Variation of Arterial and Central Venous Catheter Use in United States Intensive Care Units

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ABSTRACT

Background: Arterial catheters (ACs) and central venous catheters (CVCs) are common in intensive care units (ICUs). Few data describe which patients receive these devices and whether variability in practice exists.

Methods: The authors conducted an observational cohort study on adult patients admitted to ICU during 2001–2008 by using Project IMPACT to determine whether AC and CVC use is consistent across U.S. ICUs. The authors examined trends over time and patients more (mechanically ventilated or on vasopressors) or less (predicted risk of hospital mortality ≤2%) likely to receive either catheter.

Results: Our cohort included 334,123 patients across 122 hospitals and 168 ICUs. Unadjusted AC usage rates remained constant (36.9% [2001] *vs.* 36.4% [2008]; $P = 0.212$), whereas CVC use increased (from 33.4% [2001] to 43.8% [2008]; $P < 0.001$ comparing 2001 and 2008); adjusted AC usage rates were constant from 2004 (35.2%) to 2008 (36.4%; $P = 0.43$ for trend). Surgical ICUs used both catheters most often (unadjusted rates, ACs: 56.0% of patients *vs.* 22.4% in medical and 32.6% in combined units, $P < 0.001$; CVCs: 46.9% *vs.* 32.5% and 36.4%, $P < 0.001$). There was a wide variability in AC use across ICUs in patients receiving mechanical ventilation (median [interquartile range], 49.2% [29.9–72.3%]; adjusted median odds ratio [AMOR], 2.56), vasopressors (51.7% [30.8–76.2%]; AMOR, 2.64), and with predicted mortality of 2% or less (31.7% [19.5–49.3%]; AMOR, 1.94). There was less variability in CVC use (mechanical ventilation: 63.4% [54.9–72.9%], AMOR, 1.69; vasopressors: 71.4% (59.5–85.7%), AMOR, 1.93; predicted mortality of 2% or less: 18.7% (11.9–27.3%), AMOR, 1.90).

Conclusions: Both ACs and CVCs are common in ICU patients. There is more variation in use of ACs than CVCs. **(ANESTHESIOLOGY 2014; 120:650-64)**

INTRAVASCULAR catheterization is a common procedure in critically ill patients. Arterial catheters (ACs) are placed to facilitate frequent blood sampling and to closely monitor blood pressure.[1–4] Central venous catheters (CVCs) are used for many reasons including facilitating administration of certain medications, augmenting hemodynamic monitoring including determination of central venous oxygenation, and providing venous access when peripheral access is limited.[5–8]

The risk–benefit calculus of these catheters may not justify their widespread use. At the American Thoracic Society International Conference (May, 2013), the Choosing Wisely campaign[9] for Critical Care Medicine highlighted the recommendation to use intravascular catheters only if specifically indicated (unpublished data: Robert Fowler, M.D., M.Sc.; presented at the American Thoracic Society International Conference [Philadelphia, Pennsylvania] in a session entitled "'Choosing Wisely' [©ABIM Foundation Symposium]: Top

What We Already Know about This Topic

- Intravascular catheterization is a common procedure in critically ill patients
- This study is an observational cohort study of adult intensive care unit admissions during 2001–2008 using Project IMPACT to determine whether arterial and central venous catheter use is consistent across U.S. intensive care units

What This Article Tells Us That Is New

- The use of intravascular catheters in the United States varies significantly across individual intensive care units, with greater variability associated with the use of arterial catheters than with central venous catheters

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Ways to Reduce Low Value Care in Pulmonary and Critical Care Medicine," May 20, 2013). Most importantly, these catheters can result in significant complications.[10–19] Second, both the supplies and the labor associated with the placement and maintenance of these devices are financially costly. Finally, there is controversy over whether their use is associated with a clinically relevant benefit for any group of patients.[20] A first step in analyzing the potential impact of these catheters is to understand whether there is variability in their use.

Small studies and surveys have reported widely varying rates of AC and CVC use in the intensive care unit (ICU) setting. Rates of AC use have been estimated to range from one third to nearly all patients in certain ICU-patient subgroups.[15,21,22] Reported rates of CVC usage range from 13 to 91% for ICU patients.[15,23,24] Most of these data on catheter epidemiology come from studies that are focused on investigating complications associated with their use rather than the decision to use them at all; a detailed understanding of in which ICUs and patient subgroups clinicians use these catheters, therefore, is lacking.

We hypothesized that there is a wide variation across ICUs in the use of ACs and CVCs in the care of critically ill patients. To test this hypothesis, we evaluated the variability in AC and CVC usage over time, across patient subgroups, and finally across individual ICUs for selected homogeneous subpopulations to characterize use of intravascular catheters.

Materials and Methods

We performed an observational cohort study on adult patients (≥18 yr of age) admitted to ICUs from 2001 to 2008 in the United States participating in the Project IMPACT database (Cerner Corporation, Kansas City, MO).[25] Project IMPACT was not created as a research database. Rather, Project IMPACT provided regular performance audits and feedback to participating ICUs. Participation in the database was voluntary and hospitals and ICUs paid for the service. Data were collected at each institution by on-site data collectors who were certified by Project IMPACT to assure standardization and uniformity in data definitions and entry. Hospitals participating in Project IMPACT tended to be larger and more urban than the general-population hospitals but were diverse in size and location. Data were either from consecutive admissions to each ICU or a random sample of admissions. Sites using the latter method collected information on 50 or 75% of all patients; the percentage was determined quarterly before data collection commenced. Only the initial ICU admission for a given hospital stay was included.

Data on patient demographics (age, sex, and race) and health problems including severity of illness as described by the mortality probability model–predicted hospital mortality at ICU admission (MPM_0-III),[26] preference for cardiopulmonary resuscitation at ICU admission, acute diagnostic category, location before ICU arrival, patient type (medical, emergent surgical, or elective surgical), number of comorbidities, year of ICU admission, and number of organs failing during the ICU admission were available. Explicit definitions for organ failures were provided by Project IMPACT (appendix 1).[27] Data on interventions included the use of invasive mechanical ventilation (MV) and vasopressor administration by continuous intravenous infusion at any point during the ICU stay. Information on patient outcomes included ICU and hospital lengths of stay and hospital mortality. ICUs and hospitals were characterized according to ICU specialty, number of operable ICU beds, ICU model (based on degree of critical care consultation mandated and/or available), community setting (urban, suburban, or rural), academic affiliation, and number of licensed hospital beds.

Statistical Analysis

The primary outcome of interest was use of an AC (including catheters placed in the radial, femoral, brachial, dorsalis pedis, or axillary arteries) or CVC (including catheters placed in the subclavian, femoral, brachial, internal, or external jugular veins) during the ICU stay. This definition included catheters inserted before admission to ICU if they remained in place for some portion of the ICU stay. We also examined the data stratified by whether catheters were inserted before or during the ICU stay. Patient characteristics and ICU/hospital characteristics associated with AC and CVC use were analyzed using chi-square test and ANOVA as appropriate. The exact dates of catheter use—specifically in relation to dates of other interventions (*e.g.*, vasopressor use)—were not available.

We calculated the absolute (unadjusted) rate of catheter use in each study year; statistical differences over time in the adjusted odds of use were assessed using univariable linear regression (with modeling using one or two trend lines determined by visual inspection of the data for the presence of a point at which the rate of change over time may have become notably different). We then examined the adjusted odds of receiving a catheter over time using multivariate multilevel mixed-effects logistic modeling including independent variables: year, age, sex, race, comorbidities, MPM_0-III, resuscitation status on ICU admission, organ failures, use of MV, use of vasopressors, use of other indwelling catheters, acute diagnostic group, location before ICU arrival, patient type, whether the facility had an academic affiliation, and ICU specialty. Multivariate multilevel mixed-effects modeling allows for evaluation of associations of individual patient- and ICU/hospital-level variables with a given outcome after accounting for the clustering of individual patients in specific ICUs. For the purposes of the multivariate multilevel mixed-effects logistic modeling, patients were clustered by ICU rather than by hospital. Sensitivity analyses were conducted to test the robustness of the results of the model in which: (1) the independent variables of organ failures and chronic illnesses were categorized differently and (2) AC or CVC

use was excluded as an independent variable in the model of the other catheter.

