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REVIEW ARTICLE/BRIEF REVIEW

The use of extracorporeal membrane oxygenation in the anticipated difficult airway: a case report and systematic review

Recours à l'oxygénation extracorporelle en prévision de la gestion de voies respiratoires difficiles : rapport de cas et étude systématique

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Abstract *While extracorporeal membrane oxygenation (ECMO) is an effective method of oxygenation for patients with respiratory failure, further refinement of its incorporation into airway guidelines is needed. We present a case of severe glottic stenosis from advanced thyroid carcinoma in which gas exchange was facilitated by veno-arterial ECMO prior to achieving a definitive airway. We also conducted a systematic review of the MEDLINE, EMBASE, CINAHL, and Web of Science databases, using the keywords "airway/ tracheal obstruction", "anesthesia", "extracorporeal", and "cardiopulmonary bypass" to identify reports where ECMO was initiated as the a priori method of oxygenation during difficult airway management.Thirty-six papers were retrieved discussing the use of ECMO or cardiopulmonary bypass (CPB) for the management of critical airway obstruction. Forty-five patients underwent pre-induction of anesthesia institution of CPB or ECMO for airway obstruction. The patients presenting with critical airway obstruction had a range of airway pathologies with tracheal tumours (31%), tracheal stenosis (20%), and head and neck cancers (20%) being the most common. All cases reported a favourable patient outcome with all patients surviving to hospital discharge without significant complications.While most practitioners are familiar with the fundamental airway techniques of bag-mask ventilation, supraglottic airway use, tracheal intubation, and front-of-neck airway access for oxygenation, these techniques have limitations in managing patients with pre-existing severe airway obstruction. The use of ECMO should be considered in patients with severe (or near-complete) airway obstruction secondary to anterior neck or tracheal disease. This approach can provide essential tissue oxygenation while attempts to secure a definitive airway are carried out in a controlled environment.*

Résumé *L'oxygénation par membrane extracorporelle (ECMO) est une méthode d'oxygénation efficace chez les patients présentant une insuffisance respiratoire, mais il est nécessaire de mieux préciser son inclusion dans les lignes directrices concernant la gestion des voies respiratoires. Nous présentons un cas de sténose sévère de la glotte due à un carcinome de la thyroïde dans lequel l'échange gazeux était facilité par une ECMO veino-artérielle avant la réalisation d'un accès des voies respiratoires définitif. Nous avons aussi effectué une revue systématique des bases*

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de données MEDLINE, EMBASE, CINAHL et Web of Science en utilisant les mots clés « obstruction des voies respiratoires/de la trachée », « anesthésie », « extracorporelle » et « circulation extracorporelle » pour identifier des cas dans lesquels une ECMO a été mise en place comme méthode d'oxygénation a priori au cours de la gestion de voies respiratoires difficiles. Trente-six articles discutant de l'utilisation de l'oxygénation ou de la circulation extracorporelle dans la gestion des obstructions majeures des voies respiratoires ont été retenus. Quarante-cinq patients ont subi une préinduction d'anesthésie par oxygénation ou circulation extracorporelle en raison d'une obstruction des voies respiratoires. Les patients présentant une obstruction majeure des voies respiratoires étaient principalement des patients atteints de tumeurs de la trachée (31 %), sténose de la trachée (20 %) et de cancers de la tête et du cou (20 %). Dans tous les cas, l'évolution des patients a été favorable : ils ont pu quitter l'hôpital en vie et sans complications significatives. Bien que la majorité des praticiens connaissent les techniques de base de ventilation au masque et au ballon, l'utilisation des voies respiratoires supraglottiques et l'accès cervical antérieur des voies respiratoires pour assurer une oxygénation correcte, ces techniques ont des limites dans la gestion de patients ayant une obstruction préexistante sévère des voies respiratoires. L'utilisation de l'oxygénation extracorporelle devrait être envisagée chez les patients ayant une obstruction sévère (ou quasi complète) des voies respiratoires à la suite d'une maladie de la trachée ou du segment antérieur du cou. Cette approche peut procurer une oxygénation tissulaire essentielle pendant que des tentatives visant à assurer un accès définitif des voies respiratoires sont menées dans un environnement contrôlé.

Guidelines by the American Society of Anesthesiologists,[1-3] The Difficult Airway Society of Great Britain and Ireland,[4,5] and the Canadian Airway Focus Group (CAFG)[6,7] emphasize the use of four fundamental techniques of sustaining adequate tissue oxygenation: bag-mask ventilation (BMV), supraglottic airway (SGAs), tracheal intubation,[8] and the front-of-neck airway.[9] Airway obstructions, particularly at or below the level of the glottis, can present significant challenges beyond the above guidelines. While extracorporeal membrane oxygenation (ECMO) is an effective means of providing adequate oxygenation for patients with respiratory failure,[10-12] further development involving possible incorporation into airway guidelines is required.

