Anaesth Intensive Care 2010; 38: 703-709

Changes in case-mix and outcomes of critically ill patients in an Australian tertiary intensive care unit

T. A. WILLIAMS*, K. M. HO†, G. J. DOBB‡, J. C. FINN§, M. W. KNUIMAN**, S. A. R. WEBB††
Intensive Care Unit, Royal Perth Hospital, Perth, Western Australia, Australia

SUMMARY

Critical care service is expensive and the demand for such service is increasing in many developed countries. This study aimed to assess the changes in characteristics of critically ill patients and their effect on long-term outcome. This cohort study utilised linked data between the intensive care unit database and state-wide morbidity and mortality databases. Logistic and Cox regression was used to examine hospital survival and five-year survival of 22,298 intensive care unit patients, respectively. There was a significant increase in age, severity of illness and Charlson Comorbidity Index of the patients over a 16-year study period. Although hospital mortality and median length of intensive care unit and hospital stay remained unchanged, one- and five-year survival had significantly improved with time, after adjusting for age, gender, severity of illness, organ failure, comorbidity, 'new' cancer and diagnostic group. Stratified analyses showed that the improvement in five-year survival was particularly strong among patients admitted after cardiac surgery (P=0.001). In conclusion, although critical care service is increasingly being provided to patients with a higher severity of acute and chronic illnesses, long-term survival outcome has improved with time suggesting that critical care service may still be cost-effectiveness despite the changes in case-mix.

Key Words: intensive care, critical care, long-term outcomes, survival, temporal

Critical service is expensive and increasingly being provided to patients who are older and with a higher acuity of acute illness[1-4]. The changes in characteristics of the patients have potential effect on outcomes of the patients and critical service as a whole, because many older patients also have more comorbidities and with less physiological reserve to allow recovery from their critical illness[5,6].

Data on changes in survival outcome of critically ill patients over time are conflicting: studies showing improvement[2,4,7] and deterioration[8] in hospital mortality have both been reported. Although evidence suggests that hospital mortality for patients treated in intensive care units (ICU) in Australia and New Zealand has improved with time[1], whether this improvement in hospital mortality continues after hospital discharge remains uncertain. Furthermore, evidence suggests that comorbidity has a profound effect on long-term survival of hospitalised patients[9]. Previous studies on outcomes of critically ill patients are limited in their adjustment for comorbidity and as such, residual confounding could have affected the results of previous studies.

We hypothesised that the characteristics of critically ill patients have changed significantly with time and survival outcomes may have improved with advances in critical care services. We aimed to evaluate the temporal changes in characteristics of critically ill patients in a tertiary ICU in Western Australia and assess whether there was an improvement in hospital mortality and long-term survival after hospital discharge.

* Ph.D., Grad.Dip., Clin.Epi., M.Hlth.Sci. (Res), B.N., I.C.U. Cert., R.N., Nurse Researcher, Intensive Care Unit, Royal Perth Hospital and Schools of Population Health and Medicine and Pharmacology, University of Western Australia.
† Ph.D., M.P.H., M.B., B.S., M.R.C.P., F.A.N.Z.C.A., F.J.F.I.C.M., Staff Specialist Intensivist.
‡ B.Sc. (Hons), M.B., B.S., M.R.C.P. (UK), F.R.C.A., F.A.N.Z.C.A., F.F.I.C.A.N.Z.C.A., F.J.F.I.C.M., F.A.M.A., Head of Department and Staff Specialist Intensivist, Intensive Care Unit, Royal Perth Hospital and School of Medicine and Pharmacology, University of Western Australia.
§ Ph.D., M.Ed.Stud., Grad.Dip.PH., B.Sc., Dip.A.P.P.Sc. (Nsg), I.C.U. Cert., R.N., R.M., Professor (Research), School of Nursing and Midwifery, University of South Australia, Adelaide, South Australia.
**Ph.D., B.Sc. (Hons), Professor Biostatistician, School of Population Health, University of Western Australia.
††M.B., B.S., Ph.D., M.P.H., F.R.A.C.P., F.J.F.I.C.M., Staff Specialist Intensivist, Intensive Care Unit, Royal Perth Hospital and Schools of Population Health and Medicine and Pharmacology, University of Western Australia.

