

Preliminary Validation of Transcutaneous CO₂ Monitoring in Patients Undergoing Cardiac Ablation Using Jet Ventilation

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Abstract

Objectives: There is no data in the current medical literature on efficacy or accuracy of transcutaneous (tcPCO₂) monitoring during jet ventilation for cardiac ablation. The use of tcPCO₂ during cardiac ablation procedures offers the opportunity to compare end-tidal and transcutaneous methods of CO₂ measurement before and after the use of the jet ventilation. Comparison of these measurements with arterial blood gas CO₂ levels allows evaluation of the accuracy of the tcPCO₂ technique for use during jet ventilation. Design: Observational study; patients served as their own controls. Setting: Cardiac electrophysiology laboratory. Participants: 15 adult patients (9 M), ASA III-IV, aged 26 to 82 years (median 66 years) undergoing radiofrequency ablation for atrial fibrillation. Interventions: Jet ventilation (JV) versus conventional ventilation. Measurements and Main Results: Paired measurements of end-tidal CO_2 (EtCO₂) and transcutaneous CO_2 (tcPCO₂) were recorded during periods of conventional ventilation. Paired measurements of arterial blood CO₂ (Pa-CO₂) levels and tcPCO₂ were recorded during JV. ABG samples were drawn at the anesthesiologist's discretion to assess the patient's respiratory status. The level of agreement between the three methods was compared using the Bland Altman plot. We found that tcPCO₂ values consistently provided a close approximation to PaCO₂ levels. The mean difference between tcPCO₂ and EtCO₂ values in baseline and post-JV was on the order of 3 - 5 mmHg, with standard deviation of 4 - 6 mmHg. This is well within the range of variability that is accepted in clinical practice. Conclusions: These preliminary results suggest that tcPCO₂ provides an acceptable estimate of CO₂ concentration in arterial blood during JV, as well as prior to and following JV.

Keywords

High Frequency Jet Ventilation, Cardiac Ablation, Transcutaneous CO₂ Monitoring, End-Tidal CO₂ Monitoring, General Anesthesia

1. Introduction

Over the last decade cardiac catheter ablations have become a major tool in treating cardiac arrhythmias, and in particular atrial fibrillation. Catheter ablation is now considered first-line therapy for treatment of atrial fibrillation, with the cornerstone of the procedure the achievement of electrical isolation of the pulmonary veins, which are thought to be the source of triggers for atrial fibrillation. Catheter ablation. Catheter ablation success rates have improved over time based on a better understanding of mechanisms underlying atrial fibrillation, new techniques and technology, and greater physician experience, and can result in a 53% long-term freedom from atrial fibrillation after a single procedure. After multiple procedures, it can result in an 80% freedom from atrial fibrillation [1].

Over time and in light of the success of ablation therapy, the treatment modality has been expanded to include more medically complex patients, including the elderly, those with cardiomyopathy, and those with implanted devices [2] [3]. Cardiac ablation procedures can last up to 6 - 8 hours. In most cases these procedures cause minimal stimulation with little postoperative pain. However, the procedures demand absolute immobility in order to maintain the accuracy of the mapping systems and stability of the ablation catheters against cardiac tissue. For this reason, most centers perform atrial fibrillation ablations under general anesthesia. There are some solutions for respiratory compensation within the mapping system software, but shallow respiratory volumes to minimize catheter movement are often used and are more effective, and periods of apnea are occasionally used during times when catheter stability is challenging.

The use of high frequency jet ventilation (JV) has gained popularity since 2006 when Goode & colleagues at the University of Pittsburgh demonstrated a decrease in procedure duration and fewer ablation lesions required to obtain pulmonary vein isolation when JV was used compared with controlled mechanical ventilation. This difference was attributed to the lack of respiratory motion and resulting catheter stability with JV [4]. In a typical procedure, once the patient is under general anesthesia, he or she will be ventilated using a conventional anesthesia machine during the first phase (vascular access, catheter placement and trans-septal puncture) and the third phase of the procedure (emergence). JV will be used during the second phase (mapping and ablation).