We first compared the frequency of AC and CVC use across patients grouped by ICU specialty and location before ICU arrival with the use of chi-square tests. We summarized the variability by individual ICU in the use of ACs and CVCs using median, interquartile ranges (IQRs), and full ranges as well as adjusted median odds ratios (AMOR). AMORs have been promoted to describe practice-pattern variation between hospitals and are preferred to intraclass correlation coefficients when reporting multilevel modeling of binary outcomes.[28–30] The AMOR quantitatively describes the variability between clusters and can be easily calculated from the cluster variance.[28] An AMOR of 1.5 indicates that for two patients who are otherwise identical except that one was admitted to a "high catheter–using ICU" and the other was admitted to a "low catheter–using ICU," the odds of having had a catheter is 1.5-fold higher in the "high catheter–using ICU." By definition, the AMOR is 1 or greater. We quantified the predictive power of three variable sets—(1) patient factors, (2) ICU/hospital factors, and (3) being clustered in individual ICUs—on catheter use using the unitless quotient of the Akaike information criterion of a model excluding the variable set of interest to the full model as described by Harrell[31]; a number closer to one indicates a larger relative impact of the excluded variable set on catheter use prediction. We examined three specific subgroups of patients; first, patients where we expected catheter use to be high: (1) patients requiring MV and (2) patients requiring vasopressors during their ICU stay, and second, patients with low expected use: (3) predicted hospital mortality (using MPM_0-III) on ICU arrival of 2% or lesser.[32] For the analyses of each subgroup of patients, we only included ICUs with 20 patients or more in the given subgroup.

Results were considered statistically significant if P value less than 0.05. No adjustments were made to this significance level for multiple models. Database management and statistical analyses were performed using Excel (Microsoft, Redmond, WA) and Stata 11.0 (StataCorp LP, College Station, TX). Institutional Review Board approval was obtained from Beth Israel Medical Center (New York, New York, #200–10).

Results

Our cohort included 334,123 ICU patients across 122 hospitals and 168 ICUs (with 16.7% of ICUs reporting data on all admissions and 83.3% on a random sample of patients). Most of the ICUs were mixed medical–surgical units (52.9%) with an even breakdown of surgical ICUs (SICUs, 24.4%) and medical ICUs (MICUs, 22.6%; table 1). A majority of hospitals were in urban environments (54.5%) and were nonacademic (79.2%). The mean age of patients in the cohort was 60.6 ± 18.0 yr with a mean MPM_0-III–predicted hospital mortality of 13.7 ± 16.5%. Overall hospital mortality was 13.0% with a median ICU length of stay of 2 days (IQR, 1–4) and a median hospital length of stay of 7 days (IQR, 3–12).

Characteristics of Patients Who Received ACs and CVCs

In our cohort, 47.8% of patients had neither an AC nor CVC, 14.3% had only an AC, 16.2% had only a CVC, and 21.7% had both. Surgical patients were more likely than medical patients to receive either catheter (table 2). Patients at the extremes of age (<50 or 85+ yr) were less likely to receive either an AC or a CVC. The use of ACs was highest

Table 1. ICU and Hospital Characteristics of Cohort Units

	Number of Units (%)
Total no. of ICUs	168
ICU Characteristics	
ICU specialty	
Medical	
CCU	6 (3.6)
MICU	18 (10.7)
MICU/CCU	14 (8.3)
Surgical	
SICU	13 (7.7)
SICU/trauma	24 (14.3)
Trauma	4 (2.4)
Combined	
MICU/SICU	53 (31.5)
MICU/CCU/SICU	36 (21.4)
No. of operable ICU beds	
<10	14 (8.3)
10–14	65 (38.7)
15–19	43 (25.6)
20–24	25 (14.9)
25+	21 (12.5)
ICU model*	
Closed model	9 (5.4)
Mandatory critical care consultation	33 (19.8)
Possible critical care consultation	123 (73.7)
No critical care consultation available	2 (1.2)
Hospital Characteristics	**Number of Units (%)**
Hospital community*	
Urban	91 (54.5)
Suburban	58 (34.7)
Rural	18 (10.8)
Hospital organizational structure	
City/state/federal government	8 (4.8)
Community	125 (74.4)
Academic	35 (20.8)
Licensed hospital beds*	
<250	15 (9.0)
250–499	75 (44.9)
500–749	46 (27.5)
750–999	25 (15.0)
1,000+	6 (3.6)

* Data missing for 1 of 168 units.

CCU = coronary care unit; ICU = intensive care unit; MICU = medical ICU; SICU = surgical ICU.

Table 2. Patient Characteristics and Outcomes Stratified by Catheter Use*

Characteristic	N	AC (%)‖	CVC (%)‖
Total no. of patients	334,123	36.0	37.9
Age (yr)			
<50	89,199	30.5	33.9
50–64	88,727	39.2	40.2
65–84	132,549	39.3	39.7
85+	22,844	26.3	34.2
Sex			
Male	183,959	38.1	36.6
Female	149,375	33.5	39.5
Race			
White	258,925	37.4	37.7
Black	43,973	29.0	39.8
Other	19,828	36.4	39.6
MPM_0-III–predicted hospital mortality†, %			
≤2	38,104	39.5	23.1
2–5	64,312	34.1	28.8
5–10	64,792	30.1	34.6
10–20	59,661	30.3	42.4
>20	57,370	37.7	56.6
DNR at the time of ICU admission			
No	333,010	36.1	37.9
Yes	1,113	20.6	36.1
Acute diagnostic grouping			
Respiratory/thoracic	66,382	30.0	39.1
Cardiovascular/vascular	104,510	45.9	34.7
Sepsis‡	23,587	33.8	68.0
Trauma	24,614	41.7	42.1
Neurologic (nontraumatic)	48,462	34.6	25.1
Metabolic/renal	27,239	13.9	25.9
Gastrointestinal	39,308	35.0	48.0
Location before ICU arrival			
Emergency room	146,985	16.7	27.7
OpRm/PACU	98,490	71.1	47.8
Ward	28,748	22.5	48.9
Stepdown/telemetry unit	17,187	23.9	47.1
Other	42,597	35.7	39.2
Patient type			
Elective surgical	74,412	69.7	44.1
Emergent surgical	38,492	63.4	55.8
Medical	221,196	20.0	32.7
Chronic illness (no.)			
0	250,676	36.1	34.9
1	71,022	36.1	46.8
2	10,484	34.5	48.5
3+	1,941	36.5	48.2
Organs failing (no.)			
0	265,259	33.5	30.6
1	39,045	39.9	55.9
2	16,391	48.4	73.3
3+	13,428	60.5	85.9
Mechanical ventilation			
No	212,073	23.8	23.3
Yes	122,050	57.4	63.4
Vasopressors§			
No	266,748	30.7	29.3
Yes	67,375	57.4	71.9
CVC (for AC groupings)			
No	207,441	23.0	N/A
Yes	126,682	57.3	
AC (for CVC groupings)			
No	213,701	N/A	25.3
Yes	120,422		60.3

* All comparisons (AC *vs.* no AC and CVC *vs.* no CVC) have $P < 0.001$ except the difference of DNR status at the time of ICU admission for CV use for which $P = 0.126$. † MPM_0-III–predicted hospital mortality data were only available for 85.1% of the patients; data were available for race on 96.6% of patients and for all other characteristics for ≥99.8% of patients. ‡ By definition for Project IMPACT, "sepsis" means that a "patient is septic with or without significantly low blood pressure" and he/she "may or may not have positive blood cultures upon ICU admission." § Vasopressors include infusions of dopamine, epinephrine, norepineprhine, phenylephrine, and/or vasopressin. ‖ Percentages are "row percentages" and represent the percentage of patients in each group who received an AC or a CVC, respectively; these are not mutually exclusive groups and, therefore, the percentages may add up to >100%.

AC = arterial catheter; CVC = central venous catheter; DNR = do-not-resuscitate; ICU = intensive care unit; MPM_0-III = mortality probability model at ICU admission; N/A = not applicable; OpRm/PACU = operating room/postanesthesia care unit.

in patients at the extremes of illness severity (MPM_0-III–predicted hospital mortality ≤2% or >20%), whereas CVC use increased steadily with illness severity. Patients received ACs and CVCs more often with more organ failures, receipt of MV, or receipt of vasopressor medications. Patients with both ACs and CVCs had longer ICU lengths of stay (median [IQR]: 2 days [1–5] *vs.* 2 days [1–3] for AC; 3 days [2–7] *vs.* 1 day [1–2] for CVC), longer hospital lengths of stay (8 days [5–15] *vs.* 6 days [3–10] for AC; 10 days [6–19] *vs.* 5 days [3–6] for CVC), and higher hospital mortality (15.4 *vs.* 11.6% for AC; 21.4 *vs.* 7.9% for CVC) than those without. All comparisons were significant at a *P* value of less than 0.001.

