Performance determinants and flexible ICU organisation

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We faced some of the most important aspects of the problem of the appropriateness of ICU resources use, that are the relationship between volume of activity and mortality, the analysis of cost-effectiveness in intensive care medicine, and the monitoring of the human resource use in ICU. For this aim three different surveys were utilized: one at European level, the second at country level and, third, a regional survey. After developing a new measure of volume called "high-risk volume", we explored the relationship between outcome and volume, founding that such association was very strong (from 3 to 17–19% decrease in ICU/hospital mortality every five extra high-risk patients treated per bed per year), and that an occupancy rate larger than 80% was associated with higher mortality. Therefore, patients in all levels of risk are better treated in high-risk volume ICUs with a reasonable occupancy rate.

Analysing cost-effectiveness in intensive care medicine using a national case-mix categorized in different diagnostic groups, we identified brain haemorrhage, ALI/ARDS and surgical unscheduled patients as users a high volume of monetary resources less efficiently, while the scheduled abdominal surgery patients admitted to receive intensive care and patients on the ICU for minor organ support made the best use of the fewer resources spent.

Finally, we designed a new approach to measure the rate and appropriateness of nursing resource use in ICU on a daily basis. Testing this approach on a group of general non-specialist ICUs, we found that the method was powerful enough to adequately distinguish between "over" and "under-utilization" and to identify all the theoretical scenarios of nurse/resource utilization.

Key words: **Intesive care unitsresource use - Volume of activity - Cost-effectiveness.**

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The problem of the best use of the scarce available resources in intensive care can be faced from many points of view.

In the last years we studied some of these aspects using three different surveys: the European survey of the EURICUS study, which was very wide and involved 89 Intensive Care Units (ICUs), the national one from GiViTI (49 ICUs) and a regional one (32 ICUs).

With the first case mix we developed an instrument useful for classify the complexity of the supplied treatment,[1] and with the help of this we investigated the additional effect on ICU and hospital mortality of both, the level of activity and the ICU occupancy rate.[2]

With the second case mix we studied the different possibilities of limiting variable costs according to the level of complexity/intensity of treatment delivered to the patient and the pathology which determined that treatment.[3]

With the third case mix we proposed a method useful for describing and monitoring the level and the appropriateness of ICU utilization.[4]

Volume of activity and mortality

In health care, experience and skill are gained and maintained by activity (volume of work). This is often inversely related to mortality as for severe trauma,[5] for single surgical or medical conditions [6-13] and for paediatric ICUs.[14] Such an association is controversial in neonatal ICUs. Volume, a crude proxy indicator of quality of care,[15-17] is easier to quantify than experience. Moreover, ICU activity does not refer to single diseases or procedures. It rather consists of a collection of different interventions in patients with different diagnoses. We therefore explored the relationship between outcome and volume after developing a measure of volume of activity adjusted for adverse risk factors of critically ill patients. We analyzed data gathered for the European ICUs-I (EURICUS-I) study by the Foundation for Research on Intensive Care in Europe on all new consecutive admissions to 89 adult ICUs in 12 European countries.[18] We designed a new measure of volume called high-risk volume (high-risk patient/bed/year) to test the hypothesis that skill is more easily gained and maintained by treating more severely ill patients. The cohort of high-risk patients included all patients who stayed more than 47 h on the ICU (in order to exclude patients with a quick recovery—too healthy—or an early death—too severe) and whose Simplified Acute Physiological Score II (SAPS II) [19] was above the median score for the overall patient population with a LOS above 47 h (in order to exclude patients with a low expected mortality rate). The association between high-risk volume of activity and mortality of the whole patient population after adjustment for all the others determinants of mortality was very strong: the clinical relevance of this association is six times larger than using total (all patients/bed/year) volume (from a 3% to a 19-17% decrease in ICU/hospital mortality every five extra high-risk patients treated per bed per year). In addition, the overall ICU occupancy rate was also identified as an explicative variable: occupancy larger than the best fit value (80% in this database) was associated with higher mortality, as shown in neonatal [20] and adult ICUs [21] and recently was suggested for medical errors.[22] The numerical value of the best fit found, not too far from the ideal figure of 85%,[18] depends on ICU size (several small units in this database [18]) and also on the possible necessity of increasing the availability of nurses when complex patients are admitted. Nevertheless, a detrimental effect of occupancy rate increase on performance, probably due to staff overwork, is suggested. Our findings do suggest that treating at least 14 high-risk patients per bed and per year may be a prerequisite for higher quality of care for critically ill patients. Our results therefore support the notion that patients in all levels of risk are better treated in high-risk volume ICUs with a reasonable occupancy rate. A notion that initiates the regional organization of intensive care medicine may need to be taken into account.

