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# Trends in the Use of the Pulmonary Artery Catheter in the United States, 1993-2004

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**T**HE PULMONARY ARTERY (PA) catheter first became available as a practical diagnostic tool in 1970<sup>1</sup> and was rapidly embraced by critical care physicians. The PA catheter (also known as the Swan-Ganz catheter) made quantitative hemodynamic data, such as cardiac output and pulmonary capillary wedge pressure, accessible to physicians at the bedside. Many physicians assumed that these numbers could guide treatment and ultimately reduce mortality in critically ill patients. Within several years, PA catheterization was widely used throughout the United States. In the 1980s, 20% to 43% of seriously ill patients who were hospitalized were reported to undergo the procedure.<sup>2-4</sup>

The first major challenge to widespread use was the 1985 editorial by Robin<sup>5</sup> denouncing the lack of randomized trials demonstrating the benefit of the procedure. Early attempts to conduct randomized trials were stymied by physicians' insistence that PA catheterization was ethically mandated in critically ill patients. A randomized trial conducted in the late 1980s was able to enroll only 33 of 148 eligible patients due to physician refusal.<sup>6</sup> The turning point occurred when in Sep-

**For editorial comment  
see pp 456 and 458.**

**Context** Although there is now substantial evidence that pulmonary artery (PA) catheterization does not reduce mortality in critically ill patients, it is unknown whether national utilization has decreased in response.

**Objective** To determine trends in PA catheterization use in the United States.

**Design, Setting, and Participants** A time trend analysis on national estimates of PA catheterization utilization from 1993-2004 using data from all US states contributing to the Nationwide Inpatient Sample. Hospital admissions for those participants aged 18 years or older were assessed, with primary analysis focused on admissions with a medical diagnosis related group and a secondary analysis focused on surgical admissions. PA catheterization was identified by 5 *International Classification of Diseases, Ninth Revision* procedure codes describing PA or wedge-pressure monitoring, measurement of mixed venous blood gases, or monitoring of cardiac output by oxygen consumption or other technique.

**Main Outcome Measure** Annual PA catheterization use per 1000 medical admissions.

**Results** Between 1993 and 2004, PA catheterization use decreased by 65% from 5.66 to 1.99 per 1000 medical admissions (risk ratio [RR], 0.35; 95% confidence interval [CI], 0.29-0.42). Among patients who died during hospitalization, a group whose disease severity may be consistent across time, the relative decline was similar, decreasing from 54.7 to 18.1 per 1000 deaths (RR, 0.33; 95% CI, 0.28-0.38). A significant change in trend occurred following a 1996 study that suggested increased mortality with PA catheterization. The decline in utilization was similar in surgical patients (RR, 0.37; 95% CI, 0.25-0.49). Among common diagnoses associated with PA catheterization, the decline was most prominent for myocardial infarction, which decreased by 81% (RR, 0.19; 95% CI, 0.15-0.23), and least prominent for septicemia, which decreased by 54% (RR, 0.46; 95% CI, 0.38-0.54). Sensitivity analyses suggested findings were not due to artifact of changing procedure coding practice.

**Conclusion** Use of the PA catheter, previously a hallmark of critical care practice, has decreased in the United States during the last decade, possibly due to growing evidence that this invasive procedure does not reduce mortality.

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tember 1996 a multicenter observational study by Connors et al<sup>3</sup> suggested increased mortality with PA catheterization, accompanied by an editorial<sup>7</sup> calling for a moratorium on PA catheter use until a randomized controlled trial could be conducted. Although there are still proponents of PA catheterization,<sup>8</sup> in the past 5 years mul-

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multiple randomized trials<sup>9-14</sup> and a Cochrane Collaboration meta-analysis<sup>15</sup> have shown that this technology has no impact on mortality in diverse populations of critically ill patients.

It is not known how much utilization of this technology has changed in response to the literature. In this article, we used the Nationwide Inpatient Sample (NIS) to examine national trends in utilization of PA catheterization.

## METHODS

### Data Source

We used the NIS to determine national rates of PA catheterization use. The NIS is part of the Agency for Health Care Research and Quality's Healthcare Cost and Utilization Project and contains information on all discharges from a 20% stratified sample of community hospitals in the United States (5-8 million discharges per year). Each record in the NIS contains multiple variables, including patient demographics, diagnosis related group (DRG), up to 15 *International Classification of Diseases, Ninth Revision (ICD-9)* procedure and diagnosis codes, vital status at hospital discharge, and month of hospital admission with year of discharge. Each record also includes a discharge weight to allow for national estimates.