Trends in Catheter Use

Absolute rates of AC use remained fairly constant from 2001 to 2008 (minimum rate of 34.6% of patients in 2003 to a maximum of 38.0% in 2007; $P = 0.21$ comparing 2001 and 2008), whereas CVC use increased from 33.4% in 2001 to 43.8% in 2008 ($P < 0.001$ comparing 2001 and 2008; fig. 1). Over this same time period, the use of pulmonary artery catheters steadily declined (from 13.1% in 2001 to 5.5% in 2008; $P < 0.001$). The changes in use of CVCs were due to changes in the number of catheters placed in both the pre-ICU and ICU setting. Increased use of ACs and CVCs was greater in septic patients admitted from nonoperating room/postanesthesia care unit (OpRm/PACU) locations than for nonseptic patients admitted from non-OpRm/PACU (appendix 2).

Patient-, ICU-, and hospital-level characteristics of the cohort changed over time (appendix 3). After multivariate adjustment (table 3; appendix 4), the odds of AC use decreased with time between 2001 and 2004 (regression coefficient for linear trend in odds −0.93; $P = 0.02$) but remained constant

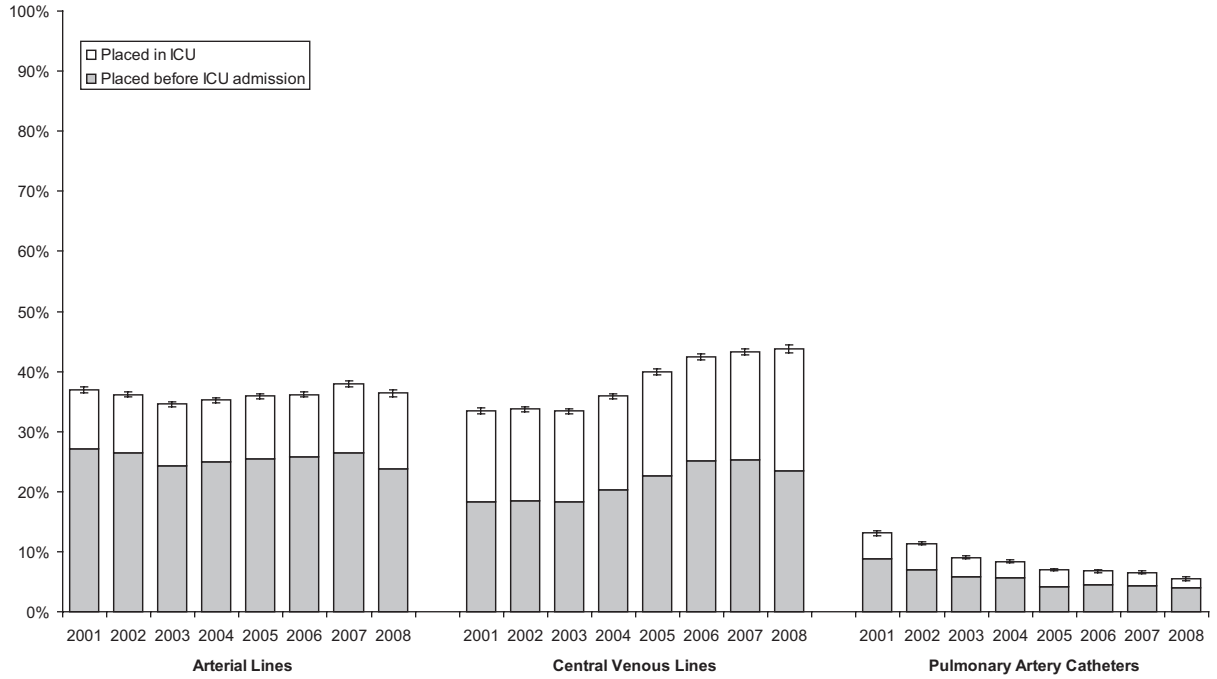

Fig. 1. Trends in catheter use, 2001–2008. Trends evaluated using logistic regression revealed odds ratio 1.01 per year ($P < 0.001$) for arterial catheter use, odds ratio 1.08 per year ($P < 0.001$) for central venous catheter use, and odds ratio 0.87 per year ($P < 0.001$) for pulmonary artery catheter use. ICU = intensive care unit.

from 2004 to 2008 ($P = 0.43$). There was no significant trend in AC placement before ICU arrival ($P = 0.79$; appendix 4). In contrast, after multivariate adjustment, the odds of receiving a CVC did not change over time ($P = 0.07$; appendix 4). These results were robust to sensitivity analyses conducted by the construction of alternative multivariate models (data not shown).

Variability in Catheter Use

AC use varied by type of ICU (fig. 2 and table 3). Compared with SICU patients (56.0% of whom received an AC), patients admitted to either a MICU (22.4%, adjusted OR [95% CI], 0.52 [0.37–0.73]) or a combined unit (32.6%, adjusted OR [CI], 0.63 [0.48–0.84]) were less likely to receive an AC (fig. 2A). The timing of placement of ACs also varied based on type of ICU. The majority of ACs used in SICU and combined unit patients were placed before arrival in the ICU, whereas in the MICU population, more were placed in the ICU itself. The high frequency of ACs placed before ICU admission in SICUs was driven by the admission of patients from the OpRm/PACU who were nearly twice as likely to receive an AC (71.2%) compared with patients coming to the ICU from other locations (≤35.7%; $P < 0.001$; fig. 2B).

Although the majority of variability was explained by patient characteristics (table 4), there was substantial variability in AC usage across individual ICUs (AMOR, 2.04; table 3). For patients who received MV, median AC use across units was 49.2% with an IQR of 29.2–72.3% (AMOR, 2.56; fig. 3; appendix 5). Similarly, there was wide variability in the rates of AC usage for patients requiring vasopressors during their ICU stay (median [IQR], 51.7% [30.8–76.2%]; AMOR, 2.64) and for low-risk patients (those with predicted mortality of ≤2%, 31.7% [19.5–49.3%]; AMOR, 1.94). SICUs used ACs more commonly across both high-risk (MV and vasopressor) and low-risk (MPM_0-III–predicted hospital mortality ≤2%) patients and account for a majority of the 10 highest usage units in each subgroup.

CVCs were also more common in the SICU population (46.9% of patients as compared with 32.5% [MICU] and 36.3% [combined]; $P < 0.001$; fig. 2C). After multivariate adjustment, this difference was not statistically significant (table 3). Nearly two thirds of CVCs were placed before ICU arrival for patients in the SICU, whereas for MICU and combined unit patients, the placement of catheters was more evenly divided between pre-ICU and in-ICU locations (fig. 2, C and D). Compared with ACs, for the entire cohort and in each patient subgroup analyzed, there was less variability in CVC use amongst individual ICUs (fig. 3, table 3, and appendix 5).

Discussion

The use of intravascular catheters in the United States varies significantly across individual ICUs, with greater variability associated with the use of ACs than with CVCs. Remarkably, the median odds of receiving an AC was more than twice as high if the same patient received MV or vasopressors in a "high catheter–using ICU" as opposed to a "low catheter–using ICU." These findings suggest that practice patterns—rather than patient factors—often determine whether or not a patient undergoes this procedure. This practice-pattern

Table 3. Multilevel Mixed-effects Models for the Use of Arterial and Central Venous Catheters

