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

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Abstract

Background—Arterial (AC) and central venous catheterization (CVC) are common in intensive care units (ICUs). Few data describe which patients receive these devices and whether variability in practice exists.

Methods—We conducted an observational cohort study of adult ICU admissions during 2001–2008 using Project IMPACT to determine whether AC and CVC use is consistent across United States ICUs. We 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) *versus* 36.4% (2008); $P = 0.212$) while 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 wide variability in AC use across ICUs in patients receiving mechanical ventilation

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(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 2% (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 2%: 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.

Introduction

Intravascular catheterization is a common procedure in critically ill patients. Arterial catheters (AC) 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 campaign⁹ 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 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 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 of adult patients (≥ 18 yr of age) admitted from 2001 through 2008 to ICUs 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, gender, race) and health problems including severity of illness as described by the mortality probability model predicted hospital mortality at ICU admission (MPM₀-III),²⁶ preference for cardiopulmonary resuscitation at ICU admission, acute diagnostic category, location prior to 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 1²⁷). 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, 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 prior to 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 prior to or during the ICU stay. Patient characteristics and ICU/hospital characteristics associated with AC and CVC use were analyzed using Chi-squared and analysis of variance 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, gender, race, comorbidities, MPM₀-III, resuscitation status on ICU admission, organ failures, use of MV, use of vasopressors, use of other indwelling catheters, acute diagnostic group, location prior to 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 prior to the ICU using Chi-squared tests. We summarized the variability by individual ICU in the use of ACs and CVCs using median, interquartile ranges (IQR) 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. 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; a number closer to one indicates a larger relative impact of the excluded variable set on catheter use prediction.³¹ 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 MPM₀-III) on ICU arrival of 2%.³² For the analyses of each subgroup of patients, we only included ICUs with 20 patients in the given subgroup.

Results were considered statistically significant if $P < 0.05$. 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 $13.7\% \pm 16.5\%$. Overall hospital mortality was 13.0% with a median ICU length of stay of 2 (IQR 1,4) days and a median hospital length of stay of 7 (IQR 3,12) days.

Characteristics of patients who received ACs and CVCs

In our cohort, 47.8% had neither an AC nor CVC, 14.3% of patients 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 in patients at the extremes of illness severity (MPM_{0-III} predicted hospital mortality $\leq 2\%$ or $>20\%$) while 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 (1,5) vs. 2 (1,3) days for AC; 3 (2,7) vs. 1 (1,2) days for CVC), longer hospital lengths of stay (8 (5,15) vs. 6 (3,10) days for AC; 10 (6,19) vs. 5 (3,6) days 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 $P < 0.001$.

Trends in catheter use

Absolute rates of AC use remained fairly constant from 2001 to 2008 (minimum rate in 2003 of 34.6% of patients to a maximum in 2007 of 38.0%, $P = 0.21$ comparing 2001 and 2008) while 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 (PACs) 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 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, table 3). Compared to SICU patients (56.0% of whom received an AC), patients admitted to either a MICU (22.4%, adjusted OR (95% confidence interval, 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 prior to arrival in the ICU whereas in the MICU population, more were placed in the ICU itself. The high frequency of ACs placed prior to 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).

While 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% to 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 (MPM₀-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 prior to ICU arrival for patients in the SICU, while for MICU and combined unit patients, the placement of catheters was more evenly divided between pre-ICU and in-ICU locations (fig. 2C 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 mechanical ventilation 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 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 prior to 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 past studies on PAC use.^{33–35} While 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 surgical ICUs might be either more familiar with managing patients using such devices and/or slow to remove catheters others have deemed necessary. Given this disparate use, potential future studies of the impact of these devices on patient outcomes should 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. While 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 not known; 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 while 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 PAC use over the past two decades.^{34,43} This lack of 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 following 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 utilize 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) as well as the thought process by the clinician (*e.g.*, “we should place an AC because all patients requiring vasopressors should have one”) were not known. 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 prior to 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. While this

information would not have changed our findings, it might have provided us with a more comprehensive explanation for the variation observed. Additionally, we were unable to confirm the exact timing of placement of the catheters beyond the basic information of whether they were placed prior to or in the ICU. Again, this information would help to further understand usage. Also, we did not 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; while diverse, these ICUs are not a completely representative sample of U.S. ICUs.

