Intensive Care Med (1996) 22: 664–669

ORIGINAL

The importance of technology for achieving superior outcomes from intensive care

P. G. Bastos
W. A. Knaus
J. E. Zimmerman
A. Magalhães Jr
X. Sun
D. P. Wagner
The Brazil APACHE III Study Group*

Received: 2 June 1995
Accepted: 22 November 1995

Supported by the Agency for Health Care Policy and Research (HSO7137); The John A. Hartford Foundation (87267); The Department of Anesthesiology, The George Washington University Medical Center; The National Council of Scientific and Technology Development (CNPq), Brazil (No. 202321/98.4); and APACHE Medical Systems Inc

P.G. Bastos · W.A. Knaus
J.E. Zimmerman · A. Magalhães Jr
X. Sun · D.P. Wagner
Hospital de Ipanema, Rio de Janeiro 22411, Brazil

P.G. Bastos · W.A. Knaus
J.E. Zimmerman (✉) · A. Magalhães Jr
X. Sun · D.P. Wagner
ICU Research Unit, The George Washington University Medical Center, 901 23rd Street, N. W., Washington, DC 20037, USA

* A complete list of study hospitals and participants appears at the end of this article.

Abstract *Objective:* To test the hypothesis that technology availability, staffing, and diagnostic diversity in an intensive care unit (ICU) are associated with the ability to decrease hospital mortality.
Design: Prospective multicenter descriptive cohort study.
Setting: Ten Brazilian medical–surgical ICUs.
Patients: 1734 consecutive adult ICU admissions.
Measurements and results: We recorded the amount of technology, number of diagnoses, and availability of nurses at each ICU. We also used demographic, clinical and physiologic information for an average of 173 admissions to each ICU to calculate standardized mortality ratios (SMRs) for each ICU. The mean SMR for the ten ICUs was 1.67 (range 1.01–2.30). A greater availability of ICU equipment and services was significantly ($p < 0.001$) associated with a lower SMR.
Conclusion: The ability of Brazilian ICUs to reduce hospital mortality is associated with the amount of technology available in these units.

Key words Intensive care · Outcome and process assessment (health care) · Probability models · Quality of health care · Resource allocation · Organization and administration

Introduction

Despite the widespread use and growing international reliance on intensive care units (ICUs), these units and many of the technologies they rely upon have not been evaluated through randomized clinical trials. Although the incremental value of these services and technologies is not precisely known, the rising cost of medical care, and in particular expensive services like intensive care, has increased the need for determining where to invest limited resources and how to monitor their performance.

One increasingly proposed measure, risk-adjusted or standardized mortality ratio (SMR), is especially useful as a performance measure for ICUs because mortality is high and variable [1–3]. Although SMRs are not yet universally accepted [4], substantial progress has been made in addressing major analytic challenges and predictive methods are increasingly able to

account reliably for variations in severity of illness, patient selection, and other patient characteristics [5–8].

We recently reported a large prospective study of factors associated with risk-adjusted mortality rates at 42 ICUs in the United States. We found substantial variation, with 10 of the 42 units having SMRs significantly higher (5) or lower (5) than expected by random variation [1]. This study concluded that the amount of technology present in an ICU directly correlated with its ability to save patients' lives [9]. In an on-site organizational analysis at 9 of the 42 ICUs, a team of clinical and management investigators could not correctly rank each unit's performance according to its SMR [10]. This led some observers to question the usefulness of measuring SMRs [11].

In the current study, we had an opportunity to address this concern and to investigate further the incremental value intensive care technology brings to modern hospital practice. This is because the Brazilian ICUs participating in this study had greater variations in SMRs [12] and technology availability than the ICUs in the United States.

Patients and methods

Patient data

Information was collected for 1734 consecutive adult ICU admissions at ten ICUs in ten Brazilian hospitals between January 1990 and May 1991 by trained data collectors using APACHE III data collection software [6]. APACHE III uses 78 mutually exclusive ICU admission diagnostic categories, 17 potential physiologic abnormalities, age, 7 comorbidities, operative status and priority (elective or emergency, which was defined as surgery for an immediately life-threatening condition), and location prior to ICU admission. Patient survival was recorded at ICU and hospital discharge. The exclusion criteria for this study were identical to those used in the APACHE III study, i.e., patients admitted to the ICU < 4 h, age < 16 years, suspected myocardial infarction, coronary bypass surgery, and burn injury. Further details about the study methods, characteristics, and outcomes for these Brazilian ICUs and patients are reported in another paper [12].

