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Comparative the impact intraoperative phrenic nerve sacrifice on prognosis patients with thymoma

Hongyun Ruan[1*†], Xuehui Shang[2†], Dongjie Yan[3†], Bin Liu[1*], Fangchao Liu[4*] and Zhi Yang[3*]

Abstract

Objectives Complete removal of the tumor and surrounding tissue is the most important prognostic factor such as survival after surgery. When the tumor invades the phrenic nerve, the impact of intraoperative phrenic nerve sacrifice on the short- and long-term prognosis of patients is not clear. This study aims to explore the differences in prognosis between patients with malignant thymoma with and without phrenic nerve sacrifice during surgery, as well as analyze related factors.

Methods A total of 209 patients who underwent thymoma resection in the Department of Thoracic Surgery at our hospital from February 2006 to November 2022 were collected for retrospective analysis. The groups were divided into two according to the presence or absence of intraoperative phrenic nerve sacrifice. A comparative analysis was conducted on postoperative complications, long-term survival recurrence between the two groups. Cox regression was used to analyze the factors related to the differences in short- and long-term prognosis between two groups.

Results 29.6% of patients developed phrenic nerve sacrifice during thymoma surgery. Compared to patients without phrenic nerve sacrifice, the long-term survival rate was lower ($P=0.031$). The independent risk factors for reduced long-term survival were intraoperative phrenic nerve sacrifice, secondary postoperative complications, and modified Masaoka staging III/IV.

Conclusion Our data show that nearly one-third of patients develop phrenic nerve sacrifice during complete resection of thymoma. Phrenic nerve sacrifice has significant impact on short-term complications and long-term survival. Secondary postoperative complications and modified Masaoka staging III/IV are also risk factors for reduced long-term survival.

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Keywords Thymoma, Surgical resection, Phrenic nerve sacrifice, Prognosis

Introduction

Thymoma is a rare type of malignancy derived from thymic epithelial cells [1]. The most effective treatment is surgical excision [2–6]. The removal of the entire thymus gland and its surrounding tissues is the most important decisive factor for survival after surgery [5–7]. However, the thymomas of modified thymoma Masaoka stage II, III, and some IV mainly metastasize to local, such as extrathymic adipose tissue, pleura, heart, lung, blood vessels, phrenic nerve etc. The phrenic nerve (PN) is anatomically connected along the mediastinal pleura to the thymus at the level of the superior mediastinum [7]. Phrenic nerve involvement has been reported in up to 33% of patients with thymoma [8]. For thymomas with phrenic nerve invasion, phrenic nerve-preserving surgery is said to have a high recurrence rate, and in some cases additional radiation therapy is performed [8, 9]. In order to achieve good long-term survival and disease-free survival after surgery, complete resection of the tumor (R0) is required during surgery, and phrenic nerve injury occurs in some patients.

The phrenic nerve is the most important nerve in the cervical plexus and belongs to the mixed nerve, which contains motor and sensory fibers, and its motor fibers mainly innervate the movement of the diaphragm. When the phrenic nerve is damaged, the diaphragm is mainly paralyzed on the same side, abdominal breathing is weakened or disappears, and in severe cases, there may be a feeling of suffocation. Diagnosis is confirmed by imaging showing full or partial elevation of one diaphragm and continuous diaphragm shadows. Phrenic nerve damage severely affects the patient's respiratory function [10, 11].

In 1996, Masaoka et al. reported that the removal of tissues such as the thymus and its extended phrenic nerve in patients with thymoma and MG can reduce the recurrence of MG after surgery [12]. Yano et al. showed that preserving thymoma was associated with similar long-term survival compared with resecting thymoma, and that postoperative lung function tests were similar [13]. However, the risk of recurrence after locally advanced surgery is still frightening to patients. Whether the phrenic nerve is removed to achieve the R0 of the tumor, or whether the phrenic nerve is protected to facilitate the recovery of postoperative respiratory function has been controversial in thoracic surgery. To determine the differential effect of phrenic nerve injury on clinical efficacy and safety during thymoma resection. We retrospectively summarized and analyzed the clinical data of patients who underwent thymoma resection from February 2008 to March 2024 and were pathologically diagnosed with thymoma after surgery, in order to obtain the pros and cons of the pros and cons between complete thymoma resection and intraoperative phrenic nerve injury, and to provide a reference for patients to choose the treatment method with the greatest benefit.

