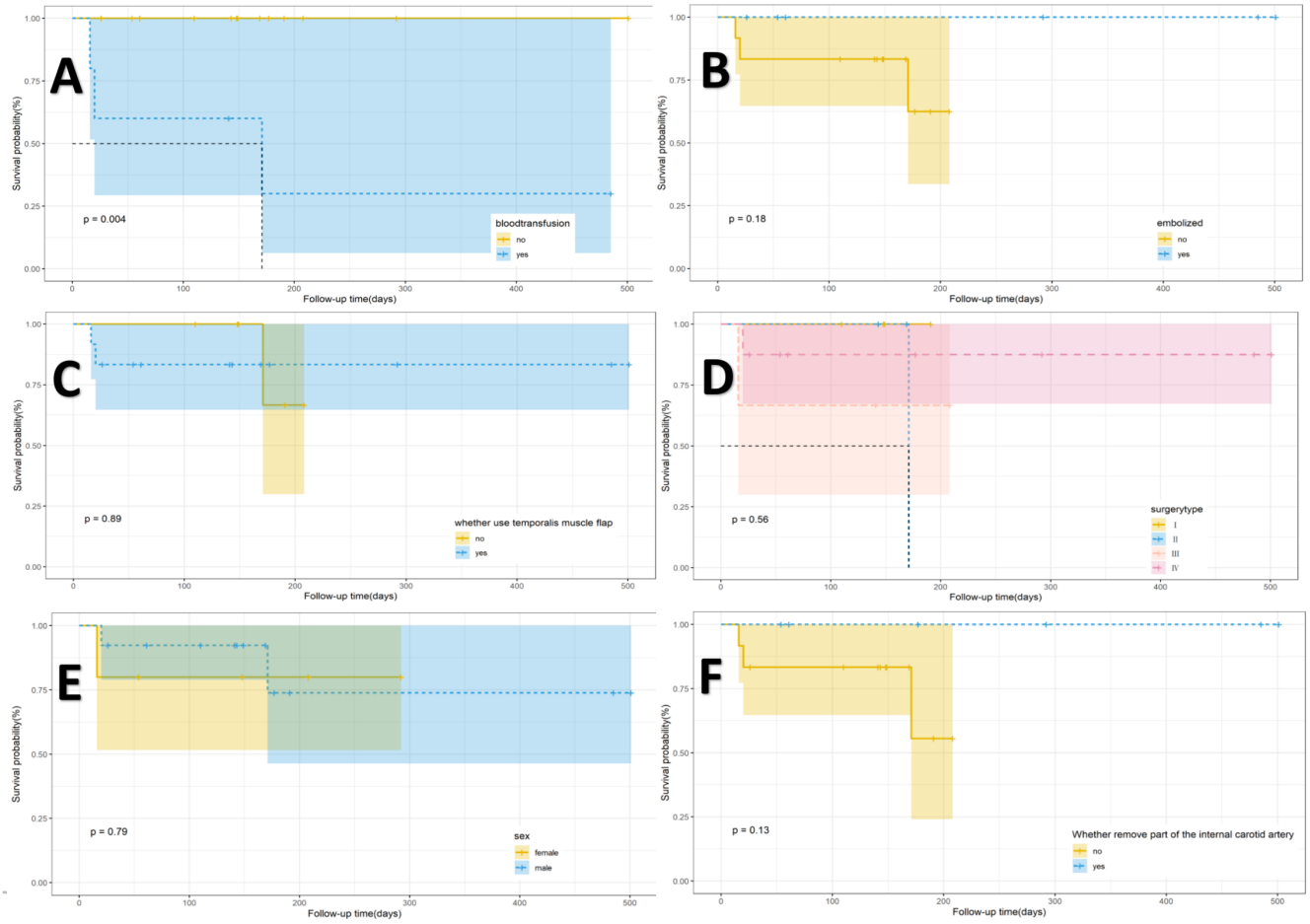

Figure 5. Kaplan–Meier curves of the OS of ORN patients: (A) intraoperative blood transfusion; (B) embolization; (C) temporal muscle flap; (D) surgery type; (E) sex; (F) whether the ICA was resected. Only intraoperative blood transfusion was significantly associated with survival.

of BOT, embolization, surgery type, temporal muscle flap, ICA resection, weight, and BMI showed collinearity; thus, only age, surgery type, sex, and blood transfusion were included in the multivariate logistic analysis (Table 4). More patient information needs to be collected in future studies, and a larger cohort is required to analyze these characteristics.

