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BRIEF REPORT

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Determining the economic cost of ICU treatment: a prospective "micro-costing" study

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Abstract *Objective:* To prospectively assess the cost of patients in an adult intensive care unit (ICU) using bottom-up costing methodology and evaluate the usefulness of "severity of illness" scores in estimating ICU cost. *Methods and design:* A prospective study costing 64 consecutive admissions over a 2-month period in a mixed medical/surgical ICU. *Results:* The median daily ICU cost (interquartile range, IQR) was €2,205 (€1,932–€3,073), and the median total ICU cost (IQR) was €10,916 (€4,294–€24,091). ICU survivors had a lower median daily ICU cost at €2,164 per day, compared with €3,496 per day for ICU non-survivors ($P = 0.08$). The requirements for continuous haemodiafiltration, blood products and anti-fungal agents were associated with higher daily and overall ICU costs ($P = 0.002$). Each point increase in SAPS3 was associated with a €305 (95% CI €31–€579) increase in total ICU cost ($P = 0.029$). However, SAPS3 accounted for a small proportion of the variance in this model ($R^2 = 0.08$), limiting its usefulness as a stand-alone predictor of cost in clinical practice. A model including haemodiafiltration, blood products and anti-fungal agents explained 54% of the variance in total ICU cost. *Conclusion:* This bottom-up costing study highlighted the considerable individual variation in costs between ICU patients and identified the major factors contributing to cost. As the requirement for expensive interventions was the main driver for ICU cost, "severity of illness" scores may not be useful as stand-alone predictors of cost in the ICU.

Abbreviations

APACHE II	Acute Physiology and Chronic Health Evaluation Score II
CI	Confidence interval
CT	Computed tomography scan
CXR	Chest X-ray
FFP	Fresh frozen plasma
ICU	Intensive care unit
IQR	Interquartile range
MRI	Magnetic resonance imaging
NICE	National Institute for Clinical Excellence
NIV	Non-invasive ventilation
SAPS 3	Simplified Acute Physiology Score 3
SD	Standard deviation
SOFA	Sequential Organ Failure Assessment Score
U/S	Ultrasound scan

Introduction

Intensive care is a high-cost speciality. Critically ill patients require therapies that vary widely in type, duration and cost. Reliable data from individual patients will allow a comprehensive understanding of cost drivers. Many studies evaluating patient cost and cost–effectiveness in the ICU focus on costs averaged across all patients and do not address individual patient-specific cost [1–9].

In order to prospectively identify individual patient costs associated with an expensive ICU stay, we performed a prospective bottom-up or "micro-costing" study, in which the costs were determined on an individual patient basis. Furthermore, the relationship between ICU cost and "severity of illness" scores on admission was examined.

Methods

Sixty-four consecutive patients were admitted to our nine-bed medical/surgical University Teaching Hospital adult ICU during a 2-month study period. In 2008, the mean day 1 SOFA score was 7.5 and APACHEII was 19, SMR (ICU) 0.6 and occupancy 104%. Demographic, clinical and outcome data were prospectively collected on all studied patients.

Patients' resource utilization was identified prospectively by a combination of a daily review of medical notes and prescriptions and also bedside checklists that were contemporaneously completed by the bedside nurse and verified by the authors.

Fixed costs included capital costs—the purchase and maintenance of equipment and buildings—and non-clinical support services such as hospital administration and catering. Fixed costs were apportioned proportionate to the ICU floor area within the hospital. Nursing staff consisted of a unit manager, four associate managers, a patient care coordinator, three clinical instructors and bedside nurses. Nurse:patient dependency was 1:1. Medical staff included an ICU attending physician with two residents (day-time) or an off-site ICU attending physician with one resident (on-call). Additional staff included a ward clerk, secretary, pharmacist, dietician and physiotherapists. Semi-fixed costs included staffing costs obtained from the human resources department. Marginal costs were the costs of the patient's treatment. Laboratory investigation and diagnostic imaging costs were calculated on a per procedure basis, taking labour, reagents, contrast and capital equipment into account. Radiology costs per procedure are apportioned into work units [10]. The hospital pharmacy supplied drug costs. The cost of ICU equipment was calculated using the Hospital Equipment Control System (HECS) from the European Care Research Institute (ECRI).

