Received: 2 November 2023 | Revised: 27 February 2024 | Accepted: 1 March 2024

DOI: 10.1002/ccr3.8650

CASE REPORT

Clinical Case Reports Open Access WILEY

Post-operative arrest following pectus excavatum repair: A case report with a systematic review of the published case reports

Ghazal Roostaei[1] | **Hesam Amini**[2] | **Hamidreza Abtahi**[1] | **Hossein Kazemizadeh**[1] | **Maryam Edalatifard**[1] | **Besharat Rahimi**[1] | **Sanaz Asadi**[1] | **Niloofar Khoshnam-Rad**[1]

[1]Thoracic Research Center, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran

[2]Department of Thoracic Surgery, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran

Correspondence
Niloofar Khoshnam-Rad, Thoracic Research Center, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran.
Email: kh.niloofar@yahoo.com

Key Clinical Message

Common complications after PE surgery include ventricular tachycardia, cardiac arrest, pneumothorax, and bar displacement. These can lead to severe outcomes, emphasizing the need for caution and meticulous post-operative monitoring. Patients and their families should be well-informed about potential risks during the consent process.

Abstract

The objective of this study was to raise awareness among medical staff and surgeons about potential complications, particularly rare and life-threatening ones, associated with pectus excavatum (PE) surgery. PE is the most common chest wall deformity, characterized by sternal depression. Patients primarily seek treatment for cosmetic concerns, but some also report exercise intolerance and shortness of breath. Although surgical repair is the standard treatment, the incidence and nature of severe complications remain unclear and underreported. This study presents a case of a lethal cardiac event following PE surgery and conducts a systematic review of published case reports. This study describes a case of a lethal complication of ventricular fibrillation and cardiac arrest following the Ravitch procedure for correction of PE in a 10-year-old boy. A systematic review of relevant cases of PE surgery complications was conducted. Of the 506 initial records retrieved, 93 case reports from 83 articles were identified over the 23 years. Among them, 72 patients were male, and 20 cases were female. The average age of patients was 19.2 ± 7.7 years (range: 5–53). Complications had occurred up to 37 years from the time of surgery, with most of the cases (22.5%) occurring during the operation. The most frequent complications included cardiothoracic issues and displacement of the implanted steel bar. In nine patients, complications led to fatal outcomes. Due to the possible risks of PE surgery, particularly in cosmetically motivated cases, surgeons must exercise extreme caution and remain vigilant for rare and potentially life-threatening complications.

KEYWORDS
cardiac arrest, complication, death, pectus excavatum, surgery, systematic review

1 | BACKGROUND

Pectus excavatum (PE) is a common chest wall deformity characterized by sternal depression. The incidence rate of PE is one in 200–1500 individuals, with males being more frequently affected than females (male-to-female ratio of 4:1).[1] Patients with PE often present with cosmetic concerns due to their abnormal appearance, but some also experience exercise intolerance and shortness of breath. Although there is controversy regarding the cardiopulmonary limitations of this disease and the benefits of surgical repair, few reports have described fatal complications associated with the procedure. The prevalence and type of life-threatening complications related to the surgical repair of PE are unknown and underreported.[2] Reported surgical complications include cardiac perforation, hemothorax, gastrointestinal problems, and injuries to major vessels, the heart, lungs, liver, and diaphragm. Mortality may occur due to surgeon inexperience, the severity of the deformity, previous thoracic surgery, and surgical technique.[3] In our center, approximately 15–20 PE surgeries are conducted annually, with our team possessing over a decade of experience in these procedures. The most prevalent complication encountered is surgical site infection. Here, we reported a lethal cardiac event following the procedure in a 10-year-old boy and systematically reviewed the published case reports to raise awareness among surgeons about the risk of these life-threatening complications.

2 | METHODS

We reported a case of serious complications associated with PE surgery. To gather all relevant cases, we conducted a systematic search of databases. This systematic review was prepared following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.1 | Search strategies and information sources

We performed an electronic literature search for all case reports on serious complications associated with PE surgery. Two authors (G.R. and N.K.) independently searched the PubMed, Scopus, and Embase electronic databases to identify the potentially relevant articles.

All database searches were performed on August 2023. The search strategy, which was tailored to each database, comprised the following terms:

'Funnel chest' OR 'chest, funnel' OR 'foveated chest' OR 'foveated thorax' OR 'funnel chest 'OR 'funnel thorax' OR 'pectus excavatum' OR 'thorax, foveated' OR 'thorax, funnel'.

AND

'Surgery' OR 'operation' OR 'operation care' OR 'operative intervention': OR 'operative repair' OR 'operative restoration' OR 'operative surgery' OR 'operative treatment' OR 'research surgery' OR 'surgery' OR 'surgery, operative' OR 'surgical correction' OR 'surgical intervention' OR 'surgical management' OR 'surgical operation' OR 'surgical practice' OR 'surgical procedures, operative' OR 'surgical repair' OR 'surgical therapy' OR 'surgical treatment'.

AND

'Mortality' OR 'mortality' OR 'mortality model' OR 'complication' OR 'complication' OR 'complications'.

Additionally, articles were added by searching the references of identified reports and those from previous reviews to identify further relevant studies that may not have been recognized by our database searches.

2.2 | Eligibility criteria

To be included, the case report must contain the characteristics of the patients, the surgical technique, the complication related to PE surgery, the treatment, and the outcome of the complication.

We excluded poorly represented or incomplete cases and case reports written in languages other than English or French.

2.3 | Data extraction and quality assessment

The titles and abstracts of cases were reviewed, and those that satisfied the inclusion criteria were evaluated. Selected cases for data extraction were assessed by the two authors (G.R. & N.K.) with an agreement value (κ) of 95%; disagreements were settled by a third reviewer

(H.A.). They also evaluated the methodologies of the studies using the tool developed by Murad et al. for assessing the methodological quality of case reports and case series. The tool covers four domains, namely selection, ascertainment, causality, and reporting, and includes eight questions to assist in determining the quality score. A study that meets all the domains is considered to be of 'good quality'. If three out of the four domains are satisfied, the study is classified as 'fair quality'. In cases where only two or one domain is met, the study is deemed to be of 'poor quality'.[4]

2.4 | Summary measures and statistical analysis

Data analysis was conducted using Microsoft Office Excel version 2010 (Microsoft, Redmond, Washington, USA). The data are summarized descriptively according to the study design in Table 2.

2.5 | Case presentation

A 10-year-old boy (height: 146 cm, weight: 34 kg) was referred to our thoracic surgery clinic in July 2023 for evaluation of a moderate PE, which was causing him significant psychosocial distress. A CT scan of the chest, performed at an outside facility, was not available. The chest X-ray of the patient is presented in Figure 1. The decision for surgical correction was based on the patient's clinical presentation and the anticipated improvements in his self-esteem and social functioning. The primary concerns of the patient and his family were cosmetic in nature. After a comprehensive discussion of the surgical risks, they elected to proceed with the surgical repair, providing their informed consent.

2.6 | Preoperative evaluations

The patient underwent a thorough preoperative evaluation, including a six-minute walk test (405 meters), electrocardiography (ECG), Doppler echocardiography, and spirometry. The six-minute walk test was within normal limits. The ECG showed normal sinus rhythm, and the Doppler echocardiography revealed no structural abnormalities. Spirometry indicated a restrictive pattern (FVC = 68%). Vital signs and laboratory data were within normal ranges (Table 1).

2.7 | Operative procedure

An experienced thoracic surgeon, specializing in the repair of congenital chest wall malformations, performed the Ravitch procedure. The surgery began with single-lumen intubation and arterial line monitoring. A mid-sternal incision was made, and the third to seventh costal cartilages on both sides were found to have severe deformities. The cartilages were resected, while the perichondrium was preserved. A single bar was placed under the elevated sternum and fixed to the chest wall. As the pleura were opened, a 28 French chest tube was inserted in the fifth right intercostal space. The surgery was uneventful, with no intraoperative complications. The heart and major vessels were intact, with no arrhythmia or cardiopulmonary dysfunction detected. The patient's images before and after surgery are presented in Figure 2, and a post-operative chest X-ray of the patient is presented in Figure 3.

