INVITED ARTICLE

Approach to Intensive Care Costing and Provision of Cost-effective Care

Binila Chacko[1], Nagarajan Ramakrishnan[2], John Victor Peter[3]

Received on: 04 October 2023; *Accepted on:* 07 October 2023; *Published on:* 30 November 2023

Abstract

Intensive care unit (ICU) service is resource-intense, finite, and valuable. The outcome of critically ill patients has improved because of a better understanding of disease pathology, technological developments, and newer treatment modalities. These improvements have however come at a price, with ICUs contributing significantly to health budgets. Several costing tools are used to assess cost. Accurate assessment has been hampered by the lack of standardized methodology and the heterogeneity of ICUs. In a costing exercise, the level of disaggregation (micro-costing vs gross-costing) and the method of costing (top-down vs bottom-up) need to be considered. Intensive care unit costing also needs to be viewed from the perspective of stakeholders. While all stakeholders aim to provide quality health care, objectives may vary. For the public health care provider, the focus is on optimizing expenditure; for the private health care provider it is bottomline; for a patient, it is affordability; for an insurance service provider, it is minimizing payout; and for the regulator, it is ensuring quality standards and fair pricing. The field of health economics deals with the application of the principles of cost-minimization, cost-effectiveness, cost-utility, and cost-benefit to identify treatments that result in the best outcome at the lowest cost, without limiting resources to other competing interests. In the ICU setting, studies on the efficient use of available resources, and interventions that reduce cost and minimize avoidable cost, would not only translate to cost savings, lives saved, and quality-adjusted life years gained but also enable policymakers to better allocate health care resources.

Keywords: Cost analysis, Cost-effectiveness, Cost utility.

Indian Journal of Critical Care Medicine (2023): 10.5005/jp-journals-10071-24576

Highlights

The perspectives of costing would vary depending on the stakeholder.

Health economics studies on cost-minimization, cost-effectiveness, cost-utility, and cost-benefit would enable better allocation of health-care resources.

Introduction

The world has witnessed an increase in life expectancy at birth during the last century with many demographically developed countries reporting a sustained reduction in mortality since the 1950s.[1] While much of the increase in life expectancy has come about because of better hygiene, healthier lifestyles, sufficient food, increased availability of health care services, and reduced maternal and infant mortality, a significant contributor has been scientific advancement in health care for acute and chronic illnesses.[2] Advances in science and technology have been in the form of improved diagnostics that help in the early detection and prevention of disease, procedures, and medical devices that enhance survival in patients facing life-threatening illnesses, and prescription drugs that improve the quantity and quality of life in patients with chronic illnesses. These have contributed to the exponential increase in the cost of medical treatment raising concerns that "years are being added to our lives, life is not being added to our years; the extra years are being added at the very end of our lives and are of poor quality".[2] The focus on the quantity of life appears to have come at the cost of not diligently looking at aging and age-related diseases which contribute significantly to societal and medical costs in an unsustainable way.[2]

Low- and middle-income countries have also seen an increase in life expectancy due to improvements in public health services, better delivery of primary health care, improved sanitation, immunization, maternal care, and family planning, all of which have translated to reductions in birth rate, infant mortality rate and maternal mortality rate.[3,4] In India, national health programs, focusing initially on infectious diseases such as malaria and tuberculosis and subsequently on noncommunicable diseases such as diabetes and cancer, have helped improve the quality and quantity of life.

With the reduction in the burden of preventable infectious diseases in many countries, the focus has shifted to improving outcomes in acute care, critical care, and chronic care. It is now possible to attempt complex surgical procedures and treat multi-system dysfunction, immune disorders, and malignancies more aggressively given the technological advancement, the availability of innovative therapies, and the fallback of critical care support.

[1,3]Department of Critical Care Medicine, Christian Medical College, Vellore, Tamil Nadu, India

[2]Director, Critical Care Services, Apollo Hospitals, Chennai, Tamil Nadu, India

Corresponding Author: Binila Chacko, Department of Critical Care Medicine, Christian Medical College, Vellore, Tamil Nadu, India, Phone: +91 9600272412, e-mail: binilachacko@gmail.com

How to cite this article: Chacko B, Ramakrishnan N, Peter JV. Approach to Intensive Care Costing and Provision of Cost-effective Care. Indian J Crit Care Med 2023;27(12):876–887.

Source of support: Nil

Conflict of interest: Dr. Binila Chacko is associated as the Associate Editor of this journal and this manuscript was subjected to this journal's standard review procedures, with this peer review handled independently of this editorial board member and her research group.

However, these have pushed up the cost of treatment several fold. This article details the determinants of the cost of critical care and strategies that may enable the provision of cost-effective intensive care services.

Intensive Care Resources

Intensive care units are a finite resource that is oversubscribed, expensive, and labor intensive.[5] Till recently, not much attention was paid to critical care services in India. This is exemplified by the fact that there are only about 70,000 ICU beds in India for a population of over 1 billion; a large proportion of these beds (estimated to be around 90%) are in the private sector where patients must pay for the cost of treatment.[6] Although the 70,000 intensive care beds in the country would probably translate to around 0.5–0.6 beds per 100,000 population, information on the nature (in terms of the proportion of level I, II, or III beds) and location of beds (rural, semiurban, urban) is lacking. The deficiency in ICU beds in India contrasts with other countries where the number of ICU beds per 100,000 population is 20 beds in the United States, 3.5 in the United Kingdom, and 2.5 in Sri Lanka.[7] Further, in the hospital setting, it is recommended that about 10% of the beds are earmarked as critical care beds. In the United States, 13.4% of the beds are allocated for critical care, while in Cape Town in South Africa, it is about 6.6%.[8,9] These estimates are not available for India. Although the Indian Society of Critical Care Medicine (ISCCM) guidelines suggest that at least 5% of hospital beds must be allocated to intensive care, this may vary depending on the nature of the hospital and its case mix and may go up to 25% of the total beds.[10]

Several factors contribute to the slow pace of critical care development in India. There is a perception, rightly so, that critical care is expensive, resource-intense, and can potentially "steal" resources from other more reversible disease processes. Hence hospital administrators often try to balance cost-effectiveness with efficiency. It must be highlighted that running an ICU with less than 6 beds is not cost-effective or efficient.[10]

Another factor that has limited the growth of critical care, particularly in the public sector, is the quantum of allocation of the gross domestic product (GDP) for health. The World Bank estimated that the GDP allocation for health in India in 2019 was about 3.01% compared with 5.35% in China, 9.91% in Australia, 10.15% in the United Kingdom, and 16.77% in the United States.[11] To compound this, India loses about 6% of its annual GDP to preventable illnesses and premature deaths, seriously compromising the health and productivity of the nation.[12] With several competing needs for the GDP allocation to health in India for primary, secondary, and tertiary health care, it is not surprising that allocation for critical care services was not a priority in the public sector until recently. During the recent COVID-19 pandemic, the exponential increase in the need for ICU beds placed tremendous stress on the already stretched public health system. This impact was probably most felt by the "average" Indian and the "day laborer" for whom the cost of ICU care in the private sector was unaffordable and estimated to equate to around 7 months and 16 month's wages respectively.[13,14] Thus, it is imperative that the critical care scenario in India is carefully studied.

Cost of Critical Care

Intensive care is expensive since this field demands a multidisciplinary approach along with high-technology monitoring and interventions.[15] The high capital cost of equipment, salaries and wages of health care workers, and expensive drugs and consumables, push up the cost. Various studies have attempted to assess the "cost" of providing critical care services using various costing tools.