Traditionally, in anesthetized patients, monitoring of carbon dioxide (capnography) is done either by taking samples of arterial blood for laboratory analysis ("arterial blood gas analysis", ABG) and/or by monitoring expired breath of intubated patients ("end-tidal CO_2 " or EtCO₂), measured by a sampling line on the anesthesia machine [5]. Unfortunately, $EtCO_2$ is not available during jet ventilation and furthermore is not free of artifacts and measurement problems [6].

Use of jet ventilation requires frequent sampling of arterial blood gas in order to monitor arterial blood CO_2 level [7]. Based on the result of the intermittent ABG analysis, the anesthesiologist will make adjustments to the ventilator's settings. Case times often run 2.5 - 4 hours so this is a considerable length of time during which the anesthesiologist has limited information on the patient's ventilation status. Without monitoring the patient's lung ventilation status, pulse oximetry alone does not provide sufficient information to assure optimal outcomes.

Transcutaneous monitoring of carbon dioxide $(tcPCO_2)$ is a technique which records CO₂ levels in the tissue noninvasively and continuously using a skin sensor which detects tissue gas perfusion [8]. TcPCO₂ monitoring has been used successfully in anesthesia [9] [10] [11] and with critically ill patients in the ICU [12] [13]. For these clinical applications, tcPCO₂ measurements correlate well with the gold standard of arterial PaCO₂ levels [5]. In fact, in studies which have recorded both measures concurrently, tcPCO₂ has correlated higher with arterial PaCO₂ than did EtCO₂ [14] [15]. It is difficult to find studies comparing tcPCO₂ and EtCO₂ directly. Furthermore, there are no studies which have evaluated the use of tcPCO₂ in cardiac ablation procedures.

Our objective was to 1) evaluate the accuracy of $tcPCO_2$ when used with jet ventilation in patients undergoing cardiac ablation procedures; and 2) to directly compare the results from $tcPCO_2$ and $EtCO_2$ in periods of conventional ventilation in the same patients.

2. Methods

2.1. Research Setting

The study was conducted in the Electrophysiology Laboratory (EP Lab), Heart Center, Stony Brook University Hospital, Stony Brook, New York, USA.

2.2. IRB Approval

This study was approved by our university Institutional Review Board (IRB) before any patients were enrolled. All patients provided written informed consent prior to any research interventions.

2.3. Patient Population

We studied adult patients undergoing atrial fibrillation ablation procedures under general anesthesia between December 2015 and November 2016. Eligible patients were identified and recruited to the study during consultation with the cardiac electrophysiologist in the cardiology clinic. Written informed consent was obtained by the anesthesiology team prior to any procedures being performed.

Inclusion/Exclusion Criteria

Adults over 18 who were undergoing cardiac ablation at Stony Brook University

Hospital EP Lab were included in the study. Patients were excluded if they had any contraindication for jet ventilation such as obesity (BMI \ge 40), lung disease or respiratory disease (e.g. severe COPD), or abnormality of the skin preventing application of tcPCO₂ probe such as jaundice (which affects skin pigmentation, interfering with function of tcPCO₂ sensor).

2.4. Equipment

We used the SenTec AG (Therwil, Switzerland, www.sentec.com) Digital Monitoring System (see **Figure 1**) which monitors $tcPCO_2$ levels. $TcPCO_2$ measurements were recorded with the V-SignTM Sensor 2, recording at 42.0°C, under software version MPB-SW:V05.03.02/SMB-SW:V07.03.1. The Sentec DMS monitor also records O₂ saturation and pulse rate but we did not utilize those measurements for this study. End-tidal CO₂ was recorded using the standard inline sampling line incorporated into the GE Aestiva 5 anesthesia machine.

2.5. Procedures

This was an unblinded observational study. Patients were **not** randomized; they were used as their own control. Respiratory support was performed in three phases. The order of phases was determined by the requirements of clinical care and did not vary.

1) *Baseline*—Conventional ventilation (CV) using GE Aestiva 5 anesthesia machine.

2) *During Cardiac Ablation*—High Frequency Jet Ventilation (JV) using Acutronic Monsoon III high frequency jet ventilator (Susquehanna Micro Inc., Windsor PA, http://www.susquemicro.com/).



