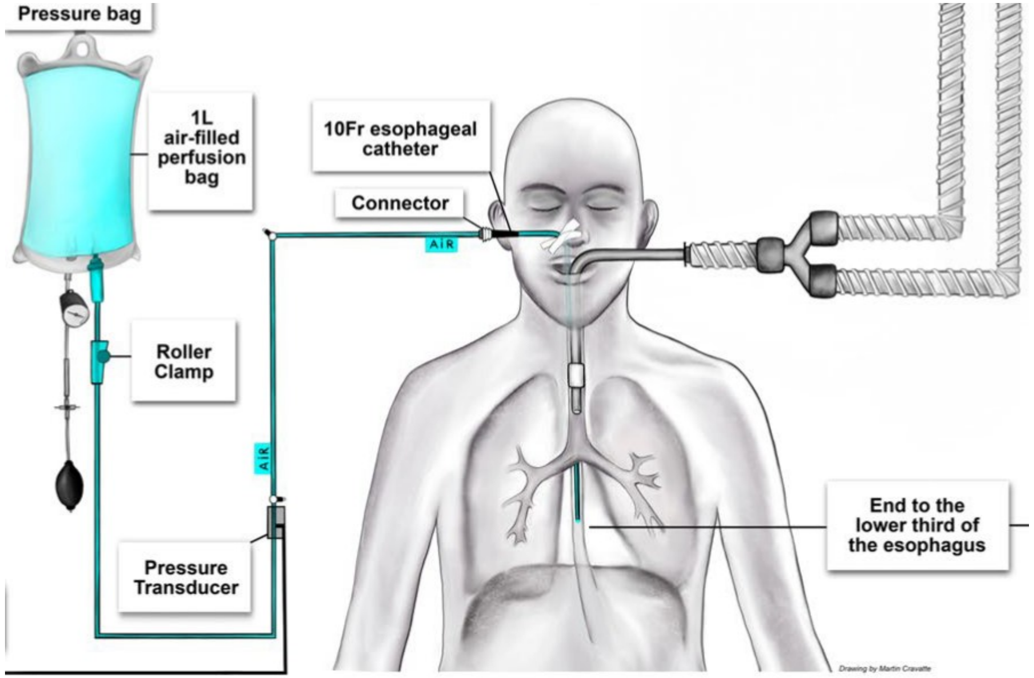
Novel method of transpulmonary pressure measurement with an air-filled esophageal catheter



www.esophageal-pressure-calculator.be

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Intensive Care Medicine Experimental

METHODOLOGIES Open Access

Novel method of transpulmonary pressure measurement with an air-filled esophageal catheter

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- No conflict of interest

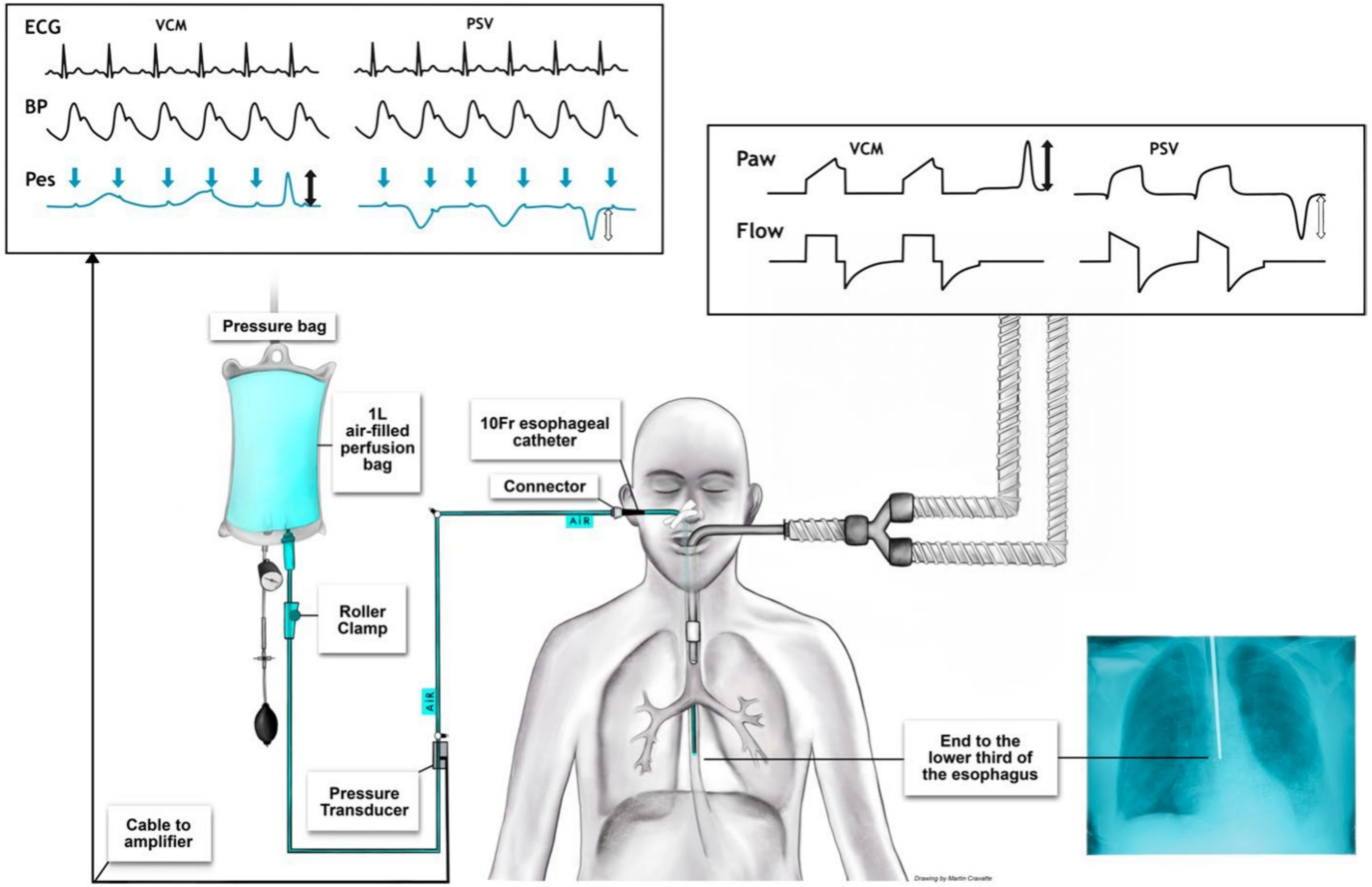
Introduction

- Transpulmonary pressure measurements may be helpful e.g.
  - to reduce barotrauma, atelectotrauma and lung stress in ARDS patients
  - to measure wall chest eleastance and optimize ventilation in postoperative patients
  - to avoid VV ECMO in some refarctory hypoxemic patients
  - to measure autoPEEP and to find best PEEP during weaning trial in COPD patients
  - to diagnose patient-ventilator asynchronies
  - to diagnose diaphragmatic paralysis

- The reference balloon esophageal method requires:
  - Expensive, non-refundable and unusual ICU material
  - time for in vivo calibration to find the best volume of the balloon
  - Expertise

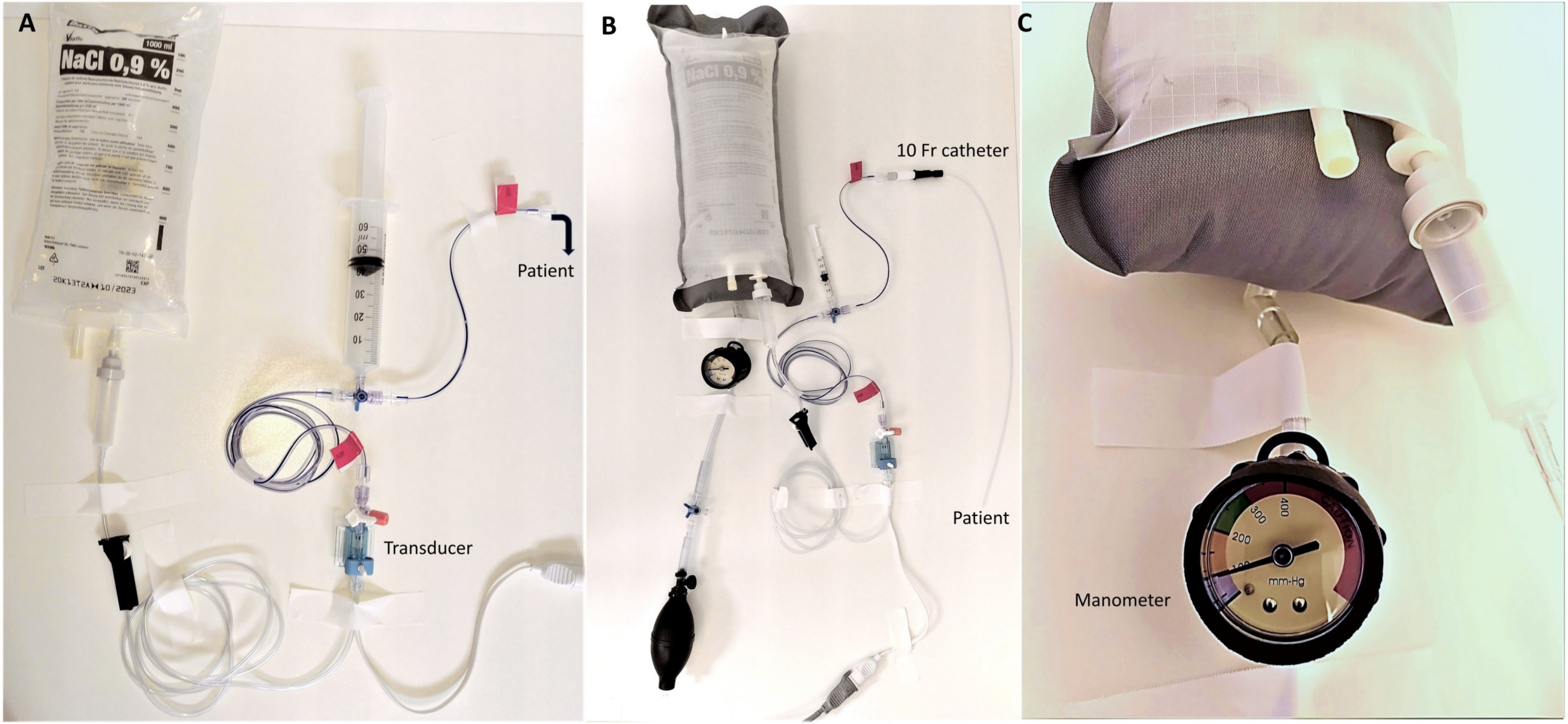
- There is a need for an alternative simple and accurate esophageal pressure method at the bedside

Method



Martin Cravatte Drawing

- 10Fr 49cm oral and tracheobronchial suction catheter
- Benched guide wire from NG tube feeding
- Positioned in lower third of the esophagus
- Connected to air-filled circuit
- Pressurized with air-filled perfusion bag
- Air flags for security
- Proper positioning tests



Air-filled circuit assembly. The 1L saline infusion bag is emptied and backfilled with air through the pressure transducer using a 50-ml syringe (A), then pressurized with a pressure infusion bag (B) with a manometer at 100 mmHg (C).