In 2013/14, it was estimated that the mean cost per ICU patient bed-day was around AUD $5000, and accounting for about 1.4% of the total health care cost in Australia.[16] Intensive care unit cost has been reported to be similar in the UK, higher in the United States, and lower in France and Germany.[16] In a study from South Africa published in 2019, the cost per patient per day in a public hospital was ZAR 22870 (US$ 1346), the cost being 58% higher in the combined ICU when compared with trauma ICU.[17] A study from Vietnam reported that the median total ICU cost per patient admitted with tetanus, dengue, and sepsis was US$ 4,250 and US$ 2,590 for ventilated and non-ventilated patients respectively.[18]

There are only a few intensive care costing studies from India.[19–21] This is probably because critical care service is heterogenous with the computed cost of "critical illness" varying not only because of the type of illness and its severity but also on the type of ICU (public, private for-profit, not-for-profit) and method of costing (direct and indirect cost vs fixed and variable cost). While the cost and charge/price of care may be on par in public and not-for-profit hospitals, these are widely variable in for-profit organizations depending on the profit margin. In one of the earliest costing studies from a multi-disciplinary ICU of a tertiary care public hospital in India published in 1999, the cost per survivor was estimated to be INR 17,029 (average INR 1,973 per day, US$ 32).[19] In another study published in 2013, ICU cost was estimated as INR 10,364 (US $222) per day.[20] In a study from a not-for-profit hospital published in 2015, the total cost of treatment for a critical illness (median stay 7 days) was INR 132,000 (US$ 2164), which included bed charges, nursing and professional fees, laboratory tests, radiology, blood products, oxygen, and medication.[22] In this study, the authors observed that the cost of treatment was significantly ($p = 0.0001$) higher during the first 3 days of ICU admission (INR 19,218 per day, US$ 315) than in the subsequent days (INR 14,690 per day, US$ 241). A recent study from a public hospital in India showed that the cost per day in a surgical ICU was INR 11,241 (US$ 155).[23] In this study, the apportioned infrastructure cost (building cost depreciated over 100 years) and electricity cost per patient per day appeared to be grossly underestimated at INR 97.40 (US$ 1.4) and INR 40.16 (US$ 0.56) respectively, while equipment cost per patient per was INR 4,088 (US$ 43.3).[23] Given the diverse service providers (government, for-profit, not-for-profit), varying levels of care (levels I, II, III), and location in different areas (metro, city, town), it has been challenging to determine the cost of critical care in India.

Cost should be measured not only in terms of direct medical cost but also in terms of indirect medical and nonmedical costs. In one study from India, this was estimated to be INR 40,000 (US$ 655) in a semiurban setup; the low-cost estimate attributed to the large proportion of patients who belonged to the lower socioeconomic status.[24] The component of intangible cost of a critical illness, which is generally not assessed and transcends monetary value also needs to be factored.

The cost of health care must be looked at in the context of family earnings. In India, it is estimated that an episode of hospitalization accounts for about 58% of the per capita expenditure that pushes about 2.2% of families below the poverty line.[6] Many patients borrow heavily, pledge jewellery, or sell assets to fund treatment and this eventually pushes them to economic ruin. Reports suggest that out-of-pocket expenses in India for health have increased from an already alarming 60% in 2012 to 70% in 2015.[12] In an ICU-based

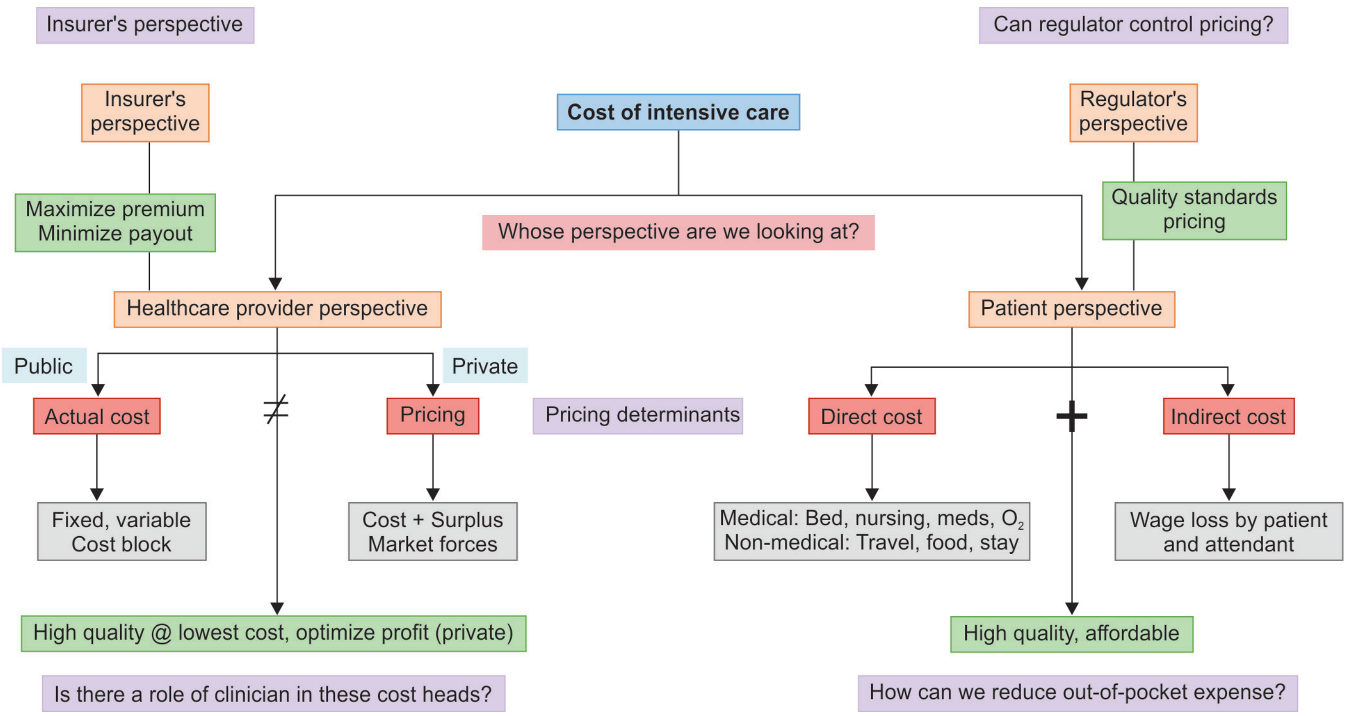

Fig. 1: Stakeholders' perspectives of cost

study, in 2/3rd of the patients admitted, the total family earnings per annum was estimated to be less than the total direct medical cost of intensive care.[24] This was further reflected in the family's willingness-to-pay (WTP) assessments where families were willing to contribute to only 53% of the total cost of treatment, despite the family borrowing heavily to support treatment.[22,24] The burden of this shortfall often falls on the health care provider.

Considering these factors, it is important to not only look at ways by which ICU capacity is enhanced but also to understand the determinants of cost and pricing from the perspective of various stakeholders and how cost-effective and affordable medical care can be provided to the majority.

Stakeholders' Perspective of Cost

The perspectives of the various stakeholders in the delivery of critical care, namely the health care provider (public vs private), the recipient, the regulator, and the insurer (Fig. 1) need to be understood.

In most countries, the largest health care provider is the government. The objective of the government or public health care provider would be to provide equitable services that benefit the maximum number of people at the lowest cost. In this context, the "cost" of health care equals the expenditure incurred by the service provider (government) and the cost is met through resources raised by the government, including taxation. Health care services are offered free of cost to the patient. In the context of reimbursement of health care expenditure in public hospitals by insurance providers for patients who have additional private health insurance, the pricing of services may be different from the calculated cost.

The objective of a for-profit private health care provider would include, in return for services rendered, recovery of investment costs, offset the operational costs as well as make a "profit" to disburse returns to its investors/shareholders and invest in further growth and development. In this context, "pricing" or "charge" and "cost-to-charges" ratios are used as a substitute for "cost".[25] It is well documented that these "charges" do not reflect actual "cost" and are dependent on several factors including return-on-investment, market forces, monopoly of service as well as the need to fund cross-subsidy or other services.[25] In not-for-profit health care organizations which are managed by stakeholders rather than shareholders, in addition to meeting investment and running costs some "surplus" is factored in its "charges" to fund further development.

From a patient's perspective, the expectation is to receive prompt, effective, and quality health care. In public hospitals, despite the provisions of not needing to spend on direct medical costs, the recipient (patient) may be impacted by delays in the provision of non-emergent health care due to overstretched health care systems, high insurance premiums, deductibles, and co-pays when insured, out-of-hospital expenses and loss of income during protracted illness. When patients need to pay for treatment (as in a private hospital), the expectation would be affordable health care, in addition to the above.

In developing countries, patients bear health care costs in situations where certain aspects of health care may not be provided by the government or where demand-supply mismatch compels patients to seek private health care providers. The cost burden can be huge if patients do not have insurance for health care in private hospitals. In this situation, the patient would seek the "best" treatment at the lowest possible cost.

The insurance provider's perspective would be to empanel institutions that offer cost-benefit services. Their aim would be to maximize profits through lower reimbursements by placing restrictions on room rent and geographical location, disallowances (e.g., food), limits on policy and procedural costs, and clauses on co-payment.

Regulation is an important entity in health care and health care insurance. The role of regulatory bodies is to protect health care consumers from health risks, provide a safe working environment for health care professionals, and ensure public health and welfare are served by monitoring quality standards of health programs and regulating pricing.[26]

Determinants of Costing and Pricing

It has been challenging to accurately assess the cost of intensive care due to the heterogeneity of ICUs and the lack of standardized methodology. A structured and reproducible approach to ICU costing allows for better comparison of data and to explore mechanisms to reduce cost.[5]

From an institutional perspective, cost is measured in monetary units and involves capital cost (fixed cost) and operational cost (variable cost) and includes all the resources utilized to provide the service. From a patient's perspective, it involves direct and indirect costs of treatment. Costing can also be approached in terms of cost blocks (Table 1).