Address for correspondence: Dr T. A. Williams, Intensive Care Unit, Royal Perth Hospital, Wellington Street, Perth, WA 6000.

Accepted for publication on February 12, 2010.

MATERIALS AND METHODS

Setting and participants

The ICU cohort has been described in detail in our previous publications when determinants of long-term survival of critically ill patients were evaluated[9,10]. The 22-bed adult tertiary general ICU was a 'closed ICU' with all admission and discharge decisions managed by a team of full-time intensivists during the study period.

The ICU clinical data, collected prospectively by the duty intensivists between 1987 and 2002, were linked to the Western Australian (WA) Hospital Morbidity Data System, which contains data for all public and private hospital separations and the WA Death Register[11], which contains records of all deaths in the State. All patients were assumed to be alive at 31 December 2003 if there was no record of their death. The loss to follow-up was likely to be low because of low emigration rate of WA[12] and deaths out of the state have been shown to be less than 2%[12].

In this study, only patients admitted to the ICU for the first time in the hospital morbidity database were included. This first ICU admission was defined as the index admission. Patients who were younger than 16 years or non-residents of WA were excluded. A small number of patients (n=45) whose data did not achieve complete linkage were also excluded. This study was approved by the Institutional Ethics Committees.

Outcomes and predictors of interest

The primary outcomes were: 1) hospital mortality; 2) proportion of the patients who survived to hospital discharge, who were still alive at one year; and 3) proportion of the patients who were alive at one year who were still alive at five years. The ICU and hospital length of stay were the total of number of calendar days from date of admission until day of discharge, inclusive of both days.

The secondary outcomes and predictors assessed included age, gender, admission diagnoses, severity of acute illness, organ failure and comorbidity[10,13]. The patient's primary ICU admission diagnosis was classified according to the International Classification of Diseases (ICD-9-CM) and was grouped as one of nine mutually exclusive categories: cardiac surgery, trauma, sepsis, cardiac arrest, non-traumatic brain condition (surgical and non-surgical), vascular conditions (surgical and non-surgical), drug overdose/poisoning, other (non-vascular, non-neurological, non-cardiac) surgery and other medical conditions[10]. The type of ICU admission was classified as elective surgical, non-elective surgical or medical emergencies. Severity of illness was estimated using the acute physiology score component of the Acute Physiology and Chronic Health Evaluation II score[14]. The maximum number of organ failures that occurred on any single ICU day was defined as the 'peak number of organ failures'. The definitions used for the organ failures have been published elsewhere[10]. Comorbidity prior to hospitalisation for the index admission was estimated using the Charlson Comorbidity Index[15], a weighted index that takes into account the number and severity of 17 pre-existing diseases to produce a comorbidity score for each patient. It has been adapted for use with administrative data[16]. Patients with no prior hospital admissions were coded as having a comorbidity score of zero. 'New cancer' was defined as malignant conditions that were diagnosed during the hospitalisation in which the first ICU admission occurred, identified from the Hospital Morbidity Data System and excluded patients with cancer comorbidities included in the Charlson Comorbidity Index.

Statistical analysis

Patient characteristics were presented as means and standard deviation (SD) and compared using Student's t-tests for normally distributed data and non-parametric tests for non-normally distributed data. The year of index admission was categorised into four eras (1987 to 1990, 1991 to 1994, 1995 to 1998, 1999 to 2002). Logistic regression with Cox proportional hazards regression was used to assess the effect of year era of admission on hospital mortality and one- and five-year survival respectively, after adjusting for age, gender, severity of illness, organ failure, comorbidity, 'new cancer' and diagnostic group. Proportional hazards assumption of the continuous predictors and also the non-linear relationship between survival and the continuous predictors have been assessed in our previous studies[17,18]. Survival data were censored on 31 December 2003.

