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Thoracoscopic sympathectomy decreases disease burden in patients with medically refractory ventricular arrhythmias

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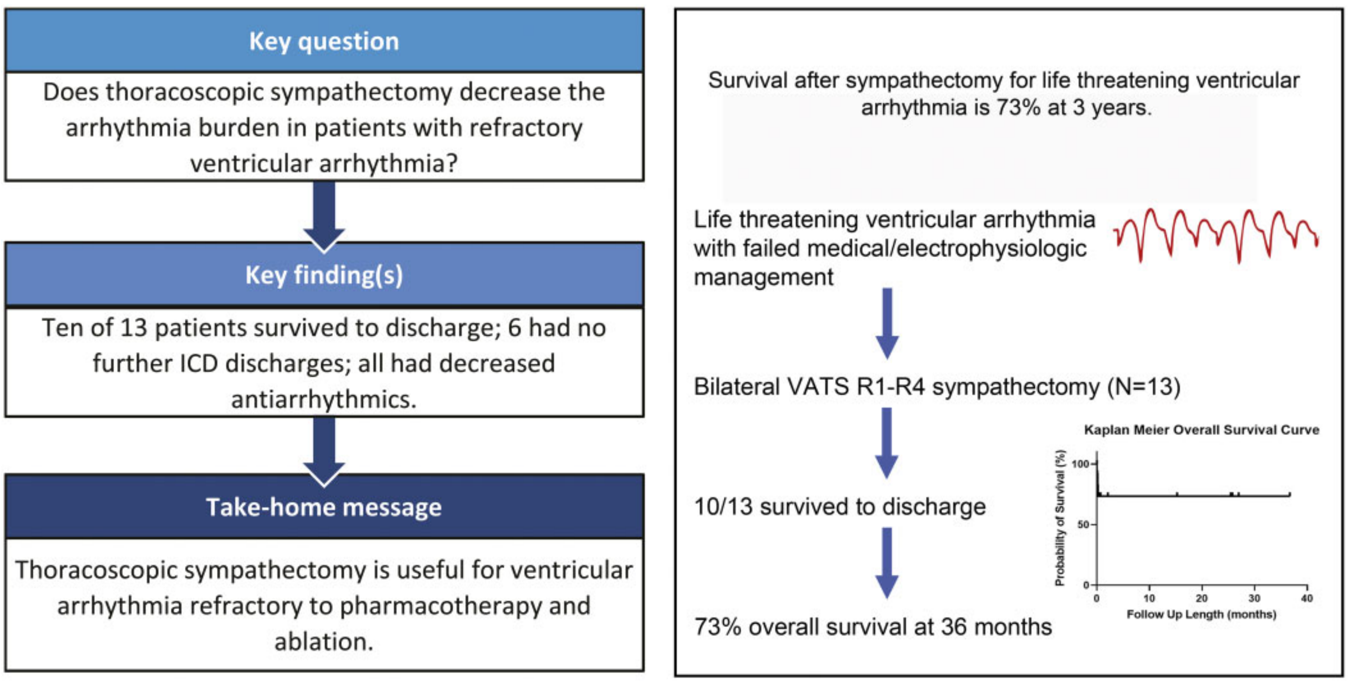

Abstract

OBJECTIVES: Thoracic sympathectomy has been shown to be effective in reducing implantable cardioverter-defibrillator (ICD) shocks and ventricular tachycardia recurrence in patients with channelopathies, but the evidence supporting its use for refractory ventricular arrhythmias in patients without channelopathies is limited. This is a single-centre cohort study of bilateral R1–R4 thoracoscopic sympathectomy for medically refractory ventricular arrhythmias.

METHODS: Clinical information was examined for all bilateral thoracoscopic R1–R4 sympathectomies for ventricular arrhythmias at our institution from 2016 through 2020.

