Swan-Ganz Catheter Location and Left Atrial Pressure Determine the Accuracy of the Wedge Pressure When Positive End-expiratory Pressure is Used*


In 43 percent of 30 consecutive open heart surgery patients, Swan-Ganz catheter tips lodged within 1 cm of or above the left atrium. When in this position the wedge pressure measured by the catheter was not an accurate estimate of left atrial pressure when positive end-expiratory pressure (PEEP) was used, especially when left atrial pressure was low. Catheters located below the left atrium were accurate at all levels of PEEP tested. The position of Swan-Ganz catheters should be confirmed by a lateral chest roentgenogram when PEEP is used, and catheter tips not below the left atrium should be repositioned.

Patients with severe acute respiratory failure frequently require positive end-expiratory pressure (PEEP) to maintain adequate oxygen delivery. However, oxygen delivery is dependent on cardiac output, and PEEP can depress cardiac output.1-5

Left ventricular filling pressure is an important determinant of cardiac output and of pulmonary edema fluid formation and therefore is an important parameter in patients with respiratory failure on PEEP. Swan-Ganz catheter measurement of pulmonary artery wedge pressure is the most common clinical method of assessing left ventricular filling pressure. However, reports in animals and in humans have noted discrepancies between the wedge pressure and a directly measured left atrial pressure when PEEP is used.2-6,8 In the animal studies, the position of the catheter and the level of the left atrial pressure were important determinants of wedge pressure accuracy.2-6,8

We studied 30 consecutive open heart surgery patients to determine where Swan-Ganz catheters lodge in supine humans and whether the location of the catheter and the left atrial pressure determined the accuracy of the wedge pressure when PEEP was used.

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Methods

Swan-Ganz catheters (No. 7, Edwards Laboratories) are routinely placed just before surgery in all open heart surgery patients at the Denver Veterans Administration Hospital. The catheters are inserted transcutaneously into the internal jugular vein and advanced, using the flow directed balloon. In 30 consecutive patients, a metal clip was placed on the left atrium at its junction with the right upper lobe pulmonary vein during surgery. Postoperatively, the relative positions of the catheter tip and the left atrial marker were determined using a portable supine lateral chest roentgenogram taken immediately before the hemodynamic measurements. The film cassette was carefully held in a sagittal plane, and the film was slightly overpenetrated to allow better identification of the radiodense catheter tip and metal marker. The vertical distance to the catheter tip and the metal clip were measured from the inferior margin of the cassette and the difference in these heights is reported (all films were taken at a distance of 60 ± 2 inches and the magnification factor using a radiodense grid was 1.3). Before taking the roentgenogram, a wedge position for the catheter was confirmed by inflating the catheter balloon with ≤1.2 ml of air, observing a typical wedge tracing that fluctuated with respiration and had A and V waves present, and then observing a return of the arterial pulse contour when the balloon was deflated.

In 12 of the 30 patients, left atrial catheters were also placed at the time of surgery and pulmonary artery, left atrial, systemic arterial, and airway pressure were simultaneously recorded (on an Electronics for Medicine VR6 recorder) while the patients were mechanically ventilated in the early postoperative period. Pulmonary arterial, systemic arterial, and left atrial pressures were measured with Statham PD23 transducers. Airway pressure was measured directly by connecting plastic tubing from the endotracheal tube to a Statham P131 transducer. All transducers were calibrated separately for each patient.
Hemodynamic and airway pressures were recorded at ventilator settings of 0, 5, 10, and 15 cm H₂O (3.7, 7.4, and 11.0 mm Hg) PEEP. At each level of PEEP, hemodynamic pressures were allowed to stabilize and then at least ten respiratory cycles were recorded. The three cycles with the most stable end expiratory plateau of airway pressure at each level of PEEP were selected, and the averages of the pulmonary artery wedge and mean left atrial pressures from these cycles are reported. Hemodynamic pressures typically varied <1.5 mm Hg from one cycle to the next.

The protocol was approved by the committee for research on human subjects of the University of Colorado Health Sciences Center, and informed consent was obtained from each individual.

