

Clinical Workshop

C. PHILIP LARSON, JR., M.D., *Editor*

Errors in Sampling Pulmonary Arterial Blood with a Swan-Ganz Catheter

H. M. SHAPIRO, M.D.,* G. SMITH, M.D.,† A. H. PRIBBLE, M.D.,‡ J. A. MURRAY, M.D.,‡
F. W. CHENEY, JR., M.D.‡

With increasing frequency, the Swan-Ganz catheter is being employed in critical care units for the collection of mixed venous blood, thereby permitting determination of cardiac outputs with the Fick technique when oxygen consumption is simultaneously measured.¹⁻² This balloon-tipped catheter is positioned by a flow-directed technique in the absence of fluoroscopic control, and pressure tracings are used to determine its location in the pulmonary vasculature. On occasion, we have noted apparently inappropriately high mixed venous oxygen tensions ($P\bar{V}O_2$) in samples obtained from the Swan-Ganz catheter in critically ill patients and during animal studies. Other investigators have indicated similar findings in their patients.⁴ Such contamination would result in erroneously high calculated cardiac outputs.

While it is common knowledge that mixed venous blood obtained from the most distal ramifications of the pulmonary artery is subject to contamination due to retrograde withdrawal of pulmonary capillary blood into the sample,¹ the presence of a pulmonary-artery

pressure trace is supposed to preclude this sampling artifact. The present controlled study was performed to see whether artifacts of mixed venous sampling could be obtained with this catheter in the presence of well-defined pulmonary arterial pressure tracings in dogs and man. Recently it was reported that pulmonary "wedge" samples have a lower P_{CO_2} than that found in the true mixed venous blood ($P\bar{V}CO_2$). This phenomenon was evaluated to ascertain whether it might improve our ability to detect sampling errors with use of the Swan-Ganz catheter.⁵

METHODS

Canine. Nine dogs (body weights approximately 25 kg) were anesthetized with pentobarbital (30 mg/kg) and ventilated with pure oxygen via a Harvard respirator adjusted to maintain P_{aCO_2} 35–40 torr. Muscular relaxation was obtained by intravenous injection of succinylcholine, 20–40 mg. Two Swan-Ganz catheters (#5 French) were inserted via the external jugular veins into the pulmonary artery, and intravascular pressures were measured with a common transducer (Statham P23BC). The tip of one catheter (the static catheter) was positioned just distal to the pulmonary valve, and the other (the mobile catheter) was advanced to the wedge position using the flow-directed technique with the balloon inflated. Samples were obtained from the mobile catheter in the following positions:

Position	Location Determined by Pressures
1	Catheter inserted into the wedge position with balloon inflated

* Assistant Professor, Department of Anesthesia, University of Pennsylvania.

† Instructor.

‡ Associate Professor.

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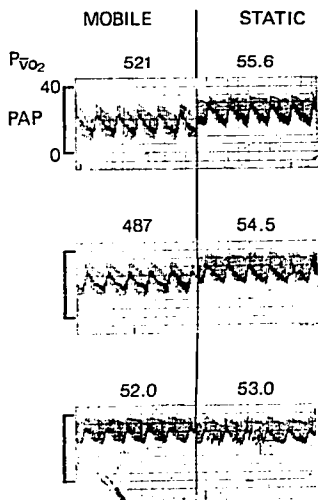


FIG 1. Comparison of oxygen tensions (torr) and pulmonary arterial pressures (cm H₂O) obtained simultaneously with two Swan-Ganz catheters in the dog whose data are given in table 1. From above downward, the mobile catheter (balloon deflated) is in positions 3, 4, and 5 as defined in the text.

- 2 Same position as 1, with the balloon deflated
- 3 Catheter manipulated to a position of damped pulmonary arterial tracing, balloon deflated (fig. 1, top left trace)
- 4 Catheter withdrawn from position 3 until a good pulmonary arterial pressure tracing was obtained, balloon deflated (fig. 1, middle left trace)
- 5 Further withdrawn from 4 to approximately the same position as the static catheter, balloon deflated (fig. 1, bottom left trace)

With each sample from the mobile catheter, blood was withdrawn from the static catheter for comparison. Blood samples were obtained by the same technique from both catheters

and analyzed for P_{aO_2} , P_{aCO_2} and pH on an Instrumentation Laboratories 113 analyzer, which was calibrated between each two determinations. Oxygen consumption was measured directly by means of a Collins spirometer, and cardiac output was computed from the Fick equation. In one animal, cardiac output was measured by the dye-dilution technique, employing indocyanine green.

