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Frequency of technical problems encountered in the measurement of pulmonary artery wedge pressure

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A total of 2711 pulmonary artery wedge pressure (WP) measurement attempts were made prospectively from WP recordings in 44 (30 men) critically ill patients, using 77 flow-directed catheters. Of these, 322 (12%) failed to yield a WP measurement, and 521 (18%) were associated with technical problems. One half of these technical problems were due to poor dynamic response or damped pressure tracings; other problems included balloon overinflation, partial WP, and inability to aspirate blood from the pulmonary artery (PA) port. Only 50% of wedge blood sampled at the time of initial PA catheterization yielded capillary blood ($P_{O_2} \geq 10$ torr higher than Pa_{O_2}). In 12 stable patients in whom paired measurements were available, there were clinically important differences (−13 to +22 torr) between paired WP measurements made before and after rapid correction of technical problems. Technical problems are common and may be associated with clinically important errors. Those due to poor dynamic response are easily and rapidly detected at the bedside.

The introduction of the balloon-tipped flow-directed catheter was followed by its widespread use in intensive care medicine.[1-10] Although the catheter can usually be easily passed into the PA, the measurement of WP is frequently unsuccessful. Rapaport and Dexter[11] reported that WP could be measured satisfactorily only about three quarters of the time in the cardiac catheterization laboratory, and Swan et al.[12] reported the same success rate with the balloon-tipped flow-directed catheter in both the cardiac catheterization laboratory and the ICU.

In the process of routinely recording WP waveforms in the Intermountain Respiratory ICU (IRICU), we encountered technical problems with disturbing frequency. Because many of these problems were associated with clinically important errors in WP measurement, we carried out a prospective study to determine the incidence with which technical problems are encountered during WP measurement in our ICU.

Five criteria have been used by cardiologists to assess the validity of WP measurements:

1. The mean WP must be less than the mean pulmonary artery pressure (PAP).[11,13]
2. The phasic WP recording must be consistent with an atrial pressure waveform.[11,13,14]
3. Free flow should be present with the catheter in the wedge position in order to ensure that the tip is not against a vessel wall.[11]
4. A palpable "give" or "jerk" should be detected as the catheter tip is pulled back from the wedge position.[13,14]
5. Highly oxygenated blood from the wedged catheter (high oxygen saturation [S_{O_2}] or high P_{O_2}) should be aspirated from the wedge position.[8,10-12,14-20] Although not mentioned by some workers[13] and dismissed by others,[1] this was considered by Rapaport and Dexter[11] to be the most important criterion.

MATERIALS AND METHODS

All WP measurements were obtained by specialized respiratory ICU nurses in the IRICU from May 19, 1979, to March 19, 1980. Triple-lumen, 7-Fr, flow-directed thermodilution catheters (Catalog No. 93A-301, American Edwards Laboratories, Santa Ana, CA 92711, or Catalog No. 44166, Instrumentation Laboratory, Inc., Lexington, MA 02173) were used with a continuous flush system (C.F.S., Intraflo, Sorenson Research Co., Salt Lake City, UT 84115).[21] Pressure (mm Hg) was measured with P23ID (Gould Inc., Statham Instruments Div., Oxnard, CA 93030) or Model 800 (Bentley Trantec, Irvine, CA 92705) pressure transducers and recorded simultaneously with the ECG at a paper speed of 25 mm/sec (1 mm/small division-all figures) with a direct-writing, 2-channel ink recorder (Model 2007, Gould, Inc., Instrument Division, Cleveland, OH 44114). Pressure transducers were statistically calibrated with a water column. All vascular pressures were measured manually at *end-expiration*[10] from *phasic* high fidelity (natural frequency ≥15 Hz; damping coefficient ≤.35) pressure *recordings* and averaged over several respiratory cycles. Patients were supine and the transducers were zeroed to atmospheric pressure at the midaxillary line[22] before each set of measurements. The WP was measured at end-expiration from the

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difference between the zero pressure level and the visually averaged WP recording. The pressure amplification system had a flat frequency response to 100 Hz.[23]

Technical problems associated with the PA catheter can lead to failure to satisfy these criteria. The dynamic response and the ability to aspirate blood through the PA port of the catheter were included among technical problems used as substitutes for "free flow" (criterion 3). (Saline manometers, originally used to determine if free flow is present,[11] are not used with flow-directed catheters.) We prospectively evaluated all 2711 WP measurements with respect to criteria 1, 2, and 3. (Criterion 4 is not applicable to flow-directed balloon-tipped catheters. Criterion 5 was explored in only 18% of the WP measurements.)