RESULTS: Thirteen patients underwent bilateral thoracoscopic R1–R4 sympathectomy. All patients had prior ICD implant. Patients had a recent history of multiple ICD discharges (12/13), catheter ablation (10/13) and cardiac arrest (3/13). Ten patients were urgently operated

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on following transfer to our centre for sustained ventricular tachycardia. Seven patients had ventricular tachycardia ablations preoperatively during the same admission. Five patients were in intensive care immediately preoperatively, with 3 requiring mechanical ventilation. Three patients suffered in-hospital mortality. Kaplan–Meier analysis estimated 73% overall survival at 24-month follow-up. Among the 10 patients who survived to discharge, all were alive at a median follow-up of 8.7 months (interquartile range 0.6–26.7 months). Six of 10 patients had no further ICD discharges. Kaplan–Meier analysis estimated 27% ICD shock-free survival at 24 months follow-up for all patients. Three of 10 patients had additional ablations, while 2 patients underwent cardiac transplantation.

CONCLUSIONS: Bilateral thoracoscopic sympathectomy is an effective option for patients with life-threatening ventricular arrhythmia refractory to pharmacotherapy and catheter ablation.

Keywords: Ventricular tachycardia • Ventricular arrhythmia • Sympathectomy

ABBREVIATIONS

ICD	Implantable cardioverter-defibrillator
ICU	Intensive care unit
IQR	Interquartile range
VT	Ventricular tachycardia
VF	Ventricular fibrillation

INTRODUCTION

The sympathetic nervous system plays a prominent role in the genesis of many life-threatening ventricular arrhythmias. Beta-blockade has been the mainstay of therapy for this problem. However, many patients continue to experience persistent arrhythmias despite beta-blockade therapy and remain at risk of sudden death [1]. Cardiac sympathetic denervation (sympathectomy) is an uncommon procedure that has been performed on patients with medically refractory malignant ventricular arrhythmias as a last resort. This procedure removes the distal half of the stellate ganglion (R1) and thoracic ganglia R2–R4, thereby diminishing the noradrenergic input to the left ventricular myocardium [2]. Current results for this procedure, while encouraging, are not based on randomized trials [3].

Sympathectomy has been reported as successful primarily in patients with channelopathies such long QT syndrome to mitigate symptoms such as syncope and has been shown to decrease implantable cardioverter-defibrillator (ICD) discharge frequency [4–6]. Similarly, sympathectomy has been successfully used in another channelopathy, catecholaminergic polymorphic ventricular tachycardia (VT), to mitigate symptoms and ICD shocks [4, 7]. A recent meta-analysis pooling data from 14 non-randomized trials reported cardiac sympathetic denervation resulted in a freedom from recurrent ventricular tachycardia rate of 60% at 15 months follow-up among patients with refractory VT or ventricular fibrillation (VF) [8].

Although sympathectomy has been shown to be beneficial in patients with channelopathies, it is increasingly being used in patients with refractory ventricular arrhythmias due to other causes like cardiomyopathy, arrhythmogenic right ventricle and idiopathic VF. However, the evidence supporting its use in these situations is limited. Thus, we aim to examine whether bilateral R1–R4 thoracoscopic sympathectomy is effective in reducing arrhythmia burden for patients who suffer from medically refractory ventricular arrhythmias either due to channelopathies or other aetiologies. We hypothesize that R1–R4 thoracoscopic sympathectomy may be beneficial to patients who have refractory ventricular arrhythmias when all other medical therapies fail, with minimal inherent risk for surgical complications.

PATIENTS AND METHODS

Ethics statement

This retrospective study was approved by the Institutional Review Board at University of Chicago [IRB20-1487]. Formal consent was waived due to the retrospective nature of the research and the study was deemed to be of minimal risk.

Data collection

Patients who underwent thoracoscopic sympathectomy for ventricular arrhythmia from January 2016 through October 2020 at our centre were identified by querying institutional data submitted to the Society of Thoracic Surgeons database. Medical records were viewed for demographic variables, medical history, indications for surgery, details of operative procedures, intraoperative events and postoperative course. Particular attention was given to the use of preoperative antiarrhythmics either during the index hospitalization for urgent operations on an outpatient basis if the procedure was non-urgent.

