# Video Fluoroscopy for Positioning of Pulmonary Artery Catheters in Patients Undergoing Cardiac Surgery

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***Objectives:*** **To determine whether video fluoroscopy combined with traditional pressure waveform analyses facilitates optimal pulmonary artery catheter (PAC) flotation and final positioning compared with the traditional pressure waveform flotation technique alone.**

***Design:*** **Prospective, single-center, randomized, controlled trial.**

***Setting:*** **Single-center university teaching hospital.**

***Participants:*** **The study included 50 cardiac surgery patients at higher risk for PAC complications.**

***Interventions:*** **Use of video fluoroscopy to facilitate optimal PAC flotation and positioning.**

***Measurements and Main Results:*** **The primary outcome was the time taken to float and position the PAC balloon in the pulmonary artery as confirmed by transesophageal echocardiography. Secondary outcomes included number of attempts at flotation, ventricular rhythm disturbances, and catheter malposition. Patients were evenly matched in baseline demographics, New York Heart Association symptoms of heart failure, severity of left and right ventricular dysfunction, end-diastolic pressures and dimensions, severity of tricuspid valvular disease, and atrial and pulmonary artery pressures. Mean (SD) time to float the PAC was significantly shorter in the video fluoroscopy group than in the usual care group: 73 seconds (SD, 65.1) versus 176 seconds (SD, 180.6), respectively; p = 0.014. The median (interquartile range [IQR]) number of attempts to successful flotation was fewer in the video fluoroscopy group than in the usual care group: 1 (IQR 1:2) attempt versus 2 (IQR 1:4) attempts, respectively; p = 0.007. The composite complication rate (malposition and arrhythmias) was lower in the video fluoroscopy group than in the usual care group (16% *v* 52%, respectively; p = 0.01).**

***Conclusions:*** **In cardiac surgery patients at higher risk for PAC complications, video fluoroscopy facilitated faster and safer catheter flotation and positioning compared with the traditional pressure waveform flotation technique.**


***KEY WORDS: cardiac surgery, pulmonary artery catheter, video fluoroscopy, complications***

SINCE THEIR INTRODUCTION in clinical practice 4 decades ago, balloon-tipped, flow-directed pulmonary artery catheters (PACs) have found widespread use in the clinical management of critically ill patients undergoing cardiac surgery. The PAC originally was developed as a "balloon-tipped catheter" to be used at the bedside without requiring radiology or fluoroscopy for insertion. PAC-derived hemodynamic data can provide information critical to the effective management of critically ill patients, even if other monitoring modalities, such as transesophageal echocardiography (TEE), are used.[1,2] Correct positioning of the PAC in the pulmonary artery (PA) is essential for its safe use, and pressure waveform analysis is the most common method used to guide flotation of the PAC tip into position. However, due to abnormal or slow intracardiac blood flow, this technique may be difficult in patients with poor cardiac function or severe valvular heart disease, resulting in repeated attempts at flotation, arrhythmias, and catheter malposition. Therefore, in patients undergoing cardiac surgery who are considered at higher risk for PAC complications, the authors hypothesized that video fluoroscopy combined with pressure waveform analysis would achieve a faster, more reliable and therefore safer catheter flotation and final positioning compared with the traditional pressure waveform flotation technique alone.