Data and methods

Through the hospital's electronic medical record system, we collected data from 209 patients who underwent thymoma surgery in our thoracic surgery department between February 2006 and November 2022. Intraoperative phrenic nerve sacrifice occurred in 62 (29.7%) of these patients. Preoperative images showed phrenic nerve invasion in 5 patients, 4 of which were located on the right side, with slight elevation of the diaphragm, and further elevation of the diaphragm was seen on postoperative images. Definition of Phrenic Nerve Sacrifice: The patient clearly had a phrenic nerve resection during surgical manipulation for thymoma.

Inclusion criteria: Patients must meet all the following criteria to be included: age ≥ 18 years and < 70 years; pathologically diagnosed with thymoma after surgery via our hospital's thoracic surgery department; patients with underlying diseases must have their conditions under control and be deemed surgically tolerant by the doctor; and their medical records must be relatively complete.

Exclusion criteria: Patients meeting any of the following criteria will be excluded from participation: bronchial asthma, chronic obstructive pulmonary disease, history of malignancy, chronic cardiac insufficiency, preoperative respiratory failure and Incomplete removal of thymic tumor.

The study design complied with the Helsinki Research Ethics Statement. The written informed consent was waived by the Beijing Chest Hospital of Capital Medical University of the committee/IRB (Ethics number: Clinical Research 2019 (85)).

The phrenic nerve is sacrificed in order to accomplish an R0 resection. The patients with thymoma were divided into two groups according to whether the phrenic nerve was injured during thymectomy: thymectomy without phrenic nerve sacrifice and thymectomy with phrenic nerve sacrifice. The general clinical data of the patients, including gender, age, body mass index (BMI), smoking status, and major complications (including hypertension, coronary heart disease, chronic lung disease, and diabetes), were collected. The maximum diameter of the tumor was measured, and the tumor was classified into stages II, III, and part IV based on the modified Masaoka staging system [14]. Osserman MG staging system: 0 stage (no MG), ≥ 1 stage (MG) [15], . Whether or not MG drugs were used was divided into MG drug use and

no MG drug use. Preoperative evaluation of dyspnea was based on the modified British MRC dyspnea grading scale (mMRC), with mMRC ≥ 2 indicating dyspnea.

The pulmonary function indicators included the percentage of forced expiratory volume in one second to the predicted value (FEV_1%pred) and the percentage of carbon monoxide diffusing capacity to the predicted value (DLCO% pred) [16]. The venous blood indicators included hemoglobin (Hb), albumin (ALB), C-reactive protein (CRP), and other measured values. All preoperative testing data indicators were completed within one week before surgery.

The surgical methods included thoracoscopy, left or right thoracotomy, and median sternotomy. Intraoperative blood loss and operation time were recorded. Postoperative short-term outcomes included death within 30 days of hospitalization and discharge, postoperative complications (postoperative infection, respiratory failure, cardiac failure), invasive ventilatory support and duration.

The follow-up period was from February 2008 to June 2024, and patients with thymoma surgery were followed up by trained healthcare professionals through face-to-face or telephone interviews. The main outcomes of postoperative follow-up: overall survival (OS), secondary outcomes: MG recurrence and rehospitalization, which were confirmed by 3 senior attending physicians.

Quality control

The study is to adopt standardized methods for data entry, verification, follow-up plans, training protocols, and follow-up techniques. The follow-up plan and its contents were audited and validated by senior respiratory medicine and thoracic surgery clinicians, and the follow-up plan was supervised by highly trained general practitioners.

Statistical analysis

The patients with histopathological diagnosis of thymoma were divided into two groups based on whether the phrenic nerve was injured during surgery. Normal distribution of measurement data was presented as mean ± standard deviation, and the inter-group comparison was conducted using t-test. Non-normal distribution of measurement data was presented as median (25th, 75th percentiles), and the inter-group comparison was conducted using Z-test. Categorical data were presented as constituent ratio or rate (%) and compared between groups using chi-square ($\chi 2$) test. The patients' intraoperative phrenic nerve sacrifice, postoperative short-term mortality, and postoperative complications were recorded. The patients were followed up to observe OS and MG recurrence. Based on the literature reports and clinical experience, key factors closely related to adverse prognosis included gender, age, smoking history, comorbidities, MG, modified Maskao staging, Hb, ALB, CRP, FEV_1%pred, DLCO%pred [8, 9, 17, 18]. Univariate meaningful associated key factors were BMI, maximum tumor diameter, operative procedure, operative time, intraoperative emergence, intraoperative partial pericardiectomy, vascularization and preoperative concomitant dyspnea mMRC ≥ 2.COX regression analysis was conducted for all factors related to adverse prognosis, with $P < 0.05$ considered statistically significant. All calculations were performed using SPSS 25.0 (SPSS Inc., Chicago, IL, USA).

