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ORIGINAL ARTICLE

Cardiopulmonary Bypass in Non-Cardiac Surgery

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Background Cardiopulmonary bypass (CPB) and extracorporeal membrane oxygenation (ECMO) are used to facilitate circulatory support in standard cardiac surgery and emergency intervention, but CPB and ECMO are not used routinely in non-cardiac surgery involving the thorax and major vessels. The primary aim of this study was to identify the type of non-cardiac procedures and bypass used in our institution and review the patient outcomes including perioperative and bypass complications.

Methods A retrospective study was performed within the Royal Adelaide Hospital Cardiothoracic Surgery Unit (CTSU) that examined all operations between 2006 and 2014. There were 1,816 non-cardiac cases, of these nine used CPB or ECMO. Cases excluded from the study were those that required cardiac surgical management with the use of CPB or ECMO.

Results Twelve (12) non-cardiac surgery cases were reviewed, with three, and nine cases, respectively, using ECMO and CPB standby or support. The non-cardiac surgical procedures included eight thoracic cases, two renal cases and two tracheal cases. Of the thoracic cases, five were elective, two were bailout and one was an emergency. Both renal cases were bailout (with one as major vessel support and one as standby). Both tracheal cases were bailout (one as an emergency and one as standby). Intraoperative complications included severe haemorrhage in three cases. General postoperative complications included increased analgesia requirement, atelectasis, fever; and prolonged ECMO support and ICU stay which occurred in seven cases. No direct complications of CPB or ECMO are reported. Four of the 12 cases that encompassed thoracic, renal and tracheal surgery are discussed in detail.

Conclusions Our review of 12 cases managed under the CTSU has shown that extracorporeal circulatory support can be used in a range of thoracic, renal and tracheal surgery. These surgical procedures have involved the management of haemodynamically unstable patients. Patient outcomes have been encouraging with few complications. With further research including the use of a larger sample size and control groups, more definitive conclusions could be made on the benefit of CPB and ECMO to patients in non-cardiac surgery.

Keywords Cardiopulmonary bypass • Thoracic surgery • Non-cardiac surgery • Extracorporeal circulation • ECMO

Introduction

The primary use of extracorporeal circulation including cardiopulmonary bypass (CPB) is to facilitate operations involving the heart by providing artificial circulatory support. Cardiopulmonary bypass use in non-cardiac surgery has been associated with increased morbidity and mortality and therefore remains controversial [1]. Cardiopulmonary bypass in non-cardiac surgery facilitates the ability to perform complex, technically challenging

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Table 1 Publications in the literature of non-cardiac surgical procedures with ECMO or CPB and associated complications.

Author year	Surgical indication	Study dates	Total patients	General complications	Bypass category
Gillnox 1996 [4]	Pulmonary or central malignant or vascular tumours	1996	4	Intraoperative blood loss. No postoperative complications	Bailout
Neville 1965 [5]	Pulmonary tumours	1965	Not known	Nonspecific intraoperative morbidity reported and postoperative mortality reported without specific detail	Elective
Danton 1998 [6]	Pulmonary tumours	1990–1997	13	Increased blood loss and ventilation requirements intraoperatively. No postoperative complications	Bailout
Baron 2003 [7]	Pulmonary tumours	1994–2001	4	Intraoperative AF in 2 patients, No postoperative complications	Elective
Mei 2012 [8]	Pulmonary tumours	2001–2008	4	Nonspecific intraoperative complications in 3 patients. No postoperative complications	Elective
Byrne 2004 [9]	Pulmonary tumours	1992–2002	14	Intraoperative blood loss and low cardiac output. Postoperative complications include pulmonary oedema and mortality in 1 patient	Bailout
Hasegawa 2003 [10]	Pulmonary tumours	2003	11	No intraoperative complications. Postoperative mortality reported in 1 patient due to MRSA	Elective
De Perrot 2005 [11]	Pulmonary tumours	1998–2004	7	No intraoperative complications, Postoperative complications include ARDS and atelectasis.	Elective
Wiebe 2006 [12]	Great vessel tumours	1993–2003	13	Intraoperative mortality reported in 1 patient, Day 4 postoperative mortality reported in 1 patient due to ARDS	Bailout
Vaporciyan 2002 [13]	Great vessel tumours	1995–2000	19	No intraoperative complications. 58% postoperative complication rate due to pneumonia, haematoma and ARDS	Elective
Torre 2012 [14]	Great vessel tumours	1996–2009	9	Intraoperative complications include prolonged operation duration and 1 mortality due to inability to remove bypass. No postoperative complications	Bailout
Dogan 2003 [15]	Great vessel tumours	2003	3	No intra or postoperative complications	Elective
Mao 2003 [16]	Thoracic tumours	1975–2000	26	Intraoperative complication of recurrent laryngeal nerve injury. Postoperative complications included infection and pneumonedaema	Elective
Arif 2015 [17]	Thoracic tumours	2002–2014	15	Intraoperative mortality reported in 1 patient, <30 day mortality postoperatively reported in 2 patients	Bailout
Guan 2004 [18]	Thoracic aortic aneurysm	2004	488	No intraoperative complications. Postoperative complications include paraplegia in 3 patients and a 11.9% total mortality	Elective
Sugimoto 1993 [19]	Thoracic aorta aneurysm	1993	3	No intra or postoperative complications	Elective
Adwan 2008 [20]	Tracheal and laryngeal pathology	2008	2	No intra or postoperative complications	Elective
Dewitt 2004 [21]	Tracheal and laryngeal pathology	2003	1	No intra or postoperative complications reported	Elective
Shahabuddin 2015 [22]	Tracheal and laryngeal pathology	1999–2009	6	Intraoperative blood loss postoperative mortality reported in 1 patient	Bailout