Definitions

Fixed Costs

Fixed costs are costs that are not saved by the hospital over the short term if a particular service is not provided.[27] These costs are spent independent of patient volume since the resource will be utilized by all patients and not dependent on the number of patients who are treated. These include buildings, some equipment, and some salaried labor. Fixed costs do not change over the short term with a change in output.[27]

Variable Costs

Variable costs are those that change with output and can be saved by the hospital if the service is not provided.[27] Examples include gloves, syringes, hand rubs, and medications. In the short term, a reduction in variable costs would reduce the total cost spent on treatment. However, in for-profit organizations that charge for treatment, a reduction in variable cost would impact top-line revenue. Some costs that are defined as fixed costs in the short term can become variable over the long term if staffing is downsized.[27]

Marginal Cost

Marginal cost is the change in the total cost to the institution because of a change in output.[27] In simple terms, it is the additional cost of treating each additional patient or increment of patients or a reduction in the cost due to reduction in some services. For example, an additional laboratory test will result in an increase in the cost of reagents (variable cost) but not the cost of salaries or the cost of equipment or buildings (fixed cost) up to a certain threshold. On the other hand, a reduction in the output of a particular service would only save marginal cost since fixed costs are fixed. This is particularly important in private institutions, where bed occupancy or service provision (e.g., laboratory, radiology) beyond the break-even point (the productivity point where the revenue equals the expenses incurred) would enable surplus funds to be generated. For example, if the break-even point for bed occupancy is 60%,

Table 1: Components of cost: Organization vs patient perspectives and cost block method

Organizational perspective		*Patient perspective*	
Fixed cost	*Variable cost*	*Direct cost*	*Indirect cost*
Land and buildingsˆ	Salaries (variable component)	Direct medical cost[24]	Wage loss by patient
Equipment	Drugs, consumables,[27] oxygen	Bed and nursing, professional charges	Wage loss of attendants
Nonclinical support	Test reagents[27]	Investigations	Years of life lost
Salaries (fixed component)	Dietary cost	Equipment, monitoring, ventilation	Ongoing disability
Utilities*	Linen and Laundry	Procedural cost[18] (e.g., dialysis)	Further hospitalization
Administrative*	Equipment maintenance	Drugs and consumables, oxygen	Higher insurance cost post-illness
Depreciation	Building maintenance	Nutritional support	
		Iatrogenic∞	
		Others	
		Direct nonmedical expenditure†	
		Travel cost	
		Boarding and lodging (attendant)	
		Communication	

Cost block method[6,17]					
Capital cost	*Estates*	*Nonclinical support*	*Clinical support*	*Consumables*	*Manpower*
Medical equipment	Land	Administrative*	Laboratory	Drugs	Medical
General equipment	Buildings	Cleaning	Pharmacy	Consumable	Nursing
Information tech.	Building maintenance		Dietary	Blood products	Technical
Annual maintenance	Utilities*		Radiology	Nutrition	Support staff
Lease/hire charges	Taxes		Cardiology		
			Nephrology		
			Neurology		
			Physiotherapy		

ˆCost of land and buildings may vary depending on the location; *Utilities (water, sewage, waste disposal, energy); *Administrative includes expenditure involved in statutory compliances, taxes, general administration, insurance; †nonmedical expenditure incurred by family during hospitalization; ∞,includes additional cost due to iatrogenic problems such as nosocomial infections since fixed cost (e.g., manpower, equipment, building) remains unchanged by occupancy rate, an additional bed occupancy, say 5%, would result in revenue surplus despite an increase in the variable cost (e.g., drugs, consumables). On the other hand, bed occupancy of less than 60% in this case would only result in a reduction in the variable cost since the fixed cost would continue to be incurred.

Another way of approaching fixed and variable costs is to look at it from the point of view of who is paying for the cost of health care. For an insurance provider, the cost incurred by its insured client is a variable cost, dependent on whether the client utilizes health care or not and is billed or not. If health care is not provided or if the bill is not reimbursed, then it is funds saved for the insurer, making it a variable cost. In contrast, if the hospital does not provide the service, it still incurs fixed cost.[27]

From the physician and patient point of view, cost has traditionally been defined as death, loss, or productivity, or pain and suffering, while benefit is looked at as cure, relief of suffering, or accurate diagnosis. The "total cost to society" integrates all the different perspectives of the cost to arrive at cost-benefit ratio.[27]

Opportunity Cost

Opportunity cost is the value of what is lost when choosing between two or more options. An alternate definition is the loss that is taken to make a gain or the loss of one gain for another gain.[28] Opportunity cost rests on two principles: scarcity of resources and choice.[25] Societies and institutions choose between which health programs to fund and which ones to forego.[25] For example, during the COVID-19 pandemic, there was an excess demand for ICU beds, resulting in opportunity costs for other patients who could not be admitted as beds were not available.[29] In such situations, scarce resources need to be used most efficiently. Another study looked at the opportunity cost due to utilization of beds by patients colonized or infected with multi-drug resistant organisms.[30] A hospital may often be required to provide a particular service at the cost of not being able to provide another service due to resource constraints.

Efficiency

Efficiency measures whether health care resources are being used to get the best value for money.[31] Inefficiency exists when resources could be allocated in a manner that would affect health outcomes. Efficiency helps understand the relationship between input and output.[25] The inputs may be in the form of capital cost, equipment, and manpower while the output relates to health outcomes such as lives saved and quality-adjusted life years (QALY). Intermediate outputs can also be measured, such as numbers treated, but these are suboptimal.[31] Different types of efficiency are described in health economics.[31,32] Technical efficiency refers to the physical relation between resources and health outcome, while productive efficiency refers to the maximization of health outcome for a given cost or minimization of cost for a given outcome, and allocative efficiency deals with the allocation of resources to different groups of patients with different health problems.[25,31] Technical efficiency thus addresses the utilization of the resources to the maximum, productive efficiency of choosing a different combinations of resources to achieve the maximum benefit at the lowest cost, and allocative efficiency of achieving the right mixture of programs to maximize the health of society.[31,32]

Methods of Measurement of Cost

Since the measurement of cost or costing is resource-intensive, it is important to decide how accurate and precise the cost estimates need to be. Accuracy is required for internal and external validity while precision is required to ensure reproducibility.[33]

Two decisions need to be taken prior to embarking on a costing exercise: (a) the degree of disaggregation to be employed (micro-costing vs gross-costing) and (b) the method for evaluation (top-down vs bottom-up).[33] Micro-costing looks at detailed assessments of costs (e.g., activity-based costing) while gross-costing identifies resources at a more aggregated level (e.g., cost block method). The top-down method apportions the institutional cost or the cost center cost down to units of activity while the bottom-up approach identifies all the resources utilized by individual patients, costs them, and calculates the total cost.[33] Based on these dimensions, four categories have been proposed by Tan et al.[34] and include top-down micro-costing, top-down gross-costing, bottom-up micro-costing, and bottom-up gross costing.[33] The commonly used micro-costing is activity-based costing (ABC), although a simplified version of this, termed time-driven activity-based costing (TDABC), has also been described.[35] The features of these costing methods and variations of these are detailed in Table 2. The top-down approach is generally done retrospectively while the bottom-up approach is prospective.

There has been interest in ascertaining whether intensive care costs, determined through both the methods of health care costing, *viz.*, bottom-up and top-down, are similar or not. A systemic review evaluated studies that calculated the total ICU costs in countries belonging to the Organization for Economic Co-operation and Development (OECD) countries.[36] The study found that there was a wide variation in the mean total patient cost per day ranging from € 200.75 (US$ 252.24) to € 4321.91 (US$ 4329.62) (based on 2020 cost; conversion to US done based on average conversion rate in 2020 of US$ 1.142 for € 1.0). The highest cost center was for manpower, while the length of stay, mechanical ventilation, continuous hemodialysis, and severe illness were the main cost drivers of total ICU cost.[36] Another study estimated the nursing service costs using a top-down micro-costing approach and compared it with a bottom-up micro-costing approach.[37] Based on the nursing activity score, the authors observed that the top-down method overestimated costs for patients requiring lower intensity of care, while it underestimated costs for patients requiring higher intensity of care.[37] In another study that compared the direct cost of ICU days at seven ICU departments in Germany, Italy, the Netherlands, and the United Kingdom found wide variations.[38]

These studies suggest that one size does not fit all. Costing studies would need to take into consideration the type of study to be undertaken (top-down vs bottom-up), detailing of costing (gross vs micro-costing), the type of institution (government vs private), and location where service is being provided (urban vs semiurban vs rural). Despite these considerations, it will be difficult to generalize the cost of ICU care obtained in one study given the variability of methods used for costing, the type of ICU, the services provided, and the spectrum of illness severity and support that is required for each patient.