2.8 | Postoperative course

Following the surgery, the patient was extubated and transferred to the ICU. Approximately three hours after

FIGURE 1 Preoperative posteroanterior (PA) and lateral chest X-ray views.

TABLE 1 Laboratory data of patient at admission.

Test (Unit)	Value for the case	Reference range
SBP/DBP	110/70	90–130/65–85
PR (beats/min)	80	60–100
RR (breaths/min)	15	12–16
Temperature (°C)	36.9	36.1–37.2
O_2 saturation (%)	98%	95%–100%
BS (mg/dL)	90	80–200
WBC (10^3/μL)	4.1	4.5–11
Hemoglobin (g/dL)	12.3	12–15 (F), 14–17 (M)
Platelet (10^3/μL)	208	150–450
AST (U/L)	22	10–40
ALT (U/L)	20	7–56
ALP (U/L)	89	50–250 (for 9–13 years)
Urea (mg/dL)	22	15–40
Creatinine (mg/dL)	0.6	0.5–1.4
Sodium (mEq/L)	141	135–145
Potassium (mEq/L)	4.1	3.5–5.5
Magnesium (mg/dL)	1.8	1.8 to 2.6
PTT (seconds)	30	25–35
INR	1.01	0.8–1.2

Abbreviations: ALT, Alanine aminotransferase; ALP, Alkaline phosphatase; AST, Aspartate aminotransferase; ALP, Alkaline phosphatase; BS, blood sugar; DBP, Diastolic blood pressure; INR, International normalized ratio; PR, Pulse rate; PTT, Partial thromboplastin time; RR, Respiratory rate; SBP, Systolic blood pressure; WBC, White blood cell.

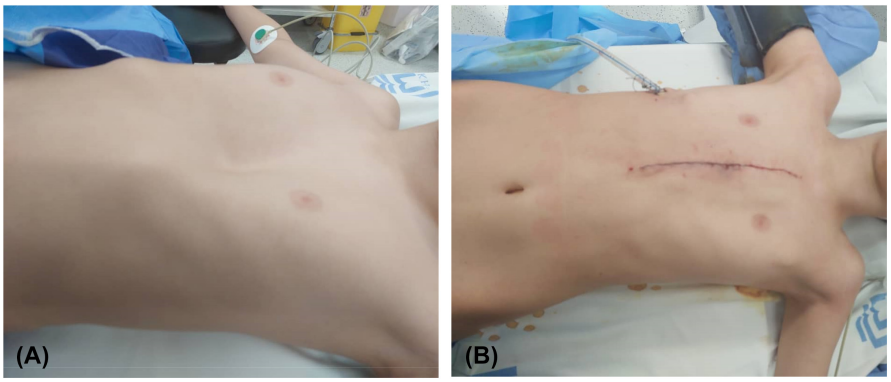

FIGURE 2 Before (A) and after (B) surgery photos of the patient.

the procedure, the patient experienced sudden bradycardia (45 beats per minute) and cardiac arrest. Immediate consultation with a cardiologist was requested, and advanced life support procedures were initiated, including airway management via endotracheal intubation, establishment of vascular access, and administration of epinephrine (0.1 mg/kg or 3.5 mg) every three minutes.

After three to four minutes of continuous ECG monitoring, ventricular fibrillation (VF) was detected. Electric cardioversion was performed and repeated ten times due to persistent VF. Intravenous amiodarone (5 mg/kg), intravenous calcium gluconate (60 mg/kg), and sodium bicarbonate (1 mEq/kg) were administrated. The thoracic surgeon removed the bar to facilitate better chest compression. Echocardiography during the procedure revealed no sign of massive emboli. Despite continued cardiopulmonary resuscitation for more than an hour, resuscitation efforts were unsuccessful, and the patient unfortunately passed away.

3 | RESULTS

The initial records retrieved from databases totaled 506, out of which 479 were deemed eligible for further evaluation. In the final screening phase, 163 studies were

acquired (Figure 4). Consequently, 93 case reports derived from 82 articles and our case were identified over a span of 23 years, as summarized in Table 2.

Among these total 93 cases, 72 patients were male and 20 cases were female. The gender of one patient was not disclosed. The average age of cases was 19.2 ± 7.7 years (range: 5–53). The time of occurrence of complications was up to 37 years from the time of surgery, with most of the cases (22.5%) occurring during the operation.

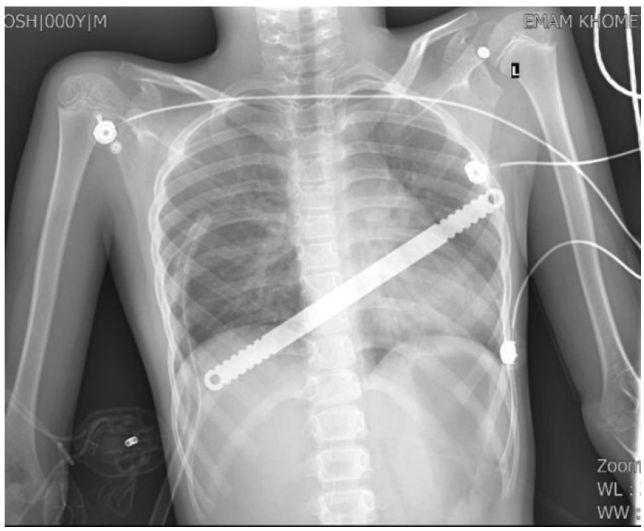

FIGURE 3 Postoperative chest X-ray.

As presented in Table 2, the most common complications experienced were cardiothoracic complications, such as cardiac arrest, heart rhythm disturbances (e.g., ventricular tachycardia, ventricular fibrillation), pneumothorax, pleural effusion, pericarditis, cardiac tamponade, cardiac perforation, penetrating lung injury, post-surgical site infection, and surgical wound dehiscence with hardware exposure. Additionally, allergic reactions to metal, hemorrhage, and pulmonary embolism were observed. Displacement of the implanted steel bar was also common and could lead to complications like right ventricular outflow tract compression and thoracic outlet syndrome. Complications resulted in death in nine cases.

4 | DISCUSSION

PE is a congenital deformity of the chest wall characterized by a depression of the sternum. It can be symmetric or asymmetric and accounts for 90% of anterior chest wall deformities. PE is usually sporadic, with male predominance seen in one in every 400–1000 live births. About one-third of patients present in infancy, and after 12 years old, the deformity worsens in one-third of adolescents.[86] The etiology is not

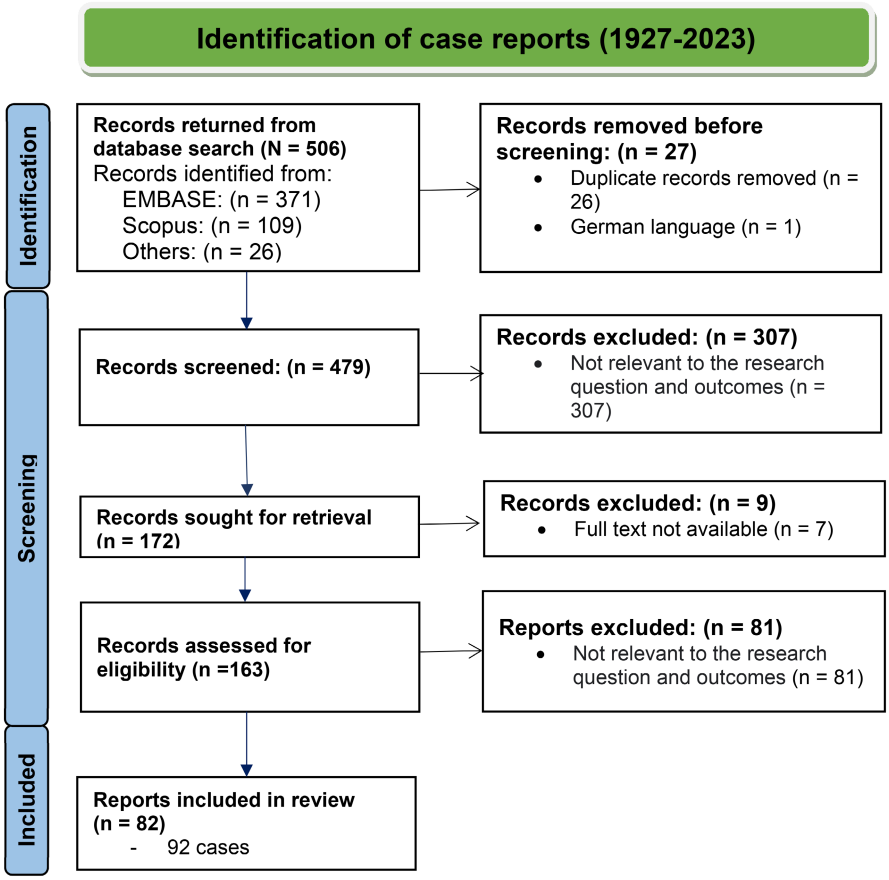

FIGURE 4 PRISMA diagram.