	Arterial Catheters OR (95% CI)	Central Venous Catheters OR (95% CI)
Age (per 5 yr)	1.02 (1.02–1.03)	1.00 (1.00–1.00)
Sex		
Male	1	1
Female	0.86 (0.84–0.88)	1.33 (1.30–1.35)
Race		
White	1	1
Other	1.14 (1.10–1.18)	0.86 (0.83–0.89)
Black	1.09 (1.03–1.16)	0.78 (0.74–0.82)
Comorbidities		
0	1	1
1+	0.88 (0.87–0.90)	1.28 (1.25–1.30)
MPM_0-III–predicted hospital mortality (per 10% increase)*	0.94 (0.94–0.95)	1.02 (1.01–1.02)
Acute diagnostic group		
Trauma	1	1
Respiratory/thoracic	0.51 (0.49–0.54)	0.82 (0.79–0.86)
Cardiovascular/vascular	1.15 (1.10–1.21)	0.85 (0.81–0.88)
Sepsis†	0.61 (0.58–0.65)	2.41 (2.28–2.54)
Neurologic (nontraumatic)	1.07 (1.02–1.12)	0.62 (0.60–0.65)
Metabolic/renal	0.40 (0.37–0.42)	1.09 (1.04–1.15)
Gastrointestinal	0.47 (0.44–0.49)	2.08 (1.99–2.18)
DNR on ICU admission	0.78 (0.64–0.96)	0.89 (0.75–1.05)
Organs failing (per one organ increase)	1.24 (1.22–1.27)	1.61 (1.59–1.64)
Mechanical ventilation	3.36 (3.27–3.46)	3.71 (3.09–3.25)
Vasopressors‡	2.18 (2.11–2.25)	2.77 (2.70–2.85)
Arterial catheter		
None		1
In-place on ICU arrival	N/A	2.57 (2.50–2.65)
Placed while in ICU		4.27 (4.12–4.42)
Central venous catheter		
None	1	
In-place on ICU arrival	2.82 (2.74–2.90)	N/A
Placed while in ICU	3.77 (3.66–3.89)	
Location before ICU arrival		
Ward	1	1
Emergency room	1.11 (1.06–1.16)	0.42 (0.40–0.43)
OpRm/PACU	5.82 (5.51–6.14)	0.61 (0.58–0.64)
Stepdown/telemetry unit	1.04 (0.98–1.10)	0.88 (0.84–0.93)
Other	2.00 (1.91–2.10)	0.73 (0.70–0.76)
Patient type		
Medical	1	1
Elective surgical	3.84 (3.66–4.04)	1.14 (1.08–1.19)
Emergent surgical	1.81 (1.72–1.90)	1.33 (1.27–1.39)
ICU type§		
SICU	1	1
MICU	0.52 (0.37–0.73)	0.80 (0.60–1.05)
Combined	0.63 (0.48–0.84)	1.02 (0.81–1.29)
Academic hospital		
No	1	1
Yes	1.88 (1.35–2.61)	1.24 (0.95–1.61)
ICU admission year		
2001	1	1
2002	0.94 (0.89–0.98)	1.05 (1.00–1.09)
2003	0.86 (0.82–0.91)	1.01 (0.97–1.06)
2004	0.72 (0.68–0.75)	0.93 (0.88–0.97)
2005	0.72 (0.69–0.76)	1.01 (0.97–1.06)
2006	0.76 (0.72–0.80)	1.12 (1.06–1.17)
2007	0.78 (0.74–0.83)	1.11 (1.06–1.17)
2008	0.75 (0.71–0.80)	1.13 (1.07–1.19)
Adjusted MOR‖	2.04 (1.86–2.21)	1.77 (1.65–1.89)

* MPM_0-III is the mortality probability model at ICU admission. † By definition for Project IMPACT, "sepsis" means that a "patient is septic with or without significantly low blood pressure" and he/she "may or may not have positive blood cultures upon ICU admission." ‡ Vasopressors include infusions of dopamine, epinephrine, norepineprhine, phenylephrine, and/or vasopressin. § MICU and combined units can include coronary care. ‖ Sensitivity analyses excluding patients coming to the ICU directly from the OpRm/PACU resulted in Adjusted MOR of 2.44 for AC and of 1.81 for CVC.

AC = arterial catheter; CVC = central venous catheter; DNR = do-not-resuscitate order; ICU = intensive care unit; MICU = medical ICU; MOR = median odds ratio; MPM_0-III = mortality probability model at ICU admission; N/A = not applicable; OpRm/PACU = operating room/postanesthesia care unit; OR = odds ratio; SICU = surgical ICU.

variation persisted even among the patients with the lowest predicted mortality (AMOR, 1.94).

Patients in surgical units receive both ACs and CVCs more frequently than patients admitted to medical units, and the timing of insertion of these catheters is different—patients in surgical units more commonly have catheters placed before ICU arrival, whereas patients in medical units are more likely to have their ACs/CVCs placed once in the ICU. These findings are consistent with the trends seen in previous studies on pulmonary artery catheter use.[33–35] Although specific differences in patient casemix may justify this difference in use, it may also be a consequence of clinician experience and comfort. In our cohort, a significant proportion of patients admitted to the SICU arrive with an AC (44.0%) and/or a CVC (30.0%) already in place. There are studies that report on the discordance of noninvasive blood pressure and intra-arterial measurements intraoperatively[36,37]; however, the practice patterns and clinical implications of intravascular catheter use in the operating room setting are unknown. Regardless, healthcare providers in SICUs might be either more familiar with managing patients using such devices and/or slow to remove catheters others have considered necessary. Given this disparate use, potential future studies on the impact of these devices on patient outcomes should

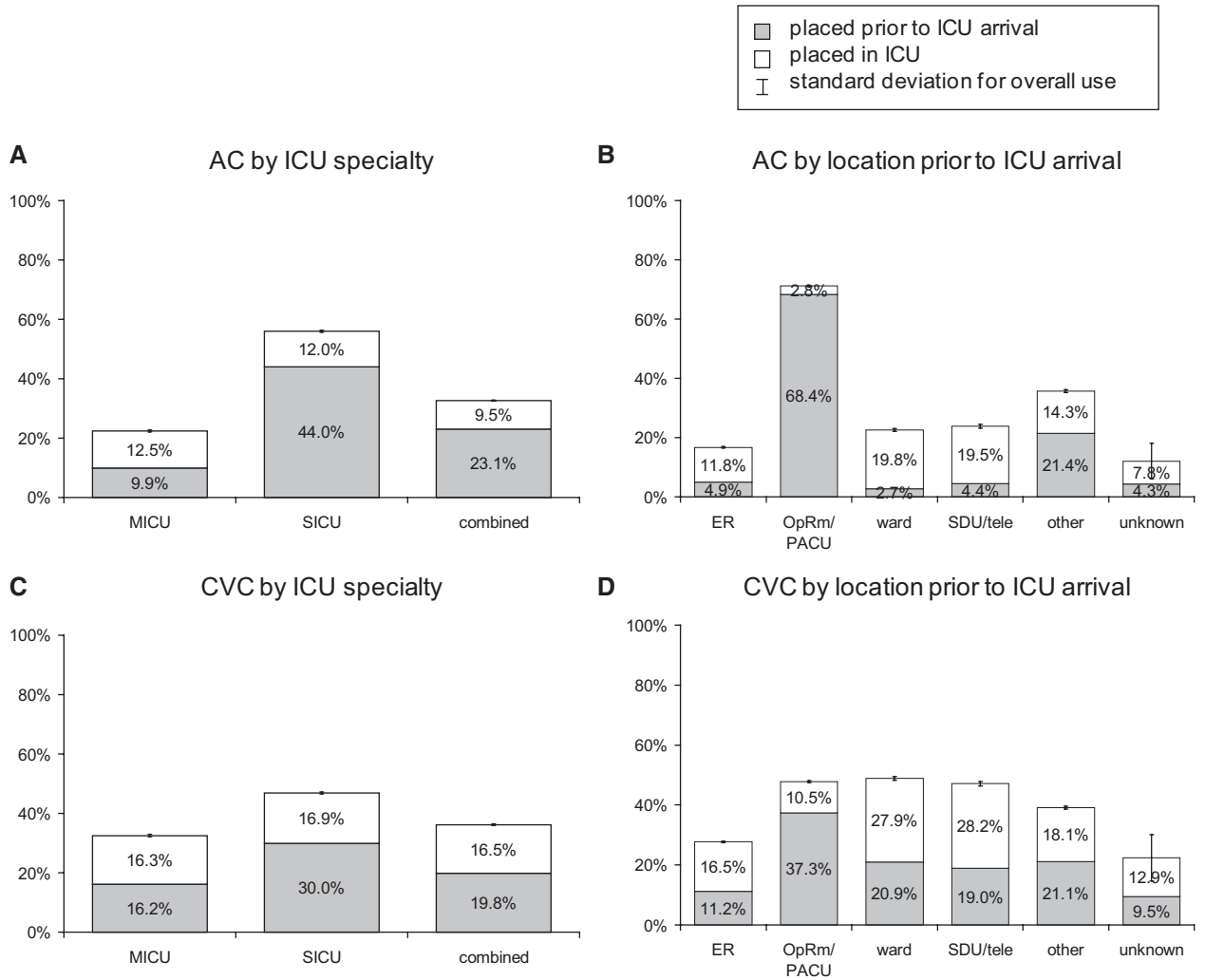

Fig. 2. Catheter use by intensive care unit (ICU) specialty and location before ICU arrival. (*A*) Arterial catheter (AC) by ICU specialty, (*B*) AC by location before ICU arrival, (*C*) central venous catheter (CVC) by ICU speciality, (*D*) CVC by location before ICU arrival. Combined = medical and surgical ICU; ER = emergency room; MICU = medical ICU; OpRm/PACU = operating room/postanesthesia care unit; SDU/tele = step-down unit/telemetry unit; SICU = surgical ICU.

be stratified by unit type and generalization to other unit types may not be appropriate.