Limiting costs. Cost-effectiveness analysis in intensive care medicine

We planned an observational, prospective study to assess the performance of intensive care medicine in predefined diagnostic groups stratified according to the level of care provided.[3] This study analysed only, using the "bottom up" approach, variable costs,[25] *i.e.* the ones mostly dependent on pathology and intensity of treatment (drugs, diets, infusions and blood products, laboratory and imaging tests, surgical interventions, therapeutic procedures, consultations from other departments, disposable, and special beds). Cost-effectiveness analysis attempts to provide tools for decision making in circumstances where resources are scarce.

In the GiViTI ICU-cost project each ICU had to enrol two cohorts of patients with ICU stay >48 hours selected among the following most prevalent diagnosis groups in Italian ICUs [trauma, brain trauma, non-traumatic brain haemorrhage, stroke, acute exacerbation of chronic obstructive pulmonary disease (COPD), acute lung injury/acute respiratory distress syndrome (ALI/ARDS), heart failure, scheduled or unscheduled abdominal surgery],[23] as decided by the Coordinating Centre.

We classified as High Level of Care (HLC) or Low Level of Care (LLC) the intensity of daily medical treatment in the ICU.[1, 24] Patients who spent the entire ICU stay in LLC (less critically ill) were analyzed separately from those with at least 1 HLC day.

As inferred by multivariate regression one can achieve the containment of costs by reducing LOS (in stroke, abdominal surgery and LLC) or by accurately weighing the intensity of care (HLC days) in trauma, brain trauma, brain haemorrhage, acute on COPD, ALI/ARDS, heart failure). Accordingly, death in the ICU decreases the cost of patients who die within a short time (brain haemorrhage) or who die without organ support (LLC patients). On the contrary, death in ICU (COPD and unscheduled abdominal surgery) and in hospital (scheduled abdominal surgery) increases the variable cost when patients die with unrestricted allocation of resources.

In addition to cost-containment, we can improve the use of resource, *i.e.* the efficiency of intensive treatment. Efficiency (variable costs for hospital survivors as a percentage of the cost spent on all patients in the same group) identifies brain haemorrhage, ALI/ARDS and surgical unscheduled as the patients using a high volume of monetary-resources less efficiently, while the scheduled abdominal surgery patients admitted to receive intensive care and patients on the ICU for minor organ support [1, 24] made the best use of the fewer resources spent. At variance, we found the poorly efficient but non expensive groups of stroke and heart failure patients and the highly expensive/highly efficient groups of trauma patients with or without brain injury. Finally, acute COPD group represents the median of efficiency and costs.

Interestingly some conditions (in this study brain trauma, brain haemorrhage, stroke), show a better overall efficiency in the use of monetary resources (by 8-27%) than treatment effectiveness because the ICU cost of non-survivors (as a result of a short LOS and intensity of care) was less than that of survivors. These conditions are characterised by brain failure which is at the same time the more dramatic and the more evident (*e.g.* brain death) proof of the futility of prolonged intensive care. Hence, any improvement in the (poor) efficiency of brain haemorrhage and stroke care as well as of the (good) efficiency of brain trauma should rely on improvements in effectiveness of their specific treatments.

On the other side, we found a number of conditions (acute COPD, ALI/ARDS, heart failure) whose efficiency in the use of monetary resources was worse (by 8-11%) than their treatment effectiveness because the ICU cost for non-survivors was higher than that for survivors. Careful day by day evaluation of complexity and duration of care in poorly responding patients may improve efficiency, particularly for expensive acute COPD and ALI/ARDS patients.

Care of unscheduled abdominal surgery patients has a high ICU cost, poor effectiveness and efficiency. In this group, patients also tend to die after ICU discharge, this implies that a substantial physiological reserve was consumed during ICU stay, affecting post-ICU survival.[26] The achievement of physiological stability at the end of ICU stay, (avoiding any premature or inappropriate ward discharge), and/or improved ward care is therefore desiderable.