Results

A total of 209 patients with thymoma were included in the study, 106 of them were male and 103 were female, with a mean age of 50.6 ± 12.6 years. 29.6% (62/209) of the patients suffered from phrenic nerve sacrifice during thymoma surgery, among which, 36 cases were male and 26 were female, with a mean age of 50.9 ± 11.0 years. Left phrenic nerve sacrifice occurred in 34 cases, while right phrenic nerve sacrifice occurred in 28 cases. 12 patients (5.7%) underwent chemotherapy induction therapy preoperatively to reduce tumor volume and thus reduce the need for neuroresection, Fig. 1. Two patients underwent diaphragm repair.Diaphragmatic repair in 2 patients,. Postoperative patients who needed invasive ventilator support accounted for 14.8% (31/209), among which, 25 patients were transferred to the ICU for ventilator support after surgery, while the other 6 patients received reintubation after surgery within 5–168 h. The median time of ventilator support for these patients was 85 h. elevated diaphragms in 5 patients, 4 of them on the right side, and postoperative images showed further elevation of the diaphragm. 6 patients with phrenic neurectomy had preoperative symptoms of shortness of breath and wheezing, but one of them had a 20-year preoperative history of concomitant tuberculosis and the other had a preoperative history of radiation pneumonitis.

As of January 31, 2024, a total of 209 patients who underwent thymectomy for thymoma were monitored for follow-up, including 3 deaths during the postoperative hospitalization, for a loss-of-field rate of 8.4% (16/206). 190 patients completed follow-up, for a total of 863.6 person-years of follow-up, with a median follow-up time of 3.3 years. In the long-term follow-up of postoperative patients, 19 patients (33.3%) died of pneumonia or respiratory failure from recurrent lung infections; 38 patients (66.7%) eventually died of multiple organ failure due to tumor metastasis. 57 patients, or 40.3% (23 /57), who died during postoperative follow-up had the phrenic nerve sacrificed during surgery.

Compared with the group without phrenic nerve sacrifice, the group with phrenic nerve sacrifice had higher mean body mass index (BMI) ($P < 0.001$), larger