ICU characteristics

Concurrent with patient data collection, each ICU director provided information about hospital and ICU structure, defined as selected characteristics of the providers of care, their tools, resources, and physical and organizational setting. ICU level was classified according to criteria outlined by the 1983 United States National Institutes of Health critical care consensus conference [13]. Data were collected using a translated questionnaire adapted from the APACHE III study [9, 10]. Data on hospital structure included size, type (public or private), and teaching status. For each ICU, structural information included the amount of technology available, nurse and physician staffing, and diagnostic diversity – the same factors tested in the APACHE III study [9]. Technology availability was measured by the percentage of 38 items of equipment or services recommended in guidelines published between 1983 and 1988 [13–15] (Table 1). Nurse staffing was assessed by computing the average nurse-to-patient ratio in each ICU across all shifts. Diagnostic diversity was defined by the number of different diseases treated in each ICU, using the 78 major disease categories [6] in the APACHE III prognostic system. Because the number of patients studied varied from 135 to 200, we measured diagnostic diversity by counting the number of disease categories for the first 135 admissions to each unit.

Data analysis

To calculate the risk-adjusted ratio or SMR, we predicted each patient's probability of hospital mortality using a previously validated multiple logistic regression equation [1] and compared observed to predicted hospital mortality. The relationship between each of the four previously described structural characteristics and the SMRs were examined using ordinary least squares regression across the ten hospitals. A significance level of $p < 0.05$ was accepted as important.

To test for potential bias in predicted mortality due to differences in availability of laboratory tests, we compared the proportion of patients in the United States and Brazil who had missing laboratory measures, stratifying by levels of severity. To construct the severity strata for the missing value comparison we used vital signs data and the APACHE III weights for heart rate, mean blood pressure, temperature, and respiratory rate. This was done because very few ICU patients have missing vital signs, and there is a clear expectation for intensive care physicians to order more laboratory tests when vital signs are very deranged. We then examined the frequency of missing data for the 11 APACHE III physiologic measures based on laboratory testing across vital sign-based severity strata for both countries. This analysis compared only the number of patients who had no measurement during the first 24 h, not the total number of laboratory tests per day or the frequency of testing across hospitals.

Results

Four of the ten ICUs were in teaching hospitals, as defined by their affiliation with a medical school and the presence of critical care residency programs; five were private and five public. The mean number of hospital beds was 397 (range 60–1107), with an average of 3.5% designated for intensive care. The mean number of ICU beds was 14 (range 6–26). There were two level I and eight level II ICUs. All units were mixed medical–surgical and staffed by physicians, usually part-time intensivists, on a 24-h on-site basis. At five hospitals, the nurse-to-patient ratio was 1:1, the remaining hospitals had a slightly lower ratio, especially during night shifts, with the lowest ratio of 1:2. Brazil has a severe shortage of registered nurses, so that the majority of these nurses did not have an undergraduate degree. Nurses with undergraduate degrees have leadership and administrative roles and are not routinely involved with patient care in Brazil.

The characteristics and outcomes for the 1734 consecutive ICU admissions are summarized below and

Table 1 Technology availability measurements in 10 Brazilian ICUs and 42 ICUs in the USA (*NA* not available, SVO_2 mixed venous O_2 saturation)