TABLE 2 Cases of complications of pectus excavatum surgery in the literature review with treatment and clinical outcome.

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
1	2023, Iran, 10-year-old, M (our case)	Moderate	HMRR	VF and cardiac arrest	During operation	CPR, bar removal	Died	Good
2	2023, Colombia, 16-year-old, M[5]	Severe	MIRPE	Ventricular tachycardia, bilateral pneumothorax, cardiac arrest, and PEA	During surgery and postoperatively	Bilateral thoracostomies, cardiopulmonary resuscitation, Nuss bar removal	Recovered	Fair
3	2023, Colombia, 46-year-old, F[6]	NR	HMRR	Multiple sites of malunion at the lower costosternal junctions, underlying Bio Bridge material was partially fragmented, and degraded	7 months after a Ravitch procedure	A hybrid repair with placement of Nuss bars posteriorly and titanium plating to reapproximate segments of malunion was performed.	Recovered	Poor
4	2023, Slovak Republic, 16-year-old, M[7]	Severe	MIPRE	Multisegmented acute transverse myelopathy	First postoperative day	Antibiotics, virostatics, and corticosteroids	Gradually improved	Fair
5	2023, USA, 30-year-old, F[8]	NR	MIPRE	Pericarditis	NR	NSAIDs, colchicine, and corticosteroids	Recovered	Poor
6	2023, USA, 20-year-old, F[9]	NR	HMRR	Tamponade	6 months after a Ravitch procedure	Emergent bedside pericardiocentesis	Recovered	Poor
7	2023, USA, 13-year-old, F[10]	Severe	MIPRE	Galactorrhea	16 days after surgery	Managed without intervention	Recovered	Fair
8	2022, Latvia, 12-year-old, F[11]	Severe	MIRPE	Cardiac perforation	During operation	Emergency thoracotomy without bar removal	Recovered	Fair
9	2022, China, 23-year-old, M[12]	NR	MIRPE	Bar displacement	10 years later	Bar removed successfully	Recovered	Fair
10	2022, USA, 41-year-old, M[13]	NR	MIPRE	Right ventricular outflow tract compression caused by a displaced intrathoracic bar	6 months later	Bar removed successfully	Recovered	Fair
11	2022, United Kingdome, 21-year-old, M[14]	NR	MIRPE	TOS	NR	NR	NR	Poor
12	2022, Portugal, 15-year-old, M[15]	Severe	MIRPE	TOS	2 weeks later	Conservative management with rehabilitation exercising and nerve nourishing was initiated	Recovered	Poor
13	2022, Netherlands, adolescent, M[16]	NR	MIRPE	Spontaneous sub diaphragmatic bar migration	1 month after surgery	The bar was removed and a new bar was inserted	Recovered	Fair
14–15	2022, China, 13-year-old, M[17]	NR	MIRPE	VF	During surgery	External massage and electric shock defibrillation	Recovered	Fair
	2016, China, 15-year-old, M[17]	NR	MIRPE	Death	1 year later	NR	Died	Poor

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
16	2021, USA, 21-year-old, F[18]	Severe	HMRR	Pectus bar displacement causing right ventricular outflow tract obstruction	4 months later	Emergency thoracoscopic removal of the bar with cardiac surgery	Recovered	Fair
17	2021, Poland, 35-year-old, F[19]	NR	HMRR	Cardiac tamponade caused by a broken metal sternal wire that injured the wall of the ascending aorta	19 years after surgery	Salvage repair of this segment of the aorta in cardiopulmonary bypass	Recovered	Poor
18	2021, USA, 16-year-old, M[20]	NR	MIRPE	Post-surgical site infection	2 months after surgery	I.V clindamycin, topical corticosteroids, and an allergy consult	Recovered	Poor
19	2021, China, 19-year-old, M[21]	NR	MIRPE	Multiple organ dysfunction	1 month after the bar removal and 4 years after surgery	Surgery	Recovered	Fair
20	2020, Korea, 17-year-old, M[22]	Severe	MIRPE	Sudden cardiac arrest	During operation	Resuscitation (chest compressions, electric cardioversion, and anti-arrhythmic agents)	Recovered	Poor
21	2020, Germany, 15-year-old, M[23]	NR	MIRPE	Malposition of the metal pectus bar in the pericardial sac	14 days after surgery	Open-heart surgery, bar removal	Recovered	Fair
22	2020, Finland, 26-year-old, F[24]	NR	MIRPE	Aortic hemorrhage during late pectus bar removal	9 years after surgery	Sternotomy and aortic ligation	Recovered	Poor
23	2020, United Kingdome, 22-year-old, M[25]	Severe	MIRPE	Extra-thoracal migration of the Nuss bar into the stomach	2.5 years after surgery	Bar removal	Recovered	Good
24	2020, Italy, 24-year-old, M[26]	Moderate	HMRR	Surgical wound dehiscence with hardware exposure	Eight postoperative days	Vacuum-assisted closure and surgical debridement	Recovered	Fair
25	2020, South Korea, NR-year-old, F[27]	NR	MIRPE	Penetrating lung injury and pneumothorax	During surgery	Bar was repositioned	Recovered	Poor
26	2020, USA, 26-year-old, M[28]	NR	HMRR	Cardiac perforation	7 months after surgery	Bar removal	Recovered	Poor
27–28	2019, USA, 14-year-old, M[29]	Severe	MIRPE	Scoliosis progression	3 months after surgery	Posterior instrumented spinal fusion 3 months later	Recovered	Fair
	2019, USA, 13-year-old, M[29]	Severe	MIRPE	Scoliosis progression	7.5 months after surgery	Posterior instrumented spinal fusion	Recovered	Fair
29	2019, USA, 20-year-old, M[30]	Severe	MIRPE	Right ventricle laceration	30 days post operation during bar removal	Clamshell thoracotomy, peripheral cardiopulmonary bypass	Recovered	Poor

(Continues)

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
30	2019, Serbia, 16-year-old, M[31]	Severe	HMRR	Bilateral arterial and venous lower limb thrombosis	2 months after surgery	Urgent cardiac Procedure was performed and the bar removed	Died	Fair
31	2018, China, 27-year-old, M[32]	Severe	MIRPE	TOS	1 months after surgery	Nerve nourishing medicine and rehabilitation	Recovered	Fair
32	2018, USA, 26-year-old, M[33]	NR	HMRR	Misplacement of Nuss bar into right ventricle caused a ventricular septal defect	6 months after surgery	Emergent open-heart surgery with peripheral cardiopulmonary bypass. Bar removal	Recovered	Poor
33	2018, Croatia, 14-year-old, M[34]	Severe	MIRPE	Metal allergy	8 months after surgery	Steroid therapy	Recovered after 2 years	Good
34	2018, Hong Kong, 11-year-old, M[35]	Severe	MIRPE	Massive pericardial effusion, post pericardiotomy syndrome	Fifth post-operative day	Oral prednisolone	Recovered	Poor
35	2015, Japan, 13-year-old, M[2]	NR	MIRPE	Collapsed suddenly while playing basketball at school before bar removal	1 years after surgery	CPR	Died	Fair
36	2015, Denmark, 40-year-old, M[36]	NR	MIRPE	Right ventricular outflow tract obstruction due to displaced pectus bar	30 months after surgery	Bar was removed	Recovered	Poor
37	2015, USA, 13-year-old, F[37]	Severe	MIRPE	Arteriovenous fistula between the left internal mammary artery and the pulmonary venous system	3 years after surgery, immediate postoperative after bar removal	Coil embolization of fistula from the left internal mammary artery	Recovered	Poor
38	2005, China 18-year-old, M[38]	Severe	Modified extra pleural Nuss procedure with a subxiphoid incision	Cardiac arrest while the Nuss bar was being inserted into the chest	During operation	Nuss bar was immediately removed, and CPR was performed.	Recovered	Fair
39	2014, United Kingdome, 25-year-old, M[39]	NR	MIRPE	Second cardiac arrest during rotation of the Nuss bar	During operation	Poor initial response to resuscitation and defibrillation until the retrosternal bar was removed	Recovered	Poor
40	2014, Turkey, 22-year-old, M[40]	NR	HMRR	Intracardiac erosion of a pectus bar Pulmonary embolism	9 years after surgery 2 years after surgery	Extraction of the bar and tricuspid valve repair Pulmonary endarterectomy	Recovered	Fair