Figure 1. Results of End-tidal (blue circles) and Transcutaneous CO_2 (orange triangles) measurement compared to $PaCO_2$ in arterial blood (black diamonds). N = 1 (patient JV-02).

3) *Post-Ablation*—patient was reconnected to GE Aestiva anesthesia machine for respiratory support.

2.5.1. Measurement of CO₂

The V-Sign^{∞} probe was placed on the patient at induction of general anesthesia and was removed at the end of the procedure. The probe was positioned on the left pectoralis muscle for 12 patients and on the left deltoid muscle for 3 patients. Measured tcPCO₂ values did not appear to vary systematically between probe placements.

2.5.2. Anesthetic Management

Standard anesthesia monitoring was used for these procedures as per ASA guidelines (invasive and non-invasive blood pressure, heart rate, pulse oximetry, ECG). EtCO₂ was measured during conventional ventilation through the sampling line on the anesthesia machine (GE/Marquette capnography). At least one ABG sample (baseline) was obtained during this period to serve as a baseline value. During baseline, tcPCO₂ and EtCO₂ were recorded at variable intervals according to clinician judgment. On switching to jet ventilation, EtCO₂ measurement was no longer available. ABGs were taken during jet ventilation as needed for clinical care, at the discretion of the anesthesiology team. A final ABG sample was taken at emergence from anesthesia.

2.5.3. Measurement of Arterial Blood Gas

Heparinized samples were hand-carried to the hospital respiratory lab for processing. Samples were processed on a blood gas analyzer(Roche Cobas B221). While the cost for sample processing is under \$3, in our hospital patients are billed well over \$200 per ABG analyzed.

2.6. Data Recording and Analysis

A researcher in the OR manually recorded tcPCO₂ and EtCO₂ at variable intervals (10 - 15 minutes in most cases). Measurements were taken at frequent intervals during the entire procedure, including periods before, during and after jet ventilation. ABG samples were taken at the discretion of the anesthesia provider. These measurements were entered into an Excel file and graphed over time. Relevant events in the management of the patient (e.g. onset and offset of jet ventilation) were noted on the datasheet. For statistical analysis, measurements of pCO_2 (EtCO₂, tcPCO₂, PaCO₂) were averaged within-subject to give one measurement in each of the three conditions (Baseline, Jet Ventilation, Post-Jet Ventilation). Measures were compared to each other within condition by paired t-test, with a significance level of P < 0.05. Statistical analyses were performed using IBM SPSS Statistics v22.

2.6.1. Power Analysis

A power analysis was calculated before beginning data collection. A review of the literature indicated that in anesthetized patients using conventional ventilation, the correlation of $tcPCO_2$ with ABG is r = 0.8, suggesting a large effect size. Similarly, the one study we found which directly compares $tcPCO_2$ to $EtCO_2$ gave a correlation of r = 0.71, also suggestive of a large effect size. For both these cases, a sample size of N = 21 would provide 80% power at the conventional alpha = 0.05. Since we assumed the correlation will be positive, these estimates were for a one-tailed test.

2.6.2. Agreement between Methods of Measurement

We used the Bland-Altman technique [16] [17] to plot the mean of the two measures versus the difference of the two measures with 95% limits of agreement. If the two methods are well correlated, the differences should be near zero. If there are consistent differences, this is considered "bias". Some variability is to be expected, from error of measurement if nothing else; this is referred to as "precision".

3. Results

3.1. Study Patients

Twenty patients were enrolled in the study. Of these, one was a screen failure (BMI over the limit of 40); one had surgery cancelled; and 3 had unusable data due to recording problems. We have evaluable data for 15 patients. Patients (9 M, 6 F) were ASA 3 and 4, and ranged in age from 26 to 82 years (median 66 years). BMI ranged from 24 to 35 m/kg² (median 28.5). No patient admitted to being a current smoker; 8 (53.3%) were former smokers. Hypertension was common, with 10 (66.7%) patients having this diagnosis. Pulmonary disease was rare in this sample, with one patient having a history of asthma and one having mild COPD. Two patients (14.3%) had been diagnosed with kidney disease; one of these had undergone nephrectomy. There were no diabetic patients in this sample.