We abstracted information for preoperative arrhythmia-related symptoms such as syncope or cardiac arrest, the frequency of implantable cardioverter-defibrillator (ICD) or life vest discharges, the specific ventricular rhythm documented, and left ventricular ejection fraction measured using echocardiograms when available. Prior attempts to control ventricular arrhythmia using electrophysiologic procedures were noted. Postoperative outcomes including perioperative mortality and complications, further cardiac interventions, further anti-tachytherapies by ICD or life vests, recurrence of VT or fibrillation (excluding short runs of non-sustained VT that resolved without any escalation of maintenance medical therapy, hospitalization or any recorded ICD defibrillation or anti-tachycardia pacing), patient-reported symptoms, usage of antiarrhythmics at the last follow-up and survival status were documented. Records from index hospitalization as well as postoperative follow-up in thoracic surgery clinic and cardiology clinic were reviewed. The time origin of the follow-up is the date the bilateral sympathectomy was performed. Duration of follow-up was recorded. Follow-up was censored as of October 2020.

Techniques

Bilateral sympathectomy was performed thoracoscopically by a single surgeon (M.K.F.). The patient was positioned supine with the arms alongside of the head and in mild reverse Trendelenburg. Defibrillation pads were usually applied. General endotracheal anaesthesia was induced with a double-lumen tube in place. The lungs were isolated sequentially, beginning on the right side. Two 3 mm operating ports were placed in the third and fifth intercostal spaces in the anterior axillary line and a 5 mm port was placed in the midclavicular line in the second interspace for the camera/telescope. CO_2 was insufflated to 8 cm H_2O to assist with lung collapse. The pleura overlying the sympathetic chain was opened from the head of the fourth rib to the thoracic inlet. The sympathetic chain was divided just below the R4 ganglion and was dissected upwards circumferentially and then transected across the distal half of the stellate ganglion. Small drains were placed through the 3 mm ports to assist with CO_2 evacuation as the lung was re-expanded. The procedure was replicated on the left side. The catheters were removed prior to concluding the operation. The larger port site was sutured and the smaller port sites were glued. Patients who had elective admission for sympathectomy were monitored postoperatively for 1–2 days. Patients transported from the intensive care unit (ICU) for urgent surgery were returned to the ICU for recovery and management.

Statistics

Continuous variables such as age and body mass index were reported as median and interquartile range (IQR). Categorical variables such as underlying cardiac pathology, ejection fraction categories and arrhythmic medication usage were reported as frequencies and percentages. Censored data including overall survival and ICD discharge-free survival following sympathectomy were presented using Kaplan–Meier survival analysis.

RESULTS

Patients

Thirteen patients, 11 men and 2 women, underwent bilateral thoracoscopic sympathectomy at our centre during the study period. All relevant data are contained within the manuscript. Only 2 patients had a history of channelopathies. Twelve of 13 patients had a history of multiple ICD discharges prior to the operation. Ten patients had one or more electrophysiologic ablations prior to sympathectomy, 7 during the index hospitalization. Eleven patients had left ventricular ejection fraction <50% prior to procedure (Table 1). Ten of 13 patients underwent bilateral sympathectomy as an urgent procedure after being admitted for symptomatic ventricular arrhythmia. Five patients were in the ICU immediately prior to sympathectomy (Table 2).

Table 1: Patient preoperative cardiac history

Demographics		
Male/female	11	2
	Median	**IQR**
Age	66	55–70
BMI	29.65	23.42–43.41
Duration of arrhythmia history (years)	6	2.25–11
	Number	**Percentage**
Caucasian	12	92
Hispanic	1	8
Symptoms		
Multiple ICD shocks	12	92
Syncopal episodes	5	39
VT arrest	3	23
Palpitations	3	23
Rhythm		
Monomorphic ventricular tachycardia	8	62
Polymorphic ventricular tachycardia	6	46
Ventricular fibrillation	4	31
Underlying EP pathologies		
Long QT	1	8
CPVT	1	8
No channelopathies	11	85
Prior EP procedures		
ICD placement	13	100
Single VT ablation	2	15
Multiple VT ablations	8	62
Structural heart disease		
Hypertrophic cardiomyopathy	2	15
Non-ischaemic cardiomyopathy	10	77
Comorbidities		
DM	2	15
CAD	6	46
CVA	3	23
Renal insufficiency	2	15
COPD	1	8
HTN	6	46
LVEF		
<29%	5	39
30–39%	3	23
40–49%	3	23
50–59%	1	8
>60%	1	8

BMI: body mass index; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; CPVT: catecholaminergic polymorphic ventricular tachycardia; ICD: implantable cardioverter-defibrillator; IQR: interquartile range; LVEF: left ventricular ejection fraction; VT: ventricular tachycardia; EP: electrophysiologic; DM: diabetes mellitus; CVA: cerebrovascular accident; HTN: hypertension.