## METHODS

After receiving Austin Health Research Ethics Committee approval (H2009/03740) and written informed participant consent, the authors conducted a single-center, randomized, clinical trial between July 2010 and July 2012 at a university teaching hospital that is experienced in complex cardiac surgery. The study was registered with the Australian New Zealand Clinical Trials Registry (number: 12614001081606). Inclusion criteria included adult patients considered to be at higher risk for difficult PAC insertion who were undergoing elective or semi-urgent cardiac surgery that necessitated a PAC as part of routine perioperative care. Because there are no validated criteria for patients at "high risk" for difficult PAC insertion, the authors defined "high-risk" as 1 or more of the following criteria: left ventricular ejection fraction $<35\%$, low-cardiac-output syndrome (cardiac index $<1.5$ L/min/m$^2$), severe pulmonary hypertension (mean pulmonary artery pressure $>40$ mmHg), and severe tricuspid insufficiency. Criteria for inclusion were obtained from routine preoperative transthoracic or transesophageal echocardiography, coronary angiography, and right heart catheterization studies. Exclusion criteria included age $<18$ years, inability to provide informed and written consent (eg, patients awaiting surgery in the intensive care unit who had been administered sedatives), and time-critical surgery in which induction of anesthesia was imperative before the PAC being inserted (eg, acute aortic dissection). Patients were assigned randomly into 2 groups using a computer-generated program: those in whom the PAC was floated using video fluoroscopy combined with real-time pressure

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waveform monitoring (fluoroscopy group) and those in whom the PAC was floated by real-time pressure waveform monitoring alone (usual-care group). If the PAC was unable to be floated within a 10-minute period, patients were transferred to the alternative group.

Three senior consultant cardiac anesthesiologists, who are proficient in PAC insertion and video fluoroscopy, performed all PAC insertions using a protocol designed to standardize care in both groups. On arrival to the operating room, all patients underwent placement of a peripheral intravenous cannula and an arterial blood pressure monitoring line. A conscious sedation technique with midazolam (0.02-0.05 mg/kg) and fentanyl (0.5 ug/kg) was used to place patients supine in the Trendelenberg position (30-degree tilt of the bed below horizontal, with the head in lowest position) on a standard radiolucent operating room table. Per the authors' institution's radiology protocols, the anesthesiologists were not required to wear a dosimeter because the procedure was performed in the cardiac operating room and screening times were of very short duration. A trained radiologist operated the fluoroscopy machine. In keeping with stringent hospital policy, protective garments, including thyroid shielding, were worn by all personnel. The standard garment worn is a 0.5-mm lead apron, which stops approximately 95% of the scatter radiation. Fixed screening barriers provided additional protection from scattered radiation for all personnel, except for the anesthesiologist performing the procedure. Using real-time ultrasound guidance and the standard aseptic Seldinger technique, a 9-French Arrow-Flex Sheath (Teleflex Inc., Morrisville, NC) was inserted into the internal jugular vein of all patients. The PAC sheath was primed with normal saline and sutured to the neck. A Swan-Ganz CCOmbo PAC (Edwards Lifesciences, Irvine, CA) was prepared per normal protocol and used in all patients.

## Technique for PAC Flotation in the Usual-Care Group

1. The distal port of the PAC was connected to a pressure transducer and monitor.
2. The patient was repositioned by rotating the operating table 15 degrees to the right from the supine position in the reverse Trendelenberg position (30-degree tilt of the bed above the horizontal, with the head in the highest position).
3. The patient was connected to an electrocardiograph, which continuously recorded the electrocardiogram (ECG) tracing.
4. An independent research nurse started timing when the catheter was inserted 5 cm into the PAC sheath. Two stopwatches were used for timing.
5. When the catheter tip first entered the vessel lumen and oscillations appeared on the pressure tracing, the balloon was inflated with 1.5 mL of air.
6. The catheter then was advanced continually at a rate of 2 cm every second using slow continuous motions and rotated as required by the operator. Conventional pressure waveform analyses were used to identify the position of the PAC as it traversed from the superior vena cava (SVC) into the right atrium (RA) (central venous pressure trace), into the right ventricle ([RV] pressure trace), and then into the PA (PA pressure waveform trace).
7. The number of attempts at insertion were recorded. An attempt was defined as the necessity to withdraw the catheter back into the RV, RA, or SVC to assist with PAC insertion.
8. If more than 4 attempts to advance the catheter into the PA were unsuccessful, the following technique was used to facilitate placement of the PAC in the PA:

First, the catheter was removed from the PA sheath and "stiffened" by flushing 20 mL of cold normal saline at a temperature of 4°C through it after its tip was bent into a three-fourths circle. Three further attempts to position the PAC in the PA were allowed.

