An Innovative Technique to Improve Safety of Volatile Anesthetics Suction from the Cardiopulmonary Bypass Circuit

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Abstract

Context: Myocardial injury during cardiac surgery on cardiopulmonary bypass (CPB) is a major determinant of morbidity and mortality. Preclinical and clinical evidence of dose- and time-related cardioprotective effects of volatile anesthetic drugs exist and their use during the whole surgery duration could improve perioperative cardiac protection. Even if administering volatile agents during CPB are relatively easy, technical problems, such as waste gas scavenging, may prevent safe and manageable administration of halogenated vapors during CPB. **Aims:** The aim of this study is to improve the safe administration of volatile anesthesia during CPB. **Settings and Design:** Tertiary teaching hospital. **Subjects and Methods:** We describe an original device that collects and disposes of any volatile anesthetic vapors present in the exit stream of the oxygenator, hence preventing its dispersal into the operating theatre environment and adaptively regulates pressure of oxygenator chamber in the CPB circuit. **Results:** We have so far applied a prototype of this device in more than 1300 adult cardiac surgery patients who received volatile anesthetics during the CPB phase. **Conclusions:** Widespread implementation of scavenging system like the one we designed may facilitate the perfusionist and the anesthesiologist in delivering these cardioprotective drugs with beneficial impact on patients' outcome without compromising on safety.

Keywords: *Anesthesia, cardiac surgery, cardiopulmonary bypass, sevoflurane, volatile*

Introduction

Experimental evidence shows that halogenated anesthetics reduce morbidity and mortality in cardiac surgery and their administration is recognized as a mortality reducing strategy by the scientific community.[1-6]

Volatile agents can be mixed with the sweep rate and can diffuse through the polypropylene membrane oxygenator during cardiopulmonary bypass (CPB) as performed worldwide for decades. An inhaled anesthesia maintenance regimen during CPB is feasible, as recently confirmed by our group measuring sevoflurane blood concentration through gas chromatography and bispectral index™ (BIS).[7-9]

Scavenging of volatile vapors is technically challenging because of the risks of air pollution or membrane oxygenator dysfunction. Regulatory agencies often do not provide standards for such devices, jeopardizing the widespread implementation of this technique of pharmacological cardiac protection. Furthermore, there is no proprietary scavenging equipment specifically designed for CPB oxygenators.[10]

We describe the evacuation device we implemented on extracorporeal circulation apparatus with means of real-time monitoring of anesthetic gas in and out of the oxygenator gas chamber.

Subjects and Methods

The CPB polypropylene hollow-fiber oxygenator [Figure 1, panel A, 3] displays one main discharge port for waste gas scavenging [Figure 1, panel C, 2] and may display some secondary ports [Figure 1, panel B, 2]. When excessive pressure builds up in the oxygenator gas chamber, indicating an obstruction of the main exit port, the secondary ports discharge waste gas directly into the operating room.

The importance of such mechanisms cannot be overemphasized because oxygenator overpressurization may force gas into the bloodstream, leading to massive gas embolism.[8,10,11]

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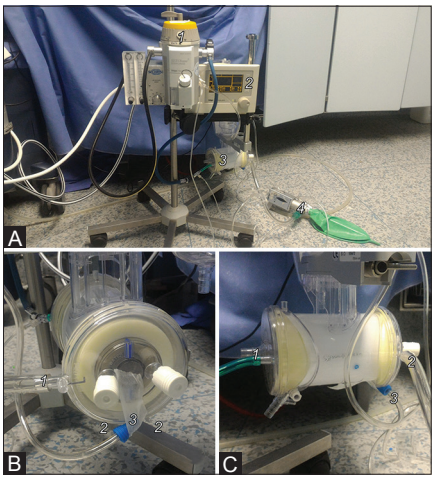

Figure 1: Panel A depicts the cardiopulmonary bypass circuit with the vaporizer (1) connected to the oxygenator (3), and the Venturi system (4) implemented on the suction line, and the monitoring device (2) connected to the inflow circuit and to the oxygenator secondary ports to measure volatile agent concentration. Panel B shows the oxygenator main exit port (1), the secondary ports along the edge of the oxygenator cylindrical case (2) and the sampling line for the volatile agent (3). Panel C shows a side view of the oxygenator: inlet gas port (1), main exit port (2), sampling line (3)