	Percentage of units with technology available	
	US	Brazil
Equipment and services		
Electrocardiograph monitor	100	100
Intra-arterial pressure	100	100
Pulmonary artery catheter	100	100
Transvenous pacer wire	100	100
Defibrillator	100	100
Resuscitation cart	100	100
Intubation equipment	100	100
Chest/abdominal X-ray (24 h a day)	100	100
Infusion pumps	100	100
Peritoneal dialysis	100	100
In-hospital blood gas testing[a]	100	100
In-hospital chemistry testing[a]	100	100
In-hospital hematologic testing[a]	100	100
Continuous positive airway pressure apparatus	100	90
Mechanical ventilator, volume	100	90
Mechanical ventilator, pressure[a]	NA	100
Cardiac pacemaker (external)	100	60
Sengstaken-Blakemore tube	97.6	100
Positive-end expiratory pressure capable manual ventilation device	97.6	30
Pulse oximeter	95.2	90
Computerized tomography (24 h a day)	95.2	80
Isolation beds	95.2	70
Nutritional support services	95.2	80
Cardiac pacemaker (atrial-ventricular sequential)	90	40
Portable electrocardiograph[b]	88	100
Ultrasound (24 h a day)	85	90
Nuclear medicine (24 h a day)	85	10
Hemodialysis	83	90
Intracranial pressure monitor	80	70
Plasmapheresis	75	70
Ventriculostomy	70	40
Continuous arterial-venous hemofiltration	68	70
Fluoroscopy	67	50
End-tidal CO_2 monitor	67	40
Intra-arterial vasopressin infusion	58	10
Portable ventilator	50	80
Intra-aortic balloon pump	50	30
Pulmonary artery catheter with continuous SVO_2	43	20

[a] Not available in Shortell et al. [9]
[b] Data from the USA includes portable electrocardiographic and pressure monitoring

are reported in detail in another paper [12]. The most common diagnoses were trauma ($n = 306$), cerebral hemorrhage ($n = 139$), surgery for a gastrointestinal neoplasm ($n = 75$), and sepsis ($n = 75$). The mean age of the patients was 52 years; more than half (58.5%) were less than 59 years old. The mean first-day APACHE III score was 55 ± 27. Fourteen percent of patients ($n = 246$) were transferred from other hospitals or ICUs. Observed ICU mortality was 29% and hospital mortality was 34% (range 21–57%). The mean SMR for all patients was 1.67, ranging from 1.01 to 2.30 among the ten units.

In aggregate, 95.4% of Brazilian patients and 99.7% of patients in the United States had all four vital signs (heart rate, mean blood pressure, temperature, respiratory rate) measured during the first ICU day, implying that a severity scale based only on those four APACHE III components would not be substantially biased by missing data between the two countries. Figure 1 shows the mean number of missing laboratory tests across severity strata based on APACHE III weights for the four vital sign measurements. For each country, the mean number of missing tests declines substantially as the severity

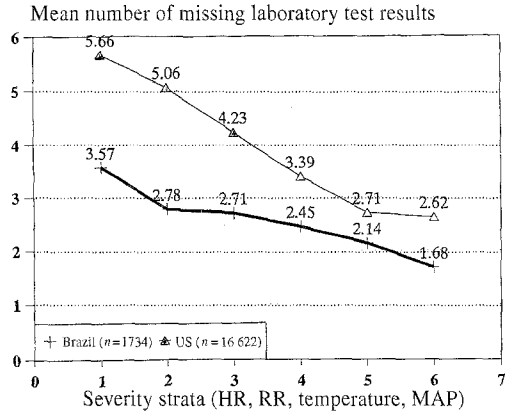

Fig. 1 The relationship between severity strata, based on the weights and frequency of vital-sign measurement, and missing laboratory tests used in APACHE III [6] for 1734 Brazilian *plus* and 16622 US patients *delta*. The vital signs measured in APACHE III include heart rate *HR*, mean blood pressure *MAP*, respiratory rate *RR*, and temperature. The 11 possible missing laboratory tests include pH, arterial O_2 and CO_2 (PaO_2, $PaCO_2$), hematocrit, white blood cell count, creatinine, blood urea nitrogen, sodium, albumin, bilirubin, and glucose

of vital sign abnormality increases. Within each severity range the number of missing laboratory values in Brazil is significantly lower, not higher, than in the United States.