While invasive interventions will likely always have a place in the care of the critically ill, there are numerous examples in healthcare 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.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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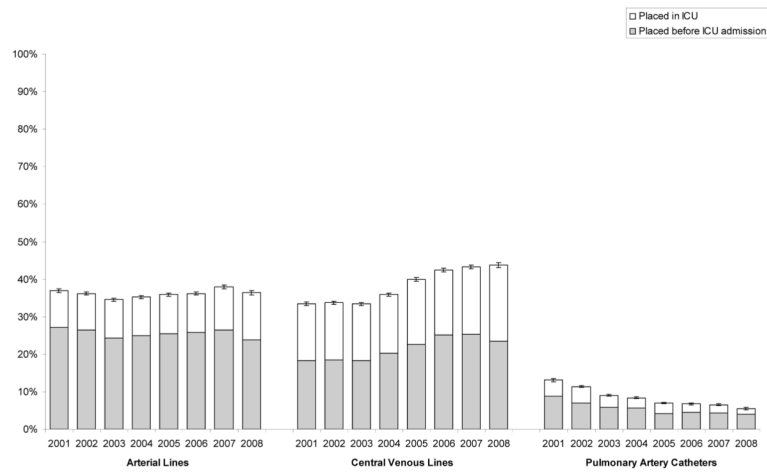
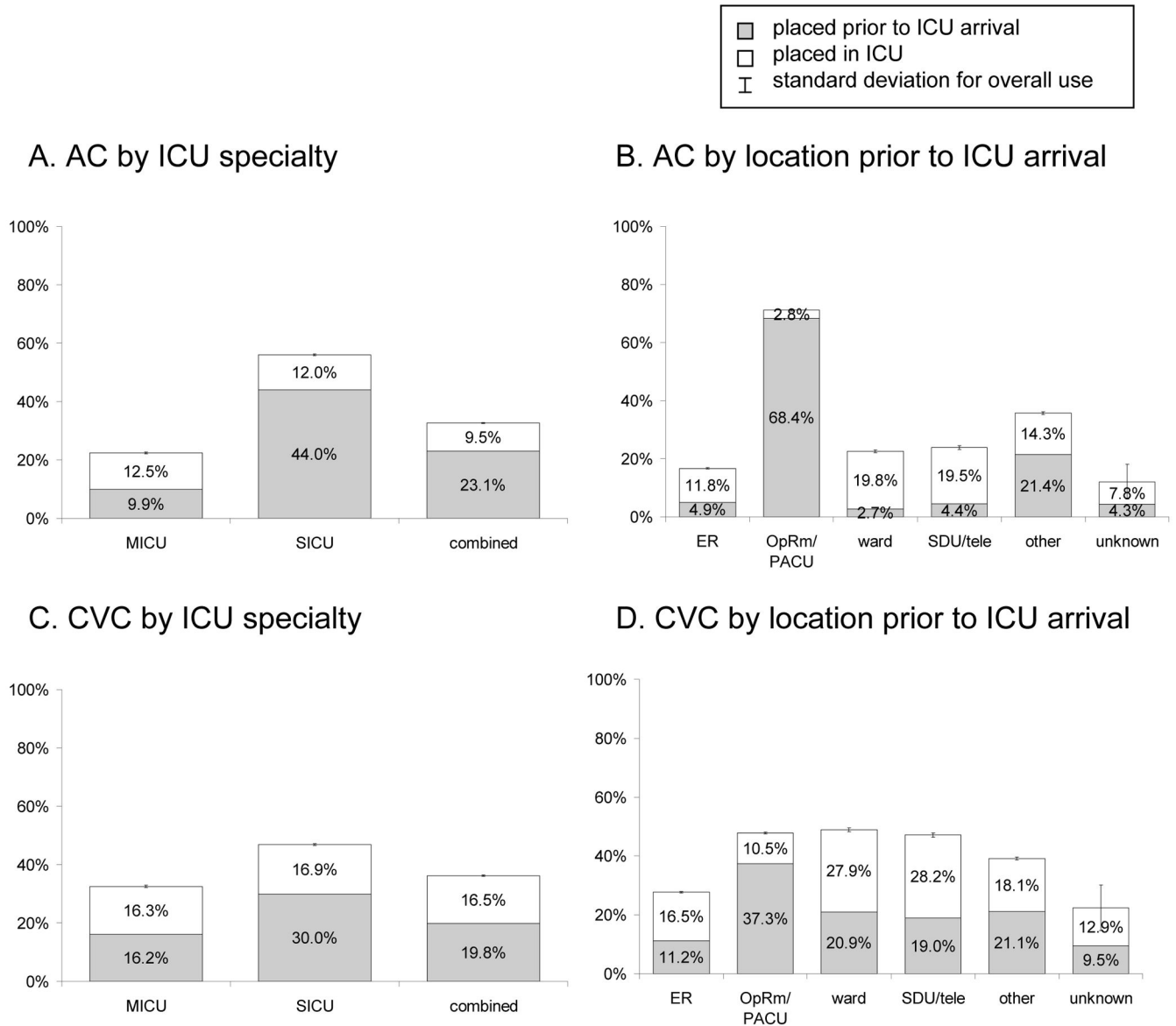