Human. Nine patients referred for cardiac catheterization underwent right heart catheterization with a #5 or #7 Swan-Ganz flow-directed catheter, using both fluoroscopic and pressure monitoring of position as part of clinically indicated diagnostic procedure. Only one catheter was used, and it was defined as the mobile or static catheter according to its position to permit comparison with the canine study. Blood samples (0.5 ml) were obtained from catheter positions similar to those employed in the canine study with the patients breathing room air. Oxygen saturations were immediately measured photometrically (American Optical Model #182) and the samples iced for later measurement of P_{O_2} and pH on the same electrodes used for the canine study. In both canine and human studies a low-negative-pressure sampling technique was used to avoid extraction of oxygen (in bubbles) from the blood.

RESULTS

Canine. The most striking evidence of contamination of mixed venous samples with arterialized blood pulled back from pulmonary capillaries was seen in blood from one dog (table 1), in which there was a difference in P_{vO_2} of more than 400 mm Hg between the samples taken from static and mobile catheters. As shown in figure 1, despite some improvement in the fidelity of the pulmonary arterial trace when the mobile catheter was manipulated from position 3 (top left trace, "damped") to position 4 (middle left trace, "improved") considerable pulmonary arteriovenous admixture remained. In a second dog, a difference in P_{vO_2} of 15 torr between the blood samples from static and mobile catheters in position 2 was found in the presence of a good pulmonary arterial trace. In a third dog, for which dye-dilution cardiac-output measurements were obtained, blood of

TABLE 1. Comparison of Pressures and Blood Oxygenation Obtained by Sampling with Swan-Ganz Catheters in the Main Pulmonary Arterial Outflow Tract (Static) and More Distally (Mobile) in the Pulmonary Arterial Vasculature of a Dog, $F_{I_{O_2}} = 1.0$

Position of Mobile Catheter	Mobile Catheter			Static Catheter		
	Pressure (cm H ₂ O)	P _{O₂} (torr)	Calculated O ₂ Content (ml/100 ml)	Pressure (cm H ₂ O)	P _{V_{O₂}} (torr)	Calculated O ₂ Content (ml/100 ml)
1	15/5	445	23.09	30/15	62	17.74
2	22/9	477	23.19	32/15	56	16.86
3	22/9	521	23.33	33/18	55	16.74
4	27/13	487	23.32	35/20	53	16.59
5	37/22	52	16.02	36/21	53	16.13

high $P\bar{V}_{O_2}$ was obtained in the presence of good pulmonary arterial pressure tracings. For this animal, cardiac outputs calculated by the Fick method using the oxygen contents ranged from 1.98 to 10.82 l/min, while dye-dilution measurements indicated that the actual range was 1.93 to 2.78 l/min. This wide divergence of results between simultaneous dye-dilution and Fick methods was caused by the falsely high "mixed venous" oxygen contents calculated from the artifactual $P\bar{V}_{O_2}$ data. In the six remaining dogs blood samples drawn from the mobile catheter in positions 2 through 5 had essentially the same P_{O_2} 's as the samples drawn from the static catheter. Blood samples drawn with the balloon inflated were contaminated with pulmonary capillary blood in all animals.

When admixture occurred to the extent that the oxygen saturation and P_{O_2} differences between blood samples taken from the proximal and distal pulmonary-artery catheters were more than 3 per cent or 10 torr, there was a distinct decrease in the P_{CO_2} of the "mixed venous" blood from the distal catheter compared with CO_2 tensions in blood from the more proximal pulmonary sampling site or with systemic arterial values. Figure 2 demonstrates the reduction in the CO_2 tension of the "mixed venous" sample that occurred when evidence of contamination (elevation of $P\bar{V}_{O_2}$) with pulmonary capillary blood was present.

