Near-fatal pulmonary embolism: capnographic perspective

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For the comparison between hemodynamic, gas exchange, and respiratory variables at T0, T1, T2, and T3, we used repeated-measures ANOVA (Winstat, version 3.1). Values of p < 0.05 were considered statistically significant.

PetCO2, MValv, and the alveolar dead space volume presented significant differences among the various time points evaluated, whereas RR did not. It is well known that MPE leads to an increase in RR and in lung volumes. The increase in RR and in lung volumes can be evidenced by a significant increase in MValv, which, in turn, leads to alveolar washout and, as a consequence, to a significant decrease in PetCO2. Another factor that contributed to the reduction in PetCO2 was a significant decrease in pulmonary perfusion (resulting from a decrease in cardiac output). There was a significant increase in the volume of the alveolar dead space, which does not take part in gas exchange. Following the rationale of this variable behavior, the volumes of VCap phases I and II were obtained in mL and per respiratory cycle. Those volumes increased significantly over the study period.

Other variables were provided by VCap or associated with other variables: VCO2; SII; SIII; VCO2/VTe; alveolar VCO2/VTe; SII/exhaled CO2 partial pressure (SII/Pco2); SII/PetCO2; SIII/PetCO2; and SIII/VTe. The expected decrease in VCO2 at T1 (p < 0.001 vs. T0) can be attributed to the increase in MValv, as well as to a significant reduction in pulmonary blood flow (resulting from a decrease in cardiac output). There were also significant reductions in other metabolic variables, such as VCO2/VTe and alveolar VCO2/VTe.

With similar pathophysiology, SII and SIII variables also presented significant variations (p < 0.0001). The SII represents removal of CO2 from the alveoli, which are the most distal elements of the small airways. The SII represents the elimination of CO2 from most alveoli and, in normal organisms, its shape is similar to a plateau, with a slight upward slope. Higher SIII/VTe and SII/PetCO2 values suggest structural damage in the peripheral and distal part of the lungs, which promotes this heterogeneous distribution of ventilation.5,6 The same principle applies to the significant drop in the normalization of SII/Pco2, SII/Pco2, SIII/PetCO2, and SIII/VTe (p < 0.0001 for all). Negative SIII values seem to be associated with vascular damage,2,3 whereas an excessive increase in these values may be associated with airway damage.

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It was necessary to normalize $VCO_2/V_{Te}$, $SII/PECO_2$, $SIII/PECO_2$, $SIII/PetCO_2$, and $SIII/V_{Te}$, in order to allow

Figure 1. A: representative curves of the volumetric capnography (volume × CO$_2$) at baseline ($T_0$, black) and at 1 h after the endpoint ($T_3$, red). B and C: representative curves of trends seen throughout the experiment. Figures obtained and adapted from the Analysis Plus software (Novametrix, Wallingford, CT, USA). $T_0$: baseline; $T_1$: endpoint; $T_2$: 30 min after $T_1$; $T_3$: 1 h after $T_1$; $V_{aw}$: anatomical dead space volume; End-Tidal CO$_2$: end-tidal expiratory pressure of CO$_2$; $VCO_2$: CO$_2$ production (mL/m); Airway dead space: anatomical dead space volume; MV, Alveolar spon: spontaneous alveolar minute volume; $V_T$, Alveolar spon: spontaneous alveolar tidal volume; Phase III Slope: phase III slope of the capnogram; Phase II Intercept: intercept of the phase II slope of the capnogram; Phase III Intercept: intercept of the phase III slope of the capnogram; Phase I Volume: volume of the phase I slope of the capnogram; and Phase II Volume: volume of the phase II slope of the capnogram.

(such as that occurring in bronchiectasis, cystic fibrosis, and COPD).($^{7,8}$)
In conclusion, recording, observing, and analyzing the behavior of the parameters of respiratory mechanics, especially VCap, made it possible to identify MPE. When carefully applied and analyzed, our results can make a major contribution to decreasing morbidity and mortality in patients presenting with a clinical profile suggestive of MPE.

Further studies of MPE, either experimental or clinical, are still needed. Such studies could broaden our knowledge of the disease and of its implications for the cardiopulmonary system.

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### Table 1. Respiratory mechanics, gas exchange, and hemodynamic variables.

