Original Article

Tricks, tips, and literature review on the adapted vaporize system to deliver volatile agents during cardiopulmonary bypass

Caetano Nigro Neto, Francesco De Simone[1], Luigi Cassarà[1], Carlos Gustavo dos Santos Silva, Thiago Augusto Azevedo Maranhão Cardoso, Francesco Carcò[1], Alberto Zangrillo[1,2], Giovanni Landoni[1,2]

Department of Surgery and Anesthesia, Dante Pazzanese Institute of Cardiology, São Paulo, Brazil, [1]Department of Anesthesia and Intensive Care, IRCCS San Raffaele Scientific Institute, [2]Vita-Salute San Raffaele University, Milan, Italy

ABSTRACT

Background: Recently, evidence of cardio-protection and reduction in mortality due to the use of volatile agents during cardiac surgery led to an increase in their use during cardiopulmonary bypass (CPB). These findings seem to be enhanced when the volatile agents are used during all the surgical procedure, including the CPB period. **Aims:** Since the administration of volatile agents through CPB can be beneficial to the patients, we decided to review the use of volatile agents vaporized in the CPB circuit and to summarize some tricks and tips of this technique using our 10-year experience of Brazilian and Italian centers with a large volume of cardiac surgeries. **Study Setting:** Hospital. **Methods:** A literature review. **Results:** During the use of the volatile agents in CPB, it is very important to analyze all gases that come in and go out of the membrane oxygenators. The proper monitoring of inhaled and exhaled fraction of the gas allows not only monitoring of anesthesia level, but also the detection of possible leakage in the circuit. Any volatile agent in the membrane oxygenator is supposed to pollute the operating theater. This is the major reason why proper scavenging systems are always necessary when this technique is used. **Conclusion:** While waiting for industry upgrades, we recommend that volatile agents should be used during CPB only by skilled perfusionists and physicians with the aim to reduce postoperative morbidity and mortality.

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INTRODUCTION

The use of volatile anesthetic agents during cardiopulmonary bypass (CPB) was described for the 1st time about 40 years ago.[1] Originally, volatile agents were vaporized and administered in the early-generation bubble oxygenators. Today, most cardiac surgery interventions are performed with standard membrane oxygenators. Unfortunately, the newest CPB machines are not equipped routinely for the use of these anesthetic agents, and this means that we still need to adapt anesthetic vaporizers in the bypass circuit.

Some studies showed an evidence of cardioprotection and reduction in mortality due to the use of volatile agents during cardiac surgery.[2-6] These findings seems to be enhanced when the volatile agents are used during all the surgical procedure, including the period of CPB.[7]

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Address for correspondence: Dr. Giovanni Landoni, Department of Anesthesia and Intensive Care, IRCCS San Raffaele Scientific Institute, Via Olgettina 60, 20132 Milan, Italy. E-mail: landoni.giovanni@hsr.it

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Since the administration of volatile agents through CPB can be beneficial to the patients, we decided to review the use of volatile agents vaporized in the CPB circuit and to summarize some tricks and tips of this technique in our 10-year experience of Brazilian and Italian centers with a large volume of cardiac surgeries.

Table 1 summarizes the problems that we found in our extensive experience that can be related to the use of volatile agents vaporized in the CPB circuit. All these problems are associated to the vaporizer and to the analysis of the exhaled gases from the membrane oxygenator.

Until now, the technique of the use of volatile agents during CPB is an adaptation which includes the volatile agent vaporized into the circuit of the CPB machine mixed with the fresh gas flow (oxygen and compressed

Table 1: Tricks and tips for the adapted vaporize system using volatile agents during cardiopulmonary bypass based on the 10 years' experience of two teaching hospitals (one in Italy and one in Brazil)