1. When the anesthesiologist was satisfied that the catheter was in an optimum position in the PA, timing was stopped and the catheter was secured.
2. If the PAC was unable to be floated into the PA within 10 minutes, patients were transferred to the video fluoroscopy group.

## Technique for PAC Flotation in the Fluoroscopy Group

The technique for PAC flotation in the fluoroscopy group was identical to that performed in the usual-care group; however, before the commencement of floating the PAC, the video fluoroscopy machine was positioned over the patient, enabling direct visualization of the course of the PAC from the distal end of the PAC sheath to the PA. Video fluoroscopy was used to visualize catheter positioning from the SVC into the RA, into the RV, and then into the PA. Video fluoroscopy demonstrating flotation of the PAC in a patient undergoing re-do cardiac surgery is presented in Figure 1 and Video 1. If the PAC was unable to be floated into the PA within 10 minutes, patients were transferred to the usual-care group.

After the PAC was inserted in both groups, anesthesia was induced using a standardized opioid induction technique (fentanyl, 10 ug/kg). After intubation of the patient's trachea, an independent echocardiographer, who was blinded to the randomization and was not present during the PAC insertion, performed standardized TEE views to ascertain the position of the PAC in the main PA, proximal or distal right PA, or

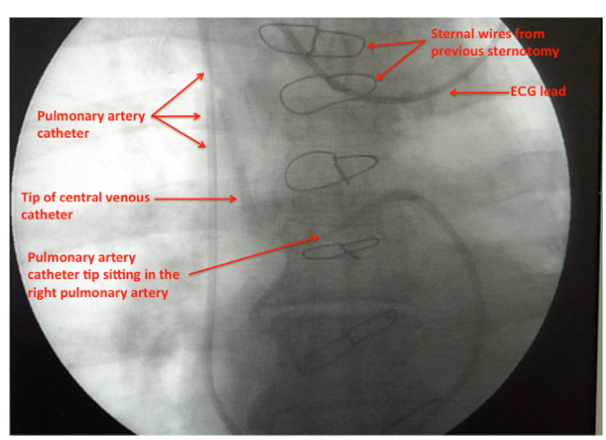


**Fig 1. Video fluoroscopy image demonstrating the normal position of the pulmonary artery catheter tip in the right pulmonary artery.**

proximal left PA. The evaluation of arrhythmias from the continuous ECG recordings was performed by a cardiologist blinded to the intervention.

Variables collected included patient baseline characteristics, indication for procedure, baseline cardiac structure and function, resting pulmonary artery pressures, EuroSCORE II measurements, and routine hematologic and biochemical function test values. The primary outcome was time taken to float and position the PAC balloon in the PA. The time taken to insert the PAC sheath, suture the sheath to the patient's neck, flush each lumen of the PAC, and connect the distal lumen of the PAC to the monitor were not included in this measurement. Secondary outcomes included the number of attempts at flotation; rate of complications, defined as either the occurrence of any malignant arrhythmia (sustained or non-sustained ventricular tachycardia, ventricular fibrillation, or any supraventricular tachyarrhythmia) or malposition of the PAC demonstrated using TEE. An "attempt" was defined as the necessity to withdraw the catheter back into the RV, RA, or SVC to assist with PAC insertion. "Malposition" was defined as the final position of the deflated PAC balloon resting in the RA, RV, or RV outflow tract or the deflated PAC balloon being greater than 4 cm beyond the main PA bifurcation (increased risk of inadvertent wedging and PA rupture). Other data collected included delay in getting the video fluoroscope into the room, time taken to position the video fluoroscope, time taken to remove the video fluoroscope from the room, and the total radiation dose that each patient received.

## Power Analysis

Based on surveillance data of high-risk patients who underwent cardiac surgery and PAC insertion in the authors' institution, the mean time to float a PAC into the PA was 320 seconds (SD = 130 seconds). Assuming a standard deviation in both groups (video fluoroscopy and usual-care groups) of 130 seconds, a sample size of 20 patients in each group was required for a power of 90%, a statistical significance level of 0.05, and to detect a clinically important difference of 50% between the interventions (video fluoroscopy and usual care). A total of 25 patients were enrolled in each group.