Discussion

ORN has a significant impact on patient QOL and has a high mortality rate [3,4]. According to the literature, postradiation nasopharyngeal necrosis can be described as a process with three stages. The severe stage, third in the process, aligns with the characteristics of skull base ORN. Of the 3 stages, ORN is one of the most serious and devastating complications, with an incidence rate of 10.1% [12].

In our study, many patients suffered from unbearable headaches and often used painkillers to control the pain. The patients experienced strong and persistent foul odors, which seriously affected their ability to communicate and severely decreased their QOL. After surgery, the patients' QOL was improved to some extent.

Before 2019, we investigated the effects of endoscopic debridement on skull base ORN for 10 years [13]. We enrolled 59 NPC patients with skull base ORN who underwent endoscopic nasopharyngectomy. In our study, 26 patients died. Most deaths in the study occurred during the first 2 years. Twenty-four of them died of sudden severe hemorrhage, which may be associated with ICA rupture. The 2-year OS rate was 54.2% [13].

During that time, we only used endoscopic debridement because of its limitations. Although repeated endoscopic debridement was reported as an effective traditional treatment, only 13.4%-28.6% of these patients could be cured [5,6]. However, we improved the reconstruction technique by using a different type of flap, which led to an OS of 75% [9]. To improve the efficacy of the treatment, many researchers have also developed reconstruction techniques using different flaps, such as the vastus lateralis muscle free flap [8] and nasoseptal flap [9]. Open salvage surgery following vascularized flap transfer has also been reported as an effective treatment for tissue necrosis after irradiation for head and neck cancers [14,15].

Endoscopic endonasal approaches have been rapidly developed in recent years. Zou et al. [7] designed a curative-intent endosco-

Table 2. Associations between clinical characteristics and survival.

		Survival (N=15)	Mortality (N=3)	P
Age (years)		55.53±10.25	63.67±7.37	0.214
Weight (kg)		53.87±9.59	58.50±7.47	0.445
Height (cm)		163.73±6.04	164.67±11.02	0.832
BMI (kg/m^2)		20.01±2.74	21.96±5.43	0.351
Sex	female	4 (26.7)	1 (33.3)	1.000
	male	11 (73.3)	2 (66.7)	
Surgery type	I	4 (26.7)	0 (0.0)	0.552
	II	2 (13.3)	1 (33.3)	
	II	2 (13.3)	1 (33.3)	
	IV	7 (46.7)	1 (33.3)	
BOT	positive	7 (46.7)	1 (33.3)	1.000
	negative	8 (53.3)	2 (66.7)	
Embolization	yes	6 (40.0)	0 (0.0)	0.502
	no	9 (60.0)	3 (100.0)	
ICA resection	yes	6 (40.0)	0 (0.0)	0.502
	no	9 (60.0)	3 (100.0)	
Blood transfusion	yes	2 (13.3)	3 (100.0)	0.019*
	no	13 (86.7)	0 (0.0)	
Temporal muscle flap	yes	10 (66.7)	2 (66.7)	1.000
	no	5 (33.3)	1 (33.3)	

BOT: balloon occlusion test; ICA: internal carotid artery. * means significant.

Table 3. NRS scores for QOL, pain and foul odour before and after surgery.