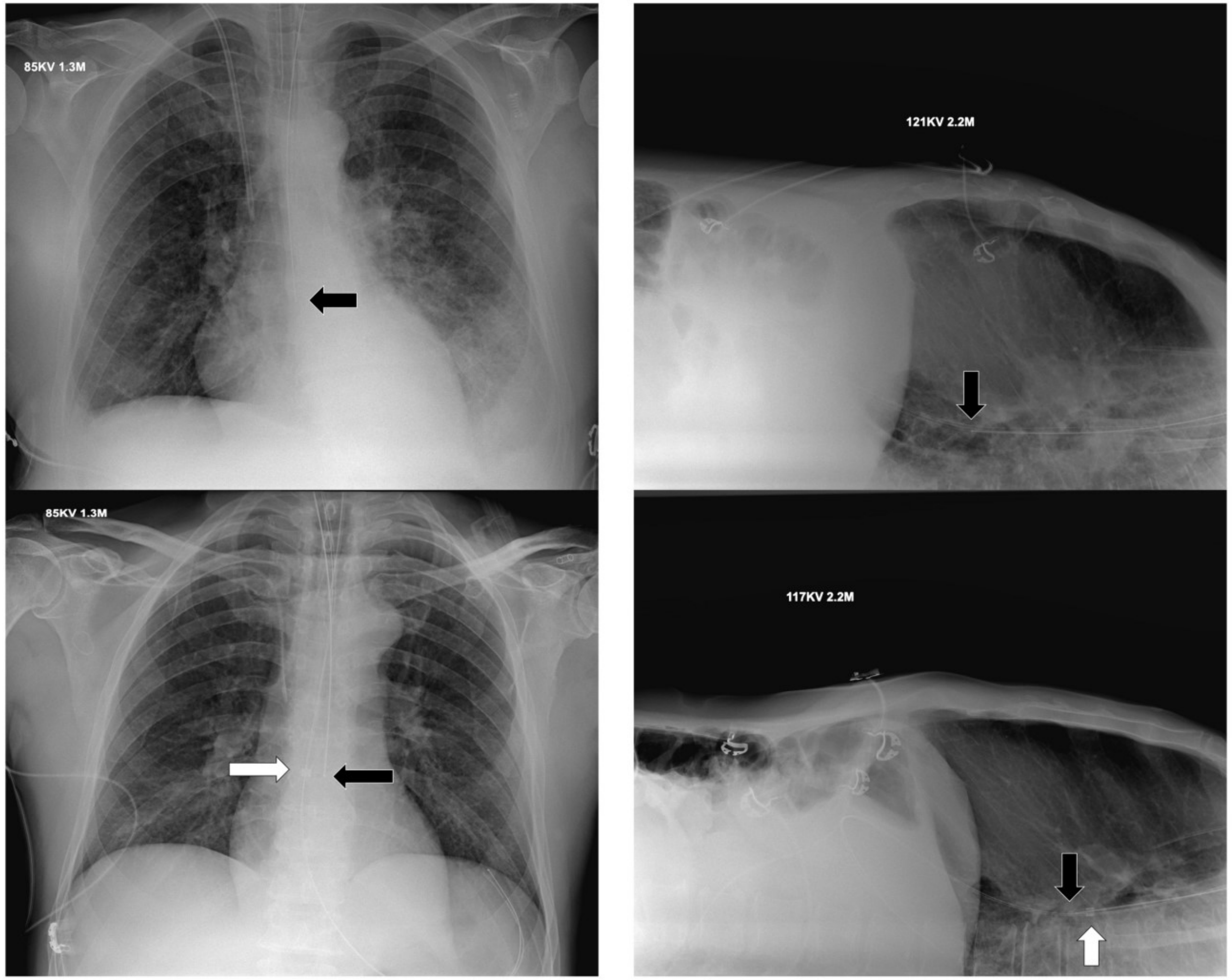
Proper positioning of the esophageal catheter

- The chest X-rays with the guide wire
- The presence of cardiac artifacts on the esophageal curve
- The occlusion test (Baydur maneuver in PSV, chest compression in VCM) confirms esophageal-to-airway pressure chage ratio (ΔPes/ΔPaw) close to 1.0 (+- 20%)
- NB: the catheter is initially inserted in the stomach, as assessed by air flush auscultation and stomach compressions, before to be withdrawn by 6 ±3cm in the lower third of the esophagus by calculation (so that its outer part at the nostril equals (49cm – [nasal-tragus-xyphoid distance – 10cm]).

Esophageal pressure measurement

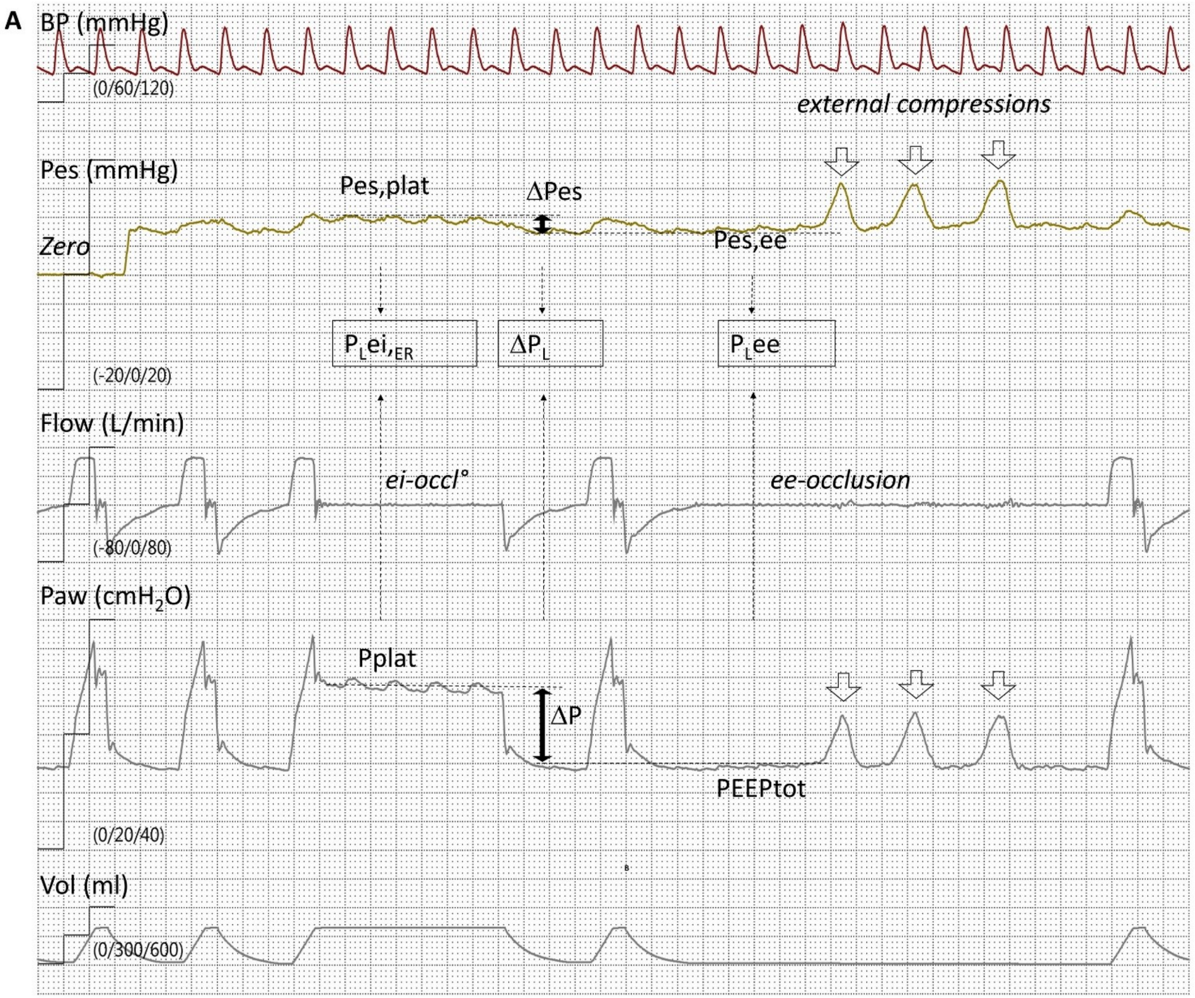
- The transducer is zeroed to atmosphere (accurate whatever its level)
- The roller clamp of the pressurized air-filled infusion bag is opened
- Values are recorded in mmHg on monitor, and converted in cmH_2O
- To avoid secretions at the open-ended catheter:
  - Our pressurized air-filled system maintains catheter patency (1 bubble/sec, 2ml/min)
  - 3ml of air is flushed, gently reaspirated and let few seconds open for equilibration before any reading session
  - If subocclusion occurs on the waveform, 1 ml – 3ml of air are reinjected; if necessary, the catheter is either pushed back in the stomach with its guide wire for 10ml of air and rewithdrawn in the esophagus, or changed.
- After all readings, roller clamp is closed to preserve bag pressure and the air system is disconnected for clarity and security.

Chest X-rays of patients with the air-filled esophageal catheter.



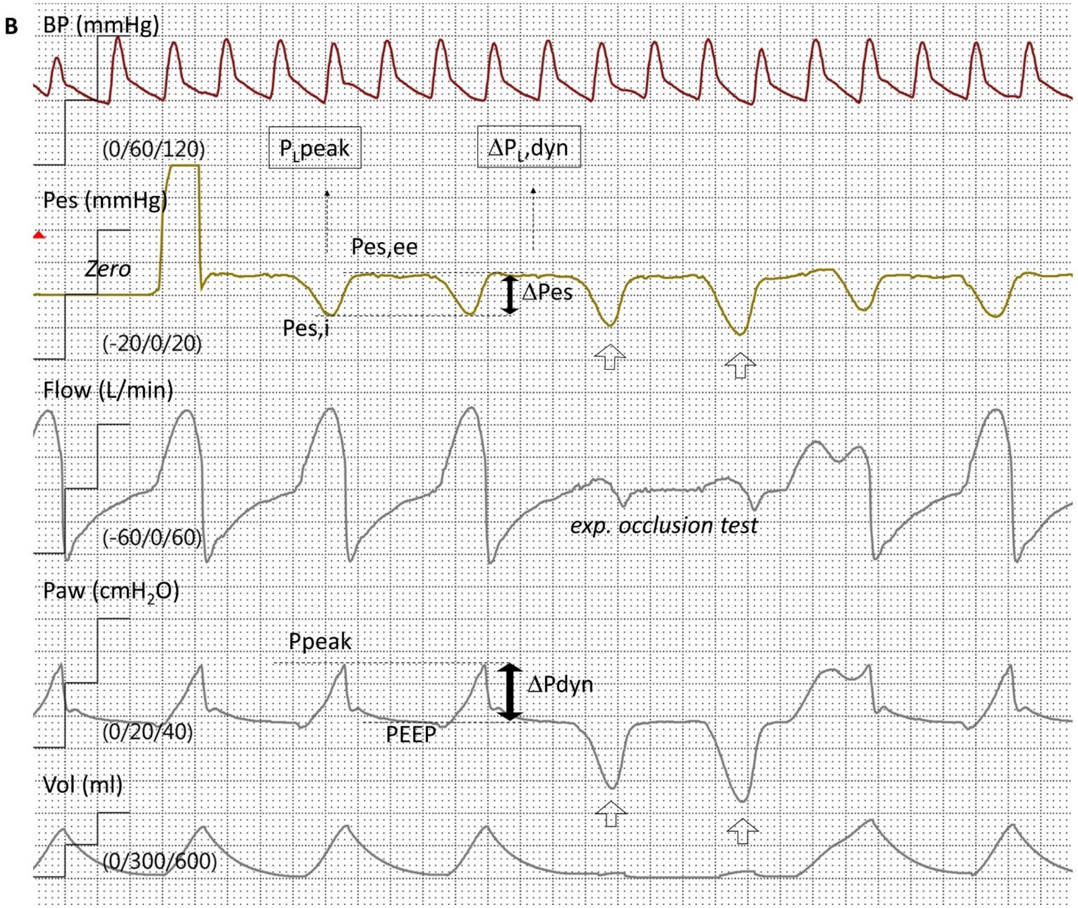
Conventional anteroposterior (left) and lateral (right) chest X-rays display the extremity (black arrow) of the air-filled esophageal catheter (containing its guide wire) at the third lower part of the esophagus in two patients without (upper panel) and with (lower panel) balloon catheter (white arrow).

