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### Authors

Judge, Onkar
Ji, Fuhai
Fleming, Neal
et al.



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# Current Use of the Pulmonary Artery Catheter in Cardiac Surgery: A Survey Study

Onkar Judge, MD,* Fuhai Ji, MD,*† Neal Fleming, MD, PhD,* and Hong Liu, MD*

***Objective:*** **Because of its invasive nature, debated effect on patient outcome, and the development of alternative hemodynamic monitoring technologies, the intraoperative use of the pulmonary artery catheter (PAC) has significantly decreased. The authors conducted a survey of the members of the Society of Cardiovascular Anesthesiologists (SCA) to assess current use of the PAC and alternative hemodynamic monitoring technologies in patients undergoing cardiac surgery.**

***Design:*** **A survey study.**

***Setting:*** **Hospitals in North America, Europe, Asia, Australia, New Zealand, and South America.**

***Participants:*** **SCA members in North America, Europe, Asia, Australia, New Zealand, and South America.**

***Interventions:*** **The survey was e-mailed by the SCA to roughly 6,000 of its members.**

***Measurements and Main Results:*** **The survey was left open for 30 days. Respondents accessed the survey via a secured web-based database. A total of 854 questionnaires were completed. A total of 705 (82.6%) were from North American members. Four hundred twelve of the respondents (48.1%) worked in a private practice setting, while 350 (40.9%) were from an academic practice. A majority of the respondents (57.9%) were from hospitals that performed more than 400 cardiac surgeries a year, a subset of which (29.6%) did more than 800 cases annually. For cases using cardiopulmonary bypass, 583 (68.2%) of the respondents used a PAC more than 75% of the time, while 30 (3.5%) did not use the PAC at all.**

**Ninety-four percent of respondents used transesophageal echocardiography (TEE) as part of the intraoperative monitoring. When not using a PAC, FloTrac/Vigileo was the alternative cardiac monitoring modality in 15.2% of the responses. Similar trends in monitor preferences were seen in off-pump coronary artery bypass grafting and minimally invasive/robotic heart surgery.**

***Conclusions:*** **The results of this study suggested that a majority of the respondents still prefer to use the PAC for most cardiac surgeries. Subgroup analysis of the data revealed that geographical location, type of practice, and surgeon support played a significant role in the decision to use a PAC. Although most respondents prefer to use TEE as a complimentary tool, TEE also remains the most popular supplemental/alternative hemodynamic monitoring technology.**



***KEY WORDS: pulmonary artery catheter, cardiac surgery, hemodynamic monitoring***

COMPREHENSIVE HEMODYNAMIC MONITORING and optimization of cardiac function provide the foundation for critical care and perioperative patient management. Numerous strides have been made to improve hemodynamic monitoring of patients undergoing cardiac surgery. Perhaps the largest came in 1970 when Swan et al[1] first used the pulmonary artery catheter (PAC) at beside to assess cardiac function. Through subsequent advances in technology and some simple calculations, the PAC now allows routine measurements of central venous pressure, pulmonary artery pressure, continuous cardiac output (in specially designed catheters), systemic vascular resistance, and mixed venous oxygen ($SvO_2$ with oximetric PAC).[2] These measurements allowed for better characterization of preload, afterload, contractility, and tissue oxygenation. Although it was first introduced for use in critically ill patients, use of the PAC quickly expanded into the operating room such that hemodynamic monitoring with a PAC has become an integral aspect of the anesthetic management of cardiac surgery patients. It provides invaluable information both intra- and postoperatively in the intensive care unit (ICU). However, because of its invasive nature-associated complications, debated effect on patient outcome and the development and clinical introduction of alternative, less invasive hemodynamic monitoring technologies, the intraoperative use of the PAC has decreased significantly over the years.[3–5] The authors conducted this survey of the Society of Cardiovascular Anesthesiologists (SCA) members to assess the current usage of the PAC and other hemodynamic monitoring technologies in patients undergoing cardiac surgery.