To evaluate system dynamic response (natural frequency and damping), the pressure applied against the transducer was raised to approximately 300 mm Hg (the pressure in the saline flush bag) by opening the rubber fast-flush valve of the Intraflo continuous flush system. (The rubber flush valve is opened by firmly pulling the projecting rubber piece.) This produces a flow of 1 ml/sec.[21] A sudden (step) decrease in pressure from approximately 300 mm Hg to pulmonary vascular levels was then induced by suddenly releasing the opened rubber flush valve and letting it snap shut (see + in Figures). The dynamic response (natural frequency and damping coefficient) was then assessed from the recorded pressure oscillations which followed[24] (Fig. 1).

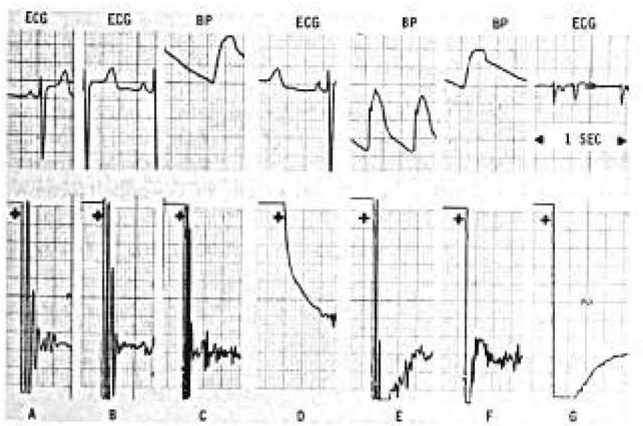

FIG. 1. Dynamic response testing results after a sudden (step) decrease in pressure (at +) from approximately 300 mm Hg to vascular levels. The balloon is inflated and the catheter is in the wedge position (lower panels) with simultaneously recorded ECG or systemic BP in the upper panels. Panels A, B, and C indicate the satisfactory dynamic response of an underdamped second-order system with an adequate natural frequency (natural frequency increases from panel A to panel C). Panel D indicates the response of an overdamped system. Panels E, F, and G indicate the response of a system within which fluid cannot move freely (prolonged saturation or "pegging" of the pen in the downgoing direction). Oscillations may be present (panel E) or absent (panels F, G) after the induction of a step decrease in pressure (at +). Panels D, E, F, and G indicate unsatisfactory dynamic responses.

Because pressure-measuring systems with inadequate dynamic response due to overdamping will not permit these oscillations (Fig. 1, panel D), the dynamic response of the measuring system (catheter, transducer, and amplifier) must be adequate.[24-26] Under optimal conditions, our system's undamped natural frequency was 17 Hz and 15 Hz and damping coefficient 0.35 and 0.20 for the Edwards Laboratories and Instrumentation Laboratory catheters, respectively.[24] Dynamic response was evaluated 3 times in rapid succession before each measurement of PAP and WP (Fig. 2). Because the absence of technical problems when the catheter tip is positioned in the proximal PA (balloon deflated for PAP measurement) does not guarantee an absence of technical problems when the catheter tip is positioned in the distal PA (balloon inflated for WP measurement), all quality control tests were applied both with the balloon deflated and with the balloon inflated. According to the manufacturer's recommendation, the balloon was never inflated with more than 1.5 ml of air.

Technical problems associated with failure to satisfy criteria 1–3 were listed under the following categories (technical problems identified by letters):

Criterion 1: The mean WP must be less than the mean PAP[11,13] (Fig. 3).
- a. "No WP"—when no waveform of atrial character could be obtained after balloon inflation in spite of multiple attempts.