The occlusion test in controlled mode.



A. In passive condition, illustrative waveforms of blood pressure (BP), esophageal pressure (Pes, in mmHg), air flow, airway pressure (Paw, in cmH 2 O) and volume (Vol). After zeroing and subsequent end-inspiratory and end-expiratory occlusions, three sternal compressions (white arrows) induce equivalent increases in esophageal and airway pressures.

The Baydur's occlusion test in assisted mode.



Same waveforms in active condition. In spontaneous breathing, dynamic end-expiratory occlusion test induces two equivalent esophageal and airway depressions (white arrows)

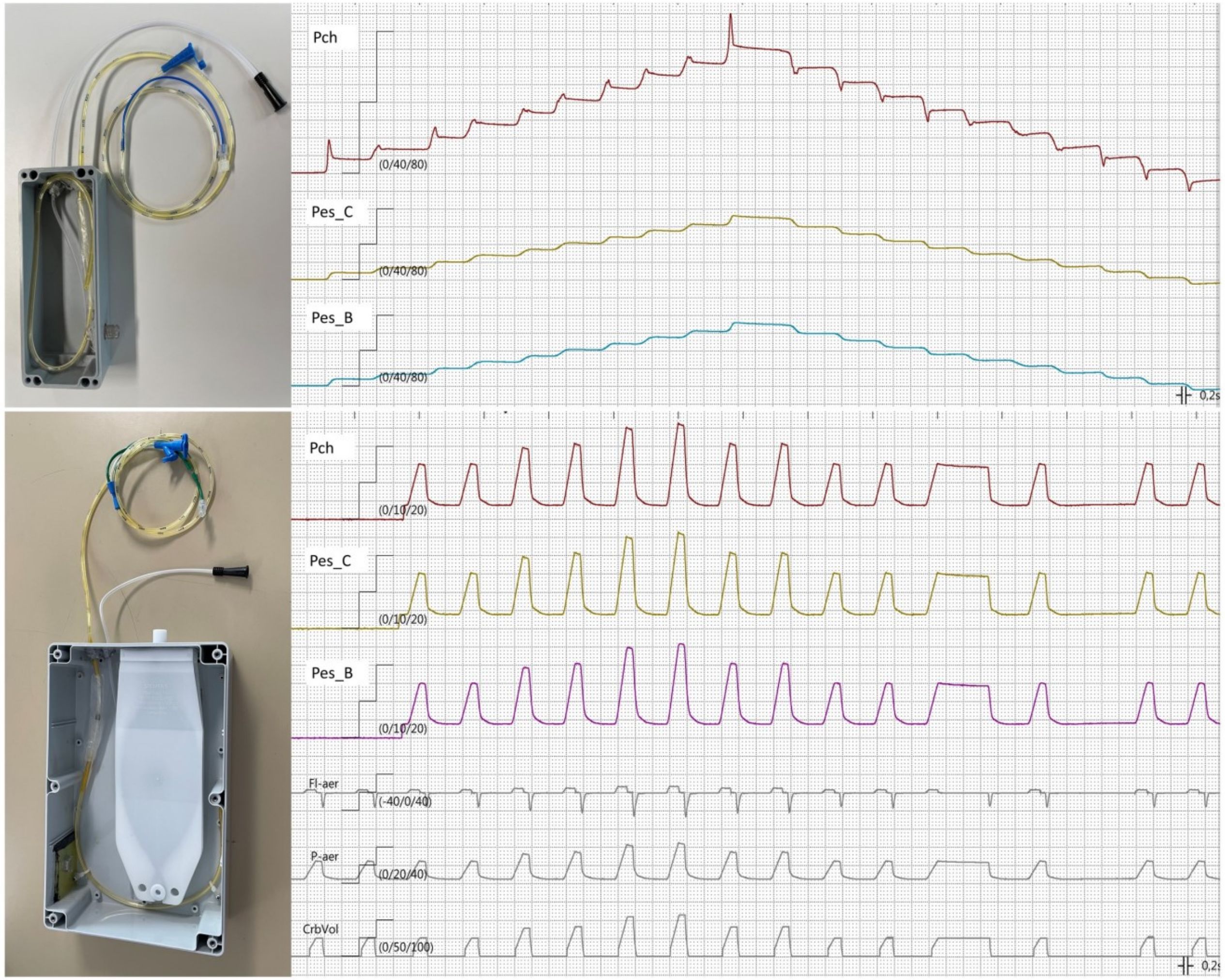
Validation of our air-filled esophageal pressure method without balloon with the reference balloon method

- Ex vivo validation

Simultaneous recordings of both methods and direct chamber pressure

Two different pressure chambers (400ml and 4.4L), for static with incremental air injection and dynamic measurements with tidal inflations

Exactly equal pressures



In vivo validation of our novel air-filled esophageal method

- Population:
  - 15 ICU patients with prolonged ventilation (>48h)
  - Monocentric validation in a tertiary 50-beds ICU center - University hospital of Liege – Belgium;
  - During both volume controled (in paralyzed conditions) and pressure support modes.

- In vivo comparison with the reference balloon method
  - Nasogastric NutriVent 14Fr feeding tube, connected with an non-pressurized air-filled line and locked pressure transducer;
  - In vivo calibration of the balloon method with end-expiratory and end-inspiratory pressure volume curves according to Mojoli et al. to determine best volume of the balloon
  - Comparison of esophageal-to-airway pressure change ratios of both methods

Design

- Sequential recordings of esophageal pressures from both methods, randomly and sequentialy recorded, in order to avoid interference of the inflated balloon.
  - Each serie of Pes measuremtents included six specific timepoints: the positive amplitude during external chest compression, plateau and end-expiratory pressures in VCM; the negative amplitude during Baydur's occlusion, inspiratory and end-expiratory pressures in PSV
  - Each serie was repeated six times by observer A and reproduced 3 times by observers B and C, to test intra- and inter-observers variability, respectively.
- Simultaneous recordings of both esophageal pressures and ventilatory curves by Philips spirometry module, and high-definition 500Hz ones by I-Care Pro Software to analyse signal stability and frequency components applying fast Fourier transforms by Python
- Simultaneous recordings with direct pleural pressures in ICU patients with pleural catheter (n=2)

Results

Population :

- Patients n=15
- VCM n=15
- PSV n=13
- Series n=336

Table 1 Demographic and respiratory parameters of patients included in the study

Variables ($n = 15$)	**Values**
Age (yr)	55.8 ± 8.8 (34–66)
Male (%)	10 (66)
Body mass index (kg/m^2)	28 ± 7 (17–40)
Obesity (%)	6 (40)
Diagnosis:	
ARDS SARS-CoV-2 (%)	6 (40)
Neurological injury (intracerebral hemorrhage, stroke, post-anoxic) (%)	6 (40)
Non-ARDS pulmonary injury (COPD, pneumonia) (%)	3 (20)
Extracorporeal membrane oxygenation (%)	2 (13)
SAPS III	60 ± 11 (45–84)
Parameters in volume-controlled mode ($n = 15$):	
Tidal volume (ml/kg predicted body weight)	6.1 ± 1.3 (2.7–7.4)
Plateau pressure (cmH_2O)	19 ± 4 (12–25)
PEEP (cmH_2O)	7 ± 3 (5–10)
Respiratory rate (min^{-1})	19 ± 5 (15–34)
PaO_2/FiO_2 (mmHg)	172 ± 88 (63–380)
$PaCO_2$ (cmH_2O)	52 ± 15 (34–92)
Respiratory system elastance (cmH_2O/(ml/kg))	1.8 ± 1.2 (0.9–5.5)
Parameters in pressure support ($n = 13$):	
PEEP (cmH_2O)	5 ± 1 (5–10)
Inspiratory pressure (cmH_2O)	8 ± 3 (2–12)
Respiratory rate (min^{-1})	18 ± 4 (13–25)
PaO_2/FiO_2 (%)	184 ± 53 (81–267)
$PaCO_2$ (mmHg)	46 ± 10 (34–67)

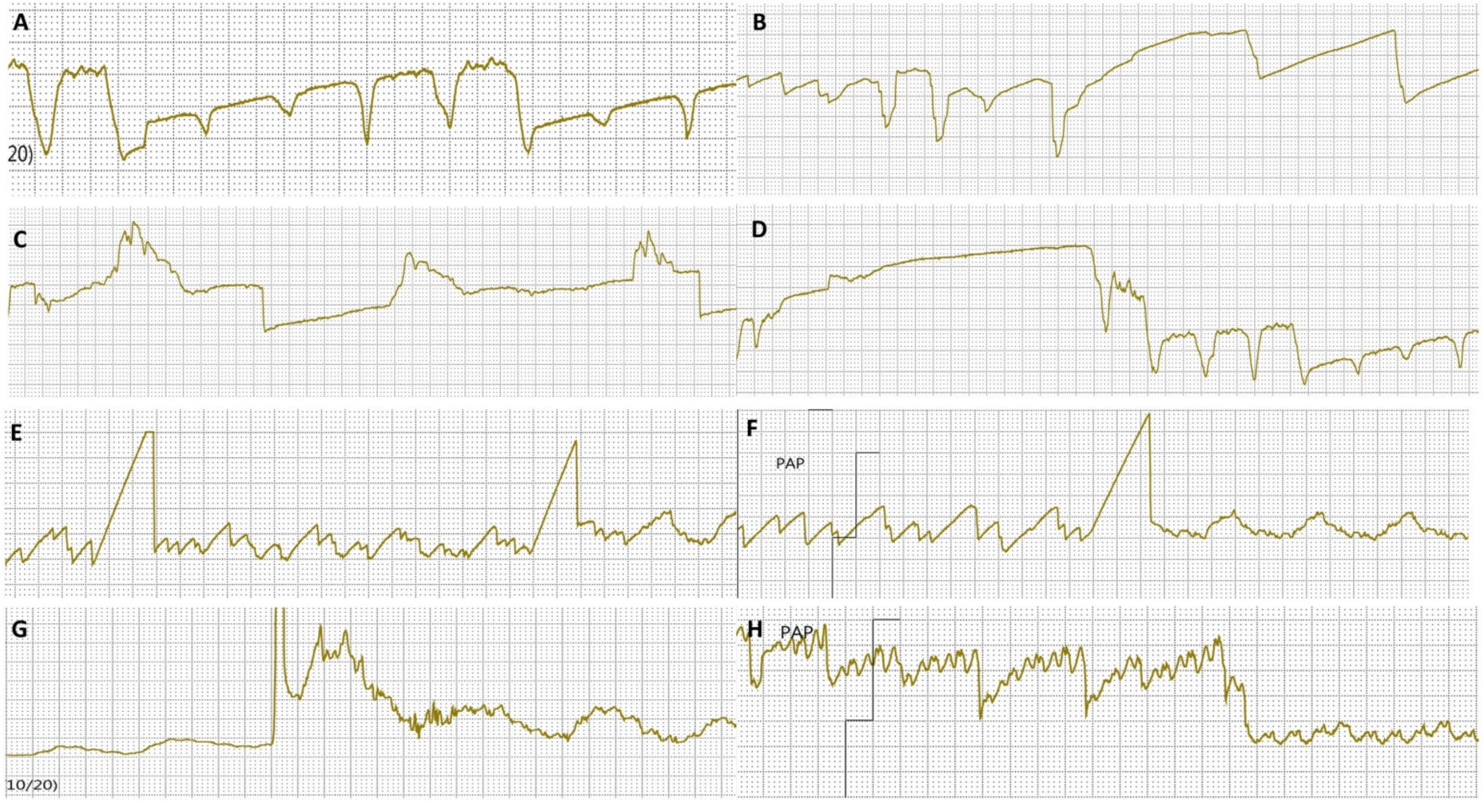
ARDS, adult respiratory distress syndrome; SARS-COV-2, severe acute respiratory syndrome—coronavirus-2; COPD, chronic obstructive pulmonary disease; SAPS, Simplified Acute Physiology Score; PEEP, positive end-expiratory pressure