The NIS began in 1988. In the first year, 8 states contributed data; now 27 states do. Although participating states tend to continue to contribute data after entering the database, the individual hospitals reporting within a state vary from year to year. Because 1993 was the first year the NIS sampling frame represented more than 50% of US hospital discharges, the Healthcare Cost and Utilization Project recommends conducting time trend analyses beginning in 1993.

### Study Design

Given this recommendation, we conducted our primary time trend analysis on national estimates of PA catheterization utilization from 1993-2004 using data from all states

contributing to the NIS. To examine rates of PA catheterization use in earlier years and to avoid the potential confounding effect of the changing distribution of states in the NIS, we performed a secondary time trend analysis based only on hospital discharges from the 9 states continuously contributing data from 1989-2004 (California, Colorado, Florida, Illinois, Iowa, Maine, New Jersey, Washington, and Wisconsin).

The Dartmouth Institutional Review Board has deemed studies using de-identified, publicly available data (such as that used here) to be exempt from institutional review board review.

### Study Population

We restricted our primary analysis to adult medical admissions ( $\geq 18$  years). We first excluded pediatric admissions by removing all discharges in patients younger than 18 years. We then separated medical from surgical admissions by removing discharges with a surgical DRG to avoid inclusion of PA catheters placed for routine perioperative monitoring. For the purposes of our study, selected surgical DRGs that are conventionally considered medical admissions (eg, tracheostomy with prolonged mechanical ventilation, bone marrow transplant, and percutaneous transluminal coronary angioplasty) were retained in this analysis (defined as medical admissions) (available from authors upon request). Finally, to avoid analysis of PA catheterization for routine titration of pulmonary vasodilators, we excluded hospital stays with a primary diagnosis of pulmonary hypertension (ICD-9 codes 416.0 or 416.8: primary or secondary pulmonary hypertension, respectively; or DRG 144: other circulatory system disorders).

### Main Outcome Measure

We identified hospital stays in which PA catheterization was performed using 5 ICD-9 procedure codes: 89.63 (pulmonary artery pressure monitoring), 89.64 (pulmonary artery wedge monitoring), 89.66 (measurement of mixed venous blood gases), 89.67 (monitor-

ing of cardiac output by oxygen consumption technique [Fick method]), and 89.68 (monitoring of cardiac output by other technique [thermodilution indicator]). A medical admission containing 1 of these codes in any of the 15 procedure fields was included. We specifically excluded ICD-9 procedure code 37.21 (right heart catheterization), which is intended for procedures performed in the cardiac catheterization laboratory rather than for bedside monitoring procedures.<sup>16</sup> If a patient had multiple PA catheters inserted during an admission, only 1 was counted.

The primary outcome measure was the number of PA catheterizations per 1000 medical admissions in each year of the study period. Because the average disease severity of hospital admissions may change over time, we repeated the analysis on the subset of inpatients whose disease severity is arguably consistent over time—those patients who died (100% mortality). This method of standardizing disease severity in large administrative databases has been previously used by Fisher et al.<sup>17</sup>

### Trends Among Various Subgroups

We stratified PA catheterization use by patient age and hospital characteristics (region, urban/rural location, and teaching status). Region is based on US Census region. An urban hospital is defined as a hospital in a Metropolitan Statistical Area. A teaching hospital is defined as a hospital having a residency program approved by the Accreditation Council for Graduate Medical Education or belonging to the Council of Teaching Hospitals. Of note, the definition of teaching hospital used by the NIS was relaxed between 1993 and 2004 to also include those hospitals with a ratio of full-time equivalent residents to beds of 0.25 or higher.<sup>18</sup>

### Trends Among Selected Medical Diagnoses

For the first and last years studied (1993 and 2004), we identified the 25 most common primary diagnosis codes associated with PA catheterization in

medical admissions. These ICD-9 codes were collapsed into 5 clinically relevant diagnostic categories (available from authors upon request). The number of PA catheterizations per 1000 medical admissions in each of these categories was calculated for 1993 and 2004.