## METHODS

A 17-question survey was developed by the authors and approved by the SCA to assess the current use of hemodynamic monitoring technologies during cardiac surgery (Table 1). Three questions were related to demographic data and practice type. One question was included to evaluate the opinion of the cardiac surgeon with respect to alternative hemodynamic monitoring technologies. The remaining questions were related to the types of procedures and monitoring technologies used. Before dissemination, a pilot questionnaire was sent to cardiac anesthesia faculty at the authors' institution to evaluate the survey's clarity and reliability. The survey then was e-mailed by the

*From the *Department of Anesthesiology and Pain Medicine, University of California, Davis, California; and †Department of Anesthesiology, First Affiliated Hospital of Soochow University, Suzhou, Jiangsu, China.*

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*Address reprint requests to Hong Liu, MD, Department of Anesthesiology and Pain Medicine, University of California Davis Health System, 4150 V Street Suite 1200, Sacramento, CA 95817. E-mail: hualiu@ucdavis.edu*



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**Table 1. Society of Cardiovascular Anesthesiologists Survey Questions**

1. How many cardiac surgeries does your hospital do per year?
2. Practice type.
3. Geographical locations of your practice.
4. What percentage of your patients is monitored intraoperatively with a PAC for cardiopulmonary bypass (CPB) surgery?
5. Do you use another monitor during cardiopulmonary bypass surgery?
6. If you answered yes to question 5, which monitors do you use besides PA catheter?
7. If you do not use a PAC, which alternative hemodynamic do you use most often?
8. Do you routinely do off pump CABG?
9. What percentage of your patients is monitored intraoperatively with a PAC for off pump CABG?
10. If you do not use a PAC for your off pump CABG, which alternative hemodynamic monitors do you use most often?
11. Does your hospital routinely perform minimally invasive/robotic assisted CABG?
12. What percentage of your patients is monitored intra-operatively with a PAC for your minimally invasive/robotic assisted CABG?
13. If you do not use a PAC for your minimally invasive/robotic assisted CABG, which alternative hemodynamic monitors do you use most often?
14. Does your hospital perform minimally invasive/robotic assisted valve cases?
15. What percentage of your patients is monitored intraoperatively with a PAC for your minimally invasive/robotic assisted valve cases?
16. If you do not use a PAC for your minimally invasive/robotic assisted valve cases, which alternative hemodynamic monitors do you use most often?
17. If using alternative hemodynamic monitoring other than pulmonary artery catheter, what is the opinion of your CT surgeon?

Abbreviations: CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; CT, computed tomography; PA, pulmonary artery; PAC, pulmonary artery catheter.

SCA to roughly 6,000 of its members. The survey was left open for 30 days (January 17-February 16, 2012) and respondents accessed the survey via a secure web-based database (Survey Monkey, Palo Alto, CA, USA). Categoric data were analyzed and expressed as percentage of respondents using a given type of hemodynamic monitoring.

## RESULTS

The overall response rate was approximately14%. Of the 854 questionnaires completed, 705 (82.5%) were from North American members. European members completed 81(9.5%) (Fig 1). The majority of all respondents were working in the private sector (48.1%), but academic practice was very common as well (40.9%). Government hospital employment represented 11% of the respondents (Fig 2). Subgroup analysis revealed that the majority of the private and academic practitioners were in North America (Fig 3). A majority of the respondents (57.9%) worked at hospitals that performed more than 400 cardiac surgeries a year, a subset of which did more than 800 annually (Fig 4).

For procedures using cardiopulmonary bypass (CPB), 583 (68.2%) of the respondents used a PAC more than 75% of the time (Table 2). Subgroup analysis by practice type revealed that for CPB cases, 79.2% of private practitioners used a PAC more than 75% of the time (Table 3). This percentage declined in academic practice (64.5%) and more substantially (34%) in the government practice subgroups (Tables 4 and 5). Similarly, as summarized in Table 2, the use of a PAC remained comparably frequent in off-pump coronary artery bypass grafting (CABG) and minimally invasive cardiac surgery as well. However, the percent of patients in whom a PAC was never used increased from 3.5% for CPB cases to more than 13% for minimally invasive cardiac procedures. This percentage of no PAC monitoring for minimally invasive procedures was comparable in the private and academic practice settings but markedly increased (40%) for respondents practicing in government hospitals.

