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Clinical Utility of a Position-monitoring Catheter in the Pulmonary Artery

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Unsuspected distal migration of the tip of the pulmonary artery catheter may cause life-threatening complications. We prospectively evaluated the clinical utility of the PA Watch Catheter® in 25 patients after cardiac surgery by hourly measurements of pulmonary artery (distal lumen), right ventricular (middle lumen), and central venous (proximal lumen) pressures. The catheter was considered to be in the proper position when the middle lumen port, located 10 cm from the tip, transmitted a right ventricular pressure waveform. Satisfactory initial catheter placement was obtained in 24 of 25 patients. During the 28.4 ± 1.8 h of postoperative monitoring, clinically unsuspected distal catheter migration, indicated by the presence of a pulmonary artery pressure waveform in the middle lumen port, occurred in 12 of the 25 patients (48%). In these patients, 20 episodes occurred and required catheter withdrawal distances of 1.8 ± 0.3 cm (range 1–6 cm). The PA Watch Catheter® proved to be a useful indicator of unsuspected distal catheter migration in the postoperative period. The PA Watch Catheter® allows assessment of catheter tip placement in the proximal pulmonary artery and may decrease catheter-induced complications. (Key words: Anesthetic techniques: pulmonary artery catheterization. Complications. Monitoring: pulmonary artery pressure.)

PULMONARY ARTERY CATHETERIZATION of cardiac surgical patients may be complicated by distal catheter migration occurring during surgery[1] and in the postoperative period.[2] Distal migration can cause the catheter tip to lodge in a small pulmonary vessel, resulting in pulmonary infarction, pulmonary artery perforation, or rupture of the pulmonary artery after balloon inflation.[2–6] These complications can cause significant patient morbidity and mortality. One technique to diagnose distal catheter tip migration is continuous monitoring of pressure through the distal lumen of the catheter. When the tip becomes lodged in a pulmonary vessel of similar size, the pulmonary artery tracing dampens. However, significant distal catheter migration into smaller pulmonary vessels can occur without causing the waveform to dampen,[7] in which case it becomes apparent only after balloon inflation and pulmonary artery rupture.[4–6] As the lumen of the pulmonary vessel decreases, the inflating balloon is deformed, inflates eccentrically, and can force the catheter tip to erode through the vessel wall.[7,8] In addition, direct intimal disruption by the inflating balloon may not be the only mechanism causing catheter rupture of the pulmonary artery.[4,9] We have previously reported that catheter balloon deflation represents a particularly vulnerable period for direct vessel injury by the catheter tip, particularly in patients with pulmonary hypertension.[10] These mechanisms may explain the high incidence of pulmonary artery perforation with experimental pulmonary hypertension in cases in which permanent wedging of the catheter tip was not a factor.[11],†† Consequently, a technique to assess on-line the location of the pulmonary artery catheter tip is needed.

A recent modification of the pulmonary artery catheter (PA Watch Catheter®; Baxter Healthcare, Santa Ana, CA), has a lumen (middle lumen) located 10 cm from the catheter tip.[12,13] Transducing a right ventricular (RV) waveform through the middle lumen, particularly prior to balloon inflation, ensures a proximal location of the catheter tip within 10 cm of the pulmonic valve. Transducing a pulmonary artery pressure waveform from the position-monitoring lumen indicates distal migration and potential danger in the location of the catheter tip if left in this location. We prospectively studied the clinical utility of the PA Watch Catheter® as an indicator of catheter position after cardiac surgery.

Materials and Methods

The institutional review board approved this study, which did not require patient consent. Twenty-five patients (9 females, 16 males) undergoing elective cardiac surgery for coronary artery bypass grafting (n = 18), aortic valve replacement (n = 5), mitral valve replacement (n = 1), and aortic valve replacement with excision of a left atrial myxoma (n = 1) were studied. The mean age of

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the patients (± SEM) was 61.1 ± 2.1 yr (range 26–75 yr). The mean body surface area was 1.89 ± 0.04 m^2.