Abbreviations: ECMO, extracorporeal membrane oxygenation; CPB, cardiopulmonary bypass; AF, atrial fibrillation; ARDS, acute respiratory distress syndrome; MRSA, methicillin-resistant *Staphylococcus aureus*.

procedures which may otherwise not be possible. Cases that are reported often deal with patients with severe acute or chronic pathology of the thorax with a poor long-term prognosis [2].

The non-cardiac applications of CPB have been extended and modified, and principally the applications include firstly: the surgical resection of lesions that cannot be managed safely and effectively by conventional techniques, or techniques that carry significant risks to the patient [1]. These include thoracic tumour resection and transplantation, aortic pathology and lesions involving the great vessels, neurosurgery for aneurysms and tumours, urological surgery for renal cell carcinomas and transplant, and haemodynamic support during liver implantation in transplant procedures. Secondly, the management of acute respiratory failure or obstruction for which endotracheal intubation is not possible. These include mediastinal lymphadenopathy or tracheal lesions involving the lower trachea and carina [2]. Thirdly, the emergency use including interventions in the catheterisation laboratory, and resuscitation of patients with cardiac arrest, severe hypothermia, pulmonary embolism, or multiple traumas [2,3].

Current literature findings of CPB in non-cardiac surgery have mainly been limited to case reports. The literature shows that general complications (including intra and postoperative) was reported in 10 cases. Six publications reported intraoperative or short-term postoperative mortality (see Table 1) [7–19].

Seven of the 19 publications used CPB for bailout support or standby in previously considered inoperable cases including, thoracic, major vessel and tracheal surgery. Bailout support is defined as ''the emergency use of CPB where the procedure had been started without any plan for its use''. Bailout standby is defined as ''the preparation of the CPB circuit without its active use during surgery''.

Extracorporeal membrane oxygenation uses a smaller bypass circuit compared to CPB, and is intended for use when other cardiac and respiratory treatment modalities have failed, circulatory and respiratory support is needed, or as a bridge to transplantation. It has the advantage that it is transportable and is weaned when cardiac and respiratory function is improving. Blood is removed from the venous system either peripherally via cannulation of a femoral vein or centrally via cannulation of the right atrium, oxygenated, has its carbon dioxide extracted

Table 2 Publications in the literature in the use of extracorporeal membrane oxygenation (ECMO) in non-cardiac surgery.

Author year	Surgical indication	Study dates	Total patients	Outcomes	Bypass category
Smith et al. 2005 [23]	ECMO in tracheal resection	2009	2	Overall survival was 100%	Elective
Fung et al. 2017 [24]	ECMO in resection of malignant airway obstruction	2017	1	Overall survival was 100%	Elective
Yoann et al. 2013 [25]	ECMO in chest trauma	2013	1	Overall survival was 100%	Bailout
Voelckel et al. 1998 [26]	ECMO in chest trauma	1998	2	Overall survival was 100%	Bailout
Heward et al. 2016 [27]	ECMO in lung cancer segmentectomy	2016	1	Overall survival was 100%	Elective
Biancosino et al. 2016 [28]	ECMO in reconstruction of transected main bronchi	2016	1	Overall survival was 100%	Elective
Acharya et al. 2016 [29]	ECMO in ruptured mediastinal teratoma	2016	1	Overall survival was 100%	Bailout
Yuba et al. 2016 [30]	ECMO in tracheal resection	2016	1	Overall survival was 100%	Elective
Chacon-Alves et al. 2016 [31]	ECMO in tracheal haemorrhage	2016	1	Overall survival was 100%	Bailout
Fermin et al. 2017 [32]	ECMO in tracheal injury	2017	1	Overall survival was 100%	Bailout

Table 3 Summary of the types and frequency of surgical procedure utilising cardiopulmonary bypass (CPB) or extracorporeal membrane oxygenation (ECMO).