Criterion 2: The phasic WP must be consistent with an atrial waveform.[11,13,14]
- b. "Variable WP"—when the recorded WP waveform revealed spontaneous variation in WP at end-expiration (Fig. 4).
- c. "Partial WP"—when the waveform

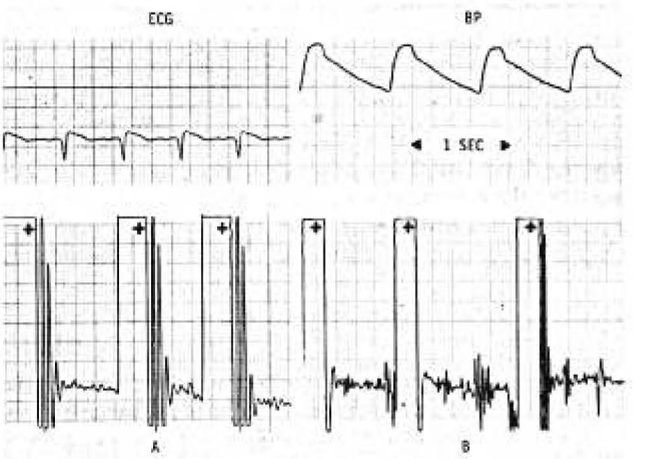

FIG. 2. See Figure 1 legend for explanation. Panel A—3 reproducible dynamic responses. Panel B—absence of reproducibility of the dynamic response. The first 2 responses of Panel B are unsatisfactory because of lack of oscillations following the step decrease in pressure (at +). The third response of panel B is satisfactory.

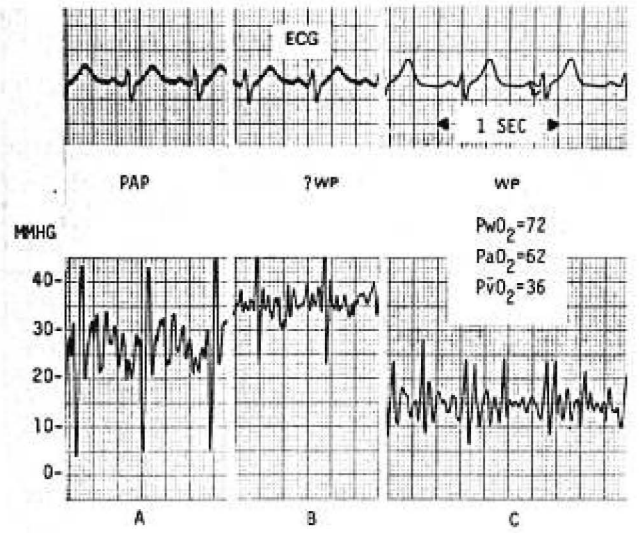

FIG. 3. The symbols in Figure 3 are: ECG = electrocardiogram; PAP = phasic pulmonary artery pressure (panel A); ?WP = wedge pressure, after balloon inflation, which exceeds PAP (panel B); WP = wedge pressure subsequently confirmed by aspiration of highly oxygenated blood (panel C); Pw_{O_2}, Pa_{O_2}, $P\bar{v}_{O_2}$ = oxygen pressures in wedge, arterial, and mixed venous blood, respectively.

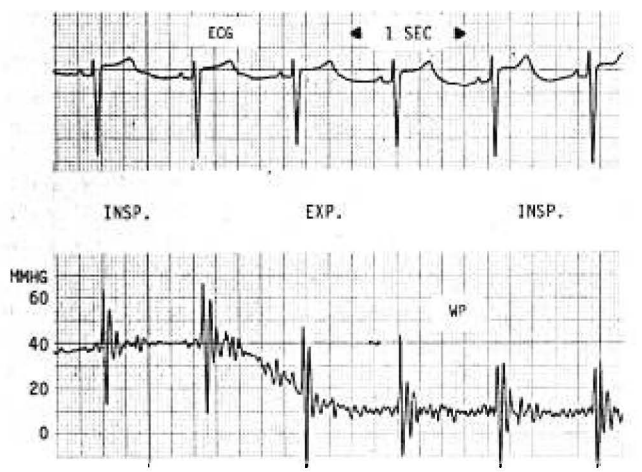

FIG. 4. Spontaneous variation in WP. The change in WP from 40 to 10 mm Hg is not induced by the respiratory cycle but represents an unexplained spontaneous variation. The tracing occupies 5 sec and includes 1 complete respiratory cycle which can be detected in the changing S-wave amplitude of the ECG (upper panel). INSP. = inspiration; EXP. = expiration.

is clearly different from the phasic PA waveform but appears intermediate between the phasic PA and an atrial waveform (Fig. 5). This waveform may be difficult to distinguish from that of a patient with mitral insufficiency and a prominent "V" wave.