Table 1 Patient demographics and admission diagnosis

$n = 64$	n (%) or median (IQR)
Age (years)	58.5 (45.8–69)
Male sex	42 (66%)
Severe co-morbid disease	26 (41%)
Pre-existing chronic renal replacement therapy	4 (6%)
Non-operative patients	42 (66%)
Operative patients	22 (34%)
APACHE II score	19.0 (10.25–24.0)
SAPS 3 score	69 (52–102)
Day 1 SOFA score	7 (5–11)
ICU length of stay	2.9 (1.2–9.0)
ICU mortality	17 (26%)
Diagnosis on admission to ICU	
Respiratory	
Pulmonary sepsis	5 (8%)
Asthma	2 (3%)
COPD	2 (3%)
Other	4 (6%)
Sepsis (non-pulmonary)	10 (16%)
Gastrointestinal	
Gastrointestinal haemorrhage	4 (6%)
Other gastrointestinal pathology	3 (5%)
Cardiovascular	
Cardiac arrest	6 (9%)
Other cardiac pathology	6 (9%)
Post-operative	
Gastrointestinal surgery	7 (11%)
Vascular surgery	3 (5%)
Neurological-intracranial haemorrhage	6 (9%)
Others	4 (6%)
ICU interventions	
Mechanically ventilated	49 (76%)
Inotropes	34 (53%)
Renal replacement therapy	17 (27%)
Use of blood products	
Red cells	23 (36%)
Platelets	11 (17%)
FFP	13 (20%)
Cryoprecipitate	11 (17%)
Antibiotic therapy	53 (83%)
Antifungal therapy	22 (34%)
Enteral or parenteral nutrition therapy	33 (52%)

Statistical analysis was performed using GraphPad Prism 5.0 (GraphPad, San Diego, CA) and SPSS 11.0 (SPSS, Chicago, IL). Non-parametric data were compared using Mann–Whitney U or Kruskal–Wallis tests as appropriate and are presented as medians (IQR). The relative contribution of individual variables to ICU cost was explored using univariate analysis, linear or logistic regression, as appropriate. Our binomial regression model compared the most expensive 1/3 with the least expensive 2/3 of the population, allowing a clinically meaningful comparison while maintaining sufficient numbers in each group for regression analysis. Only one ICU score (SAPS3) was used in this model, due to high multicollinearity among SAPS3, APACHEII and SOFA. $P < 0.05$ was taken to represent statistical significance.

Table 2 Itemised ICU costs

Investigations	Total cost (€)	Percentage of total cost	Cost per bed day (€)
Radiology			
Portable CXR	77,682	7.2	157.89
CT[a]	9,203	0.9	18.71
U/S[b]	2,562	0.2	5.21
MR[c]	2,618	0.2	5.32
Laboratory			
Haematology	36,456	3.4	74.10
Biochemistry	49,647	4.6	100.91
Microbiology	15,107	1.4	30.71
Consumables			
Blood products			
Red cells[d]	33,176	3.1	67.43
Platelets[e]	51,600	4.8	104.88
FFP	5,888	0.5	11.97
Cryoprecipitate	14,756	1.4	29.99
Renal replacement therapy			
Dialysis fluids[f]	28,952	2.7	58.85
Line sets	19,090	1.8	38.80
Drugs			
Vasopressors	4,398	0.4	8.94
Sedatives	6,304	0.6	12.81
Proton pump inhibitors	2,482	0.2	5.04
Epoprostenol (*Flolan*®)	5,640	0.5	11.46
Fluids			
Colloids	728	0.1	1.48
Crystalloids	4,581	0.4	9.31
Anti-bacterials	55,193	5.1	112.18
Anti-fungals[g]	94,959	8.8	193.01
Disposables			
Miscellaneous	4,335	0.4	8.81
Dressings	1,945	0.2	3.95
Intravenous lines and giving sets	13,950	1.3	28.35
Feeds			
Parenteral[h]	7,125	0.7	14.48
Enteral	5,759	0.5	11.71
Ventilation (incl. circuits, masks, NIV)	9,241	0.9	18.78
Salaries			
Nursing[i]	282,408	26.2	574.00
Medical staff[i]	188,928	17.5	384.00
Professions allied to medicine[i]	29,520	2.7	60.00
Non ICU Costs			
Nursing administration	6,519	0.6	13.25
Maintenance	2,228	0.2	4.53
Catering	964	0.1	1.96
Laundry	546	0.1	1.11
General administration	3,950	0.4	8.03
Total	1,078,440	100	