Catheter placement results

- Air-filled esophageal catheter:
  - Proper esophageal position when nostril-funnel distance (outer part) = 10cm ±3cm
  - Roller clamp opening stabilizes Pes wave at + 4cm H2O higher value
  - Pressurization makes Pes amplitude stabilization for >20min
  - Subocclusion by secretions occured occasionnaly, but resolved by our flushing procedure, except twice in two profusely secreting patients requiring catheter change
  - Implementation takes 7.3 ± 1.9 min;
  - disposable cost = 18€

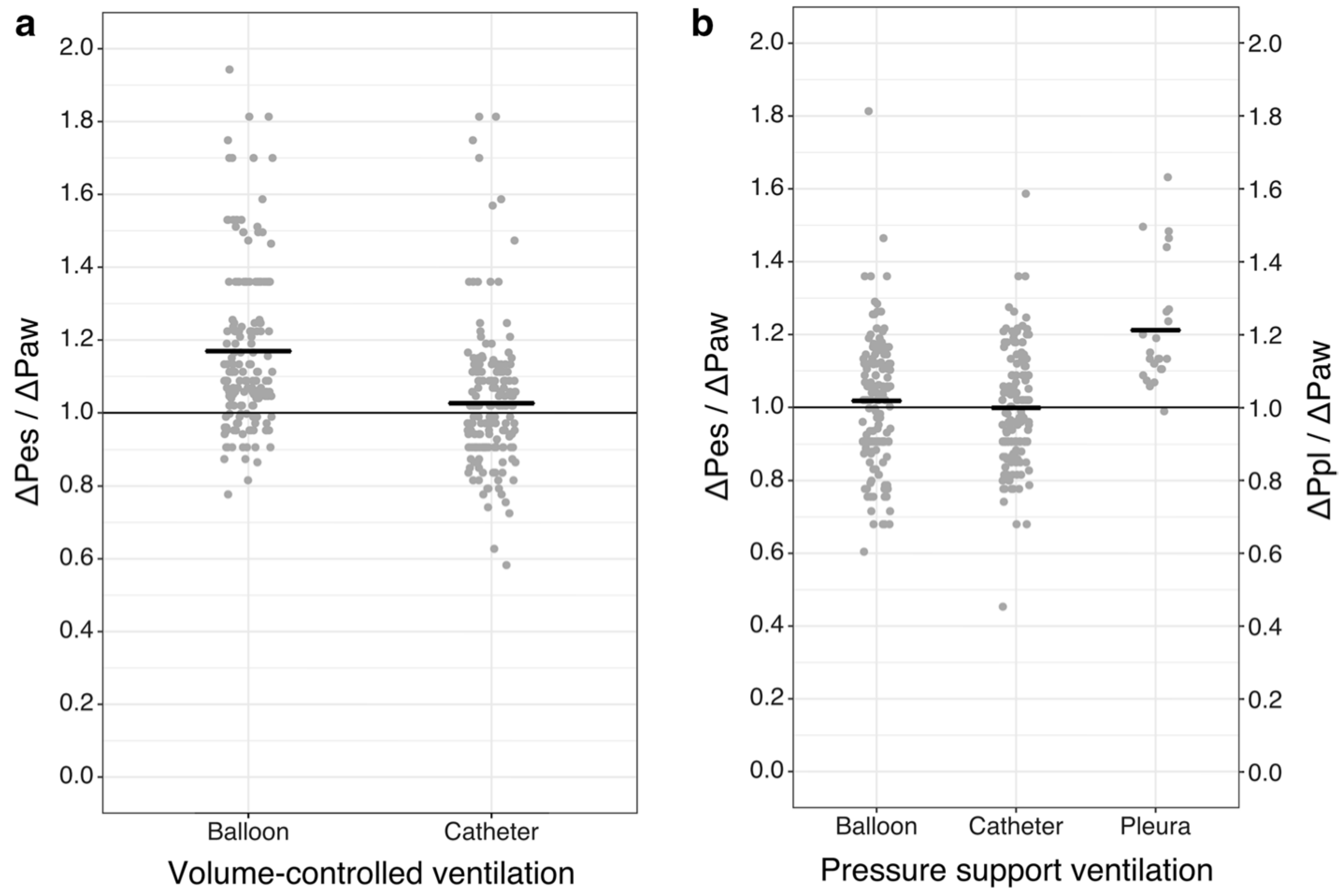
- Air-filled balloon esophageal catheter
  - In vivo calibration found optimal balloon volume = 2.5 ± 0.5 ml; esophageal wall elastance 1.1 ± 0.4 cmH_2O/L
  - Implementation takes 26 ± 7.4 min
  - Disposable cost = 183€

Subocclusion of the air-filled esophageal catheter and the flushing procedure



Abrupt vertical falls, staircase steps or increasing slopes in the esophageal pressure wave (A to D) indicate subocclusion by secretions. Flushing 3 ml of air (E, F) or 10 ml of air (G) or pulling out for 2 cm (H) enables deobstruction in most cases.

In vivo comparison 1): Esophageal-to-airway pressure change ratios



a in volume-controlled mode, induced by external chest compressions during end-expiratory occlusion (dynamic positive pressure occlusion test), using both balloon (left) and catheter (right) method;

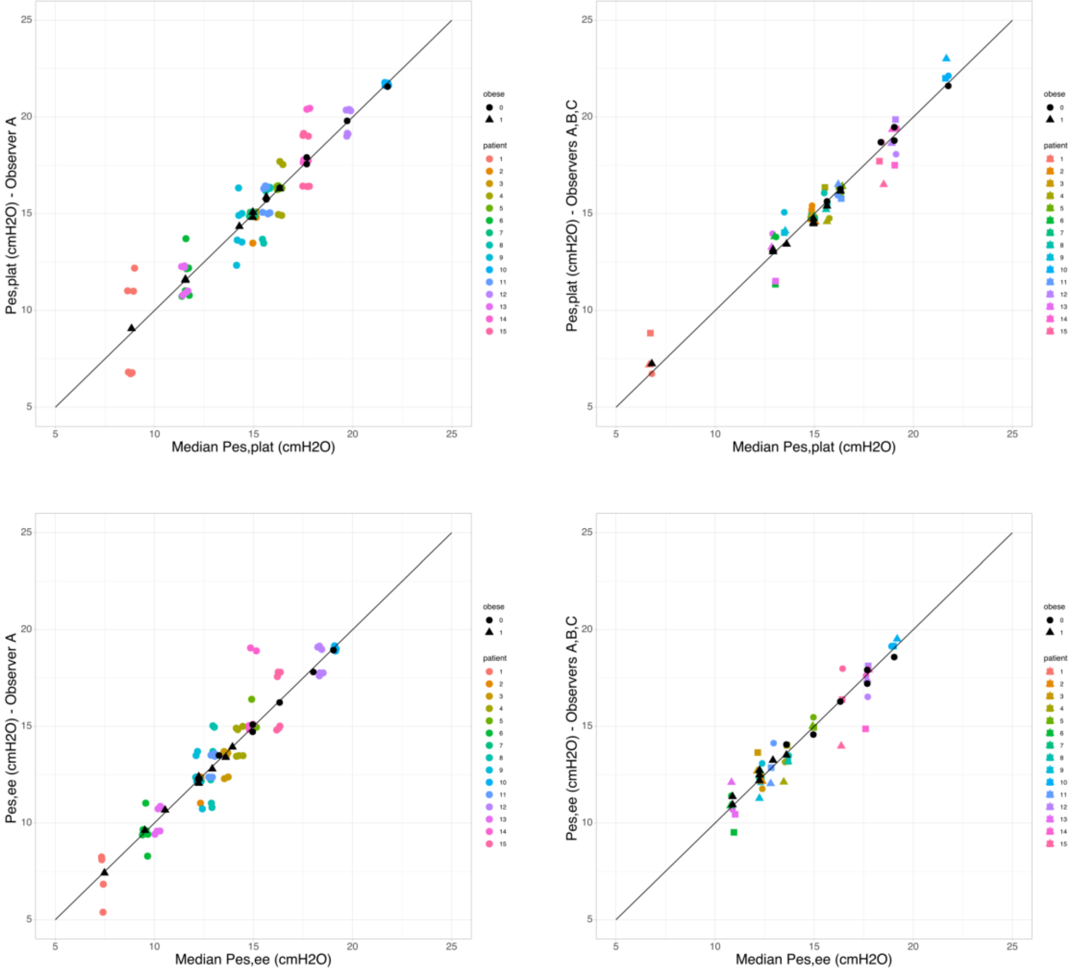
b in assisted mode, induced by spontaneous inspiratory efforts against airway occlusion test (Baydur's maneuver).
For comparison in b, pleural-to-airway pressure change ratios obtained in patients with pleural pressure measurements

In vivo validation 2) intra- and inter-observers variability

Correlation coefficients:

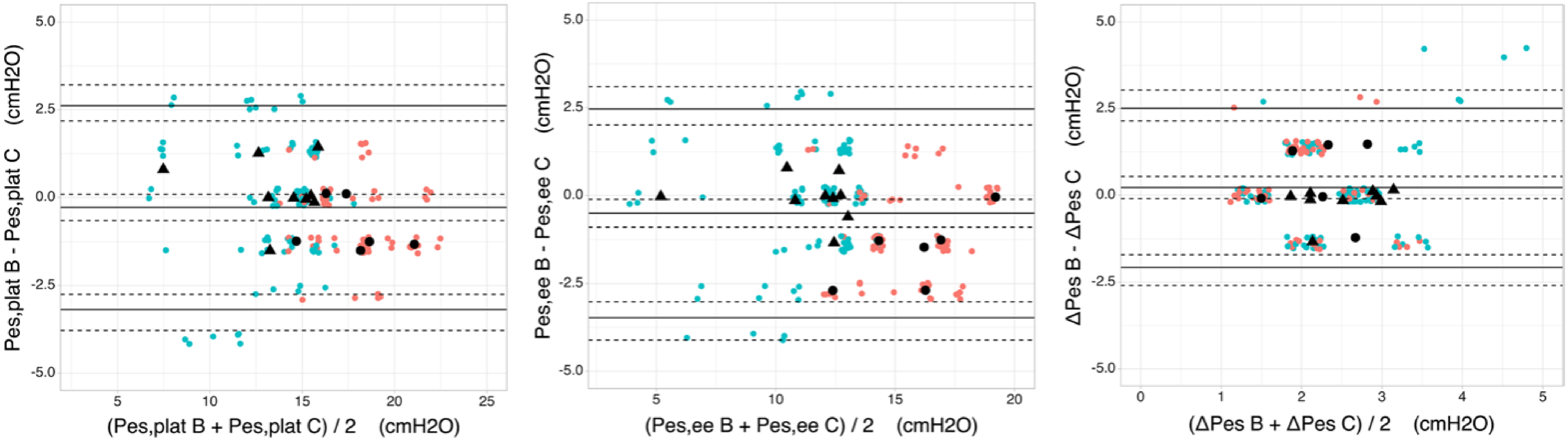
- For Catheter: repeatability & reproducibility
  all between 0.89 [0.76;0.96] and 0.99 [0.96; 1.00]
- For Balloon: repeatability & reproducibility
  all between 0.86 [0.71;0.95] and 0.91 [0.84; 0.97]