### Potential Effect of Coding Practices

To address the possibility that temporal changes in PA catheterization use reflect changes in hospital coding practices, we performed 2 additional analyses. It is possible that PA catheterization reporting might be influenced by the number of fields available to code procedures. Although the NIS allows up to 15 procedure codes per discharge record, the number permitted by each state ranges from 6 to 15 and may vary from year to year. To avoid the potential confounding introduced by the number of procedure fields available, we conducted an analysis restricted to those states that consistently allowed the reporting of at least 10 procedures during the study period.

As the level of acuity of patients who are hospitalized has increased over time, more procedures may have been performed in later years of the study period. Because the number of fields available to code procedures is limited, it is possible that more minor procedures like

PA catheterization may be “crowded out” of the discharge record in later years. To address this possibility, we conducted a secondary analysis of utilization of procedures of similar (or arguably lesser) magnitude that may also be performed in critically ill patients. Specifically, we examined change between 1993-2004 in utilization of arterial catheterization and endotracheal intubation (ICD-9 procedure codes 38.91 and 96.04, respectively).

### Trends in Surgical Admissions

As a secondary analysis, we studied PA catheterization use in adult surgical admissions. We first identified all admissions with a surgical DRG, excluding those few that were reclassified as medical admissions for this study (available from authors upon request). We then separated those admissions undergoing cardiac surgery (coronary artery bypass grafting and cardiac valve surgery, ICD-9 procedure codes 36.1x and 35.1x-35.2x, respectively) from all other types of surgery.

### Statistical Analysis

The primary analyses were performed using Stata software package, release 9 (StataCorp Inc, College Station, Texas). We derived national estimates of PA catheterization utilization by applying each record's discharge weight using the

SVY series of commands. We determined risk ratios (RRs) and 95% confidence intervals (CIs) using the SVY: ratio and nlcom commands.  $P < .05$  was considered statistically significant.

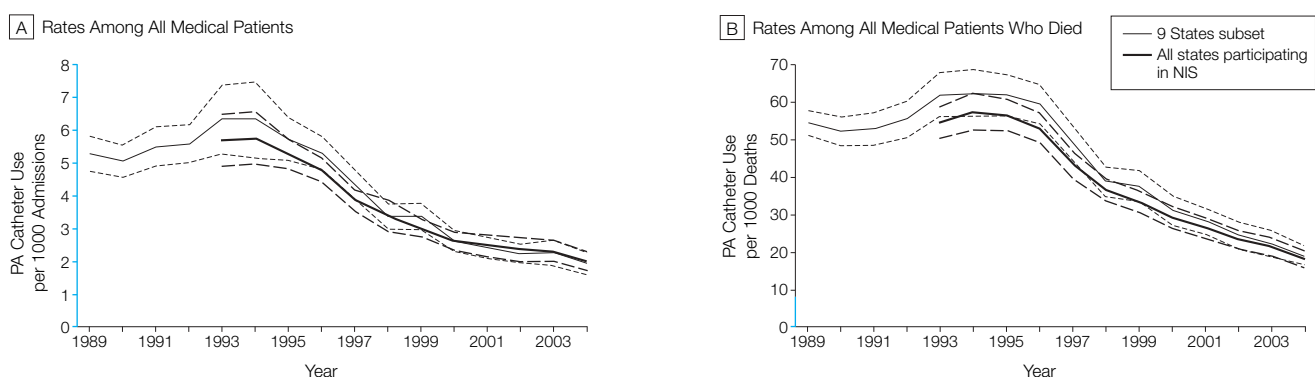
We used Joinpoint Regression Program version 3.0 (Statistical Research and Applications Branch, National Cancer Institute, Bethesda, Maryland)<sup>19</sup> to test for significant changes in time trends that may have occurred during the study period. This is the software used by the Surveillance, Epidemiology, and End Results program to determine changes in cancer incidence. We used the default settings, which allow up to 3 joinpoints (4 distinct temporal trends), require at least 2 observations between joinpoints, and use a log-linear regression model and the Monte Carlo permutation method to assess significant changes in time trends. We allowed the Joinpoint Regression Program to identify the years at which a significant change in trend occurred rather than specifying a priori years in which a joinpoint might have occurred.