Health Economics

Many ICU therapies are supportive rather than curative, and precise cost data is hard to come by. Although long-term quality-adjusted

Table 2: Methods used in costing

Method of costing	*Explanatory notes*
Top-down costing approach	
Top-down costing	Retrospective method used to assign total costs for a system to individual services; assignment based on ratio method (not ideal) or apportionment method (preferred). Total cost includes direct and indirect costs. Indirect costs are apportioned to individual services. Fixed and variable overheads are also apportioned.[33] Resource allocation does not consider variation in expenses.
Variable top-down costing	Organizational direct cost and variable overheads are assigned to all cost objects. Fixed overhead cost not assigned to cost objects. Used to estimate marginal cost.[33]
Full costing or absorption costing	A managerial accounting method for capturing all costs associated with a product or service. All direct and indirect costs, such as materials, labor, rent, and insurance, are accounted for.
Cost block method	Costs divided into defined categories called cost blocks and costs apportioned to each block; including capital equipment, estates, nonclinical support services, clinical support services, consumables, and staff.[5]
Bottom-up costing approach	
Bottom-up approach (Direct costing)	Based on a detailed assessment of costs to individual patients according to the use of resources.[5] It is usually done prospectively, is labor intensive, and requires accurate knowledge of lower-level components of costs including medical and nursing activities and unit cost of support services, drugs, and consumables.[5] Three estimates are used: resource estimates, duration estimates, and cost estimates. Gross- or micro-costing can be done.
Micro-costing methods	
Activity-based costing (ABC)	Method of micro-costing where cost allocation is based on activities required to provide a service. It measures cost based on three premises: products (or services) require activities, activities consume resources and resources cost money.[35]
Time-driven activity-based costing (TDABC)	The fundamental difference from ABC is that ABC uses many cost drivers while TDABC only uses time as a cost generator by using two key parameters—the capacity cost rate and time necessary to perform the activity.[35]

survival would be preferable for cost-effective analysis, it is not often determined in ICU research. Additionally, the financial burden of critical illness on family members is rarely reflected in studies.

Despite the dearth of information on cost efficacy in ICU, there is a lack of impetus in studying this aspect with only a small increase in the proportion of studies focusing on cost-effectiveness in critical care from 1.2% in the early 2000s to just 4.0% in the last 10 years.[39] Reasons could be reluctance, or sometimes the inability of health care professionals to be involved in domains that are normally handled by nonmedical administrators as well as the lack of understanding of costing methods and analysis. Cost-minimization, cost-effectiveness, cost-utility, and cost-benefit are the primary economic evaluations that are done in health care.

Economic Evaluations in Health Care

Cost Minimization

Aims to minimize expenses by considering a variety of treatment options and comparing their respective costs. To make a fair comparison of the various interventions, it is assumed that all treatment choices have the same level of effectiveness, and the only difference is in the cost. Based on the results, the treatment with the lower cost would be opted.

Cost-Effectiveness

Quantifies the outcome in terms of naturally occurring, health-related measures, such as the number of lives saved, the number of life years gained, or the number of instances of ventilator-associated pneumonia that is avoided. When the cost and result (effect) are taken into consideration, a ratio is calculated termed as cost-effectiveness ratio. This ratio is calculated by dividing the net change in costs (between two treatments) by the net change in outcome and is expressed as the cost per outcome gained, such as the cost per life year gained or the cost per life saved. The American Thoracic Society (ATS) has suggested cost-effectiveness analyses as the primary method to analyze the cost and effects of interventions in critical care.[25]

Cost Utility Analysis

Measures benefit in terms of health year equivalents, usually QALY. Cost-utility analyses make it possible to compare various interventions over a wide range of illness states to ascertain which interventions result in the greatest gain for a certain amount of expenditure. From a health administrator's point of view, this analysis can help decide which intervention to invest in.

Cost Benefit Analysis

In cost-benefit evaluations, the benefit in health care is quantified monetarily. After assigning a financial value to each of the outcomes, all associated costs are tallied and then deducted from the total value that was determined for the outcomes. If the sum that is arrived at is positive, this indicates that the outcomes have a greater value than the costs, which makes the intervention more desirable. Cost-benefit evaluations are rarely employed because it is difficult to place a monetary value on the results, such as adding years to a person's life. This can be done by either the human capital strategy or the WTP method. The human capital approach considers a person's improved health to be of value based on their ability to go back to work. According to the WTP, the value of a health improvement is determined by how much individuals are prepared to pay in exchange for the "normalization" of health or improvement.[22] However, there are concerns that an individual's response in an interview may not reflect his or her actions in real life, and as a result, the values that are ascribed to a given outcome may not be correct in a clinical setting that is more representative of real life.

Evidence for Cost-effectiveness and Optimizing ICU Cost

At the heart of health care is the principle of optimizing treatment costs. This may be through optimal utilization of resources, optimizing monitoring and investigations, interventions to reduce cost, as well as focusing on avoidable costs. In this context, the cost of ICU survival and the effect of limitation of ICU care should also be considered.

To evaluate the cost-effectiveness of an intervention, its efficacy must first be demonstrated. Regrettably, few strategies have been shown to improve outcomes in intensive care. Additionally, patient management is multifaceted given the range of differential diagnoses, complexity of disease, and comorbidities. This heterogeneity makes it challenging to conduct and interpret single-item-focused cost-effective analysis in critical care. Future research in this area may benefit from the implementation of criteria, like the STROBE criteria, to enhance the quality of the studies and facilitate cost and efficacy comparisons. In Tables 3 and 4, it can be observed that several cost-effective ratios that indicated good value for money had no significant clinical impact. It is hence recommended that cost-effective analysis be done only for interventions with highly demonstrated utility to prevent premature promotion of inadequately researched interventions.

Optimal Utilization of Resources

Health care service in any country strives to maximize output for a given resource by prioritizing or choosing interventions that deliver the greatest health benefit for cost. The principles of technical and allocative efficiency help optimize resource utilization in the ICU.

Allocative efficiency, which is concerned with ensuring that the value derived from a service outweighs the cost of its production, can be applied in the ICU setting by using stepdown or Emergency Department (ED) based ICU beds and the use of long-term acute care facilities.[32,40–42] Some of these strategies have demonstrated a reduction in the cost of managing a critical illness (Table 3).

Technical efficiency is concerned with maximizing the outcomes for a given level of resources.[32] Thus, the more outcomes that can be produced for a given budget, the more technically efficient the services are. Table 3 summarizes some of the interventions in the ICU setting that can be considered under technical efficiency. Withdrawal of pulmonary artery (PA) catheters was associated with a cost per QALY and per life gained of £ 2892 and £ 21,164 respectively.[43] Procalcitonin (PCT)-guided antibiotic therapy, rapid diagnostic test (RDT) for bacteremia, and avoiding daily chest X-rays (CXR) in the ICU were cost-effective interventions while the introduction of tele-ICU did not impact hospital length of stay.[44–47]

Interventions that may Reduce ICU Cost

Critical care literature has focused on several interventions that have the potential to reduce cost (Table 4). The studies have been diverse and include mechanical ventilation, lung protection ventilation strategies, 24 hour physiotherapy, dialysis, sepsis protocols and education, activated protein C, antibiotics, stop-cock devices, timing of tracheostomy, palliative care consultation, and extracorporeal membrane oxygenation.[48–63] Some studies such as mechanical ventilation for stroke, demonstrated cost-effectiveness in terms of life-saved but not in terms of quality of life.[49] Therapies