Preoperatively, a PA Watch Catheter® was placed through an introducer inserted by the Seldinger technique into the right internal jugular vein as described previously.[14] With a 1.5-ml balloon inflation volume, the catheter was flow-directed into the pulmonary artery until a wedge pressure was obtained, and the balloon was deflated. At that time, the pressure through the middle lumen was transduced and showed a RV pressure trace. The patients were anesthetized with midazolam and fentanyl and their tracheas intubated, and they underwent cardiac surgery in a routine fashion. Immediately prior to institution of cardiopulmonary bypass, the catheter was withdrawn 3–4 cm to minimize inadvertent displacement.[1] After separation from bypass, the catheter was readvanced as necessary to obtain a wedge pressure tracing with a 1.5-ml balloon inflation volume, and the balloon was deflated.

After surgery, the patients were transferred to the intensive care unit, where proper catheter location was verified by 1) transducing a RV pressure trace through the middle catheter lumen and 2) obtaining a wedge pressure with 1.5 ml air. Pulmonary artery wedge pressure was not obtained on a regular basis, but only when deemed clinically indicated. The distance of catheter insertion, noted where the catheter entered the introducer sheath, was recorded upon arrival at the intensive care unit and hourly thereafter. Pulmonary artery (distal lumen), RV (middle lumen), and central venous (proximal lumen) pressures were recorded at hourly intervals during the entire period of catheterization in the intensive care unit. Unsuspected distal catheter migration was defined when a pulmonary artery pressure trace instead of a RV pressure trace was displayed on the monitor screen while transducing the middle lumen. This diagnosis was made by visual inspection of the pressure tracing on the monitor screen as well as observation of the abrupt change in diastolic pressure. Under these circumstances, the catheter was pulled back just enough to reveal the reappearance of the RV pressure waveform in the middle lumen. In each case, that distance withdrawn was measured and recorded. In 23 patients, chest radiographs obtained upon entry in the intensive care unit were examined for baseline catheter tip location; chest radiographs from 2 patients were not available for review.

Results

Satisfactory initial catheter placement was obtained in 24 of 25 patients. In 1 patient with long-standing pulmonary hypertension secondary to a left atrial myxoma, the balloon could not be wedged from a position in which the middle lumen transduced RV pressure; further advancement of the catheter by 3–4 cm was required. In this patient, the determination of wedge pressure was not necessary, and the catheter was positioned with the middle lumen in the right ventricle. Overall, in these patients, the central venous pressure averaged 7.9 ± 0.9 mmHg during the postoperative study period.

Representative waveform tracings recorded simultaneously from the middle and distal lumens during catheter balloon inflation in two patients are shown in figures 1 and 2. In one of these patients (fig. 1), a wedge pressure was obtained while the middle lumen remained in the right ventricle. In the other (fig. 2), a wedge pressure was obtained as the middle lumen migrated from the right ventricle across the pulmonic valve into the pulmonary artery. In both cases, the middle lumen transduced a RV

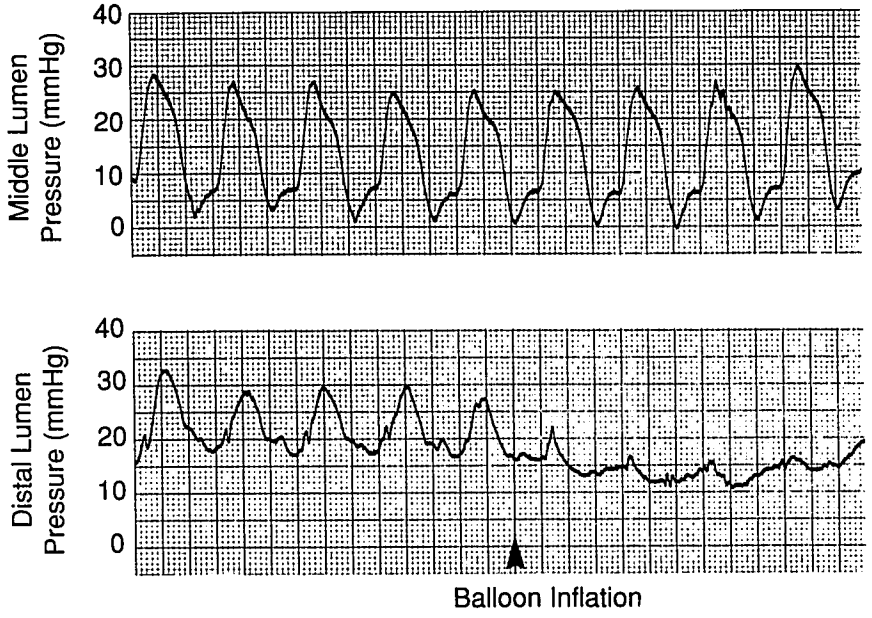

FIG. 1. Simultaneous tracings from the middle (*top*) and distal (*bottom*) lumens of the PA Watch Catheter® during inflation of the catheter balloon to obtain wedge pressure. Note that the middle lumen remained in the right ventricle throughout balloon inflation.