Stratified analyses of patients admitted after cardiac surgery and patients admitted with other conditions were performed because patients admitted after cardiac surgery were more homogeneous and survival for these patients could be very different from other diagnostic groups[8,9,19,20]. Continuous variables that did not meet the linearity assumption were entered into models with their significant squared terms to allow non-linear association modelled. Data were analysed using SPSS, v17.0 (SPSS; Chicago, IL, USA). Two-sided comparisons with 95% confidence intervals (CI) were used and P values less than 0.05 were considered statistically significant.

RESULTS

A total of 22,980 critically ill patients over a 16-year study period were considered. There was a significant change in admission diagnosis, age, severity of acute illness and comorbidity of the patients during the study period. The number of admissions for patients undergoing cardiac surgery decreased from 732 in 1987 to 284 in 2002. In contrast, there was an increase in admissions due to other indications (Figure 1). Overall, the total number of admissions per year decreased from 1604 in 1987 to 1241 in 2002 (Figure 1). The most notable were an increase in non-traumatic brain conditions from 1.4% in 1987 to 15.1% in 2002, a three-fold increase in sepsis (4.3% in 1987 to 13.6% in 2002) and a two-fold increase in trauma (7.5% in 1987 to 14.8% in 2002) and other surgery (3.7% in 1987 to 8.5% in 2002). The proportion of patients who had 'new cancer' increased four-fold over the study period from 1.1% of patients in 1987 to 4.8% in 2002 (P <0.001 for trend). There was a concomitant decrease in admissions for other medical conditions, from 18.6% in 1987 to 8.4% in 2002.

The mean age for patients admitted for conditions other than cardiac surgery has been steady over time, but there has been an increase has been the proportion of patients in the youngest and oldest age groups, with a concomitant decrease in the other groups. While the proportion of patients aged '75+' years increased from 8.5% in 1987 to 11.1% in 2002 for those admitted to ICU with conditions other than cardiac surgery, there was a four-fold increase in the proportion of older patients admitted after cardiac surgery, 5.4% in 1987 to 24.3% in 2002 (P <0.001 for trend).

There was a significant increase in severity of acute illness (mean acute physical score 7.8 [SD 5.5] in 1987 and 8.0 [SD 5.8] in 2002; P=0.001 for trend), maximum number of organ failure (0.83 [SD 1.3] in 1987, increasing to 1.39 [SD 1.5] in 2002; P <0.001 for trend), and comorbidity (mean Charlson Comorbidity Index was 0.75 [SD 1.2] in 1987, increasing to 1.34 [SD 2.1] in 2002; P <0.001 for trend) during the study period (Figure 2). Despite a significant increase in age, comorbidity, and severity of acute illness of the critically ill patients, there was no significant increase in length of stay in ICU (Figure 3).

There was a steady increase in unadjusted hospital mortality (from 9.3% in 1987 to 14.4% in 2002)