Furthermore, all these data underline the importance of categorizing the case-mix while dealing with ICU costs. Moreover, even if costs alone do not determine physicians' treatment decisions, cost analysis per diagnosis can contribute to the decision-making process regarding the distribution of the scarce resources.

Monitoring the human resource use

Intensive Care Units are not all equivalent. One important difference between them concerns the severity of illness of patients and consequently the complexity of treatments and use of resources. As the provision of intensive care depends mainly on the availability of nurses, figures for this resource serve as a proxy for overall resource consumption.

Historically, the nursing workload at patient level has been measured based on level of clinical assistance (TISS, TISS 28, NEMS) [27-29] resulting in cumulative points, such as 40-50 points representing 24 h of nursing workload [27, 29] or in minutes of workload (TOSS, NAS).[29, 30] Quantifying nursing workload and defining the average number of patients that a nurse can manage defines the average complexity of care required by patients under treatment. Four levels of care were first defined by the Bethesda Consensus Conference in 1981.[31] Miranda and Langrehr revised these to define three levels of intensive care,[32] and these levels were later endorsed by a task force of the European Society of Intensive Care Medicine.[33]

Recent studies have shown that use of resources in European ICUs is often inefficient. A major reason is the "waste" of nursing manpower,[34, 35] which constitutes the largest part of resources allocated to the ICU. "Waste" is measured by comparing the capacity for delivering nursing work with work actually delivered.[34] "Annual delivery" is calculated based on a therapeutic index [24] summing the scores obtained daily at patient level; "annual capacity" is derived from the total number of nurses in the ICU, taking into account the amount of work (total index score) possible in a year by one full-time nurse.[32] Originally designed for research purposes, this method is time-consuming and laborious, and therefore demands more than the normal efforts expected for management purposes in ICUs. However, assuming that such studies might enable ICU managers to monitor practice patterns and determine the rate and appropriateness of human and fixed resource use, we have designed a new approach to quantify the provision of and demand for nursing manpower on a daily basis.[4]

The approach quantifies the mean "*actual nurse assistance*" devoted to the patients over a defined period of time. Recording the number of occupied beds and classifying the use of nurses at patient level (provided level of care) is mandatory for each day of the test-period. To offer a real-time and friendly-to-use instrument for the frequent appraisal and guidance of resource-allocation in the unit, we propose only two levels of care.

We used six out of nine NEMS items [24] to define 2 grades of intensity/complexity of care at patient level.[1] The level is defined as highly-intensive/complex (HLC) if monitoring is coupled with active respiratory support, and/or multiple vasoactive drugs, or less active support of at least two organs (*e.g.* supplementary ventilatory care, single vasoactive drug, dialysis). All other combinations are classified as low-level care (LLC). HLC includes levels II and III from the classification of ICUs [32, 33] and LLC corresponds to level of care I.

Method

The instrument is devoted to medium-high level ICUs, with HLC beds sometimes used for LLC, even if only before patients are discharged from ICU.[36] It might also be used to evaluate a single organisation/performance or for benchmarking to audit several ICUs.[4]

Data can be cross-sectionally collected on certain days in the week (*e.g.* Monday, Tuesday, Thursday and Saturday) to sample the weekly patterns of the case mix during a 2-3 month-period or year to capture seasonal variations.

The application of the tool requires some basic assumptions which need to be defined at ICU level:

— the list of the equipment necessary to provide active life-support (monitoring, ventilation, titrated infusion capacity);

— the theoretical "*appropriate patient to nurse ratio*" for HLC (*e.g.* 1, or 1.5 or 2), and for LLC (*e.g.* 3). This can be defined at the unit level according to case mix, therapeutic strategies and nursing workload;

— the need for care is constant around the clock. This assumption limits the nurse to