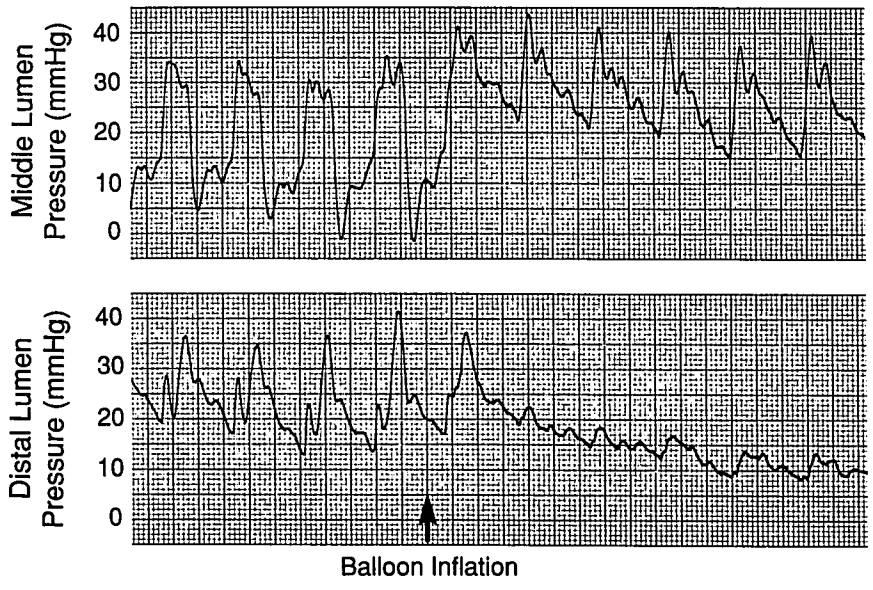

FIG. 2. Simultaneous tracings from the middle (*top*) and distal (*bottom*) lumens of the PA Watch Catheter®, as described in figure 1. Note that, in this patient, catheter balloon inflation caused the middle lumen to migrate from the right ventricle to the pulmonary artery.

waveform prior to balloon inflation. In the 23 patients with initial chest radiographs, the catheter tip was located to the left or at the midspinal area. This location was proximal to that described previously for traditional pulmonary artery catheters.[1,9] A radiograph illustrating proper location of the PA Watch Catheter® is shown in figure 3.

The catheter insertion distance measured at the introducer was 50.3 ± 0.5 cm (range 47–56 cm) and did not change during the postoperative period unless the cath-