Table 3: Improving allocative and technical efficiency

Improving allocative efficiency			
Study details	*Intervention*	*Economic analysis*	*Effect size*
Bassin BS et al.,[41] 2022 (USA)	ED based ICU	Direct cost analysis	ED-ICU deployment did not increase inflation-adjusted total direct cost per ED encounter. Inflation-adjusted net revenue per encounter rose 7.0% (95% CI, 3.4%–10.6%; $p < 0.001$).
Richards BF et al.,[40] 2012 (USA)	Stepdown following neuro-interventions	Direct cost analysis	Lower mean (SD) total cost per patient admitted to the stepdown unit as compared to the ICU [$ 19,299 ($ 6955) vs $22,716 ($ 8052)].
Seneff MG et al.,[42] 2000 (USA)	Use of LTAC facility for ventilated patients	Direct cost analysis	Average total hospital cost for non-transferred patients $78,474, estimated cost for LTAC facility admissions $56,825.
Improving technical efficiency			
Chen et al., 2018[47]*	Tele ICU	Cost minimization	Tele-ICU program did not reduce hospital stay. In the first year, cost US$ 50,000–100,000. Tele-ICU anticipated cost per patient is US$ 2600 to US$ 5600.
Westwood M et al.,[44] 2015*	PCT-guided antibiotic therapy for sepsis	CEA	At willingness-to-pay thresholds of £ 20,000 and £ 30,000 per QALY, PCT-guided treatment was 84% cost-effective.
Pliakos EE et al.,[45] 2018 (USA)	RDT for bacteremia MALDI TOF	Cost utility	MALDI-TOF analysis with ASP was the most cost-effective strategy, resulting in savings of $29,205 per QALY compared to conventional methods without ASP.
Scott J et al.,[46] 2021 (USA)	Avoiding daily CXR in the ICU	Direct cost analysis	The average monthly cost of portable CXR fell by 37%, from $11,633 prior to the intervention to $7,348 after the intervention.
Smith KJ et al.,[64] 1994 (USA)	PA catheterization in COPD requiring MV	Cost utility, CEA	Incremental cost/QALY saved in CEA was $77,407 when catheterization-driven therapeutic changes resulted in a 5% improvement in survival.
Stevens et al.,[43] 2005 (UK)	Withdrawal of PACs ICU PAC man trial	CEA, utility	The cost per QALY and per life gained from the withdrawal of PACs were £ 2892 and £ 21,164, respectively.

*Systematic review; ASP, antimicrobial stewardship program; CEA, cost-effectiveness analysis; COPD, chronic obstructive pulmonary disease; CXR, chest X-ray; ICU, intensive care unit; LTAC, long-term acute-care facility; MV, mechanical ventilation; PA, pulmonary artery; PAC, PA catheter; PCT, procalcitonin, QALY, quality-adjusted life-years; RDT, rapid diagnostic test such as lung protective ventilation showed cost-effectiveness in terms of life saved as well as QALY.[50] Early tracheostomy was associated with lower cost and ICU-weighted stay.[59,60]

Attributable Cost of ICU Events

Certain ICU-associated events (Table 5), such as nosocomial infections and delirium that contribute to increased length of stay and cost, should be minimized.[65,66] In one study, delays in transferring patients out of ICU contributed to 12.8% of ICU bed days and 6.4% of total ICU costs.[67] Adherence to pharmacological prophylaxis for venous thromboembolism appeared to be associated with better cost-utility than screening for venous thrombosis.[68]

Cost of ICU Survival

The cost of intensive care extends beyond discharge to the hospital given residual disabilities as well as the cost of ongoing care of underlying problems in survivors. In one study (Table 6), the incremental cost-effectiveness ratio (ICER) was US$ 1,150 per

Table 4: Interventions that may reduce ICU cost

Study details	*Intervention*	*Economic analysis*	*Effect size*
Rotta BP et al.,[51] 2018 (Brazil)	24 hrs vs 12 hrs physiotherapy	Direct, medical and staff costs	Significantly lower in the 24-hr physiotherapy arm. Baseline demographics, including APACHE II, were similar in both arms.
Hamel MB et al.,[48] 2000 (USA)	MV support for ARF for pneumonia, ARDS	ICER	Patients requiring MV had ≥70% likelihood of survival, saved $29,000 per QALY. Cost-effectiveness dropped to $110,000 for high-risk patients (< 50% survival).
Mayer SA et al.,[49] 2000 (USA)	MV for life-threatening stroke	Cost-effectiveness, utility	MV ventilation was cost-effective in terms of life ($ 37,600) but not in terms of quality of life (cost per QALY $174 200).
Cooke CR et al.[50] 2009 (USA)	LPV vs no LPV	Cost-effectiveness, utility	ICER ratios for LPV were $22,566 per life saved at hospital discharge and $11,690 per QALY gained.
Cox et al.,[69] 2007 (USA)	Economic evaluation of PMV	Cost-effectiveness, utility	Compared to withdrawal, PMV $55,460 per life-year, $82,411 per QALY. Patients >68 years and expected 1-year mortality >50%, PMV $100,000 per QALY gained.
Hamel MB et al.,[52] 1997 (USA)	Dialysis and continuing aggressive care	Cost utility	Aggressive care saved $128,200 per QALY compared to withholding dialysis. In best prognostic group, cost per QALY $61,900, above $ 50,000 threshold for cost-effective care.
Desai et al.,[53] 2008 (USA)	Daily vs intermittent dialysis	Cost utility	Daily hemodialysis was more cost-effective when compared with alternate-day hemodialysis and was $5084 per QALY gained. (CRRT and SLED were excluded).
Manns et al.,[56] 202l (Canada)	Economic evaluation of APC for sepsis	Cost-effectiveness	Treating sepsis with APC cost $27,936 per life-year gained. More cost-effective when APACHE II score ≥ 25 ($ 24,484 per life-year gained) than with lower scores ($ 35,632).
Jones et al.,[54] 2010 (USA)	ED early sepsis resuscitation protocol	Cost utility	Early goal-directed therapy was cost-effective with a cost of $5397 per QALY gained.
De Cock et al.,[70] 2004 (Germany)	Linezolid vs Vancomycin[†]	ICER	Linezolid-treated patients gained 2.3 life-years compared to vancomycin (14.0 vs 11.7). Linezolid cost € 3,171 for each death saved and € 4,813 for each patient healed.
Socal MP et al.,[57] 2022 (USA)	Substitutions of high-cost generic medicines	Savings potential	With lower-cost alternatives, total spending would have been reduced from $7.5 million to $873 711, resulting in 88.3% savings.
Peek et al.,[62] 2009 (UK)	ECMO CESAR trial	Cost utility	Lifetime model predicted cost per QALY of ECMO to be £ 19252 (95% CI 7622–59 200).
Park et al.,[63] 2014 (Brazil)	ECMO respiratory failure	Cost utility	In this hypothetical study, the cost-utility ratio associated with ECMO in Brazil was potentially acceptable according to this hypothetical study.
Noritomi et al.,[55] 2014 (Brazil)	Sepsis education problem	Cost-effectiveness	For each QALY, full compliance saves US$ 5,383.
Rosenthal VD et al.,[58] 2015 (India)	3WSC vs SS	Cost utility	Using SS represented savings of $402.88 and an increase in QALY of 0.0008 per patient. For each extra dollar invested in an SS, $124 was saved.
Siddiqui et al.,[59] 2015 (Pakistan)	Early tracheostomy in head injury pts	Actual costs	Total inpatient cost was considerably less (US$ 8027) in the early tracheostomy group compared with the intubated group (US$ 9961).
Herritt B et al.,[60] 2018*	Early vs late tracheostomy	Actual costs	Early tracheostomy US$ 4316 lower ICU stay than late. Subgroup, extremely early (<4 days) US$ 3672 less than late ones; early (<10 days but >4) cost US$ 6385 less.
Kyeremanteng K et al.,[61] 2016*	Palliative care (PC)	Direct costs	ICU costs were US$ 7533 and US$ 6406 (control vs PC, $p <0.05$) and hospital direct variable costs were US$ 9518 and US$ 8971 ($p <0.05$) per admission.

*Systematic review; for nosocomial pneumonia; ARDS, acute respiratory distress syndrome; ARF, acute respiratory failure; APC, activated protein C; ECMO, extracorporeal membrane oxygenator; ICER, incremental cost-effectiveness ratio; ICU, intensive care unit; LPV, lung protective ventilation; MV, mechanical ventilation; PMV, prolonged MV; QALY, quality-adjusted life years; 3WSC, 3-way stop-cock; SS, split system with single use prefilled flushing devices

Table 5: Minimizing attributable cost of events in critical care

Study details	*Intervention*	*Economic analysis*	*Effect size*
Dziegielewski C et al.,[66] 2021*	Impact of delirium	ICU and hospital costs	Delirium patients had $3,921 significantly higher ICU expenses and $ 5,936 higher hospital expenditures.
Chacko et al.,[65] 2017 (India)	Attributable costs of nosocomial infection	Actual costs	Doubling of costs with nosocomial infection without a significant difference in mortality.
Bagshaw SM et al.,[67] 2021 (Canada)	Cost of avoidable delay in ICU discharge	Actual costs	Cumulative avoidable time 19,373.9 days and estimated attributable cost CAD$ 34,323,522. Avoidable time accounted for 12.8% of total ICU bed-days and 6.4% of total ICU costs.
Sud et al.,[68] 2011 (Canada)	Screening and prevention of venous thromboembolism	Cost utility	Screening led to 3 fewer PE than case-finding alone but also 2 extra bleeding episodes. Cost $223,801 per QALY gained. In contrast, enhanced pharmaceutical prophylaxis adherence was associated with a cost of $27,953 per QALY gained.