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
41	2014, South Korea, 17-year-old, M[41]	Moderate	MIRPE	Delayed-onset hypovolemic shock (right-side hemothorax)	1 days after surgery	Nuss bars were removed and a lower sternotomy was performed. The bleeding was found to originate from a small laceration of the right ventricle, which was repaired. The Nuss bar was reinserted.	Recovered	Poor
42	2014, South Korea, 27-year-old, M[42]	NR	MIRPE	Axillary artery to pulmonary artery fistula	5 years after surgery	Embolization	Recovered	Poor
43	2014, Taiwan, 22-year-old, M[43]	Severe	MIRPE	Complex regional pain syndrome	2 weeks after surgery	Rehabilitation program and transcutaneous electrical nerve stimulation. The pectus bars were removed 3 years after the operation	Recovered	Poor
44	2014, Japan, 17-year-old, M[44]	Severe	MIRPE	Metal allergy to titanium bars	Few days after surgery	Oral steroids and replacing the stainless-steel bars with titanium bars	Recovered	Poor
45	2014, USA, 19-year-old, F[45]	Severe	MIRPE	Life-threatening hemorrhage	During Nuss bar removal	Thoracotomy, exploration and ligation and transfusion of blood products	Recovered	Poor
46	2013, South Korea, 15-year-old, M[46]	NR	HMRR	Cardiac tamponade caused by broken sternal wire	14 months after surgery	Pericardial paracentesis and wire removal	Recovered	Poor
47	2013, Germany, 16-year-old, M[47]	NR	MIRPE	Right atrial and a right ventricular perforation during surgery, malignant cerebral edema the next morning	During and 1 day after surgery	The atrial hole was clamped, the right ventricle was closed, emergent craniotomy and cerebral decompression	Died	Poor
48	2013, South Korea, 23-year-old, M[48]	Severe, NR	MIRPE	Pan-cord brachial plexus injury	1 day after surgery	Steroid and physical therapy	Improved, not fully recovered.	Poor
49	2013, United Kingdom, 25-year-old, M[49]	NR	MIRPE	Late coronary artery and tricuspid valve injury (intracardiac position of the bar)	8 years after surgery	Cardiopulmonary bypass (CPB) was instituted and sternotomy was performed	Recovered	Poor
50	2013, Italy, 16-year-old, M[50]	Severe	MIRPE	Migration of the bar into the ribs with extensive ossification around its right end	3 years later while attempting to remove the bar	The bar was progressively cleared of new bone, mobilized, rotated, and removed uneventfully	Recovered	Poor

(Continues)

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
51	2013, Turkey, 22-year-old, M[51]	Severe	MIRPE	Vascular TOS	1 month after surgery	Nonsteroidal anti-inflammatory therapy did not alleviate the symptoms. the first rib, anterior scalene muscle and all fibrous adhesions around the first rib were resected via an axillary incision under general anesthesia	Recovered	Poor
52	2013, Switzerland, 14-year-old, M[52]	Severe	MIRPE	Metal allergy	36 days after surgery	Steroid therapy initiated first and failed, bar removal after 6 months subsequently	Recovered	Fair
53	2013, USA, 29-year-old, M[53]	Severe	MIRPE	Cardiac perforation	During operation	Emergent cardiopulmonary bypass	Recovered	Poor
54	2012, France, 15-year-old, M[54]	Severe	MIRPE	Mechanical occlusion of the inferior vena cava, tension pneumothorax, cardiac arrest	During operation	I.V fluid bolus and placement of bilateral chest tubes, the bar was rapidly removed, Cardiopulmonary resuscitation	Recovered	Fair
55	2012, Taiwan, 13-year-old, M[55]	NR	MIRPE	Late-onset bilateral hemothorax with hypovolemic shock	5 months after surgery	Emergency tube thoracostomy was performed on both hemi thoraces with two 20 Fr. chest tube	Recovered	Poor
56	2012, USA, 23-year-old, M[56]	Severe	MIRPE	Fibrous band causing severe right ventricle outflow obstruction	11 years after surgery	video-assisted thoracoscopic removal of the obstructive fibrotic band	Recovered	Fair
57	2012, China, 15-year-old, M[57]	Severe	MIRPE	Delayed right brachial plexus injury and palsy (painful and enlarged sub axillary lymph node)	15th postoperative day	Anti-inflammatory medications and physical therapy	Recovered	Poor
58	2011, South Korea, 13-year-old, M[58]	NR	MIRPE	TOS	3 days postoperative	Bar removal after 2 months	The patient no longer complained of sensory loss in the forearm and arm. However, the claw hand deformity did not improve.	Fair

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
59	2011, Germany, 53-year-old, M[59]	NR	HMRR	Intrapericardial migration of dislodged sternal struts, perforated the left upper lobe bronchus, perforation of two struts into the right ventricle and RVOT	37 years post-surgery	Removal of the steel struts, pericardiotomy, the bronchial perforation was surgically repaired, cardiopulmonary bypass	Recovered	Fair
60	2011, France, 18-year-old, M[60]	Moderate	MIRPE	Cardiac perforation, arrhythmia, cardiac tamponade	During retrosternal dissection beginning a Nuss procedure	Sternotomy, massive transfusion	Recovered	Fair
61	2010, Taiwan, 29-year-old, M[61]	NR	HMRR	Restrictive Chest Wall Deformity, severe pulmonary hypertension and restrictive lung disease	26 years post-surgery	He denied operation and received pulmonary hypertension medications and supplemental oxygen	Recovered	Poor
62–65	2009, USA, 11-year-old, M[62]	Moderate	MIRPE	Cardiac injury	During operation	Cardiac surgery was notified, and sternotomy was immediately performed. The dissector was removed and myocardium repaired on cardio pulmonary bypass	Recovered	Good
	2009, USA, 14-year-old, M[62]	Severe	MIRPE	Cardiac tamponade	During operation	Immediate sternotomy, pericardium was opened and drained followed, bar was removed	Recovered	Good
	2009, USA, 18-year-old, M[62]	Severe	HMRR at 11 and MIRPE at 18	Cardiac tamponade and perforation, malignant supraventricular arrhythmia	During operation	Open cardiac massage was performed, the wounds were repaired, and the patient was placed on cardiopulmonary bypass	Survived but sustained a severe hypoxic brain injury	Good
	2009, USA, 17-year-old, M[62]	Severe	MIRPE	During bar removal, there was a "symphysis," of the space between the pericardium and the heart. There was also a 2-cm hole in the left ventricle from where a probable adhesion from the bar tore the pericardium and the underlying heart.	6 months after surgery	The hole was repaired, and he was aggressively resuscitated	Died on operating room table	Good

(Continues)

