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Inadequacy of Pulse Oximetry in the Catheterization Laboratory. An Exploratory Study Monitoring Respiratory Status Using Arterial Blood Gases during Cardiac Catheterization with Conscious Sedation

Zaher Fanari [a,b,*], Asim A. Mohammed [a,c], Jaya D. Bathina [a], Desiree T. Hodges [a], Kelsey Doorey [a], Nicholas Gagliano [a], Kirk N. Garratt [a], William S. Weintraub [d], Andrew J. Doorey [a]

[a] Division of Cardiology, Christiana Care Health System, Newark, DE, United States of America
[b] Heartland Cardiology/Wesley Medical Center, University of Kansas School of Medicine, Wichita, KS, United States
[c] Division of Cardiology, Medical College of Wisconsin, Milwaukee, WI, United States of America
[d] Division of Cardiology, MedStar Washington Hospital Center, Washington, DC, United States of America

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ABSTRACT

Background: Benzodiazepines and opioids are commonly used for conscious sedation (CS) in cardiac catheterization laboratory (CCL) patients. Both drugs are known to predispose to hypoxemia, apnea and decreased responsiveness to PCO_2, resulting in decreased arterial pH and PO_2, as well as increased PCO_2. We want to determine the effects of CS on arterial blood gas (ABG) in CCL patient, and identify if pulse oximetry monitoring is adequate.
Methods: We enrolled 18 subjects undergoing elective catheterization. Measurement of ABGs at one-minute intervals was done from the moment of arterial access until case end. The results of ABGs were not available to the clinician who administered sedation. Relationships of pH, PCO_2, PaO_2 and SaO_2 were studied by plotting time series graphs. Significant changes were defined as pH <7.30, SaO_2 < 90, and PCO_2 > 50 mmHg.
Results: No significant change in pH, PCO_2, PaO_2 and SaO_2 was noted in 4/18 (22%) subjects. A significant drop in SaO_2 was noted in 4/18 (22%). A significant change in PCO_2 and/or pH was noted in 10/18 (55%) cases. Among the 16 (16/18) subjects receiving supplemental oxygen, 7 (7/18, 39%) had no drop in SaO_2, but developed respiratory acidosis. At the end of the case, 5/18 (28%) subjects had respiratory acidosis with normal PaO_2.
Conclusion: Significant hypercarbia and acidosis occurred frequently in this small study during CS in patients undergoing cardiac catheterization. Relying on pulse oximetry alone especially with patients on supplemental oxygen may lead to failure in detecting respiratory acidosis in a significant number of patients.

1. Background

Conscious sedation (CS) with benzodiazepines in combination with opioids is commonly used in cardiac catheterization laboratory (CCL) patients. The benzodiazepines variably [1,2] and all opioids consistently [3] decrease the spontaneous minute ventilation and the slope of the ventilatory response to carbon dioxide (CO_2) in a dose dependent fashion. A reduction in ventilatory response to hypoxemia has also been evidenced with both classes of medications [3–5]. The combination of benzodiazepines and opioids has been shown to predispose to hypoxemia, apnea and decreased responsiveness to CO_2, resulting in an increase in PCO_2 and a decrease in arterial pH and PO_2 [6]. Myocardial tissue is sensitive to changes in extracellular pH and hypoxemia, which can result in impaired contractility and electrical instability [6–9].

However, in the CCL, ventilatory status is not specifically monitored as the patient's respiratory status is usually monitored only by continuous pulse oximetry. But ventilator status is increasingly assessed during conscious sedation outside of the CCL with the use of capnography. In fact some CCL are now required to use capnography, likely because of a Joint Commission requirement for this in some setting [10]. But cardiologists are often skeptical of the need for yet another monitor in the CCL setting, given the long history of conscious sedation in this setting without ventilator monitoring and the perceived low incidence of significant ventilatory impairment. The purpose of this small exploratory study was to determine the effects of CS on ventilation by measuring arterial blood gases (ABGs) in CCL patients. In addition, by simultaneously measuring oxygenation and ventilation, we could assess if pulse oximetry monitoring alone is adequate in monitoring respiratory status during CS. It is known that O_2 saturation can remain normal when supplemental oxygen is used, as it often is during CS in the CCL, even

* Corresponding author at: University of Kansas School of Medicine- Wichita, Wichita, KS, Heartland Cardiology/Wesley Medical Center Structural Program, 551 N. Hillside, Suite 520, Wichita, KS 67214, United States of America.
E-mail address: zfanari@gmail.com (Z. Fanari).