## RESULTS

### Overall Trends in PA Catheterization Use for Medical Admissions

As shown in FIGURE 1A, utilization of PA catheterization in the United States

**Figure 1.** National Estimates of PA Catheter Use Among Medical Patients, 1989-2004



PA indicates pulmonary artery; NIS, Nationwide Inpatient Sample. Solid lines indicate PA catheters placed per 1000 patients and dashed lines indicate 95% confidence intervals around the annual rate. Y-axis intervals shown in blue indicate range from 0 to 8. An observational study suggested increased mortality with PA catheterization (abstract was presented in 1994<sup>3</sup> and the paper published in 1996<sup>20</sup>). Two randomized controlled trials (published in 2002 and in 2003)<sup>11,12</sup> showed no decrease in mortality with PA catheterization.

from 1993 to 2004 for all medical admissions decreased by 65% from 5.66 to 1.99 per 1000 medical admissions (RR, 0.35; 95% CI, 0.29-0.42). The joint-point regression identified 3 distinct trends within this period as the most parsimonious model. Between 1993 and

1995, there was no significant change in utilization. Beginning in 1996, there was a significant decrease in PA catheterization use through 2000, with a smoothed annual percentage change of -13.5% (95% CI, -17% to -10%). Subsequently, the decline slowed to a

smoothed annual percentage change of -5.1% (95% CI, -11% to 1%).

Figure 1A also shows that the trend in the 9 states subset appears to be representative of the Healthcare Cost and Utilization Project–recommended data for time trend analysis, generally falling within the 95% CI around the primary analysis. This subset, however, provides information on utilization before 1993. In this subset, PA catheterization use increased from 5.26 per 1000 medical admissions in 1989, peaked at 6.30 per 1000 admissions in 1993, and decreased to 1.92 per 1000 admissions by the end of the study period.

Although PA catheterization use was consistently an order of magnitude higher among patients who died in the hospital than among all medical admissions, Figure 1B shows the rate of decline to be remarkably similar (decreasing from 54.7 to 18.1 per 1000 deaths; RR, 0.33; 95% CI, 0.28-0.38). This suggests that there was no shift in PA catheterization use toward the most severely ill patients over time. A joint-point regression showed 2 distinct trends within this period as the most parsimonious model. Between 1993 and 1995, there was no significant change in utilization. Beginning in 1996, there was a significant decrease in PA catheterization use throughout the remainder of the study period, with a smoothed annual percentage change of -12.1% (95% CI, -13% to -11%).

### Trends Among Various Subgroups

Rates of utilization of PA catheterization decreased from 1993 to 2004 in all subgroups of medical admissions, regardless of region of the country, urban or rural location, teaching status of the hospital, or age of the patients (TABLE). The mean age of patients undergoing PA catheterization decreased slightly over the study period from 66.8 to 65.1 years ( $P = .005$ ). Although the decrease in PA catheterization use was substantial in both teaching and nonteaching hospitals, the most recent year of data (2004) demonstrates that teaching hospitals are sig-

