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

Andy Chao Hsuan Lee, Roderick Tung and Mark K. Ferguson

Section of Thoracic Surgery, Department of Surgery, The University of Chicago, Chicago, IL, USA
Division of Cardiology, Department of Internal Medicine, University of Arizona, Phoenix, AZ, USA

Corresponding author. Section of Thoracic Surgery, Department of Surgery, The University of Chicago, MC 5047, 5841 S. Maryland Avenue, Chicago, IL 60637, USA. Tel: +1-773-795-0675; e-mail: mferguso@bsd.uchicago.edu (M.K. Ferguson).

Received 10 November 2021; received in revised form 22 November 2021; accepted 8 December 2021

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

Presented at the 29th European Conference on General Thoracic Surgery of the European Society of Thoracic Surgeons, June 20, 2021, Virtual conference.
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-arrhythmic therapies 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 inter-sphere for the camera/telescope. CO₂ was insufflated to 8 cm H₂O 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 CO₂ 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).

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 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.
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/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).

**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.
| 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                                                         | VT ablation × 2 for recurrent VT              | Alcohol septal ablation for recurrent VT | No major symptoms                         |
| 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                                                       | OHT, tricuspid de Vega, and removal of AICD for ischaemic cardiomyopathy, tricuspid valve insufficiency and acute systolic heart failure | Compensatory sweating                      | NSVT and PVCs, procedural pain             |
| 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                      | NSVT and PVCs, procedural pain             |
| 8   | Neuropathic pain     | No                        | None                | Yes                     | 25.5                        | No ICD shock                                               | No ICD shock                                   | None                                     | No major symptoms                         |
| 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                                     | No major symptoms                         |
| 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                                                       | 20                                             | None                                     | Shortness of breath, fatique               |
| 13  | None                 | Yes, septic shock versus non-ischaemic dilated cardiomyopathy leading to an unstable tachyarhythmia | 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.
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 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

| Antiarrhythmic usage | 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) |
| Procaainamide (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.
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 cardiac morbidities. 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, 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.

Funding

This work was supported by Donald J. Ferguson, MD, Surgical Research Fund at the University of Chicago.

Conflict of interest: none declared.

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.
Reviewer information

Interactive CardioVascular and Thoracic Surgery thanks Tomonobu Abe, Georges Decker and the other anonymous reviewers for their contribution to the peer review process of this article.

REFERENCES

[1] Moss AJ, Zareba W, Hall WJ, Schwartz PJ, Crampton RS, Benhorin J et al. Effectiveness and limitations of beta-blocker therapy in congenital long-QT syndrome. Circulation 2000;101:616–23.

[2] Odero A, Bozzani A, De Ferrari GM, Schwartz PJ. Left cardiac sympathetic denervation for the prevention of life-threatening arrhythmias: the surgical supraclavicular approach to cervicothoracic sympathectomy. Heart Rhythm 2010;7:1161–5.

[3] Collura CA, Johnson JN, Moir C, Ackerman MJ. Left cardiac sympathetic denervation for the treatment of long QT syndrome and catecholaminergic polymorphic ventricular tachycardia using video-assisted thoracic surgery. Heart Rhythm 2009;6:752–9.

[4] Olde Nordkamp LR, Driessen AH, Odero A, Blom NA, Koolbergen DR, Schwartz PJ et al. Left cardiac sympathetic denervation in the Netherlands for the treatment of inherited arrhythmia syndromes. Neth Heart J 2014;22:160–6.

[5] Schwartz PJ, Priori SG, Cerrone M, Spazzolini C, Odero A, Napolitano C et al. Left cardiac sympathetic denervation in the management of high-risk patients affected by the long-QT syndrome. Circulation 2004;109:1826–33.

[6] Li J, Wang L, Wang J. Video-assisted thoracoscopic sympathectomy for congenital long QT syndromes. Pacing Clin Electrophysiol 2003;26:870–3.

[7] Wilde AA, Bhuyan ZA, Crotti L, Facchini M, De Ferrari GM, Paul T et al. Left cardiac sympathetic denervation for catecholaminergic polymorphic ventricular tachycardia. N Engl J Med 2008;358:2024–9.

[8] Murtaza G, Sharma SP, Akella K, Turagam MK, Rocca DGD, Lakireddy D et al. Role of cardiac sympathetic denervation in ventricular tachycardia: a meta-analysis. Pacing Clin Electrophysiol 2020;43:828–37.

[9] Irie T, Yamakawa K, Hamon D, Nakamura K, Shivkumar K, Vaseghi M. Cardiac sympathetic innervation via middle cervical and stellate ganglia and antiarrhythmic mechanism of bilateral stellctomy. Am J Physiol Heart Circ Physiol 2017;312:H392–H405.

[10] Bourke T, Vaseghi M, Michowitz Y, Sankhla V, Shah M, Swapna N et al. Neuromodulation for refractory ventricular arrhythmias: value of thoracic epidural anesthesia and surgical left cardiac sympathetic denervation. Circulation 2010;121:2255–62.

[11] Coleman MA, Bos JM, Johnson JN, Owen Hj, Deschamps C, Moir C et al. Videoscopic left cardiac sympathetic denervation for patients with recurrent ventricular fibrillation/malignant ventricular arrhythmia syndromes besides congenital long-QT syndrome. Circ Arrhythm Electrophysiol 2012;5:782–8.

[12] Hofferberth SC, Cecchin F, Loberman D, Fynn-Thompson F. Left thoracoscopic sympatheticectomy for cardiac denervation in patients with life-threatening ventricular arrhythmias. J Thorac Cardiovasc Surg 2014;147:404–11.

[13] Ajijola OA, Lellouche N, Bourke T, Tung R, Ahn S, Mahajan A et al. Bilateral cardiac sympathetic denervation for the management of electrical storm. J Am Coll Cardiol 2012;59:91–2.

[14] Assis FR, Krishnan A, Zhou X, James CA, Murray B, Tichnell C et al. Cardiac sympathectomy for refractory ventricular tachycardia in arrhythmogenic right ventricular cardiomyopathy. Heart Rhythm 2019;16:1003–10.

[15] Vaseghi M, Gima J, Kanaan C, Ajijola OA, Marmureanu A, Mahajan A et al. Cardiac sympathetic denervation in patients with refractory ventricular arrhythmias or electrical storm: intermediate and long-term follow-up. Heart Rhythm 2014;11:360–6.

[16] Richardson T, Lugo R, Saavedra P, Crossley G, Clair W, Shen S et al. Cardiac sympathectomy for the management of ventricular arrhythmias refractory to catheter ablation. Heart Rhythm 2018;15:56–62.

[17] Ajijola OA, Vaseghi M, Mahajan A, Shivkumar K. Bilateral cardiac sympathetic denervation: why, who and when? Expert Rev Cardiovasc Ther 2012;10:947–9.

[18] Hong JC, Crawford T, Tandri H, Mandal K. What is the role of cardiac sympathetic denervation for recurrent ventricular tachycardia? Curr Treat Options Cardiovasc Med 2017;19:11.

[19] Lin TS, Kuo SJ, Chou MC. Uniporal endoscopic thoracic sympathectomy for treatment of palmar and axillary hyperhidrosis: analysis of 2000 cases. Neurosurgery 2002;51:584–7.