Notes: To enable comparison, indicative unit or salary costs are given below
[a] €240–400 per procedure, [b] €270–436 per procedure, [c] €430–630 per procedure, [d] €280–600 per unit, [e] €800–1,000 per unit, [f] €312–430 per day, [g] €600–700 per day, [h] €100–150 per day, [i] Mid-scale annual basic salaries. General nurse €39,630. Clinical nurse manager (II) €55,478. Senior house officer (resident) €49,280. Consultant (attending physician) €146,000. Physiotherapist €44,801. Pharmacist €52,621

Results

Table 1 shows the baseline characteristics of the studied population. Sixty-four consecutive patients were admitted for 492 bed-days in total. Forty-one (63%) were male. The median age (IQR) was 58.5 (46.5–69) years. The median ICU length of stay (LOS) in the ICU was 2.9 days (1.2–9.0). ICU occupancy in the study period was 97%.

The median daily and total ICU costs were €2,205 (€1,932–€3,073) and €10,916 (€4,294–€24,091), respectively. Mean daily and total costs (±SD) were €2,659 (±€1,817) and €20,487 (±€24,187), respectively. The daily and total costs for the study period are shown in Table 2.

The requirement for continuous haemodiafiltration, blood products and antifungals was associated with higher

Table 3 ICU costs in patients receiving specific interventions

Variable	Intervention	No intervention	P
Daily cost	Cost (IQR)	Cost (IQR)	
Continuous haemodiafiltration ($n = 17$)	€3,180 (2,693–3,590)	€1,996 (1,850–2,290)	<0.0001
Use of anti-fungals ($n = 22$)	€2,662 (2,202–3,391)	€2,027 (1,838–2,440)	0.002
Blood products ($n = 31$)	€2,724 (2,175–3,550)	€1,973 (1,692–2,263)	<0.0001
Non-operative patients ($n = 42$)	€2,412 (1,967–3,391)	€2,026 (1,838–2,297)	0.02
Total cost			
Continuous haemodialysis ($n = 17$)	€42,798 (13,985–67,327)	€7,220 (3,983–17,552)	<0.0001
Use of anti-fungals ($n = 22$)	€31,677 (14,988–58,006)	€6,244 (3,796–13,564)	<0.0001
Blood products ($n = 31$)	€22,188 (10,884–41,935)	€4,974 (3,625–11,426)	<0.0001
Non-operative patients ($n = 42$)	€12,371 (4,974–31,179)	€8,540 (3,760–22,187)	0.22
Independent predictors of an expensive ICU stay (≥66 centile of daily ICU cost)			
Variable	P	OR	95% CI
Continuous haemodiafiltration	<0.0001	37	5.5–247
Provision of blood and blood products	0.01	9.2	1.7–51

Use of antifungals, death in the ICU, ICU length of stay, the presence of severe co-morbid disease and SAPS III score were not significant in this model

ICU costs, shown in Table 3. On multivariate analysis, continuous haemodiafiltration [$P < 0.0001$, odds ratio (OR) 37, 95% confidence interval (CI) 5.5–247] and the requirement for blood products ($P = 0.01$; OR 9.2; 95% CI 1.7–51) were independent risk factors for more expensive daily ICU costs. The mean daily cost of continuous haemodiafiltration was €570 and antifungal therapy €700.

Figure 1 compares the median daily costs of survivors and non-survivors. The median LOS of survivors was 3.3 days (1.2–10.8) and non-survivors 1.9 (1.1–5.7). Non-survivors tended to be more expensive than survivors on a daily basis ($P = 0.08$). Non-survivor care also became more expensive as time went on, although small numbers limit the interpretation of these data.