**Table.** Change in PA Catheterization Use in Various Subgroups, 1993 and 2004

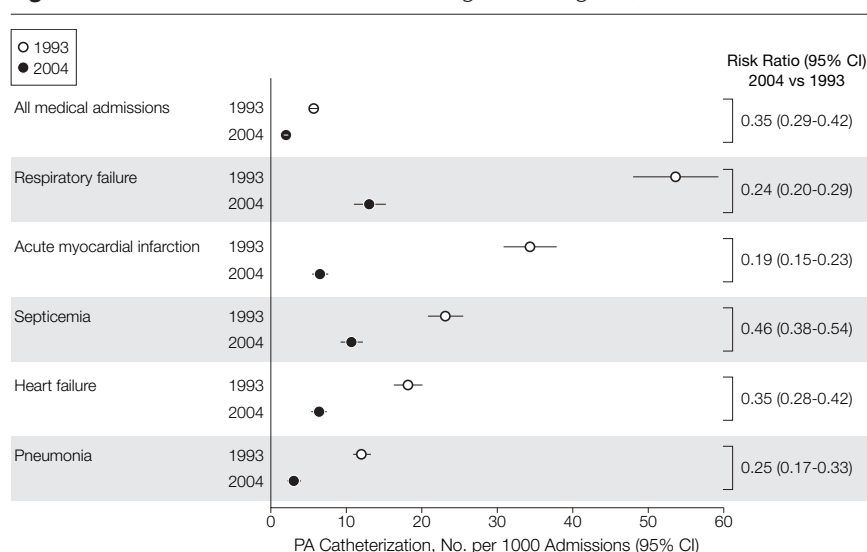
	Risk Ratio (95% CI)		
	PA Catheterization per 1000 Admissions		Change in PA Catheterization <sup>a</sup>
	1993	2004	
Overall	5.66 (5.05-6.26)	1.99 (1.69-2.28)	0.35 (0.29-0.42)
US region <sup>b</sup>			
Northeast	5.37 (4.09-6.66)	2.12 (1.33-2.91)	0.39 (0.22-0.57)
Midwest	4.25 (2.78-5.72)	1.81 (1.07-2.55)	0.43 (0.20-0.65)
South	6.18 (5.20-7.16)	1.99 (1.56-2.42)	0.32 (0.24-0.41)
West	6.92 (5.90-7.94)	2.06 (1.68-2.44)	0.30 (0.23-0.37)
Location of hospital <sup>b</sup>			
Urban	6.23 (5.50-6.95)	2.09 (1.77-2.41)	0.34 (0.27-0.40)
Rural	3.17 (2.61-3.73)	1.42 (0.60-2.25)	0.45 (0.18-0.72)
Teaching hospital status <sup>b</sup>			
Teaching	6.47 (4.80-8.14)	2.41 (1.90-2.92)	0.37 (0.25-0.50)
Nonteaching	5.33 (4.86-5.81)	1.69 (1.33-2.04)	0.32 (0.24-0.39)
Age of patients, y			
18-44	1.53 (1.28-1.78)	0.71 (0.58-0.83)	0.46 (0.35-0.57)
45-64	7.03 (6.13-7.93)	2.54 (2.16-2.93)	0.36 (0.29-0.43)
65-74	9.55 (8.49-10.62)	3.05 (2.63-3.48)	0.32 (0.26-0.38)
≥75	7.65 (6.91-8.40)	2.30 (1.87-2.73)	0.30 (0.24-0.36)

Abbreviations: CI, confidence interval; PA, pulmonary artery.

<sup>a</sup>Risk ratios and 95% CIs are for utilization in 2004 vs 1993.

<sup>b</sup>Region is based on US Census region. An urban hospital is defined as a hospital in a Metropolitan Statistical Area. A teaching hospital is defined as a hospital having a residency program approved by the Accreditation Council for Graduate Medical Education or belonging to the Council of Teaching Hospitals.

**Figure 2.** PA Catheterization Use in Selected Diagnostic Categories, 1993 and 2004



PA indicates pulmonary artery; CI, confidence interval.

nificantly more likely to use the technology than nonteaching hospitals (RR, 1.43; 95% CI, 1.01-1.85).

PA catheterization use for various regions of the United States is shown in the Table. In both 1993 and 2004, PA catheterization use was lowest in the midwest. In 1993, PA catheterization use was most common in the west, whereas in 2004, utilization was highest in the northeast. In general, the geographic variability in PA catheterization use decreased over time (in 1993, there was a 1.6-fold difference [95% CI, 1.02-2.24] in the highest vs lowest region compared with a nonsignificant 1.2-fold difference in 2004 [95% CI, 0.53-1.81]).

### Trends Among Selected Medical Diagnoses

The 5 most common medical diagnostic categories associated with PA catheterization in both 1993 and 2004 included respiratory failure, acute myocardial infarction, septicemia, heart failure, and pneumonia. These categories represented approximately half of all medical PA catheterizations performed during 1993 (55%) and 2004 (47%). As shown in FIGURE 2, PA catheterization use was roughly 2- to 10-fold more common in these "high-risk" diagnostic categories than in all medical admissions. PA catheterization use decreased in all of these categories over the study period. The decline was most striking for patients with

acute myocardial infarction (81% decrease; RR, 0.19; 95% CI, 0.15-0.23) and least marked for patients with septicemia (54% decrease; RR, 0.46; 95% CI, 0.38-0.54).