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
66	2009, USA, 14-year-old, F[63]	NR	HMRR	Endocarditis	2 months after surgery	Emergent removal of the pectus bar. An endocardial inflammatory mass involving the septum as well as the anterior papillary muscle to the tricuspid valve was debrided	Recovered	Poor
67	2009, Switzerland, 20-year-old, F[64]	NR	MIRPE	Near-fatal bleeding after trans myocardial ventricle lesion during removal of the pectus bar	3 years after surgery	Volume resuscitation included 25 U of packed red blood cells, numerous platelet concentrates, and 10 fresh frozen plasmas, inserting bilateral chest tubes and a retrosternal drain	Recovered	Fair
68	2008, Israel, 17.5-year-old, M[65]	Severe, NR	HMRR	Cardiac perforation by a pectus bar, pneumothorax, hemothorax	During operation	Chest tube insertion, emergency thoracotomy, bar removal, suturing cardiac and pulmonary injuries	Died	Fair
69	2008, Taiwan, 22-year-old, M[66]	NR	MIRPE	Cardiac tamponade	Postoperative period	Emergency echocardiographically guided pericardiocentesis with insertion of a central venous catheter for drainage without removal of the steel bar	Recovered	Fair
70	2008, USA, 19 year-old, M[67]	NR	MIRPE	Erosion of the Nuss bar into the internal mammary artery and hemothorax	4 months after surgery	A chest tube was placed, and 2 L of bloody drainage was evacuated, angiography and embolization	Recovered	Fair
71	2008, USA, 21-year-old, F[68]	NR	MIRPE	Erosion of a Pectus bar through the sternum	8 weeks after surgery	She was taken to the operating room for sternal reconstruction	Recovered	Poor
72	2006, Norway, 17-year-old, M[69]	NR	MIRPE	Cardiac tamponade (laceration in the adventitial layer of the ascending aorta)	2 months after surgery	Immediate needle aspiration of blood from the pericardium, the Nuss bar was removed, tear closed	Recovered	Fair

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
73–74	2005, Germany, 14-year-old, F[70]	Deep funnel chest	MIRPE	Massive hemorrhage from both chest wounds during removal of the pectus bar	After bar removal	Emergency sternotomy	Recovered	Fair
	2005, Germany, 13-year-old, F[70]	Severe	MIRPE	Bilateral sternoclavicular dislocation of the bar	6 months after operation	Repositioning and new fixation of the bar	Recovered	Poor
75	2005, USA, 19-year-old, M[71]	NR	MIRPE	VF at 35 months after pectus repair	35 months after surgery	CPR was performed immediately	Died	Fair
76	2004, Switzerland, 17-year-old, F[72]	NR	MIRPE	Bilateral pneumothorax, bilateral pleural effusion and pericardial effusion	During and postoperative period	Chest tube insertion, anti-inflammatory therapy with diclofenac-sodium and prednisolone	Recovered	Fair
77	2004, United Kingdom, 24-year-old, M[73]	NR	MIRPE	Cardiac tamponade	2 years after surgery	Urgent thoracotomy	Recovered	Poor
78	2004, United Kingdom, 24-year-old, M[74]	NR	A method developed by one of the authors to support the sternum without the use of metal bars	Hemopericardium	NR	The pericardium was opened and the pericardial space was evacuated	Recovered	Poor
79	2003, Germany, 14-year-old, M[75]	NR	MIR14PE	Post pericardiotomy syndrome (pericardial effusion)	10 days after surgery	I.V methylprednisolone	Recovered	Poor
80	2003, Germany, 21-year-old, M[76]	NR	MIRPE	The central tendon of the left diaphragm was unnoticed injured (The thorax was found to contain not only the entire, twisted stomach, but also the transverse colon and the spleen)	4 months after surgery	Emergency operation to repair an incarcerated diaphragmatic hernia, thoraco-abdominal surgery was performed and the diaphragm closed from the thoracic side	Recovered	Poor
81	2002, USA, 13-year-old, M[77]	Severe	MIRPE	Pectus carinatum	1 year after surgery	Pectus bar removal	The pectus carinatum was persistent for 2 months	Poor

(Continues)

TABLE 2 (Continued)

No	Publication year, country, Age, sex	PE severity[a]	Surgery type	Complication	Time	Treatment	Outcome	Quality[b]
82–86	2001, USA, 8-year-old, M[78]	Moderately deep and slightly asymmetric	MIRPE	Cardiac perforation	During operation	Urgent sternotomy with right atrial, and right ventricle repair followed by tricuspid valve repair on cardiopulmonary bypass	Recovered	Poor
	2001, USA, 13-year-old, M[78]	Moderately deep	MIRPE	MRSA sepsis, bilateral empyema thoracis, and bacterial pericarditis	13 days after surgery	Bilateral pleural debridement followed 2 days later by open debridement of his heart	Recovered	Poor
	2001, USA, three adolescent boys ages 13 through 15 (78)	NR	MIRPE	Thoracic outlet like syndrome	Postoperative period	Bar removed The symptoms resolved with the bar in place in two cases	All recovered	Poor
87	1999, Turkey, 18-year-old, M[79]	NR	Fixation with steel strut	Broken steel strut that embedded in the myocardium	4 years after surgery	Stutt removal and thoracotomy	Recovered	Poor
88	1998, USA, 14-year-old, M[80]	NR	A standard surgical technique	Asphyxiating thoracic dystrophy (restrictive pulmonary disease, recurrent pneumonia, and cor pulmonale)	6–8 years after surgery	Operative procedure	Recovered	Fair
89	1998, Italy, 20-year-old, F[81]	Severe	NR	Migration of a metal support into peritoneal cavity	8–9 months after surgery	Video laparoscopic removal of the wire	Recovered	Poor
90	1997, United Kingdom, 19-year-old, NR[82]	NR	Correction with 2 bars	Migration of PE correction bar into the left ventricle and several systemic embolic events	At least 6 months following surgery	Removal of the bar	Recovered	Fair
91	1995, Switzerland, 7-year-old, M[83]	Severe	Sterno-chondroplasty	Cardiac perforation	5 days after surgery	The ventricular septal defect was patched, the tricuspid tear was sutured, and the torn aortic cusp was resuspended	He was discharged with complications	Poor
92	1992, Turkey, 22-year-old, M[84]	NR	HMMR	Pulmonary embolism	2 years after surgery	Pulmonary endarterectomy	Recovered	Poor
93	1989, Japan, 5-year-old, M[85]	NR	NR	Rupture of descending aorta in marfanoid patient	During operation	NR	Died	Poor

Abbreviations: CPR, cardiopulmonary resuscitation; F, Female; HMMR, Highly modified Ravitch repair; I.V, Intravenous; M, Male, MIRPE, Minimally invasive repair of pectus excavatum; MRSA, methicillin-resistant *Staphylococcus aureus*; NR, Not reported; PE, Pectus excavatum; PEA, Pulseless electrical activity; RVOT, Right ventricular outflow tract; TOS, Thoracic outlet syndrome; VF, Ventricular fibrillation.

[a]A Haller index between 2 and 3.2 is considered mild; between 3.2 and 3.5, moderate; 3.5 or greater, a severe deformity.

[b]Using the tool described by Murad et al.[4]

well understood but may involve abnormal rib and cartilage growth or muscular forces. Symptoms of PE include exercise intolerance, shortness of breath, poor endurance, and chest pain.[87] The PE severity index (Haller index) measures the depth of the defect by dividing the transverse diameter of the chest by the anterior–posterior distance on the CT scan of the chest on the axial image. A normal Haller index is two or less. Haller indexes between 2 and 3.2, 3.2 and 3.5, and 3.5 or greater are considered mild, moderate, and severe, respectively.[88] Surgical repair is recommended for patients with a Haller index greater than 3.25 or those with cardiac compression, abnormalities such as mitral valve prolapse, murmurs, conduction abnormalities, restrictive defects in pulmonary function tests, cosmetic issues, progressive symptoms over time, or failed previous repair. Surgery is typically performed between eight years of age and before the end of adolescence.[89]

4.1 | Surgical repair

The two most common PE surgical repair methods are open repair (Ravitch procedure) and minimally invasive repair with a placement of a metal bar (Nuss procedure). In Nuss surgery, a bar is inserted to lift the sternum, which is removed at least two years later. In the modified Ravitch procedure, open resection of the sub-pericondrial cartilage and sternal osteotomy with the insertion of a stabilizing device are performed. A meta-analysis indicated no significant difference between the Nuss and Ravitch procedures in pediatric patients. However, for adult patients, the Ravitch procedure has been found to result in fewer complications.[90]

4.2 | Complications

Each surgical method has specific types of complications, but the overall frequency is similar for both procedures. The most common complications after the Nuss procedure are bar displacement, postoperative pain, pleural effusion, pneumothorax, recurrence, and cardiac complications.[91] The most common complications associated with the Ravitch procedure are secondary thoracic deformity, pneumothorax, and recurrence of PE. Complications may occur during the operation, immediately postoperatively, or as many years after the procedure.[92]