Intra-observer | Inter-observers

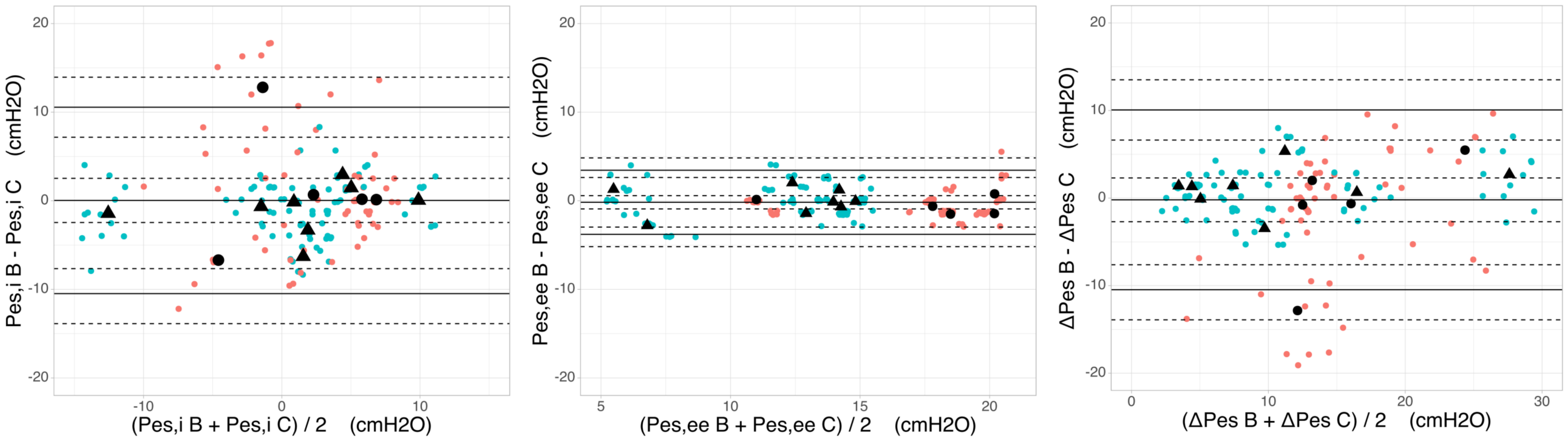


Repeatability and reproducibility of air-filled esophageal catheter measurements. Variability of plateau (upper panel) and end-expiratory (lower panel) esophageal pressures measured using the air-filled catheter in 15 patients under volume-controlled ventilation.

In vivo validation 3): Bland-Altman analysis



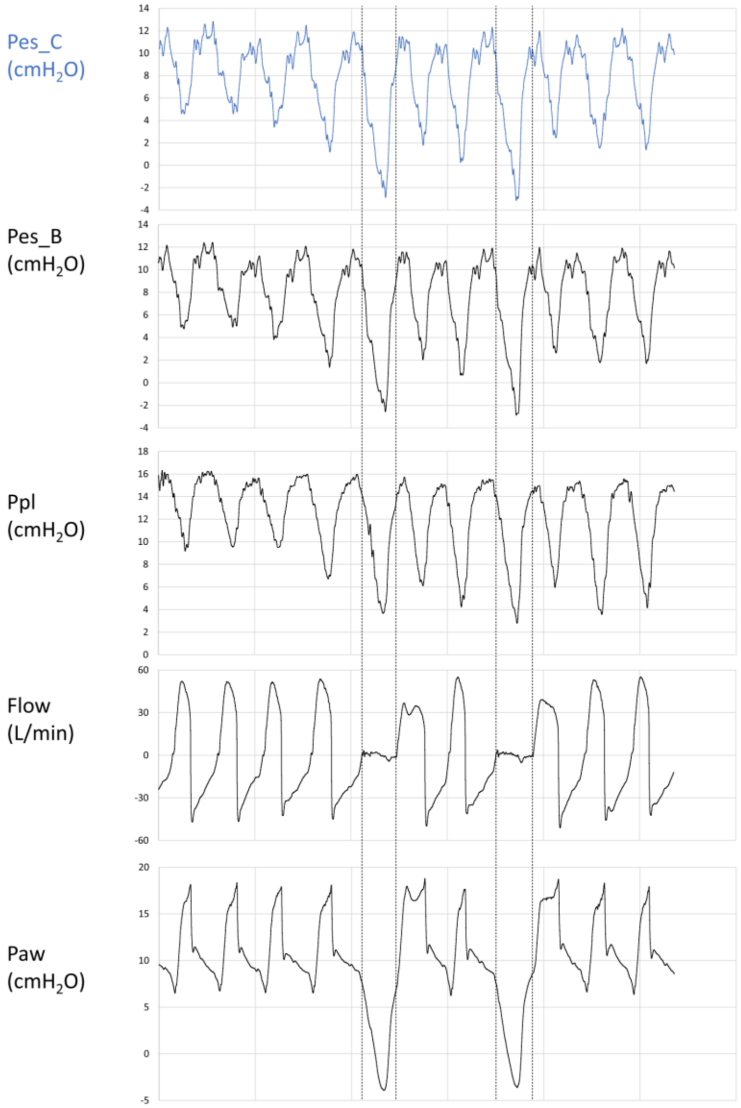
Bland–Altman analyses in obese and non-obese patients <u>under controlled mode</u>. The difference between the plateau (left), end-expiratory (middle) and delta (right) esophageal pressures measured by the air-filled catheter and the balloon catheter in volume-controlled mode are plotted against the mean of the two measurements. Solid lines represent the mean differences and the limits of agreement. Dashed lines represent their respective 95% confidence interval. The colored circles represent single measurements (n = 12 for each patient), with non-obese patients (n = 9) in green and obese ones (n = 6) in red. Black triangles and circles represent the medians of all measurements in non-obese and obese patients, respectively



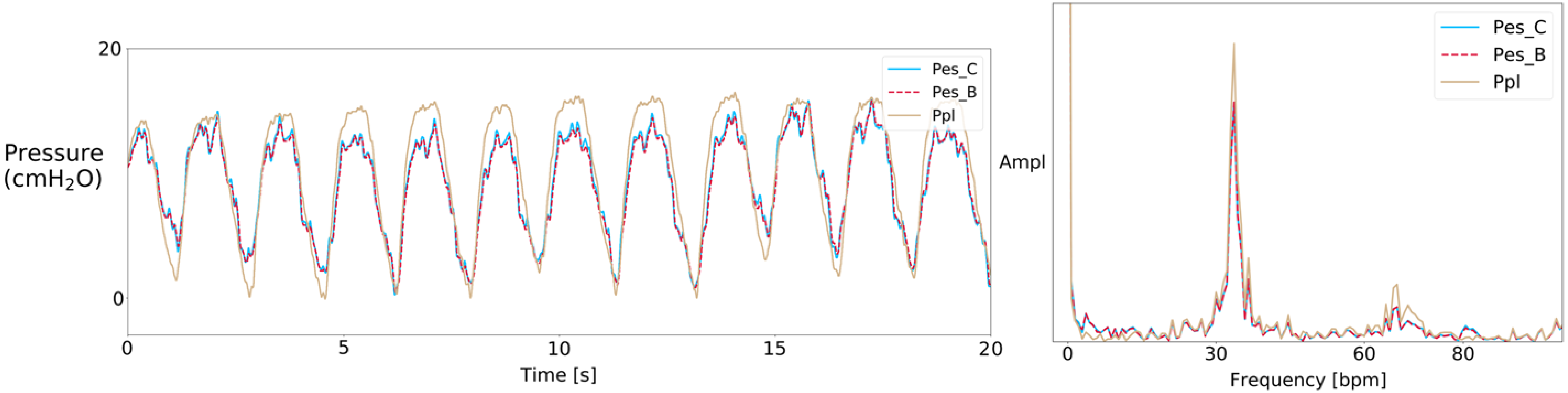
Bland–Altman analysis in patients <u>under assisted mode</u>. The difference of the peak (left), end-expiratory (middle) and delta (right) esophageal pressure measurements by the air-filled catheter and the balloon methods in assisted mode are plotted against the mean of the measurements. Solid lines represent the mean differences and the limits of agreement. Dashed lines represent their respective 95% confidence interval. The colored circles represent single measurements (n = 12 for each patient), with non-obese patients (n = 8) in green and obese ones (n = 5) in red. Black triangles and circles represent the medians of all measurements in non-obese and obese patients,respectively.

In vivo validation 4) simultaneous HD recordings with both esophageal and pleural pressures

Representative simultaneous esophageal and pleural pressures waveforms.
Simultaneous esophageal and pleural pressure traces are recorded from air-filled esophageal catheter (Pes_C), esophageal balloon catheter (Pes_B) and pleural catheter (Ppl), together with airway pressure (Paw) and Flow traces in a patient in assisted mode. Two successive end-expiratory occlusion tests induce increased esophageal, pleural and airway pressure deflections and are delimited by vertical lines.