Our data reveal a wider variation in the rates of use for AC catheters across individual units than for CVCs, even within fairly homogeneous subgroups of patients. Although some variation can likely be attributed to unmeasured differences in patient casemix, it is more likely this variability stems from differences in practice patterns and culture within each unit. We know that these devices are not without risk; the complication of bloodstream infections is associated with an increased mortality, cost, and length of stay.[38–40] Moreover, whether the routine use of these catheters confers quantifiable meaningful benefits to the care of critically ill patients is unknown; thus, the optimal rate of use of these catheters is unclear. However, with this degree of disparity, all providers cannot be operating optimally[32,41,42]; some clinicians likely use these catheters more often than is necessary, whereas others may not use them frequently enough.

The lack of change in adjusted CVC use and the transient (early) nature of the decrease in adjusted AC use over time stands in contrast to the steady reduction in pulmonary artery catheter use over the past 2 decades.[34,43] This lack of

Table 4. Amount of Variability Explained by Patient *vs*. ICU/Hospital Characteristics as Indicated by the Quotient of AIC

	Quotient of AICs*	
Variable Set	AC	CVC
Patient characteristics	0.73	0.83
ICU/hospital characteristics	0.001	0.001
Individual ICU	0.08	0.05

* Quotient of AICs = $(AIC_{full} - AIC_{reduced})/(AIC_{full} - AIC_{null})$, where AIC_{full} = AIC for the multivariate multilevel mixed-effects logistic model including all patient level, ICU/hospital level, and clustering variable information; $AIC_{reduced}$ = AIC for the multivariate multilevel mixed-effects logistic model excluding one of the variable sets; AIC_{null} = AIC for the multivariate multilevel mixed-effects logistic model including no independent variables or clustering.[31]

AC = arterial catheter; AIC = Akaike information criteria; CVC = central venous catheter; ICU = intensive care unit.

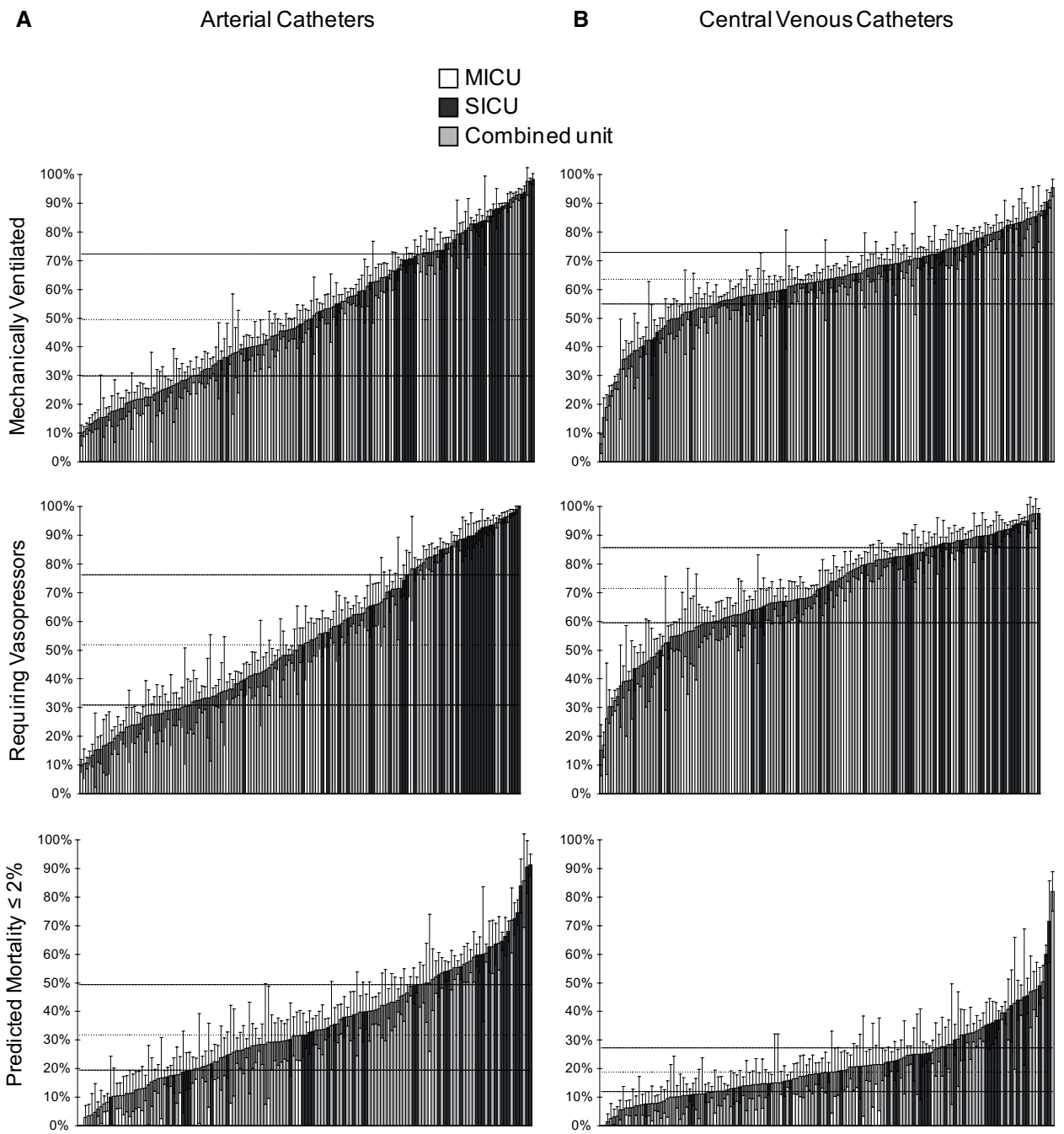

Fig. 3. Variation in catheter use across individual intensive care units (ICUs). (*A*) Arterial catheters and (*B*) central venous catheters. *Error bars* = 95% CI for each ICU's use rate; *dotted line* = median of all unit rates; *solid lines* = interquartile range of all unit rates. MICU = medical ICU; SICU = surgical ICU.

persistent decline in adjusted AC/CVC use over time may be due to a recent focus on two very important paradigms of thinking in critical care. The first is a heavy reliance on standardized/protocolized care.[44,45] To this end, bundles of care (*e.g.*, from the Surviving Sepsis Campaign) have been promoted which call for early and frequent use of ACs and CVCs although those components of the bundles have not been separately assessed.[46–48] Similarly, recent guidelines to care for cardiogenic shock after myocardial infarction have encouraged intravascular catheterization.[49,50] Coincident with this focus on protocols of care—which may push clinicians to use catheters more than they might otherwise—has been a move to eliminate the use of "unnecessary" intravascular devices. The Centers for Disease Control's checklist to prevent central line–associated bloodstream infections recommends, firstly, that clinicians should "perform daily audits to assess whether each central line is still needed."[51] These two competing movements—on the one hand to use catheters more

quickly and more often in certain situations and on the other to seriously contemplate their prompt removal—may have offset one another and led to a fairly constant rate of AC and CVC use in U.S. ICUs.