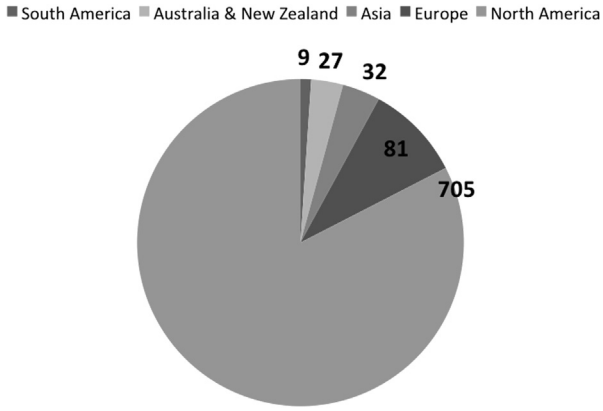


**Fig 1. Number of respondents from each geographic location.**

Transesophageal echocardiography (TEE) was the most commonly (97.9%) used complementary hemodynamic monitor to the PAC during cardiac surgery (Fig 5). When not using a PAC during CPB, 94% of respondents used TEE as the complementary and/or alternative monitor (Table 6). Similarly, TEE remained the most commonly used complementary and/or alternative hemodynamic monitoring technology in both off-pump CABG and minimally invasive cardiac surgery (Table 6). More than 56% of the respondents stated that the cardiac surgeons were not supportive of alternative hemodynamic monitoring technologies and preferred the PAC (Fig 6). Subgroup analysis demonstrated that cardiac surgeons in the private sector were least likely to be supportive of alternative monitor technologies, while a majority of the surgeons

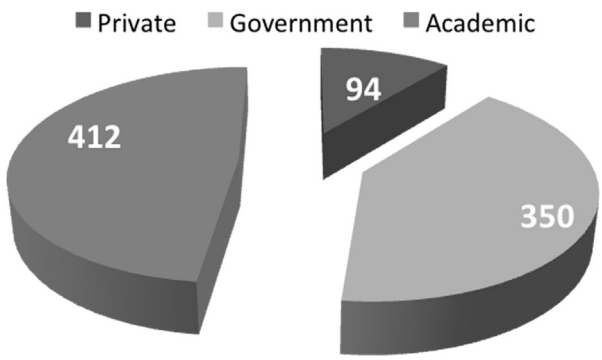


**Fig 2. Practice type of respondents.**

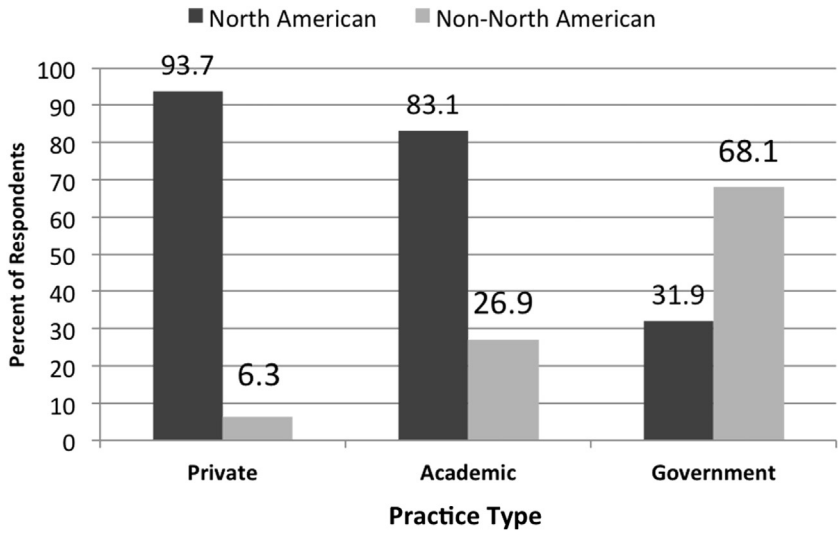


**Fig 3. Practice type of respondents by geographic location.**

practicing in government hospitals were supportive of alternative technologies (Fig 7).

## DISCUSSION

The results of this study indicated that the majority of respondents still prefered to place a PAC for hemodynamic monitoring during cardiac surgery, even with many less invasive hemodynamic monitoring technologies currently available, ranging from the esophageal Doppler to PiCCO (Pulsion Medical Systems, Munich, Germany) systems requiring both central venous and arterial catheters. Although they are often promoted as alternatives to the PAC, the data with respect to both accuracy and outcomes for these less invasive devices are limited and controversial when they are compared head-to-head with a PAC in cardiac surgical patients. The PAC was the preferred monitor among cardiac anesthesiologist during cardiac surgery, which was in agreement with previous survey studies.[6] The best-supported alternative hemodynamic monitoring technology seemed to be TEE, which, based on this survey, most cardiac anesthesiologists prefered to use as a complementary monitor rather than a replacement for the PAC.