The availability of the 38 recommended ICU technologies is listed in Table 1. The Brazilian units varied from a low of 24 items (63%) to a high of 36 (95%); the average was 76%. The majority of units (90%) had what would be considered standard ICU equipment. Compared to ICUs in the United States [10], there was more variation in newer technologies (external cardiac pacemakers, in-unit laboratory testing) and more specialized services, such as intra-aortic balloon pumps, ventriculostomy, and the capability of treating gastrointestinal bleeding using intra-arterial vasopressin infusion (Table 1).

There were 66 ICU admission diagnoses. The mean frequency of diagnoses was 44 (range 28–59) among all admissions and 38 (range 26–48) among the first 135 admissions to each unit. The overall nurse-to-patient ratio was 0.85, with a range of 0.5 to 1.3.

Findings from the regression analysis of structural and organizational associations with risk-adjusted hospital mortality are summarized in Table 2. There was a significant association between the percentage of recommended technology available and the SMR ($p < 0.001$). The units with the highest SMRs had 70% or less of the 38 items, and units with lower SMRs had 90% or more (Fig. 2). Variations in nurse-to-patient ratio and diagnostic diversity did not demonstrate a significant association with risk-adjusted mortality in this study.

Table 2 Factors associated with standardized mortality ratios (SMRs) in ten Brazilian hospitals

	Model for all ten hospitals ($R^2 = 0.89$)	
Dependent variable	Coefficient	*p*-value
Technology availability	− 0.118	0.001
Nurse-to-patient ratio	0.32	0.12
Diagnostic diversity	− 0.01	0.11

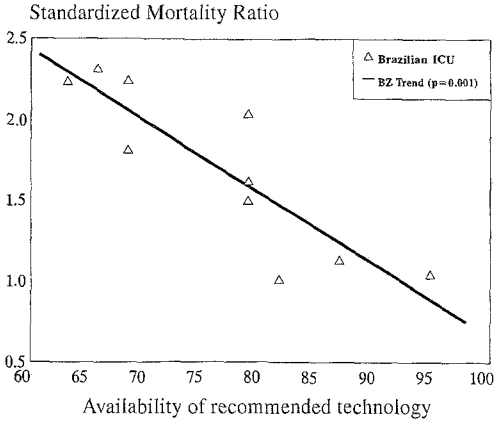

Fig. 2 The relationship between the percentage of available recommended technologies and standardized mortality ratio in ten Brazilian ICUs. Individual ICU *solid triangle*, univariate regression *line* (regression coefficient = − 0.444; $p = 0.001$)

Discussion

We found that variations in SMRs among these 10 Brazilian ICUs are strongly ($p < 0.001$) associated with differences in the availability of ICU technology. These results confirm and extend findings from an earlier examination of associations with SMRs among 42 ICUs in the United States [9, 10]. Compared to that study in the United States, the Brazilian units had a wider range of risk-adjusted performance (SMRs from 1.01 to 2.30 vs 0.67 to 1.25 in the USA), and there was also greater variation in the amount and type of technology available. In Brazil, the availability of ICU technology is more severely limited than in the United States because of severe economic constraints and political pressures [16, 17]. The results of this study, however, suggest that in both countries variations in risk-adjusted outcomes are related to the availability of the tools and devices that make modern intensive care possible. This study, therefore, replicates findings from a study in ICUs in the United States, which indicated that greater availability of technology in ICUs is associated with improved risk-adjusted survival [9]. In this regard, we suggested in the study in the United States

that it was not the availability of technology alone but an institutional and unit commitment to obtain resources that would keep the unit performing well. Most likely, similar imperatives apply in Brazil, where the economic support and infrastructure of ICUs is much more variable than in the United States and thus leads to greater variation in technology availability (Table 1) and risk-adjusted outcome (Fig. 2). A recent report of increased mortality among patients who were denied ICU admission because of a limited number of beds also supports this suggestion [18].

The lack of a relationship between diagnostic diversity and risk-adjusted mortality was not consistent with our initial study and with a growing body of literature suggesting that concentrating on fewer diagnoses is associated with better patient outcomes [19–21]. The most likely reason is that we studied only a small number (10) of Brazilian units compared to 42 in the United States. In other words, the lack of an association between diagnostic diversity and SMR represents poor evidence that this variable is not important due to the limited power of a 10-unit study to reject a false-negative result. The lack of association between nurse-to-patient ratio and SMR is also likely due to the small number of units studied and low variation in nurse-to-patient ratio (0.86). Similar to the study in the United States, none of these units had major shortfalls in nurse staffing during data collection.