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when hypercarbia has occurred. [11–14] To our knowledge, this direct measurement of ABGs has not been studied in the CCL setting during CS.

2. Methods

Our study was designed to be a prospective, observational evaluation of the effects of sedation on ABGs in cardiac catheterization patients. The study was approved by IRB. Informed consent was obtained from all subjects. Subject data were collected in a secure electronic spreadsheet system via the Intranet and kept on a secure drive. The investigators vouch for the accuracy and completeness of the recorded data.

2.1. Study population

Patients undergoing non-emergent cardiac catheterization were enrolled at a single academic center. The patients were not consecutive catheterization patients. In our laboratory >95% of patients receive intravenous sedation, typically a short-acting narcotic and a benzodiazepam. Pregnant patients, hemodynamically unstable patients, patients requiring mechanical ventilation, and patients requiring agents other than intravenous benzodiazepines and opioids were excluded. All patients were assessed for existing diagnoses of COPD and obstructive sleep apnea, and were also evaluated by the STOP-Bang sleep apnea questionnaire [7].

Subjects were fasting for at least 6 h before the scheduled procedure. Each subject was allowed to acclimatize to the cath lab environment before baseline recordings of sedation level, vital signs and pulse oximetry were conducted. Following the insertion of an arterial sheath in the femoral artery, continuous measurement of ABGs at one-minute intervals was conducted until the end of the case. Arterial blood was extracted from the side arm of the sheath. Aliquots of approximately 0.5 mL were used to run blood gases on the I-stat (Abbott, Princeton, NJ) system, and the maximum amount of blood used for each patient's analysis was 30 cc. All blood extracted from the sheath, except the 0.5 mL used for each analysis, was flushed back into the sheath. One dedicated research person silently performed ABG sampling using a small-bore extension tube from the foot of the bed opposite the operator. The volume of this tubing was approximately 3 mL, and at least 8–10 mL was withdrawn from the system before each sample was extracted. The process was out of the direct sight line of the catheterization operator in order to minimize any disruption of cardiac procedures. Three I-stat machines were used simultaneously so there was no wait for sample measurement. The process of withdrawing the blood, flushing the access line, inserting the cuvette for ABG analysis and awaiting the analysis took approximately two minutes. All results were immediately uploaded into the Christiana Care clinical laboratory computer to minimize the need for any record keeping during the withdrawal process. The procedure start was time stamped as were all analyzed samples to allow correlation of the values with the case times, i.e. beginning and end of case, and administration of sedation). The I-stat machines were calibrated biannually according to the CCHS Laboratory protocol, and each batch of cartridges were tested for linearity.

All vital signs, along with transcutaneous O_2 saturation, were monitored continuously and automatically by the cath lab computer system. Administration of all sedatives was recorded and timed. The results of ABG determinations were not available to the cardiologist performing the catheterization and the researchers did not communicate with the operators during the procedure. Operators were instructed to perform the procedures in their typical fashion in all respects, especially to give CS per their usual protocol. Supplemental oxygen was similarly used at the discretion of the operators. There were no CCL protocols mandating oxygen.