*Systematic review; ICU, intensive care unit; PE, pulmonary embolism; QALY, quality-adjusted life years

Table 6: Cost of intensive care survival

Study details	*Intervention*	*Economic analysis*	*Effect size*
Heyland DK et al.,[71] 1998 (Canada)	Continuation of ICU care beyond 14 days	ICER	Sustaining treatment for long-term ICU patients may be an efficient use of hospital resources (ICER CAD$ 4,350 per life-year saved).
Sznajder et al.,[72] 2001 (France)	Cost-effectiveness of stay in ICU	Cost-effectiveness and utility	ICER US$ 1,150/life-year saved, incremental cost-utility ratio US$ 4,100/QALY saved. Intoxication lowest US$ 620/QALY, acute renal insufficiency highest US$ 30,625/QALY.
Graf et al.,[73] 2005 (Germany)	ICU 5-year survival	Cost utility	Increasing severity of illness associated with higher costs per life year and per QALY gained.
van Mastrigt,[74] 2006 (Netherlands)	Short stay ICU (SSIC) post CABG-RCT	Cost utility	Total hospital costs and ICER for SSIC were significantly lower compared with those for the control group.
Ridley et al.,[75] 2007 (UK)	UK ICU cost assessment	Cost utility	Incremental cost per QALY gained for ICU treatment was £ 7,010, compared to non-ICU treatment. Despite high cost per day of ICU, cost-effectiveness measured up to other widely used health therapies.
Graf et al.,[76] 2008 (Germany)	Postcardiac arrest survivors	Costs per life gained, cost utility	Total cost per life year gained 10,107 €. The costs per life year gained were 9,816 € or 14,487 € per QALY when only 5-year survivors were considered.
Linko et al.,[77] 2010 (Finland)	Acute respiratory failure (ARF) survivors	Cost utility	The mean estimated costs per hospital survivor were 20,739 €, and the mean expected lifetime cost-utility for all ARF patients was 1,391 € per QALY.
Cubro et al.,[78] 2016 (Europe)	Cost-effectiveness of intensive care in a low-resource setting	Cost utility	Cost of treating critically sick patients ranged from $1,820 to $2,010/ survivor and from $.100 to $.2,514 per QALY gained. ICER for ICU treatment was $.3,254 per QALY, corresponded to 35% of per capita GDP or WHO's very cost-effective category.
Thomas K et al.,[22] 2015 (India)	No intervention	Utility scores, WTP	Likelihood ratio to predict mortality increased as utility values decreased; WTP by caregiver 53% of total cost and not influenced by utility score; WTP (as subsidy) by care provider showed inverted U-shaped relationship with utility.

CABG, coronary artery bypass graft; ICER, incremental cost-effectiveness ratio; ICU, intensive care unit; QALY, quality-adjusted life years; WTP, willingness to pay, WHO, World Health Organization

life-year saved, with intoxication having the lowest cost per QALY of US$ 620 and acute renal failure the highest cost at US$ 30,625 per QALY.[71] In another study by Graf et al.,[73] increasing severity of illness was associated with higher cost per life-years and per QALY gained. Other studies that have looked at cost-utility in the setting of cardiac arrest and acute respiratory failure as well as cost-effectiveness in low-resource settings and utility and WTP are summarized in Table 6.[22,76–78]

Conclusion

Intensive care unit resources are valuable, finite, and resource-intense. Many costing tools have been used to assess the cost of critical care services, Accurate assessment of cost is limited by the heterogeneity of ICUs and the lack of standardized methodology. From an institutional perspective, cost involves fixed and variable costs while from a patient's perspective, it involves the direct and indirect costs of treatment. Stakeholders' perspectives need to be kept in mind while approaching cost.

The objective of health economics is to find the most cost-effective treatment that can be provided at the lowest cost without limiting resources to other competing interests. In the ICU setting, efficient use of resources, and focusing on interventions that reduce cost and minimize avoidable cost would translate to improved outcomes and cost-savings. More studies, particularly from developing countries, would enable policymakers to better plan allocation for health care.

The stakeholders in health care include the health care provider (public or private), the recipient (patient), the regulator and the insurance service provider. From the patient's perspective, health care should be affordable and include the components of direct treatment cost and indirect expenditure. A health care provider's objective is to provide the best possible care at the least costs. The components of cost include fixed (capital) and variable (operational) cost. However, private health care providers would not only need to factor in cost but also price services in a manner that would allow surplus. The insurer's objective would be to maximize profit by balancing premium and payout. The regulator's role is to ensure fair pricing and maintenance of quality standards.

Orcid

Binila Chacko https://orcid.org/0000-0002-1609-2208
Nagarajan Ramakrishnan https://orcid.org/0000-0001-5208-4013
John Victor Peter https://orcid.org/0000-0002-3423-1830