	Preoperative	First month	Third month	Sixth month	Ninth month	Twelfth month	P
No. of patients	18	17	10	5	3	2	
QOL	3.61±1.54	4.47±0.94	4.80±1.32	5.00±0.71	5.67±1.53	4.50±0.71	0.045*
Pain	6.44±2.62	3.53±2.48	1.00±0.94	0.80±0.84	0.67±0.58	0.50±0.71	<0.001*
Foul odour	1.89±1.08	1.18±0.88	0.80±0.79	0.80±0.84	1.33±0.58	1.00±0.00	0.045*

NRS: numeric rating scale; QOL: quality of life. * means significant.

pic surgery comprised of radical endoscopic necrectomy and reconstruction of the nasopharyngeal defect using a nasal septum and floor mucoperiosteal flap and analyzed the treatment outcomes in a cohort of 72 NPC patients, of which fifty-one patients (70.8%) achieved successful complete nasopharyngeal defect re-epithelialization. The 2-year OS rate of the entire cohort was 77.9%, which was similar to that in our study.

These results indicate that using endoscopic debridement with reconstruction by using different flaps could increase the OS rate of patients compared to the results in previously published studies, for which the risk of death ranged between 41.8% and 42.9% [4-6].

We previously successfully applied nasal septum and temporal muscle flaps to promote wound healing in recurrent NPC patients [10]. Although temporal muscle flaps have been widely used in the reconstruction of skull base defects after open approaches, their application in the endoscopic reconstruction of skull base defects has rarely been described in the literature. Our group has proven that temporal muscle flaps can be used to reconstruct skull base defects after extended endoscopic nasopharyngectomy and can effectively prevent the occurrence of serious complications in patients with recurrent NPC (16). However, whether these flaps could be effectively used to repair old and infected necrotic wounds in patients with ORN remained unknown until we obtained the results of the present study, which show that nasal septum and temporal muscle flaps can

Table 4. Independent risk factors for survival.

Characteristics		analysis		Multivariate analysis	
	Level	HR (95% Univariate CI)	P	HR (95% CI)	P
Age (years)		1.03 (0.96-1.11)	0.383	1.16 (0.94-1.40)	0.1009
BOT	positive	reference	reference		
	negative	0.66 (0.2-2.2)	0.502		
Surgery type	I	reference	reference	reference	reference
	II	0.66 (0.12-3.68)	0.634	0.37 (0.05-2.76)	0.3335
	III	0.71 (0.12-4.09)	0.701	0.25 (0.02-3.67)	0.3139
	IV	0.45 (0.1-1.92)	0.28	0.75 (0.15-3.79)	0.7253
Temporal muscle flap	yes	reference	reference		
	no	1.06 (0.33-3.37)	0.924		
Embolization	yes	reference	reference		
	no	2 (0.51-7.89)	0.323		
	no	0.52 (0.07-4.19)	0.543		
ICA resection	yes	reference	reference		
	no	2.74 (0.71-10.62)	0.146		
Sex	male	reference	reference	reference	reference
	female	1.07 (0.32-3.53)	0.913	22.27 (0.33-1502.53)	0.1487
Weight (kg)		1 (0.94-1.07)	0.942		
Blood transfusion	yes	reference	reference	reference	reference
	no	1.96 (0.43-8.95)	0.386	0.68 (0.08-5.73)	0.7228
BMI (kg/m2)		1 (0.82-1.23)	0.97		

BOT: balloon occlusion test; ICA: internal carotid artery.

be effectively used to repair necrotic wounds. While we harvested the nasoseptal flap prior to posteroinferior septectomy [17], we harvested the temporalis muscle flap after necrectomy [18]. The decision of what flap to use was dependent on the necrotic area and surgical history. When a nasoseptal flap cannot be used or when adequate bulk is needed, a temporalis muscle flap is an excellent alternative option for the reconstruction of endoscopic skull base defects [16]. Furthermore, all flaps survived.