	Surgery type	Number of total procedures using bypass	Number of total procedures
ECMO	Tracheal bailout standby/emergency	2	2
	Renal standby	1	1
Cardiopulmonary bypass	Thoracic elective resection	5	5
	Thoracic bailout/emergency	3	3
	Renal bailout	1	1

Table 4 The 12 cases included in the study, associated surgical procedure, site of treatment, use of bypass and bypass category, preoperative patient data, complications associated with surgery and complications associated with bypass.

Surgical site	Year	Surgery	Reason for bypass	Bypass category	Age (<or >65 years)	Admission status	ASA	Comorbidity	General complications	CPB or ECMO complications
Thoracic	2006	Wedge resection of upper lobe due to pulmonary malignancy	CPB used due to involvement of the great vessels	Elective	>65 years	Elective	3	IHD HTN	Nil	None reported
Thoracic	2007	Parathyroid resection and pulmonary artery repair	CPB used due to pulmonary artery bleed	Bailout major vessel	>65 years	Elective	3	Primary hyperparathyroidism IgA nephropathy Supraventricular tachycardia Hypercalcaemia HTN IDA	Intraoperative bleeding Left sided pneumothorax postoperatively	Non reported
Thoracic	2007	Mediastinal thymoma resection	CPB used for anatomical location of surgery	Elective	<65 years	Elective	1	Nil known	Increasing analgesia requirements using PCA and bibasal pleural effusions	None reported
Thoracic	2008	Resection of left mid thoracic paraspinal lesion	CPB used for anatomical location of surgery	Elective	>65 years	Elective	1	Nil known	Increased analgesia requirement using PCA and atelectasis	None reported
Thoracic	2009	Posterior mediastinal tumour resection	CPB used for anatomical location of surgery	Elective	<65 years	Elective	Unknown	Nil known	Postoperative febrile illness which subsequently resolved	None reported
Thoracic	2011	Emergency management of gunshot wounds	CPB for bleeding. Uncontrollable.	Emergency	<65 years	Emergency	5	Nil known	Death due to injuries	None reported
Thoracic	2012	Wedge resection of upper lobe due to pulmonary malignancy	CPB due to anatomical location of surgery	Elective	>65 years	Elective	3	IHD HTN T2DM Hyperlipidaemia	Nil	None reported
Thoracic	2015	Resection of anterior mediastinal tumour	CPB due to extension of tumour intraoperatively	Bailout major vessel	<65 years	Bailout	2	AF Chronic renal failure GORD ETOH abuse	Intraoperative bleeding and failed complete resection of tumour	None reported

Table 4. (continued).

Surgical site	Year	Surgery	Reason for bypass	Bypass category	Age (<or >65 years)	Admission status	ASA	Comorbidity	General complications	CPB or ECMO complications
Renal	2014	Nephrectomy and IVC thrombectomy	CBP due to anatomical location of surgery and bleeding	Bailout major vessel	>65 years	Bailout	3	IHD OA T2DM High cholesterol GORD Anaemia Aortic stenosis	Intraoperative bleeding	None reported
Renal	2016	Resection of adrenal mass	ECMO standby as adrenal mass was in close proximity to major abdominal vessels	Bailout standby	<65 years	Bailout	3	Papillary thyroid Ca Hypoparathyroidism Dysmenorrhoea Migraine Psoriasis Provoked DVT	Nil reported	None reported
Tracheal	2014	Tracheal stent removal	ECMO standby due to location and previous operative site of large malignancy	Bailout standby	<65 years	Bailout	5	Gullian Barre syndrome Recurrent tracheal stenosis Failed tracheal reconstruction Tracheostomy	Partial airway obstruction requiring use of hydrocortisone	None reported
Tracheal	2014	Tracheal tumour removal	ECMO standby due to anatomical location of surgery and bleeding and interval desaturations	Bailout emergency	<65 years	Bailout	3	Nil	Intraoperative bleeding and patient desaturations	None reported

Abbreviations: ECMO, extracorporeal membrane oxygenation; CPB, cardiopulmonary bypass; GORD, gastro-oesophageal reflux disease; IHD, ischaemic heart disease; DVT, deep vein thrombosis; OA, osteoarthritis; AF, atrial fibrillation; HTN, hypertension; PCA, patient-controlled analgesia; ETOH, alcohol; T2DM, type 2 diabetes mellitus.