2.2. Study definitions and data analysis

Relationships of pH, arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide (PCO_2), and percent saturation of arterial hemoglobin by oxygen (SaO_2) measured by pulse oximetry were studied by plotting time series graphs. Significant changes were defined as pH <7.30, SaO_2 < 90 and PCO_2 > 50 mmHg. For analysis, subjects were initially divided into those with normal or abnormal function. The Normal group was defined as subjects who did not develop significant changes in ABG values as described above at any time during the case. The abnormal subjects were divided further into 3 groups, composed of subjects with hypoxia alone (Hypox group), those with both hypercarbia/acidosis and hypoxia (Hypercarb+Hypox group), and those with hypercarbia/acidosis alone (Hypercarb group). Continuous variables are reported as means and ranges, categorical variables as percentages (summarized as frequency (%)). Differences in demographic and clinical variables were analyzed by linear regression for continuous variables using student's *t*-test or logistic regression for dichotomous variables using $\chi 2$ test. ANOVA test was used to compare STOP-Bang scores.

3. Results

We studied 20 subjects during catheterization, although ABG data upload was unsuccessful in two of the subjects due to technical difficulties. The data from the remaining 18 with successful data upload constitutes our study population (Table 1). Of these, 16 were on supplemental O_2, begun before arterial access was obtained in 12 and after desaturation occurred in 4. All subjects received some CS during the procedures, typically a combination of fentanyl and midazolam, with a range of 1–8 occasions at which sedatives were given. Pulse oximetry tracked the directly measured ABG oxygen saturation.

No patient had pharmacologic reversal of the sedatives during the case. In patients not on baseline supplemental oxygen, oxygen by nasal cannula was added if significant pulse oximetry desaturation occurred. Operators were not aware of any of the blood gas analysis results, so no response to hypercapnia occurred.

The Normal group included 4/18 (22%) subjects without significant change in pH, PCO_2 and PaO_2 (Fig. 1). The remaining 14/18 subjects had significant change in pH, SaO_2 or PCO_2. When compared to Normal group, the pooled abnormal subjects were older and had more subjects with higher BMI, COPD and OSA and Stop Bang scores (Table 1).

The Hypox group consisted of 4/18 subjects (22%; Fig. 2). In all of these cases, the hypoxia was treated successfully with the application of supplemental O_2. The Hypercarb group consisted of 8/18 subjects (44%), in whom hypercarbia evolved despite normal oxygen saturations, all in the setting of O_2 supplementation (Fig. 3). The Hypercarb +Hypox group consisted of 2/18 subjects, in whom repeated episodes of hypercarbia and hypoxia were noted. These 2 subjects were the only subjects not on supplemental O_2 (Fig. 4).

Overall, supplemental O_2 was used in 16/18 subjects. Hypercarbia developed at some time during the case in 10/18 (56%) of subjects. At the end of the case, when arterial access was discontinued and subjects typically went to a recovery area, 5/18 (28%) subjects, all on supplemental O_2, had hypercarbia with normal SaO_2. (Fig. 5).

Acidosis developed in 7 subjects, all in the Hypercarb group. The lowest pH recorded was 7.24. The highest PCO_2 recorded was 57. The average STOP-bang scores were higher in the abnormal groups, but due to small sample size, it was statistically non-significant ($P = 0.89$).

No subject had any adverse outcomes requiring activation of the rapid response team during or after the catheterization.

4. Discussion

In this small exploratory study, ventilatory impairment as assessed by hypercarbia occurred in a substantial percentage of unselected patients undergoing cardiac catheterization with CS. Unfortunately, supplemental Oxygen may mask this ventilatory issues if only pulse oximetry is being used to monitor respiratory function. These respiratory abnormalities are not necessarily surprising given the comorbidities of

Table 1
Baseline and procedural characteristics of consecutive patients.