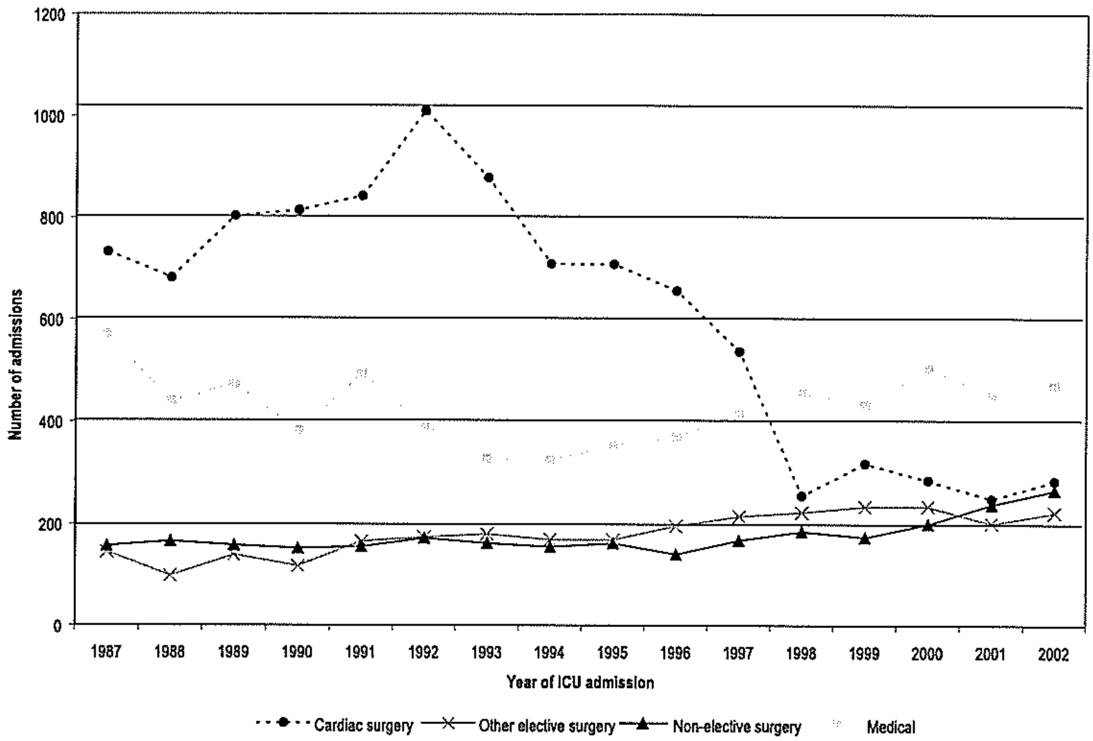

FIGURE 1: Number of admissions to the intensive care unit (ICU) per year, 1987 to 2002, for those admitted (a) after cardiac surgery, (b) after other elective surgery, (c) after non-elective surgery and (d) with medical admissions.

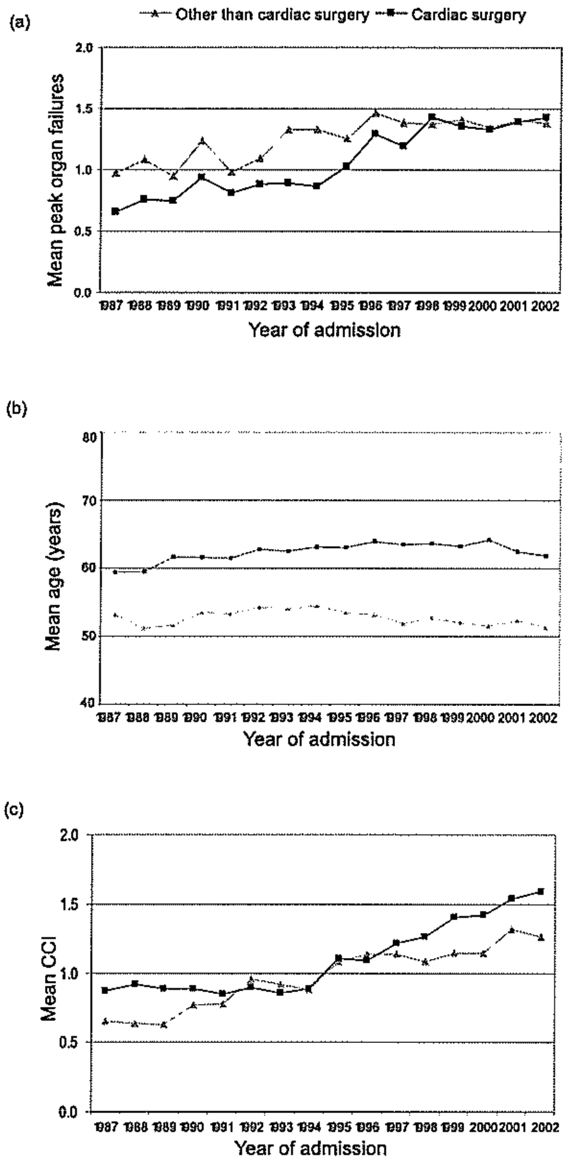

FIGURE 2: Changes in mean (a) number of peak number of organ failures, (b) age, (c) Charlson Comorbidity Index (CCI) from 1987 to 2002 for admissions to intensive care unit for conditions other than cardiac surgery and for those after cardiac surgery.