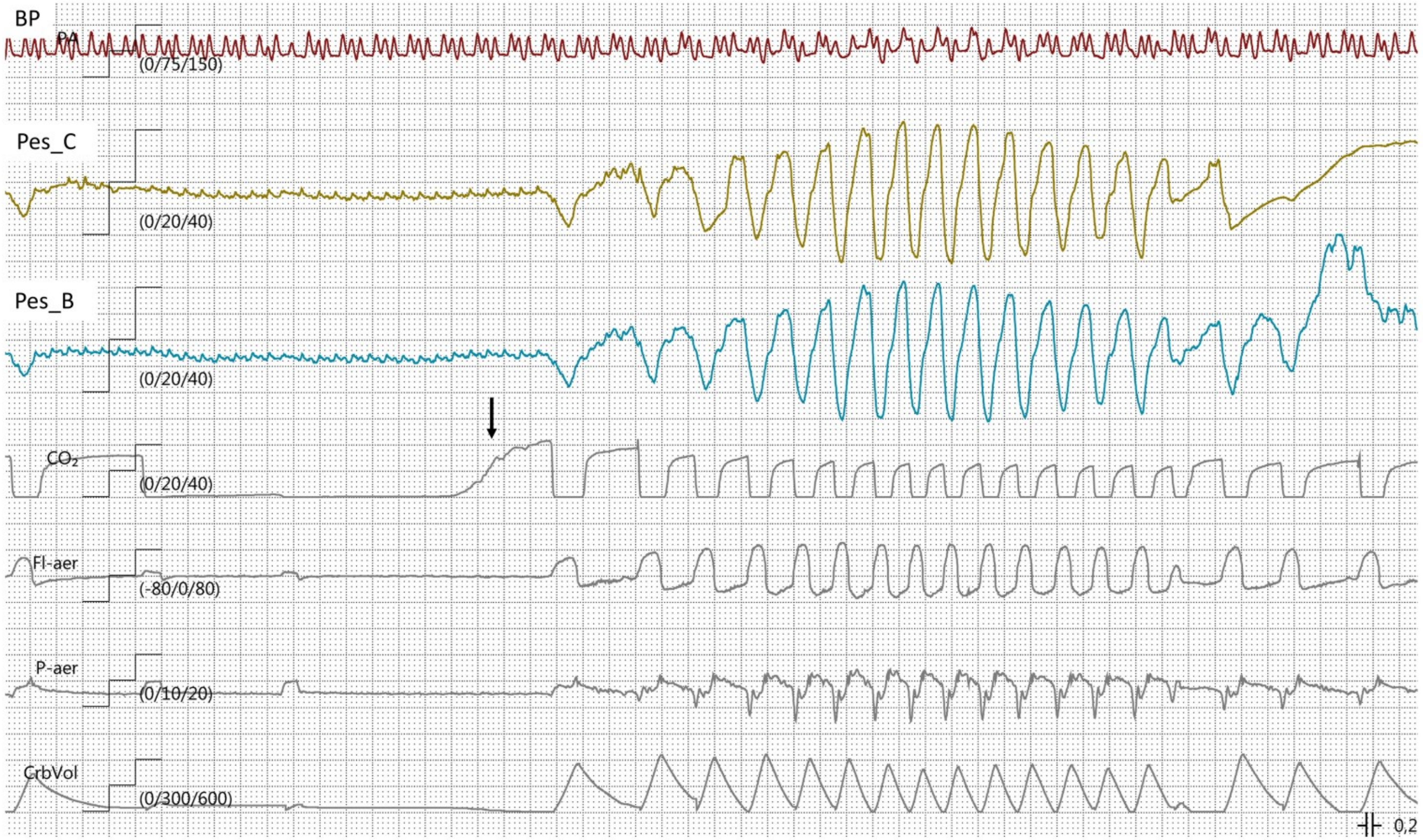


Fast Fourier transform of superposed esophageal and pleural pressures



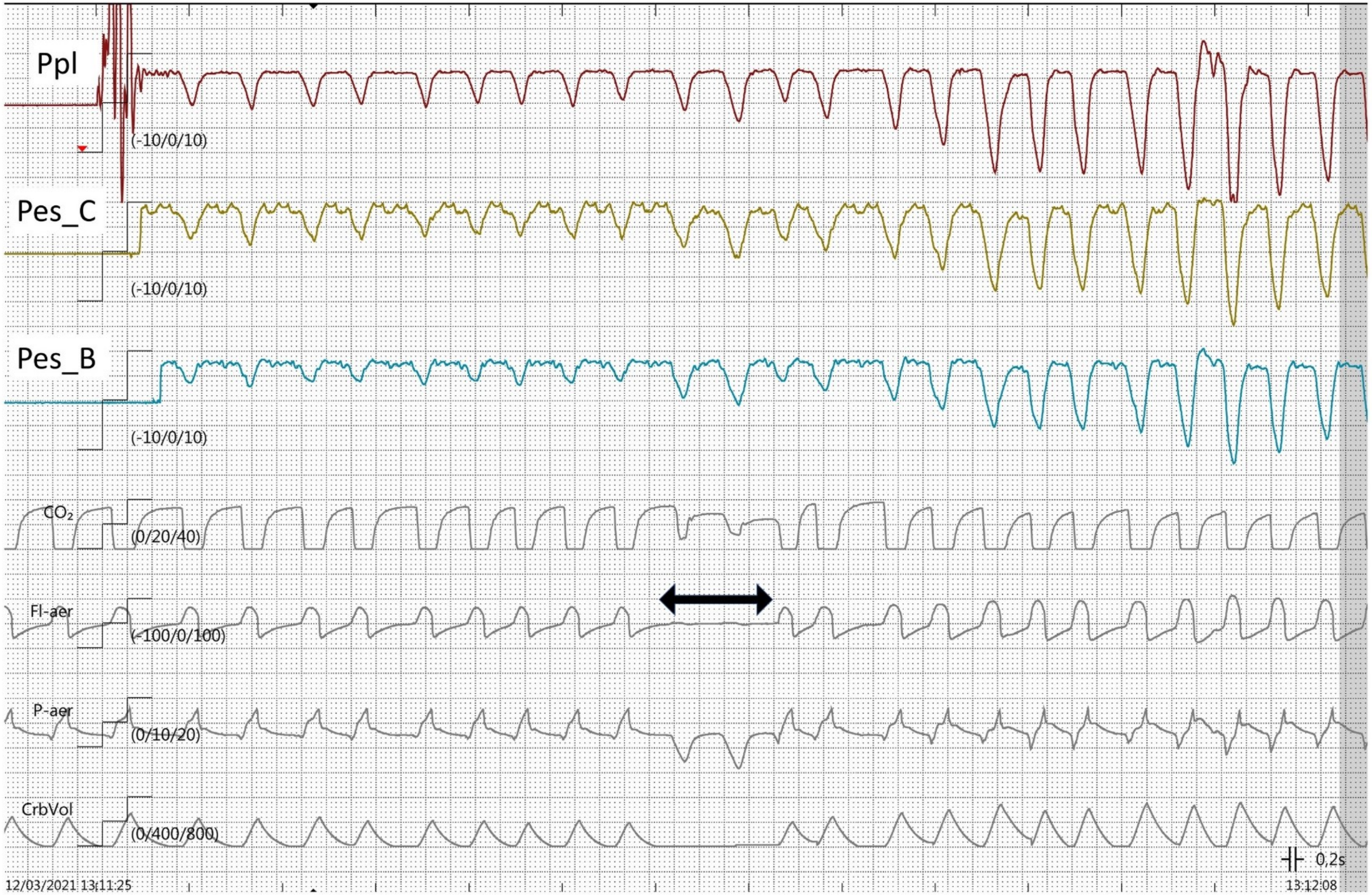
Power spectral analysis of esophageal and pleural pressure signals. The frequency spectra (right) and esophageal pressure signals (left) of both air-filled catheter and balloon catheter revealed concordant predominant respiratory component (large peak at 33 bpm) but also cardiogenic noise from heart rate component (second peak at 80 bpm). Pleural pressure curve and superposition of the three curves with their spectra are shown

Esophageal pressures curves during Cheyne–Stokes respiration

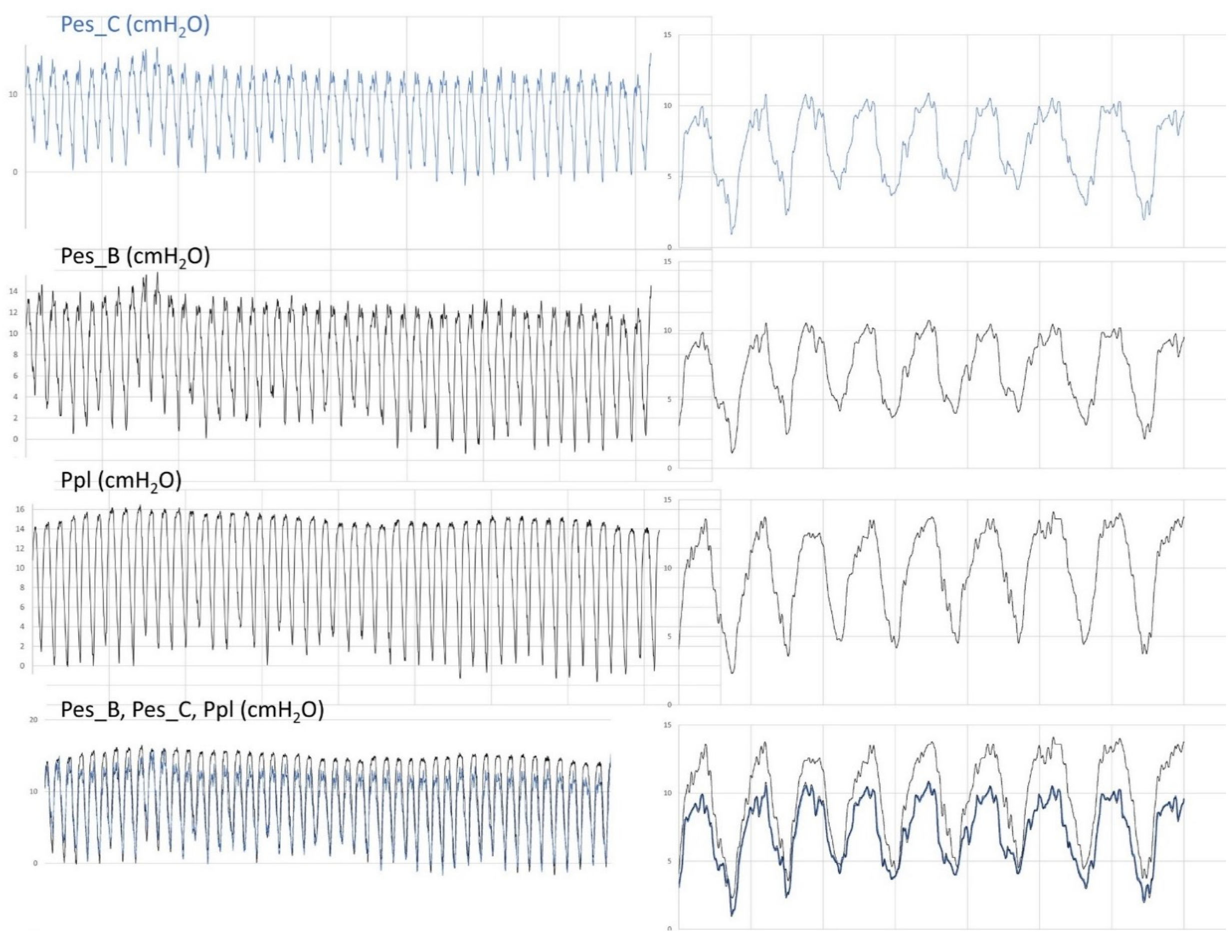


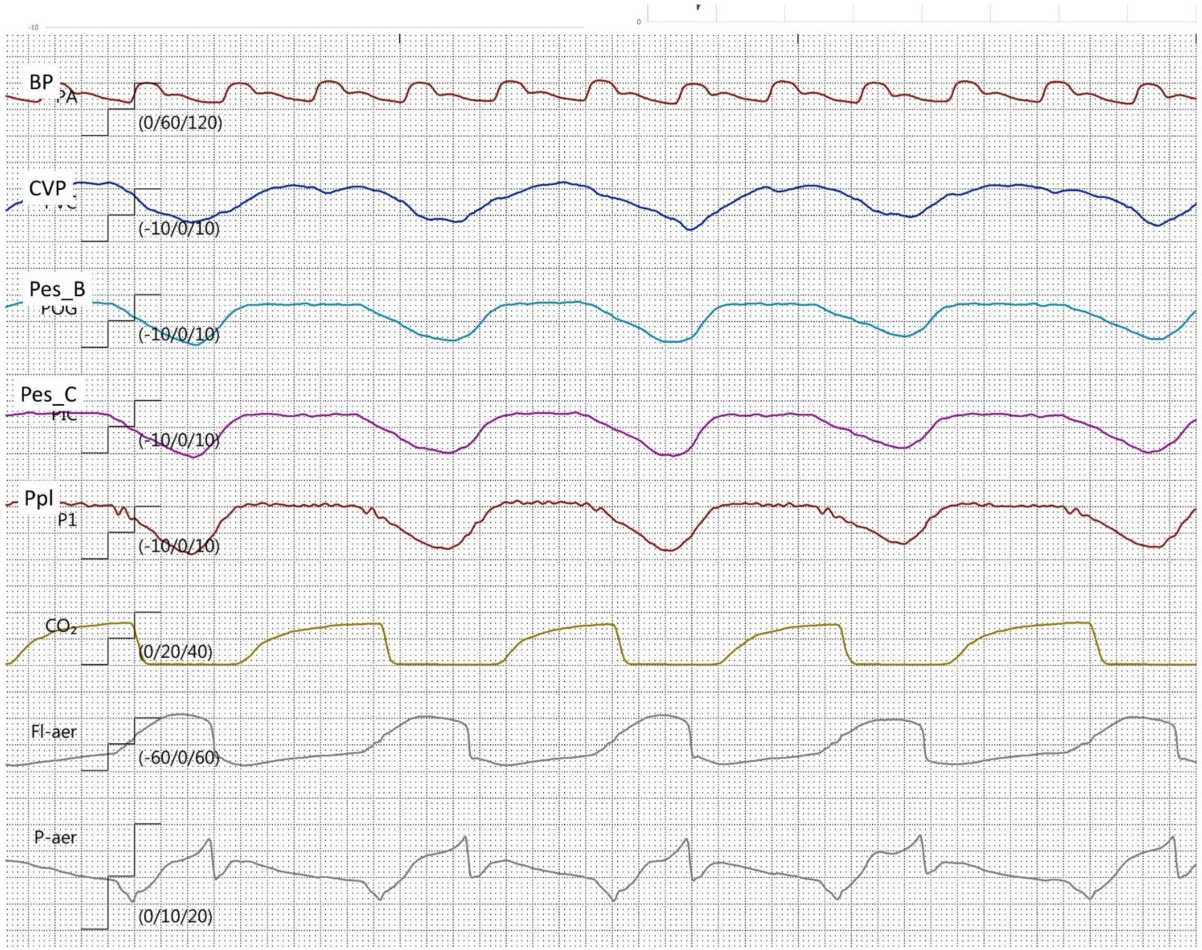
Simultaneous esophageal pressures are recorded with the air-filled esophageal catheter and the balloon catheter in one patient with spontaneous Cheyne–Stokes respiration. Note the increase in expired CO_2 before starting polypnea in the lower panel due to active expiration at the end of the respiratory pause (arrow).

