**ARTIGO ORIGINAL** ORIGINAL ARTICLE

# BENEFITS OF CONTINUOUS MONITORING OF $PCO_2$ OBTAINED FROM A SYSTEM APPLIED TO MEMBRANE OXYGENATOR EXHAUSTION OF THE CARDIOPULMONARY BYPASS CIRCUIT

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## Abstract

**Objective:** To observe the impact of the use of capnography system adapted to cardiopulmonary bypass (CPB). To measure the concordance between values obtained from continuous monitoring of partial pressure of carbon dioxide in membrane oxygenator exhaustion (PeCO2) and the results observed on arterial blood gas test.

**Methods:** Participated in this study 40 patients submitted to elective cardiovascular surgery with CPB. They were divided into two groups: Group 1, with 20 patients submitted to the surgical procedure using blood gas analysis at intermittent intervals (20 - 30 minutes); Group 2, with 20 patients operated with a capnography system adapted applied to membrane oxygenator exhaustion and blood gas test. A test was used to compare *arterial partial pressure* of carbon dioxide ($PaCO_2$) from group 1 and group 2. In group 2, the strength of the correlation between $PeCO_2$ and $PaCO_2$ was evaluated by a linear regression test. The Bland-Altman method was used to determine the degree of agreement between the two variables.

**Results:** Average and standard deviation of Group 1's PaCO2 (34.6 ± 7.44) and Group 2's $PaCO_2$ / $PeCO_2$ (36.5 ± 4.42) / (39.9 ± 3.98). There was *no statistically significant difference* in PaCO2 *between* the *groups* (P = 0.21). In group 2, $PeCO_2$ and PaCO2 analyzed corrected for esophageal temperature obtained a positive linear correlation (r = 0.79, P <0.001), the degree of agreement presented an average 3.47 ± 2.70 mmHg.

**Conclusion:** The continuous $PeCO_2$ monitoring from cardiopulmonary bypass circuit has a positive impact on the result of PaCO2. This instrument confirms and maintains the carbon dioxide ($CO_2$) values into reference parameters.

## INTRODUCTION

Respiratory acidosis on the cardiopulmonary bypass (CPB) is most related to the retention of carbon dioxide ($CO_2$) in the membrane oxygenator. Acidosis promotes the appearance of cardiac arrhythmias, decreases inotropic action and causes an increase in pulmonary vascular resistance. Respiratory alkalosis is related to the fast elimination of $CO_2$ by the oxygenator. This disturbance is crucial for the appearance of neurological complications in the postoperative period of cardiac surgery.[1,2]

The capnography system is a very important method for the monitoring of the patient's respiratory function during surgery. This instrument enables the real-time monitoring of the partial pressure of carbon dioxide ($PCO_2$) on the expired mixture.[3] The capnographer applied to membrane oxygenator exhaustion of the CPB circuit comprises a system that makes a real-time analysis of the measurement of carbon dioxide elimination in the intervals between arterial blood gases collections. It's presumed that this system assist in the observation and management critical incidents during the cardiopulmonary bypass.[4]

Continuous inline blood gas monitors are not accessible to all cardiac surgery services. An alternative is the adaptation of the capnography to the CPB circuit which permit excellent monitoring of $PCO_2$, doing it a useful practice and efficient in cardiac surgery.

## METHODS

This is a prospective and observational study performed in surgery department of *Instituto Dante Pazzanese de Cardiologia* (IDPC) in São Paulo, SP, Brazil, in June and July, 2018. The study was approved for the Ethics and Research Committee of the IDPC with CAAE number: 91256018.9.0000.5462.

Participated in this study 40 patients undergoing to elective cardiovascular surgery with cardiopulmonary bypass. The inclusion criteria were adult age 18 to 80 years that underwent myocardial revascularization, valve replacement and combined surgeries in moderate hypothermia (27° C - 32° C). The research excluded patients submitted to reoperation, surgical correction of congenital heart diseases, circulatory arrest and cardiac transplantation.