Figure 1.

Trends in Catheter Utilization, 2001–2008.

Trends evaluated using logistic regression revealed odds-ratio (OR) 1.01 per year ($P < 0.001$) for arterial catheter use, OR 1.08 per year ($P < 0.001$) for central venous catheter use, and OR 0.87 per year ($P < 0.001$) for pulmonary artery catheter use.

ICU = intensive care unit

**Figure 2.**

Catheter use by ICU specialty and location prior to ICU arrival.

(A) AC by ICU specialty, (B) AC by location prior to ICU arrival, (C) CVC by ICU specialty, (D) CVC by location prior to ICU arrival.

AC = arterial catheter; combined = medical and surgical ICU; CVC = central venous catheter; ER = emergency room; ICU = intensive care unit; MICU = medical ICU; OpRm/PACU = operating room/postanesthesia care unit; SDU/tele = step-down unit/telemetry unit; SICU = surgical ICU.

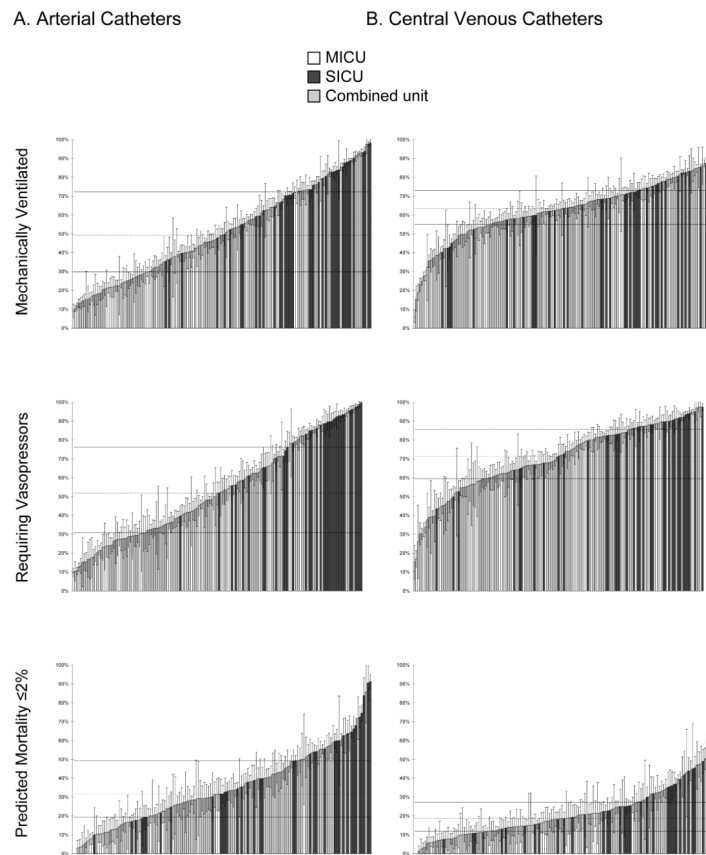


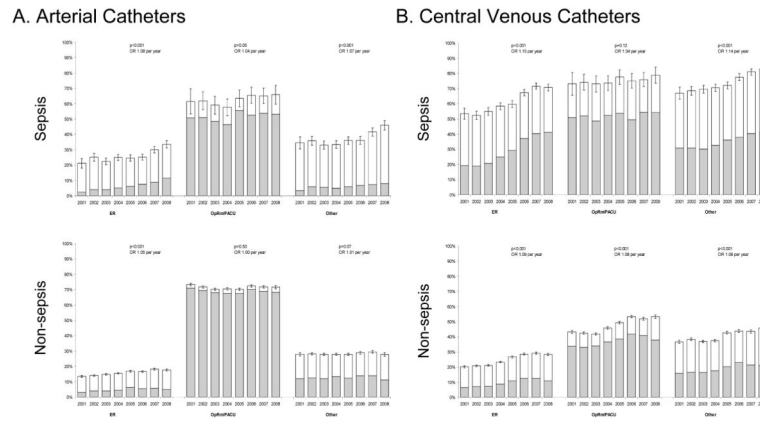
Figure 3.

Variation in catheter use across individual ICUs.

(A) arterial catheters, (B) central venous catheters

Error bars = 95% confidence interval for each ICUs utilization rate; dotted line = median of all unit rates; solid lines = interquartile range of all unit rates.

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



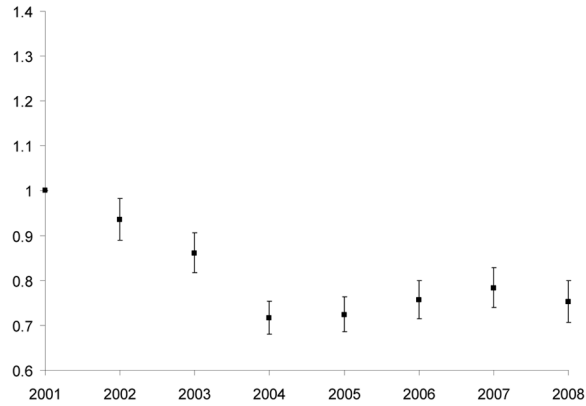
Appendix 2 - Figure 4.

Trends in AC and CVC (2001–2008) stratified by sepsis diagnosis and location prior to ICU arrival.

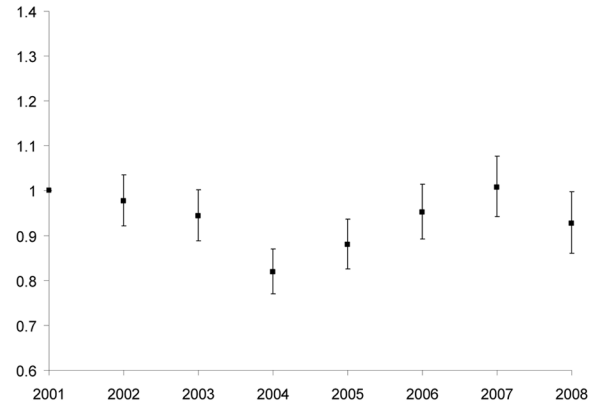
(A) arterial catheters, (B) central venous catheters

ER = emergency room; ICU = intensive care unit; OpRm/PACU = operating room/postanesthesia care unit; OR = odds-ratio calculated by logistic regression.