Linear regression was used to determine if a linear relationship existed between disease severity scores and ICU cost. On first analysis, APACHEII ($P = 0.03$) and day 1 SOFA ($P = 0.005$) had statistically significant linear relationships with daily ICU cost. Day 1 SOFA ($P = 0.02$) and SAPS3 ($P = 0.03$) had statistically significant linear relationships with total cost. However, APACHEII and SOFA were strongly affected by one outlier in daily cost and two outliers in total cost. Daily SOFA scores did not have a consistent relationship with daily cost and were also affected by outliers. The linear association between SAPS3 and total cost persisted when outliers were removed ($P = 0.03$): total ICU cost increased by €305 (95% CI €31–€579) for each point increase in SAPS 3, as illustrated in Fig. 2a.

Patient cost is driven by the requirement for expensive interventions, especially haemodiafiltration, blood products and antifungals. When patients were stratified according to requirements for these three interventions, total cost increased significantly with the need for additional ICU interventions ($P < 0.0001$), which are shown in Fig. 2b. A regression model including these three

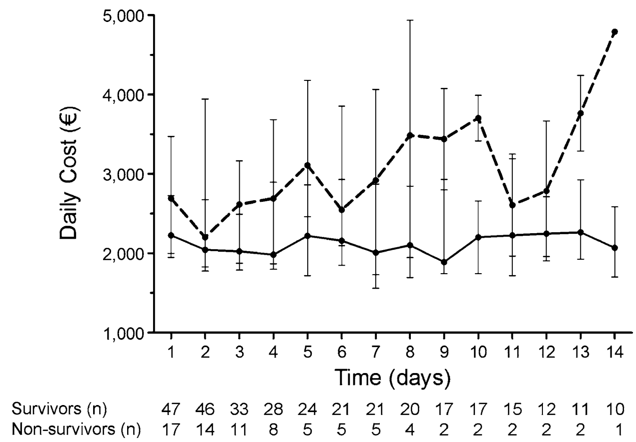

Fig. 1 Median daily ICU costs in survivors and non-survivors. Error bars represent the interquartile range for each data point. Survivors are represented by the *continuous line*. Non-survivors are represented by the *dotted line*

markers of ICU expense accounted for 54% of the variance in total cost. The addition of LOS into this model accounted for 92% of the variance in total cost.

Discussion

This study shows the median daily and total ICU cost established by micro-costing. Even though non-survivors cost more on a daily basis, survivors and non-survivors were comparable in terms of overall resource utilisation due to survivors' longer LOS.

Fixed costs including salaries account for 51% of ICU cost. The main driver of patient marginal cost in this study is the requirement for "expensive" interventions, specifically dialysis, blood products and antifungal treatment.