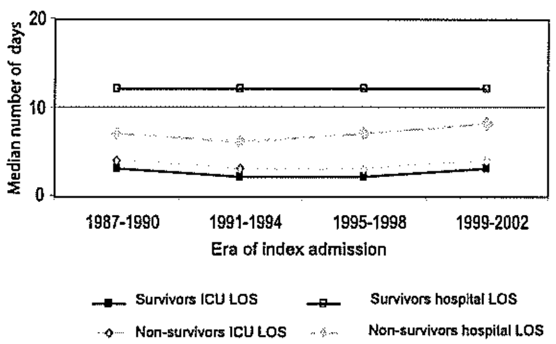

FIGURE 3: Median length of stay (LOS) in intensive care unit (ICU) hospital in different admission era.

and five-year mortality (22.6% in 1987 to 30.6% in 1998) with time. After adjustment for potential confounders, era of admission was, however, not an independent predictor of risk for in-hospital death (P=0.317, Hosmer and Lemeshow Test P <0.001 and Nagelkerke R^2 0.408), consistent across both cardiac surgical patients and other diagnoses (P=0.226 and P=0.155, respectively). Table 1 shows hospital mortality by diagnostic group and shows similar (but non-significant) results for the majority of diagnostic groups.

Considering patients who survived to hospital discharge and to one year respectively, one-year (P=0.006) and five-year (P <0.001) survival had increased over time, after adjustment for other predictors of long-term survival (Table 1). In the stratified analyses, the improvement in one- and five-year survival was most evident in patients with sepsis and cardiac surgery, respectively.

DISCUSSION

Our study confirmed some of the findings of previous studies, that there was an increase in age, comorbidity and severity of acute illness of the patients in our ICU. Despite these changes, length of stay in ICU and adjusted hospital mortality remained unchanged and long-term survival after discharge had improved.

Critical care service is expensive and the demand for such service is increasing across many developed countries. Our results have a few clinical implications. First, the age, comorbidity and severity of illness of critically ill patients admitted to the ICU are likely to continue to increase if the observed trend persists. Second, our data showed that the adjusted hospital mortality remained stable and long-term survival of our patients had improved despite an increase in complexity of the case-mix of the patients. The improvement in long-term survival of sepsis and cardiac surgery were particularly evident from our data. This was most likely due to an improvement in technological advances and efficiency of both critical care and overall healthcare services. For example, the use of angiotensin-converting-enzyme inhibitors and beta-blockers in patients with heart failure has significantly improved their long-term survival. An improvement in the survival of the general population of Western Australia may also play a role, although this is unlikely to account for the magnitude of changes we observed in this study. Without knowing the mechanisms of the improvement in long-term outcomes of critically ill patients, whether we can

TABLE 1

Effect of era of admission on adjusted (a) hospital mortality and (b) one-year survival (for patients who survive to hospital discharge) and (c) five-year survival (for patients who survived one-year), for the entire cohort, patients admitted to ICU after cardiac surgery and patients admitted to ICU with other conditions. All odds ratios or hazard ratios were referenced to the admission era 1987 to 1990.