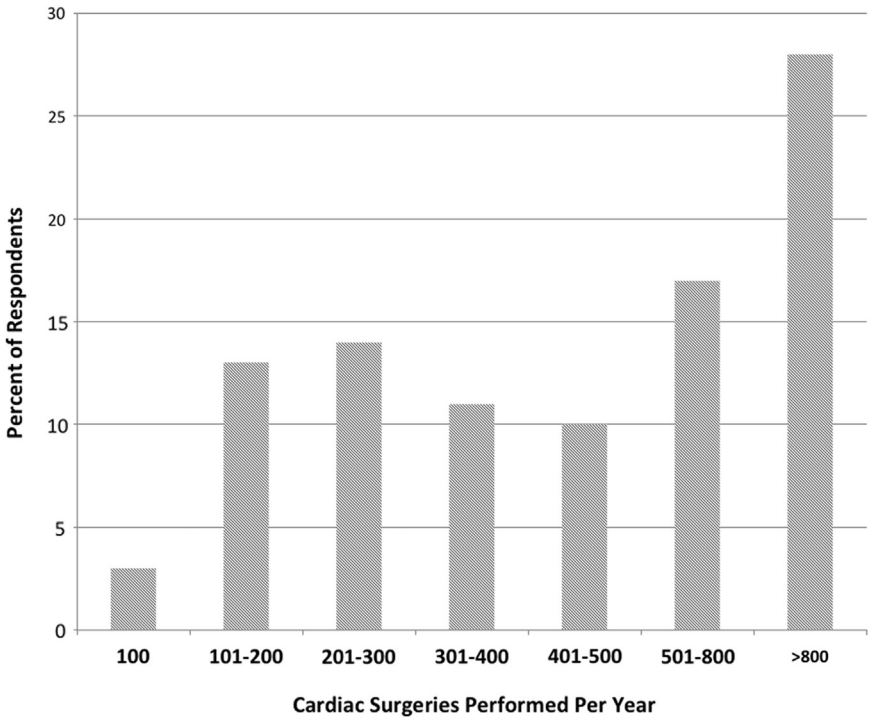


**Fig 4. Cardiac surgeries performed per year.**

**Table 2. Type of Surgery and Percentage of Respondents Using Pulmonary Artery Catheter**

| Percentage of Patients Monitored with PAC | CPB (%) | OPCAB (%) | Minimally Invasive CABG (%) | Minimally Invasive Valve (%) |
|---|---|---|---|---|
| 100% | 34.6 | 45.2 | 42.4 | 46.3 |
| 75%-99% | 33.6 | 22.5 | 16.2 | 17.3 |
| 50%-74% | 7.1 | 5.5 | 6.8 | 5.4 |
| 25%-49% | 6.1 | 3.5 | 5.8 | 2.8 |
| 1%-24% | 15.1 | 14.2 | 15.2 | 12.8 |
| 0% | 3.5 | 9.2 | 13.6 | 15.3 |

Abbreviations: CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; OPCAB, off-pump coronary artery bypass; PAC, pulmonary artery catheter.

**Table 3. Type of Surgery and Percentage of Respondents Using Pulmonary Artery Catheter: Private Practice**

| Percentage of Patients Monitored with PAC | CPB (%) | OPCAB (%) | Minimally Invasive CABG (%) | Minimally Invasive Valve (%) |
|---|---|---|---|---|
| 100% | 49.5 | 55.4 | 62.2 | 63.4 |
| 75%-99% | 29.7 | 21.6 | 13.4 | 11.8 |
| 50%-74% | 6.0 | 5.0 | 4.9 | 5.0 |
| 25%-49% | 2.9 | 2.3 | 1.2 | 0.6 |
| 1%-24% | 8.9 | 9.9 | 9.8 | 6.8 |
| 0% | 2.9 | 5.9 | 8.5 | 12.4 |

Abbreviations: CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; OPCAB, off-pump coronary artery bypass; PAC, pulmonary artery catheter.

**Table 4. Type of Surgery and Percentage of Respondents Using Pulmonary Artery Catheter: Academic Practice**

| Percentage of Patients Monitored with PAC | CPB (%) | OPCAB (%) | Minimally Invasive CABG (%) | Minimally Invasive Valve (%) |
|---|---|---|---|---|
| 100% | 21.2 | 37.1 | 30.3 | 33.5 |
| 75%-99% | 43.3 | 25.3 | 19.2 | 24.2 |
| 50%-74% | 8.3 | 6.5 | 8.1 | 6.2 |
| 25%-49% | 7.4 | 4.3 | 9.1 | 5.6 |
| 1%-24% | 16.6 | 18.3 | 17.2 | 16.8 |
| 0% | 3.2 | 8.6 | 16.2 | 13.7 |

Abbreviations: CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; OPCAB, off-pump coronary artery bypass; PAC, pulmonary artery catheter.