Continuous data were tested for normality. Measures of central tendency were compared as means ± standard deviations (SD), using the Student's t-test for normally distributed variables, and as medians (interquartile range [IQR]) using the Mann-Whitney U test for skewed data. Categorical variables were compared using the chi-square test or the Fisher's exact test for $n < 5$. Logistic regression analysis was performed to determine the predictive ability of video fluoroscopy, preoperative cardiac function, pulmonary hypertension, and left atrial size for determining prolonged catheter flotation or complications (eg, catheter malposition or arrhythmias). Univariate and multivariate techniques were used. Multivariate associations were reported as odds ratios (OR) with 95% confidence intervals. A 2-sided p value of $<0.05$ was considered statistically significant. All analyses were performed using SPSS Statistics for Windows, Version 22.0 (IBM, Armonk, NY). This study is reported in accordance to the CONSORT guidelines.

**Table 1. Baseline Patient Characteristics**

| | Usual-care Group n = 25 | Fluoroscopy Group n = 25 |
|---|---|---|
| Baseline Characteristics | | |
| Age (yr) | 65 (15.2) | 66 (9.5) |
| Sex | | |
| Male | 15 (60%) | 17 (58%) |
| BMI (kg/m$^2$) | 27 (5.3) | 28 (9.7) |
| NYHA classification (median) | 3 | 3 |
| Indications for Surgery | | |
| Ischemic heart disease | 9 (36%) | 7 (28%) |
| Isolated aortic valve | 1 (4%) | 2 (4%) |
| Isolated mitral valve | 2 (8%) | 3 (12%) |
| Combined aortic and mitral valves | 6 (24%) | 7 (28%) |
| Combined mitral and tricuspid valves | 4 (16%) | 3 (12%) |
| Ischemic heart disease and valve disease | 3 (12%) | |
| Redo surgery: number (%) | 6 (24%) | 7 (35%) |
| Previous tricuspid valve annuloplasty | 0 (0%) | 0 (0%) |
| Previous right-sided cardiac surgery | 0 (0%) | 0 (0%) |
| EuroSCORE II: mean (SD) | 10.07 (2.5) | 9.6 (2.3) |
| Preoperative Echocardiography | | |
| LV systolic function | 6 (24%) | 7 (28%) |
| Normal | 2 (8%) | 2 (8%) |
| Mild | 11 (44%) | 10 (40%) |
| Moderate | 6 (24%) | 6 (24%) |
| Severe | | |
| LV Diastolic Impairment | | |
| Normal | 3 (12%) | 2 (8%) |
| Grade 1 | 6 (24%) | 7 (28%) |
| Grade 2 | 16 (64%) | 15 (60%) |
| Grade 3 | 2 (8%) | 1 (4%) |
| LA size (cm$^2$) | 26.3 (7.1) | 28.8 (10.8) |
| PASP (mmHg) | 40 (13.5) | 49.8 (16.3) |
| Tricuspid Valve Insufficiency | | |
| Nil | 5 (20%) | 6 (24%) |
| Mild | 14 (56%) | 10 (40%) |
| Moderate | 5 (20%) | 7 (28%) |
| Severe | 1 (4%) | 2 (8%) |
| Preoperative Cardiac Catheterization | | |
| LVEDP (mmHg) | 20.2 (9.55) | 21.9 (9.95) |
| LV dilation | | |
| Dilated | 11 (44%) | 12 (44%) |
| Normal | 14 (56%) | 13 (56%) |
| LV Systolic Function | | |
| Normal | 6 (24%) | 5 (20%) |
| Mild dysfunction | 3 (12%) | 3 (12%) |
| Moderate dysfunction | 11 (44%) | 9 (36%) |
| Severe dysfunction | 6 (24%) | 8 (32%) |
| Coronary Occlusive Disease | | |
| Normal | 12 (44%) | 15 (60%) |
| Double-vessel | 8 (32%) | 7 (28%) |
| Triple-vessel | 5 (20%) | 3 (12%) |

NOTE. Values are expressed as number of patients (proportion [%]) or mean (standard deviation), unless otherwise stated.