	(a) Hospital mortality (n=22,298)				(b) One-year survival (n=19,921)				(c) Five-year survival (n=18,848)			
	OR	Upper 95% CI	Lower 95% CI	*P* value	OR	Upper 95% CI	Lower 95% CI	*P* value	OR	Upper 95% CI	Lower 95% CI	*P* value
All patients												
1987-1990	1.00	–	–	0.317*	1.00	–	–	0.006*	1.00	–	–	<0.001
1991-1994	1.03	0.89	1.19	0.699	0.94	0.79	1.11	0.462	0.81	0.72	0.91	<0.001
1995-1998	0.92	0.79	1.07	0.267	0.78	0.65	0.93	0.007	0.77	0.68	0.86	<0.001
1999-2002	0.92	0.79	1.06	0.260	0.76	0.63	0.91	0.002	–	–	–	–
Cardiac surgery												
1987-1990	1.00	–	–	0.226*	1.00	–	–	0.361*	1.00	–	–	0.001*
1991-1994	1.31	0.94	1.83	0.117	1.08	0.78	1.48	0.644	0.83	0.70	0.98	0.030
1995-1998	1.17	0.80	1.72	0.411	0.88	0.61	1.27	0.488	0.70	0.57	0.85	<0.001
1999-2002	1.53	0.99	2.37	0.058	0.74	0.47	1.17	0.203	–	–	–	–
Vascular surgery/ condition												
1987-1990	1.00	–	–	0.352*	1.00	–	–	0.066*	1.00	–	–	0.395*
1991-1994	0.66	0.41	1.07	0.095	0.95	0.59	1.53	0.841	0.95	0.72	1.24	0.689
1995-1998	0.92	0.58	1.47	0.736	0.51	0.30	0.89	0.017	0.83	0.63	1.10	0.194
1999-2002	0.78	0.47	1.30	0.339	0.90	0.54	1.51	0.694	–	–	–	–
Non-traumatic brain condition/surgery												
1987-1990	1.00	–	–	0.040*	1.00	–	–	0.624*	1.00	–	–	0.542*
1991-1994	1.75	0.94	3.27	0.080	0.68	0.25	1.87	0.452	1.03	0.42	2.53	0.950
1995-1998	1.00	0.55	1.79	0.991	0.88	0.39	1.99	0.767	0.69	0.29	1.63	0.396
1999-2002	0.81	0.47	1.39	0.445	0.69	0.32	1.52	0.358	–	–	–	–
Sepsis												
1987-1990	1.00	–	–	0.209*	1.00	–	–	0.034*	1.00	–	–	0.121*
1991-1994	0.92	0.64	1.33	0.673	0.83	0.46	1.50	0.535	0.61	0.38	0.99	0.044
1995-1998	0.81	0.57	1.15	0.241	0.51	0.28	0.92	0.026	0.84	0.55	1.30	0.435
1999-2002	0.71	0.50	1.01	0.057	0.49	0.28	0.86	0.014	–	–	–	–
Trauma												
1987-1990	1.00	–	–	0.697*	1.00	–	–	0.738*	1.00	–	–	0.171*
1991-1994	0.83	0.55	1.24	0.360	0.95	0.36	2.48	0.916	0.76	0.42	1.38	0.375
1995-1998	0.86	0.58	1.28	0.466	1.43	0.61	3.36	0.410	0.57	0.32	1.02	0.060
1999-2002	1.00	0.67	1.49	0.998	1.26	0.53	2.99	0.595	–	–	–	–
Cardiac arrest												
1987-1990	1.00	–	–	0.859*	1.00	–	–	0.040*	1.00	–	–	0.325*
1991-1994	0.92	0.56	1.51	0.742	0.51	0.21	1.25	0.143	0.83	0.43	1.62	0.583
1995-1998	1.15	0.69	1.91	0.598	0.13	0.03	0.59	0.008	0.60	0.31	1.18	0.139
1999-2002	0.97	0.58	1.62	0.904	0.84	0.34	2.03	0.692	–	–	–	–
Overdose/poisoning												
1987-1990	1.00	–	–	0.538*	1.00	–	–	0.175*	1.00	–	–	0.371*
1991-1994	0.75	0.27	2.13	0.594	1.72	0.71	4.17	0.233	1.61	0.72	3.63	0.250

TABLE 1

Effect of era of admission on adjusted (a) hospital mortality and (b) one-year survival (for patients who survive to hospital discharge) and (c) five-year survival (for patients who survived one-year), for the entire cohort, patients admitted to ICU after cardiac surgery and patients admitted to ICU with other conditions. All odds ratios or hazard ratios were referenced to the admission era 1987-1990 (continued).