and then returned back to the body, either peripherally via a femoral artery or centrally via the ascending aorta. ECMO can be inserted in a veno-venous (VV) configuration which provides oxygenation (thus is used for respiratory failure), or can be used in a veno-arterial (VA) configuration (providing both respiratory and cardiac support). The common applications for ECMO are surgical and non-surgical and include [20]:

1 Post-cardiotomy — inability to get the patient off CPB following cardiac surgery.
2 Post-heart transplant (usually due to primary graft failure).
3 Severe cardiac failure e.g. cardiomyopathy, myocarditis, acute coronary syndrome (ACS) with cardiogenic shock, or sepsis; and
4 Respiratory failure e.g. acute respiratory distress syndrome (ARDS), pneumonia, trauma or primary graft failure following lung transplantation, or as a bridge to transplantation.

The role of ECMO as a rescue therapy is widely reported and includes applications in chest trauma and cardiopulmonary arrest situations. Its role in cardiac, pulmonary and organ dysfunction is also reported. The Extracorporeal Life Support Organisation (ELSO) publishes statistics on worldwide centres using ECMO and for what purpose. The three main categories in which use of ECMO is reported, include cardiac, respiratory and emergency cardiopulmonary resuscitation (CPR) uses. Of these core categories, the literature scope is great. The use of ECMO in non-cardiac surgical procedures including bailout, emergency and elective surgery is not widely reported in the literature.