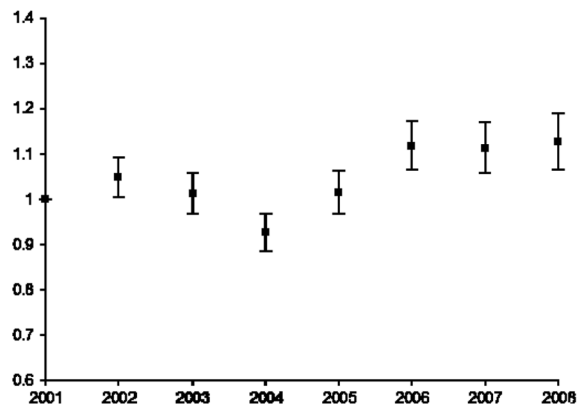
A. AC placed either in-ICU or pre-ICU



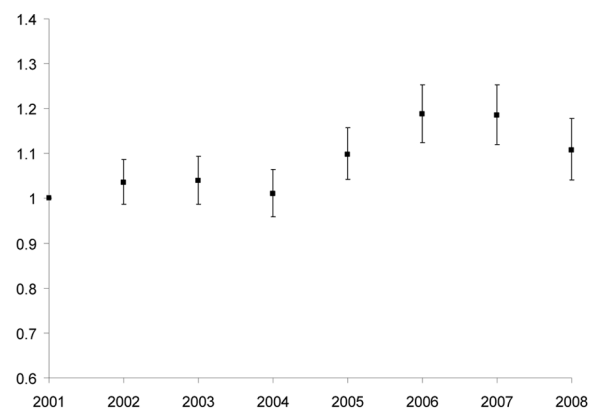
B. AC placed only pre-ICU



C. CVC placed either in-ICU or pre-ICU



D. CVC placed only pre-ICU

**Appendix 4 - Figure 5.**

Adjusted odds of catheter use by ICU admission year, 2001–2008.

(A) AC placed either in-ICU or pre-ICU, (B) AC placed only pre-ICU, (C) CVC placed either in-ICU or pre-ICU (D) CVC placed only pre-ICU

AC = arterial catheter; CVC = central venous catheter; ICU = intensive care unit.

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: <ul style="list-style-type: none"> • SBP <90 mmHg (unless known baseline is <90) • SBP ↓ 40 mmHg from baseline • MAP <70 mmHg • Vasopressors (dopamine equivalent >5 mcg/kg/min) need to keep SBP >90 mmHg or MAP >70 mmHg
Hyperlactatemia	Both of: <ul style="list-style-type: none"> • Cardiovascular organ failure (by above criteria) • Serum lactate > upper limits of normal for local laboratory
Respiratory	Noncardiogenic pulmonary edema <i>and</i> Either of: <ul style="list-style-type: none"> • PaO₂/FiO₂ 300 • PEEP >5 mmHg
Renal	Patient not on chronic dialysis <i>and</i> Either of: <ul style="list-style-type: none"> • Serum creatinine ↑ by 1mg/dl above baseline after adequate fluid resuscitation • Serum creatinine 2 mg/dl if no known baseline
Hematologic	Any of: <ul style="list-style-type: none"> • Platelets ↓ to ½ the highest value of the previous 3 days • Platelets < 100,000/mm³ • 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: <ul style="list-style-type: none"> • Acutely altered sensorium • No known CNS injury or insult • Sedation holiday performed • No tracheal intubation • GCS 12

CNS = central nervous system; FiO₂ = fraction of inspired oxygen; GCS = Glasgow coma score; MAP = mean arterial pressure; PaO₂ = 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 3 - Table 6

Characteristics of Cohort over Time, 2001–2008

	2001	2002	2003	2004	2005	2006	2007	2008	p-value**
Age (years), 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
Gender, %									<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	
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	

	2001	2002	2003	2004	2005	2006	2007	2008	p-value**
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 prior to ICU, %									<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

DNR = do-not-resuscitate order; ICU = intensive care unit; MICU = medical ICU; OpRm/PACU = operating room/post-anesthesia care unit; SICU = surgical ICU.

* MPM0-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, norepinephrine, phenylephrine, and/or vasopressin.

// MICU and combined units can include coronary care.

** p-values calculated using Chi-square or ANOVA as appropriate.

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)
I+ 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)
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 1 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						

	Arterial Catheters			Central Venous Catheters		
	MV	Vasopressors	MPM _{0-III} 2%	MV	Vasopressors	MPM _{0-III} 2%
none	I	I	I			
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 prior to ICU						
ward	I	I	I	I	I	I
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	I	I	I	I	I	I
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	I	I	I	I	I	I
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	I	I	I	I	I	I
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)

DNR = do-not-resuscitate order; ICU = intensive care unit; MICU = medical ICU; MOR = median odds-ratio; OpRm/PACU = operating room/postanesthesia care unit; SICU = surgical ICU.

* MPM0-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, norepinephrine, phenylephrine, and/or vasopressin.

^{//} MICU and combined units can include coronary care.