	(a) Hospital mortality (n=22,298)				(b) One-year survival (n=19,921)				(c) Five-year survival (n=18,848)			
	OR	Upper 95% CI	Lower 95% CI	*P* value	OR	Upper 95% CI	Lower 95% CI	*P* value	OR	Upper 95% CI	Lower 95% CI	*P* value
1995-1998	0.53	0.19	1.48	0.227	1.66	0.72	3.84	0.235	1.66	0.79	3.48	0.183
1999-2002	0.52	0.19	1.42	0.204	0.73	0.28	1.93	0.529	-	-	-	-
Other medical condition												
1987-1990	1.00	-	-	0.399*	1.00	-	-	0.559*	1.00	-	-	0.004*
1991-1994	1.10	0.78	1.55	0.602	0.86	0.59	1.25	0.433	0.59	0.43	0.81	0.001
1995-1998	0.79	0.55	1.16	0.229	0.90	0.61	1.34	0.607	0.94	0.68	1.32	0.732
1999-2002	1.00	0.69	1.44	0.992	0.75	0.49	1.12	0.161	-	-	-	-
Other surgery												
1987-1990	1.00	-	-	0.699*	1.00	-	-	0.156*	1.00	-	-	0.986*
1991-1994	1.37	0.78	2.39	0.272	0.81	0.47	1.39	0.440	1.02	0.64	1.64	0.922
1995-1998	1.28	0.71	2.29	0.409	0.83	0.49	1.40	0.484	1.04	0.66	1.64	0.867
1999-2002	1.13	0.66	1.93	0.652	0.58	0.36	0.94	0.026	-	-	-	-

ICU=intensive care unit, OR=odds ratio, CI=confidence interval. **P* value is the overall *P* value for comparisons of all era groups.

continue to improve the long-term outcomes of critically ill patients in Australia remains uncertain. It is well known that healthcare cost increases faster than average inflation index. Our data did provide some assurance, albeit limited, that the increasing health cost of critical care was, at least in part, due to changes in case-mix of the patients and was associated with an improvement in long-term survival. Third, although our data showed that hospital mortality remained unchanged after adjusting for other predictors and the overall length of stay in hospital also remained stable, we also noted that there was an increase in crude overall hospital mortality (9 vs 14%) and also hospital length of stay of the non-survivors in the more recent admission era. These results suggested that critical care and hospital services faced an increasing pressure from the increased complexity of the critically ill patients. Although critical care service has been regarded as largely cost-effective[21], the incremental cost-effectiveness ratio of providing critical care services to patients with advanced age, severe comorbidity and acute illness remains uncertain and needs to be thoroughly evaluated.

This study has some limitations. First, this is a single-centre study and factors specific to this ICU may not be generalisable to other ICUs. Second, while quality of life is clearly important, the linked database contains no direct measurement of quality of life in patients discharged from hospital. The lack of specific health and functional status before and after the ICU admission restricts an in-depth examination of the changes in these outcomes over time. Third, although we had comprehensive data on the patient's characteristics and severity of illness, we have not been able to adjust for some specific changes in critical care systems in this study. Advances in medications and technology, improvements in ICU medical and nursing staff level and overall healthcare services might have affected our patients' outcomes. Without these specific data, the mechanism behind the improvement in long-term survival of our patients remains uncertain. Furthermore, whether this improvement was cost-effective also remains uncertain. A prospective multi-centre cost-effectiveness cohort study is needed in view of the increasing demand of such service and the increasing complexity of critically ill patients.

In conclusion, older patients with more co-morbidity and severity of acute illness were increasing in our ICU. Although their long-term survival had improved after adjusting for the increased complexity of disease, the overall unadjusted hospital and five-year survival were both decreasing. The trend we observed suggested that the demand for critical care service will increase among those with comorbidity and high acuity acute illness. This information may be important in the planning of critical care services for our ageing population in Australia.

ACKNOWLEDGEMENT

The work undertaken in this study was supported by the BUPA Foundation. Dr Williams is a National Health and Medical Research Council doctoral scholar. We also acknowledge the foresight of Drs Geoff Clarke, John Weekes, Karl Donovan and KY Lee who (in conjunction with Dr Geoffrey Dobb) established the ICU database.