### Potential Effect of Coding Practices

Repeating the analysis using only those states that consistently allowed 10 or more procedures to be reported had little effect on our results. We found a 59% decrease in PA catheterization use in this subset (RR, 0.41; 95% CI, 0.28-0.53) compared with a 65% decrease in our primary analysis (RR, 0.35; 95% CI, 0.29-0.42). Analysis of 2 other minor procedures commonly performed in the intensive care unit suggested that the decline in PA catheterization use was not an artifact of "crowding out" of the procedure codes on the discharge record. As shown in FIGURE 3A, among medical admissions, reported utilization of endotracheal intubation increased by 23% (RR, 1.23; 95% CI, 1.15-1.30) and arterial catheterization was roughly stable (RR, 0.92; 95% CI, 0.76-1.09).

### Trends in Surgical Admissions

To determine whether the decline in PA catheterization use was unique to medical inpatients or extended to other types of hospital admission, we repeated our analysis in surgical patients. We found that the 63% decrease in PA catheterization use in all surgical admissions be-

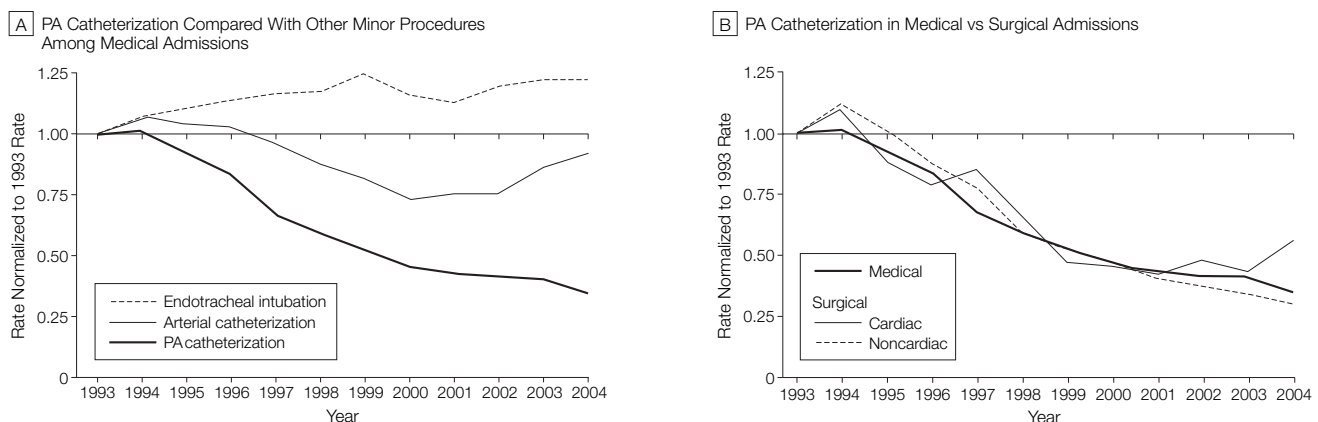
tween 1993 and 2004 (RR, 0.37; 95% CI, 0.25-0.49) was remarkably similar to the 65% decline observed in all medical patients. As shown in Figure 3B, the decline was evident in both cardiac and noncardiac surgery.

### COMMENT

We found that PA catheterization use in both medical and surgical admissions has declined substantially across the United States over the study period. Although this decline clearly preceded the randomized controlled trials published in the past 5 years, there appears to be a temporal relationship between the decrease in utilization and the 1996 publication of the first multicenter study,<sup>3</sup> suggesting increased mortality with PA catheterization, and its accompanying editorial.<sup>7</sup>

Although the joinpoint regression analysis identified 1996 as the first year in which a statistically significant change in trend occurred, our data showed that the initial decrease in utilization of PA catheterization predated the 1996 Connors et al<sup>3</sup> study. Because this study was presented in abstract form at the 1994 American Thoracic Society conference,<sup>20</sup> it is possible that certain prominent critical care physicians acted as early adopters and not only discontinued PA catheter placement but also influenced the local culture in their hospitals through

**Figure 3.** Minor Procedure Utilization and PA Catheterization Use Among Medical and Surgical Admissions, 1993-2004



PA indicates pulmonary artery.

their role as opinion leaders.<sup>21</sup> This may explain the decrease in PA catheterization use that is visually apparent (although not statistically significant) before 1996.