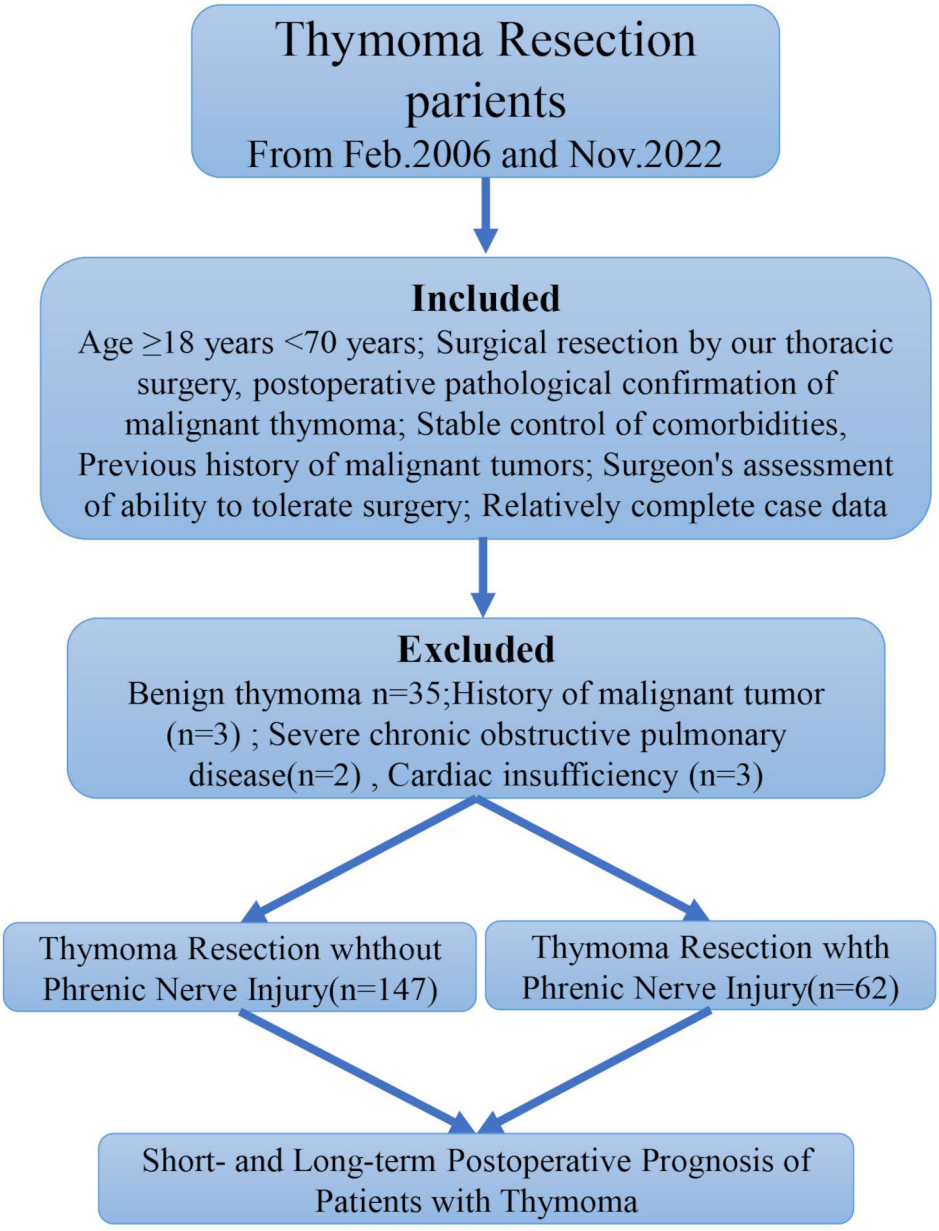

Fig. 1 Flowchart of patients underwent for Thymoma Resection

maximum tumor diameter ($P<0.001$), longer surgical time ($P=0.002$), and higher intraoperative blood loss ($P<0.001$). Preoperative respiratory index score mMRC ≥ 2, modified Masaoka staging III and IV, midline sternal splitting, partial pericardial resection, and vascular replacement occurred more frequently in the group with phrenic nerve sacrifice, with *P*-values of 0.037, < 0.001, 0.019, 0.001, and < 0.001, respectively, Table 1.

The incidence of postoperative short-term complications was higher in the phrenic nerve sacrifice group (15.0% vs. 29.0%, $P=0.018$). At the end of the follow-up period, the long-term survival rate was lower in the phrenic nerve sacrifice group (24.8% vs. 40.4%, $P=0.031$), while there was no difference in the rate of MG recurrence (6.8% vs. 10.5%, $P=0.379$), Table 2.

The Logistic proportional-hazards model analysis for risk factors of severe postoperative complications with thymoma resection regression analysis showed that the independent risk factors for the increased incidence of postoperative complications were midline sternotomy (aHR: 3.237, 95% CI: 1.493–7.020, $P=0.003$), longer operation time (aHR: 1.007, 95% CI: 1.002–1.012, $P=0.009$), and preoperative dyspnea index mMRC ≥ 2 (aHR: 2.928, 95% CI: 1.547–5.543, $P=0.001$), Tables 3 and Fig. 2.

The Cox regression analysis revealed that the independent risk factors for postoperative long-term survival

Table 1 Baseline characteristics of thymoma patients with or without intraoperative phrenic nerve sacrifice