Human. Only when the catheter was in the wedge position with the balloon inflated was it possible to obtain mixed venous samples contaminated with pulmonary capillary blood. Contamination was defined as an oxygen

content increase of more than 0.5 ml/100 ml of blood in a distally obtained sample compared with a sample taken from the proximal main pulmonary artery.

DISCUSSION

It is important to appreciate that in dogs, blood of a higher oxygen tension than mixed pulmonary venous blood may be withdrawn from the flow-directed catheter in the presence of acceptable pressure values and waveforms indicative of a pulmonary arterial tracing. This artifact was demonstrated in three of nine dogs. In our nine human studies, contaminated mixed-venous blood was not sampled with the distally situated catheter with the balloon deflated. However, in their series of 20 patients, Suter *et al.* found increases in $P\bar{V}_{O_2}$ in samples from segmental or subsegmental branches of the pulmonary artery with the balloon deflated.⁴ They used radiographic control of catheter position and did not specify pulmonary arterial pressure waveform. As expected,⁶ we found that blood taken from the "wedge" position (balloon inflated) in dog or man was contaminated with pulmonary capillary blood.

In dogs the increased incidence of pulmonary arteriovenous admixture in blood obtained with the Swan-Ganz catheter may be the result of the ease with which the catheter "wedges" due to the smaller size of the canine lung. Additionally, the dogs were anesthetized, receiving positive-pressure ventilation, and breathing pure oxygen. The first two factors could cause capillary contamination of the mixed venous samples, and the third factor would magnify any capil-

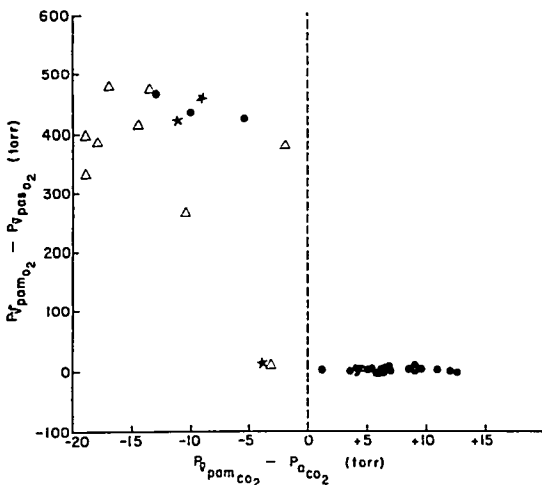


FIG. 2. Increase in "apparent" mixed venous blood oxygen tension sampled from the peripheral Swan-Ganz catheter (PAM) is accompanied by a decrease in the $\overline{P_{CO_2}}$ of the same sample. This is demonstrated as the difference between the mixed venous oxygen tensions ($\overline{P_{V_{O_2}}}$) obtained from the distally (PAM) and proximally (PAS) situated catheters (ordinate) vs. the difference between the arterial carbon dioxide tension ($\overline{P_{a_{CO_2}}}$) and the mixed venous $\overline{P_{CO_2}}$ sampled from the distal (PAM) catheter (abscissa). Δ = wedged; \bullet = incomplete wedge (damped pulmonary artery tracing); \circ = acceptable pulmonary arterial pressure and waveform.

lary contamination. However, our canine findings may be applicable to man in some situations. This artifact may occur in patients in whom the balloon catheter is left in place for extended periods with ample opportunity for "uncoiling" and migration into smaller or more peripheral pulmonary vessels despite secure anchoring of the catheter at the skin. Suter suggests that distally situated catheters may sample higher oxygen contents due to pulmonary capillary admixture or to diffusion of alveolar gas through the wall of a small vessel.⁴ The admixture error may be further enhanced by the application of too much negative pressure on the sampling syringe, causing the catheter to "pop" into the wedge position during sampling when the pressure trace from the catheter is unavailable for monitoring. During cardiogenic shock, the situation which prompted the present study, it may be easier to withdraw pulmonary capillary blood through catheters.