The PAC now is used routinely to measure or calculate pulmonary artery occlusion pressure, cardiac output (CO), right ventricular end-diastolic volume, right atrial pressure, systemic vascular resistance, continuous CO and mixed venous $O_2$ ($SvO_2$).[2] It provides clinicians with an objective measure of almost all the essential components of hemodynamic function (preload, afterload, contractility, and tissue oxygenation). Clinical experience suggests that access to this critical information, coupled with accurate interpretation and appropriate treatment, may reduce perioperative mortality and morbidity through reduced complications, reduced length of stay in the hospital and ICU, enhanced postoperative functional status, and reduced need for transfused blood products through

**Table 5. Type of Surgery and Percentage of Respondents Using Pulmonary Artery Catheter: Government Practice**

| Percentage of Patients Monitored with PAC | CPB (%) | OPCAB (%) | Minimally Invasive CABG (%) | Minimally Invasive Valve (%) |
|---|---|---|---|---|
| 100% | 20.2 | 30.6 | 0 | 26.7 |
| 75%-99% | 13.8 | 16.3 | 11.1 | 6.7 |
| 50%-74% | 7.4 | 2.0 | 0 | 3.3 |
| 25%-49% | 14.9 | 6.1 | 11.1 | 0 |
| 1%-24% | 36.2 | 18.4 | 44.4 | 23.3 |
| 0% | 7.4 | 26.5 | 33.3 | 40 |

Abbreviations: CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; OPCAB, off-pump coronary artery bypass; PAC, pulmonary artery catheter.

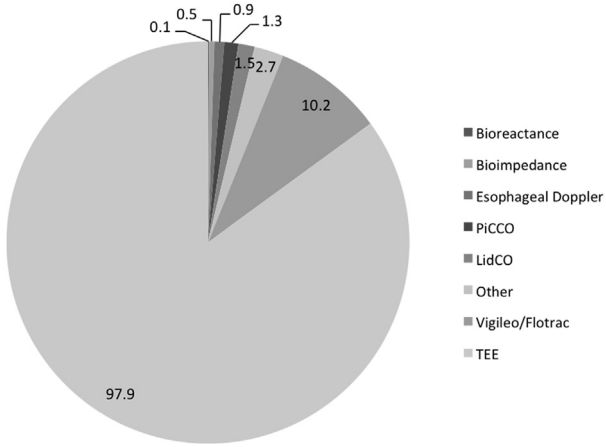


**Fig 5. Complementary monitoring to pulmonary artery catheter during cardiopulmonary bypass procedures. Bioreactance: 0.1%; Bioimpedance: 0.5%; Esophageal Doppler: 0.9%; PiCCO: 1.3%; LidCO: 1.5%; Other: 2.7%; Vileo/Flotrac: 10.2%; transesophageal echocardiography: 97.9%.**

**Table 6. Alternative Monitoring Used Instead of Pulmonary Artery Catheter for Specific Surgical Procedures**

| Alternative Monitor Used Instead of PAC | % Used During CPB | % Used During OPCAB | % Used During Minimally Invasive CABG | % Used During Minimally Invasive Valve Cases |
|---|---|---|---|---|
| Esophageal Doppler | 0.2 | 0.4 | 0 | 0.4 |
| Vigileo/FloTrac | 15.2 | 17.3 | 13.6 | 8.8 |
| PiCCO | 1.1 | 0.7 | 1.5 | 0.9 |
| LiDCO | 2.4 | 1.4 | 3.8 | 3.1 |
| Bioimpedance | 0.8 | 0.7 | 0.8 | 0.9 |
| Bioreactance | 0 | 0 | 0 | 0 |
| TEE | 94 | 90.6 | 94.7 | 97.3 |
| Other | 6.8 | 9.4 | 5.3 | 3.5 |

Abbreviations: CABG, coronary artery bypass graft; CPB, cardiopulmonary bypass; OPCAB, off-pump coronary artery bypass; PAC, pulmonary artery catheter; TEE, transesophageal echocardiography.