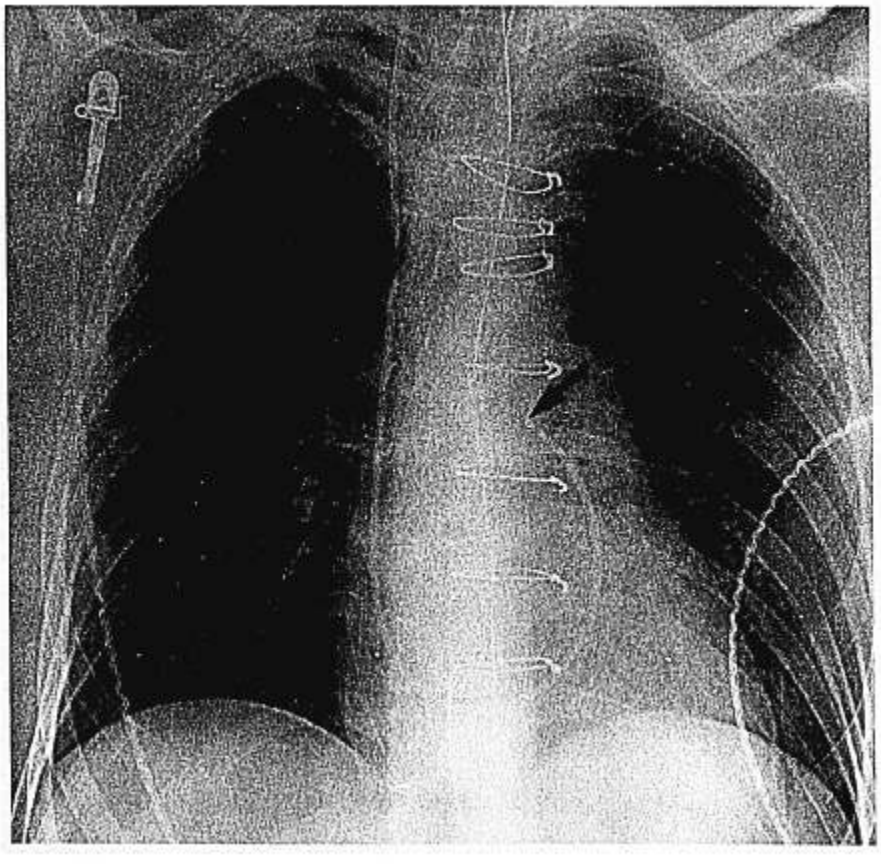

FIG. 3. Chest radiograph of a patient with a PA Watch Catheter® showing typical placement of the catheter tip (arrow). In all patients, the catheter tip was located to the left or at the midspinal level of the thoracic vertebrae.

eter was manipulated directly. Patients were monitored postoperatively with the PA Watch Catheter® for 28.4 ± 1.8 h (range 14– 42 h). Unsuspected distal catheter migration occurred in 12 of the 25 patients (48%). Chest radiographs from 1 patient (fig. 4) showed that after initial catheter placement (fig. 4A), spontaneous distal migration of the catheter tip occurred (fig. 4B). At that time, the middle lumen transduced a pulmonary artery tracing; catheter withdrawal of 3 cm was needed until RV pressure was transduced again. Overall, in the 12 patients in whom distal catheter migration occurred, there were 20 episodes, 18 of which required catheter withdrawals of 1.8 ± 0.3 cm (range 1–6 cm; fig. 5). In 2 patients, distal migration was encountered but reverted back to RV pressure without catheter withdrawal. In both of these patients, only 1 episode of distal catheter migration was noted. Reliable tracings were obtained from all lumens of the PA Watch Catheter®, and there were no complications from its use. In no patient, with or without hemodynamic evidence of distal catheter migration, did the catheter tip become permanently lodged in a "wedged" position such as to cause catheter dampening. In addition, a RV pressure tracing was not transduced through the distal lumen during the postoperative period.

Discussion

Perforation of the pulmonary artery represents a serious and potentially lethal complication from the use of flow-directed catheters.[2,4–6] Catheter balloon inflation to obtain a pulmonary artery wedge pressure has been implicated as the precipitating cause.[6,15] Lozman *et al.*[8] and Lemen *et al.*[11] hypothesized that peripheral positioning of the catheter tip and eccentric balloon inflation can cause this perforation. With eccentric balloon inflation, the catheter tip may be forced into the vessel wall and thereby cause erosion and possibly perforation. In addition, if the catheter migrates distally into a pulmonary branch smaller than the size of the inflated balloon and the balloon is inflated further, direct intimal disruption may occur due to the high pressure within the balloon.[15,16]

Distal catheter migration may occur spontaneously secondary to a reduction in the size of the loop within the right ventricle with repeated balloon inflations[3,17] or secondary to RV decompression during cardiopulmonary bypass.[1] Transducing a dampened pressure waveform through the distal lumen prior to balloon inflation suggests a permanently wedged catheter tip. However, significant distal migration of the catheter tip may occur without permanent wedging[1,7,10] and may cause vascular damage.[9,††] Indeed, balloon inflation of a permanently wedged catheter does not account for all cases of pulmonary artery perforation.[2,4–6,9] We previously found that significant distal catheter migration occurs during balloon deflation, particularly in patients with pulmonary hypertension.[10] This mechanism may account for the exceedingly high incidence of pulmonary artery rupture in experimental animals with pulmonary hypertension.[11,††] In these studies, there was no evidence of permanent catheter wedging prior to repeated balloon inflations, although pulmonary artery rupture occurred in 50–75% of animals. In contrast, proximal location of the catheter tip in the main pulmonary artery prevented this complication.[††] Conse-