Variables	Total (*n* = 209, %)	Thymoma Resection group (*n* = 147, %)	Thymoma Resection + Phrenic Nerve Sacrifice (*n* = 62, %)	*P* value
Gender, M	106.0 (50.7)	70.0(47.6)	36.0(58.1)	0.168
Age, Y	50.6 ± 12.6	50.6 ± 13.2	50.9 ± 11.0	0.874
BMI, kg/m^2	24.9 ± 3.6	24.3 ± 3.5	26.2 ± 3.5	<0.001
Smoking history	57.0(27.3)	35.0(23.8)	22.0(35.5)	0.083
Complications*	96.0(45.9)	68.0(46.3)	28.0(45.2)	0.884
Course, M	1.0(0.5,3)	1.0(0.5,3)	1.0(0.5,3.0)	0.580
Tumor size, cm	6.0(4,8.1)	6.0(4,7.8)	7.0(5,10)	<0.001
Location, front	96.0(45.9)	68.0(46.3)	28.0(45.2)	0.884
MG, Y	34.0(16.3)	25.0(17.0)	9.0(14.5)	0.656
MG Medications	18.0(8.6)	15.0(10.2)	3.0(4.8)	0.207
Preoperative mMRC, ≥2	45.0(21.5)	26.0(17.7)	19.0(30.6)	0.037
Revised Masako Staging	16.0(12.9)	10.0(12.2)	6.0(14.3)	0.742
Revised Masako Staging				
Stage II	130.0(62.2)	101.0(68.7)	29.0(46.8)	ref
Stage III	70.0(33.5)	39.0(26.5)	31.0(50.0)	--
Stage IV	9.0(4.3)	7.0(4.8)	2.0(3.2)	0.004
ALB	41.2 ± 6.3	40.9 ± 5.7	41.9 ± 7.4	0.308
CRP	1.6(0.6,6.6)	1.3(0.5,6.6)	1.8(0.7,5.9)	0.525
Preoperative Pulmonary function test				
FEV_1% pred	90.1 ± 15.5	90.2 ± 16.2	90.1 ± 13.9	0.970
PEF% pred	88.2 ± 21.6	87.7 ± 22.3	89.3 ± 20.2	0.603
DLCO % pred	82.3 ± 16.4	82.6 ± 16.0	81.4 ± 17.4	0.638
Surgical approach				
VAST	88.0(42.1)	71.0(48.3)	17.0(27.4)	ref
Side opening	80.0(38.3)	51.0(34.7)	29.0(46.8)	--
Splitting of the sternum right in the middle	41.0(19.6)	25.0(17.0)	16.0(25.8)	0.019
Time of operation	127.4 ± 58.4	119.5 ± 55.3	146.1 ± 61.5	0.002
Intraoperative bleeding	100(50,295)	110(80,147)	200(50,562.5)	<0.001
Concomitant pericardiotomy	22.0(10.5)	9.0(6.1)	13.0(21.0)	0.001
Vascular replacement	9.0(4.3)	1.0(0.7)	8.0(12.9)	<0.001
postoperative treatment#	54.0(25.8)	28.0(19.0)	26.0(41.9)	0.001

Note: *,Complications including 31 cases of hypertension and 6 cases of coronary heart diseas;11cases of Diabetes;#, postoperative treatment: 12 were chemotherapy alone, 36 were radiotherapy alone, 4 were chemotherapy + radiotherapy, chemotherapy + immunization, radiotherapy + immunization and chemotherapy + radiotherapy + immunization were all 1

Abbreviations: BMI, body mass index; Hb, hemoglobin; ALB, albumin; CRP, C-reaction protein; FEV_1 (% pred), forced expiratory volume in one second of predicted; PEF (% pred), Pef peak expiratory flow of predicted; D L CO (% pred), lung diffusion capacity of predicted; VAST : Video-assisted thoracospy; mMRC: ModifiedBritish Medical Research Council; MG: myasthenia gravis

were intraoperative phrenic nerve sacrifice (aHR: 6.588, 95% CI: 1.583–27.413, $P = 0.010$), postoperative complications (aHR: 1.953, 95% CI: 1.086–3.512, $P = 0.025$), and patients with modified Masaoka staging III/IV of thymoma (aHR: 2.607, 95% CI: 1.092–6.225, $P = 0.031$), Tables 4 and Fig. 3.

Discussion

For operable thymoma, surgical complete resection is the preferred treatment [3, 19]. Complete clearance of the thymus and surrounding tissue is key to the optimal prognosis after surgery [20–22]. During complete resection of thymoma, approximately one-third of patients have invasion of the phrenic nerve, resulting in intraoperative damage. Damage to the phrenic nerve directly leads to phrenic paralysis and affects respiratory function. Our study found that intraoperative phrenic nerve sacrifice in thymoma resection had a significant impact on short-term complications and long-term survival. Secondary postoperative complications and modified Masaoka staging III/IV also affected long-term survival. Previous studies have clearly shown that modified Masaoka staging is associated with postoperative survival. Our study data also showed In the complete thymoma resection + phrenic nerve sacrifice group, the proportion of Masaoka stage III was 50%, This could be previous studies have shown that 33% of progressive thymomas (Masaoka stage III, IV) invade the phrenic nerve

Table 2 Outcomes of thymoma patients with or without intraoperative phrenic nerve sacrifice