optimization of fluid therapy and, consequently, reduce the costs associated with complications.[7] Because of these benefits, the PAC has been widely used in critically ill patients. However, it also has been overused frequently without proper indications in both the operating rooms and the ICUs.[8,9] One

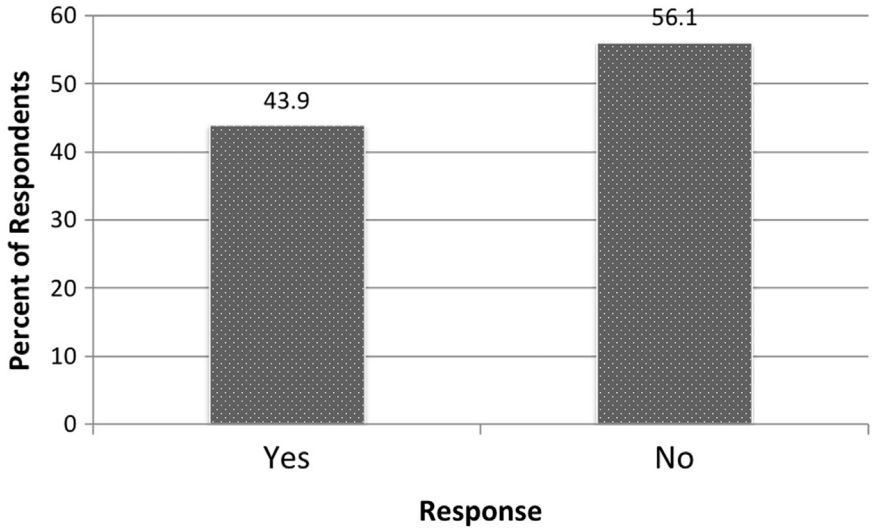


**Fig 6. Cardiac surgeon's opinion of alternative hemodynamic monitoring versus the pulmonary artery catheter.**

estimate of the use of PAC monitoring in the United States showed that as of 2000, more than 1.2 million PACs were placed annually, with associated costs of more than $2 billion.[8] At the same time, the clinical benefits of the PAC have been challenged. Multiple large-scale clinical trials demonstrated no clear benefit of PAC monitoring.[8–14] There are, however, some common limitations that have been suggested to contribute to the inconclusive results of these studies including: Inadequate sample size; lack of randomization; lack of standardization of therapies based on PAC information; uncertainty relating to hemodynamic goals needed to improve outcomes; uncertainty as to which therapeutic intervention is most important in impacting outcomes; inappropriate low-risk patient populations receiving a PAC, and lack of standardization of user knowledge. PAC data must be obtained properly and interpreted by knowledgeable clinicians to ensure the delivery of appropriate therapeutic interventions.

Other studies have suggested that the hemodynamic data obtained from the PAC are valuable in guiding therapy and improving outcomes.[7,15–17] The benefits of PAC monitoring will be most apparent when it is used in the appropriate patient population, for the appropriate situation, in the appropriate setting and in a timely manner.[18] Ranucci suggested 5 categories of cardiac surgical patients who may benefit from the intraoperative placement of a PAC: Severely depressed left ventricular systolic function, impaired right ventricular function, left ventricular diastolic dysfunction, acute ventricular septal defect, and left ventricular assist device.[19] A recent meta-analysis revealed that mortality was reduced in those studies using a PAC to guide fluid and inotrope administration.[7] The use of cardiac index or oxygen delivery as therapeutic endpoints has been shown to improve outcomes, especially when targeting supranormal values of oxygen