Patients were divided in two groups, each group containing 20 individuals. For both groups, the technique used during the cardiopulmonary bypass was taken into consideration. Group 1 was composed of patients who would undergo surgical procedures with CPB using blood gas analysis at intermittent intervals (20 - 30 minutes). Group 2 was specific to patients that underwent surgical procedures with a capnography system adapted to the membranes oxygenator exhaustion and blood gas test.

All the patients received similar perioperative care; the CPB circuit was prepared with 2000 ml of 0.9% sodium chloride, 100 ml of human albumin and 50 ml of 8.4% sodium bicarbonate, the heparinization was performed at a dose of 4 mg / kg, the start of cardiopulmonary bypass occurred when the activated coagulation time (ACT) exceeded values over 480 seconds. After CPB initiation, stabilization of the total flow (40ml/kg/min - 60ml/kg/min) and cessation of lung ventilation, a PVC tube was connected to the outlet of the CPB circuit, being sequentially adapted to a capnograph sensor connected to the Dräger Primus® anesthesia machine, the data was digitized and transferred to the monitor of the device, being possible to monitor the oxygenator gas exhaustion in real time (Figure 1). Continuous measurement of oxygenator $PCO_2$ was performed based on reference values between 35mmHg - 45mmHg, which are the parameters related to arterial PCO2. The pH-stat technique was used during the CPB procedure and the adjustment of the carbon dioxide pressure was done according to the strategies used by the perfusionist. Blood pressure was maintained at values of 50 to 70 mmHg.

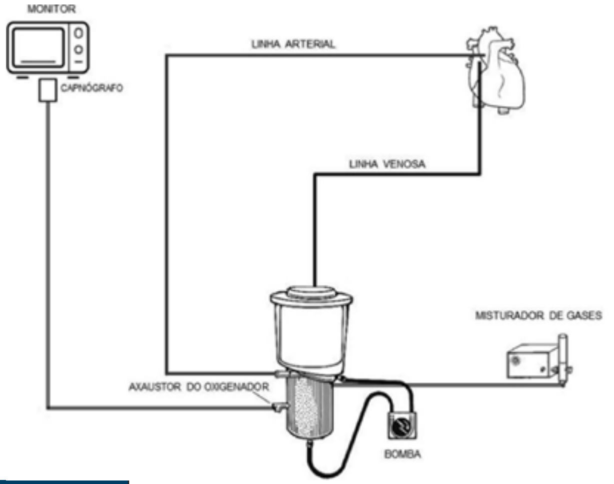


**Figure 1** *Configuration of the capnograph adapted to the membrane oxygenator.*

Arterial blood samples were collected for blood gas test using a GEM® Premier™ 4000 automatic device, which measured the concentration the parameters. The temperature of the sample was corrected according to the patient esophageal temperature.

Three brands of membrane oxygenator were used: Medtronic Affinity, Sorin Inspire 6F / 8F and Nipro Vital, operated combined with continuous flow centrifugal pumps.

In group 1, the blood samples were collected for the blood gas analysis and obtained through an arterial line of the cardiopulmonary bypass circuit and then sent to laboratory analysis. Simultaneously, we recorded esophageal temperature.

Group 2 continuous monitoring of $CO_2$ partial pressure of membrane oxygenator exhaustion ($PeCO_2$) was observed through the capnographer adapted to the CPB. Blood samples were collected for the arterial blood gas test, and we recorded the values presented by the capnography and the esophageal temperature.

The average and standard deviation of the data collected from both groups were obtained. T-test was used to compare *arterial partial pressure* of carbon dioxide ($PaCO_2$) in group 1 and group 2. The value $p < 0.05$ was considered statistical significance. In group 2 the correlation between $PeCO_2$ and $PaCO_2$ were evaluated by linear regression. The Bland-Altman method was used to determine the degree of agreement between the two variables.