Characteristics:	All subjects N = 18	Normal group N = 4	HYPOX group N = 4	HYPERCARB group N = 8	HYPOX + HYPERCARB N = 2	*P* value
Age (mean)	64 (45–84)	61(46–76)	75 (66–84)	61 (45–68)	59 (50–680	0.18
Males	56%	25%	25%	75%	50%	0.13
BMI > 28	72%	75%	0%	63%	100%	0.07
COPD	6%	0%	0%	0%	0%	0.91
OSA	6%	0%	0%	13%	0%	0.11
Neck circumference > 17 Male, 16 Female	6%	0%	0%	13%	0%	0.09
Mallampati score	1.8	1.5	2.0	1.8	2.5	0.8
Stop-Bang	4.4	3.75	4.25	4.75	5.5	0.87
Average procedure time (min)	27 ± 8	28 ± 7	27 ± 7	27 ± 6	28 ± 5	0.69
PCI Performed (number of case)	3	0	1	2	1	0.13
Average Contrast used (ml)	65	64	67	63	61	0.45
Average Total sedation Dose	Versed 1.0 ± 1.5 mg Fentanyl 50 ± 50 μg	Versed 0.5 ± 1.5 mg Fentanyl 50 ± 50 μg	Versed 1.0 ± 1.0 mg Fentanyl 50 ± 25 μg	Versed 1.0 ± 0.5 mg Fentanyl 50 ± 50 μg	Versed 1.0 ± 1.5 mg Fentanyl. 50 ± 50 μg	0.65

the patients undergoing cardiac catheterization such as obesity and increased Stop-Bang scores. Also, cardiologists are performing more complex and lengthy procedures requiring multiple rounds of sedation, as in our sample. Our study is unique in that arterial access allowed full documentation of the acid-base effects of respiratory changes, not dependent on oximetry or expired gas analysis alone.

CCL patients on supplemental oxygen are especially at risk for hypoventilation with hypercarbia since pulse oximetry, typically the only respiratory monitor used in this setting, is often normal and provides false reassurance to the operator. Almost half of our subjects had this scenario develop. Only 22% of subjects had no significant abnormalities in any ABG parameter during the procedure. Stable ABG during CS were associated with lower STOP-Bang scores, but such scores were not common among our subjects.

Hypoxia alone was noted in 22% of our cases. A drop in the SaO_2 was often noted within a few minutes of giving IV doses of both fentanyl and midazolam, likely secondary to blunting of the ventilatory response to hypoxia and easily reversed with supplemental O_2.

A more common complication of CS was hypercapnia and respiratory acidosis, presumably due to hypopnea, occurring at some time during the procedure in over half of our patients. Bailey et al. [6] showed apnea in 6 of 12 subjects receiving combination of fentanyl and midazolam and Qadeer and colleagues [11] found apnea in approximately one-half of cases of patients undergoing GI procedures under CS In our study, hypercapnia and respiratory acidosis was noted in 56% of cases.

Our data show that hypercapnia is especially problematic in subjects who receive supplemental O_2, since subjects on supplemental oxygen often had no drop in SaO_2 despite half of them developing significant hypercapnia. Furthermore, a sizeable minority of these cases left the lab in an unrecognized acidotic state despite continued normal oximetry readings. This failure of pulse oximetry to identify hypercapnia during administration of supplemental oxygen is well described in the literature [11–14]. But while Deitch et al. [14] reported a controlled trial in which there was no apparent advantage to using supplemental oxygen during CS for emergency department procedures, preventing hypoxia by supplemental O_2 has been shown to be effective in reducing ischemic EKG changes in cardiac patients undergoing gastrointestinal procedures [15]. In fact, the development of recurrent hypoxia and hypercarbia in the only two subjects in our study who did not receive supplemental O_2 suggests that withholding supplemental O_2 in this