Our findings must be considered within the context of several limitations. We acknowledge that some of the variations in risk-adjusted mortality may be related to chance variations because study data were collected over a relatively brief time period [22], inadequately measured individual patient characteristics, and selection or lead-time bias due to differences in patient referral [1, 12, 23]. Differences in the frequency of missing laboratory tests appears not to have caused biased underprediction, although a reduced frequency of testing within each day in Brazil compared to the United States is still possible. Analysis of the relationship between the proportion of patients with missing results for physiologic measures and SMRs in hospitals in the United States, however, revealed no association [24]. The small number of hospitals and ICUs studied also reduced our ability to test the associations of private versus public, and teaching versus nonteaching hospital status with their SMRs.

The large amount of variation in risk-adjusted mortality found among these 10 Brazilian ICUs indicates that detecting these differences is important and worthy of ongoing evaluation. We hope this study will improve the focus of subsequent studies relating ICU structure and process with risk-adjusted mortality by defining variables of interest and those which require further study. More needs to be learned concerning which aspects of intensive care medical and nursing practice are related to improving risk-adjusted mortality for ICU patients, especially at a time when increased emphasis is being placed on reducing new investment in medical technology. In the specific case of these 10 ICUs, we cannot conclusively claim it is the availability of any one or more of the specific items listed in Table 1 that was causally related to the variation in risk-adjusted outcome. We do conclude that SMRs appear to be a useful and sensitive measure that correlates with one important component of modern intensive care, the amount of life-saving technology available.

Acknowledgements All the authors certify that affiliations with or involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in this article are disclosed as follows: Drs. Knaus, Zimmerman, and Wagner are founders and minority equity shareholders of APACHE Medical Systems (AMS), Inc., a for-profit Delaware-based corporation that funded, in part, the research for the APACHE III study. AMS markets a software-based clinical information system based upon some of the concepts described in this article. Neither Dr. Knaus, Dr. Zimmerman, not Dr. Wagner, as full-time employees of George Washington University, is permitted to receive any direct financial payment from AMS. Dr. Bastos has received research support from AMS. None of the other authors has any formal affiliation with or receives any financial or other consideration from APACHE Medical Systems.

The Brazil APACHE III Study Group

Paulo Gabriel Bastos, M.D., Coordinator; Dino Roberto Gomes, M.D., Coordinator in Brazil; Celso Dias Coelho, M.D., Hospital Municipal Souza Aguiar; Paulo Cesar Silva Pereira de Souza, M.D., Hospital do Andaraf; Ricardo Lima, M.D., Hospital Samaritano; Joel Tavares Passos, M.D., Irmandade São João Batista de Macaè; Janete Livianu, M.D., Hospital Albert Einstein; Mariza D'Agostino Dias, M.D., Hospital das Clínicas F.M.U.S.P. and Hospital Nove de Julho; Renato G.G. Terzi, M.D., Hospital das Clínicas, UNICAMP; Marcelo Rocha, M.D., Santa Casa da Misericórdia de Porto Alegre; Silvia Regina Reis Vieira, M.D., Hospital de Clínicas de Porto Alegre.