TABLE I.—*Use of the instrument in three different ICU scenarios.*

	ICU A	ICU B	ICU C
Nurses shifts in 24 h	5	3	3
Study period: days	30	30	30
Available nursing days	150	90	90
Delivered patient treatment days	175	136	187
Actual nurse assistance	175/150 = 1.167	136/90=1.51	187/90=2.08
Delivered HLC/LLC treatment days	95/80	80/56	152/35
Theoretical appropriate patient/nurse ratios: HLC;LLC	1:1; 3:1	1:1; 3:1	2:1; 3:1
Theoretical appropriate number of nurses for HLC + LLC provided treatments	95 + 80/3 95 + 26.6 = 121.7	80 + 56/3 80 + 18.7 = 98.7	152/2 + 35/3 76 + 12 = 88
Theoretical nurse assistance	175/121.7 = 1.44	136/98.7 = 1.378	187/88 = 2.135
Nursing resource use	1.167 - 1.44 = -0.273	1.51-1.378 = + 0.133	2.08 - 2.13 = -0.05
Rate of utilization (%)	81%	109.6%	97.7%
Theoretical maximum number of HLC patient-days (all nurses devoted to HLC):	5x30x1 = 150	3x30x1 = 90	3x30x2 = 180
HLC utilization rate (%)	95/150 = 63.3%	80/90 = 88.9%	152/180 = 84.4%
Patient treatment days without HLC provided	150 - 95 = 55	90 - 80 = 10	180 - 152 = 28
Theoretical maximum number of possible LLC patient-days	55/1x3 = 165	10/1x3 = 30	28/2x3 = 42
LLC utilization rate (%)	80/165 = 49%	56/30 = 186.6%	35/42 = 83.3%

patient ratio used to that of the lower staffed shift (usually the night shift) to provide a constant value for the whole day. This number multiplied by the number of days during the test-period provides the "*available nursing-days*" during the test period:

available nursing days =
night nurse × days in test period

— per day each bed can only serve one patient with only one level of care. If a bed is used within the same day by more than one patient with different levels of care, or by a single patient with modification of the level of care, the highest level is selected. This provides the number of patients treated each day or "delivered treatment days" during the test period. Delivered patient treatment days are recorded separately as HLC or LLC.

Calculating rate of resource use at ICU level

a) The "*actual nurse assistance*" is computed by dividing the total number of *delivered patient treatment days* by the total number of available nursing days in the period:

actual nurse assistance = delivered patient treatment days / available nursing days.

b) The "theoretical number of nurses" required to manage the treatment days delivered incorporates the level of care for each patient treatment day (HLC and LLC) and attributes the appropriate assistance (number of nurses) as defined by the ICU staff, *i.e.* the "*theoretical appropriate patient/nurse ratio*".

c) The "*theoretical nurse assistance*" is computed by dividing the overall actual delivered *patient treatment days* by the *theoretical number of nursing days* needed to manage the actual HLC and LLC *patient treatment days* delivered during the test-period (Table I).

d) The "*nursing resource use*" in the test period is calculated as the difference between the actual and *theoretical nurse assistance*. A positive difference indicates a higher number of patient treatment days delivered than appropriate for the nursing resources, *i.e.* over-utilization, and a negative difference indicates a lower number of patient treatment days than appropriate with the available nursing resources, *i.e.* under-utilization.

Calculating appropriateness of resource use

Records of the delivered patient treatment days as HLC or LLC allows a separate calculation of utilisation rate.

a) The "*theoretical maximum number of HLC patient treatment days*" is computed as if all members of the nursing staff were devoted to HLC (Table I).

b) Knowing the total number of delivered HLC days and the theoretical maximum number of HLC days, the percentage of "resources used for HLC" can be calculated.

c) For nursing days not used for HLC, due to empty beds or beds dedicated to LLC, it is possible to calculate from the remainder (*i.e.* the patient treatment days without HLC), the "*theoretical maximum availability of LLC patient treatment days*": (patient treatment days without HLC/theoretical number of HLC patients per nurse) x theoretical number of LLC patients per nurse.

d) Knowing the total number of delivered LLC days and the theoretical maximum number of LLC days the percentage of "resources used for LLC" can be calculated.

Application of the method in the field

In Table I we present three hypothetical scenarios of nurse (resource) use and appropriateness.

ICU A is an example of under-utilization of (nursing) resources, as shown by the remarkable negative difference between actual and theoretical nurse assistance. The ICU uses 81% of the overall resources: only 63% of the resources were completely devoted to HLC, and only 49% of the residual nursing time remaining from under HLC utilisation were devoted to LLC. This is an oversized or overstaffed ICU, even if some HLC/LLC patients required higher nurse assistance than reported by the ICU team during the test period. In any event, the method allows the ICU director to quantify this possibility.