Abbreviations: BMI, body mass index; LA, left atrium; LV, left ventricle; LVEDP, left ventricle end-diastolic pressure; NYHA, New York Heart Association; PASP, pulmonary artery systolic pressure.

## RESULTS

Fifty high-risk patients undergoing cardiac surgery necessitating PAC insertion consented to this study. Twenty-five patients were assigned randomly to the fluoroscopy group and 25 to the usual-care group. There were no breaches in the study protocol, and all patients completed the interventions. Both groups were similar with respect to baseline characteristics, EuroSCORE II measurements, New York Heart Association classification of heart failure, tricuspid valve insufficiency, severity of LV and RV dysfunction, RV and LV end-diastolic pressures and dimensions, LA and RA size, and PA systolic pressure (Table 1). Cardiac output measurements were performed via a right heart catheter study in 6 patients during preoperative cardiac catheterization. Only 2 patients, both in the video fluoroscopy group, had a cardiac index $<1.5$ L/min/m$^2$. No patients in either group had undergone previous right-sided cardiac surgery. The PAC was inserted via the right internal jugular vein of all patients.

Mean (SD) time to float the PAC was significantly shorter in the fluoroscopy group: 73 seconds (SD, 65.1) versus 176 seconds (SD, 180.6) in the usual-care group; $p = 0.014$. The median (IQR) number of attempts to successful flotation was lower in the fluoroscopy group: 1 (IQR, 1:2) attempts versus 2 (IQR, 1:4) attempts in the usual-care group; $p = 0.007$. There was no significant difference in the number of patients who experienced an arrhythmia during PAC insertion (8 patients in the usual-care group *v* 4 patients in the fluoroscopy group; $p = 0.32$). The composite complication rate (malposition and arrhythmias) was greater in the usual-care group than in the fluoroscopy group (52% *v* 16%, respectively; $p = 0.01$). Although there were no overall differences between the groups regarding final position of the PAC in the PA, in patients in whom the PAC was positioned distal to the PA bifurcation, the mean (SD) position was farther from the PA in the usual-care group compared with that in the fluoroscopy group (2.4 cm *v* 1.8 cm, respectively; estimated difference, 0.6 cm; $p = 0.041$). The PAC was unable to be floated into the PA in 1 patient in the usual-care group and that patient was transferred to the video fluoroscopy group; the catheter then was floated successfully in 56 seconds using video fluoroscopy. A summary of the key study endpoints is summarized in Table 2.

There was a delay in access to fluoroscopy in 3 patients. For these patients, the delay was 6, 4, and 6 minutes, respectively. The median time in setting up the video fluoroscope was 4 minutes (IQR, 3.2:5.5). The median fluoroscopy exposure time was 58 seconds (IQR, 32:89). The median total effective dose of radiation was 1.7 mSv (IQR, 1:2.2).

## DISCUSSION

The authors performed a single-center, randomized, controlled study in high-risk patients undergoing cardiac surgery, comparing flotation of a PAC with the aid of video fluoroscopy with the conventional technique of pressure waveform analysis alone. Even though it previously has been suggested that use of an image intensifier can reduce the incidence of mechanical complications of PAC insertion,[3] there are no studies directly comparing the flotation of PACs using video fluoroscopy with a conventional pressure waveform technique. The authors found that use of video fluoroscopy required fewer attempts to float the PAC into the PA, was quicker, was more accurate, and was associated with fewer complications. To the authors' knowledge, this was the first study directly comparing pressure waveform analysis with fluoroscopy assistance for insertion of a PAC in adult patients considered to be at high risk for difficult PAC insertion.