Postoperative outcomes

Median skin to skin operating room time was 77 min (IQR 65.5–100.5). The median estimated blood loss was 5 ml (IQR 3.75–5). Ten of the 13 patients were extubated prior to leaving the operating room, while 3 patients who were intubated and in the ICU prior to sympathectomy remained intubated. Ten patients who underwent thoracoscopic bilateral sympathectomy survived to discharge. Besides adverse events directly related to arrhythmia burden and underlying medical comorbidities, the only surgical complications arising directly from the operation were sinus bradycardia in patient #2 which was managed with antiarrhythmic medication dosage modification and ICD setting adjustment, and neuropathic pain in patient #8 from the incisions which was managed with gabapentin (Tables 2 and 3).

Three mortalities occurred during the index hospitalization, of which only 1 was directly related to a refractory ventricular arrhythmia that did not respond to medical and surgical management. Patient #3 was initially transferred to our centre following an episode of VT arrest. The patient was placed on various intravenous antiarrhythmics, intubated, placed on intravenous dopamine for haemodynamic support and underwent VT ablation. However, because of continued sustained VT, the patient underwent bilateral sympathectomy. Postoperatively, the patient continued to experience VT storms that were not responsive to continued intravenous antiarrhythmics and repeat VT ablation. Due to the refractory and aggressive nature of his VT and lack of return to normal mental status, medical care was withdrawn (Table 3).

The other 2 patients expired due to underlying comorbidities rather than refractory VT storm. Patient #6 was transferred to our

Table 2: Preoperative status

No.	Age (years)	Gender	Race	Arrhythmia type	Underlying diagnosis	Same admission VT ablation	Surgical status	Preoperative ICU status
1	35	Male	W	VF	Long QT, NICM	No	Elective	No
2	17	Male	H	Polymorphic VT, bidirectional VT, monomorphic VT, bigeminy PVCs	CPVT, NICM	No	Urgent, admitted for polymorphous v-tach	Yes
3	72	Male	W	Sustained monomorphic VT	NICM	Yes	Urgent, admitted for VT ablation after VT storm and an episode of VT arrest	Yes, intubated and on vasopressors
4	66	Male	W	Multifocal VT	NICM	No	Elective	No
5	68	Male	W	Monomorphic, VT Storm	NICM	Yes	Urgent, admitted for VT electrical storm	No
6	71	Female	W	VF, monomorphic VT, polymorphic VT	NICM	No	Urgent, admitted for syncopal episode from recurrent sustained VT/VF	No
7	66	Male	W	Paroxysmal VT, polymorphic VT	NICM	Yes	Urgent, admitted for VT storm and received 2 shocks	Yes
8	58	Male	W	Monomorphic VT	NICM	No	Elective	No
9	69	Male	W	Monomorphic VT	HCM	Yes	Urgent, admitted for VT ablation for management of recurrent ICD shocks	No
10	59	Male	W	Monomorphic VT	NICM	Yes	Urgent, admitted for recurrent VT storm, multiple ICD shocks	No
11	80	Male	W	Polymorphic VT, VF	None	Yes	Urgent, admitted for VT storm and syncope, ICD shocks	No
12	52	Female	W	Polymorphic VT, VF	HCM	No	Urgent, admitted for VT storm, ICD discharges	Yes, intubated
13	61	Male	W	Monomorphic VT	NICM	Yes	Urgent, admitted for palpations and AICD shock	Yes, intubated

CPVT: catecholaminergic polymorphic ventricular tachycardia; H: Hispanic; HCM: hypertrophic cardiomyopathy; ICD: implantable cardioverter-defibrillation; ICM: ischaemic cardiomyopathy; ICU: intensive care unit; NICM: non-ischaemic cardiomyopathy; PVC: premature ventricular contraction; VF: ventricular fibrillation; VT: ventricular tachycardia;W: White.

hospital after a syncopal episode due to recurrent VT. The patient was started on intravenous antiarrhythmics and underwent bilateral sympathectomy. During her postoperative stay, she was weaned off intravenous antiarrhythmics and had no documented VT/VF episodes while on oral amiodarone. On postoperative Day 8, the patient developed acute respiratory distress with pleural effusions, pulmonary oedema and increased oxygen requirement for which the patient was transitioned from peritoneal dialysis to intermittent haemodialysis to remove excess fluid. Unfortunately, the patient did not tolerate haemodialysis and suffered a cardiac arrest during the session. The likely immediate cause of the cardiac arrest was acidosis (Table 3).