Criterion 3: Free flow should be present with the catheter in the wedge position in order to ensure that the tip is not against a vessel wall.[11]

d. "Poor dynamic response"—when a sudden reduction in pressure, induced to test dynamic response,[24-26] either failed to produce oscillations (Fig. 1, panels D, F, G; Fig. 2, panel B), or produced oscillations of <12.5 Hz. Saturation of the recording system for >1/25 sec (1 mm at our 25-mm/sec chart speed) corresponds to a damped natural frequency of <12.5 Hz) (Fig. 1, panels E,F,G).
e. "Damped tracing"[7,17]—when the recorded WP waveform appeared to contain little high-frequency content (Fig. 6, panel A).
f. "Overinflation"[7,27]—when balloon inflation was followed by progressively increasing pressure. This is believed due to occlusion of the distal

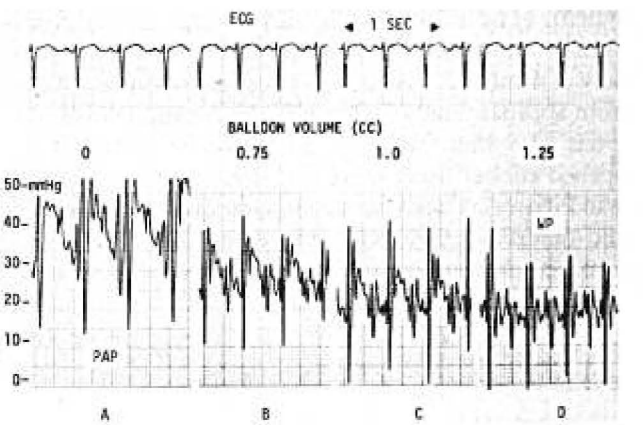

FIG. 5. Panel A—phasic PAP with balloon deflated (0 ml); panel B—partial WP with balloon inflated with 0.75 ml of air; panel C—partial WP with balloon inflated with 1.0 ml of air; panel D—WP tracing with balloon inflated with 1.25 ml of air; ECG—simultaneously recorded ECG (upper panels).

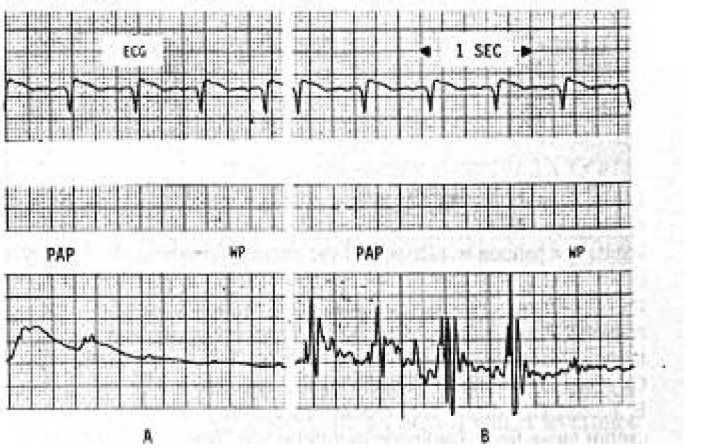

FIG. 6. Panel A—overdamped phasic PAP and WP; panel B—PAP and WP after correction of overdamping by removing air bubbles from the pressure transducer; ECG—simultaneously recorded electrocardiogram.

catheter port by the balloon. Flow from the continuous flush system causes the pressure to rise (Fig. 7).

g. "Unable to aspirate blood from the WP or PA position"[19]—No blood could be withdrawn through the distal port, before (PA) or after (WP) balloon inflation, even though fluids could be easily injected through this port and problems a–f might be absent (Fig. 8). This might be produced by impingement of the catheter tip against a vessel wall or web, or by a clot resulting in a one-way valve at the catheter tip.