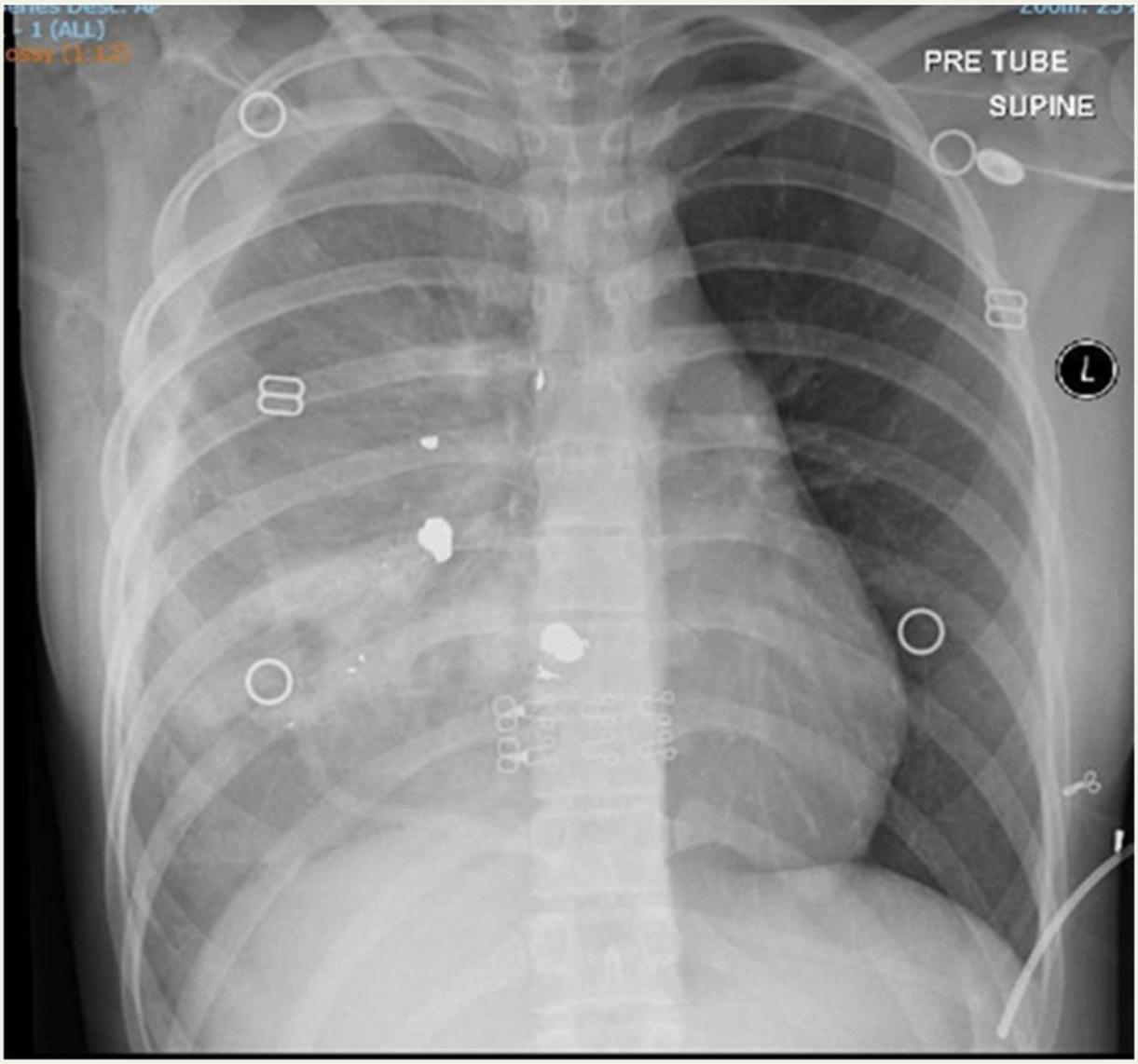


Figure 1 The chest X-ray above is pre-chest drain insertion. A large opacity of the right hemithorax is noted with loss of the right heart border. Metal fragments are noted in the region of the left mid chest in keeping with metallic/bullet fragments.

We reviewed 10 of the most recent publications on the use of ECMO in non-cardiac surgical applications. Five of the 10 cases utilised ECMO in surgical management for bailout support. Most cases reported are single case studies. The surgical indication, and bypass category are reported in Table 2 [20–29]. Outcomes reported in these cases showed no perioperative mortality.

The aim of this study was to determine if non-cardiac surgery of the thorax, trachea and major vessels could be supported with CPB or ECMO.

Materials and Methods

From 2006 to 2014 at the Royal Adelaide Hospital CTSU, 2,930 surgical procedures were performed which included 1,816 non-cardiac procedures. Nine cases documented the use of CPB and three cases of ECMO. Inclusion criteria was non-cardiac surgical cases managed by the CTSU that required CPB or ECMO as a standby, intraoperative bailout or emergency bailout support. Cases excluded from the study were those that required cardiac surgical management with the use of CPB or ECMO.

Preoperative data was collected with reference to the Royal Australian College of Surgeons (RACS) morbidity and mortality guidelines of 2012 and these included age at operation, gender, indication for non-cardiac surgery, presence or absence of major co-morbidities, and previous surgical procedures. Operative data included indication for CPB and ECMO use, and intraoperative and postoperative complications. Data was