Patient #13 was admitted urgently for management of VT storm. He was intubated and placed on intravenous antiarrhythmics, had VT ablation and then underwent sympathectomy. Postoperatively, the patient was off intravenous antiarrhythmics and had no documented VT. However, he became febrile and hypotensive postoperatively despite being on intravenous antibiotics. Given concern for septic shock secondary to healthcare-associated pneumonia, he received a dose of methylene blue, following which he went into monomorphic VT and was not able to be resuscitated. The immediate cause of the cardiac arrest was thought to be sepsis (Table 3).

Post-discharge outcomes

Kaplan–Meier analysis estimated 73% overall survival at 24-month follow-up (Fig. 1). Among the 10 patients who survived to discharge, median follow-up time was 8.7 months (IQR 0.6–26.7 months). Six of 10 patients had no further ICD discharges for sustained VT, of whom 5 required no further cardiac intervention while one required epicardial ablation for frequent premature ventricular contractions. Of the 7 patients who had attempted but failed VT ablations during index hospitalization, 5 patients did not have any documented ICD shocks following sympathectomy. Kaplan–Meier analysis estimated 27% ICD shock-free survival at 24 months follow-up for all patients (Fig. 2). Of the 4 patients who sustained ICD discharge due to recurrent VT postoperatively following hospital discharge, the median duration from the most recent ICD shock to the last follow-up was 21.6 months (IQR 5.9–27.7 months), and 3 of these patients required cardiac reintervention. One had additional VT ablation only, 1 had VT ablation followed by cardiac transplantation and 1 had cardiac transplant only due to recurrent VT and heart failure (Table 3). Among all 10 patients who survived to discharge, 5 reported no major symptoms at last follow-up, including palpitations or syncope. Only 1 patient reported compensatory sweating at last follow-up. No patient exhibited signs of Horner's syndrome at last follow-up (Table 3).

Antiarrhythmic usage

Bilateral sympathectomy decreased requirements for all antiarrhythmics for ventricular arrhythmia, most notably intravenous antiarrhythmics. Eight of the 13 patients received intravenous lidocaine and/or procainamide during the index hospitalization

Table 3: Postoperative outcomes

No.	Surgical complication	Peri-procedural mortality	30-day adverse event	Alive at last follow up	Length of follow up (months)	Time to first ICD shock following sympathectomy (months)	Shock free length since last ICD shock (months)	Postoperative cardiac reintervention	Reported symptoms at most recent follow-up
1	None	No	None	Yes	15.2	No ICD shock	No ICD shock	None	Episodes of syncope, heart racing, diaphoresis. Noncompliant with life vest, no ICD. On Methadone
2	Sinus bradycardia	No	None	Yes	25.8	8.1	17.7	None	No major symptoms
3	None	Yes, VT storm, toxic/metabolic encephalopathy, respiratory failure	VT arrest, respiratory failure	No	0.1	0		Alcohol septal ablation for recurrent VT	
4	None	No	None	Yes	36.7	3.4	28.5	VT ablation × 2 for recurrent VT, OHT for dilated cardiomyopathy and congestive heart failure	No major symptoms
5	None	No	None	Yes	0.7	No ICD shock	No ICD shock	None	No major symptoms
6	None	Yes, pulseless VF, acute respiratory failure	Acute respiratory failure, pleural effusion, c diff colitis	No	0.3	0.3			
7	None	No	Shortness of breath, cardiogenic shock requiring readmission	Yes	27.0	1.5	25.5	OHT, tricuspid de Vega, and removal of AICD for ischaemic cardiomyopathy, tricuspid valve insufficiency and acute systolic heart failure	Compensatory sweating
8	Neuropathic pain	No	None	Yes	25.5	No ICD shock	No ICD shock	PVC ablation × 2 for recurrent PVC's	NSVT and PVCs, procedural pain
9	None	No	None	Yes	0.6	No ICD shock	No ICD shock	None	No major symptoms
10	None	No	None	Yes	0.0	No ICD shock	No ICD shock	None	Procedural pain
11	None	No	None	Yes	0.1	No ICD shock	No ICD shock	None	No major symptoms
12	None	No	None	Yes	2.1	0.1	2.0	None	Shortness of breath, fatigue
13	None	Yes, septic shock versus non-ischaemic dilated cardiomyopathy leading to an unstable tachyarrhythmia	Sepsis	No	0.0	0			