Variables	Thymoma Resection group (*n* = 147, %)	Thymoma Resection + Phrenic Nerve Sacrifice (*n* = 62, %)	*P* value
Short-term postoperative outcome			
Death with 30 days	2(1.4)	1(1.6)	1.000
Post-operative invasive ventilator	18(12.3)	13(21.0)	0.110
Ventilator duration, h	13.5	22.9	0.225
Complications, D	22(15.0)	18(29.0)	0.018
Respiratory failure	18(12.2)	13(21.0)	0.105
Lung infections	4(2.7)	4(6.5)	0.199
Acute pulmonary embolism	4(2.7)	2(3.2)	0.575
Acute renal failure	0(0)	1(1.6)	0.297
Duration of complications (median, IQR)[a]	8(5,11)	8(1.8,12)	0.327
Long-term postoperative outcome[b]	(*n* = 133, %)	(*n* = 57, %)	
overall survival rate, Y[c]	33 (24.8)	23(40.4)	0.031
Follow-up survival time (median, M, IQR)	39.1(17.3,66.0)	32.9(11.7,71.4)	0.920
Relapse or MG relapse	9(6.8)	6(10.5)	0.379

Note: a, Wilcoxon Signed rank-sum test; b: 3 perioperative deaths and deletion of 16 lost cases during follow up; c: The time of death (from any cause) was from the time the patient was discharged from hospital to the end of follow-up

Abbreviation: IQR, Inter Quartile Range; mMRC: ModifiedBritish Medical Research Council

Table 3 Logistic proportional-hazards model analysis for risk factors of severe postoperative complications with thymoma resection

Variables	postoperative complication	
	P value	Adjusted OR (95% CI)
Surgical approach		
VAST	--	Ref
Side opening	0.826	1.113(0.429–2.899)
Splitting of the sternum right in the middle	0.003	3.237(1.493–7.020)
Time of operation	0.009	1.007(1.002–1.012)
Preoperative MmRC, ≥2	0.001	2.928(1.547–5.543)

Note: Dependent variables include: Gender; Age; Smoking history; Preoperative

mMRC; BMI; Complications; Phrenic Nerve Sacrifice; Tumor size; MG; Revised Masako Staging; HB; ALB; CRP; FEV_1% pred; D L CO % pred; Surgical approach; Time of operation; Intraoperative bleeding; Concomitant pericardiotomy; Vascular replacement

Abbreviation: VAST: Video-assisted thoracospy; mMRC: ModifiedBritish Medical Research Council; Masako Staging, BMI, body mass index; MG: myasthenia gravis; Hb, hemoglobin; ALB, albumin; CRP, C-reaction protein; FEV $_1$% pred, forced expiratory volume in one second of predicted; D L CO % pred, lung diffusion capacity of predicted

[8], while the proportion of patients who are Masaoka stage IV at the time of their first diagnosis and who still have a chance of having surgery is small.

This study found that the incidence of postoperative complications in patients with thymoma resection with phrenic nerve sacrifice was higher than in patients without phrenic nerve sacrifice. This is related to the surgical approach of median sternotomy, long operation time, and preoperative respiratory difficulties. Some scholars have studied the use of median sternotomy as a technique that increases the risk of postoperative ventilator support treatment by 12.5 times [23]. The median sternotomy approach is required for the high degree of disease severity and wide range of lesions, resulting in greater surgical trauma, more intraoperative blood loss, and longer operation time [23, 24]. Transsternal thymectomy, as the gold standard for thymoma resection, has the advantages of sufficient surgical exposure and complete resection of anterior mediastinal adipose tissue, effectively removing the tumor [23, 25]. The thoracoscopic approach reduces trauma but is less effective in complete resection of tumor tissue, especially when expanding the resection range and undergoing vessel replacement surgery. Failure to completely remove thymoma tissue can lead to abnormal function, causing autoimmune tolerance disorders and serious postoperative complications in the short and long term. Therefore, early detection of thymoma can help reduce operation time and postoperative complications.