Extracorporeal membrane oxygenation is a life-support technique using mechanical devices to support both cardiac and respiratory function when the native systems fail.[13] Two forms of ECMO exist: veno-arterial (VA) ECMO, which has the potential to provide complete respiratory and hemodynamic support, and veno-venous (VV) ECMO, which supports the respiratory system alone, allowing gas exchange outside the body.[14] Dorson *et al.* first reported the use of a membrane oxygenator for cardiopulmonary bypass in infants in 1969;[15] following that, ECMO was successfully used as support in infants with congenital heart defects undergoing cardiac surgery.[16] The use of both forms of ECMO in adult patients only began to flourish after the publication of the randomized-controlled trial comparing conventional ventilatory support *vs* ECMO for severe adult respiratory failure in 2009.[17] This trial reported a significant improvement in the mortality rate without severe disability at six months in patients with severe respiratory disease who were transferred to a specialist centre for consideration for ECMO treatment compared with continued conventional ventilation. Since then, the use of either form of ECMO has been used for a wide range of conditions that require cardiac and/ or respiratory support,[16,18,19] as well as for support during a range of cardiac and thoracic[20] interventions.

The objective of this report is to present a case of advanced thyroid carcinoma causing severe glottic and proximal tracheal obstruction in which adequate gas exchange was facilitated by ECMO prior to achieving a definitive airway under total intravenous anesthesia. This case serves to illustrate the use of ECMO in the obstructed airway, when the previously mentioned four fundamental techniques of oxygenation are likely to fail. This less understood technique for management of gas exchange in the difficult airway setting was then systematically reviewed.

Case presentation

A 77-yr-old male (who consented to this report) presented to the preoperative anesthesia clinic as an urgent outpatient consult from the ear, nose, and throat (ENT) service.

On presentation, the patient was stridorous at rest and only able to ambulate less than a few steps. He stated that the stridor had been increasing over the past few weeks and that he was no longer able to sleep flat in bed. He had been seen in the emergency department earlier in the week and given a short course of oral prednisone 30 mg daily for airway edema, but he did not feel it had made a significant improvement.

The patient had a complex cardiac history consisting of coronary artery bypass graft surgery in 2003, with pre-

existing pacemaker-dependent complete heart block, with subsequent infection at his pacemaker site, requiring removal and replacement with a right infraclavicular pacemaker. Echocardiography in 2015 reported normal biventricular function with no suggestion of elevated pulmonary artery pressures. He denied any recent chest pain, but, because of his increasing difficulty with breathing, had not been able to undertake any significant activity for the past four months.

Physical examination revealed an elderly obese male with a body mass index of 35 $kg{\cdot}m^{-2}$, severe stridor, sitting upright, using his accessory muscles of respiration. His oxygen saturation on room air was 95%.

A computed tomographic (CT) view of the head and neck was performed, which revealed a 1-mm opening at the level of the glottis (Fig. 1). Previous anesthetic records showed a Cormack-Lehane grade 1 view using a Macintosh laryngoscope. The remainder of his history and investigations was unremarkable.

Consultation among the anesthesia and ENT specialists followed. Due to the anticipated difficulties with BMV, SGA, and tracheal intubation due to both the distorted anatomy and very small tracheal lumen, these were all dismissed as viable options. A front-of-neck airway access under local anesthesia was also excluded as an option because of the extensive nature of the thyroid carcinoma distorting the anatomy and the ability of the patient to tolerate the supine position. A cardiac surgeon was then consulted about the possibility of instituting ECMO in the awake state to allow for oxygenation before securing a definitive airway under total intravenous anesthesia. He was admitted to the ENT ward for intravenous steroids.

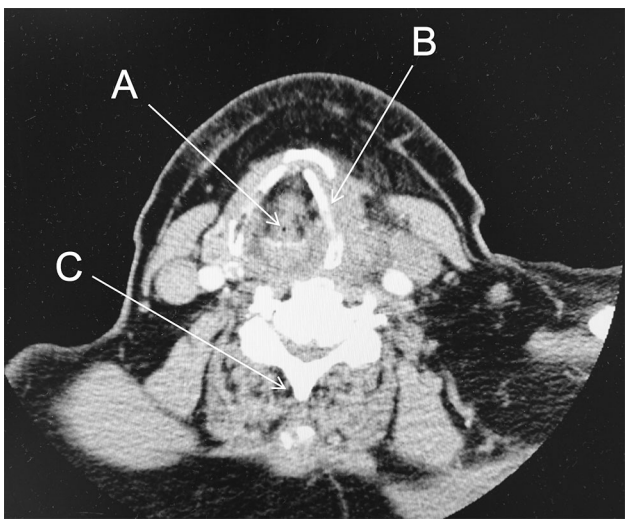

Fig. 1 Coronal view showing 1-mm internal airway diameter. (A: 1-mm Subglottic airway; B: left thyroid ala; C: C5 spinous process)

Heliox (a mixture of helium and oxygen) was administered through a non-rebreathing face mask prior to surgery.

Preoperative CT angiography was performed to assess the arterial and venous access sites for ECMO and showed significant calcific atherosclerotic disease of both femoral arteries.