Most common complications associated with the Ravith procedure are secondary thoracic deformity, pneumothorax, and recurrence of PE. Complications may occur during operation, immediately post-operation, or as many years after the procedure. Performing the Ravitch procedure is one of the best techniques for PE repair in pediatrics, adolescents, and adults. Although lethal complications are rare, lung, heart, and major vessel injuries can occur.[93]

Cardiac arrest during the procedure is the most serious complication and is more related to cardiac injury caused by the metallic bar and surgical instruments. In addition, cardiac arrest may occur due to physical stimulation of the heart with a surgical instrument and oppression of the right ventricular outflow.[5] In previous studies, almost all related cardiac arrests were secondary to heart or major vessel injury; however, some cases of arrest have been reported without direct cardiac injury or cardiac abnormalities in perioperative studies.[22] The mortality rate for PE surgery is generally low, and it is uncommon for patients to experience unexpected fatalities post-surgery. One possible explanation for cardiac complications could be the presence of an undiagnosed underlying cardiac condition that might have been aggravated by the surgical procedure. However, our patient had undergone an extensive preoperative evaluation, and no cardiac irregularities were found. Two possible mechanisms are hypothesized: first, rotation of the heart by sternal elevation could twist the coronary to pulmonary arterial shunts and may result in a directional change of blood flow in the shunts and subsequently cause acute ischemia of myocardium and ventricular fibrillation; second, nerve stretching caused by sudden enlargement of the substernal space may unsettle the balance between vagal and sympathetic innervations and trigger inhibition of cardiac function and lead to cardiac arrest.[38] Our case underscores the significance of being vigilant during low-risk procedures, as unexpected outcomes can still occur. Surgeons must have a strategy in place to address complications effectively. Furthermore, this situation emphasizes the importance of thorough preoperative evaluation and informed consent. Patients should be made aware of all potential risks associated with surgery, even if they are considered low-risk, particularly when it comes to cosmetic procedures.

4.3 | Management

Based on the type of complication and the team expertise, the management of a specific complication should be decided, as summarized in Table 2. Advanced CPR is challenging for medical teams since the metallic bar placement makes chest compression more complicated. There are no specific guidelines for patients with a bar in their chest. Based on clinical recommendations, compressions should increase substantially in force, and metallic bars should be removed. Determining the place for external defibrillation paddles, taking into account that some complications may occur with electrical

cardioversion, is also essential. It is recommended to place one anterior paddle on the sternal midline and one posterior paddle between the scapulae.[71]

Finally, the PE deformity fixation procedure needs an experienced surgery team and medical staff, including the intensive care unit (ICU) team. All the team members should be trained for encountering and managing possible complications. In addition, the CPR maneuvers for these patients should be discussed preoperatively. The administration of anti-arrhythmic drugs should also be investigated.

5 | CONCLUSION

Although life-threatening arrhythmia is an infrequent complication of pectus excavatum (PE) surgery, cardiac arrest can still occur in patients with no preoperative cardiac abnormalities and no cardiac injury during the fixation procedure. Consequently, it is imperative to stay vigilant regarding the potential complications of PE surgery and to be adept at managing them appropriately.

AUTHOR CONTRIBUTIONS

Ghazal Roostaei: Conceptualization; methodology; visualization; writing – original draft. **Hesam Amini:** Investigation; methodology; project administration. **Hamidreza Abtahi:** Methodology; supervision; validation; visualization. **Maryam Edalatifard:** Supervision; visualization; writing – review and editing. **Besharat Rahimi:** Conceptualization; supervision. **Hossein Kazemizadeh:** Supervision; writing – review and editing. **Sanaz Asadi:** Writing – original draft. **Niloofar Khoshnam-Rad:** Conceptualization; methodology; visualization; writing – original draft; writing – review and editing.

ACKNOWLEDGMENTS

We thank the family of the patient for their permission to publish this case.

FUNDING INFORMATION

We did not receive any fund or any financial support for this study.

CONFLICT OF INTEREST STATEMENT

We wish to confirm that there are no known conflicts of interest associated with this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, [N.K], upon reasonable request.

CONSENT

Written informed consent was obtained from the relative of the patient to publish this article, in accordance with the journal's patient consent policy.

ORCID

Niloofar Khoshnam-Rad https://orcid.org/0000-0001-6700-3570

REFERENCES

1. Parikh D, Rajesh PB. *Tips and Tricks in Thoracic Surgery*. Springer; 2018:1-508.
2. Nakahara O, Ohshima S, Baba H. Cardiopulmonary arrest during the Nuss procedure: case report and review. *Acute Med Surg*. 2015;2(4):250-252.
3. Hebra A, Kelly RE, Ferro MM, Yüksel M, Campos JRM, Nuss D. Life-threatening complications and mortality of minimally invasive pectus surgery. *J Pediatr Surg*. 2018;53(4):728-732.
4. Murad MH, Sultan S, Haffar S, et al. Methodological quality and synthesis of case series and case reports. *BMJ Case Rep*. 2013;2(2):38-43.
5. Cujiño-Álvarez IF, Torres-Salazar D, Velásquez-Galvis M. Cardiorespiratory arrest during and after nuss procedure: case report. *J Cardiothorac Surg*. 2023;18(1):166.
6. Jaroszewski DE. BioBridge prosthesis failure after a Ravitch repair for pectus excavatum. *Ann Thorac Surg*. 2023;116(1):202-203.
7. Omanik P, Funakova M, Babala J, Beder I. Devastating neurological complication after pectus excavatum surgery. *J Pediatr Surg Case Rep*. 2023;92:102620.
8. Yaker ZS, Majid M, Honnekeri B, et al. A rare case of pericarditis caused by pectus excavatum surgery. *J Am Coll Cardiol*. 2023;81(8):3613.
9. Atallah I, Das D, Srinivasamurthy R, et al. Bloody business: a case of tamponade caused by pectoris rod erosion of the pericardial space. *J Am Coll Cardiol*. 2023;81(8):2885.
10. Walsh LR, Nguyen QH, Bagrodia N, Bodenstein L. Galactorrhea after pectus excavatum repair with intercostal cryoablation. *J Pediatr Surg Case Rep*. 2023;89:102562.
11. Senica SO, Gasparella P, Soldatenkova K, Smits L, Ābola Z. Cardiac perforation during minimally invasive repair of pectus excavatum: a rare complication. *Int J Surg Case Reports*. 2022;2022(11):rjac538.
12. Gu H, Xu G, Liu T, Zhang S. The influence of 10-year Nuss bar placement on bar removal: a case report. *J Cardiothorac Surg*. 2022;17(1):271.
13. Farina JM, Gotway MB, Larsen CM, et al. Chest pain and dyspnea after a minimally invasive repair of pectus excavatum. *JACC Case Rep*. 2022;4(8):476-480.
14. Gopalaswamy M, Waterhouse B, Dunning J. Thoracic outlet syndrome after NUSS procedure for pectus excavatum: an unusual complication of a common procedure. *Br J Surg*. 2022;109(SUPPL 1):i39.
15. Fernandes S, Soares-Aquino C, Monteiro J, Estevinho N, Borges-Dias M. Thoracic outlet syndrome after minimally invasive repair of pectus excavatum in a 15-year-old boy: a case report. *Eur J Pediatr Surg Reports*. 2022;10(1):e89-e92.
16. Hamming A, Versteegh H, Schnater JM. Spontaneous subdiaphragmatic bar migration after pectus excavatum treatment. *BMJ Case Rep*. 2022;15(12):e251757.