REFERENCES

1. Moran J, Bristow PJ, Solomon P, George C, Hart G, for the Australian and New Zealand Intensive Care Society Database Management Committee. Mortality and length-of-stay outcomes, 1993–2003, in the binational Australian and New Zealand intensive care adult patient database. Crit Care Med 2008; 36:46-61.
2. Jakob SM, Rothen HU. Intensive care 1980-1995: change in patient characteristics, nursing workload and outcome. Intensive Care Med 1997; 23:1165-1170.
3. McLean RF, Tarshis J, Mazer CD, Szalai JP. Death in two Canadian intensive care units: institutional difference and changes over time. Crit Care Med 2000; 28:100-103.
4. Kvale R, Flaatten H. Changes in intensive care from 1987 to 1997 – has outcome improved? A single centre study. Intensive Care Med 2002; 28:1110-1116.
5. Bion JF, Bennett D. Epidemiology of intensive care medicine: supply versus demand. Br Med Bull 1999; 55:2-11.
6. Strauss MJ, LoGerfo JP, Yeltatzie JA, Temkin N, Hudson LD. Rationing of intensive care unit services. An everyday occurrence. JAMA 1986; 255:1143-1146.
7. Cook DA, Joyce CJ, Barnett RJ, Birgan SP, Playford H, Cockings JG et al. Prospective independent validation of APACHE III models in an Australian tertiary adult intensive care unit. Anaesth Intensive Care 2002; 30:308-315.
8. Needham DM, Bronskill SE, Sibbald WJ, Pronovost PJ, Laupacis A. Mechanical ventilation in Ontario, 1992-2000: incidence, survival, and hospital bed utilization of noncardiac surgery adult patients. Crit Care Med 2004; 32:1504-1509.
9. Williams T, Dobb G, Finn J, Knuiman M, Lee K, Geelhoed E et al. Determinants of long-term survival after intensive care. Crit Care Med 2008; 36:1523-1530.
10. Williams T, Dobb G, Finn J, Knuiman M, Lee K, Geelhoed E et al. Data linkage enables evaluation of long-term survival after intensive care. Anaesth Intensive Care 2006; 34:307-315.
11. Holman CD, Bass AJ, Rouse IL, Hobbs MS. Population-based linkage of health records in Western Australia: development of a health services research linked database. Aust NZ J Public Health 1999; 23:453-459.
12. Bradshaw PJ, Jamrozik K, Jelfs P, Le M. Mobile Australians: a moving target for epidemiologists. Med J Aust 2000; 172:566.
13. Ho K, Lee K, Williams T, Finn J, Knuiman M, Webb S. Comparison of Acute Physiology and Chronic Health Evaluation (APACHE) II score with organ failure scores to predict hospital mortality. Anaesthesia 2007; 62:466-473.
14. Knaus WA, Draper EA, Wagner DP, Zimmerman JE. APACHE II: a severity of disease classification system. Crit Care Med 1985; 13:818-829.
15. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987; 40:373-383.
16. Romano PS, Roos LL, Jollis JG. Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: differing perspectives. J Clin Epidemiol 1993; 46:1075-1079.
17. Ho KM, Knuiman M, Finn J, Webb SA. Estimating long-term survival of critically ill patients: the PREDICT model. PLoS One 2008; 3:3226.
18. Williams T, Ho K, Knuiman M, Finn J, Dobb G, Webb S. Effect of length of stay in intensive care unit on hospital and long-term mortality of critically ill adult patients. Br J Anaesth (accepted on 11 January 2010).
19. Behrendt CE. Acute respiratory failure in the United States: incidence and 31-day survival. Chest 2000; 118:1100-1105.
20. Kern H, Redlich U, Hotz H, von Heymann C, Grosse J, Konertz W et al. Risk factors for prolonged ventilation after cardiac surgery using APACHE II, SAPS II, and TISS: comparison of three different models. Intensive Care Med 2001; 27:407-415.
21. Ridley S, Biggam M, Stone P. A cost-benefit analysis of intensive therapy. Anaesthesia 1993; 48:14-19.