With the heliox continuing, the patient was taken to the operating room (OR) and transferred to an OR table in a semi-recumbent position where routine monitors were placed in addition to a radial arterial cannula, processed EEG, and non-invasive near-infrared spectroscopy (NIRS) tissue oximetry (INVOS^{TM}, Medtronic, Minneapolis, MN, USA).

Following positioning and placement of monitoring, an airway strategy was communicated to the OR personnel. The strategy consisted of insertion of the ECMO cannulae under local anesthesia and establishing ECMO flow. Once established, induction of anesthesia would occur. Following induction of anesthesia, the anesthesiologist would undergo one attempt at tracheal intubation with a video-laryngoscope using a styletted micro-laryngoscopy tube (MLT). If this was unsuccessful, the surgeon would consider an attempt at rigid bronchoscopy prior to proceeding to tracheotomy through the thyroid carcinoma if that were to fail. Following endotracheal intubation, ECMO would then be weaned preventing the need for continued anticoagulation.

The patient's right-sided pacemaker precluded the use of the axillary vessels, and the planned thyroidectomy and laryngectomy precluded access to the internal jugular vessels. Due to the anticipated time required to achieve exposure of the femoral vessels resulting from the patient's body habitus and semi-recumbent position, the decision was made to establish ECMO via unilateral femoral vessels. Given the clinical indication, VV-ECMO would have been the preferred ECMO mode because of the sole need for oxygenation and the reduced requirement for anticoagulation. Nevertheless, the anatomical and pre-morbid conditions, as well as the availability of equipment, led to VA-ECMO being selected by the cardiac surgeon as the most suitable ECMO mode.

After sedation with midazolam 0.5 mg *iv*, the right groin was prepped, draped, and infiltrated with lidocaine. After the administration of heparin 5,000 units *iv* and the post-heparin activated clotting time confirmed adequate anti-coagulation, a femoral arterial perfusion cannula was placed and secured into position. The femoral vein was then cannulated and attached to the ECMO circuit with its position in the right atrium confirmed by transthoracic echocardiography following which full ECMO flow was incrementally instituted.

Anesthesia was then induced and maintained with propofol/remifentanil and rocuronium for neuromuscular

blockade. Using video Macintosh laryngoscopy (C-MAC #4 blade; Karl Storz Endoscopy, Culver City, CA, USA), the glottis was easily visualized but appeared edematous and stenotic. One attempt at intubation with a styletted 5.0-mm internal diameter (ID) MLT was made but was unsuccessful because of an inability to advance beyond the solid tumour at the glottic opening. In discussion with the ENT surgeon, it was elected to proceed to tracheotomy and forgo any attempt at rigid bronchoscopy.

Saturations of 72-80% were recorded by the pulse oximeter (right index finger) likely related to the fact that ECMO was providing highly oxygenated blood to the lower extremity while poorly oxygenated blood was being ejected into the ascending aorta. Despite this, cerebral oximetry as measured by NIRS was acceptable at 72%, perhaps owing to sufficient super-oxygenated blood supply flowing up the descending aorta and mixing sufficiently at the level of the distal aortic arch.

The tracheotomy, though technically challenging because of the presence of the large anterior obstructive mass, allowed placement of a reinforced 7.0-mm ID endotracheal tube (ETT) (Mallinckrodt^{TM} Lo-Contour Reinforced Tracheal Tube, Covidien, Minneapolis, MN, USA). Following tracheal intubation, anesthesia was transitioned to an inhalational anesthetic using sevoflurane. The ECMO was then weaned and the femoral vessels were decannulated. Heparin was reversed using protamine prior to proceeding with the thyroidectomy, laryngectomy, and central lymph node dissection.

At the conclusion of the surgery, the 7.0-mm ID reinforced ETT was replaced by an 8.0-mm ID Shiley tracheostomy tube (Covidien, Minneapolis, MN, USA) and the patient was taken to the intensive care unit for overnight monitoring followed by transfer to the ENT ward, where he remained until discharge home the following week.

The tissue pathology confirmed an aggressive multifocal papillary thyroid carcinoma with high-grade transformation, predominantly to squamous cell cancer, and focal insular carcinoma. Central neck nodes were negative for malignancy.

Systematic review methods

We conducted electronic literature searches for all published articles up until September 2017 from the MEDLINE, EMBASE, CINAHL, and Web of Science databases using the key words "airway obstruction", "airway management", "tracheal obstruction", "CPB/heart lung bypass/cardiopulmonary bypass", "anesthesia/anaesthesia", and "ECMO/extracorporeal membrane oxygenation" (see Appendix for details). Reference lists of the selected articles were also searched for additional papers. Published meeting abstracts were included (if all inclusion criteria were addressed and met) and publications in languages other than English were only included if all inclusion criteria were fulfilled by the English-language abstract.