3.2. Cardiac Diagnosis

The majority (n = 11) had paroxysmal atrial fibrillation (Afib); 3 patients had persistent Afib and 1 was described with atrial flutter. Left ventricle ejection fraction was available on 7 patients and ranged from 27 to 65 (median 57). Seven patients (46.7%) had a history of cardiac artery disease. One patient (6.7%) had had a prior MI, and another one (6.7%) had a prior TIA. Two patients (13.3%) had a pacemaker (one of these was also stented) while a third patient had a stent only. Five patients had undergone prior cardiac surgery, including 3 patients who had prior AF ablation, but none had prior CABG surgery.

3.3. Anesthesia Care

The median duration of anesthesia was 6 hours 22 minutes (range 2:43 to 9:28). Jet ventilation was employed for a median of 2 hours 56 minutes (range 1:41 to 4:45 hours). The anesthesia provider was free to choose the anesthesia technique

and medications provided to the patient. All patients were treated with midazolam premedication. During baseline, 8 patients received inhalational anesthesia using sevoflurane or desflurane, and 7 were given propofol infusion. During the JV phase, all patients were given total intravenous anesthesia (TIVA) using propofol infusion and narcotics. Fentanyl was used in 13 cases (86.7%) and remifentanil in 5 cases (33.3%); some patients received both agents. Muscle relaxant (rocuronium) was used in all patients with reversal by either neostigmine (n = 6) or sugammadex (n = 9). Fluid hydration was maintained with normal saline. All patients received low dose (0.1 - 0.5 mcg/kg/min) phenylephrine infusion during the ablation phase.

14 patients (93.3%) were extubated at the conclusion of the procedure in the EP Lab suite; only 1 patient remained intubated on transfer to the recovery area. There were no reports of serious adverse events or anesthesia complications in this sample. Patients remained overnight for observation as per standard procedure, and were discharged to home the next day.

3.4. Results of TcPCO₂ during Jet Ventilation

The mean values of measured tcPCO₂, EtCO₂ and PaCO₂ are given in **Table 1**. Both tcPCO₂ and EtCO₂ slightly (but statistically significantly) underestimated PaCO₂ in all conditions (except tcPCO₂ in baseline). However, tcPCO₂ values were consistently higher than were EtCO₂ values in baseline (P = 0.009) and post-jet ventilation (P = 0.009) by paired t-test. Results from a typical patient are shown in **Figure 1**.

3.5. Correlations between Measures of CO₂

Correlations between the different measures of CO_2 are shown in Table 2. During baseline, correlations between arterial blood and both $EtCO_2$ and $tcPCO_2$ were low and not statistically significant. The higher variability of measurements during baseline is reflected in the low correlations from this period. During jet ventilation, the correlation between arterial blood CO_2 and $tcPCO_2$ rose to a highly significant value (r = 0.843, P < 0.001). End-tidal measure of CO_2 was not available during this period. Post-jet ventilation, the high correlation between $tcPCO_2$ and $PaCO_2$ was maintained (r = 0.874, P < 0.001) and was matched by a similarly high correlation between $EtCO_2$ and $PaCO_2$ (r = 0.741, P = 0.002). Correlations between the two measures of $tcPCO_2$ and $EtCO_2$ were non-significant

Table 1. Measures of PCO_2 by condition (mean \pm standard deviation).

Measure	Baseline	Jet Ventilation	Post-Jet Ventilation
PaCO ₂	38.3 ± 4.1	39.0 ± 4.6	41.5 ± 6.20
$TcPCO_2$	37.3 ± 4.3	35.8 ± 5.5***	$39.4 \pm 5.1^{*}$
EtCO ₂	32.7 ± 2.6 ^{##++}		36.1 ± 5.3 ^{###++}

Results of paired t-tests are indicated as follows: TcPCO₂ versus PaCO₂: *P < 0.05 ***P = 0.001. EtCO₂ versus PaCO₂: *P < 0.01 ^{##}P < 0.001. TcPCO₂ versus EtCO₂: *P < 0.01.

at baseline (r = -0.423, P < 0.12) but quite high during the post-jet period (r = 0.696, P = 0.006).