Our follow-up results show that the overall survival of patients with thymoma surgery with phrenic nerve sacrifice is lower than those without phrenic nerve sacrifice. CT comparison before and after surgery shows that whether it is left or right phrenic nerve sacrifice, postoperative CT can be seen that the injured diaphragm is significantly elevated. Phrenic nerve damage can cause ipsilateral phrenic paralysis, leading to respiratory muscle fatigue, limiting self-respiration and

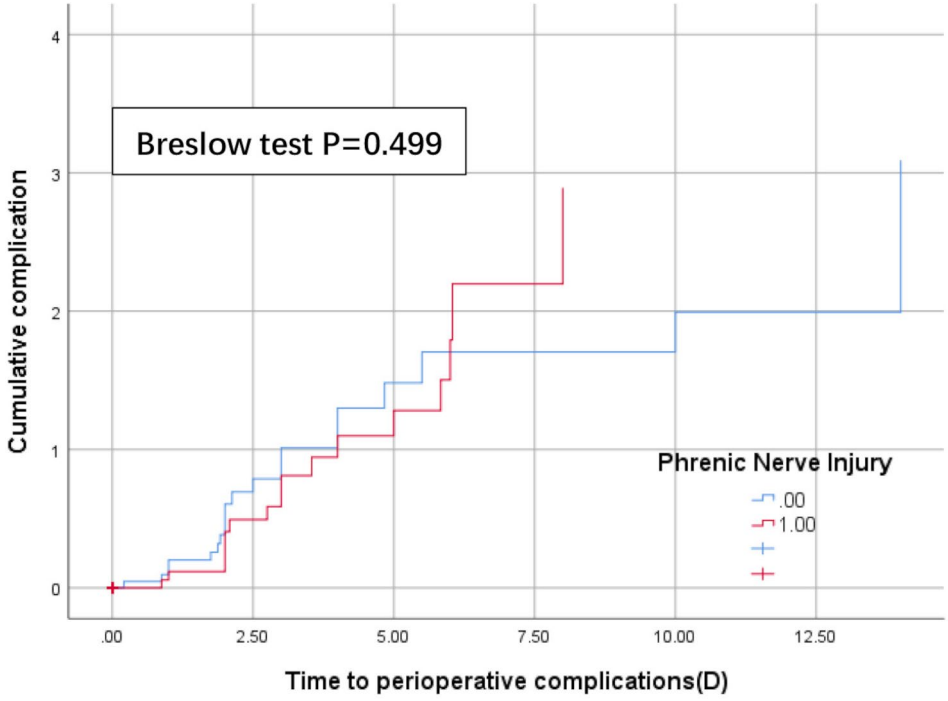

Fig. 2 Short-term postoperative prognosis of Thymoma Resection group and Thymoma Resection + Phrenic Nerve Sacrifice group

Table 4 Cox proportional-hazards model analysis for risk factors of long-term mortality with thymoma resection

Variables	Death	
	P value	Adjusted OR (95% CI)
Phrenic Nerve Sacrifice	0.010	6.588(1.583–27.413)
postoperative complication	0.025	1.953(1.086–3.512)
Revised Masako Staging		
Stage II	--	Ref
Stage III	0.040	2.514(1.043–6.060)
Stage IV	0.031	2.607(1.092–6.225)

Note: Dependent variables include: Gender; Age; Smoking history; Preoperative mMRC; BMI; Complications; Phrenic Nerve Sacrifice; Postoperative complication; MG; Revised Masako Staging; HB; ALB; CRP; FEV_1% pred; D L CO % pred; postoperative radiotherapy and immunotherapy

Abbreviation: BMI, body mass index; MG: myasthenia gravis; Hb, hemoglobin; ALB, albumin; CRP, C-reaction protein; FEV_1% pred, forced expiratory volume in one second of predicted; D L CO % pred, lung diffusion capacity of predicted

pulmonary ventilation, causing pulmonary ventilation and gas exchange disorders [26]. In severe cases, it can lead to CO_2 retention and increased risk of respiratory failure [27, 28]. Sarah Hamdi and other scholars have found that protecting the phrenic nerve during thymectomy can lead to better long-term survival, which is consistent with our research results [8]. Our data also show that the Masaoka stage III and IV of thymoma are related to postoperative survival, which is consistent with the conclusions of many scholars [29–32]. Patients with severe postoperative complications, especially those who require a longer duration of ventilator support, have a significantly higher risk of death. This suggests that when thymoma invades the phrenic nerve, it is beneficial for patients' long-term survival to protect the phrenic nerve during surgery. Although there was no significant difference in MG recurrence rate between the two groups of patients with phrenic nerve sacrifice, this may be related to the small sample size of MG in our data.