| Variable | Time point | T0 | T1 | T2 | T3 | p |
|----------|------------|----|----|----|----|---|
| RR (breaths/min) | | 47 ± 9 | 48 ± 8 | 53 ± 11 | 54 ± 12 | 0.061 |
| MValv (L) | | 4.0 ± 0.9 | 10.6 ± 2.9 | 9.9 ± 3.8 | 7.8 ± 1.6 | < 0.0001 |
| VDalv (L) | | 2.4 ± 0.6 | 4.0 ± 0.8 | 4.1 ± 1.4 | 3.8 ± 1.1 | < 0.0001 |
| PetCO2 (mmHg) | | 40.1 ± 2.0 | 11.0 ± 2.7 | 16.9 ± 5.5 | 19.7 ± 4.6 | < 0.0001 |
| VCO2 (ml/min) | | 95 ± 23 | 83 ± 20 | 126 ± 25 | 114 ± 27 | 0.001 |
| VCO2/Vp (mL/L/min) | | 0.69 ± 0.10 | 0.28 ± 0.08 | 0.49 ± 0.10 | 0.53 ± 0.10 | < 0.0001 |
| VCO2/Valv (mL/L/min) | | 1.09 ± 0.16 | 0.40 ± 0.13 | 0.70 ± 0.16 | 0.79 ± 0.15 | < 0.0001 |
| SII (mmHg/L) | | 1414.3 ± 232.5 | 185.1 ± 66.8 | 330.7 ± 128.4 | 441.1 ± 125.0 | < 0.0001 |
| SIII (mmHg/L) | | 56.73 ± 11.86 | −1.10 ± 1.16 | 7.93 ± 10.06 | 13.02 ± 10.22 | < 0.0001 |
| SII/PetCO2 | | 107.61 ± 33.42 | 31.15 ± 8.06 | 38.86 ± 12.09 | 51.35 ± 12.92 | < 0.0001 |
| SII/P1V | | 28.0 ± 5.1 | 43.5 ± 5.9 | 41.5 ± 7.4 | 38.0 ± 6.0 | < 0.0001 |
| Interception Y3 (mmHg) | | 35.8 ± 1.7 | 11.8 ± 2.1 | 15.7 ± 4.1 | 18.2 ± 3.0 | < 0.0001 |
| Interception Y2 (mmHg) | | −48.7 ± 3.7 | −9.5 ± 2.1 | −15.0 ± 5.8 | −19.2 ± 4.8 | < 0.0001 |
| SIII/VTe | | 0.427 ± 0.137 | 0.04 ± 0.004 | 0.31 ± 0.037 | 0.36 ± 0.037 | < 0.0001 |
| P1V (mL) | | 36.0 ± 5.0 | 63.0 ± 9.3 | 59.3 ± 11.4 | 52.7 ± 8.7 | < 0.0001 |
| P2V (mL) | | 28.0 ± 5.1 | 43.5 ± 5.9 | 41.5 ± 7.4 | 38.0 ± 6.0 | < 0.0001 |
| PFE (L/min) | | 16.3 ± 3.4 | 49.2 ± 9.8 | 39.4 ± 16.2 | 31.8 ± 9.4 | < 0.0001 |
| PFI (L/min) | | 25.5 ± 3.6 | 38.7 ± 4.9 | 38.6 ± 7.7 | 34.6 ± 3.1 | < 0.0001 |
| Ti (s) | | 0.49 ± 0.06 | 0.65 ± 0.11 | 0.57 ± 0.09 | 0.53 ± 0.12 | < 0.0001 |
| T2 (s) | | 0.85 ± 0.20 | 0.74 ± 0.26 | 0.66 ± 0.21 | 0.65 ± 0.20 | 0.0348 |
| PaCO2 (mmHg) | | 44.92 ± 4.44 | 48.22 ± 5.97 | 45.37 ± 5.82 | 43.52 ± 6.21 | < 0.0001 |
| P(a-et)CO2 (mmHg) | | 4.8 ± 2.8 | 37.2 ± 5.8 | 28.5 ± 4.5 | 23.8 ± 3.5 | < 0.0001 |
| DC (L/min) | | 4.9 ± 1.0 | 2.7 ± 1.0 | 3.6 ± 1.1 | 3.9 ± 1.3 | < 0.003 |

T0: baseline; T1: endpoint; T2: 30 min after T1; T3: 1 h after T3; RR: respiratory rate; MValv: alveolar minute volume; VDalv: alveolar dead space volume; PetCO2: end-tidal CO2 partial pressure; VCO2: CO2 production; Vp: expiratory tidal volume; VValv: alveolar tidal volume; SII: phase II slope of the capnogram; SIII: phase III slope of the capnogram; P1V, P2V: partial pressure of CO2 in exhaled air; Intercept Y2: intersection between SII and the y axis; Intercept Y3: intersection between SIII and the y axis; P1V: volumetric capnography phase 1 volume; P2V: volumetric capnography phase 2 volume; PIF: peak inspiratory flow; PEF: peak expiratory flow; Ti: inspiratory time; T2: expiratory time; P(a-et)CO2: arterial to end-tidal CO2 gradient; and CO: cardiac output.

In table 1, it can be seen that there is a significant variation in those two variables (p < 0.0001 for both).

Other variables that are not usually described in the literature are intercept Y2 and intercept Y3 (both in mmHg), which indicate an increase or a decrease in the inclination of the slopes. Scheffzek et al.[100] were able to verify that. In the present study, there was a significant variation in those two variables (p < 0.0001 for both).
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