3.6. Comparison of Methods by Bland-Altman Plot

Figure 2 shows tcPCO₂ compared to the gold standard, arterial blood gas measurement (PaCO₂) in baseline, JV and post-JV conditions, using the Bland-Altman technique [17]. This technique plots the difference between measures versus their mean, giving 95% limits of agreement (*i.e.* 95% confidence limits). Comparing PaCO₂ to tcPCO₂, these plots show a small but consistent bias where the mean difference between these two measures is 0.94 + 6.7 at baseline, and 3.15 + 2.94 during JV (see **Table 1**). Under JV conditions, variability of the measurements was reduced, as shown by the narrower 95% confidence interval. Reduced variability of the difference scores appears to persist into the post-JV period (see **Figure 2** and **Table 3**). During and post-JV, the 95% confidence interval for the mean (shown by the dashed orange lines) does not include zero, indicating that the mean difference of tcPCO₂ is significantly (P < 0.05) different from zero.

Comparison of $tcPCO_2$ to traditional $EtCO_2$ before and post-JV is shown in **Figure 3**, using the same graphical technique. In both cases, the mean difference between the two measures is approximately 3 - 5 mmHg, with standard deviation of 4 - 6 mmHg (see **Table 3**). This is well within the range of variability that is accepted in clinical practice. Variability in the 95% limits of agreement (as

Table 2. Correlations (Pearson r) between transcutaneous and end-tidal measures of CO_2 and arterial blood gas $PaCO_2$ before, during and after Jet Ventilation.

	Baseline PaCO ₂	Jet Ventilation PaCO ₂	Post-Jet Ventilation PaCO ₂
EtPCO ₂	-0.385 (P = 0.156)		+0.741 (P = 0.002)
TcPCO ₂	-0.274 (P = 0.323)	+0.843 (P < 0.001)	+0.874 (P < 0.001)



Figure 2. Bland-Altman plots for agreement between $tcPCO_2$ and $PaCO_2$ in baseline, during JV, and post-JV. The dashed red lines indicate the 95% confidence interval (95% limits of agreement) for the mean difference between methods of measurement, calculated as mean \pm 1.96 * standard deviation (SD). 95% of the observations are expected to fall within these limits; data points falling outside the dashed red lines may be considered outliers. The dashed orange lines indicate the 95% confidence interval for the sampling error of the mean difference, calculated as mean \pm 1.96 * standard error of the mean (SEM). Where the interval between the dashed orange lines does not include zero, the mean difference is interpreted as significantly (P < 0.05) different from zero.

Condition	PaCO ₂ vs. TcPCO ₂	PaCO ₂ vs. EtCO ₂	TcPCO ₂ vs EtCO ₂
Baseline			
Bias	0.94	5.54	4.6
Bias SD	6.7	5.7	5.9
95% limits	-12 to 14	-5.5 to 17	-7.0 to 16
Jet Ventilation			
Bias	3.15		
Bias SD	2.94		
95% limits	-2.6 to 8.9		
Post-Jet Ventilation			
Bias	2.1	5.4	3.33
Bias SD	3.0	4.2	4.1
95% Limits	-3.8 to 8.0	-2.9 to 14	-4.7 to 11.3

Table 3. Results of Bland-Altman analyses comparing measures of PCO_2 by condition. Values shown are bias (mean difference), the standard deviation of the bias, and 95% limits of agreement. Note that $EtCO_2$ is not available during Jet Ventilation.



Figure 3. Bland-Altman plots for agreement between $tcPCO_2$ and $EtCO_2$ during conventional ventilation in baseline and post-JV. Interpretation of the dashed red and orange lines is as described in **Figure 2**.

shown by the dashed red lines) is slightly decreased after JV. However, for both baseline and post-JV, the 95% confidence interval for the mean (as shown by the dashed orange lines) does not include zero, indicating a significant difference (P < 0.05) between the end-tidal and the transcutaneous measures.