## RESULTS

25 male patients and 15 female, age 41-79 years (av. 61,6 years) participated in this study. 83 blood samples were collected and analyzed. The esophageal temperature varied between 28° and 32,9° C (av. 32,1° C). The cardiopulmonary bypass time varied from 43 to 205 minutes (av. 96 minutes) and the anoxia time, from 36 to 185 minutes (av. 53 minutes). Table 1 shows the average and standard deviation of group 1's PaCO2 and group 2's $PaCO_2$ / $PeCO_2$.

For the conventional criteria, the difference between group 1 and group 2 is considered not statistically significant ($P = 0.21$). The average $PaCO_2$ in both groups was not significantly different, and these data are presented in table 2.

**Table 1** **Group 1 and Group 2 - Average ± SD (mmHg)**

| | n | Av. ± SD |
|---|---|---|
| Group 1's $PaCo_2$ | 42 | 44% |
| Group 2's $PaCo_2$<br>$PeCo_2$ | 41 | 36.5 ± 4.42<br>39.9 ± 3.98 |

$PaCO_2$ - arterial $CO_2$ partial pressure (mmHg); $PeCO_2$ - $CO_2$ partial pressure of oxygenator exhaust (mmHg)

**Table 2** **Average ± SD (mmHg) $PaCO_2$**

| | Group 1 | Group 2 | *p* |
|---|---|---|---|
| $PaCO_2$ (Max/Min) | 34.6±7.44 (20/53) | 36.5 ± 4.42 (27/48) | 0,21 |

$PaCO_2$ - arterial $CO_2$ partial pressure (mmHg); P - T-test comparing Group 1 and Group 2. (P <0.05)

Figure 2 demonstrates the correlation between $PaCO_2$ and $PeCO_2$ measured in group 2. The temperature of the sample was corrected according to the esophageal temperature of the patients and showed a significant positive correlation (r = 0.79, p <0.001). Figure 3 presents the graphical analysis of Bland-Altman between the values of PaCO2 corrected from esophageal temperature and the PeCO2. It's possible to verify an average agreement of difference between the results corresponding to 3.47 ± 2.70 mmHg. The 95% upper and lower limits (dashed lines) correspond to -1.8 and 8.76 mmHg, respectively.

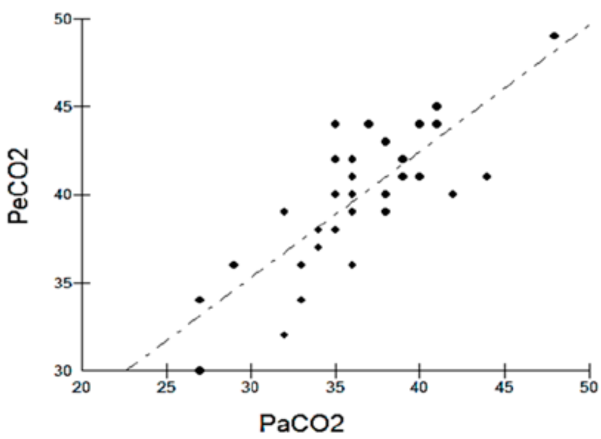


**Figure 2** *Relation between $CO_2$ partial pressure of membrane oxygenator exhaust ($PeCO_2$) and arterial $CO_2$ partial pressure ($PaCO_2$). r = 0.79, P <0.001.*