This study has certain limitations. Firstly, although there are registered cases of surgical resection of thymoma in the past nearly 20 years, the observational, single-center, and retrospective design may limit the significance of this study. However, this study included all cases of thymoma patients in our center in the past 20 years. For the surgical treatment of thymoma, this is still a relatively large sample size for a rare tumor disease. Secondly, the time span of this study is large, and the professional skills of thoracic surgeons may vary, which may lead to biased patient outcomes. Finally, the long-term prognosis of patients with thymoma may be influenced by potential confounding factors such as lifestyle, environment, and psychological factors.

Conclusion

In our retrospective study comparing whether intraoperative phrenic nerve sacrifice occurred in patients undergoing surgical complete resection of thymoma. we found that nearly one-third of patients had phrenic nerve sacrifice during complete resection of thymoma. Phrenic nerve sacrifice has significant impact on short-term complications and long-term survival. Secondary postoperative complications and Masaoka staging III/IV

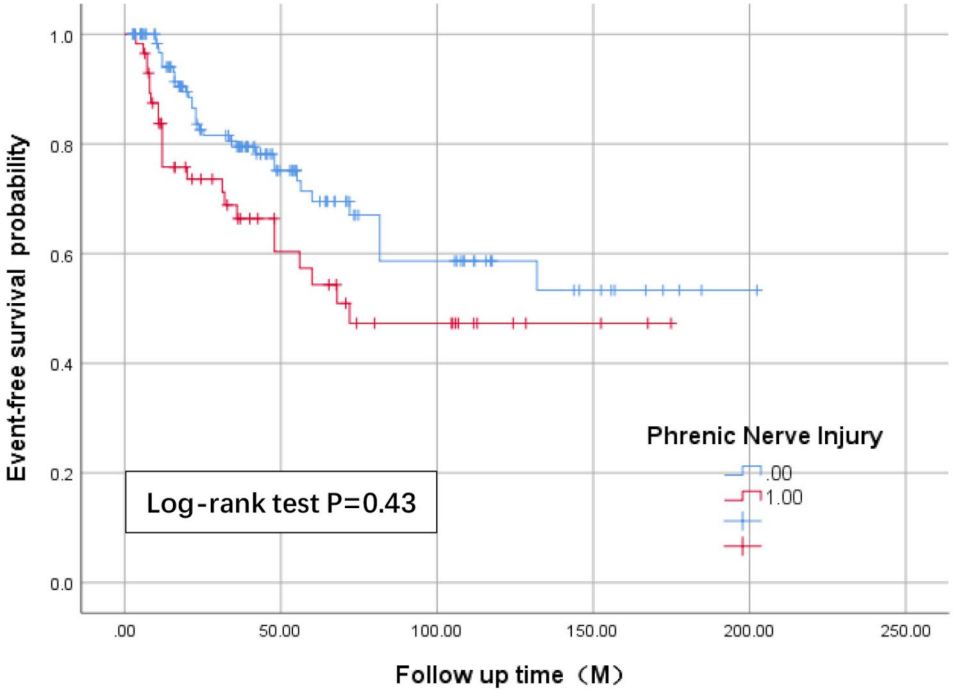

Fig. 3 Long-term postoperative prognosis of Thymoma Resection group and Thymoma Resection + Phrenic Nerve Sacrifice group.

of modified thymoma also affected long-term survival. When the phrenic nerve is invaded by thymoma, it is necessary to protect the phrenic nerve as much as possible during the operation, which may prolong the survival of patients. Early detection, early diagnosis and early surgery are still the key to the prevention and treatment of thymoma.

Abbreviations

BMI	Body mass index
MG	Myasthenia gravis
PFT	Pulmonary function test
FEV1% pred	Forced expiratory volume in one second of predicted
PEF% pred	Peak expiratory flow of predicted
DLCO% pred	Lung diffusion capacity for carbon monoxide of predicted
CRP	C-reaction protein
OR	Odds ratio
CI	Confidence interval

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Author contributions
H.R. and Z.Y. wrote the main manuscript text and F.L. prepared Figs. 1, 2 and 3. All authors reviewed the manuscript.

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Data availability
The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Approved by the Ethics Committee of Beijing Chest Hospital, Capital Medical University (Ethics No: Clinical Research 2019 (85)).Clinical data were extracted from the hospital's electronic medical records system. publication of such data does not compromise anonymity or confidentiality. Any participants will fully anonymous. The Ethics Committee of Beijing Chest Hospital of Capital Medical University waived the written informed consent of the patients in this study.

Clinical trial number
Not applicable.

Consent for publication
Not applicable.

Conflict of interest
None.

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