AICD: automatic implantable cardioverter-defibrillator; CD: implantable cardioverter-defibrillator; NSVT: non-sustained ventricular tachycardia; OHT: orthotopic heart transplant; PVC: premature ventricular contraction.

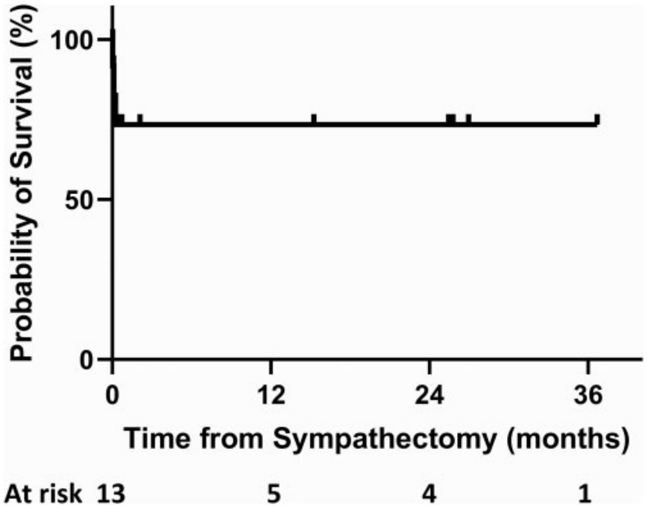

Figure 1: Kaplan–Meier overall survival curve. The time origin of the follow-up is the date the bilateral sympathectomy was performed.

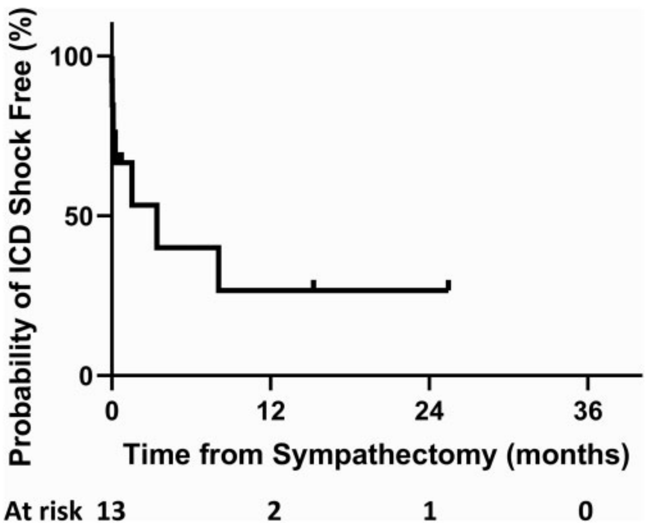

Figure 2: Kaplan–Meier ICD shock-free curve. The time origin of the follow-up is the date the bilateral sympathectomy was performed.

prior to sympathectomy (7 patients received intravenous lidocaine; 5 patients received intravenous procainamide). At the last clinical encounter, either as inpatient prior to discharge from index hospitalization or outpatient, all but one of the patients no longer required intravenous lidocaine and procainamide. The patient who was unable to be weaned off intravenous lidocaine and procainamide ultimately expired from recurrent VT storm (Patient # 3; Table 4).