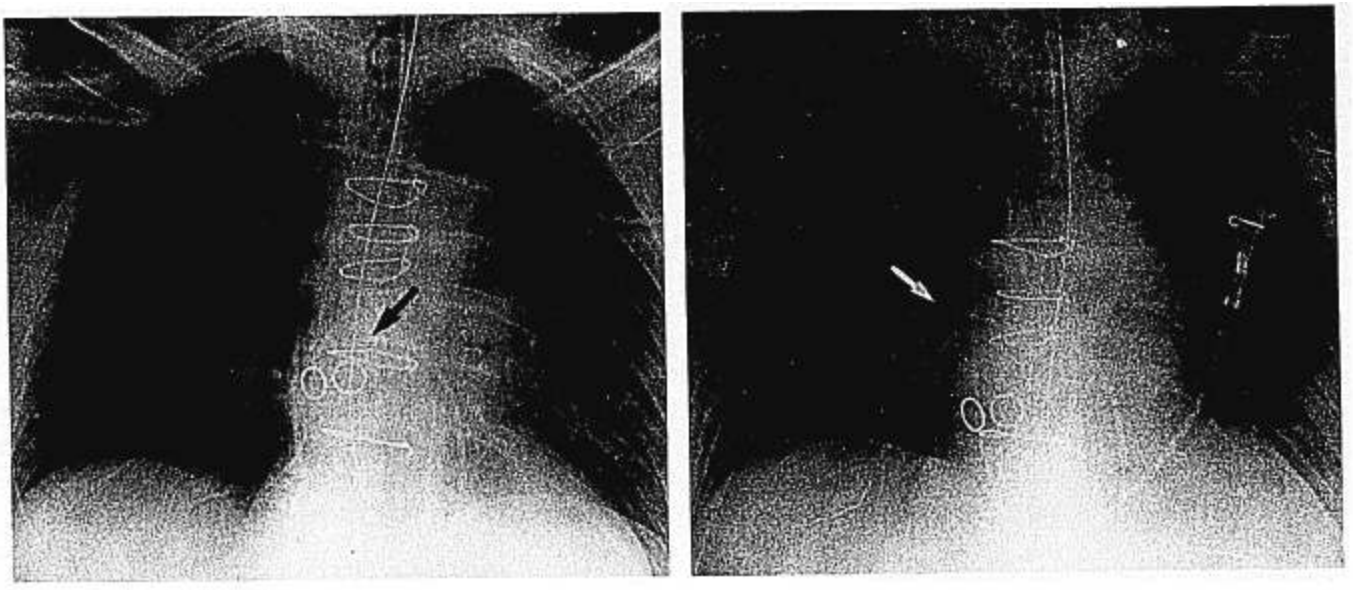

FIG. 4. Chest radiographs of a patient before (*A*) and after (*B*) unsuspected distal catheter migration; arrows indicate the catheter tips. The middle lumen of the catheter transduced a right ventricular waveform (*A*) and pulmonary artery waveform (*B*). After radiograph *B* was taken, the catheter was pulled back as needed (3 cm) so that the middle lumen transduced a right ventricular waveform.

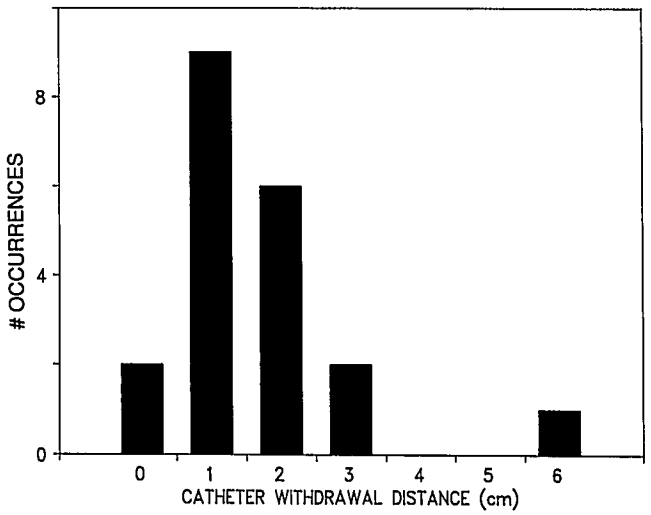

FIG. 5. The number and distance of catheter withdrawals necessary for the middle lumen to transduce a right ventricular pressure tracing instead of a pulmonary artery pressure tracing.