This study confirmed that the use of video fluoroscopy-guided insertion of a PAC in high-risk cardiac surgery patients was associated with a clinically and statistically significant reduction in the time taken to position the device successfully. This was highlighted by the experience of 1 patient who started in the usual-care group and in whom it proved impossible to float the catheter during the allotted 10 minutes. The patient was transferred to the fluoroscopy group, and the device was positioned correctly in 56 seconds. Use of video fluoroscopy also was associated with a reduction in complications, specifically malposition and ventricular arrhythmia.

In both groups of patients, the final position of the PAC was distal to the PA bifurcation. However, the PAC was positioned farther, or "deeper," into the PA in the usual-care group. This has

**Table 2. Study Endpoints**

| | Usual Care Group n = 25 | Fluoroscopy Group n = 25 | p Value |
|---|---|---|---|
| Mean time to float (seconds) | 176 (180.6) | 73.2 (65.1) | 0.014 |
| Median number of attempts to position the PAC | 2 (1:4) | 1 (1:2) | 0.01 |
| Arrhythmias | 8 (32%) | 4 (16%) | 0.32 |
| Final position of the PAC in all patients | | | |
| • Proximal to the bifurcation | 3 (12%) | 4 (16%) | 1.0 |
| • At the level of the bifurcation | 4 (16%) | 6 (24%) | 0.72 |
| • Distal to the bifurcation | 17 (68%) | 15 (60%) | 0.55 |
| Distance (cm) of the PAC balloon from the PA bifurcation | | | |
| • Proximal to the bifurcation | 2.3 (0.9) | 0.8 (0.3) | 0.0001 |
| • Distal to the bifurcation | 2.4 (0.8) | 1.8 (0.8) | 0.041 |
| Number of patients in whom the PAC was repositioned | 7 (28%) | 0 (0%) | 0.01 |
| Number of patients with either a catheter malposition or an arrhythmia | 13 (52%) | 4 (16%) | 0.01 |

NOTE. Values are expressed as mean (standard deviation), median (interquartile range), or number of patients (proportion [%]).
Abbreviations: PA, pulmonary artery; PAC, pulmonary artery catheter.

important clinical implications regarding complications, such as PA trauma and hemorrhage. PA rupture is more common if the PAC is positioned deep into the PA, especially with the balloon overinflated while in the wedged position—a complication reported to occur in only 0.2% of patients, but associated with a 50% mortality rate.[4] Similarly, if the PAC is positioned too proximal to the PA bifurcation (ie, close proximity to the pulmonary valve—a finding observed in the usual-care group), complications can include pulmonary valve trauma and migration of the catheter into the RV with subsequent ventricular arrhythmias, which, even though usually transient, can convert to sustained ventricular tachycardia.

From the authors' pilot data, based on surveillance data of high-risk patients undergoing cardiac surgery who received a PAC in the authors' institution, the mean time to float the catheter into the PA was 320 seconds, with a fairly wide standard deviation. Pilot data took into account "all comers" inserting a PAC (eg, senior anesthesiology trainees and junior attending cardiac anesthesiologists). It was not unexpected that in the usual-care group, the mean time to insert the PAC was shorter than the pilot data stated.

The benefits of using fluoroscopy therefore should always outweigh the potential limitations. There are many advantages to the use of fluoroscopy for the insertion of a PAC, particularly in patients in whom flotation is predicted to be difficult due to abnormal flow in the heart (eg, atrial or ventricular septal defects or low-cardiac-output states). First, fluoroscopy provides real-time visualization of the catheter as it traverses the right heart, allowing early recognition of malposition. In particular, entry of the catheter into the left subclavian vein (Figure 2 and Video 2) or inferior vena cava or coiling in the RA or RV (Figures 3 and 4 and Video 3) are recognized rapidly, and this allows for prompt and accurate redirection of the catheter. Secondly, coiling or knotting of the catheter is prevented, notably by recognition of excessive insertion length. Finally, fluoroscopy facilitates better accuracy in confirming that the PAC sits in an ideal position within the main PA,