All case reports and observational studies reporting the use of ECMO in adults (> 18 yr) for airway management were considered and individually evaluated. For the purpose of this study, we only selected cases in which extracorporeal life support (ECMO or CPB) was initiated as the *a priori* method of oxygenation and not as a rescue technique following a failed intubation, failed ventilation, or cardiorespiratory arrest. This was determined following review of titles meeting the initial search criteria. All patients included in this review had ECMO or CPB cannulae inserted and flows established prior to airway intervention. Patients were included if ECMO or CPB was used as a substitute to definitive airway management.

Articles describing the use of ECMO for patients with deteriorating circulation or primarily cardiac support were excluded. Information on the authors, institution, population, and dates was checked to identify duplicate publications. Duplicated patients in consecutive reports from the same institution or author were excluded.

All cases were then analyzed and tabulated, displaying the indication for ECMO, the condition of the patient prior to ECMO initiation, the mode and duration of ECMO, the pathology leading to airway obstruction, the definitive management of the patient, and the clinical outcome.

Results

Literature search

Our search yielded 784 titles with a further five additional records identified through the reference lists. Following the removal of duplicates, 621 records were screened for inclusion criteria (Fig. 2). Five hundred and thirty-five records were removed, leading to 86 abstracts considered appropriate for full-text evaluation. There were no randomized-controlled trials on the use of ECMO for severe airway obstruction.

Study characteristics

Thirty-six papers published between 1976 and 2017 discussing cases utilizing ECMO or CPB for the management of critical airway obstruction were included in the review, including 28 case reports and eight case series. Within these case series, only select cases met

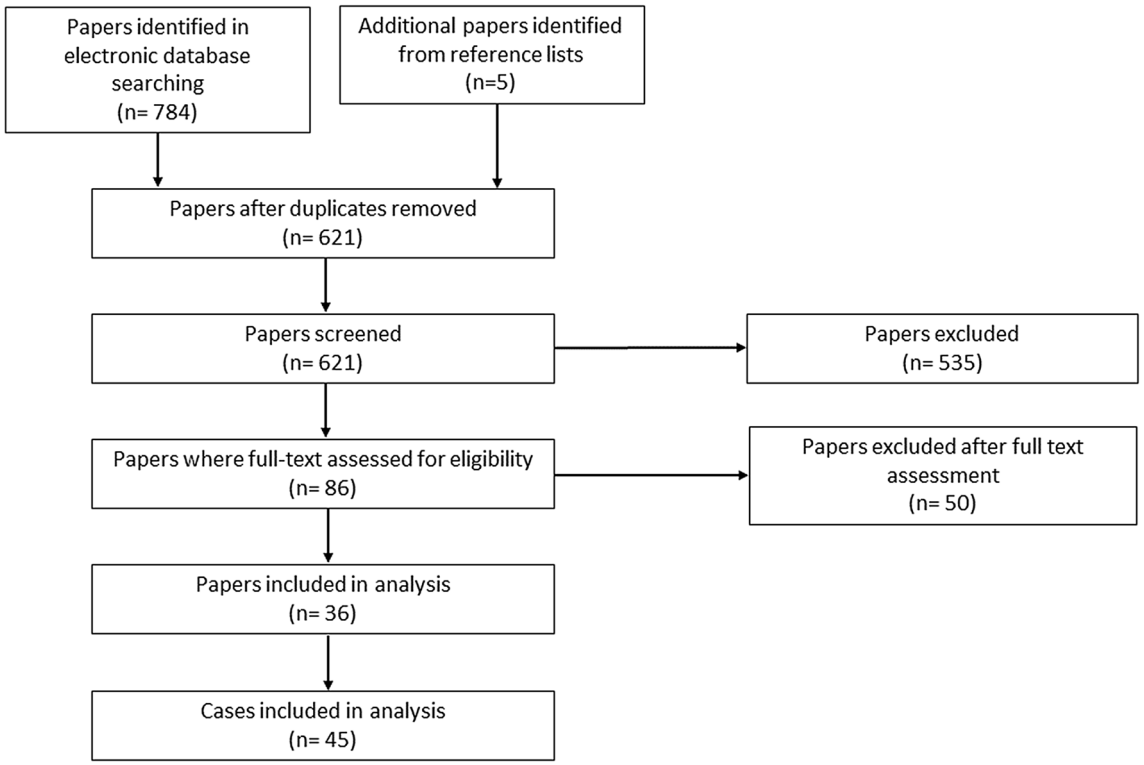

Fig. 2 Bibliographic search of the literature

criteria for inclusion in the review.[21] One included paper was published in Japanese,[29] and one published only as an abstract,[30] but these abstracts revealed sufficient clinical information to be included in the review. The most frequent reasons for exclusion were failing the predetermined inclusion criteria, patients < 18 yr, and inability to obtain detailed patient information. Eight papers reported a case series in which ECMO was used in airway management. A total of 45 patients are included in this review. Results are summarized in the Table.