This study is limited by the fact that we did not have information about why an AC or CVC was placed. Specifically, the indication (*e.g.*, frequent phlebotomy, blood pressure monitoring) and the thought process by the clinician (*e.g.*, "we should place an AC because all patients requiring vasopressors should have one") were unknown. This dearth of information rendered further study of specific findings (*e.g.*, the relatively higher use of both ACs and CVCs in the extreme age groups) infeasible. Moreover, many of the ACs/CVCs were placed before ICU arrival in patients coming to the ICU from the OpRm/PACU and we did not have information about their OpRm/PACU course of events. Although this information would not have changed our findings, it might have provided us with a more comprehensive explanation for the variation observed. In addition, we were unable to confirm the exact timing of placement of the catheters beyond the basic information of whether they were placed before or in the ICU. Again, this information would help to further understand usage. Also, we did neither have information about protocols/guidelines available or reimbursement schemes at each ICU nor information about the individual physician whose decision it was to insert an AC or a CVC; the ability to adjust for this information may have improved our understanding of residual variability. Finally, Project IMPACT is a database which consists of patients in ICUs which paid for the service; although diverse, these ICUs are not a completely representative sample of U.S. ICUs.

Although invasive interventions will likely always have a place in the care of the critically ill, there are numerous examples in health care of movement away from the more invasive alternative when a less-invasive option becomes available (*e.g.*, the evolution of surgeries from open to laparoscopic; cardiac valvular interventions from surgical to endovascular; diagnostic testing for pulmonary embolism from angiography to computed tomography scanning). Our data demonstrate that there has been no recent change in the incidence of AC and/or CVC placement in the ICU setting, but that use is disproportionately driven by care in surgical units with certain individual units being higher users. As technology evolves to allow for potential replacement of these invasive interventions and/or new studies reveal information about their impact on clinically meaningful outcomes, it will be imperative to target efforts to standardize use.

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Competing Interests

The authors declare no competing interests.

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Appendix 1

Table 5. Project IMPACT Definitions for Organ Failures

Organ System	Definition of Failure
Cardiovascular	Any of the following for >1 h despite adequate fluid resuscitation: SBP <90 mmHg (unless known baseline is <90) SBP ↓ 40 mmHg from baseline MAP <70 mmHg Vasopressors (dopamine equivalent >5 μg kg^{-1} min^{-1}) need to keep SBP >90 mmHg or MAP >70 mmHg
Hyperlactatemia	Both of: Cardiovascular organ failure (by above criteria) Serum lactate greater than upper limits of normal for local laboratory
Respiratory	Noncardiogenic pulmonary edema *and* Either of: Pa_{O_2}/F_{IO_2} ≤300 PEEP >5 mmHg
Renal	Patient not on chronic dialysis *and* Either of: Serum creatinine ↑ by 1 mg/dl above baseline after adequate fluid resuscitation Serum creatinine ≥2 mg/dl if unknown baseline
Hematologic	Any of: Platelets ↓ to ½ the highest value of the previous 3 days Platelets <100,000/mm^3 PT or PTT >×1.5 control (not due to anticoagulation therapy)
Hepatic	Serum total bilirubin >2 mg/dl (must be acute, not chronic)
Neurologic	All of: Acutely altered sensorium Unknown CNS injury or insult Sedation holiday performed No tracheal intubation GCS ≤12

CNS = central nervous system; F_{IO_2} = fraction of inspired oxygen; GCS = Glasgow coma score; MAP = mean arterial pressure; Pa_{O_2} = partial pressure of oxygen in the arterial blood; PEEP = positive end-expiratory pressure; PT = prothrombin time; PTT = partial thromboplastin time; SBP = systolic blood pressure.

Appendix 2

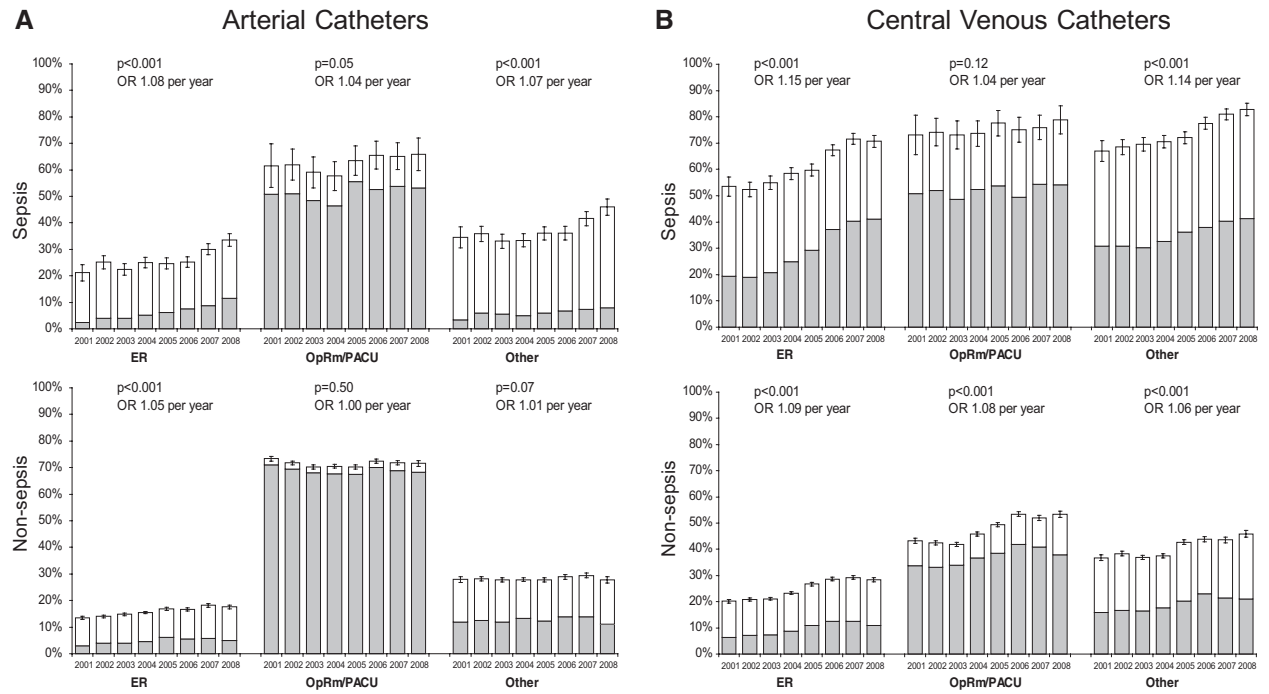

Fig. 4. Trends in arterial catheter and central venous catheter (2001–2008) stratified by sepsis diagnosis and location before intensive care unit arrival. (*A*) Arterial catheters and (*B*) central venous catheters. ER = emergency room; OpRm/PACU = operating room/postanesthesia care unit; OR = odds ratio calculated by logistic regression.

Appendix 3

Table 6. Characteristics of Cohort over Time, 2001–2008

	2001	2002	2003	2004	2005	2006	2007	2008	*P* Value‖
Age (yr), mean ± SD	61.6±17.5	61.4±17.8	61.4±17.8	60.7±18.0	60.1±18.1	59.8±18.1	59.6±18.2	59.5±18.1	<0.001
Sex, %									<0.001
Male	53.8	54.5	54.4	55.3	55.5	56.3	56.1	55.4	
Female	46.2	45.5	45.6	44.7	44.5	43.7	43.9	44.6	
Race, %									<0.001
White	79.7	81.5	83.0	80.5	78.7	79.1	79.0	79.6	
Other	15.8	13.8	11.5	12.5	14.0	14.2	13.7	15.2	
Black	4.6	4.7	5.5	7.0	7.3	6.7	7.3	5.1	
Comorbidities, mean ± SD	0.3±0.6	0.2±0.5	0.3±0.5	0.3±0.5	0.3±0.5	0.3±0.6	0.3±0.5	0.3±0.5	<0.001
MPM_0-III–predicted hospital mortality (%)*, mean ± SD	13.2±16.1	13.6±16.6	13.9±17.0	13.6±16.5	13.6±16.3	13.8±16.5	13.8±16.4	14.4±16.6	<0.001
Acute diagnostic group, %									<0.001
Trauma	5.1	5.7	5.5	7.0	8.2	8.6	9.5	10.2	
Respiratory/ thoracic	21.1	21.7	21.6	19.5	19.8	18.2	17.8	18.9	
Cardiovascular/ vascular	33.9	33.2	33.1	33.2	29.2	31.0	29.0	25.2	
Sepsis†	4.8	5.5	6.0	6.6	7.3	7.9	9.1	10.5	
Neurologic (nontraumatic)	13.2	13.0	13.2	13.8	15.1	15.5	16.3	17.1	
Metabolic/renal	8.7	8.5	8.6	8.2	8.2	7.8	7.6	7.5	
Gastrointestinal	13.1	12.4	12.2	11.7	12.1	10.9	10.8	10.6	

(*Continued*)