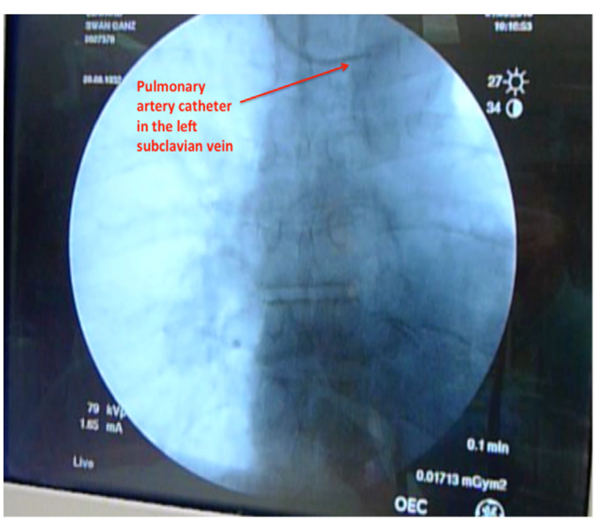


**Fig 2. Video fluoroscopy image demonstrating the pulmonary artery catheter tip in the left subclavian vein.**

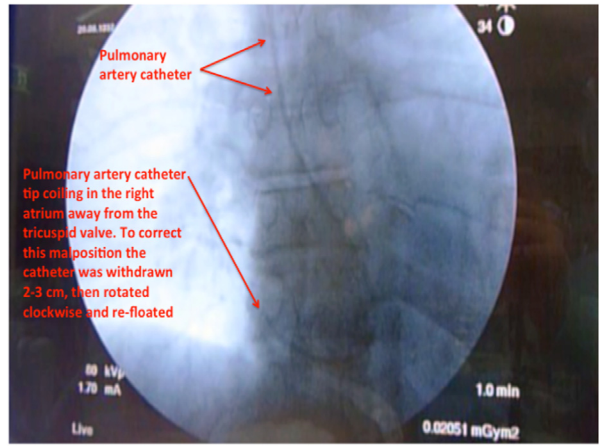


**Fig 3. Video fluoroscopy image demonstrating the pulmonary artery catheter tip coiling in the right atrium.**

sufficiently distal to the pulmonary valve, thus minimizing arrhythmias and avoiding excessive proximal insertion into a smaller PA branch. This minimizes the risk of PA perforation through inadvertent catheter "wedging." Prolonged catheterization time also is a recognized risk factor for ventricular arrhythmias during PAC insertion,[5,6] and excessive insertion length is the major contributing factor to catheter knotting. Hence, the use of fluoroscopy during PA insertion in cardiac surgery patients at higher risk of a PAC-related complication is a pragmatic, rational, and feasible intervention to minimize complications.

When using fluoroscopy in this setting, it is important to minimize the patient radiation dose. In this study, additional strategies to reduce radiation exposure to the patient and anesthesiologist included minimizing the use of the following: steep angles of x-ray beam, magnification modes, frame rates of fluoroscopy, and cine.[7] A maximum distance of operator and patient from the x-ray source was maintained, and the radiation field was minimized to include only the anatomic region of interest because proper collimation of the x-ray beam substantially decreases patient dose.[8,9] This study involved the additional exposure of radiation of up to 300 seconds of video fluoroscopy in patients for the purpose of image-guided insertion of the PAC. Based on a single session of fewer than 5 minutes, fluoroscopic time, at a 20 mGy/min dose rate, a radiation beam of 20-cm diameter, and air gap to flat panel of 5 cm, the authors estimated that patients may have received a radiation dose of approximately 3.5 $mSv^2$. Most people during normal daily activities are exposed to naturally occurring background radiation and receive a dose of radiation of about 2 mSv each year. The effective dose from this study dose was 1.7 mSv. The dose is comparable with that received during many other diagnostic medical x-ray and nuclear medicine procedures.[10] At the dose level used during this study, no harmful effects of radiation have been demonstrated because any effect is too small to measure. The additional risk of an induced fatal cancer is believed to be low and theoretically is approximately equivalent to 1 in 4,200.[10] To justify the risks involved, a moderate benefit therefore still needs to be demonstrated. In the context of this study, the benefits of using