17. Wang DW, Long DW, Liu DY, Bin CD, Luo DJ. Death cases related to Nuss procedure. *Int J Surg Sci*. 2022;6(4):8-10.
18. Purrman KC, Ziazadeh D, Loria A, Jones C. Pectus Bar displacement causing right ventricular outflow tract obstruction. *Ann Thorac Surg*. 2021;112(4):e267-e270.
19. Greberski K, Jarząbek R, Perek B, Łuczak M, Bugajski P. Exceptional life-threatening complication 19 years after Ravitch correction of pectus excavatum. *J Card Surg*. 2021;36(10):3971-3972.
20. Adib F, Tam J, Ferdman R. M305 not a case of post-surgical site infection. *Ann Allergy Asthma Immunol*. 2021;127(5):S126.
21. He XX, Dai K, Deng Q, Guo JY. Multiple organ dysfunction due to a rare complication of Nuss procedure for pectus excavatum: a case report. *Chin J Traumatol*. 2021;24(5):306-310.
22. Kim DY, Jeong JY. Sudden cardiac arrest during Nuss procedure for pectus excavatum. *J Cardiothorac Surg*. 2020;15(1):139.
23. Rubarth K, Cesnjevar R, Cuomo M, Dittrich S, Schöber M. Life-threatening complication after pectus excavatum repair due to malposition of the metal pectus bar in the pericardial sac. *Thorac Cardiovasc Surg*. 2020;68:5551.
24. Dahlbacka SJM, Ilonen IK, Kauppi JT, Räsänen JV. Aortic haemorrhage during late pectus bar removal. *Eur J Cardio-Thoracic Surg*. 2020;57(1):191-192.
25. Simon N, Kolvekar S, Khosravi A. Extra-thoracal migration of the Nuss Bar in corrective surgery for pectus excavatum: a very rare late complication. *Int J Surg Case Reports*. 2020;2020(10):rjaa388.
26. Aramini B, Morandi U, De Santis G, et al. Wound complication after modified Ravitch for pectus excavatum: a case of conservative treatment enhanced by pectoralis muscle transposition. *Int J Surg Case Rep*. 2020;66:322-325.
27. Kim DY, Jeong JY. Penetrating lung injury during Nuss procedure for pectus excavatum. *J Cardiothorac Surg*. 2020;15(1):184.
28. Nissen AP, Kilbourne MJ, Jeschke R, Lee R, Rice RD. Delayed presentation of cardiac perforation after modified Ravitch pectus excavatum repair. *Ann Thorac Surg*. 2020;109(1):e29-e31.
29. Floccari LV, Sucato DJ, Ramo BA. Scoliosis progression after the Nuss procedure for pectus excavatum: a case report. *Spine Deform*. 2019;7(6):1003-1009.
30. Krause E, Encarnacion C, Taylor B, Carr S. Nuss bar removal complicated by right ventricle laceration. *Innov Technol Tech Cardiothorac Vasc Surg*. 2019;14(1):41S-42S.
31. Stajevic M, Bijelovic M, Kosutic J, Simic R. Devastating complications of metal strut migration following pectus excavatum repair. *Eur J Pediatr Surg Reports*. 2019;07(1):e51-e54.
32. Zhang W, Pei Y, Liu K, Tan J, Ma J, Zhao J. Thoracic outlet syndrome (TOS): a case report of a rare complication after Nuss procedure for pectus excavatum. *Medicine (Baltimore)*. 2018;97(36):e11846.
33. Moore FC, Harris D, Ramage A, Dwight D. Malplacement of Nuss bar into right ventricle. *J Invest Med*. 2018;66(2):542.
34. Navratil M, Batinica M, Ivković-Jureković I. Metal allergy as a late-onset complication of the Nuss procedure in a pediatric patient. *Pediatr Pulmonol*. 2018;53(8):E24-E26.
35. Yu PSY, Ng VWK, Lau RWH, Ng CSH. Massive pericardial effusion after Nuss procedure: to drain or not to drain? *J Thorac Dis*. 2018;10(1):E27-E30.
36. Maagaard M, Udholm S, Hjortdal VE, Pilegaard HK. Right ventricular outflow tract obstruction caused by a displaced pectus bar 30 months following the Nuss procedure. *Eur J Cardio-Thoracic Surg*. 2015;47(1):E42-E43.
37. Bean JF, Wax D, Reynolds M. Arteriovenous fistula: a rare complication after nuss procedure for pectus excavatum. *Ann Thorac Surg*. 2015;100(4):1463-1465.
38. Zou J, Luo C, Liu Z, Cheng C. Cardiac arrest without physical cardiac injury during Nuss repair of pectus excavatum. *J Cardiothorac Surg*. 2017;12(1):61.
39. Rajwani A, Richardson JD, Kaabneh A, Kendall S, De Belder MA. Intra-cardiac erosion of a pectus bar. *Eur Heart J Cardiovasc Imaging*. 2014;15(2):229.
40. Abaci O, Cetinkal G, Kocas C, et al. Pulmonary embolism: a late complication of pectus excavatum repair. *Congenit Heart Dis*. 2014;9(4):E113-E115.
41. Jeong JY, Suh JH, Yoon JS, Park CB. Delayed-onset hypovolemic shock after the Nuss procedure for pectus excavatum. *J Cardiothorac Surg*. 2014;9(1):15.
42. Cho SH, Sung YM, Kim JH, Kim YK, Lee JI. Axillary artery to pulmonary artery fistula following nuss procedure for pectus excavatum. *Ann Thorac Cardiovasc Surg*. 2014;20:570-573.
43. Chen YL, Chen LC, Chen JC, Cheng YL. Complex regional pain syndrome following the nuss procedure for severe pectus excavatum. *Ann Thorac Cardiovasc Surg*. 2014;20:542-545.
44. Sakamoto K, Ando K, Noma D. Metal allergy to titanium bars after the nuss procedure for pectus excavatum. *Ann Thorac Surg*. 2014;98(2):708-710.
45. Notrica DM, McMahon LE, Johnson KN, Velez DA, McGill LC, Jaroszewski DE. Life-threatening hemorrhage during removal of a Nuss bar associated with sternal erosion. *Ann Thorac Surg*. 2014;98(3):1104-1106.
46. Lee SH, Cho BS, Kim SJ, et al. Cardiac tamponade caused by broken sternal wire after pectus excavatum repair: a case report. *Ann Thorac Cardiovasc Surg*. 2013;19(1):52-54.
47. Schaarschmidt K, Lempe M, Schlesinger F, Jaeschke U, Park W, Polleichtner S. Lessons learned from lethal cardiac injury by nuss repair of pectus excavatum in a 16-year-old. *Ann Thorac Surg*. 2013;95(5):1793-1795.
48. Choi SI, Park JH. Pan-cord brachial plexus injury after the mirpe for the correction of extreme pectus excavatum. *J Neurol Sci*. 2013;333:e449-e450.
49. Bibiloni Lage I, Khan K, Kaabneh A, Kendall S. Late coronary artery and tricuspid valve injury post pectus excavatum surgery. *Interact Cardiovasc Thorac Surg*. 2013;17(4):748-750.
50. De Giacomo T, Diso D, Francioni F, Anile M, Venuta F. Minimally invasive pectus excavatum repair: migration of bar and ossification. *Asian Cardiovasc Thorac Ann*. 2013;21(1):88-89.
51. Kiliç B, Demirkaya A, Turna A, Kaynak K. Vascular thoracic outlet syndrome developed after minimally invasive repair of pectus excavatum. *Eur J Cardio-Thoracic Surg*. 2013;44(3):567-569.
52. Sesia SB, Haecker FM, Shah B, Goretsky MJ, Kelly RE, Obermeyer RJ. Development of metal allergy after Nuss procedure for repair of pectus excavatum despite preoperative negative skin test. *J Pediatr Surg Case Reports*. 2013;1(6):152-155.
53. Craner R, Weis R, Ramakrishna H. Emergent cardiopulmonary bypass during pectus excavatum repair. *Ann Card Anaesth*. 2013;16(3):205-208.
54. Ballouhey Q, Léobon B, Trinchéro JF, Baunin C, Galinier P, De Gauzy JS. Mechanical occlusion of the inferior vena cava: an early complication after repair of pectus excavatum using the Nuss procedure. *J Pediatr Surg*. 2012;47(12):e1-e3.