References

1. Knaus WA, Wagner DP, Zimmerman JE, Draper EA (1993) Variations in mortality and length of stay in intensive care units. Ann Intern Med 118: 753–761
2. Pollack MM, Getson PR, Ruttimann VE, Steinhart CM, Kanter RK, Katz RW, Zucker AR, Glass NL, Spohn WA, Fuhrman BP, Wilkinson JD (1987) Efficiency of intensive care: a comparative analysis of eight pediatric intensive care units. JAMA 258: 1481–1486
3. Rapoport J, Teres D, Lemeshow S, Gehlbach (1994) A method for assessing the clinical performance of intensive care units: a multicenter inception cohort study. Crit Care Med 22: 1385–1391
4. Boyd O, Grounds RM (1993) Physiologic scoring systems and audit. Lancet 341: 1573–1574
5. Pollack MM, Ruttimann UE, Getson PR and Members of the Multi-Institutional Study Group (1987) Accurate prediction of the outcome of pediatric intensive care. N Engl J Med 316: 134–139
6. Knaus WA, Wagner DP, Draper EA, Zimmerman JE, Bergner M, Bastos PG, Sirio CA, Murphy DJ, Lotring T, Damiano A, Harrell FE (1991) The APACHE III prognostic system: risk prediction of hospital mortality for critically ill hospitalized adults. Chest 100: 1619–1636
7. Lemeshow S, Teres D, Klar J, Avrunin JS, Gehlbach SH, Rappaport J (1993) Mortality probability models (MPM II) based on an international cohort of intensive care unit patients. JAMA 270: 2478–2486
8. Le Gall JR, Lemeshow S, Saulnier F (1993) A new simplified acute physiology score (SAPS II) based on a European/North American multicenter study. JAMA 270: 2957–2963
9. Shortell SM, Zimmerman JE, Rousseau DM, Gillies RR, Wagner DP, Draper EA, Knaus WA, Duffy J (1994) The performance of intensive care units: does good management make a difference? Med Care 32: 508–525
10. Zimmerman JE, Shortell SM, Rousseau DM, Duffy J, Gillies RR, Knaus WA, Devers K, Wagner DP, Draper EA (1993) Improving intensive care: observations based on organizational case studies in nine intensive care units: a prospective multicenter study. Crit Care Med 21: 1443–1451
11. Boyd O, Grounds M (1994) Can standardized mortality ratio be used to compare quality of intensive care unit performance Crit Care Med 22: 1706
12. Bastos PG, Sun X, Wagner DP, Knaus WA, Zimmerman JE and The Brazil APACHE III Study Group (1996) Application of the APACHE III prognostic system in Brazilian intensive care units: a prospective multicenter study. Intensive Care Med 22: 564–570
13. Members of the Consensus Panel (1983) NIH consensus development conference on critical care. Crit Care Med 11: 466–469
14. Joint Commission for Accreditation of Health Care Organizations (1988) Accreditation manual for hospitals. JCAHCO, Chicago
15. Task Force on Guidelines, Society of Critical Care Medicine (1988) Recommendations for services and personnel for delivery of care in a critical care setting. Crit Care Med 16: 809–811
16. Banta HD (1986) Medical technology and developing countries: the case of Brazil. Int J Health Serv 16: 363–373
17. Perry S, Marx ES (1992) What technologies for health care in developing countries? World Health Forum 13: 356–361
18. Frisho-Lima P, Gurman G, Schapira A, Porath A (1994) Rationing critical care – what happens to patients who are not admitted? Theor Surg 9: 208–211
19. Bennett CL, Garfinkle JB, Greenfield S, Draper D, Rogers W, Mathews WC, Kanouse DE (1989) The relation between hospital experience and in-hospital mortality for patients with AIDS-related PCP. JAMA 261: 2975–2979
20. Farley DE, Ozminkowski RJ (1992) Volume–outcome relationships and in-hospital mortality: the effect of changes in volume over time. Med Care 30: 77–94
21. Hannan EL, Kilburn H, Bernard H, O'Donnell JF, Lukacik G, Shields EP (1991) Coronary artery bypass surgery: the relationship between inhospital mortality rate and surgical volume after controlling for clinical risk factors. Med Care 29: 1094–1107
22. Park RE, Brook RH, Kosecoff J, Keesey J, Rubenstein L, Keeler E (1990) Explaining variations in hospital death rates: randomness, severity of illness, quality of care. JAMA 264: 484–490
23. Luft HS, Garnick DW, Mark PH, Peltzman DJ, Phibbs CS, Lichtenberg E, McPhee SJ (1990) Does quality influence choice of hospital. JAMA 163: 2899–2906.
24. Knaus WA (1992) Methodologic studies on APACHE III: technical report. Agency for Health Care Policy and Research Grant No. HS05787, Washington, DC