All pressure tracings were reviewed by the authors. Wedge blood was sampled at the time of initial insertion of each pulmonary artery catheter, or whenever a persistent technical problem was encountered with WP. Wedge blood was defined as "capillary" when (P_{WO_2} - P_{AO_2}) >10 mm Hg.[11,12,14–20] An average of 19 ± 9 (SD) ml of blood was withdrawn ("waste") to flush the catheter and the balloon-occluded pulmonary vessel before sampling wedge blood for oxygen measurements.[12,27]

Effective thoracic compliance (C_{Th}) was obtained by dividing the expired tidal volume (corrected for system compression volume) by the difference between the static transthoracic pressures at end-inspiration and end-expiration. Right-to-left shunt fraction was computed by dividing the pulmonary capillary-arterial O_2 content difference by the pulmonary capillary-mixed venous O_2 content difference. Oxygen contents in systemic arterial and mixed venous blood specimens were calculated from measurements of P_{O_2}, S_{O_2}, Hgb, and carboxy- and methemoglobin saturations. Oxygen content in the pulmonary capillary blood was calculated from Hgb, carboxy- and methemoglobin saturations, and from the alveolar air equation, using F_{IO_2}, barometric pressure, P_{ACO_2}, and assuming a respiratory quotient of 0.8.

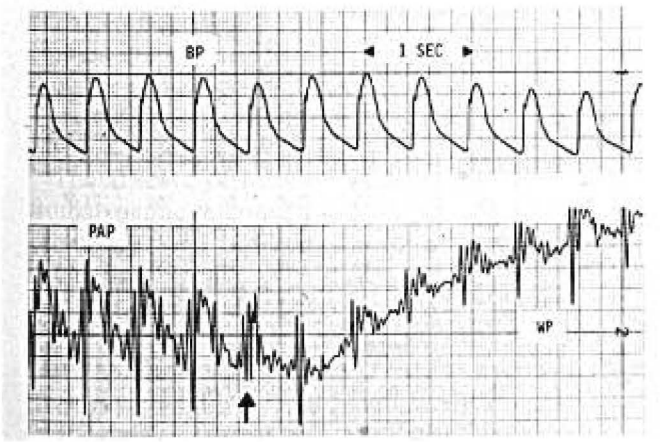

FIG. 7. "Balloon overinflation" suggested by a steadily increasing WP after balloon inflation (at *vertical arrow*) with WP exceeding the phasic PAP. BP = simultaneously recorded systemic arterial pressure.

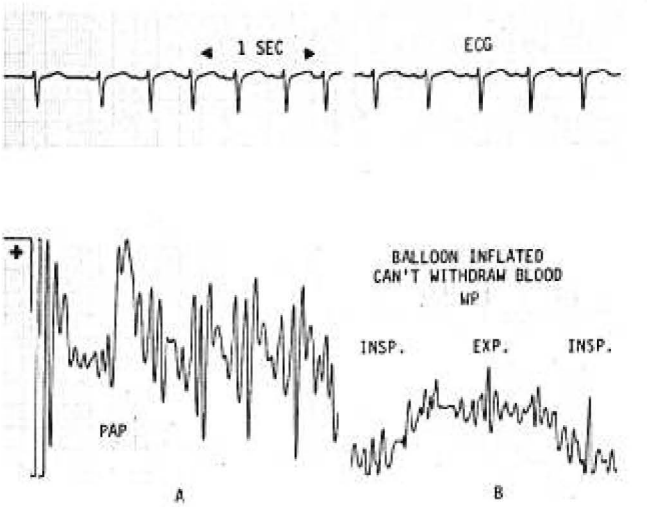

FIG. 8. Panel A—phasic PAP with satisfactory dynamic response after sudden (step) decrease in pressure (at +) from approximately 300 mm Hg to vascular levels. Panel B—WP recorded during spontaneous breathing (EXP. = expiration, INSP. = inspiration). Although the WP tracing appears satisfactory, blood could not be withdrawn in spite of several attempts, indicating a lack of fluid column continuity between the transducer and the vascular lumen. ECG = simultaneously recorded electrocardiogram (upper panels).