Additionally, when the ICA is exposed, aggressive endoscopic debridement is not advocated to prevent ICA rupture and severe massive bleeding. As such, an efficient technique to remove the necrotic lesion and to safely and completely re-epithelialize the defect must be developed as a key step for the successful treatment of ORN lesions. ICA injury during endoscopic debridement and reconstruction is rare but fatal. We also recommend a safety assessment through the ICA grading scale and strategy to obtain the maximum total resection rate while ensuring patient safety [19].

Moreover, a preoperative BOT was used to determine whether the ICA could be safely occluded without cerebral ischemia when the ICA was exposed to the ORN lesion. Furthermore, endovascular coiling embolization was performed for patients suffering from vascular wall trauma or pseudoaneurysm when the result of the BOT was negative. These methods successfully solved the issues regarding a sudden intra- or postoperative rupture and fatal nasopharyngeal hemorrhage of the ICA and could be helpful to sufficiently increase the confidence of surgeons to remove necrotic tissues even if the lesion is close to the ICA [20,21]. Even if the patient had a sudden intra- or postoperative rupture or even a massive nasopharyngeal hemorrhage of the ICA when the BOT result was negative, they could be rescued by endovascular coiling embolization. However, in our study, whether the patient underwent embolization or partial ICA resection was not significantly associated with survival. On the other hand, intraoperative blood transfusion was significantly associated with survival. In this study, 2 patients also died because of hemorrhage, which means that embolization was important during surgery.

Despite the promising results of the present study, there are several potential limitations worth mentioning. First, the data of this study are from prospective studies, but we included only 18 patients, resulting in an inadequate evaluation of patient QOL.

We will improve our evaluation method in future studies. Additionally, the small sample size was a limitation regarding multivariate logistic analysis. Therefore, a larger cohort is required to validate these results. Second, the median follow-up time was relatively short because our study duration was 2 years, and the follow-up time ranged from 2 weeks to 16 months, with a median of 3.68 months. We expect future studies to have a longer follow-up time.

Conclusions

Skull base ORN is a devastating postradiation complication in NPC patients that not only severely impacts QOL but also endangers patients' lives. Thus, in the present study, we investigated and evaluated the clinical efficacy of salvage treatment using endoscopic necrectomy and reconstruction of the skull base defect using a septal pedicled mucosal flap or temporal muscle flap in NPC patients with ORN lesions. We think this technique is a valuable treatment option for NPC patients with skull base ORN, as this surgery can relieve the symptoms and improve the QOL of most patients.

List of abbreviations

ORN: osteoradionecrosis; NPC: nasopharyngeal carcinoma; OS: overall survival; QOL: quality of life; NRS: numeric rating scale; ICA: internal carotid artery; BOT: balloon occlusion test; TEN: transnasal endoscopic nasopharyngectomy; ROC: receiver operating characteristic.

Acknowledgements

We appreciate all the participants for their contribution and participation.

Authorship contribution

HMY and XCS conceived and designed the study. QD, YXS, HKZ, XLS, QL, KQZ, JYY, LW collected the clinical and imaging data. HMY, XCS, QD and YXS analyzed the data and wrote the manuscript.

Ethics approval and consent to participate

This study was approved by the independent ethics committee of the Eye, Ear, Nose and Throat Hospital of Fudan University (IEC No. 2019095-1). Written informed consent was obtained from all patients.

Data availability

All patients in the study were treated at the Department of Otolaryngology, Eye & ENT Hospital, and the authors ensured the reliability of the presented data and material. The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

Conflicts of interest

The authors have no conflicts of interest to declare.

Funding

This work was sponsored by the Shanghai Sailing Program (21YF1405700), the National Natural Science Foundation of China (81970856), the National Key Clinical Specialty Construction Project (Z155080000004), the Shanghai Science and Technology Committee Foundation (19411950600 and 21JC1401100), the Shanghai Xuhui District Science and Technology Committee Foundation (No. 2021-008), and the New Technologies of Endoscopic Surgery in Skull Base Tumor: CAMS Innovation Fund for Medical Sciences (CIFMS) (2019-I2 M-5-003).

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