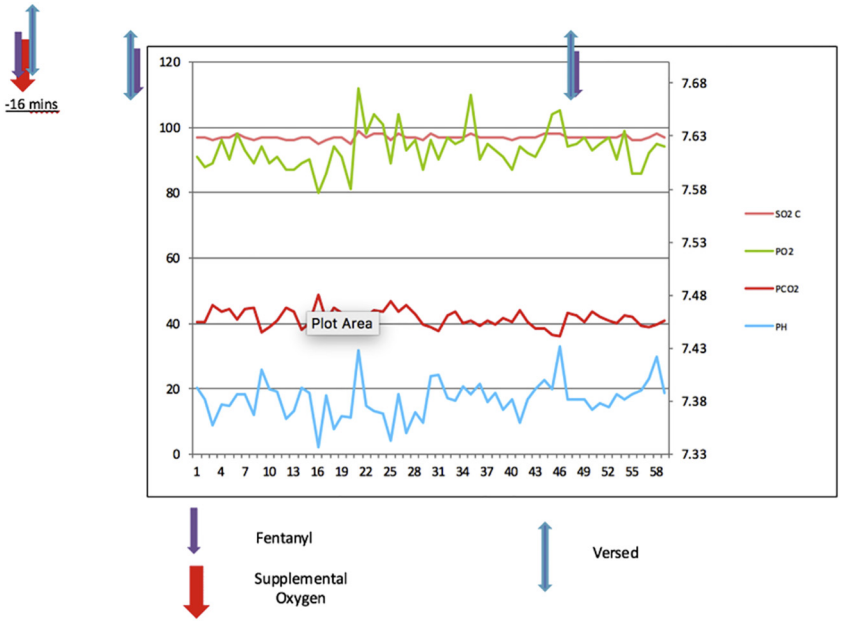

Fig. 1. Normal ABG Values Over The Entire Case (Normal Group). [Values are plotted against the Left Y axis except the pH, which is plotted against the Right Y axis. The Y axis for pH varies for each subject to afford figure legibility and avoid overlap of curves].

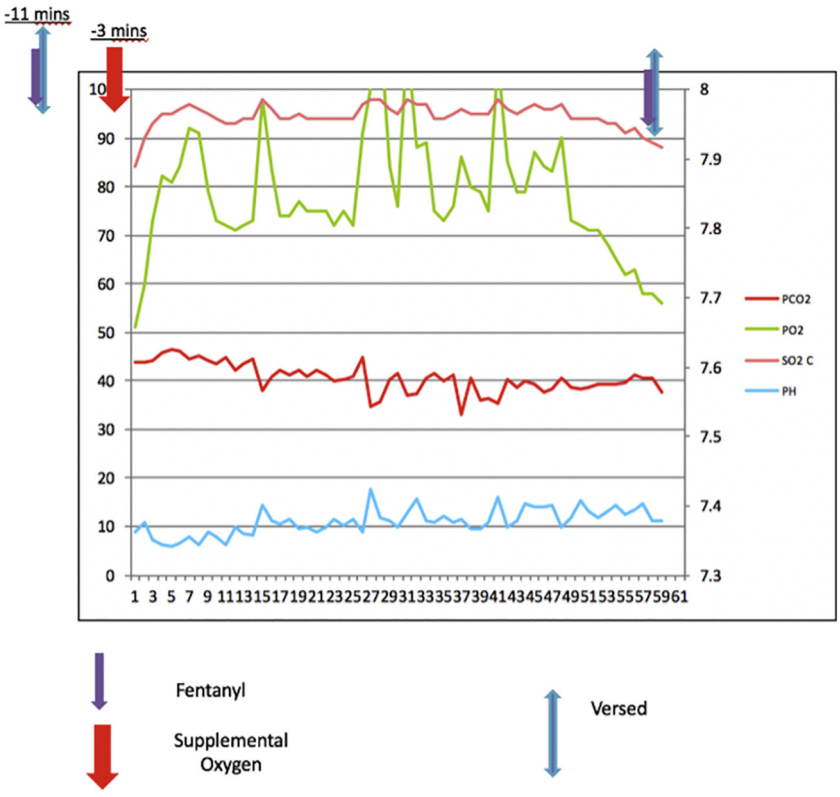

Fig. 2. Decreasing PO2 with No Hypercarbia or Acidosis (Hypox Group). [Values are plotted against the Left Y axis except the pH, which is plotted against the Right Y axis. The Y axis for pH varies for each subject to afford figure legibility and avoid overlap of curves].