The difference between left atrial and pulmonary artery wedge pressures at different levels of PEEP were compared using a one-way analysis of variance with multiple comparisons (Student-Newman-Keuls test).

**RESULTS**

A representative lateral roentgenogram (Fig 1) shows where the catheter tip and left atrial marker are clearly seen. The distribution of the catheter tips relative to the left atrium is shown graphically in Figure 2. Forty-three percent of the catheters lodged within 1 cm of or above the left atrial marker.

In the 12 patients with left atrial catheters, 1 catheter was 2.2 cm above the left atrial marker, 6 catheters were within 1.0 cm of the marker, and 5 catheters were more than 2.0 cm below the marker.

Figure 3 shows the changes that occurred in the difference between the pulmonary artery wedge pressure and the left atrial pressure at increasing levels of PEEP for catheters in the different positions. For the catheter 2.2 cm above the left atrial marker, the difference increased from 2.8 mm Hg at no PEEP to 8.3 mm Hg at 12 mm Hg PEEP. One of the catheters located within 1 cm of the left atrium was associated with a left atrial pressure of 2.8 mm Hg. For this catheter, the difference between the wedge and left atrial pressures at no

**Distribution of Catheter Tips Relative to the Left Atrial Marker**

![Diagram showing the distribution of catheter tips relative to the left atrial marker.]

**Figure 2.** Distribution of Swan-Ganz catheter tips relative to left atrial marker in 30 consecutive open heart surgery patients.
PEEP was less than 1 mm Hg. However, at 13 mm Hg PEEP, this difference increased to 13.5 mm Hg. Five other catheters were within 1 cm of the marker but were associated with left atrial pressures of 5 mm Hg or more at no PEEP. The tip of one of these catheters was demonstrated to be in the mediastinum, a location that precluded this catheter from actually measuring a wedge pressure despite the appearance of a wedge-type tracing with the balloon inflated. The large discrepancy between left atrial and pulmonary artery wedge pressures noted with this catheter supports this interpretation, and, therefore, the data from this catheter were not used in the statistical analyses. For the other four catheters at left atrial level, the difference between the left atrial and wedge pressure remained negligible with increasing PEEP until 11.0 mm Hg PEEP, when the difference increased to 3.0 mm Hg (P < .05). For those catheters 2.0 cm or more below the left atrium, the difference between mean left atrial and pulmonary artery wedge pressure did not change with increasing PEEP (P > .20). The tip of one of these catheters was also in the mediastinum, where it could not measure a wedge pressure, and the catheter did not accurately reflect left atrial pressure (Fig 3). The wedge pressure of another of the catheters whose tip was ≥2.0 cm below the left atrial marker actually became less than left atrial pressure. This discrepancy was never greater than 2.0 mm Hg, however.

**Discussion**

In our study 43 percent of Swan-Ganz catheters lodged at or above the level of the left atrium. When the catheter tip was above the left atrium or when the catheter tip was at the level of the left atrium but left atrial pressure was low, large differences developed between left atrial and pulmonary artery wedge pressures when PEEP was increased. When the catheter tip was at the left atrial level but left atrial pressure was ≥5 mm Hg, smaller but statistically significant differences developed between left atrial and pulmonary artery wedge pressures as PEEP was increased. Since in many patients with severe acute respiratory failure, left atrial pressure is kept low to minimize pulmonary edema, the large fraction of catheters at left atrial level is clinically significant.

This is the first study in humans to determine the significance of the relative vertical positions of Swan-Ganz catheter tips and the left atrium when exact location of the left atrium was known. Orta et al injected radiopaque dye into Swan-Ganz catheters and estimated their position relative to the left atrium using A-P roentgenograms and classic anatomic relationships. They suggested that
30 percent of catheters lodged above the left atrium. Cross et al.\textsuperscript{10} used lateral chest roentgenograms to localize catheter tips relative to midheart level and found all of them at or below the midheart. They also studied some patients with direct left atrial pressure readings and noted good agreement between the wedge and left atrial pressures. However, the relative location of the catheter tips, the left atrial pressure, and whether PEEP was used in these patients was not reported in the abstract. Davison et al.\textsuperscript{11} measured the wedge pressure with and without PEEP in 13 patients. They found no significant differences between PEEP and no PEEP, but catheter position was not evaluated and the highest PEEP was 10 cm H$_2$O. Most of the significant changes we observed were at 15 cm H$_2$O PEEP.