RESULTS

All 2711 WP measurements from the 44 (30 men) patients requiring 77 PA catheters for their clinical evaluation were included. An average of 60 measurements per patient (range 1 to 255) and 35 measurements per catheter (range 1 to 112) were made. Fifteen (10 men) patients were between 25 and 54 yr of age and 29 (20 men) between 55 and 84 yr of age. The mean right-to-left shunt was 26 (range 6 to 55)%, thoracic compliance was 37 (range 17–71) ml/cm H_2O, PEEP was 8 (range 2–30) cm H_2O, and therapeutic F_{IO_2} was .53 (range .21–1.00). There was no hemoptysis nor other ill-effects from dynamic response testing of catheters in the PA occlusion (WP) position (after balloon inflation).

There were no significant differences between the fractions of the 2711 WP measurements obtained during the day (32%), evening (35%), and night (33%) nursing shifts. Failure to satisfy criteria 1, 2, or 3 (Table 1) occurred 31% of the time. Twelve percent of attempts failed to produce WP measurement, and 20% of attempts produced a WP measurement associated with technical problems resulting in failure to satisfy criteria 2 (6%) and 3 (14%). Of these problems, one half were due to poor dynamic response (7%) or damped tracings (2%) (Table 1). There were no significant differences between the failure rates for criteria 1 to 3 encountered during the day (34%), evening (30%), and night (29%) shifts. No patient, catheter, or disease category was free

TABLE 1. WP technical problems in 2711 WP measurements of 44 (30 men) IRICU patients

	No. of WP measurements[a]	% of WP measurements[b]	% of Technical problems
No problem	1868	69	
Technical problems	843	31	
Criterion 1 (Total)	(322)	(12)	(38)
No WP[c]	322	12	38
Criterion 2 (Total)	(156)	(6)	(19)
Partial WP[d]	100	4	12
Variable WP[e]	56	2	7
Criterion 3 (Total)	(381)	(14)	(45)
Poor dynamic response[f]	184	7	22
Damped tracing[g]	65	2	8
Overinflation[h]	42	2	5
Cannot aspirate (PA)[i]	36	1	4
Cannot aspirate (WP)[i]	54	2	6

[a] Number of WP measurements with indicated problem.
[b] % of total (2711) measurements (rounded to nearest %).
[c] No WP = unable to obtain an "atrial waveform."
[d] Partial WP = WP waveform intermediate between the phasic PA waveform and an atrial waveform.
[e] Variable WP = spontaneous variation of WP.
[f] Poor dynamic response = absent oscillation, low frequency, or inadequate duration of oscillations after a sudden pressure decrease from approximately 300 mm Hg to vascular levels. See text.
[g] Damped tracing = WP waveform appears to have reduced high frequency content.
[h] Overinflation = slow, frequently linear, increase in pressure after balloon inflation.
[i] Cannot aspirate (PA and WP) = unable to aspirate blood with the catheter in the pulmonary artery or the wedge position.

from these technical problems. They were uniformly distributed among patients, disease categories, and catheters.

Wedged blood samples were obtained in 18% of the 2711 WP measurements. Fifty percent of the wedge blood specimens were "capillary" ([P_{WO_2} - P_{AO_2}] ≥10 mm Hg) at the time of initial PA catheterization. Failure to obtain capillary blood and simultaneously satisfy criteria 1, 2, and 3 occurred 55% of the time.

Within the total group of 44 patients, we identified 12 stable patients in whom initial measurements of WP were associated with technical problems which were rapidly corrected and followed by measurements of WP confirmed by aspiration of highly oxygenated blood (Table 2). For these 12 patients, the mean absolute difference between initial and confirmed WP was 11 ± 6 (SD) mm Hg. The range of differences was −13 to +22 mm Hg. Seven of these 12 initial measurements satisfied criteria 1 and 2 and would probably have been unchallenged had dynamic response testing (criterion 3) and wedge blood sampling (criterion 5) not been applied.

When clinical decision-making required a high level of confidence in the WP measurement, multiple catheter manipulations, though time-consuming, were often carried out. These manipulations ultimately yielded highly oxygenated (capillary) wedge blood in all patients, in spite of right-to-left shunt fractions ($\dot{Q}sp/\dot{Q}t$) as large as 0.63 (Table 3).