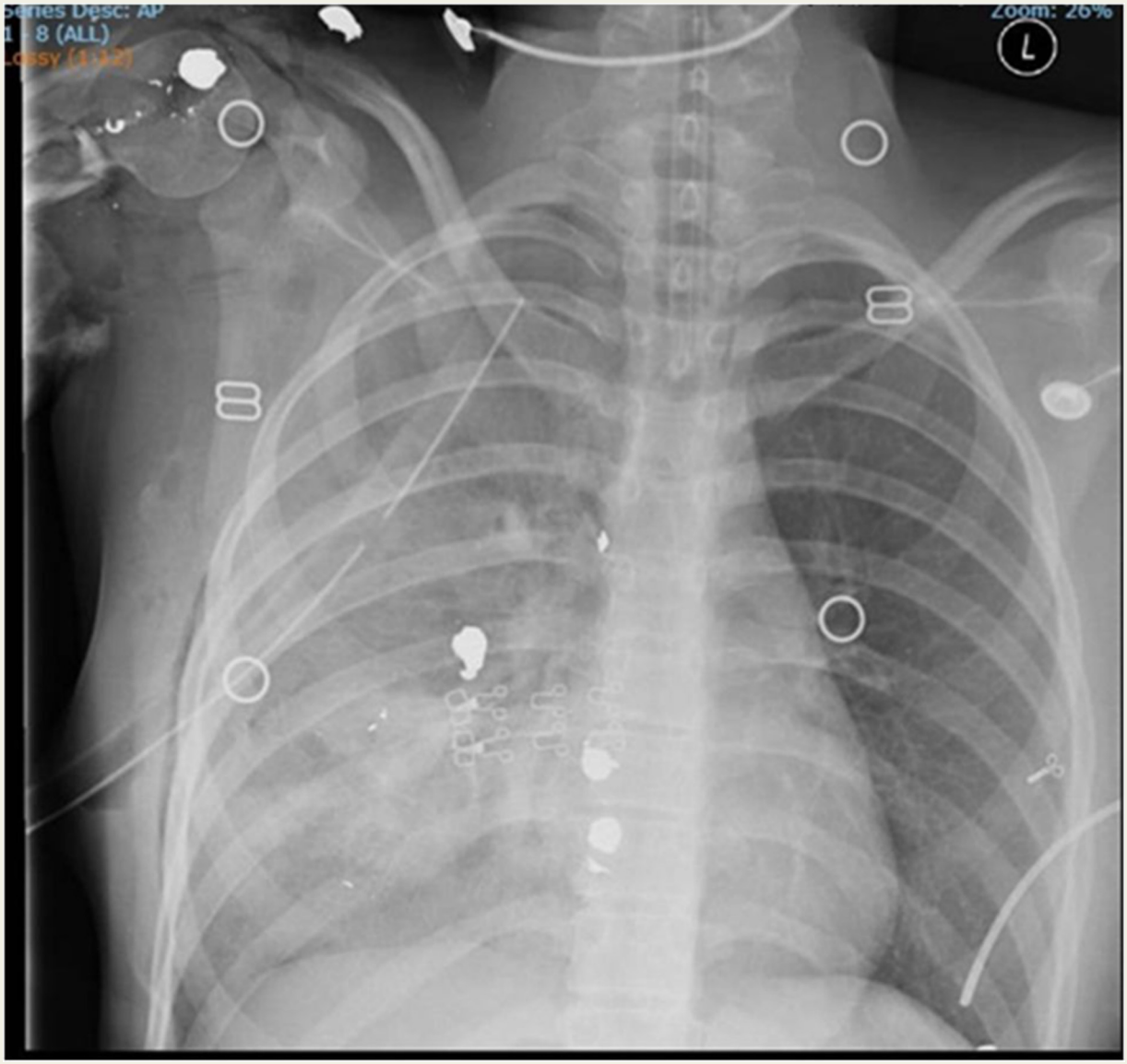


Figure 2 The chest X-ray image above show post chest drain insertion views. Further metallic fragments are seen in the region of the right shoulder with a comminuted right neck of humerus fracture.

obtained from patient hospital records and operative reports.

Bypass category was described as elective (planned procedure), emergency (unplanned procedure), and bailout (intraoperative complications requiring intervention or standby preparation of bypass support). Patient cases were divided into type of bypass used, and type of procedure. The frequency of procedure type was also documented (Table 3).

Results

The 12 cases documented in this report include eight thoracic, two renal and two tracheal surgeries. Three cases involved the use of ECMO and nine cases used CPB. Of the three ECMO cases, one was a renal surgical case and two were for tracheal surgery. Of the CPB cases, eight were for thoracic surgery, and one was for a renal surgery case (Table 3).

Of the thoracic cases, all eight cases used CPB or ECMO, and required CPB to assist in haemodynamic support during intraoperative bleeding complications. One of these cases used CPB in emergency support; however, this patient died from their traumatic injuries.

Of the renal cases, one required CPB bailout due to intraoperative bleeding. The second renal case involved resection of an adrenal mass, and was considered high bleeding risk. ECMO was at standby in the event of an intraoperative bleeding complication but was not used.

Of the tracheal cases one required ECMO bailout due to intraoperative bleeding and respiratory dysfunction. The second tracheal case was considered high risk of intraoperative bleeding due to previous surgical resection of a large tracheal malignancy and proximity to major vessels. ECMO was available but not used in this case (Table 4).

Cardiorespiratory morbidity was documented in seven cases including previous myocardial infarction (MI), ischaemic heart disease (IHD) and diabetes; and five patients were over 65 years of age. There were no increased general complications or complications of bypass amongst patients with increased medical and surgical morbidity.

General morbidity intraoperatively or postoperatively was documented in five cases. Complications requiring the bailout use of CPB and ECMO included intraoperative bleeding, and haemodynamic instability including severe hypotension and oxygen desaturations. Intraoperative mortality was reported in one case. Haemodynamic stability was maintained with the use of emergency CPB to allow for surgical exploration and assessment of injuries. This patient died from their injuries. No CPB or ECMO complications were reported.

Discussion

The current literature suggests that the use of CPB and ECMO support in non-cardiac surgery allows for haemodynamic stabilisation when unexpected complications occur. The following non-cardiac surgical cases used CPB or ECMO intraoperatively in situations of life-threatening complications including uncontrollable bleeding, and respiratory and circulatory compromise.

Case 1

A 16-year-old female presented following multiple gunshot wounds to the right chest and arm. On arrival, she was in circulatory shock with a heart rate of 180 and systolic blood pressure of 60. Chest X-ray showed a right haemopneumothorax (Figure 1). Approximately 600 mls of blood was drained from the right chest. She then developed circulatory arrest, with no recordable blood pressure (Figure 2).

The patient underwent an emergency clamshell thoracotomy. It was noted that there was a large penetrating injury to the right atrial appendage and atrial groove temporarily controlled with finger pressure until the patient was transferred to theatre. Cardiopulmonary bypass was performed with a right femoral arterial and venous access through the right atrial appendage. The right lung showed bleeding from the hilar vessels with a large lung haematoma and multiple pellet wounds. Further penetrating wounds and bleeding was noted from the intercostal vessels and thoracic vertebrae. It was noted that there was likely spinal penetration. Catastrophic bleeding ensued and a decision was made to proceed no further. As a result of the injuries the patient died.