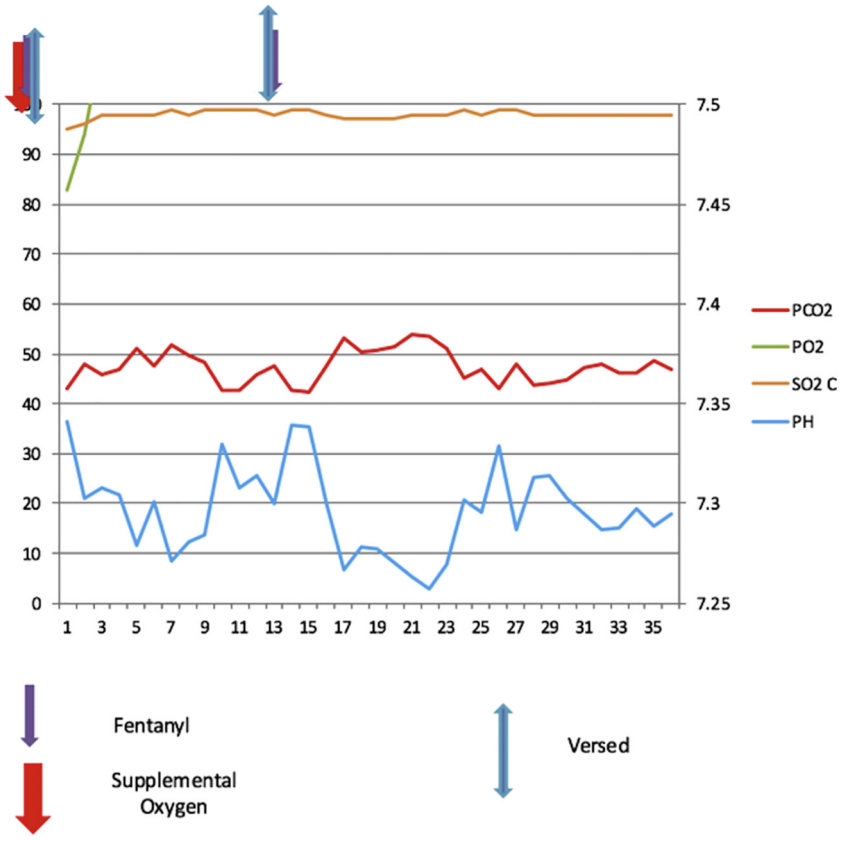

Fig. 3. Stable PO2 with Hypercarbia and Acidosis (Hypercarb Group). [Values are plotted against the Left Y axis except the pH, which is plotted against the Right Y axis. The Y axis for pH varies for each subject to afford figure legibility and avoid overlap of curves].