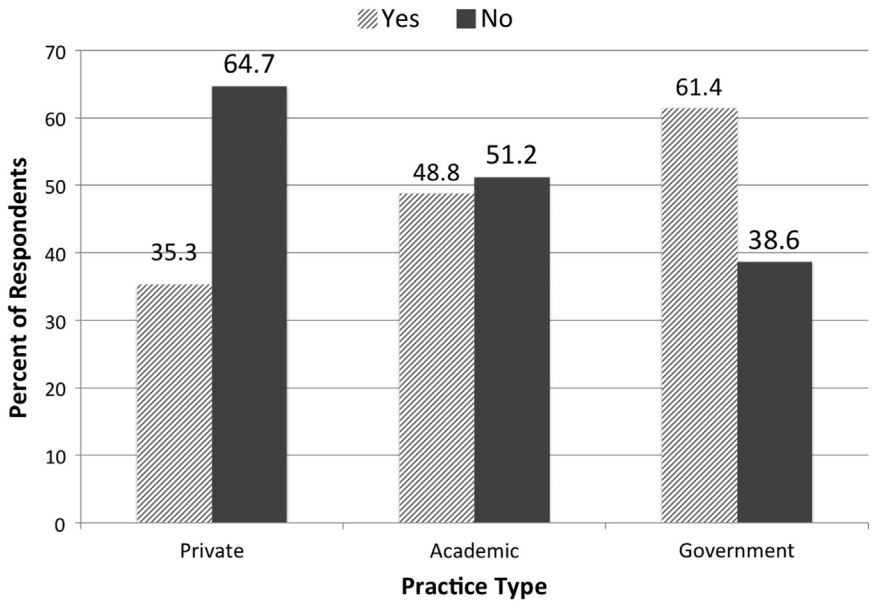


**Fig 7. Cardiac surgeon support of alternative monitoring by practice type.**

delivery.[7] Unexpected decreases in $SvO_2$ frequently are observed after cardiac surgery, emphasizing the potential benefit of continuous $SvO_2$ monitoring.[20,21] Maintaining $SvO_2 > 70\%$ during cardiac surgery also has been correlated with a better postoperative clinical outcome.[22]

Despite the demonstrated benefits of PAC monitoring during cardiac surgery, the debate regarding its routine use continues. The use of the PAC in this surgical setting varies considerably from routine to never.[23] The authors' survey demonstrated that the majority of respondents (68.2%) still used the PAC in patients requiring CPB. Only 3.5% of the respondents did not use it at all. In addition, most of the respondents still chose to use a PAC for routine monitoring in patients undergoing minimally invasive CABG and valve surgery. However, the survey revealed there was a large variation in the use of the PAC based on practice type, geographical location, and surgeon preferences. Surgeon preferences also suggested that this survey actually may have underreported PAC usage if significant numbers of PACs are placed postoperatively in patients with compromised hemodynamic status. The "objective" data from the PAC is what surgeons are accustomed to use when evaluating patients after surgery.[24]

The survey also found most respondents used TEE as a complementary tool to the PAC. Intraoperative TEE monitoring allows for the assessment of cardiac anatomy, left ventricular function, preload, and wall motion abnormalities. The PAC is superior in the characterization of pressure, flow, and resistance; whereas TEE provides a good assessment of left ventricular size, ejection fraction, fractional area change, and wall motion abnormalities. TEE is also the best tool to diagnose and grade diastolic function. TEE-derived variables (left ventricular end-diastolic area, peak blood velocity variation) also may be used to determine fluid responsiveness.[25–28] Combined PAC and TEE monitoring may be more useful than either one alone.

Although the survey also found that alternative monitoring technologies including esophageal Doppler, Vigileo/FloTrac, PiCCO, LiDCO (LiDCO Ltd., London, UK), and bioimpedance were used in cardiac surgical patients, PAC and TEE monitoring were significantly more common. These alternative monitoring technologies are less invasive than the PAC, but there are still many limitations to their use in patients requiring CPB.[29–33] The reliability of minimally invasive technologies has come under question, especially in the setting of hemodynamic instability and rapid changes in peripheral vascular resistance even with newer software modifications.[33–36]

The possible limitations of this study should be considered. The results may have been affected by sampling and nonresponse bias. The response rate of the study was about 14% (854/6000). The survey was left open for 1 month and there was no reminder sent out during that period. This may have contributed to the low response rate. The responding anesthesiologists may not have been representative of the majority view. Electronic and e-mail surveys have limitations associated with distribution and response; however, the authors attempted to reduce these limitations by specifically targeting cardiac anesthesiologists through the SCA.

In conclusion, the results demonstrated that a majority of cardiac anesthesiologists were still placing a PAC for most of their cardiac surgeries. Whether this was by personal choice or because of strong encouragement from cardiac surgeons remains unclear. There was a large variability in PAC use based on practice type and geographic location. As more cardiac anesthesiologists become skilled at using TEE, this monitor may surpass the PAC for intraoperative CO monitoring. However, TEE use in the postoperative period is impractical and may drive the continued use of the PAC in this surgical patient population. Alternatively, with increasing familiarity and improvements in technology, less-invasive alternative hemodynamic monitoring technologies may become more widely accepted and play an increasingly prominent role in postoperative patient management.

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