The patients presenting with critical airway obstruction had a range of airway pathologies. These included: tracheal tumour (14 patients, 31%),[22,24,27,28,31] tracheal stenosis (nine patients, 20%),[21,22,38,39] head and neck cancer (nine patients, 20%),[23,29,40] large mediastinal mass (six patients, 13%),[47] primary lung cancer (two patients, 5%),[25,30] benign thyroid goiter (two patients, 5%),[53,54] esophageal cancer (one patient, 2%),[25] malignant melanoma (one patient, 2%),[55] and tracheal granulomas (one patient, 2%).[56] All surgeries included in this review were performed in tertiary institutions with ready access to CPB or ECMO. Sixteen patients underwent full CPB (as opposed to only ECMO) in reports up until 2014.

All published cases reported a favourable patient outcome with all patients surviving to hospital discharge without significant complications. In 2015, Kim *et al.*[21] published a case series of 15 patients who underwent pre-induction ECMO for airway obstruction. They reported no mortality associated with the elective use of ECMO during the management of severe airway disease; however, deaths due to hypoxic brain damage were reported when non *a priori* ECMO was only considered following failed airway management.[21] Many case series reported their complications as a cumulative composite semi-quantitative statement (e.g., low) and without detailed information about the types and severity of complications.

Discussion

The incidence of upper airway tumours in Canada has increased over the past 30 years, with an estimated 18.5 people per 100,000 diagnosed with thyroid cancer in 2016.[57] Early detection and intervention for these tumours has the potential to reduce the incidence of severe airway obstruction. On the other hand, patients who present late with these tumours may show signs of airway obstruction.

From our search, 36 articles were retrieved that discussed the use of ECMO/CPB for the urgent management of critical airway obstruction. Eighteen patients underwent pre-induction VV- ECMO and two patients VA-ECMO, 24 patients had CPB, and in one patient the support mode was unspecified. Patients with critical airway disease presented with a range of airway

Table Case reports of elective ECMO utilization in airway management

First author	Year	Age	Condition prior to ECMO	ECMO mode	ECMO duration	Obstruction type	Comments	Definitive management	Final result
Coles[46]	1976	F/25	Acute respiratory distress	CPB	Until lower tracheal exposure	Tracheal carcinoma	Near complete obstruction	Resection	Discharged
Bricker[22]	1979	F/68	Stridor and choking spells	CPB	Operative case	Tracheal tumour	Near complete occlusion	Tracheal resection and anastomosis	Discharged
Bricker[22]	1979	M/54	Dyspnea, stridor, and orthopnea	CPB	Operative case	Traumatic tracheal stenosis	2-3 mm diameter	Tracheal resection and anastomosis	Discharged
Jensen[32]	1983	F/65	Dyspnea and orthopnea	CPB	Operative case	Tracheal tumour	Near complete occlusion	Tracheotomy	Discharged
Wilson[31]	1984	M/47	Severe dyspnea	CPB	Operative case	Squamous cell carcinoma of the trachea	Near complete occlusion	Surgical resection	Discharged
Hicks[54]	1986	F/70	Dyspnea and stridor	CPB	Until definitive airway	Substernal goitre	4-mm airway	Goitre resection	Discharged
Rosa[44]	1996	F/51	Respiratory distress and stridor	CPB	Operative case	Thyroid lymphoma		Tracheotomy, resection	Discharged
Belmont[43]	1998	F/73	Dyspnea, hypoxia, stridor, and orthopnea	CPB	Operative case	Thyroid lymphoma	Near complete obstruction	Tracheotomy	Discharged
Onozawa[29]	1999	M/64	Dyspnea and orthopnea	VA	Operative case	Thyroid carcinoma	5-mm tracheal diameter	Tracheotomy and resection	Discharged
Tempe[52]	2001	M/22	Severe dyspnea, respiratory distress	CPB	6 min	Liposarcoma	Airway compression	Surgical resection	Discharged
Chiu[38]	2003	F/27	Tracheotomy, severe stridor, and respiratory distress	CPB	Until endobronchial intubation	Post-intubation tracheal stenosis	3-cm-long stenotic region	Resection and anastomosis	Discharged
Shiraishi[25]	2004	M/57	Severe dyspnea	VV	Operative case	Non-small-cell lung carcinoma	Completely obstructed RMB with severe obstruction at the carina and the LMB	Dynamic stent placement	Discharged
Shiraishi[25]	2004	F/59	Severe dyspnea	VV	Operative case	Advanced esophageal carcinoma	Severe lower tracheal and carinal obstruction	Stent placement	Discharged
Goyal[35]	2005	F/31	Weak voice and stridor	CPB	Operative case	Adenoid cystic carcinoma	Near complete obstruction	Tumour resection	Discharged
Weinbroum[45]	2005	F/70	Stridor and dyspnea	CPB	Until intubation	Thyroid lymphoma	1-mm patent airway	Tracheotomy	Not stated
Tyagi[26]	2006	M/27	Cyanosis, respiratory distress	CPB	25 min	SCC trachea	>90% occlusion	Surgical resection	Not stated