DISCUSSION

The effectiveness of sympathectomy has been described in reducing ICD shocks and symptoms in patients with channelopathies. However, descriptions of its use in refractory ventricular arrhythmias due to other causes like cardiomyopathy, arrhythmogenic right ventricle and idiopathic VF/VT have been limited. There have been no prospective, randomized trials that evaluate

Table 4: Antiarrhythmic usage

Antiarrhythmic usage (*N* = 13)	Prior to procedure, *n* (%)	At last encounter, *n* (%)
Beta-blocker (oral or intravenous)	13 (100)	8 (62)
Lidocaine (intravenous)	7 (54)	1 (8)
Amiodarone (oral or intravenous)	6 (46)	4 (31)
Procainamide (intravenous)	5 (39)	1 (8)
Mexiletine (oral)	3 (23)	1 (8)
Sotalol (oral)	2 (15)	0 (0)
Flecainide (oral)	1 (8)	1 (8)
Ivabradine (oral)	0 (0)	1 (8)

Preoperative antiarrhythmic usage was captured at index hospitalization if patient was hospitalized urgently prior to procedure; preoperative antiarrhythmic usage was captured from prescribed medication list if procedure was elective.

the role of sympathectomy in patients with refractory ventricular arrhythmias. Our single-centre review of a case series of bilateral R1–R4 thoracoscopic sympathectomy for medically refractory ventricular arrhythmias adds to the existing literature that bilateral thoracoscopic sympathectomy, when performed on patients with refractory, life-threatening ventricular arrhythmia, importantly decreases arrhythmia burden.

The mechanisms underlying the benefit of sympathectomy are likely related to both disruption of afferent as well as efferent sympathetic fibres, in a manner similar to beta-blockers, altering the course of the underlying heart disease [9]. Both exclusive left and bilateral sympathectomies have been described in the treatment of refractory ventricular arrhythmia for aetiologies other than channelopathies. Studies reporting exclusive left sympathectomies identified freedom from ventricular arrhythmia in 55–82% of patients [10–12], while studies reporting bilateral sympathectomies identified freedom from ventricular arrhythmia in 63–67% of patients [13, 14] (Table 5). Only 1 study included both techniques and reported that 30% of patients had freedom from ventricular arrhythmia after left sympathectomies and 48% after bilateral sympathectomy [15] (Table 5).

The sympathetic chains lie on either side of the vertebra. Postganglionic fibres arising from the sympathetic chains innervate the entire heart, regulating all aspects of cardiac function [17]. Thus, bilateral sympathectomy offers a theoretical advantage over unilateral left sympathectomy in that it removes sympathetic input to both right and left ventricular myocardium [15]. Furthermore, the right cardiac sympathetic chain may hypertrophy and re-innervate regions subtended by the resected left-sided ganglia if only the left sympathetic chain is resected [17].

Our series included patients whose ventricular arrhythmias were refractory to maximal pharmacotherapy and catheter ablation prior to operation. For individuals with recurrent VT, a multimodal approach should be used, including treatment of the underlying condition, implantable cardioverter-defibrillator placement, pharmacologic therapy and catheter ablation. If VT persists after exhausting medical management options, then bilateral sympathetic denervation should be considered given that these patients have a poor prognosis and quality of life. Such treatment is justified based on its demonstrated benefit in many patients and lack of important side effects [18]. In our series, 10 of the 13 patients underwent sympathectomy as an urgent procedure due to failed VT ablation and medical therapy while admitted for VT storm and recurrent ICD shock, while the other 3

Table 5: Review of literature of sympathectomies for patients with refractory ventricular arrhythmia due to causes other than channelopathies