References

1. Djeundje VB, Haberman S, Bajekal M, Lu J. The slowdown in mortality improvement rates 2011–2017: A multi-country analysis. Eur Actuar J 2022;12(2):839–878. DOI: https://doi.org/10.1007/s13385-022-00318-0.
2. Brown GC. Living too long: The current focus of medical research on increasing the quantity, rather than the quality, of life is damaging our health and harming the economy. EMBO Rep 2015;16(2):137–141. DOI: 10.15252/embr.201439518.
3. Dondorp AM, Iyer SS, Schultz MJ. Critical care in resource-restricted settings. JAMA 2016;315(8):753–754. DOI: 10.1001/jama.2016.0976.
4. Dondorp AM, Haniffa R. Critical care and severe sepsis in resource poor settings. Trans R Soc Trop Med Hyg 2014;108(8):453–454. DOI: 10.1093/trstmh/tru099.
5. Seidel J, Whiting P, Edbrooke D. The costs of intensive care. Contin Educ Anaesth Crit Care Pain 2006;6(4):160–163. DOI: 10.1093/bjaceaccp/mkl030.
6. Jayaram R, Ramakrishnan N. Cost of intensive care in India. Indian J Crit Care Med 2008;12(2):55–61. DOI: 10.4103/0972-5229.42558.
7. Adhikari NK, Fowler RA, Bhagwanjee S, Rubenfeld GD. Critical care and the global burden of critical illness in adults. Lancet 2010;376(9749):1339–1346. DOI: 10.1016/S0140-6736(10)60446-1.
8. Halpern NA, Pastores SM, Greenstein RJ. Critical care medicine in the United States 1985–2000: An analysis of bed numbers, use, and costs. Crit Care Med 2004;32(6):1254–1259. DOI: 10.1097/01.ccm.0000128577.31689.4c.
9. van Zyl-Smit R, Burch V, Willcox P. The need for appropriate critical care service provision at non-tertiary hospitals in South Africa. S Afr Med J 2007;97(4):268, 270, 272. PMID: 17446951.
10. Rungta N, Zirpe KG, Dixit SB, Mehta Y, Chaudhry D, Govil D, et al. Indian Society of critical care medicine experts committee consensus statement on ICU planning and designing, 2020. Indian J Crit Care Med 2020;24(Suppl 1):S43–S60. DOI: 10.5005/jp-journals-10071-G23185.
11. The World Bank. Current health expenditure (% of GDP). The World Bank 2023. Available from: https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS.
12. The Economic Times. India's disproportionately tiny health budget: A national security concern?. The Economic Times, 2023. Available from: https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/indias-disproportionately-tiny-health-budget-a-national-security-concern/articleshow/49603121.cms.
13. The Times of India. 'Covid ICU costs equal to 7-month pay for average Indian.' The Times of India, 2021. Available from: https://timesofindia.indiatimes.com/india/covid-icu-costs-equal-to-7-month-pay-for-average-indian/articleshow/84600389.cms.
14. Newsweek 90. India's cost of Covid ICU care treatment equals 16 months of pay for day laborers. Newsweek 90, 2021. Available from: https://www.newsweek.com/indias-cost-covid-icu-care-treatment-equals-16-months-pay-day-laborers-1613113.
15. Murthy S, Adhikari NK. Global health care of the critically ill in low-resource settings. Ann Am Thorac Soc 2013;10(5):509–513. DOI: 10.1513/AnnalsATS.201307-246OT.
16. Hicks P, Huckson S, Fenney E, Leggett I, Pilcher D, Litton E. The financial cost of intensive care in Australia: A multicentre registry study. Med J Aust 2019;211(7):324–325. DOI: 10.5694/mja2.50309.
17. Mahomed S, Mahomed OH. Cost of intensive care services at a central hospital in South Africa. S Afr Med J 2018;109(1):35–39. DOI: 10.7196/SAMJ.2018.v109i1.13268.
18. Hung TM, Van Hao N, Yen LM, McBride A, Dat VQ, van Doorn HR, et al. Direct medical costs of tetanus, dengue, and sepsis patients in an intensive care unit in Vietnam. Front Public Health 2022;10:893200. DOI: 10.3389/fpubh.2022.893200.
19. Parikh CR, Karnad DR. Quality, cost, and outcome of intensive care in a public hospital in Bombay, India. Crit Care Med 1999;27(9):1754–1759. DOI: 10.1097/00003246-199909000-00009.
20. Shweta K, Kumar S, Gupta AK, Jindal SK, Kumar A. Economic analysis of costs associated with a Respiratory Intensive Care Unit in a tertiary care teaching hospital in Northern India. Indian J Crit Care Med 2013;17(2):76–81. DOI: 10.4103/0972-5229.114822.
21. Kulkarni AP, Divatia JV. A prospective audit of costs of intensive care in cancer patients in India. Indian J Crit Care Med 2013;17(5):292–297. DOI: 10.4103/0972-5229.120321.
22. Thomas K, Peter JV, Christina J, Jagadish AR, Rajan A, Lionel P, et al. Cost-utility in medical intensive care patients. Rationalizing ongoing care and timing of discharge from intensive care. Ann Am Thorac Soc 2015;12(7):1058–1065. DOI: 10.1513/AnnalsATS.201411-527OC.
23. Singh T, Sk Pillai J, Sahoo MC. How much does it cost for a surgical ICU bed in a public hospital in India. Risk Manag Healthc Policy 2021;14:4149–4154. DOI: 10.2147/RMHP.S324551.
24. Peter JV, Thomas K, Jeyaseelan L, Yadav B, Sudarsan TI, Christina J, et al. Cost of intensive care in India. Int J Technol Assess Health Care 2016;32(4):241–245. DOI: 10.1017/S0266462316000398.
25. Cox HL, Laupland KB, Manns BJ. Economic evaluation in critical care medicine. J Crit Care 2006;21(2):117–124. DOI: 10.1016/j.jcrc.2006.02.003.
26. News Medical Life Sciences. What is the role of regulatory bodies in healthcare? News-Medical.net, 2021. Available from: https://www.news-medical.net/health/What-is-the-Role-of-Regulatory-Bodies-in-Healthcare.aspx.
27. Roberts RR, Frutos PW, Ciavarella GG, Gussow LM, Mensah EK, Kampe LM, et al. Distribution of variable vs fixed costs of hospital care. JAMA 1999;281(7):644–649. DOI: 10.1001/jama.281.7.644.
28. The Balance. What is opportunity cost? The Balance, 2022. Available from: https://www.thebalancemoney.com/what-is-opportunity-cost-357200.
29. Olivera MJ. Opportunity cost and COVID-19: A perspective from health economics. Med J Islam Repub Iran 2020;34:177. DOI: 10.47176/mjiri.34.177.
30. Hübner C, Ried W, Flessa S. Assessing the opportunity costs of patients with multidrug-resistant organisms in hospitals. Eur J Health Econ 2018;19(7):1009–1017. DOI: 10.1007/s10198-017-0949-8.
31. Palmer S, Torgerson DJ. Economic notes: Definitions of efficiency. BMJ 1999;318(7191):1136. DOI: 10.1136/bmj.318.7191.1136.
32. Abu Al-Saad N, Skedgel C, Nortje J. Principles of resource allocation in critical care. BJA Educ 2017;17(12):390–395. DOI: https://doi.org/10.1093/bjaed/mkx029.
33. Špacírová Z, Epstein D, García-Mochón L, Rovira J, Olry de Labry Lima A, Espín J. A general framework for classifying costing methods for economic evaluation of health care. Eur J Health Econ 2020;21(4):529–542. DOI: 10.1007/s10198-019-01157-9.
34. Tan SS, Rutten FFH, van Ineveld BM, Redekop WK, Hakkaart-van Roijen L. Comparing methodologies for the cost estimation of hospital services. Eur J Health Econ 2009;10(1):39–45. DOI: 10.1007/s10198-008-0101-x.