Table 6. (Continued)

	2001	2002	2003	2004	2005	2006	2007	2008	*P* Value‖
DNR on ICU admission, %	0.0	0.0	0.3	0.6	0.4	0.4	0.4	0.4	<0.001
Organs failing, mean ± SD	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.6	0.5 ± 0.9	0.5 ± 1.0	0.5 ± 1.0	0.6 ± 1.1	0.7 ± 1.1	<0.001
Mechanical ventilation, %	35.1	35.8	33.9	34.9	37.3	37.2	39.5	41.0	<0.001
Vasopressors‡, %	20.3	20.5	19.9	19.3	19.5	20.2	21.1	21.7	<0.001
Arterial catheter, %									<0.001
None	63.1	63.8	65.4	64.8	64.1	63.8	62.0	63.6	
In-place on ICU arrival	27.2	26.5	24.3	25.0	25.5	25.7	26.4	23.8	
Placed while in ICU	9.8	9.7	10.3	10.3	10.4	10.5	11.6	12.6	
Central venous catheter, %									<0.001
None	66.6	66.3	66.6	64.1	60.1	57.5	56.7	56.2	
In-place on ICU arrival	18.3	18.4	18.3	20.3	22.7	25.2	25.3	23.5	
Placed while in ICU	15.1	15.3	15.1	15.6	17.2	17.3	18.0	20.3	
Location before ICU arrival, %									<0.001
Ward	9.7	9.4	9.9	8.4	8.5	7.7	7.4	7.4	
Emergency room	42.3	43.4	43.9	43.6	43.8	45.0	44.0	47.0	
OpRm/PACU	32.7	31.5	28.7	29.1	29.3	28.2	29.6	27.0	
Stepdown/ telemetry unit	5.0	5.6	5.9	5.2	5.0	4.8	4.5	4.8	
Other	10.4	10.1	11.5	13.7	13.5	14.3	14.6	13.8	
Patient type, %									<0.001
Medical	62.9	64.6	67.2	66.5	66.5	67.6	65.2	68.8	
Elective surgical	25.9	24.4	22.8	22.6	21.1	20.6	21.5	18.9	
Emergent surgical	11.2	11.0	10.0	10.9	12.4	11.8	13.2	12.4	
ICU type§, %									<0.001
SICU	16.6	14.1	10.7	19.4	24.7	26.4	33.3	31.7	
MICU	13.2	10.9	10.9	15.1	16.9	19.8	20.3	20.3	
Combined	70.3	75.0	78.4	65.6	58.5	53.7	46.4	47.9	
Academic hospital, %	13.1	11.6	11.5	19.7	27.1	28.8	35.7	34.9	<0.001

* MPM_0-III = the mortality probability model at ICU admission. † By definition for Project IMPACT, "sepsis" means that a "patient is septic with or without significantly low blood pressure" and he/she "may or may not have positive blood cultures upon ICU admission." ‡ Vasopressors include infusions of dopamine, epinephrine, norepineprhine, phenylephrine, and/or vasopressin. § MICU and combined units can include coronary care. ‖ *P* values calculated using chi-square test or ANOVA as appropriate.

DNR = do-not-resuscitate order; ICU = intensive care unit; MICU = medical ICU; MPM_0-III = mortality probability model at ICU admission; OpRm/PACU = operating room/postanesthesia care unit; SICU = surgical ICU.

Appendix 4

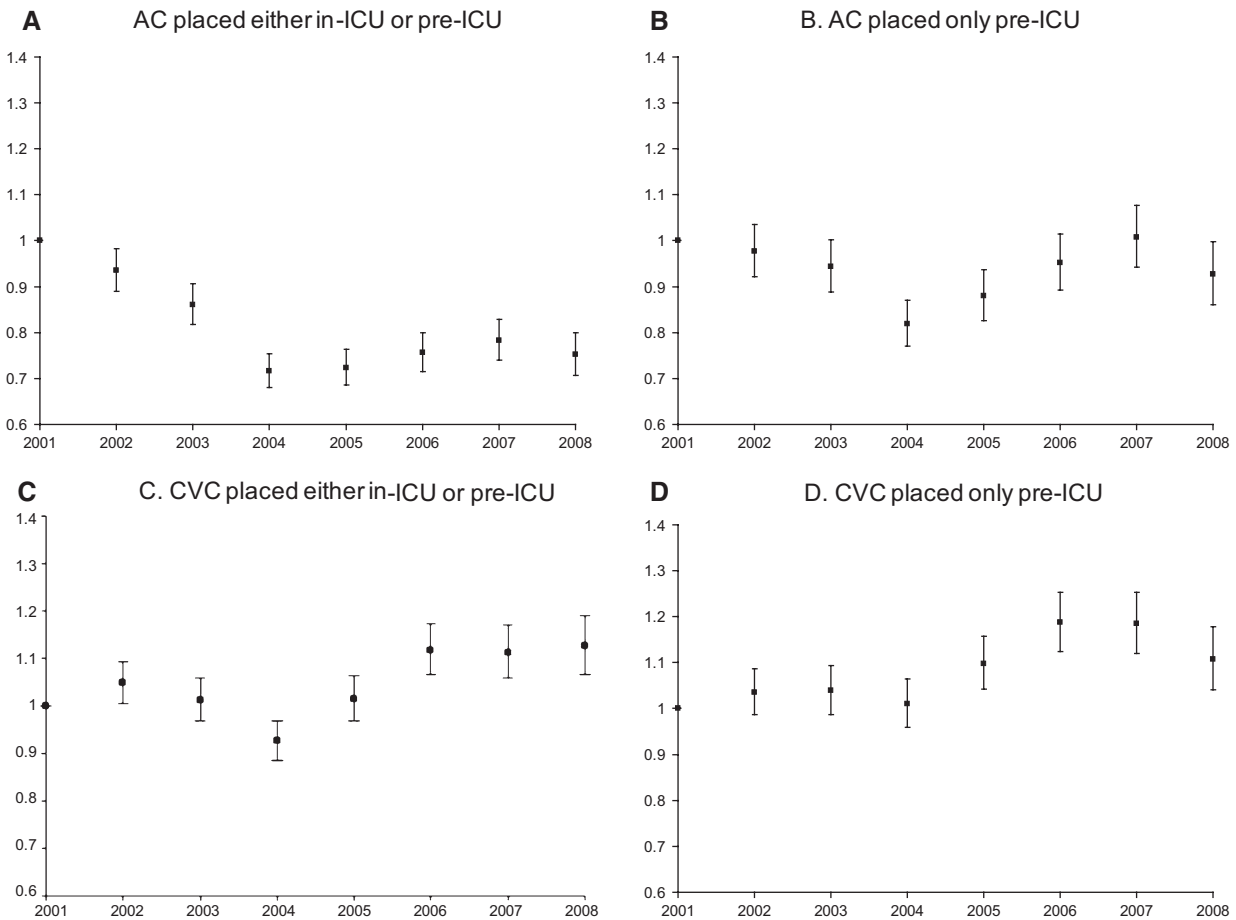

Fig. 5. Adjusted odds of catheter use by intensive care unit (ICU) admission year, 2001–2008. (*A*) Arterial catheter (AC) placed either in-ICU or pre-ICU, (*B*) AC placed only pre-ICU, (*C*) central venous catheter (CVC) placed either in-ICU or pre-ICU, (*D*) CVC placed only pre-ICU.