It is perhaps unusual that PA catheterization, a technique that was rapidly adopted and widely used by the medical community, would fall out of favor relatively quickly following an observational study, which, however well-designed, lacks the rigor of a randomized controlled trial. A more typical pattern of diffusion of technology would be a rapid uptake but a slower decline in use. Some of the decrease in PA catheterization use that occurred with the 1996 Connors et al<sup>3</sup> study may be explained by the strongly worded accompanying editorial<sup>7</sup> that called for a moratorium on use of PA catheterization. In addition, the extensive commentary this sentinel study generated not only in the medical literature but also in the general media may have influenced physician practice, as mass media coverage has been shown to strongly affect physician behavior.<sup>22-24</sup>

A limitation of our study is a probable systematic undercount of PA catheterization use. Indeed, we found lower rates than previous studies, which report PA catheterization in 20% to 43%<sup>2,4</sup> of severely ill patients in the 1980s. Although a more recent single-institution study documented PA catheter placement in 7.3% of patients admitted to the medical intensive care unit from 1995-2000,<sup>25</sup> even this lower utilization is an order of magnitude higher than that reported here. The bulk of the discrepancy is explained by 2 factors. First, although previous studies focus on severely ill inpatients (eg, often in the intensive care unit), our data include all medical admissions. We were unable to restrict our analysis to critically ill patients because the NIS does not include an indication of intensive care unit admission or clinically relevant information to determine disease severity (eg, blood pressure, urine output, oxygenation). Second, previous studies refer to use in selected academic hospitals, while our data reflect

national utilization. Nonetheless, our study undoubtedly underestimates the true frequency of the procedure, as we were unable to capture any PA catheterizations that were performed but not coded at hospital discharge.

One might wonder if this undercount of PA catheterization became more substantial over time, leading to a spurious conclusion that utilization has decreased. This is a valid concern—as more procedures are being performed during hospital admissions, the more minor procedures like PA catheterization may be “crowded out” of the 15 procedure fields allowed per discharge record in the NIS. Because utilization of similar minor procedures like arterial catheterization and endotracheal intubation is stable or increasing, we are confident that the substantial decrease in PA catheterization use we observed is real. The similar decrease in PA catheterization use in the subset of states consistently allowing 10 or more procedures to be coded per hospital discharge record, a subset which presumably mitigates concerns of “crowding out” of minor procedures, strengthens this conclusion.

A second limitation is that our data provide incomplete information on the indication for PA catheterization. Our diagnostic categories are based on the primary diagnosis recorded on the hospital discharge record. The order of diagnosis codes on the discharge record may at times be driven more by reimbursement interests than clinical relevance. Moreover, the primary diagnosis at the time of hospital discharge may differ from the primary clinical concern at the time the procedure was performed. A patient with a primary diagnosis of respiratory failure, for instance, may have had a secondary diagnosis of septicemia and a tertiary diagnosis of renal failure. If PA catheterization was performed to determine fluid status in response to low urine output, in our study it would have been erroneously coded as being placed in association with respiratory failure.

We found that teaching hospitals were no quicker than nonteaching hos-

pitals to abandon use of PA catheterization. This finding may in part be due to the more inclusive definition of teaching hospital used by the NIS in 2004 vs 1993. In particular, we were surprised that teaching hospitals were 43% more likely to perform PA catheterization than nonteaching hospitals in 2004. One would hope that the evidence showing no mortality reduction with this invasive procedure would disseminate rapidly in academic centers, resulting in lower than average rates of use. Nevertheless, the national decrease in PA catheter utilization suggests that many physicians have responded appropriately to the evidence that PA catheterization does not reduce mortality.

**Author Contributions:** Dr Wiener had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

**Study concept and design, analysis and interpretation of data, drafting of the manuscript, and critical revision of the manuscript for important intellectual content:** Wiener, Welch.

**Acquisition of data and statistical analysis:** Wiener. **Study supervision:** Welch.

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**Disclaimer:** The views expressed herein do not necessarily represent the views of the US Department of Veterans Affairs or the US government.

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I know that truth lies in the facts, and not in the mind that judges of them, and that the less I introduce of what are merely my own into the deductions I make for them, the more certain I shall be of approaching the truth.

—Jean Jacques Rousseau (1712-1778)