Case 2

A 28-year-old female presented with haemoptysis currently in her second trimester of pregnancy. Computed tomographic angiography of the neck, trachea and superior mediastinum showed a lower tracheal hemangioma, bibasal consolidation/collapse with a moderate sized pleural effusion bilaterally (Figure 3). The patient underwent fibre optic

Figure 3 Soft tissue density involving the lower trachea just above the carina, which is measuring 12 mm in thickness representative of a hemangioma.

bronchoscopy with difficulty coring through the tumour resulting in bleeding, and interval desaturations requiring ECMO to be established.

After ECMO was established, patient flow and saturations improved. Surgeons were able to core through the tumour, however, the tumour edge continued to bleed. Bleeding was controlled with endotracheal tamponade and the patient was transferred to ICU on ECMO in a stable condition and was weaned off ECMO day 1.

Case 3

A 49-year-old female was electively admitted for resection of a right adrenal lesion discovered on surveillance computed tomography (CT) in 2015 (Figures 4 and 5).

The patient underwent a laparotomy and was placed on ECMO standby due to the involvement of major vessels with this resection. The tumour was not invading vascular structures and was dissected from the retroperitoneum and off the inferior vena cava (IVC) and right renal vein. A right adrenalectomy was completed without intraoperative complications.

The patient recovered in ICU postoperatively and was managed on the ward until discharge without reported complications.

Case 4

A 56-year-old male presented to the emergency department with lower respiratory tract infection symptoms. He described a persistent non-productive cough over the last 12 months. Chest X-ray suggested a large left-sided lesion confirmed on CT chest abdomen and pelvis, which showed a large anterior mediastinal mass measuring 25 cm in maximal diameter. It was described as a vascularised lesion displacing structures anteriorly and inferiorly with a moderate pericardial effusion (Figures 6 and 7).

The patient underwent resection of the tumour via left thoracotomy approach but because of excessive

Figure.4

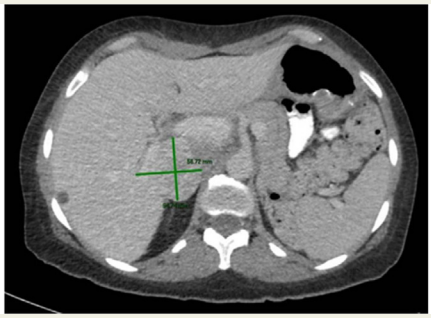
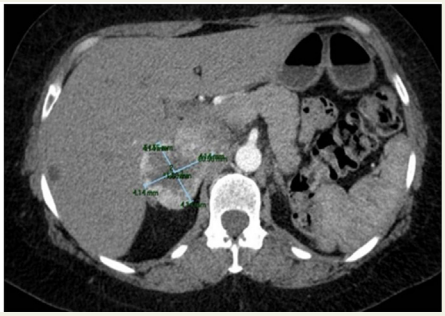


Figure.5



Figures 4 and 5 Computed tomographic axial view showing right adrenal gland lesion measuring approximately 56 × 54 mm.

Figure.6

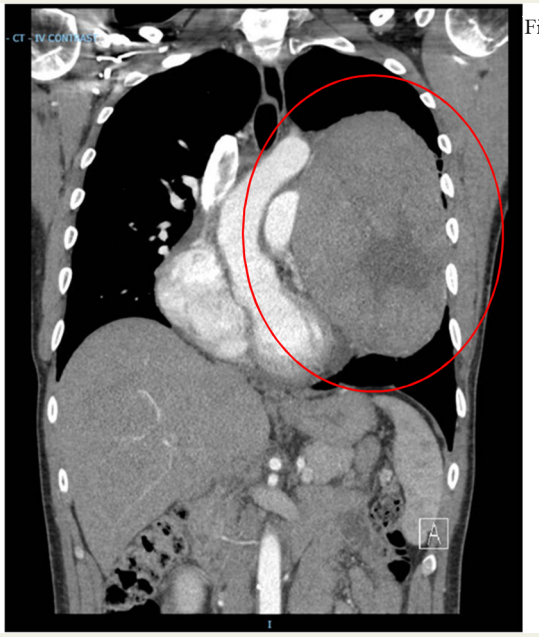
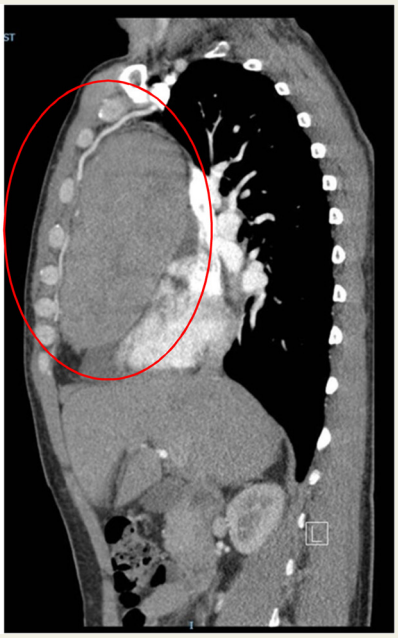