ICU B is an example of resource over-utilization as shown by the positive difference between actual and theoretical nurse assistance. It is a small unit delivering 10% more treatment-days than expected. In detail it utilizes only 89% of the overall resources devoted to HLC. However, considering the residual nursing availability, it provides an excessive number of LLC days. This suggests a possibly unsafe environment of care for all HLC or LLC patients. This unit may need more resources (nurses) to cope with the demand for LLC.

Finally, in Unit C, the management, reallocating the available manpower according to the assumed patient/nurse ratio, is able to adjust the HLC/LLC mix to use all the available resources in a quantitatively and perhaps qualitatively appropriate way. This kind of flexible organisation avoids a recovering critical patient needing to be prematurely discharged to the ward, without limiting the admission of new HLC patients.

Discussion

If the theoretical patient to nurse ratio is standardized, this method identifies the optimal adjustment of resources in ICU management. If the number of ICU beds are fixed, the number of nurses should vary according to the levels of care required, with maximum staffing when all treatments are HLC. The reverse is true with a fixed number of ICU nurses: the number of active beds should be established according to the intensity and complexity of patients, from a minimum if all patients require HLC to a maximum if all patients require LLC.

Obviously, ICUs require the actual space in order to increase the number of beds to admit additional, less complex patients. This is the rational basis of the solution to intermediate unit availability proposed in Italy [37] and in Europe.[38] Finally, overall bed occupancy rates are not a sensitive marker of ICU resource usage. ICUs whose beds are designed to serve HLC are serving well, even if all are occupied by LLC patients, without any increase in their operative number. The appropriateness of ICU personnel and resource usage can only be assessed on the basis of both HLC and LLC utilization.

We tested this new method on a group of general non-specialist ICUs without assistance of an intermediate unit, using the same agreed theoretical patient/nurse ratios.[4] In this sample, the method was powerful enough to adequately distinguish between "over" and "under-utilization" and to identify all the theoretical scenarios of nurse/ resource utilization.

Riassunto

Determinanti della performance e della flessibilità dell'organizzazione delle terapie intensive

Abbiamo affrontato alcuni degli aspetti più importanti del problema dell'appropriatezza d'uso delle risorse in Terapia Intensiva (TI) e cioè la relazione tra volume di attività e mortalità, l'analisi del costo/efficienza ed il monitoraggio dell'utilizzo delle risorse infermieristiche. A questo scopo sono state impiegate tre diverse surveys condotte rispettivamente a livello Europeo, nazionale e regionale.

Dopo avere sviluppato una nuova misura del volume di attività in TI chiamata "volume ad alto rischio", abbiamo analizzato la relazione tra quest'ultimo e l'outcome dei pazienti, trovando che sia la mortalità in TI che quella ospedaliera si riducevano sensibilmente (dal 3% al 19%) per ogni paziente ad alto rischio ricoverato in più per letto per anno, e che un tasso di occupazione dei letti maggiore dell'80% era associato ad un aumento della mortalità. Questo suggerisce che pazienti a qualunque livello di rischio sono meglio curati in TI che trattano molti pazienti ad alto rischio, mantenendo un tasso di occupazione ragionevole.

Abbiamo poi studiato il problema dei costi e dell'efficienza della medicina intensiva in un case-mix nazionale dividendo i pazienti in categorie diagnostiche e trovando che quelle che assorbono il maggior volume di risorse finanziarie in modo meno efficiente (peggior outcome) sono ARDS, emorragia cerebrale e chirurgici d'urgenza, mentre i pazienti chirurgici d'elezione ricoverati non per osservazione e quelli con un basso supporto alle funzioni d'organo consentono un buon uso delle poche risorse assorbite.

Infine, abbiamo messo a punto un nuovo metodo per misurare su base giornaliera il grado e l'appropriatezza d'uso delle risorse infermieristiche di una TI. Dal test effettuato su un gruppo di TI generali il metodo è risultato in grado di discriminare adeguatamente tra il "sovra" ed il "sotto-utilizzo" della risorsa infermieri e di identificare tutti i possibili scenari intermedi.

Parole chiave: Uso delle risorse - Volume di attività - Costo/efficienza.

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