Table continued

First author	Year	Age	Condition prior to ECMO	ECMO mode	ECMO duration	Obstruction type	Comments	Definitive management	Final result
Tyagi[26]	2006	F/31	Cyanosis, respiratory distress	CPB	25 min	Adenoid cystic carcinoma	Approx. 90% occlusion	Surgical resection	Not stated
Soon[51]	2007	F/52	Dyspnea on exertion	CPB	48 min (induction and establishment of ventilation)	Thymoma	Severe airway compression	Surgical debulking	Discharged
Zhou[27]	2007	M/25	Respiratory distress	CPB	64 min (operative case)	Benign hypervascular leiomyoma	1-mm tracheal lumen	Surgical resection	Discharged
Liu[24]	2009	Adult	Severe dyspnea	CPB	25 min	Tracheal tumour	Near complete obstruction	Resection	Unknown
Liu[24]	2009	Adult	Severe dyspnea	CPB	30 min	Tracheal tumour	Near complete obstruction	Resection	Unknown
Shao[53]	2009	F/51	Dyspnea	VA	7 hr 35min (operative case)	Multi-nodular thyroid goitre and rheumatoid arthritis	5-mm diameter		Discharged
Jeon[40]	2009	F/68	Dyspnea, voice change, intermittent hemoptysis	VV	Operative case	Thyroid carcinoma	Near complete occlusion		Discharged
Sendasgupta[47]	2010	M/65	Severe dyspnea, stridor, cyanosis	CPB	Operative case	Anterior mediastinal tumour	7-mm tracheal diameter with distortion	Surgical resection	Discharged
Mehta[30]	2011	F/46	Respiratory distress	Unspecified	Operative case	Non-small-cell lung carcinoma	2-mm diameter	Stent insertion	Discharged
Yang[42]	2012	M/48	Orthopnea and hemoptysis	CPB	Operative case	Thyroid carcinoma	Near complete obstruction	Tracheal stent	Discharged
Gourdin[56]	2012	M/27	Stridor and severe halitosis	VV	120 min (operative case)	Tracheal stent occlusions and granulomas	4.9-mm diameter	Stent removal and replacement	Discharged
Gao[37]	2013	F/51	Severe dyspnea	CPB	15 min (intubation)	Tracheal tumour	80% occlusion	Tracheal resection and anastomosis	Discharged
Hong[23]	2013	M78	Unspecified	VV	2.2 hr (Operative case)	Head and neck cancer	Case series, however only 1 patient met criteria		Discharged
Erden[48]	2014	M/73	Respiratory distress	CPB	Operative case	External mediastinal mass	1-mm tracheal stenosis	Stent placement	Not stated
Said[49]	2014	F/37	Dyspnea, orthopnea	CPB	Operative case	Mediastinal cystic teratoma	Severe airway obstruction	Surgical resection	Discharged
Villanueva[36]	2014	F/63	Stridor	CPB	Until distal intubation following sternotomy	Adenoid cystic carcinoma	Near complete airway obstruction	Surgical resection	Discharged

Table continued

First author	Year	Age	Condition prior to ECMO	ECMO mode	ECMO duration	Obstruction type	Comments	Definitive management	Final result
Liou[41]	2014	M/76	Respiratory distress and stridor	VV	Operative case	Thyroid carcinoma	3.8-mm diameter	Tracheal resection and anastomosis	Discharged
Kim[45]	2015	F/88	Dyspnea and orthopnea	VV	2 hr 20 min (operative case)	Mediastinal malignant teratoma	Near complete obstruction	Resection and cautery	Discharged
Kim[50]	2015	Adult	Dyspnea	VV	Operative case	Tracheal stenosis		Surgical repair	Discharged
Kim[50]	2015	Adult	Dyspnea	VV	Operative case	Tracheal stenosis		Surgical repair	Discharged
Kim[50]	2015	Adult	Dyspnea	VV	Operative case	Tracheal stenosis		Surgical repair	Discharged
Kim[50]	2015	Adult	Dyspnea	VV	Operative case	Tracheal stenosis		Surgical repair	Discharged
Kim[50]	2015	Adult	Dyspnea	VV	Operative case	Tracheal stenosis		Surgical repair	Discharged
Kim[50]	2015	Adult	Dyspnea	VV	Delayed ECMO weaning due to postoperative ARDS	Tracheal stenosis		Surgical repair	Discharged
Dunkman[33]	2017	M/37	Dyspnea and foreign body sensation	VV	46 min (operative case)	Endobronchial schwannoma	Carina occlusion	Resection of mass	Discharged
Fung[55]	2017	F/73	Severe dyspnea	VV	Operative case	Sino-nasal malignant melanoma	Near complete occlusion	Resection of lesions	Discharged
Giovacchini[34]	2017	M/37	Biphasic wheeze	VV	Operative case	Endobronchial schwannoma	Near complete mobile obstruction	Resection of the lesion	Discharged
Natt[39]	2017	F/53	Respiratory distress and stridor	VV	Operative case	Traumatic tracheal stenosis	2 mm diameter	Tracheal stent	Discharged
Tian[28]	2017	F/60	Severe dyspnea	VV	97 min	Tracheal adenocarcinoma	Near complete occlusion	Surgical resection	Discharged

CPB = cardiopulmonary bypass; ECMO = extracorporeal membrane oxygenation; LMB = left main bronchus; RMB = right main bronchus; VA = veno-arterial; VV = veno-venous

pathology, including tracheal tumours (31%), tracheal stenosis (20%), and head and neck cancers (20%). Cases included in this review had ECMO instigated in a controlled environment prior to airway management, and as such, all reported a favourable patient outcome with all patients surviving to hospital discharge without significant complications.