DISCUSSION

The 31% incidence of WP measurements with technical problems (Table 1) is close to the approximately 25% failure rate observed in WP measurement attempts in the cardiac catheterization laboratory[11,12] and the ICU.[2] With the continuous flush system (C.F.S. Intraflo) which is commonly used in this country and also used by us, a small continuous flow from a liquid reservoir passes through the catheter lumen to keep it free of blood. If poor dynamic response were due to the

TABLE 2. WP differences between initial measurement (with technical problem) and a subsequent confirmed measurement (after rapid resolution of the problem) in stable patients (Mean [±SD] of the absolute differences [mm Hg] and range of actual differences [mm Hg])

WP[a]		Technical problem	Corrected by
Initial	Confirmed		
22	8	Overinflation	Deflated balloon
8	12	Venous blood[b]	Advanced 2 cm
30	8	Venous blood[b]	Withdrawn
15	6	Venous blood[b]	Nothing
8	12	Poor dynamic response	Withdrawn 4 cm
24	8	Poor dynamic response	Deflated and inflated balloon
23	13	Poor dynamic response	Withdrawn
12	8	Poor dynamic response	Flushed
36	18	Partial WP	Patient coughed
21	4	Partial WP	Repositioned
7	20	Partial WP	Nothing
14	20	?	Repositioned
WP Initial-WP Confirmed = 11 ± 6 (SD), Range = (−13 → +22)[c]			

[a] Twelve comparisons of WP pairs in stable patients in whom rapid correction (Corrected by) of a technical problem associated with the initial WP measurement was followed by a WP measurement confirmed by aspiration of capillary blood ($P_{WO_2} - P_{AO_2}$) ≥10 mm Hg; 11 ± 6 mm Hg = absolute value (mean ± SD) of the difference between the Initial and Confirmed WP measurements.
[b] Venous blood = mixed venous blood aspirated from "wedge" position [($P_{WO_2} - P_{\bar{v}O_2}$) ≤2 mm Hg].
[c] Range (mm Hg) = maximum actual differences between Initial and Confirmed WP measurements (in positive and negative directions).

TABLE 3. Diagnoses and physiologic characteristics of patients with large right-to-left shunt fractions ($\dot{Q}sp/\dot{Q}t$) and confirmed WP [($P_{WO_2} - P_{AO_2}$) ≥10 mm Hg][a]

Diagnosis[b]	Age (yr)	Sex	$\dot{Q}sp/\dot{Q}t$	F_{IO_2}[c]	P_{AO_2} (torr)	P_{WO_2} (torr)	$C(a\text{-}\bar{v})O_2$[d] (ml/dl %)
ARDS	23	M	.25	1.00	367	478	2.7
Guillain-Barré	65	M	.27	0.35	59	100	5.2
COPD + CHF	61	M	.29	0.60	76	153	4.8
COPD + PE	69	M	.31	0.45	66	84	3.8
ARDS	69	M	.37	1.00	72	404	5.0
Pneumonia	50	M	.37	0.50	68	179	3.2
Trauma	65	F	.37	0.40	56	83	4.3
CHF	69	M	.43	0.40	46	69	5.0
PE	64	F	.43	0.85	50	195	6.4
ARDS	30	M	.46	0.50	53	157	3.4
ARDS	48	F	.63	1.00	38	59	5.1

[a] These data are from patients with pulmonary failure for whom WP was deemed important enough to justify a major effort to obtain highly oxygenated wedge blood. P_{AO_2}, P_{WO_2} = oxygen pressure in arterial and wedge blood, respectively. $\dot{Q}sp/\dot{Q}t$ = right-to-left shunt fraction (determined from arterial and mixed venous oxygen contents, during 100% O_2 breathing).
[b] Abbreviations: ARDS = adult respiratory distress syndrome; COPD = chronic obstructive pulmonary disease; PE = pulmonary embolism; CHF = congestive heart failure with pulmonary edema.
[c] F_{IO_2} when P_{AO_2}, P_{WO_2}, and $C(a\text{-}\bar{v})O_2$ are measured.
[d] $C(a\text{-}\bar{v})O_2$ = arterial-mixed venous oxygen content difference.

catheter tip impinging upon a vessel wall[11] or other structure (i.e., vascular web) or to a catheter tip clot,[28,29] then an increase in recorded pressure might be introduced by a flow-resistive pressure drop across the partially obstructed tip.[21] With a continuous flush system driven by a liquid source pressurized to 300 mm Hg, a flow-resistive pressure drop of 4% of the total driving pressure would elevate WP by 12 mm Hg.