Figure.7



Figures 6 and 7 Preoperative computed tomographic in coronal and sagittal views showing the mediastinal mass.

bleeding from the tumour vessels, it was impossible to free the tumour from the lung tissue. The procedure was converted to a midline sternotomy approach but it was still not possible to dissect the tumour completely from the left hilum. As a result, the patient was placed on CPB.

On bypass, it was possible to further dissect the tumour off the left main pulmonary artery and the left superior pulmonary vein. Once this was achieved, the tumour was dissected off the attachment to the right upper lobe.

The patient required transfusion of 11 units of blood, 16 units of FFP, platelets and cryoprecipitate, and cell saver replacement. The patient was transferred to ICU and subsequently to the ward without any reported postoperative complications. Histopathology of the tumour was reported as a nonspecific neuroendocrine malignancy. No adjuvant treatment was required. At 5-year postoperative follow-up there was no new evidence of tumour growth (Figures 8 and 9).

In elective cases, bypass was used in high-risk procedures involving the great vessels or large tumours with high probability of bleeding intraoperatively. Bypass has allowed for control of patient circulatory support. In bailout cases, bypass was used as standby and in emergency procedures ranging from tracheal pathology, renal pathology and large thoracic malignancies because of the high risk of involvement of the great vessels and intraoperative bleeding. Patient outcomes in these non-cardiac surgery cases were acceptable, and no complications of bypass were reported (Figures 10 and 11).

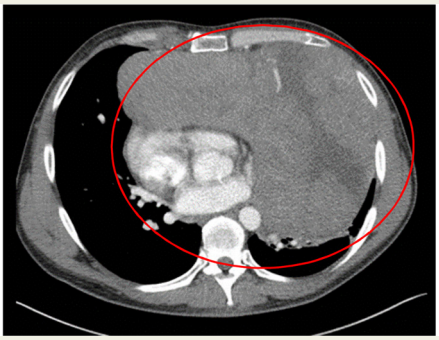
Figure.8 

Figure.9 

Figures 8 and 9 Preoperative computed tomographic in axial views on the left and the resected tumour weighing 2,916 grams and measuring 25 × 17 × 17 cm on the right.

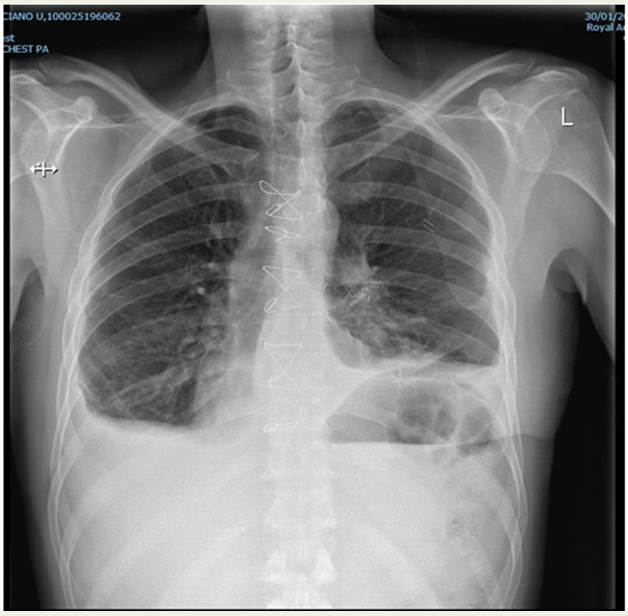
Figure.10 

Figure.11 

Figures 10 and 11 Postoperative chest X-rays in posterior-anterior and lateral views following tumour resection.

Conclusions

There are limited reports in the literature on the use of bypass as a standard procedure for all non-cardiac cases considered high risk. In our study, CPB and ECMO were documented to be used in elective, intraoperative bailout and emergency cases. Given these positive patient outcomes and lack of CPB or ECMO complications, bypass could be considered for non-cardiac surgical cases involving the great vessels and thorax where complications such as bleeding and haemodynamic instability are likely.

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Disclosures

Nil.

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