Problem	Cause	Solution
1. Insufficient blood oxygenation	Vaporizer not correctly put on the stirrup	Reposition the vaporizer correctly on the stirrup in other to avoid gas flux leakage
	Breath in fraction Luer Lock not correctly closed	Connect the breathe in reading line or a little plug in order to avoid gas leak
2. No inspired fraction reading gas	a. Reading line not positioned	Place a reading line
	b. Broken reading line	Place a new reading line
	c. Tap (if present) not correctly turned	Turn the tap in the direction of the monitoring
	d. Empty vaporizer	Reload the vaporizer
	e. Switched off vaporizer	The gas vaporizer is an electric supply and it must be connected to the net or to a new light socket that works properly
	f. Vaporizer not correctly positioned on the stirrup	Correctly reposition the vaporizer on the stirrup
	g. Nonelectronic vaporizer run out of gas even though the sentinel column is sufficient	Reload the vaporizer (see problem 9)
3. Malfunctioning of the vaporizer alarm	The electronic vaporizer was put on a stirrup where the gas input and output were inverted	Invert the gas input and output (air/oxygen) following the indication on the stirrup
4. The vaporizer does not function and the lights are flashing simultaneously	The electronic vaporizer did not pass the initial check because it was positioned on a stirrup not in axis, but turned forward	While waiting for the stirrup maintenance the vaporizer can be put on a horizontal plain. After passing the check, put it on the stirrup
5. The vaporizer flashes the heating	The electronic vaporizer (desflurane) did not reach the proper temperature	Wait the proper time to reach the optimal temperature. Inform the anesthesiologist and administer intravenous agents while waiting
6. On the vaporizer there is the gas reserve alarm but the sentinel column is full enough	The electronic vaporizer is on a stirrup that is not in axis, and the reading level on the sentinel column is altered	While waiting for the stirrup maintenance, the vaporizer must be reloaded independently of the sentinel column level
7. Alarm during the operation of the electronic vaporizer (desflurane) knob	Electronic vaporizer not connected to the electric current	Connect it to the electric current trough a functioning socket
8. Vaporizer knob is blocked	The nonelectronic vaporizer gas run out the gas	Reload the vaporizer
9. Sentinel column of the nonelectronic vaporizer is sufficient but the inhale fraction is zero	The nonelectronic vaporizer is empty but is positioned on a bar that is not in axis and this alters the reading level on the sentinel	While waiting for the stirrup maintenance, the vaporizer must be reloaded independently of the sentinel column level
10. $EtCO_2$ curve present but the reading of the exhale halogenates fraction is zero	The vaporizer is turned off	Turn it on according to the protocol
11. $EtCO_2$ curve present but the reading of the exhale halogenates fraction is zero even though the vaporizer is turned on	The vaporizer is not working	Monitor the inhale gas fraction, if it does not detect any value of halogenate see problem point-2d, point-2e, point-2g, and point-9
12. Exhale gas leakage (halogenates included) from the additional discharge doors	The bayonet socket of venturi was not correctly placed in the discharge door on the wall	Place it in the proper way and make sure that the light-emitted diode, if present, is switched on

Contd...

Table 1: Contd...

Problem	Cause	Solution
	The gas waste pipe (between the gas exit and the venturi entry) is too long	Shorten the length of the waste pipe in order to reduce the resistance to the disposal
	The gas waste pipe (between the gas exit and the venturi entry) has a section area too small	Replace it with a tube with a proper section area that does not offer too many resistances to the gas disposal
	Luer lock the exhale fraction not correctly closed	Connect the line to reading the exhale fraction or put a plug in order to avoid the discharge gas leakage
	Air/oxygen fluxes too high (higher than 2 L/min)	Reduce the fluxes if possible or, Reduce the dead space between the gas oxygen exit and the Venturi entry or Replace the gas evacuator with another one equipped with a better aspiration
	The gas reading line is positioned inside the additional oxygen discharge door	Throw it back until it is positioned in a few millimeters from the additional discharge door in order to avoid the reading (of the gas) still inside the oxygen
13. Venturi manometer on the zero position	The venturi bayonet not correctly placed in the wall socked	Place it properly and make sure that the light-emitting diode (if present) is turned on
	The discharge door is not working	IF pushing manually the valve of the discharge door on the wall you cannot feel any suction, stop the halogenate protocol
	Obstruction of the rubber tube that runs from the wall discharge door to the Venturi	Remove the obstacle
	The venturi could have been connected to the secondary discharge door of the oxygen-gas	Check *in vitro* which is the main oxygen discharge door in doubt

$EtCO_2$: End-tidal carbon dioxide

air) delivered from the blender. At first, the fresh gas flow from the blender enters into the calibrated vaporizer and is mixed with a desired concentration of the volatile agent. After that, the fresh gas flow, now mixed with a vaporized volatile agent, and enters into the circuit of the membrane oxygenator [Figure 1]. Many companies fail to mention that vaporizers can be included in their circuit and that the volatile agents can be used with standard membrane oxygenators.[8,9]

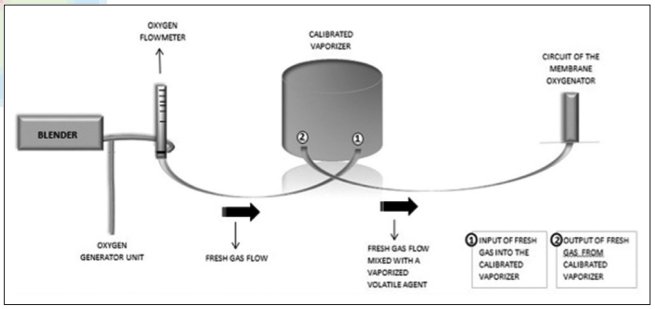

Figure 1: Schematic representation of the use of volatile agents adapted to cardiopulmonary bypass machine