quently, other means to ensure proximal catheter tip location, such as the PA Watch Catheter®, may be clinically useful.

Maintenance of the catheter balloon within 10 cm of the pulmonic valve is frequently recommended to prevent permanent wedging and catheter perforation.[18] One reason is that the catheter balloon inflates concentrically when centrally located, rather than inflating eccentrically when positioned more peripherally.[7] Concentric balloon inflation tends to maintain the catheter tip in the pulmonary arterial lumen and thereby prevent direct intimal damage. Experimental evidence supports the concept that proximal catheter tip location lessens the incidence of pulmonary artery perforation.†† Consequently, in patients with pulmonary hypertension who are at particular risk for pulmonary artery perforation, the use of the PA Watch Catheter® to maintain proximal catheter tip location may be particularly important. We and others[12,13] found that the catheter tips of PA Watch Catheters® were located centrally in all patients, usually to the left of or lying on top of the spine (fig. 3, 4A). This location represents a more proximal placement of the catheter tip than previously reported with thermodilution catheters.[1,10] The failure to reach the wedge position in the patient with pulmonary hypertension and presumably dilated pulmonary vessels suggests that in such patients the distance between tip and the middle lumen would have to be greater than 10 cm.

The relatively high incidence of unsuspected distal catheter migration that we observed in cardiac surgery patients may be greater than that in other postoperative and critically ill patients. The right ventricle has a larger end-diastolic volume after cardiopulmonary bypass,[19] which tends to decrease with diuresis in the postoperative period. A reduction in the size of the right ventricle may decrease the size of the catheter loop within the ventricle and cause distal catheter migration. Nevertheless, since cardiac surgery patients are at particular risk for pulmonary artery perforation,[2,5,9] this type of monitoring appears warranted.

Several limitations of this study warrant discussion. First, there was no control group for the testing of conventional pulmonary artery catheters relative to PA Watch® catheters. Unfortunately, other than observing different waveform tracings through the distal lumen (*i.e.*, right ventricle, pulmonary artery, or wedge), there is no practical means to indicate tip location of conventional catheters. Fluoroscopic assessment of catheter tip location, which we have previously used intraoperatively,[1,10] could not be performed in the intensive care unit and would have entailed considerable radiation exposure to patients. Second, correlation between hemodynamic evidence of distal catheter migration and radiographic findings could not be performed since chest radiographs were not obtained each time the middle lumen transduced a pulmonary artery pressure. Furthermore, any correlation would have been complicated by the changes in tip location occurring during each cardiac cycle.[10] Third, although we recorded hemodynamic parameters through the middle lumen each hour, continuous monitoring through this lumen is recommended, particularly prior to balloon inflation. An automated alarm system to detect the change in diastolic pressure as the catheter migrated distally from the right ventricle to the pulmonary artery may be clinically useful.[20] Fourth, since direct manipulation of the heart during cardiac surgery can expel the middle lumen from the right ventricle and into the pulmonary artery, we chose to evaluate the PA Watch Catheter® in the postoperative period, when catheter position is relatively constant. However, transducing the middle lumen during surgery would clearly indicate a change in the pressure tracing if it occurred. The position-monitoring catheter indicates the position of the catheter tip when catheter withdrawal is performed in preparation for cardiopulmonary bypass.[1]

The PA Watch Catheter® proved to be a useful indicator of unsuspected distal catheter migration in the postoperative period. This complication occurred in 48% of cardiac surgery patients and tended to recur. Although no evidence of pulmonary artery perforation was found in this small group of patients, we believe that the PA Watch Catheter® allows precise placement of the catheter tip in the main pulmonary artery and that this precision should reduce the incidence of catheter-induced complications.

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