The first reported successful use of ECMO in the treatment of adult airway obstruction due to thyroid carcinoma was reported by Onozawa *et al.*[29] in 1999. Since then, it has been used during a range of surgical procedures involving the respiratory tract to provide gas exchange and hemodynamic support during stenting, tracheotomy, and intubation.[58-60]

Conventional elective management of critical airway obstruction ordinarily involves methods that maintain spontaneous respiration.[4,5,7] Awake tracheal intubations via either the oral or nasal route, or an awake tracheotomy, are the usual techniques employed. Awake intubation is unsuccessful if the two key reflexes (gag and glottic closure) are not obliterated, usually with local anesthesia, as well as having recognized hazards such as complete airway obstruction occurring during topicalization of the upper airway.[61-64] Occasionally, during elective surgery for upper airway pathology, jet ventilation is used to maintain oxygenation,[65] with ventilation being maintained through passive expiration. Nevertheless, in the case of near-complete airway obstruction, jet ventilation carries an unacceptably high risk of volutrauma, barotrauma, pneumothorax, hyperventilation, and gastric insufflation.[66] Recently, active expiration techniques of jet ventilation have also been described that may reduce these risks.[65,67]

The CAFG difficult airway guidelines state, "When planning how to approach the anticipated difficult airway, the primary focus should be on ensuring adequate oxygenation and ventilation and not simply on intubating the trachea".[6] Current difficult airway guidelines focus on the management of the anticipated difficult airway using an approach of assessment of the probable success of oxygenation and ventilation; the four fundamental techniques of oxygenation are BMV, SGAs, tracheal intubation, and the front-of-neck airway. Nevertheless, the utility of ECMO in achieving the primary endpoint of oxygenation has not been discussed.

In 2015, Kim *et al.* assessed the utility of ECMO in the treatment of airway obstruction.[21] In their institution, 15 patients underwent ECMO for upper airway obstruction due to various pathologies. Based on their analysis they recommended that, when ECMO support is indicated for airway obstruction surgery, with bronchoscopic or chest CT findings determining the tracheal patency to be less than 5 mm, elective insertion of cannulae should be considered.

Typically, the outcomes following the emergency placement of ECMO for rescue of sudden cardiorespiratory arrest are poor, because it takes time to prepare and initiate ECMO.[68] Cardarelli *et al.* performed a meta-analysis of studies of adult extracorporeal cardiopulmonary resuscitation initiated for sudden witnessed cardiac arrest. They reported a negative trend in survival when manual CPR lasted > 30 min without ECMO initiation.[69] In addition, they reported that the average duration of cardiopulmonary resuscitation before ECMO was approximately 40 min, indicating that performing ECMO swiftly to prevent hypoxic brain injury is not without difficulties.[69] This point cannot be underestimated. The personnel and equipment, as well as the organizational logistics, required for the safe implementation of ECMO/CPB are critically important. For our patient, we had at least 24 hr to plan for the management. Due to significant cardiovascular co-morbidities, and technically challenging cannulae insertion with the patient placed in a semi-upright position, 70 min was taken to initiate ECMO.

The 4th National Audit Project (NAP4) of The Royal College of Anaesthetists and The Difficult Airway Society[70] reported on major complications of airway events during the management of patients with head and neck pathology. Of the 72 cases reported to the project, ten occurred during induction of anesthesia, and, of these, two patients died as a result of failure to adequately prepare for anticipated difficulties with all four fundamental techniques of oxygenation. These patients were electively anesthetized without consideration of extracorporeal life support for gas exchange. The utility of extracorporeal life support for the management of this patient group was not discussed within the NAP4 document.

Extracorporeal membrane oxygenation is used in many tertiary care centres for acute, severe reversible respiratory or cardiac failure that is refractory to conventional management. Nevertheless, its consideration has not been incorporated into guidelines for the management of ventilatory failure secondary to near complete airway obstruction. As with all oxygenation techniques, ECMO has its limitations. In the context of bridging until the airway is secured, ECMO has very few absolute contraindications. Nevertheless, the use of ECMO is continuously evolving. Clearly, it is essential to involve an ECMO specialist in discussing indications and contraindications in each instance. Long-term ECMO (and long-term intubation) use is associated with complications such as renal failure requiring continuous hemofiltration (52%), bacterial pneumonia (33%), bleeding (33%), sepsis (26%), hemolysis (18%), liver dysfunction (16%), leg ischemia (10%), venous thrombosis (10%), central nervous system complications (8%), gastrointestinal bleeding (7%), aspiration pneumonia (5%), and disseminated intravascular coagulation (5%).[71] These complications were all reported following cases in which the duration of ECMO lasted from 5.5 to 9.5 days. The reported incidence of complications with ECMO for short periods is low.[23]

This review focuses on studies utilizing CPB and ECMO as an elective procedure prior to airway intervention. This review did not include cases in which ECMO was used as a salvage technique or those in which ECMO was used during an emergency; thus, we are limiting the number of cases undergoing ECMO/CPB for all presentations of airway obstruction, which further limits the scope of this review. While all case reports of ECMO/CPB in the management of airway obstruction had favourable outcomes, the possibility of positive publication bias and the limited patient scope of this review should be considered.