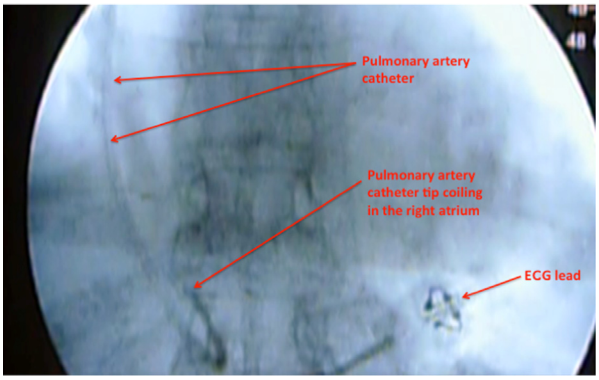


**Fig 4. Video fluoroscopy image demonstrating the pulmonary artery catheter tip coiling in the right atrium.**

fluoroscopy (ie, faster insertion times and decreased rates of complications) outweighed the risks of radiation.

The authors' findings have important implications for PA catheterization in cardiac surgery, particularly as hybrid operating rooms become increasingly widespread. Lack of availability and expense commonly are cited as reasons for not using fluoroscopy for PAC insertion. These were not considered to be prohibitive factors in using fluoroscopy at the authors' institution. Even though the authors' institution does not have hybrid operating room capability, the availability of an image intensifier in the cardiac operating room at all times with dedicated radiology technician support allowed minimal delay in access to the intensifier and a relatively fast set-up time. These factors may be more prohibitive in other institutions.

During PAC insertion, all patients were conscious and cooperative. Insertion of lines while patients were awake and before the induction of anesthesia allowed greater hemodynamic stability because patients were not under the influences of anesthetic medications or vasoactive or antiarrhythmic drugs. Even though study design, standardization of patient positioning, type and make of PAC, rate of PAC insertion, and rescue strategies used were systematic and well controlled—increasing the internal validity of this trial—there were several limitations to the study. First, it was not possible to blind the anesthesiologist performing the PAC insertion to the technique being used. Observer effect, or an observer expectancy effect, unconsciously may have influenced the anesthesiologists' flotation technique, resulting in a form of reactivity and cognitive bias during PAC flotation and potentially providing more care or attention to patients in 1 particular group. However, all anesthesiologists performing the PAC flotation are equally skilled in both techniques, have a diverse range of clinical expertise in using both video fluoroscopy and traditional waveform analyses techniques, and have clinical equipoise for the research question. Second, it is not possible to generalize the results of this study to clinicians inexperienced in the use of either PAC insertion using traditional waveform analyses or clinicians inexperienced with the use and interpretation of video fluoroscopy. Because patient selection was limited to a cardiac surgery population considered to be at high risk of PAC-related complications and from a single center, it was not possible to generalize the results to other groups of cardiac patients or to other settings where PAC is used, such as the intensive care unit. Finally, economic analysis of all costs (presence of a radiographer, time taken to position the image intensifier, and use of additional equipment) was not performed; however, this did not detract from the study objectives or the findings reported. Indeed, it could be argued that the lower incidence of complications resulting from this technique may contribute to a potential overall pharmacoeconomic cost benefit.

## CONCLUSIONS

In patients considered at higher risk for PAC-related complications who are undergoing cardiac surgery, video fluoroscopy facilitated faster and safer PAC flotation and positioning compared with the traditional pressure waveform flotation technique alone. Clinicians should have a low threshold to use video fluoroscopy as a complementary technique when the positioning of a PAC using the traditional waveform approach is anticipated to be difficult.

## APPENDIX A. SUPPORTING INFORMATION

Supplementary material cited in this article is available online at http://dx.doi.org.10.1053/j.jvca.2015.07.033.

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