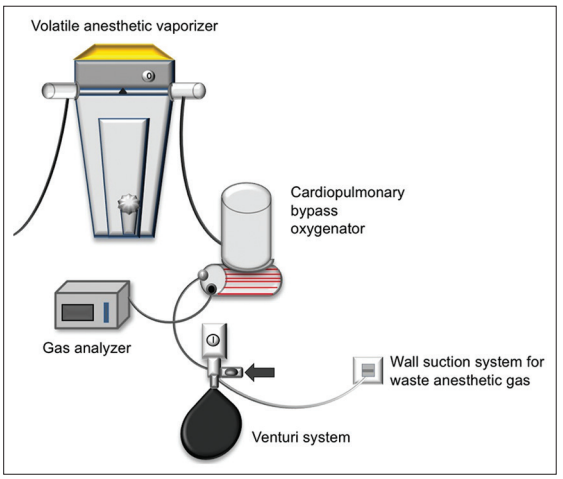

Figure 2: The device is schematically depicted: sweep gas enriched by the vaporizer with volatile anesthetic enters the gas chamber of the oxygenator through the inlet port. The main exit port is connected to the Venturi system, which regulates the pressure generated by the wall vacuum system (note black arrow indicating the air inflow port of Venturi system). A monitoring system of waste gas concentration out of the oxygenator secondary port is also described

To deliver volatile anesthetics during CPB, we need to blend them with the sweep rate [Figure 1, panel A, 1] and then we need to connect the main discharge port of the oxygenator to the hospital suction line for waste gas dismissal.

If we directly connect the oxygenator to the suction pipeline, we need to assure a balance between fresh gas inflow and waste gas outflow to prevent dangerous pressure variation inside the oxygenator chamber. In case of depressurization, blood may be forced through the microporous membrane into the gas compartment.

The suction line may generate a highly variable flow rate, e.g., 20–25 L/min, which is surely mismatched to the oxygenator gas outflow.

To safely deliver halogenated drugs, we need more than just a simple connection between the oxygenator and the suction line but a device with means of regulation. To solve this technical problem, we designed our original device [Figures 2 and 1]. The evacuation device we describe is interposed between the main exit port and the suction line. To assure the proper functioning of the oxygenator, the vacuum line flow rate should be balanced according to the sweep rate (e.g., 2–3 L/min). However, the secondary ports that are open to the atmosphere introduce the complexity of an open system, implying a nonlinear relationship between the fresh gas flow and the waste gas outflow of the oxygenator.

This scavenging device [Figure 1, panel A, 4] can be described as a Y-shaped circuit open to the environment connecting the oxygenator main exit port, the anesthetic gas disposal line, and a side branch.

The side branch presents a convergent section which is provided with an aperture open to the external environment acting as a Venturi system. The Venturi system is shaped as a convergent tube, whose interior lesser cross-section may be sized through a valve to regulate the air inflow, while its greater cross-section is faced toward the external environment.

This inflow of air through the Venturi system allows to discharge the oxygenator of any excessive negative pressure generated by the suction system and keeps the difference between the atmospheric pressure and the oxygenator gas chamber pressure equal to zero.

To assure a safe administration of volatile anesthesia, we monitor anesthetic vapors concentration at two sites: feeding conduit to the oxygenator gas chamber (as an "inspired" fraction) and one of the secondary ports of the oxygenator. Monitoring anesthetic gas concentration at the feeding line rules out any vaporizer dysfunction (such as an obstruction of the feeding line or the depletion of the vaporizer reservoir) and assures uninterrupted anesthesia administration [Figure 1, panel A, 2]. Monitoring anesthetic gas concentration at the secondary port rules out any gas chamber overpressurization because these ports are open to the environment to release any excessive pressure built up from insufficient scavenging of waste gas [Figure 1, panel B, 3]. Since the outflow of gas from these secondary ports mirrors the pressure inside the oxygenator gas chamber, the continuous measuring of anesthetic gas concentration at one secondary port also suggests the optimal suction flow rate. In our institution, we chose as threshold value, i.e., the minimal detectable concentration (such as 0.1%). We chose this value because no detectable volatile anesthetic concentration could be

related to excessive suction and depressurization of the oxygenator.

This device prevents excessive depressurization and enables effective scavenging of waste gases without jeopardizing the oxygenator integrity and function.

In another setup of such device that we realized as a prototype, we designed a device shaped as a cylindrical shell to encase the oxygenator [Figure 3]. This shell would make unnecessary a direct connection with the oxygenator exit stream, so it reduces the risk of main port obstruction in comparison of the previously described device embodiment. The oxygenator directly discharges waste gas inside the shell, and the anesthetic gas sensor is placed inside this chamber. The shell is open to the external environment through superior secondary ports, and it is connected to the suction pipeline through an inferior port. The shell is therefore put under vacuum and regulates its internal pressure allowing air entrance by Venturi effect through the superior ports. The main limitation of this setup is the need of shaping its case according to the individual oxygenator outline.