Extracorporeal oxygenation of systemic blood whilst on ECMO is determined by a combination of factors: the gas exchange capability of the membrane oxygenator, flow rates through the extracorporeal circuit, oxygen uptake within the native lung, and the native cardiac output. Oxygen exchange in the circuit oxygenator occurs across a semipermeable membrane. Diffusion occurs rapidly across the membrane because of a relatively large oxygen concentration gradient. Therefore, within the extracorporeal circuit, the critical factor for oxygen delivery is the contact of the blood within the circuit with the membrane. The greater the volume of blood in contact with the membrane is, the greater the saturation of hemoglobin with oxygen. Therefore, due to the limitation

of the surface area of the oxygenator, the amount of oxygen provided via the artificial lung is a direct function of the blood flow.[72]

In a VV-ECMO circuit, the membrane oxygenator is in series with the native lung. The improvement in arterial oxygenation in this circuit is due to the increased oxygen saturation of the venous blood flowing through shunt regions of the native lung. The VV-ECMO approach with high flow, even with a very high shunt in the native lung, can provide vital arterial oxygenation. This approach, if the anatomy of the patient (for venous cannulation) had been favourable, would have been the preferred approach for the case presented.

The VA-ECMO approach involves the membrane oxygenator in parallel with the native lung. This circuit involves the drainage of venous blood, oxygenation of the blood, and the subsequent return to the aorta through a cannulated artery. In the setting of complete cardiac failure, there is significantly better systemic oxygenation with this technique compared with the VV-ECMO approach because the artificially oxygenated blood mixes with arterial blood and directly perfuses distal organs. In the presented case, this approach was chosen because of anatomical and technical reasons precluding the use of the VV-ECMO approach. Although this approach provided adequate tissue oxygenation during airway manipulation, it is associated with higher risks of complications related to arterial cannulation and generally higher required levels of systemic anticoagulation.[16]

Conclusions

While most practitioners are familiar with the four fundamental techniques for oxygenation in airway management, the use of ECMO may not be considered by practitioners working in non-ECMO centres. The *a priori* use of ECMO is an effective means of providing adequate oxygenation for patients with a severe airway obstruction in which all four fundamental techniques of oxygenation are likely to be unsuccessful. The use of ECMO in tertiary care centres with appropriate resources should be considered in patients with severe (or near-complete) airway obstruction secondary to anterior neck or tracheal disease. This approach can provide essential tissue oxygenation while attempts to secure a definitive airway are carried out in a controlled environment.

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Appendix Search criteria

Search question:	How many cases have been reported in the literature using extracorporeal life support as the 'plan A' method of oxygenation? What is the pathology associated with this mode of primary oxygenation?
Places to search for information:	MEDLINE, EMBASE, CINAHL, and Web of Science

List of sources searched:	Date of search	Search strategy used, including any limits	Total number of results found
MEDLINE	2017/09/12	(((((((("Cardiopulmonary Bypass"[Mesh]) OR cardiopulmonary bypass) OR cpb[Title/Abstract])) OR Heart Lung Bypass)) OR (((((("Extracorporeal Membrane Oxygenation"[Mesh]) OR ecmo[Title/Abstract]) OR ECLS[Title/Abstract]) OR Extracorporeal Membrane Oxygenations) OR Extracorporeal Life Support))) AND (((tracheal obstruction) OR "Airway Obstruction"[Mesh]) OR airway obstruction)	206
EMBASE	2017/09/12	(('ECLS' OR 'extracorporeal life support') OR ('extracorporeal membrane oxygenation device' OR 'extracorporeal oxygenation' OR 'ECMO') OR ('CPB' OR 'cardiopulmonary bypass')) AND ('trachea obstruction' OR 'airway obstruction')	387

Apendix continued

List of sources searched:	Date of search	Search strategy used, including any limits	Total number of results found
CINAHL	2017/09/12	(ECMO OR extracorporeal membrane oxygenation OR ECLS OR extracorporeal life support OR cardiopulmonary bypass OR CPB) AND (trachea obstruction OR airway obstruction)	20
Web of Science	2017/09/12	(ECMO OR extracorporeal membrane oxygenation OR ECLS OR extracorporeal life support OR cardiopulmonary bypass OR CPB) AND (trachea obstruction OR airway obstruction)	171

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