While it is commonly stated that most of the pulmonary blood flow is to the dependent part of the lung, Hughes et al.\textsuperscript{12} have demonstrated that regional blood flow is dependent on lung volume. At functional residual capacity the greatest amount of flow is to the midlung. Hence, it is not surprising that most of our catheters lodged within 1 to 2 cm of the left atrium.

The significance of catheter position and the level of left atrial pressure is explained schematically in Figures 4A and 4B, where three catheters are assigned different vertical positions. In both figures, a PEEP of 11.0 mm Hg (15 cm H$_2$O) is assumed. The venous pressure at the level of the most superior catheter is less than atrial pressure because of the vertical distance between the catheter and the left atrium. For this catheter the positive pressure in the alveolus collapses the microvasculature and separates the precapillary catheter from the post-capillary venous pressure, thereby invalidating the wedge pressure as an estimate of left atrial pressure. When left trial pressure is \( \leq 5 \) mm Hg, as in Figure 4A, the catheter at left atrial level will also be separated from the postcapillary venous pressure. However, when the left atrial pressure is 12 mm Hg, the venous pressure will keep the microvasculature patent, and the catheter should be accurate. The venous pressure for the lowest catheter is greater than left atrial pressure because of the vertical gradient, the microvasculature remains patent, and the catheter should be accurate.

It is not obvious why PEEP increased left atrial pressure more than the wedge pressure in the one patient whose wedge pressure became less than the left atrial pressure at higher levels of PEEP. However, this catheter tip was 4.1 cm below the left atrial marker, and in this position the higher interstitial fluid pressures may have prevented the PEEP from being transmitted to the small pulmonary vessels as well as it was to the left atrium.

In patients with severe acute respiratory failure, compliance of the lung will be altered, and transmission of airway pressures to the microvasculature may differ from that in our patients. However, our patients were studied two to four hours after cardiopulmonary bypass, and static pressure volume relationships measured on the ventilator showed reduced compliance. In addition, in animals oleic-acid-induced pulmonary edema did not alter PEEP-induced discrepancies between wedge and left atrial pressure or prevent PEEP from reducing cardiac output.\textsuperscript{7,13}

The design of our study suggests that discontinuing PEEP would be a potential way to validate the wedge pressure estimate of left atrial pressure and avoid discrepancies caused by PEEP. However, other studies have demonstrated profound decreases in arterial oxygen tension within minutes of discontinuing PEEP, so this practice cannot be recommended in seriously ill patients.\textsuperscript{14,15}

Because 43 percent of the catheters lodged in a position where they are potentially inaccurate when PEEP is used, we recommend that a lateral chest roentgenogram be used to confirm the position of Swan-Ganz catheters in patients on PEEP. Since these patients will undoubtedly have portable A-P roentgenograms, the cost of a lateral film taken at the same time should be much less than a separate study. If the catheter tip is not below the left

\textbf{Figure 4. (A) PEEP = 11.0 mm Hg;} left atrial pressure = 5 mm Hg. (B) PEEP = 11.0 mm Hg, left atrial pressure = 12 mm Hg.
atrium on the lateral film, the wedge pressure may be inaccurate when PEEP is used, and the catheter should be repositioned.

REFERENCES

20th Annual Critical Care Medicine Symposium
The 20th Annual Critical Care Medicine Symposium will be held February 22-25 at the MGM Grand Hotel, Las Vegas, under sponsorship of the University of Southern California School of Medicine. For information, contact the Associate Dean, USC School of Medicine, Postgraduate Division, 2025 Zonal Avenue, Los Angeles 90033.