Appendix 5

Table 7. Multilevel Mixed-effects Models for the Use of Arterial and Central Venous Catheters in High- and Low-risk Patient Subgroups

	Arterial Catheters			Central Venous Catheters		
	MV	Vasopressors	MPM_0-III ≤2%	MV	Vasopressors	MPM_0-III ≤2%
Age (per 5 yr)	1.00 (1.00–1.00)	1.00 (0.99–1.00)	1.03 (1.03–1.03)	1.00 (1.00–1.00)	0.99 (0.99–1.00)	1.00 (1.00–1.00)
Female	0.86 (0.83–0.89)	0.87 (0.83–0.91)	0.93 (0.87–0.98)	1.28 (1.24–1.33)	1.27 (1.22–1.33)	1.29 (1.22–1.37)
Race						
White	1	1	1	1	1	1
Other	0.93 (0.89–0.98)	0.88 (0.81–0.94)	0.89 (0.81–0.97)	1.09 (1.03–1.14)	1.03 (0.96–1.11)	1.19 (1.09–1.30)
Black	0.98 (0.92–1.05)	0.90 (0.81–1.01)	0.99 (0.88–1.12)	0.92 (0.86–0.98)	1.03 (0.92–1.15)	0.83 (0.74–0.94)
1+ Comorbidities	0.84 (0.80–0.87)	0.79 (0.75–0.83)	0.98 (0.90–1.07)	1.23 (1.18–1.27)	1.11 (1.05–1.16)	1.39 (1.28–1.51)
MPM_0-III–predicted hospital mortality (per 10% increase)*	1.00 (0.99–1.00)	0.99 (0.99–0.99)		1.00 (1.00–1.00)	0.99 (0.99–1.00)	
Acute diagnostic group						
Trauma	1	1	1	1	1	1
Respiratory/ thoracic	0.48 (0.45–0.51)	0.34 (0.29–0.38)	0.72 (0.61–0.83)	0.71 (0.67–0.75)	0.77 (0.67–0.88)	0.71 (0.61–0.83)

(*Continued*)

Table 7. (Continued)

	Arterial Catheters			Central Venous Catheters		
	MV	Vasopressors	MPM_0-III ≤2%	MV	Vasopressors	MPM_0-III ≤2%
Cardiovascular/ vascular	0.87 (0.81–0.94)	0.52 (0.46–0.60)	1.51 (1.30–1.75)	0.82 (0.77–0.88)	0.58 (0.51–0.66)	1.03 (0.89–1.20)
Sepsis†	0.64 (0.59–0.70)	0.43 (0.38–0.49)	0.38 (0.29–0.50)	1.69 (1.55–1.85)	1.35 (1.18–1.55)	4.74 (3.78–5.95)
Neurologic (nontraumatic)	1.02 (0.96–1.09)	0.69 (0.60–0.80)	1.29 (1.12–1.50)	0.57 (0.54–0.61)	0.48 (0.42–0.55)	0.62 (0.54–0.73)
Metabolic/renal	0.45 (0.41–0.49)	0.33 (0.28–0.38)	0.40 (0.34–0.48)	0.58 (0.53–0.62)	0.82 (0.70–0.96)	1.50 (1.28–1.75)
Gastrointestinal	0.68 (0.63–0.74)	0.39 (0.33–0.45)	0.52 (0.44–0.61)	1.85 (1.72–1.99)	1.52 (1.31–1.77)	2.90 (2.49–3.39)
DNR on ICU Admission	0.92 (0.63–1.32)	0.75 (0.52–1.10)	6.58 (1.10–39.17)	0.96 (0.68–1.36)	1.05 (0.77–1.45)	0.23 (0.06–0.89)
Organs failing (per one organ increase)	1.22 (1.20–1.24)	1.18 (1.16–1.21)	1.21 (1.09–1.34)	1.54 (1.51–1.58)	1.36 (1.32–1.39)	1.92 (1.74–2.12)
Mechanical ventilation		4.39 (4.14–4.66)	4.26 (3.70–4.91)		2.84 (2.68–3.00)	4.12 (3.62–4.69)
Vasopressors‡	2.40 (2.30–2.50)		2.40 (2.03–2.82)	2.69 (2.58–2.80)		1.98 (1.72–2.27)
Arterial catheter						
None				1	1	1
In-place on ICU arrival				3.44 (3.28–3.60)	2.36 (2.18–2.55)	2.61 (2.43–2.82)
Placed while in ICU				4.78 (4.56–5.01)	3.55 (3.31–3.81)	4.72 (4.05–5.49)
Central venous catheter						
None	1	1	1			
In-place on ICU arrival	3.62 (3.46–3.78)	2.57 (2.41–2.75)	2.90 (2.68–3.13)			
Placed while in ICU	4.67 (4.47–4.87)	3.28 (3.08–3.50)	3.27 (2.85–3.75)			
Location before ICU arrival						
Ward	1	1	1	1	1	1
Emergency room	0.93 (0.88–0.99)	1.00 (0.93–1.08)	1.87 (1.52–2.29)	0.46 (0.43–0.49)	0.58 (0.54–0.62)	0.30 (0.26–0.35)
OpRm/PACU	2.67 (2.45–2.90)	4.68 (4.16–5.27)	10.11 (8.55–11.96)	0.54 (0.49–0.59)	0.61 (0.53–0.69)	0.67 (0.58–0.77)
Stepdown/ telemetry unit	1.00 (0.92–1.09)	0.97 (0.88–1.07)	1.98 (1.46–2.67)	0.89 (0.82–0.97)	0.96 (0.86–1.06)	1.04 (0.81–1.34)
Other	1.25 (1.16–1.34)	1.42 (1.31–1.55)	3.83 (3.14–4.65)	0.87 (0.80–0.93)	0.88 (0.80–0.96)	0.57 (0.49–0.68)
Patient type						
Medical	1	1	1	1	1	1
Elective surgical	2.82 (2.60–3.05)	2.93 (2.62–3.29)	2.41 (2.05–2.84)	0.99 (0.92–1.08)	0.88 (0.78–0.99)	1.16 (1.00–1.36)
Emergent surgical	2.37 (2.20–2.55)	1.71 (1.54–1.91)	1.55 (1.30–1.86)	1.28 (1.19–1.38)	1.37 (1.21–1.54)	1.01 (0.85–1.19)
ICU type§						
SICU	1	1	1	1	1	1
MICU	0.46 (0.30–0.71)	0.43 (0.27–0.68)	0.60 (0.41–0.88)	0.98 (0.75–1.27)	0.93 (0.67–1.30)	0.85 (0.59–1.24)
Combined	0.48 (0.33–0.71)	0.41 (0.27–0.61)	0.79 (0.58–1.07)	1.02 (0.81–1.28)	0.97 (0.73–1.31)	0.86 (0.64–1.16)
Academic hospital	1.97 (1.31–2.96)	2.32 (1.51–3.57)	1.74 (1.26–2.40)	1.03 (0.81–1.30)	1.36 (1.00–1.84)	1.34 (0.98–1.84)
ICU admission year						
2001	1	1	1	1	1	1
2002	0.88 (0.81–0.95)	0.89 (0.80–0.98)	1.02 (0.90–1.16)	1.07 (1.00–1.15)	1.04 (0.95–1.14)	1.05 (0.93–1.19)
2003	0.80 (0.74–0.86)	0.72 (0.65–0.80)	0.95 (0.84–1.08)	0.96 (0.90–1.03)	0.98 (0.89–1.09)	1.14 (1.00–1.30)
2004	0.61 (0.56–0.66)	0.60 (0.53–0.67)	0.83 (0.72–0.94)	0.88 (0.81–0.94)	0.85 (0.77–0.95)	1.05 (0.92–1.20)
2005	0.61 (0.56–0.66)	0.61 (0.54–0.69)	0.82 (0.71–0.94)	0.98 (0.91–1.06)	1.02 (0.92–1.14)	1.16 (1.01–1.33)
2006	0.64 (0.58–0.69)	0.62 (0.55–0.70)	0.94 (0.81–1.08)	1.05 (0.97–1.14)	1.18 (1.05–1.32)	1.22 (1.06–1.41)
2007	0.63 (0.58–0.69)	0.69 (0.61–0.78)	1.05 (0.91–1.21)	1.07 (0.98–1.16)	1.34 (1.19–1.51)	1.09 (0.94–1.26)
2008	0.62 (0.56–0.68)	0.82 (0.71–0.93)	0.88 (0.75–1.03)	1.11 (1.02–1.21)	1.38 (1.21–1.58)	1.15 (0.97–1.35)
Adjusted MOR	2.56 (2.31–2.87)	2.64 (2.37–2.99)	1.94 (1.78–2.13)	1.69 (1.59–1.81)	1.93 (1.78–2.11)	1.90 (1.75–2.09)

* MPM_0-III is the mortality probability model at ICU admission. † By definition for Project IMPACT, "sepsis" means that a "patient is septic with or without significantly low blood pressure" and he/she "may or may not have positive blood cultures upon ICU admission." ‡ Vasopressors include infusions of dopamine, epinephrine, norepineprhine, phenylephrine, and/or vasopressin. § MICU and combined units can include coronary care.

DNR = do-not-resuscitate order; ICU = intensive care unit; MICU = medical ICU; MOR = median odds ratio; MPM_0-III = mortality probability model at ICU admission; MV = mechanical ventilation; OpRm/PACU = operating room/postanesthesia care unit; SICU = surgical ICU.