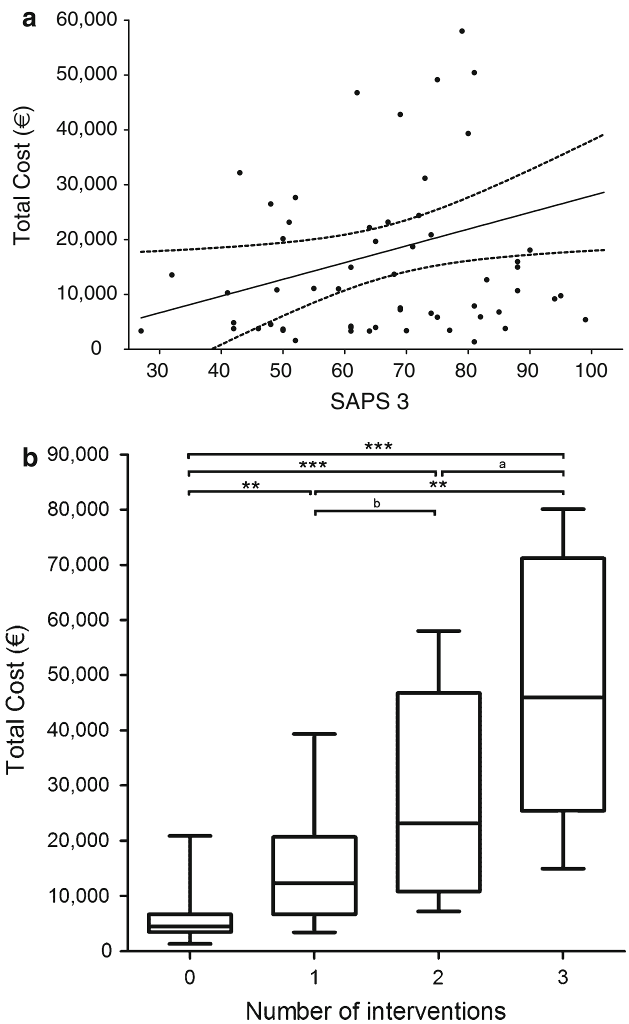

Fig. 2 **a** Linear regression of total ICU cost on SAPS 3 scores. Regression line and 95% confidence band of the regression line are shown; $P = 0.03$; $R^2 = 0.08$. **b** Total ICU cost stratified according to the number of "expensive" ICU interventions required per patient—dialysis, blood products and antifungal treatment; $P < 0.0001$. **b** Total ICU cost stratified according to the number of "expensive" ICU interventions required per patient—dialysis, blood products and antifungal treatment; Kruskal–Wallis test $P < 0.0001$. $^{**}P = 0.001$; $^{***}P < 0.0001$; **a** $P = 0.05$; **b** $P = 0.08$

Even though a statistically significant relationship between total ICU cost and SAPS3 was seen, this failed to explain the majority of variance in a regression model ($R^2 = 0.08$). The requirement for expensive treatments better explains the variance in total cost than SAPS3 alone (R^2 of 0.54). Moreover, adding LOS to this model improves its fit considerably ($R^2 = 0.92$). Although staffing costs are perceived as the main element of "global" ICU cost, our method identifies specific technological interventions as key contributors to the cost of caring for the sickest patient.

A recent top-down study by Sznajder of seven ICUs in Paris found that the mean total cost of an ICU stay was US$14,130 [11]. Chaix found a mean total cost per ICU stay of £6,279 [12]. Heyland computed a mean ICU cost per day of Can$1,565 [13]. Recently, the International Programme For Resource Use in Critical Care (IPOC), which utilised the top-down approach, estimated mean cost per patient day in the UK to be $1,512, and $934 in France [14]. Increased semi-fixed and marginal costs have been associated with University ICUs due to the specialised technology and funding for tutors and research staff [15].

Cost assessment becomes more useful with increased ICU survival. Stakeholders need to know what value they are getting for ICU expenditure; therefore, indices such as quality-adjusted life year (QALY) are becoming more important. The UK National Institute for Clinical Excellence (NICE) has adopted a cost effectiveness threshold range of £20,000 (€29,500; $40,000) to £30,000 per QALY gained. While the NICE does not accept or reject health-care technologies on cost-effectiveness grounds alone [16–18], it is undoubtedly a major deciding factor [19]. It is important to compare the cost utility of ICUs with other therapies, e.g., the unit cost per QALY of hip replacements is £1,520, coronary artery by-pass grafting £2,700, breast cancer treatment £7,460 and continuous ambulatory peritoneal dialysis £25,630 [20]. In the study by Sznajder the incremental cost-utility ratio was US$4,100 per quality-adjusted life-year saved in ICU. These data suggest that ICU costs lie within the range currently considered acceptable.

This study has a number of limitations. While we adopted a strict microcosting approach to determine marginal costs, supporting services were apportioned. Because the focus of interest of this study was the itemised, precise cost associated with more complex care, the study did not address costs once patients left ICU. Due to the labour-intensive nature of microcosting, the sample size was necessarily small. In addition the relative importance of the interventions described above may vary with case mix and other local factors.

In conclusion, our study demonstrates a method for estimating the current median and itemised total costs of intensive care in Ireland using micro-costing. As expected, ICU costs are driven both by (1) the cost of standard care common to all and (2) several costly interventions delivered to patient subgroups. Expensive cost-driving interventions, such as, haemodiafiltration, antifungals and blood products, may be more useful for identifying "expensive" patients than severity of illness scores. Our findings suggest that estimating cost effectiveness using a global approach may not have general applicability.

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Conflict of interest statement None

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