Simultaneous esophageal and pleural pressures recordings

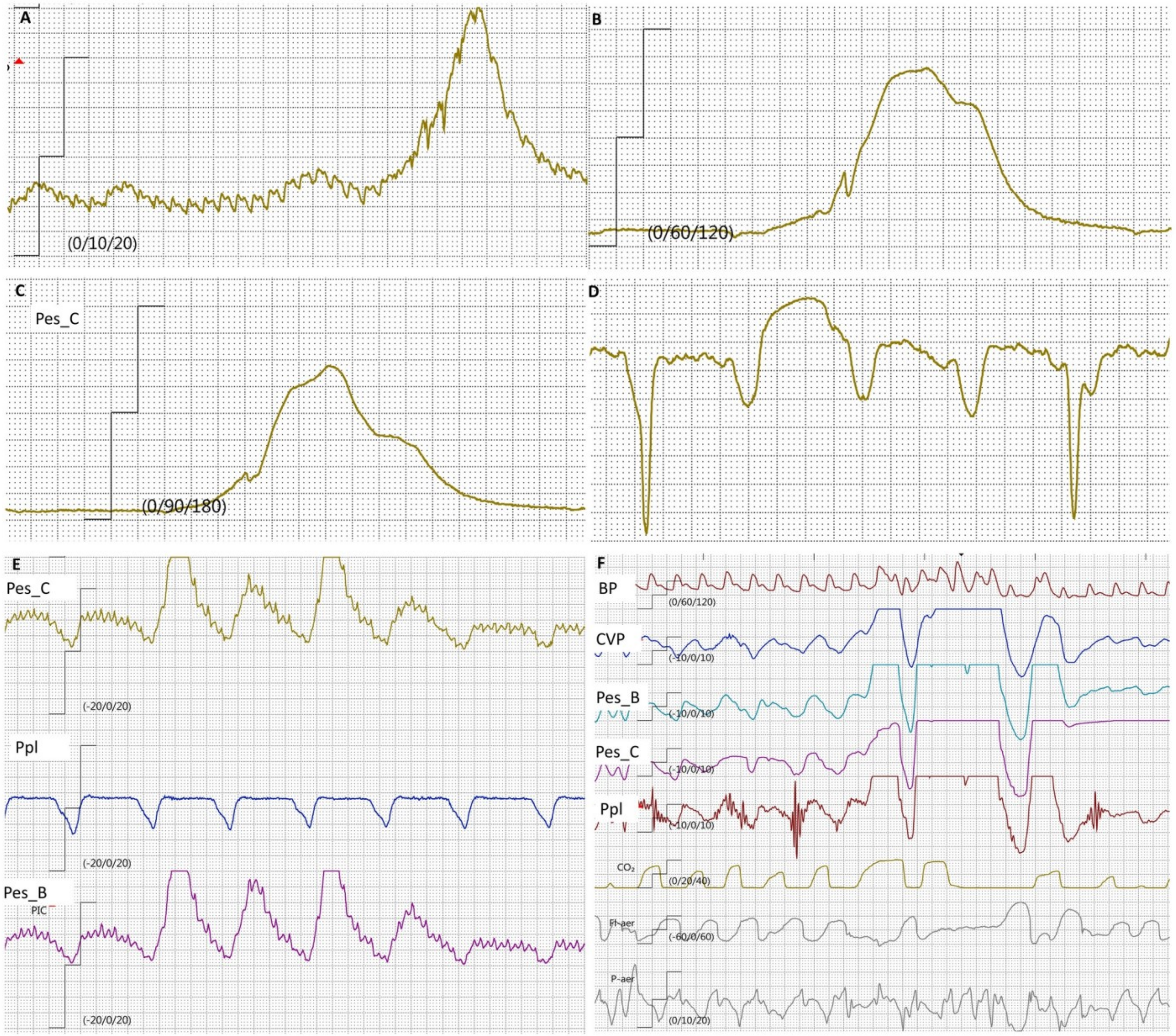


Simultaneous esophageal and pleural pressures recordings

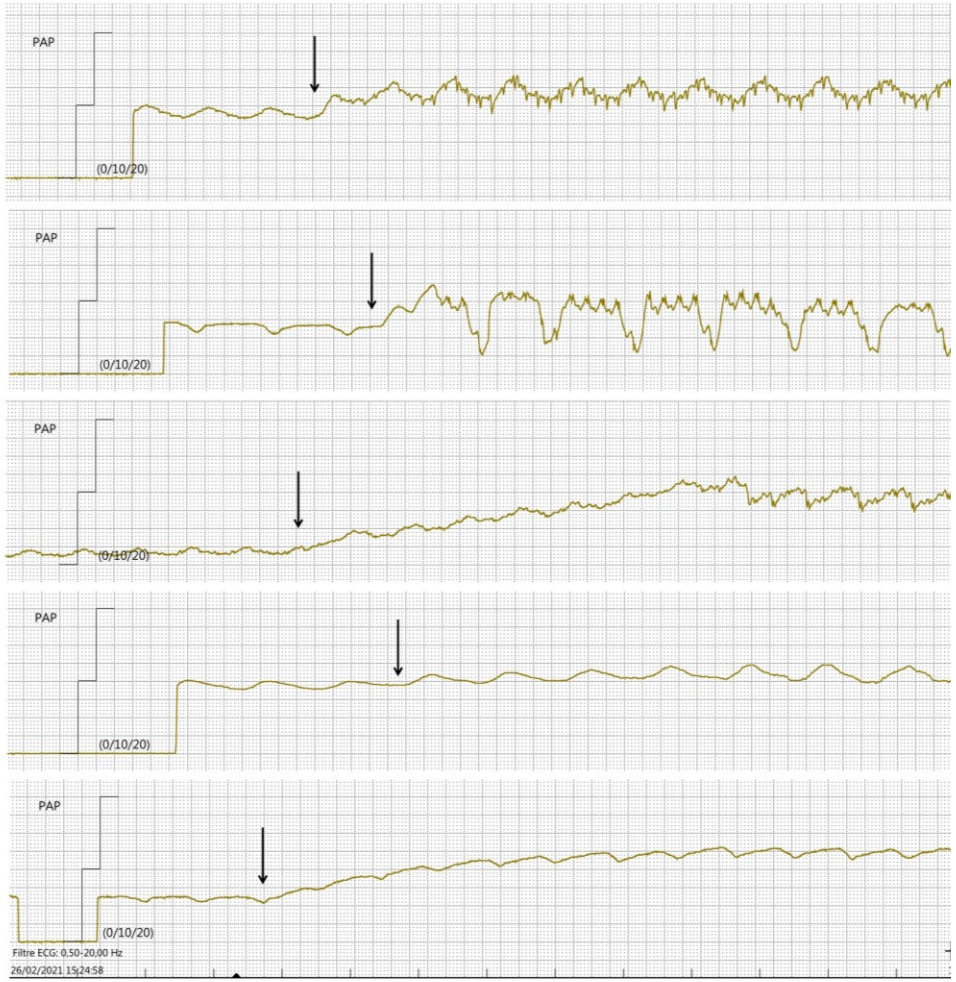


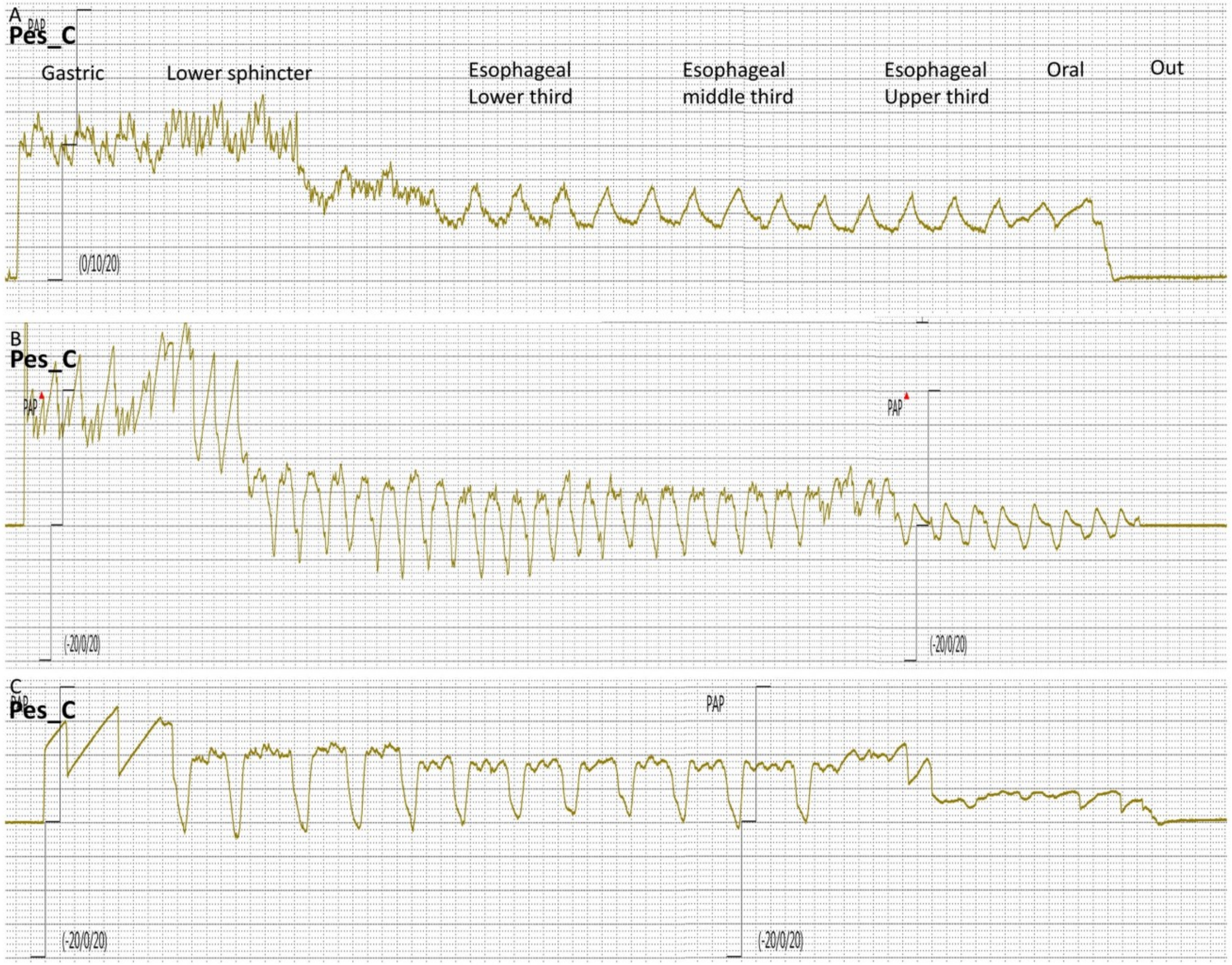


Esophageal contractions, hiccup and cough on esophageal waveforms

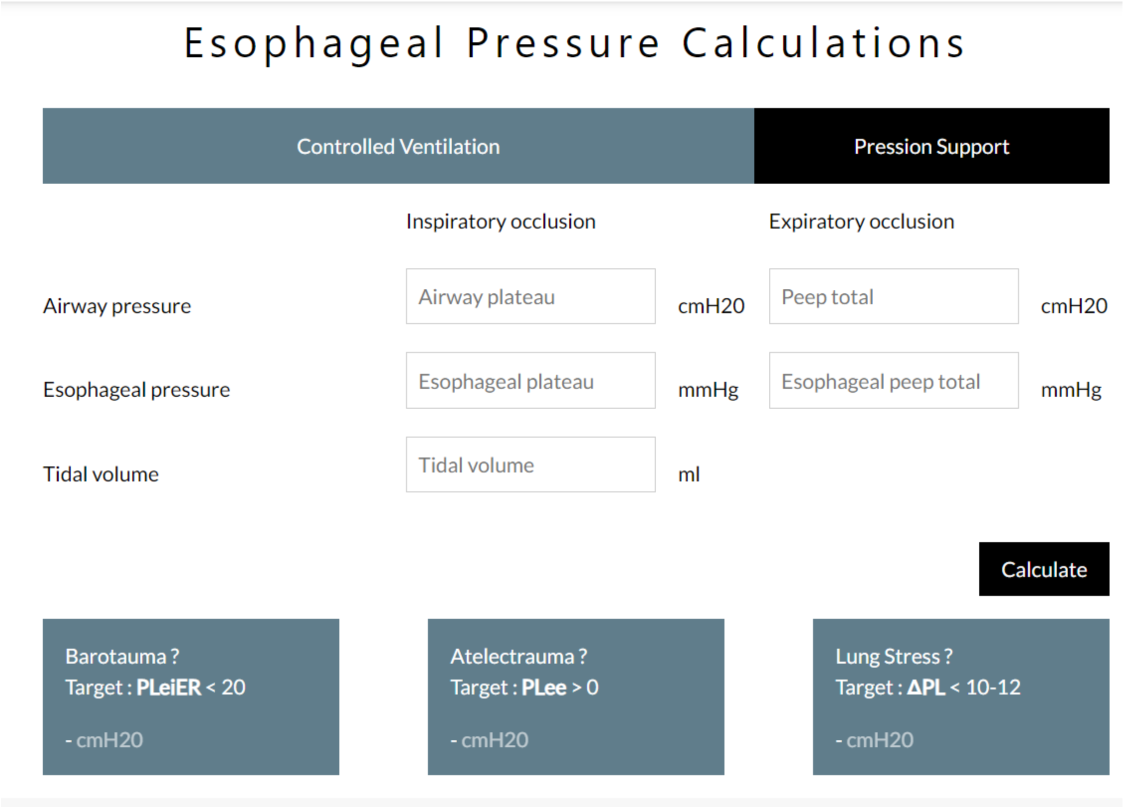


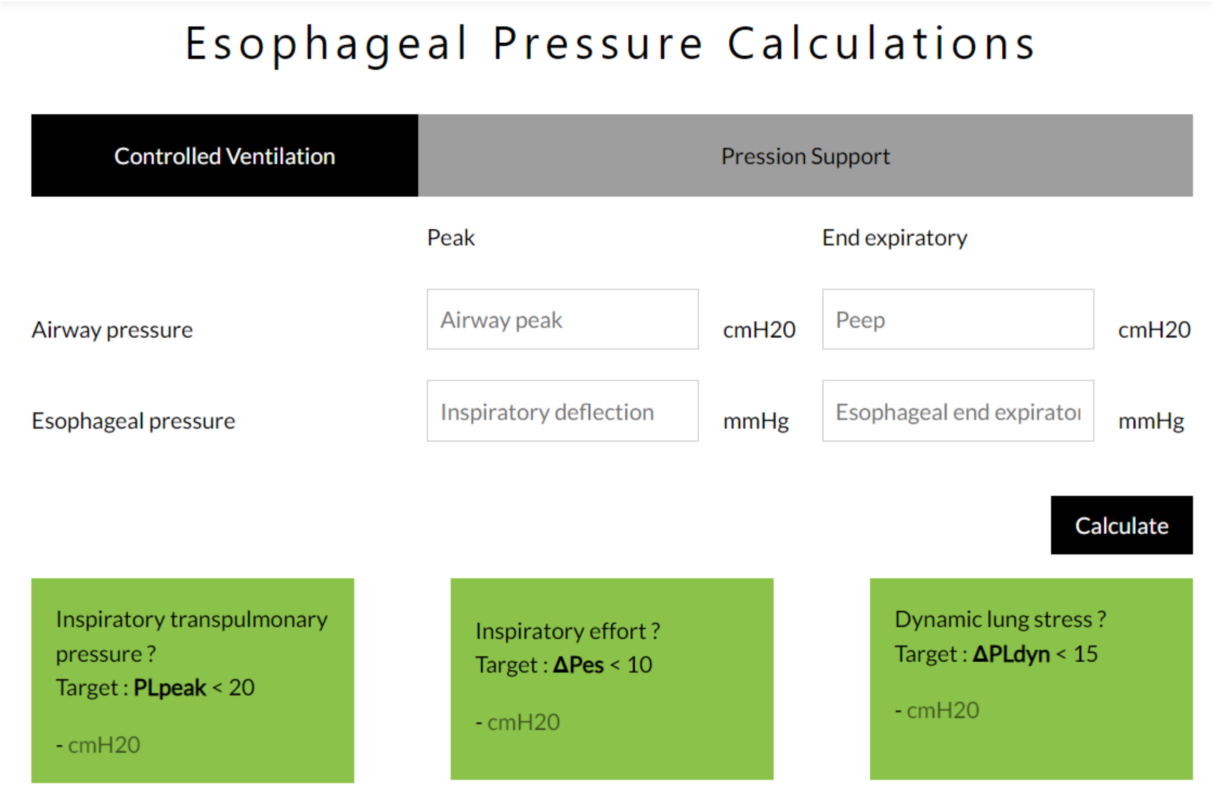
Roller clamp opening and catheter withdrawing





Transpulmonary pressure-guided lung-protective ventilation: www.esophageal-pressure-calculator.be





Done by Florian Beck, MD, 2021

Abstract presented at the belgian SIZ ICU society, 2021-05-14

Transpulmonary pressures with an air-filled esophageal catheter.

Berg J[1], Massion PB[1], Samalea N[2], Parzibut G[1], Lambermont B[1], Ledoux D[1], Massion PP[3]

ABSTRACT

INTRODUCTION: Transpulmonary pressures measurements could be useful to better characterize respiratory mechanics and to guide lung protective ventilation in ARDS1. An easy, bedside, disposable and reliable tool for esophageal pressure measurements is lacking.

OBJECTIVE: to explore the feasibility of our new transpulmonary pressure measurement method by an air-filled esophageal catheter[2] and its clinical benefit for detecting ventilator induced lung injury and for individualizing protective ventilation.

METHODS: We tested our novel method with an air-filled esophageal catheter without balloon, positioned in the lower third of the esophagus and connected to an air-filled pressurized blood pressure transducer bounded to the monitor. We collected data from 21 ventilated patients (11 covid-19 ARDS, 4 neurological injuries, 2 cardiopathies, 3 pulmonary sepsis, 1 thoracic trauma), measured end-inspiratory and end-expiratory pressures of both airway and esophageal pressures. We calculated transpulmonary pressures via our new available online calculator (www.esophageal-pressure-calculator.be).

RESULTS: We obtained esophageal and transpulmonary pressure measurements with our new method in all our 21 patients (male n=17). Signals were stable and reliable as reported[2]. According to airway pressures, 19/21 patients were under protective ventilation in volume-controlled mode (see table 1a). Esophageal pressure measurements allowed i) determination of chest wall/lung elastances, elastance ratio and esophageal delta pressure; ii) detection of risk for barotrauma (P_Lei,ER > 20cmH2O), for atelectrauma (P_Lee < 0 cmH2O) and for lung stress with the transpulmonary driving pressure (delta P_L > 12 cmH2O) (see Table 