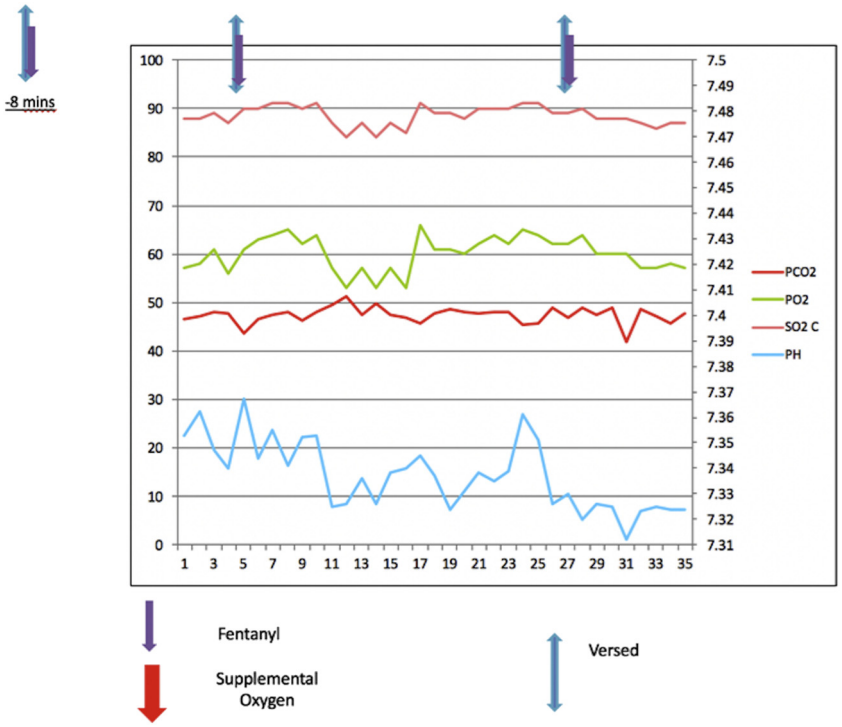

Fig. 4. Decreasing PO2, Hypercarbia And Acidosis. (Hypox+Hypercarb Group) [Values are plotted against the Left Y axis except the pH, which is plotted against the Right Y axis. The Y axis for pH varies for each subject to afford figure legibility and avoid overlap of curves].

population may be undesirable, and its frequent use in the CCL setting may be reasonable. But in patients undergoing catheterization, it is uncertain what the risk/benefit profile is for maintaining oxygenation, often at the expense of hypoventilation. While pulse oximetry is often felt to be "better than nothing" in that in can alert to hypoxic hypoventilation, the limitations during supplemental O_2 in this setting

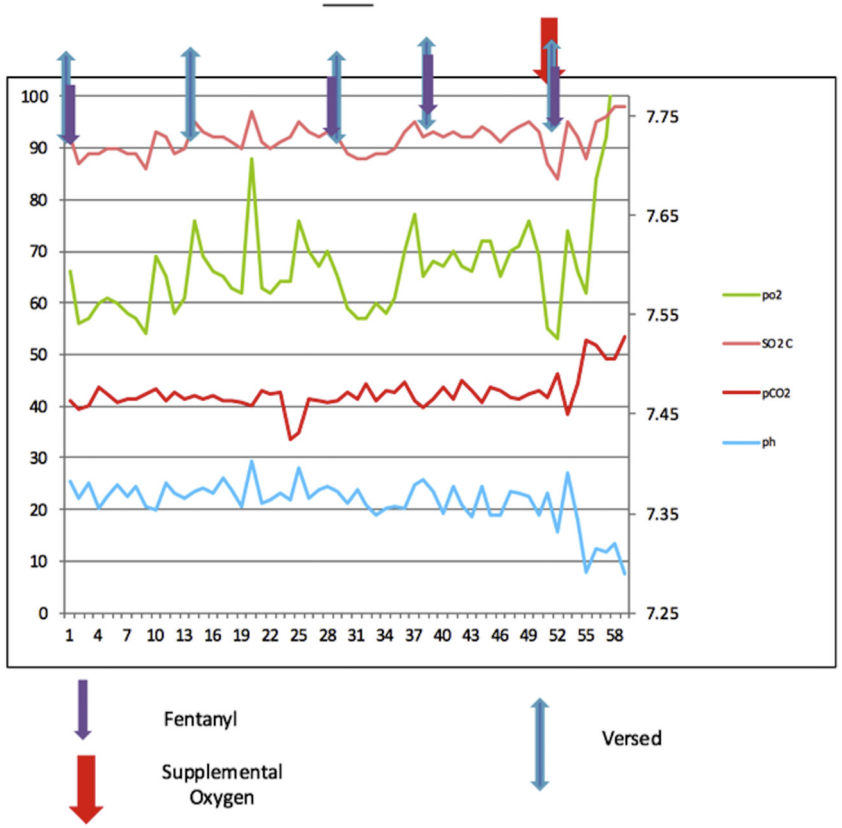

Fig. 5. Worsening Hypercarbic acidosis at end of case. [Values are plotted against the Left Y axis except the pH, which is plotted against the Right Y axis. The Y axis for pH varies for each subject to afford figure legibility and avoid overlap of curves].

must be recognized. This may be why supplemental O_2 during CS is associated with adverse outcomes in some settings [16].