The saturation of the recording system in the downgoing direction in Figure 1 (panels E, F, G) may be due to this continuous flush system. If the catheter tip was partially occluded by contact with the vessel wall or a clot and if this partial occlusion behaved like a one-way valve, the continuous flow of fluid could easily enter the vascular system. With the flush valve opened, a large flow would be induced. The inertia of this rapidly moving fluid stream would cause it to continue moving through the catheter after the flush valve was released. This inertial effect would produce an "overshoot" and reduce the pressure in the catheter lumen to a level below that in the blood vessel. The partial occlusion (vessel wall or clot) might then be pushed into the catheter tip, thus isolating the catheter lumen and its low pressure from the pulmonary circulation. The transducer would continue to detect the low pressure in the catheter lumen until the slow continuous flush delivered enough fluid to raise the pressure within the catheter, push away the obstruction at the catheter tip, and re-establish fluid column continuity between the transducer and the vascular lumen. Such a sequence of events would probably produce pressure recordings like those in Figure 1 (panels E, F, G). Note that this problem is only detected by testing the system dynamic response. The recommendation that the continuous flush system be used to exclude catheter obstruction is laudable.[27] We believe the continuous flush system should also be used to detect the large number of technical problems associated with poor dynamic response after a sudden pressure decrease (Table 1). Unfortunately, several of the newer bedside monitors have been intentionally designed with filters which, while eliminating some of the high-frequency artifact in the pressure signal, degrade the dynamic response. The dynamic response testing in this report may be impossible with some bedside monitors.

The absence of hemoptysis or other complications from dynamic response testing in the pulmonary artery occlusion (WP) position should allay any concerns about this practice. The balloon, when inflated, occludes a segmental or larger pulmonary artery.[27] The flow induced by the fast flush (1 ml/sec) is the same as that induced during balloon occlusion angiography (1 ml/sec) with a flow-directed catheter.[30]

Theoretically, the aspiration of capillary blood from the wedge position remains the only criterion of the five which cannot yield false-positive results (false-negative results are possible). All available explanations of the capillary specimens aspirated through a wedged catheter lead to the conclusion that the catheter tip has been separated from the mixed venous (pulmonary artery) blood pool and has probably produced a local lung region of high ventilation/perfusion ratio.[11,16-20,27] Our aspiration of highly oxygenated blood from the wedge position (high Pw_{O_2}) in patients with pulmonary failure and right-to-left shunt fractions as high as 0.63 confirms previous observations that highly oxygenated blood is obtained from the wedge position in patients with cardiac and pulmonary diseases as well as from normals[8,11,16,18-20,27] (Table 3). The Pw_{O_2} exceeds the Pa_{O_2} by increasing amounts as the Pa_{O_2} falls in hypoxemic patients with cardiac and pulmonary disorders,[19] and the Pw_{O_2} appears unrelated to the extent of radiographic infiltration of the lung.[8]

Suter and colleagues[27] ascribed their failure to obtain highly oxygenated wedge blood from approximately one third of their critically ill patients to atelectasis (sampling from unventilated areas). Although they confirmed WP with criteria 1 and 2, the only check for an unobstructed tip (criterion 3) was their implied absence of the progressive increase in WP which occurs with catheter tip obstruction when the continuous flush system is used (Fig. 7). They may, therefore, have included blood specimens drawn without achieving an adequate wedge position. Their intentional distal placement of the catheter tip may have increased the risk of sampling mixed venous rather than capillary blood after balloon inflation in spite of their cited disappearance of the PAP waveform. In the IRICU, the majority of technical problems have been associated with excessively distal location of the catheter tip (confirmed by chest x-ray). This is, in our experience, frequently a result of spontaneous catheter migration after proper placement.[7,17]

In summary, the measurement of WP is associated with a 31% incidence of technical problems resulting in failure to satisfy criteria 1 to 3 (Table 1). These problems can be associated with clinically important WP errors (Table 2). The routine application of dynamic response testing before every measurement of WP is a rapid and effective way of detecting errors.

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