1b). According to the transpulmonary approach, 16/21 patients presented either barotrauma (n=5) and/or atelectrauma (n=12) and/or lung stress (n=4). Respiratory settings were adapted in all 16 patients accordingly (modification of Peep n=11 or of Vt n=6). Of note, Covid-19 patients compared with non-covid patients had a higher plateau pressure, a higher PEEP, a higher ventilatory ratio[3] and a higher risk of barotrauma.

CONCLUSION: Transpulmonary pressures can easily be obtained at the bedside by our air-filled esophageal catheter's method and allow individualized protective ventilation in ICU patients.

References: [1]Yoshida T et al. (2019) ICM 535-538. [2]Massion PB et al. (2021) ICM experimental, submitted. [3]Sinha P et al (2019) AJRCCM 333-341.

	Total (n=21)	Covid 19 (n=11)	Non-covid (n=10)
1a. Airway-derived parameters:			
Tidal volume (ml/kg PBW)	6.3 ± 1.4	6.5 ± 1.1	6.6 ± 0.5
PEEP (cmH_2O)	10 ± 4	12 ± 2.8*	8 ± 3.6
Plateau pressure (cmH_2O)	20 ± 6	23.6 ± 4.7**	16.8 ± 4
Driving pressure (cmH_2O)	10 ± 4	12 ± 4	9 ± 2
Elastance of respiratory system (Ers, cmH_2O/L)	24.4 ± 11.9	29.1 ± 14.3	19.4 ± 5.4
Ventilatory ratio	2.5 ± 1.3	2.9 ± 1.1*	2.1 ± 1.4
1.B Esophageal-derived parameters:			
Esophageal plateau pressure (cmH_2O)	15 ± 4	15 ± 1	15 ± 2
Eso. End-expiratory pressure (cmH_2O)	12 ±4	12 ± 1	12 ± 2
Esophageal Delta Pressure (cmH_2O)	3 ± 2	3 ± 2	4 ± 2
Chest wall elastance (cmH_2O/L)	7.3 ± 3.6	6.8 ± 3.5	8.3 ± 3.4
Lung elastance (El, cmH_2O/L)	17.1 ± 13.1	22.3 ± 15.9	11.1 ± 5.7
Elastance ratio (ER = El/Ers)	0.64 ± 0.22	0.70 ± 0.07	0.55 ± 0.05
Barotrauma: P_Lei,ER (cmH2O)	13 ± 7	17 ± 2**	9 ± 1
Atelectrauma: P_Lee (cmH2O)	-1.5 ± 4.4	0 ± 1	-3 ± 2
Lung stress: delta P_L (cmH2O)	7 ± 5	9 ± 5	5 ± 3

*$p<0.05$; **$p<0.01$; P_L, transpulmonary pressure; ei, end-inspiratory; ee, end-expiratory.

Conclusion

- We propose a novel method of transpulmonary pressure measurement with an air-filled esophageal catheter without balloon, which is:
  - Accurate
  - validated with the reference balloon method, both ex vivo and in vivo: same esophageal-to-airway pressure change ratio, good reproducibility and repeatability, no biais compared with the balloon method and with direct pleural measurements;
  - Simple
  - Cheap and worldwide available
- We propose you to try it in your own center
- We hope the air-filled method would be accepted in future PLUG plateform trials for esophageal pressure-guided lung-protective ventilation

Thank you for your attention

Contact for any questions or suggestions?
paul.massion@chuliege.be
V. 2022-05-23