55. Lin CW, Chen KC, Diau GY, Chu CC. Late-onset vital complication after the Nuss procedure for pectus excavatum. *Pediatr Surg Int*. 2012;28(1):71-73.
56. Obert L, Munyon R, Choe A, Rubenstein J, Azizkhan R. Rare late complication of the Nuss procedure: a case report. *J Pediatr Surg*. 2012;47(3):593-597.
57. Liu T, Liu H, Yang C, Xu S, Sun C. Brachial plexus palsy, a rare delayed complication of the Nuss procedure for pectus excavatum: a case report. *J Pediatr Surg*. 2012;47(11):E19-E20.
58. Lee SH, Ryu SM, Cho SJ. Thoracic outlet syndrome after the nuss procedure for the correction of extreme pectus excavatum. *Ann Thorac Surg*. 2011;91(6):1975-1977.
59. Zhang R, Hagl C, Bobylev D, et al. Intrapericardial migration of dislodged sternal struts as late complication of open pectus excavatum repairs. *J Cardiothorac Surg*. 2011;6(1):40.
60. Becmeur F, Ferreira CG, Haecker FM, Schneider A, Lacreuse I. Pectus excavatum repair according to Nuss: is it safe to place a retrosternal bar by a transpleural approach, under thoracoscopic vision? *J Laparoendosc Adv Surg Tech A*. 2011;21(8):757-761.
61. Chen CH, Liu HC, Hung TT, Chen CH. Restrictive Chest Wall deformity as a complication of surgical repair for pectus excavatum. *Ann Thorac Surg*. 2010;89(2):599-601.
62. Bouchard S, Hong AR, Gilchrist BF, Kuenzler KA. Catastrophic cardiac injuries encountered during the minimally invasive repair of pectus excavatum. *Semin Pediatr Surg*. 2009;18(2):66-72.
63. Jou CJ, Burch PT, Mart CR, Lambert LM, Kouretas PC, Minich LLA. Endocarditis after pectus excavatum repair a case report. *Circ Cardiovasc Imaging*. 2009;2(1):71-74.
64. Haecker FM, Berberich T, Mayr J, Gambazzi F. Near-fatal bleeding after transmyocardial ventricle lesion during removal of the pectus bar after the Nuss procedure. *J Thorac Cardiovasc Surg*. 2009;138(5):1240-1241.
65. Gips H, Zaitsev K, Hiss J. Cardiac perforation by a pectus bar after surgical correction of pectus excavatum: case report and review of the literature. *Pediatr Surg Int*. 2008;24(5):617-620.
66. Yang MH, Cheng YL, Tsai CS, Li CY. Delayed cardiac tamponade after the Nuss procedure for pectus excavatum: a case report and simple management. *Heart Surg Forum*. 2008;11(2):E1 29-E131.
67. Adam LA, Meehan JJ. Erosion of the Nuss bar into the internal mammary artery 4 months after minimally invasive repair of pectus excavatum. *J Pediatr Surg*. 2008;43(2):394-397.
68. Raff GW, Wong MS. Sternal plating to correct an unusual complication of the Nuss procedure: erosion of a pectus Bar through the sternum. *Ann Thorac Surg*. 2008;85(3):1100-1101.
69. Hoel TN, Rein KA, Svennevig JL. A life-threatening complication of the nuss-procedure for pectus excavatum. *Ann Thorac Surg*. 2006;81(1):370-372.
70. Leonhardt J, Kübler JF, Feiter J, Ure BM, Petersen C. Complications of the minimally invasive repair of pectus excavatum. *J Pediatr Surg*. 2005;40(11):e7-e9.
71. Zoeller GK, Zallen GS, Glick PL. Cardiopulmonary resuscitation in patients with a Nuss bar - a case report and review of the literature. *J Pediatr Surg*. 2005;40(11):1788-1791.
72. Berberich T, Haecker FM, Kehrer B, et al. Postpericardiotomy syndrome after minimally invasive repair of pectus excavatum. *J Pediatr Surg*. 2004;39(11):e1-e3.
73. Cope SA, Rodda J. Cardiac tamponade presenting to the emergency department after sternal wire disruption. *Emerg Med J*. 2004;21(3):389-390.
74. Barakat MJ, Morgan JA. Haemopericardium causing cardiac tamponade: a late complication of pectus excavatum repair. *Heart*. 2004;90(4):e22.
75. Muensterer OJ, Schenk DS, Praun M, Boehm R, Till H. Postpericardiotomy syndrome after minimally invasive pectus excavatum repair unresponsive to nonsteroidal anti-inflammatory treatment. *Eur J Pediatr Surg*. 2003;13(3):206-208.
76. Marusch F, Gastinger I. Life-threatening complication of the Nuss-procedure for funnel chest. A case report. *Zentralbl Chir*. 2003;128(11):981-984.
77. Hebra A, Thomas PB, Tagge EP, Adamson WT, Othersen HB. Case report: pectus carinatum as a sequela of minimally invasive pectus excavatum repair. *Pediatr Endosurgery Innov Tech*. 2002;6(1):41-44.
78. Moss RL, Albanese CT, Reynolds M. Major complications after minimally invasive repair of pectus excavatum: case reports. *J Pediatr Surg*. 2001;36(1):155-158.
79. Onursal E, Toker A, Bostanci K, Alpagut U, Tireli E. A complication of pectus excavatum operation: endomyocardial steel strut. *Ann Thorac Surg*. 1999;68(3):1082-1083.
80. Weber TR, Kurkchubasche AG. Operative management of asphyxiating thoracic dystrophy after pectus repair. *J Pediatr Surg*. 1998;33(2):262-265.
81. Stefani A, Morandi U, Lodi R. Migration of pectus excavatum correction metal support into the abdomen. *Eur J Cardio-Thoracic Surg*. 1998;14(4):434-436.
82. Dalrymple-Hay MJR, Calver A, Lea RE, Monro JL. Migration of pectus excavatum correction bar into the left ventricle. *Eur J Cardio-Thoracic Surg*. 1997;12(3):507-509.
83. Pircova A, Sekarski-Hunkeler N, Jeanrenaud X, et al. Cardiac perforation after surgical repair of pectus excavatum. *J Pediatr Surg*. 1995;30(10):1506-1508.
84. McWilliams R, Hooper T, Lawson R. A late complication of pectus excavatum repair. *Postgrad Med J*. 1992;68(800):473-474.
85. Ishikawa S, Akaogi E, Sohara Y, Ijima H, Mitsui K, Hori M. Aortic disruption after operation for pectus excavatum in a infant with marfanoid hypermobility syndrome. *Nihon Geka Gakkai Zasshi*. 1989;37(9):2016-2019.
86. Biavati M, Kozlitina J, Alder AC, et al. Prevalence of pectus excavatum in an adult population-based cohort estimated from radiographic indices of chest wall shape. *PloS One*. 2020;15(5):e0232575.
87. David VL. Current concepts in the etiology and pathogenesis of pectus excavatum in humans—a systematic review. *J Clin Med*. 2022;11(5):1241.
88. Carrera Rubio S, Vallés Torres J, Bueno Torres A, Lafuente Martín FJ. Pectus excavatum. *Rev Esp Anestesiol Reanim*. 2010;57(4):262.
89. Frantz FW. Indications and guidelines for pectus excavatum repair. *Curr Opin Pediatr*. 2011;23(4):486-491. doi:10.1097/MOP.0b013e32834881c4
90. Kanagaratnam A, Phan S, Tchantchaleishvilli V, Phan K. Ravitch versus Nuss procedure for pectus excavatum: systematic review and meta-analysis. *Ann Cardiothorac Surg*. 2016;5(5):409-421.

91. Akhtar M, Razick DI, Saeed A, et al. Complications and outcomes of the Nuss procedure in adult patients: a systematic review. *Cureus*. 2023;15:e35204.
92. Jawitz OK, Raman V, Thibault D, et al. Complications after Ravitch versus Nuss repair of pectus excavatum: a Society of Thoracic Surgeons (STS) general thoracic surgery database analysis. *Surgery*. 2021;169(6):1493-1499.
93. Mao YZ, Tang ST, Li S. Comparison of the Nuss versus Ravitch procedure for pectus excavatum repair: an updated meta-analysis. *J Pediatr Surg*. 2017;52(10):1545-1552.

How to cite this article: Roostaei G, Amini H, Abtahi H, et al. Post-operative arrest following pectus excavatum repair: A case report with a systematic review of the published case reports. *Clin Case Rep*. 2024;12:e8650. doi:10.1002/ccr3.8650