Results

We implemented the above-described setup of the scavenging device in more than 1300 adult cardiac surgery interventions using sevoflurane (79% of cases) or desflurane (21% of cases) in the period from year 2008 to 2015. We observed no adverse effects, no overpressurization or cracking of oxygenators, and no dysfunction, or disruption of the CPB circuitry.

This system may be further developed with means of self-regulation through an anesthetic gas sensor placed through a secondary port of the oxygenator chamber. This sensor may regulate the cross size of the air inflow valve either reducing or increasing the Venturi effect. This would allow a self-adapting fine tuning of suction flow.

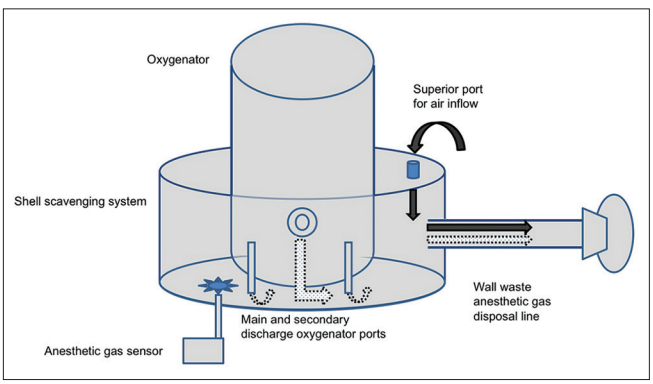

Figure 3: The shell type setup is depicted in Figure 3. The shell encases the oxygenator inferior half so that the main and secondary discharge ports freely communicate with the shell inside. The shell is directly connected to the vacuum line and pressure is constantly regulated by air inflow through the superior port open to the operating room environment. An anesthetic gas sensor can be implemented to monitor the waste gas concentration inside the shell. Dotted arrows indicate the waste gas flow; solid black arrows indicate air flow

Discussion

We presented and discussed the details of an original invention. This novel device specifically addresses major issues that prevent safe and manageable volatile anesthetics administration during CPB. It may reduce operating room pollution, and it may regulate adaptively the pressure of the oxygenator, reducing the risk of deleterious overpressurization or depressurization. Few published case reports describe the occurrence of massive gas embolism due to oxygenator gas chamber overpressurization so we believe that the advancement of CPB technology such as hollow-fiber oxygenator and the design of secondary ports had a substantial impact on this rare but dramatic complication.[8,11]

The implementation of our scavenging device does not increase the risk of such complication because most of the secondary ports are not obstructed and may allow an emergency discharge in case of kinking or obstruction of our device, whereas the Venturi system prevents excessive vacuum suction on the oxygenator. The safety of our device is confirmed by the observation of no cases of CPB circuitry dysfunction during years of daily use.

Furthermore, the variety of setups we described highlights the versatility of the fundamental mechanism of this device, which is fit to be mounted on different CPB machines and oxygenators.

In comparison to a simple scavenging device, our invention solves the problem of balancing flow in and out of the oxygenator to keep an optimal pressure for gas exchange. This device allows the perfusionist to balance suction rate and sweep rate of the oxygenator and provides means for monitoring the concentration of halogenated anesthetics exiting the oxygenator.

Limitations

In this manuscript, we have simply described our invention without presenting comparative data versus no volatile during CPB or versus using other scavenging systems. We did not routinely use BIS, but our group recently published that sevoflurane blood concentrations and BIS values are as expected while administering sevoflurane through this device.[9] Furthermore, the American National Standards Institute (ANSI) standard (ANSI Z79.11) addressing scavenging systems for anesthetic gases states that scavengers should not generate positive pressures exceeding 10 cm of water (7.4 mmHg) or negative pressures exceeding 0.5 cm of water (0.37 mmHg). We did not measure the pressure in our scavenging system because our innovative method device makes pressure measuring unnecessary: If the gas chamber is under excessive pressure we would measure volatile anesthetic flowing out of the secondary ports; if the suction flow is excessive the Venturi effect would prevent oxygenator depressurization

Conclusions

Widespread implementation of scavenging system like the one we designed may facilitate the perfusionist and the anesthesiologist in delivering these cardioprotective drugs with beneficial impact on patients' outcome without compromising on safety. We also hope that presenting our original invention may promote the technological innovation of the CPB apparatus to revert the current underuse of these cardioprotective anesthetics during CPB.

Financial support and sponsorship

Nil.

Conflicts of interest

Three of the authors (GL, FDS, CL) applied for a patent ("Evacuation device for fluid exiting an oxygenator of an extracorporeal circulation apparatus" number WO2011048054A1).

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