35. Niñerola A, Hernández-Lara AB, Sánchez-Rebull MV. Improving healthcare performance through activity-based costing and time-driven activity-based costing. Int J Health Plann Manage 2021;36(6):2079–2093. DOI: 10.1002/hpm.3304.
36. Mastrogianni M, Galanis P, Kaitelidou D, Konstantinou E, Fildissis G, Katsoulas T. Factors affecting adult intensive care units costs by using the bottom-up and top-down costing methodology in OECD countries: A systematic review. Intensive Crit Care Nurs 2021;66:103080. DOI: 10.1016/j.iccn.2021.103080.
37. Ricci de Araújo T, Papathanassoglou E, Gonçalves Menegueti M, Grespan Bonacim CA, Lessa do Valle Dallora ME, de Carvalho Jericó M, et al. Critical care nursing service costs: Comparison of the top-down versus bottom-up micro-costing approach in Brazil. J Nurs Manag 2021;29(6):1778–1784. DOI: 10.1111/jonm.13313.
38. Tan SS, Bakker J, Hoogendoorn ME, Kapila A, Martin J, Pezzi A, et al. Direct cost analysis of intensive care unit stay in four European countries: Applying a standardized costing methodology. Value Health 2012;15(1):81–86. DOI: 10.1016/j.jval.2011.09.007.
39. Wilcox ME, Vaughan K, Chong CAKY, Neumann PJ, Bell CM. Cost-effectiveness studies in the ICU: A systematic review. Crit Care Med 2019;47(8):1011–1017. DOI: 10.1097/CCM.0000000000003768.
40. Richards BF, Fleming JB, Shannon CN, Walters BC, Harrigan MR. Safety and cost effectiveness of step-down unit admission following elective neurointerventional procedures. J Neurointerventional Surg 2012;4(5):390–392. DOI: 10.1136/neurintsurg-2011-010058.
41. Bassin BS, Haas NL, Sefa N, Medlin R, Peterson TA, Gunnerson K, et al. Cost-effectiveness of an Emergency Department-Based Intensive Care Unit. JAMA Netw Open 2022;5(9):e2233649. DOI: 10.1001/jamanetworkopen.2022.33649.
42. Seneff MG, Wagner D, Thompson D, Honeycutt C, Silver MR. The impact of long-term acute-care facilities on the outcome and cost of care for patients undergoing prolonged mechanical ventilation. Crit Care Med 2000;28(2):342–350. DOI: 10.1097/00003246-200002000-00009.
43. Stevens K, McCabe C, Jones C, Ashcroft J, Harvey S, Rowan K, et al. The incremental cost effectiveness of withdrawing pulmonary artery catheters from routine use in critical care. Appl Health Econ Health Policy 2005;4(4):257–264. DOI: 10.2165/00148365-200504040-00008.
44. Westwood M, Ramaekers B, Whiting P, Tomini F, Joore M, Armstrong N, et al. Procalcitonin testing to guide antibiotic therapy for the treatment of sepsis in intensive care settings and for suspected bacterial infection in emergency department settings: A systematic review and cost-effectiveness analysis. Health Technol Assess 2015;19(96):v–xxv, 1–236. DOI: 10.3310/hta19960.
45. Pliakos EE, Andreatos N, Shehadeh F, Ziakas PD, Mylonakis E. The Cost-effectiveness of rapid diagnostic testing for the diagnosis of bloodstream infections with or without antimicrobial stewardship. Clin Microbiol Rev 2018;31(3):e00095–e000117. DOI: 10.1128/CMR.00095-17.
46. Scott J, Waite S, Napolitano A. Restricting daily chest radiography in the intensive care unit: Implementing evidence-based medicine to decrease utilizationt. J Am Coll Radiol 2021;18(3 Pt A):354–360. DOI: 10.1016/j.jacr.2020.05.035.
47. Chen J, Sun D, Yang W, Liu M, Zhang S, Peng J, et al. Clinical and economic outcomes of telemedicine programs in the intensive care unit: A systematic review and meta-analysis. J Intensive Care Med 2018;33(7):383–393. DOI: 10.1177/0885066617726942.
48. Hamel MB, Phillips RS, Davis RB, Teno J, Connors AF, Desbiens N, et al. Outcomes and cost-effectiveness of ventilator support and aggressive care for patients with acute respiratory failure due to pneumonia or acute respiratory distress syndrome. Am J Med 2000;109(8):614–620. DOI: 10.1016/s0002-9343(00)00591-x.
49. Mayer SA, Copeland D, Bernardini GL, Boden-Albala B, Lennihan L, Kossoff S, et al. Cost and outcome of mechanical ventilation for life-threatening stroke. Stroke 2000;31(10):2346–2353. DOI: 10.1161/01.str.31.10.2346.
50. Cooke CR, Kahn JM, Watkins TR, Hudson LD, Rubenfeld GD. Cost-effectiveness of implementing low-tidal volume ventilation in patients with acute lung injury. Chest 2009;136(1):79–88. DOI: 10.1378/chest.08-2123.
51. Rotta BP, da Silva JM, Fu C, Goulardins JB, Pires-Neto R de C, Tanaka C. Relationship between availability of physiotherapy services and ICU costs. J Bras Pneumol 2018;44(3):184–189. DOI: 10.1590/S1806-37562017000000196.
52. Hamel MB, Phillips RS, Davis RB, Desbiens N, Connors AF, Teno JM, et al. Outcomes and cost-effectiveness of initiating dialysis and continuing aggressive care in seriously ill hospitalized adults. SUPPORT Investigators. Study to understand prognoses and preferences for outcomes and risks of treatments. Ann Intern Med 1997;127(3):195–202. DOI: 10.7326/0003-4819-127-3-199708010-00003.
53. Desai AA, Baras J, Berk BB, Nakajima A, Garber AM, Owens D, et al. Management of acute kidney injury in the intensive care unit: A cost-effectiveness analysis of daily vs alternate-day hemodialysis. Arch Intern Med 2008;168(16):1761–1767. DOI: 10.1001/archinte.168.16.1761.
54. Jones AE, Troyer JL, Kline JA. Cost-effectiveness of an emergency department-based early sepsis resuscitation protocol. Crit Care Med 2011;39(6):1306–1312. DOI: 10.1097/CCM.0b013e31821201be.
55. Noritomi DT, Ranzani OT, Monteiro MB, Ferreira EM, Santos SR, Leibel F, et al. Implementation of a multifaceted sepsis education program in an emerging country setting: Clinical outcomes and cost-effectiveness in a long-term follow-up study. Intensive Care Med 2014;40(2):182–191. DOI: 10.1007/s00134-013-3131-5.
56. Manns BJ, Lee H, Doig CJ, Johnson D, Donaldson C. An economic evaluation of activated protein C treatment for severe sepsis. N Engl J Med 2002;347(13):993–1000. DOI: 10.1056/NEJMsa020969.
57. Socal MP, Cordeiro T, Anderson GF, Bai G. Estimating savings opportunities from therapeutic substitutions of high-cost generic medications. JAMA Netw Open 2022;5(11):e2239868. DOI: 10.1001/jamanetworkopen.2022.39868.
58. Rosenthal VD, Udwadia FE, Kumar S, Poojary A, Sankar R, Orellano PW, et al. Clinical impact and cost-effectiveness of split-septum and single-use prefilled flushing device vs 3-way stopcock on central line-associated bloodstream infection rates in India: A randomized clinical trial conducted by the International Nosocomial Infection Control Consortium (INICC). Am J Infect Control 2015;43(10):1040–1045. DOI: 10.1016/j.ajic.2015.05.042.
59. Siddiqui UT, Tahir MZ, Shamim MS, Enam SA. Clinical outcome and cost effectiveness of early tracheostomy in isolated severe head injury patients. Surg Neurol Int 2015;6:65. DOI: 10.4103/2152-7806.155757.
60. Herritt B, Chaudhuri D, Thavorn K, Kubelik D, Kyeremanteng K. Early vs. late tracheostomy in intensive care settings: Impact on ICU and hospital costs. J Crit Care 2018;44:285–288. DOI: 10.1016/j.jcrc.2017.11.037.
61. Kyeremanteng K, Gagnon LP, Thavorn K, Heyland D, D'Egidio G. The impact of palliative care consultation in the ICU on length of stay: A systematic review and cost evaluation. J Intensive Care Med 2018;33(6):346–353. DOI: 10.1177/0885066616664329.
62. Peek GJ, Mugford M, Tiruvoipati R, Wilson A, Allen E, Thalanany MM, et al. Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): A multicentre randomised controlled trial. Lancet Lond Engl 2009;374(9698):1351–1363. DOI: 10.1016/S0140-6736(09)61069-2.
63. Park M, Mendes PV, Zampieri FG, Azevedo LCP, Costa ELV, Antoniali F, et al. The economic effect of extracorporeal membrane oxygenation to support adults with severe respiratory failure in Brazil: A hypothetical analysis. Rev Bras Ter Intensiva 2014;26(3):253–262. DOI: 10.5935/0103-507X.20140036.
64. Smith KJ, Pesce RR. Pulmonary artery catheterization in exacerbations of COPD requiring mechanical ventilation: A cost-effectiveness analysis. Respir Care 1994;39(10):961–967. PMID: 10146114.
65. Chacko B, Thomas K, David T, Paul H, Jeyaseelan L, Peter JV. Attributable cost of a nosocomial infection in the intensive care unit: A prospective cohort study. World J Crit Care Med 2017;6(1):79–84. DOI: 10.5492/wjccm.v6.i1.79.

66. Dziegielewski C, Skead C, Canturk T, Webber C, Fernando SM, Thompson LH, et al. Delirium and associated length of stay and costs in critically ill patients. Crit Care Res Pract 2021;2021:6612187. DOI: 10.1155/2021/6612187.
67. Bagshaw SM, Tran DT, Opgenorth D, Wang X, Zuege DJ, Ingolfsson A, et al. Assessment of costs of avoidable delays in intensive care unit discharge. JAMA Netw Open 2020;3(8):e2013913. DOI: 10.1001/jamanetworkopen.2020.13913.
68. Sud S, Mittmann N, Cook DJ, Geerts W, Chan B, Dodek P, et al. Screening and prevention of venous thromboembolism in critically ill patients: A decision analysis and economic evaluation. Am J Respir Crit Care Med 2011;184(11):1289–1298. DOI: 10.1164/rccm.201106-1059OC.
69. Cox CE, Carson SS, Govert JA, Chelluri L, Sanders GD. An economic evaluation of prolonged mechanical ventilation. Crit Care Med 2007;35(8):1918–1927. DOI: 10.1097/01.CCM.0000275391.35834.10.
70. De Cock E, Krueger WA, Sorensen S, Baker T, Hardewig J, Duttagupta S, et al. Cost-effectiveness of linezolid vs vancomycin in suspected methicillin-resistant Staphylococcus aureus nosocomial pneumonia in Germany. Infection 2009;37(2):123–132. DOI: 10.1007/s15010-008-8046-7.
71. Heyland DK, Konopad E, Noseworthy TW, Johnston R, Gafni A. Is it "worthwhile" to continue treating patients with a prolonged stay (>14 days) in the ICU? An economic evaluation. Chest 1998;114(1):192–198. DOI: 10.1378/chest.114.1.192.
72. Sznajder M, Aegerter P, Launois R, Merliere Y, Guidet B, CubRea. A cost-effectiveness analysis of stays in intensive care units. Intensive Care Med 2001;27(1):146–153. DOI: 10.1007/s001340000760.
73. Graf J, Wagner J, Graf C, Koch KC, Janssens U. Five-year survival, quality of life, and individual costs of 303 consecutive medical intensive care patients–A cost-utility analysis. Crit Care Med 2005;33(3):547–555. DOI: 10.1097/01.ccm.0000155990.35290.03.
74. van Mastrigt GA, Heijmans J, Severens JL, Fransen EJ, Roekaerts P, Voss G, et al. Short-stay intensive care after coronary artery bypass surgery: Randomized clinical trial on safety and cost-effectiveness. Crit Care Med 2006;34(1):65–75. DOI: 10.1097/01.ccm.0000191266.72652.fa.
75. Ridley S, Morris S. Cost effectiveness of adult intensive care in the UK. Anaesthesia 2007;62(6):547–554. DOI: 10.1111/j.1365-2044.2007.04997.x.
76. Graf J, Mühlhoff C, Doig GS, Reinartz S, Bode K, Dujardin R, et al. Health care costs, long-term survival, and quality of life following intensive care unit admission after cardiac arrest. Crit Care 2008;12(4):R92. DOI: 10.1186/cc6963.
77. Linko R, Suojaranta-Ylinen R, Karlsson S, Ruokonen E, Varpula T, Pettilä V, et al. One-year mortality, quality of life and predicted life-time cost-utility in critically ill patients with acute respiratory failure. Crit Care 2010;14(2):R60. DOI: 10.1186/cc8957.
78. Cubro H, Somun-Kapetanovic R, Thiery G, Talmor D, Gajic O. Cost effectiveness of intensive care in a low resource setting: A prospective cohort of medical critically ill patients. World J Crit Care Med 2016;5(2):150–164. DOI: 10.5492/wjccm.v5.i2.150.