4. Discussion

4.1. Summary of Results

To our knowledge, this study is the first to evaluate use of $tcPCO_2$ to manage respiratory state during high frequency jet ventilation with a closed airway. It is also one of very few in the literature to directly compare $tcPCO_2$ and $EtCO_2$ during conventional ventilation. We found a correlation between $tcPCO_2$ and $EtCO_2$ ranging from -0.423 at baseline to r = +0.696 post-jet ventilation. The latter value is very similar to the value of r = 0.707 reported by Zasa *et al.* [18] for these two measures during conventional ventilation. In our patient sample, both $EtCO_2$ and $tcPCO_2$ estimates of PCO_2 were statistically lower than the measured $PaCO_2$ by paired t-tests. However these differences were small in magnitude and

are not clinically relevant. It should be noted however, that in the baseline condition with conventional ventilation, there was no significant difference between $tcPCO_2$ and arterial PaCO₂.

4.2. Difference in Mechanism of CO₂ Measurement

The reason for the consistently higher values of $tcPCO_2$ compared to $EtCO_2$ is due to the effect of alveolar dead space. End-tidal PCO_2 at the end of expiration during tidal breathing is assumed to represent the alveolar gas. However it is lower than 'ideal' alveolar P_ACO_2 , because the almost CO_2 -free gas from alveolar dead space dilutes and lowers the end-tidal PCO_2 reading. Transcutaneous CO_2 monitoring directly samples the $PaCO_2$ from the blood vessels, and is therefore expected to be closer to the true $PaCO_2$ level.

4.3. Prior Studies

There is no data in the current medical literature on efficacy or accuracy of $tcPCO_2$ monitoring during closed airway jet ventilation for cardiac ablation. The available studies on surgical patients under general anesthesia support the use of transcutaneous capnography compared to end-tidal measurement. Mizushima *et al.* (2003) described an excellent correlation (r = +0.96) between the ABG measure of PaCO₂ and the transcutaneous CO₂ monitor in 15 patients undergoing microlaryngosurgery with high frequency jet ventilation [19]. In thoracotomy patients receiving one lung ventilation, end tidal CO₂ monitoring may not be accurate to estimate PaCO₂ due to mismatch between perfusion and ventilation. Choi *et al.* (2008) found that tcPCO₂ was more accurate and useful for assessing CO₂ levels during one lung ventilation [9].

4.4. Effect of Sensor Placement

The manufacturer recommends sensor placement on the cheeks, forehead, deltoid muscle of upper arm or pectoralis muscle on the chest for maximal efficiency in measuring CO_2 , SpO_2 and pulse rate. However, these sites were not accessible in our patients due to surgical drapes. We used the left pectoralis or the deltoid muscle, which gives acceptable sensitivity in measurement of tcPCO₂ [20]. There are 3 "outlier" data points shown in **Figure 2** and **Figure 3**. All three of these patients had the sensor probe placed on the left pectoralis. None of the "outlier" patients were smokers and none had COPD. We did not find any immediate explanation for their "outlier" status. But it should be noted that by definition, 95% confidence limits will exclude 5% of the data points; *i.e.*, one in 20. Thus the number of outliers is consistent with statistical expectations.

4.5. Limitations of the Study

This pilot study is limited by the small sample size. The study design would have been improved by collecting a prescribed number of ABG samples at standardized intervals. In order to follow standard clinical practice as closely as possible, we chose to allow the anesthesiologist to use their clinical judgment in the number and timing of ABG samples. We did not perform extensive follow-up of the patients. They were monitored in a cardiac recovery unit overnight as per our standard hospital procedure, and discharged the next day. None of the patients experienced adverse sequelae. To correct the tcPCO₂ readings for change over time, we applied the "drift correction" algorithm supplied by the device manufacturer. In most cases, visual inspection showed the corrected and uncorrected values were not substantially different (1 - 2 mmHg) over a period of 4 - 6 hours of recording. The tcPCO₂ data reported in this paper are the uncorrected values recorded manually from the monitor during anesthesia.