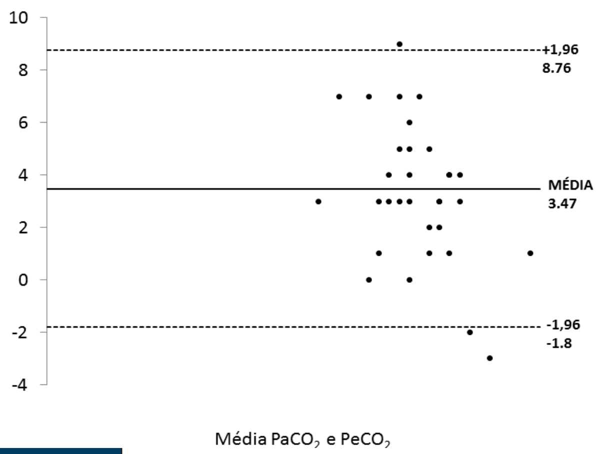


**Figure 3** *Agreement between $PeCO_2$ (Oxygenator Exhaust) and $PaCO_2$ (Arterial) during stable hypothermia in cardiopulmonary bypass..*

**DISCUSSION**

This study demonstrates that there was no statistically significant difference in the $PaCO_2$ measurements in both groups; we observed that both groups contain relatively equal average statistically. The results show that the capnography of the oxygenator provides a level of accuracy comparable to the conventional analysis of the blood gas test. Although the $PaCO_2$ of group 1 and group 2 show statistical similarity, the continuous monitoring of $PCO_2$ of the oxygenator exhaust provides a faster evaluation, which can avoid unwanted outcomes to the patient. Graham *et al.*[4] indicate in their studies that membrane oxygenator capnography is a real-time indicator for estimating arterial $PCO_2$. This device causes a safe and proper elimination of carbon dioxide during the cardiopulmonary bypass. However, despite the favorable results obtained in the research, Graham *et al.*[4] clarify that this instrument should not replace the intermittent collections of blood gases during the procedure.

The results of this study indicate that the analyzed $PeCO_2$ and $PaCO_2$ corrected from esophageal temperature obtained a positive linear correlation (r = 0.79, P <0.001) in group 2. These results come to agreement to the reports of Potger *et al.*[5] (r = 0.83 P <0.001), in which a strong positive correlation was observed between $PCO_2$ of the membrane oxygenator exhaustion and the arterial carbon dioxide. $PeCO_2$ measured by the capnographer adapted to the membrane oxygenator presented values above the average $PaCO_2$. However, the degree of agreement was with an average of (3.47 ± 2.70 mmHg). Baraka *et al.*[6] reported an average of (2.8 ± 2.0 mmHg) to express agreement in the moderate hypothermia. Although these results present different values from those presented in our study, both studies are strictly in concord. This difference can be attributed to the use of a thermometer connected directly to the CPB circuit, which demonstrated the arterial blood temperature measurement, while we used the esophageal temperature to make the correction in the arterial blood gas analysis in our study. Baraka *et al.*[6] also describe that the continuous measurement of $PCO_2$ by capnography is a reliable instrument in normothermia and stable hypothermia during CPB. However, they demonstrate that during hypothermia one should take into account the correction of the temperature of the sample to obtain great results, in this case the PH-stat strategy is the method used during the procedure.

In group 2, the results presented $PeCO_2$ average higher than those of $PaCO_2$, and we can assume that maintaining the $CO_2$ of capnography in overestimated values preserve a possible stability in arterial $PCO_2$ results. This observation agrees with Potger *et al.*[5] that identified the capnography overestimate the $PCO_2$ on some occasions during cardiopulmonary bypass. However, this difference was not considered significant. In addition, this disparity is clinically acceptable and does not interfere with the use of capnography.

The oxygenators; Medtronic Affinity, Sorin Inspire 6F / 8F and Nipro Vital were used in a random way, attesting that all of them presented a strong concordance and correlation between $PeCO_2$ and $PaCO_2$ in group 2, independent of the oxygenator used for the measurement of carbon dioxide. Previous researches have used only one oxygenator brand to validate the study, which would raise doubt about the effectiveness of capnography. The associate evaluation of several models in one single study demonstrates that the $PeCO_2$ values are totally dependent on the technique that is, the membrane type does not interfere with the results presented in the capnographer. These findings emphasize and confirm that the professional perfusionist has the responsibility to monitor and use strategies to maintain $CO_2$ levels within the appropriate physiological parameters.