Study	Number of patients	Underlying pathologies	Indications for sympathectomy	Laterality of sympathectomy	Perioperative mortality, *n* (%)	Patients with freedom from arrhythmia, *n* (%)
Bourke *et al.* [10]	9	2 ICM, 1 ARVD, 2 NICM, 2 HCM, 2 Sarcoid	VT refractory to ablation	Left	2 (22.2)	5 (56)
Ajijola *et al.* [13]	6	1 Sarcoid, 1 ARVC, 4 NICM	VT or VF refractory to ablation or unilateral sympathectomy	Bilateral	1 (16.7)	4 (67)
Coleman *et al.* [11]	27	13 CPVT, 5 JLNS, 4 IVF, 2 LVNC, 1 ICM 1 HCM, 1 ARMC	Non-long QT VA-causing syndrome	Left	0 (0.0)	18 (82)
Hofferberth *et al.* [12]	24	13 LQTS, 9 CPVT, 2 IVT	VA refractory to medical therapies and/or ablations	Left	0 (0.0)	12 (55)
Vaseghi *et al.* [15]	41	9 ICM, 22 NICM, 3 HCM, 2 sarcoidosis, 1 Chagasic, 1 ARVC, 1 valvular, 1 TGA, 1 IVF	CM and refractory VA	Left in 14 and 27 bilateral	0 (0.0)	4 (30) left and 13 (48) bilateral
Richardson *et al.* [16]	7	1 NICM, 1 ARVC, 2 ICM, 1 HCM, 1 IVT, 1 normal cardiac substrate	VA refractory to ablation	Bilateral in 6 and left in 1	0 (0.0)	7 (100)
Assis *et al.* [14]	8	8 ARVC	ARVC with VA refractory to ablations	Bilateral	0 (0.0)	5 (63)

ARMC: arrhythmogenic right ventricular cardiomyopathy; ARVD: arrhythmogenic right ventricular dysplasia; CM: cardiomyopathy; CPVT: catecholaminergic polymorphic ventricular tachycardia; HCM: hypertrophic cardiomyopathy; ICM: ischaemic cardiomyopathy; IVF: idiopathic ventricular fibrillation; IVT: idiopathic ventricular tachycardia; JLNS: Jervell and Lange-Nielsen syndrome; LQTS: long QT syndrome; LVNC: left ventricular non-compaction; TGA: transposition of the great arteries; VF: ventricular fibrillation; VT: ventricular tachycardia.

were deemed failing medical therapy as outpatient; 8 of the 13 patients were on intravenous lidocaine and/or procainamide immediately prior to sympathectomy. If these patients were to have continued with conservative management, they would likely have continued to experience life-threatening ventricular arrhythmias despite maximal medical therapy.

Our series included a relatively high mortality. Thoracoscopic sympathectomy is generally a safe operation [19]. A report of 20 patients undergoing cardiac sympathetic denervation reported no perioperative complications [3]. Patients with cardiac channelopathies undergoing sympathectomy tend to be teenagers with minimal medical comorbidities. This contrasts with patients who have refractory ventricular arrhythmias due to other causes. Our patient cohort had a median age of 66, 12 had documented structural heart disease, and 11 had left ventricular ejection fraction <50%. These additional risk factors increase the likelihood of perioperative complications. In addition, many of our patients were operated on after suffering cardiac arrest and requiring ventilatory and pharmacologic support, further increasing their operative risk. Of the 3 periprocedural mortalities included in our cohort, one expired during haemodialysis for fluid overload while another one expired due to sepsis secondary to healthcare-associated pneumonia. Both of these 2 patients were successfully weaned off intravenous antiarrhythmic following sympathectomy. As such, we believe that these 2 patients expired due to underlying comorbidities rather than refractory VT storm, hence not a failure of the surgical procedure.

There are potential limitations in our study. It represents outcomes at a major referral centre with expertise in interventional cardiology focused on life-threatening arrhythmias and experienced in performing thoracoscopic sympathotomy and sympathectomy. Therefore, the results may not be directly applicable to centres that do not perform this procedure frequently. The overall survival may be underestimated in our case series secondary to limited follow-up duration. Finally, taking into consideration the comorbidities and high sudden cardiac death risk of our cohort, the operative risk specific to the procedure itself may be overestimated.

CONCLUSION

In conclusion, bilateral sympathectomy is effective in reducing arrhythmia burden for patients who are suffering from life-threatening, medically refractory ventricular arrhythmias either due to channelopathies or other aetiologies. Future work should focus on investigating the exact cellular and molecular mechanism of antiarrhythmic effect of bilateral sympathectomy to aid in selecting patients who will most benefit from this procedure.

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Author contributions

Andy Chao Hsuan Lee: Conceptualization; Data curation; Formal analysis; Methodology; Writing—original draft; Writing—review & editing. **Roderick Tung:** Conceptualization; Methodology; Supervision; Writing—review & editing. **Mark K. Ferguson:** Conceptualization; Methodology; Supervision; Writing—review & editing).

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