While grossly contaminated mixed samples can be easily recognized, situations in which the validity of the sample is not easily determined could develop. Therefore, examination of the relationship between $\overline{P_{V_{CO_2}}}$

and $\overline{P_{a_{CO_2}}}$ might provide further aid in validating the sample. Artifactual depression of $\overline{P_{V_{CO_2}}}$ relative to $\overline{P_{a_{CO_2}}}$ obtained from a wedged catheter may be the result of sampling from a localized segment of lung with a high ventilation-to-perfusion ratio distal to the catheter.⁵ This phenomenon has been found in man⁵ and, as our study demonstrates, also exists in dogs (fig. 2). In any case, when ventilation has been stable for more than 10 minutes, a $\overline{P_{V_{CO_2}}}$ equal to or lower than a simultaneous $\overline{P_{a_{CO_2}}}$ suggests contamination of pulmonary arterial blood by pulmonary capillary blood. Blood drawn from atelectatic areas of lung would not be subject to this artifact since equilibration with alveolar gas is prevented.⁴

The canine studies emphasize that dynamic pressure recordings of "acceptable" pulmonary arterial pressures before and after sampling do not always assure a true mixed venous sample. This study points out the difficulties which can be associated with the interpretation of pulmonary arterial pressure traces and demonstrates the need for care in obtaining and interpreting blood samples obtained from the pulmonary vasculature with the Swan-Ganz catheter.

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Prolonged Neuromuscular Blockade with Pancuronium Bromide in a Young Healthy Woman

MELVIN A. BELAFSKY, M.D.,* AND HAROLD L. KLAWANS, JR., M.D.†

Prolonged neuromuscular blockade caused by nondepolarizing neuromuscular blocking agents is an unusual complication of anesthesia. When this occurs it is usually considered to be related to one or more of a variety of complicating factors. The following case report, in which this response occurred after the use of a relatively new drug, pancuronium bromide (Pavulon), illustrates the occurrence of prolonged blockade in a healthy patient without known contributing factors. This has not been previously reported with this drug.

REPORT OF A CASE

A 21-year-old woman was admitted to Presbyterian-St. Luke's Hospital with symptoms of severe lower abdominal pain for one month. Physical examination revealed moderate obesity (weight 157 lb), lower abdominal tenderness, and an exquisitely tender left adnexal mass. A diagnosis of ovarian cyst was made and the patient was scheduled for exploratory laparotomy. Current medications included diethylpropion hydrochloride (Tepanil) for diet control, iron supplements, and Demulen for birth control. The patient was allergic to penicillin. This was her first operation, although she had received general anesthesia without complications

one time for a dental procedure. Preoperative laboratory studies showed a hematocrit of 36 per cent, hemoglobin 12 g/100 ml, and normal serum electrolytes, BUN, and PBI.

Preanesthetic medication included meperidine, 50 mg; diazepam, 5 mg; and atropine, 0.4 mg, administered intramuscularly two hours prior to induction of anesthesia. Anesthesia was induced with thiopental, 250 mg iv, followed by pancuronium bromide, 6 mg iv, to facilitate endotracheal intubation. Anesthesia was maintained with nitrous oxide-oxygen, 1.5 liters each, and furoxene 4-6 per cent, delivered through an in-line vaporizer (Vermil). Incremental doses of pancuronium, 1 mg, were given 20 and 60 minutes after induction of anesthesia. The additional two doses of one milligram each of pancuronium were administered to facilitate abdominal muscle relaxation. Vital signs were stable throughout the 90-minute procedure. At the end of the procedure reversal of neuromuscular blockade was attempted twice, 10 minutes apart, with a total of 5 mg prostigmine and 4.2 mg atropine in divided doses. The patient was transferred to the post-anesthesia recovery room. Due to infrequent respirations, the endotracheal tube was left in place and respiration was controlled with a Bennett respirator. The patient had made no respiratory effort prior to the administration of neostigmine, and those efforts made after its administration were both infrequent and weak. The blood pressure was 160/70 torr and the pulse rate 116/min. The patient had normal color, weak grasp, and weak lid lift.

Two hours after operation, the patient was able to open her eyes and move her extremities. Four hours after completion of the operation, the patient was moving all extremities and responding adequately to verbal stimulation. At that time the trachea was extubated and the patient was able to exchange air well without difficulty. Catheterization of the bladder produced a urine volume of 150 ml. The

* Intern, Los Angeles County-Harbor General Hospital, Torrance, California.

† Director, Division of Neurology, Michael Reese Medical Center, 29th & Ellis, Chicago, Illinois 60616.

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Address reprint requests to Dr. Klawans.