Our study did not reveal any obvious clinical deterioration despite the recorded ABG abnormalities. The risks of moderate hypercarbia in cardiac patients have not been well described, in part because of the historic difficulty in measuring ventilation. The existence of acute myocardial ischemia, often present in the CCL, may also effect this risk. Much more profound hypercarbia has been shown to have cardiovascular sequelae in experimental situations [8,17].

But patient deterioration, if it does occur in the CCL, may be incorrectly attributed to the underlying cardiac issues in these patients. Although our study numbers are quite small, we do know of several "near misses" (in patients not in our study) in our recovery area where respiratory depression led to obtundation, requiring acute intervention. We do not believe this sort of problem has been tracked systematically in published studies of CCL complications.

CS is commonly given by cardiologists in the CCL, but they are often not extensively trained to perform CS nor to monitor ventilation. The American Society of Anesthesiologists (ASA) consensus statement for non-anesthesiologists recommends monitoring oxygenation continuously by pulse oximetry, and ventilation continually or periodically when providing moderate (conscious) sedation [18]. Some techniques suggested by the ASA such as "monitoring of ventilatory function by observation or auscultation "are not practical in the CCL since the subject's chest is typically covered by a sterile drape, making observation and access difficult for CCL staff. In fact even if possible, these methods may not be adequate. Vargo et al. have shown the insensitivity of clinical assessment in detecting procedure-related hypercapnia [19]. In their study, apnea or disordered respiration was rarely suggested by clinical evaluation alone.

Ultimately, most CCLs only monitor respiratory function using only pulse oximetry and do not formally monitor ventilation. It is difficult to determine the safety impact of this practice since in a literature search; we could not find any studies addressing complications related to CS in the CCL. Many cardiologists do not strongly consider respiratory or secondary acid-base imbalances when a patient is unstable during or post cardiac catheterization, especially when given the reassurance of normal oxygen saturation. This was illustrated in a large study by West et al. [20] in a study of 211,645 diagnostic cardiac procedures, which reported a complication rate of 7.4/1000 cases with a detailed list of cardiovascular, renal and allergic reasons accounting for majority of the complications. There was no mention of any complications related to CS. Most of the review articles on complications from cardiac catheterization do not list any complications related to CS [21,22] and such complications are not listed as a possible "adverse event" in the National Cardiovascular Data Registry database [23] The utility of capnography measurement during CS in the CCL is uncertain. As far as we know, no data exists on this practice.

But in the setting of non-cardiac procedures requiring CS, where this has been more explicitly studied, the incidence of cardiopulmonary complications secondary to sedation has been reported to be measureable. In 1995, Quine et al. [24] published an audit of upper gastrointestinal endoscopy in 14,149 patients in 36 UK hospitals. A mortality rate of 1:2000 and a morbidity rate of 1:200 were reported, primarily cardiorespiratory events related to poor sedation practice. A retrospective review of 324,737 endoscopic procedures performed under CS using the Clinical Outcomes Research Initiative (CORI) database showed a cardiopulmonary complication rate of 0.9% related to sedation [16]. Thus it is possible that in the CCL, a finite rate of complications exists due to CS, possibly masked or confounded by the underlying cardiac illnesses being studied. Finally, benzodiazepines and opioids have helped with radial spasm and are being used to help with this increasingly utilized access technique as well as for CS [25]. We used only femoral access to facilitate blood drawing, so it is possible we have underestimated the effects of sedation for patients who would be done radially.

Limitations: Our sample size was small and from one institution. Confirmation of these findings in a larger series would be important, although the resource requirement for this type of study makes large scale adoption probematic. Sedation administration in our patients was not controlled by protocol, rather given per the usual practice of the attending physicians.

5. Conclusion

In conclusion, in this small exploratory study we have shown that hypercarbia was detected frequently by ABGs among patients undergoing cardiac catheterization under CS. Patients on supplemental oxygen appeared to be at increased for hypoventilation, as the pulse oximetry readings were often normal providing false reassurance to the operator. Assessment of ventilation by capnography may be useful in higher risk patients in the CCL, especially when receiving CS and supplemental O2.

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