4.6. Patient Safety and Economic Considerations

Withdrawing arterial blood from the arterial line does carry a minimal degree of risk of introducing potential infection or an air bubble; this risk is increased when done multiple times during the procedure. In our EP Lab setting, sending an ABG sample would also require a dedicated person to carry the actual sample to our respiratory laboratory. In practice this person has to leave the floor for a period of 5 - 10 minutes, followed by an additional period of time for the ABG results to be presented via the computerized system. To that one should add over two hundred dollars for hospital charges per sample.

4.7. Benefits of Transcutaneous PCO₂ Monitoring

If validated for this purpose, $tcPCO_2$ monitoring may increase patient safety during JV for cardiac ablation procedures. It will also eliminate the need for frequent samples of arterial blood gas, and decrease the time and expense associated with STAT laboratory analysis of blood gas samples.

4.8. Conclusions

Accurate monitoring of respiratory function is a vital component of good anesthesia care. During much of the cardiac ablation procedure, the anesthesiologist is "flying blind" without real-time feedback on this vital function. This pilot study suggests that transcutaneous monitoring of CO_2 is accurate and reliable under these conditions with general anesthesia. Utilization of tcPCO₂ has the potential to replace the need for periodic sampling of ABGs during jet ventilation. This will increase patient safety by providing more information to the anesthesiologist and allowing better-informed respiratory care, while reducing costs of analysis of the blood samples.

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Conflicts of Interest

None.

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References

- Ganesan, A.N., Shipp, N.J., Brooks, A.G., Kuklik, P., Lau, D.H., *et al.* (2013) Long-Term Outcomes of Catheter Ablation of Atrial Fibrillation: A Systematic Review and Meta-Analysis. *Journal of the American Heart Association*, 2, e004549-1e004549-14. <u>https://doi.org/10.1161/JAHA.112.004549</u>
- [2] Gerstenfeld, E.P., Callans, D., Dixit, S., Lin, D., Cooper, J., et al. (2007) Characteristics of Patients Undergoing Atrial Fibrillation Ablation: Trends over a Seven-Year Period 1999-2005. *Journal of Cardiovascular Electrophysiology*, 18, 23-28. https://doi.org/10.1111/j.1540-8167.2006.00662.x
- [3] Lakkireddy, D., Patel, D., Ryschon, K., Bhateja, R., Bhakru, M., et al. (2005) Safety and Efficacy of Radiofrequency Energy Catheter Ablation of Atrial Fibrillation in Patients with Pacemakers and Implantable Cardiac Defibrillators. *Heart Rhythm*, 2, 1309-1316. <u>https://doi.org/10.1016/j.hrthm.2005.09.010</u>
- [4] Goode, J.S., Taylor, R.L., Buffington, C.W., Klain, M.M., Schwartzman, D., *et al.* (2006) High-Frequency Jet Ventilation: Utility in Posterior Left Atrial Catheter Ablation. *Heart Rhythm*, 3, 13-99. <u>https://doi.org/10.1016/j.hrthm.2005.09.013</u>
- [5] Janssens, J.P., Howarth-Frey, C., Chevrolet, J.C., Abajo, B. and Rochat, T. (1998) Transcutaneous PCO₂ to Monitor Noninvasive Mechanical Ventilation in Adults: Assessment of a New Transcutaneous PCO₂ Device. *Chest*, **113**, 768-773. <u>https://doi.org/10.1378/chest.113.3.768</u>
- [6] Folke, M., Cernerud, L., Ekström, M. and Hök, B. (2003) Critical Review of Non-Invasive Respiratory Monitoring in Medical Care. *Medical & Biological Engineering & Computing*, **41**, 377-383. <u>https://doi.org/10.1007/BF02348078</u>
- [7] Ihra, G., Gockner, G., Kashanipour, A. and Aloy, A. (2000) High-Frequency Jet Ventilation in European and North American Institutions: Developments and Clinical Practice. *European Journal of Anaesthesiology*, 17, 418-430. https://doi.org/10.1097/00003643-200007000-00003
- [8] Eberhard, P. (2007) The Design, Use, and Results of Transcutaneous Carbon Dioxide Analysis: Current and Future Directions. *Anesthesia & Analgesia*, 105, S48-S52. <u>https://doi.org/10.1213/01.ane.0000278642.16117.f8</u>
- [9] Choi, H.R., Lee, S.S., Lim, Y.H., Yoo, B.H., Yon, J.H., et al. (2008) A Comparison of Transcutaneous and End-Tidal Measurements of CO₂ in One Lung Ventilation. *Korean Journal of Anesthesiology*, 54, 129-133. <u>https://doi.org/10.4097/kjae.2008.54.2.129</u>
- [10] Xue, Q., Wu, X., Jin, J., Yu, B. and Zheng, M. (2010) Transcutaneous Carbon Dioxide Monitoring Accurately Predicts Arterial Carbon Dioxide Partial Pressure in Patients Undergoing Prolonged Laparoscopic Surgery. *Anesthesia & Analgesia*, 111, 417-420. <u>https://doi.org/10.1213/ANE.0b013e3181e30b54</u>
- [11] LeRiger, M., Thung, A., Diefenbach, K., Shepherd, E., Wishloff, E., et al. (2012) Case Report—Elective Use of High Frequency Oscillatory Ventilation with Transcutaneous Carbon Dioxide Monitoring during Thoracoscopic Diaphragmatic Hernia Repair. Anaesthesia, Pain & Intensive Care, 16, 287-292.