## CONCLUSION

It is concluded that continuous $PCO_2$ monitoring of the membrane oxygenator exhaustion of the cardiopulmonary bypass circuit has a positive impact on the $CO_2$ arterial blood gas test results. This instrument confirms and maintains the carbon dioxide values into the reference parameters, as well as being a lower cost option, which makes it accessible in services where the use of in-line blood gas monitoring is not part of the routine.

## REFERENCES

1. Pereira IB, Batista DCS. O perfusionista e o equilíbrio ácido/base durante a circulação extracorpórea. Rev Elet Acer Sau. 2013; 5(2): 456-473.
2. Luz HLM, Auler Júnior JOC. Temperature and Acid-Base Balance in Coronary Bypass Grafting with Cardiopulmonary Bypass, under Hypothermia and Normothermia. Rev Bras Anestesiol. 2002; 52(2):197-208.
3. Pereira M, Vilela H, Pina L. Capnografia como método de monitorização ventilatória durante estados de sedação induzida. Rev Soc Port Anestesiol. 2006; 14(4): 24-28.
4. Graham JM, Gibbs NM, Weightman WM, Sheminant MR. The relationship between oxygenator exhaust PCO2 and arterial PCO2 during hypothermic cardiopulmonary bypass. Anaesth Intensive Care. 2005; 33(4): 457–461.
5. Potger KC , McMillan D , Southwell J , Dando H , O'Shaughnessy K. Membrane oxygenator exhaust capnography for continously estimating arterial carbon dioxide tension during cardiopulmonary bypass . J Extra Corpor Technol. 2003; 35(3): 218-223.
6. Baraka A, El-Khatib M, Muallem E, Jamal S, Haroun-Bizri S, Aouad M. Oxygenator exhaust capnography for prediction of arterial carbon dioxide tension during hypothermic cardiopulmonary bypass. J Extra Corpor Technol. 2005; 37(2): 192–195.
7. Abreu TT. Análise da variação de eletrólitos após cirurgia cardíaca com uso de circulação extracorpórea [Monografia]. Salvador: Universidade Federal da Bahia – UFBA; 2014.
8. Antunes N, Dragosavac D, Petrucci O, Oliveira M, Kosour C, Blotta M, Braile M, Vieira R. The use of ultrafiltration for inflammatory mediators removal during cardiopulmonary bypass in coronary artery bypass graf surgery. Braz J Cardiovasc Surg. 2008;23(2):175-82.
9. Guyton AC, Hall JE. Tratado de fisiologia médica. 12ª ed. Rio de Janeiro: Elsevier; 2011.
10. Kristiansen F, Hogetveit JO, Pedersen TH. Clinical evaluation of an instrument to measure carbon dioxide tension at the oxygenator gas outlet in cardiopulmonary bypass. Perfusion. 2006; 21(1): 21–26.
11. Madias NE. Renal acidification responses to respiratory acid--base disorders. J Nephrol. 2010; 23(16): 85–91.
12. Mota AL, Rodrigues AJ, Évora PRB. Adult cardiopulmonary bypass in the twentieth century: science, art or empiricism?? Braz J Cardiovasc Surg. 2008; 23(1): 79-92.
13. Souza MHL, Elias DO. Fundamentos da Circulação Extracorpórea. 2ª ed. Rio de Janeiro: Alfa Rio; 2006.
14. Torrati FG, Dantas, RAS. Circulação extracorpórea e complicações no período pós-operatório imediato de cirurgias cardíacas. Acta Paul Enferm. 2012; 25(3): 40-345.
15. Taniguchi FP, Souza AR, Martins AS. Tempo de circulação extracorpórea como fator risco para insuficiência renal aguda. Rev Bras Cir Cardiovasc. 2007; 22(2): 201-5.