During the use of the volatile agents in CPB, it is very important to analyze all gases that come in and go out of the membrane oxygenators. The proper monitoring of inhaled and exhaled fraction of the gas allows not only the monitoring of anesthesia level, but also to detect possible leakage in the circuit. Nevertheless, most current oxygenators have redundant venting systems that eliminate the hazards of potential over pressurization inside the oxygenator which makes it difficult to measure precisely the volatile anesthetic levels in the exhaust port. In a prospective observational study, changes in sevoflurane plasma concentrations (SPCs) and bispectral index values during CPB were evaluated together with patient temperature, hemodilution, oxygenator fresh gas flow, and sevoflurane concentration in the exhaust gas from the oxygenator.[10] This study evidenced that SPCs were higher during hypothermia and with an increased fresh gas flow in oxygenator, while were lower with hemodilution. No correlation was found between SPCs and the concentration of sevoflurane in the oxygenator exhaust port gas, suggesting that leakages occurred from the main port during measurements. Moreover, most scavenging system devices used during this technique to evacuate the volatile gases from the operating room could be the cause of the reading line failure during monitoring.

Any volatile agent in the membrane oxygenator is supposed to pollute the operating theater. This is the major reason why proper scavenging systems are always necessary when this technique is used. The exposure limit for halogenated anesthetics is on average 2 parts per million (ppm), and it slightly changes according to the average over the period of anesthetic administration. It is important to mention that the olfactory thresholds typically is much higher than the 2 ppm.[11]

Recently, Nigro Neto *et al*.[8] described in a systematic review that the most serious accidents associated to the use of volatile agents during CPB are pollution of the room and cracks in the polycarbonate shell of the extracorporeal circuit components caused by spilled liquid volatile agent. Awareness is rare and seems to be associated to the type of membrane oxygenator used. Currently, there are two groups of hollow-fiber membrane oxygenators used in clinical practice [Table 2].[12] The first type includes hollow-fiber membranes, primarily composed of microporous polypropylene, which is widely for standard CPB without having performances affected by the use of volatile agents.[9] The second type (diffusion plasma-resistant oxygenators) has the basic membrane compounded primarily of poly-(4-methyl-1-pentene). This type is increasingly used for extracorporeal life support or extracorporeal membrane oxygenation, and might increase the risk of intraoperative awareness during CPB by lowering the transfer of the volatile agent to the blood.[13,14] To avoid this undesirable event, it is important to monitor the consciousness depth by monitoring systems such as bispectral index scale or by extrapolating plasma concentration from measured end-tidal anesthetic gas concentrations.[10] Moreover, proper scavenging system is utmost important along with strict patient monitoring during the delivery of these agents. Unlike bubble oxygenators (which rely on direct contact of blood and bubbles for gas exchange and are designed to separate undissolved gas from blood before the blood exits the oxygenator), membrane oxygenators are not designed to separate blood and bubbles of undissolved gas. Consequently, if large volumes of undissolved gas enter into the blood or are generated by back pressure in the membrane oxygenator, these will flow out of the oxygenator with blood. The potential for gas embolism exists if the outlet gas vent port of these oxygenators becomes either partially or totally occluded. Gas scavenging systems for these oxygenators must not cause the application of positive or negative pressures in the gas jackets as this may be dangerous. The American National Standards Institute (ANSI) standard (ANSI Z79.11) addressing scavenging systems for anesthetic gases apply to oxygenators as well as to anesthesia machines. This standard states that scavengers must not generate positive pressures exceeding 10 cm of water (7.4 mmHg) or negative pressures exceeding 0.5 cm of water (0.37 mmHg).[15]

Table 2: Difference in the hollow-fiber membrane oxygenators and their variability in transmembrane passage of volatile agents

Hollow-fiber membrane oxygenators	Transmembrane passage	Examples
Polypropylene	Yes	Standard CPB
Poly-(4-methyl-1-pentene)	No	ECMO

ECMO: Extracorporeal membrane oxygenation, CPB: Cardiopulmonary bypass

CONCLUSION

While waiting for industry upgrades, we recommend that volatile agents should be used during CPB only by skilled perfusionists and physicians with the aim to reduce postoperative morbidity and mortality.

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Conflicts of interest

There are no conflicts of interest.

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