- Bendjelid, K., Schuetz, N., Stotz, M., Gerard, I., Suter, P.M., *et al.* (2005) Transcutaneous PCO₂ Monitoring in Critically Ill Adults: Clinical Evaluation of a New Sensor. *Critical Care Medicine*, **33**, 2203-2206. https://doi.org/10.1097/01.CCM.0000181734.26070.26
- [13] Rodriguez, P., Lellouche, F., Aboab, J., Buisson, C.B., Brochard, L., et al. (2006) Transcutaneous Arterial Carbon Dioxide Pressure Monitoring in Critically Ill Adult Patients. *Intensive Care Medicine*, **32**, 309-312. https://doi.org/10.1007/s00134-005-0006-4
- [14] McBride, D.S., Johnson, J.O. and Tobias, J.D. (2002) Noninvasive Carbon Dioxide Monitoring during Neurosurgical Procedures in Adults: End-Tidal versus Transcutaneous Techniques. *Southern Medical Journal*, 95, 870-874. <u>https://doi.org/10.1097/00007611-200295080-00018</u>
- [15] Roediger, R., Beck-Schimmer, B., Theusinger, O.M., Rusch, D., Seifert, B., et al. (2011) The Revised Digital Transcutaneous PCO₂/SpO₂ Ear Sensor Is a Reliable Noninvasive Monitoring Tool in Patients after Cardiac Surgery. *Journal of Cardio*thoracic and Vascular Anesthesia, 25, 243-249. https://doi.org/10.1053/j.jvca.2010.06.021
- [16] Bland, J.M. and Altman, D.G. (2010) Statistical Methods for Assessing Agreement between Two Methods of Clinical Measurement. *International Journal of Nursing Studies*, 47, 931-936.
- [17] Giavarina, D. (2015) Understanding Bland Altman Analysis. *Biochemia Medica*, 25, 141-151. <u>https://doi.org/10.11613/BM.2015.015</u>
- [18] Zasa, M., Leone, S., Gatti, M., Malagutti, G. and Cicciarella, L. (2006) Transcutaneous Carbon Dioxide Monitoring during Controlled Mechanical Ventilation. American Society of Anesthesiologists Annual Meeting 2006, Abstract A480.
- [19] Mizushima, A., Nakamura, A., Kawauchi, Y., Miura, K., Fujino, S., *et al.* (2003) [Transcutaneous Carbon Dioxide and Oxygen Measurement in Patients Undergoing Microlaryngosurgery with High Frequency Jet Ventilation.] *Masui*, **51**, 1331-1335.
- [20] Personal Communication from J. Wirajendi, Product Manager, SenTec AG, Therwil, Switzerland, 7 June 2016.

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