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Cost and Healthcare Utilization in ARDS – Different from Other Critical Illness?

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Abstract

Costs of care in the intensive care unit are a frequent target for concern in the current healthcare system. Utilization of critical care services in the United States is increasing and will continue to do so. Acute respiratory distress syndrome (ARDS) is a common and important complication of critical illness. Patients with ARDS frequently have long hospitalizations and consume a significant amount of healthcare resources. Many patients are discharged with functional limitations and high susceptibility to new complications which require significant additional healthcare resources. There is increasing literature on the cost-effectiveness of the treatment of ARDS, and despite its high costs, treatment remains a cost-effective intervention by current societal standards. However, when ARDS leads to prolonged mechanical ventilation, treatment becomes less cost-effective. Current research seeks to find interventions that lead to reductions in duration of mechanical ventilation and ICU lengths of stay. Limited reductions in ICU length of stay have benefits for the patient, but they do not lead to significant reductions in overall hospital costs. Early discharge to post-acute care facilities can reduce hospital costs but are unlikely to decrease costs for an entire episode of illness. Improved effectiveness of communication between clinicians and patients or their surrogates could help avoid costly interventions with poor expected outcomes.

Keywords

ARDS; Mechanical Ventilation; Critical Care; Costs and Cost Analysis

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Background

Any discussion of healthcare in the 21st century must include a discussion of the costs of delivery of care. The intensive care unit (ICU) consumes a significant portion of hospital and healthcare costs. In the coming years, the ICU will remain an obvious target for attempts at cost reduction, as the number of critical care medicine beds has been increasing in the United States. Between 2000 and 2005, this number grew by 6.5% (88,252 to 93,955), and accounted for 15.2% (23.2 million) of hospital days, an increase of 10.6%.[1] In 2005, critical care medicine costs ($81.7 billion) accounted for 4.1% of overall healthcare expenditures and 0.66% of gross domestic product. Acute respiratory distress syndrome (ARDS) remains common, with an incidence of 78.9 cases per 100,000 person-years, and mortality remains high (38.5%).[2] Patients with ARDS almost always require mechanical ventilation, and they require higher lengths of stay than their non-mechanically ventilated counterparts. ARDS patients are at high risk for requiring prolonged mechanical ventilation, thus have a high potential to utilize significant healthcare resources.[3] But does ARDS cost more than other disease process? Here we will review the basics of health economics, discuss the actual costs of ARDS compared to other critical illness, and discuss whether the treatment for ARDS is cost-effective.

Terminology

In order to fully understand cost information, an appreciation of cost-related terminology is critical. Costs refer to any unit of expenditure that is incurred when providing a service. There are several types of costs when considering medical care, including direct vs. indirect, fixed vs. variable, medical vs. nonmedical, total vs. marginal.[4-7] Direct medical costs are those costs consumed in the delivery of a health intervention within the health care setting. These can be either fixed costs, i.e. costs that are incurred regardless of whether a service is provided, or variable costs, i.e. costs that are only generated when care is actually delivered. Examples of fixed costs include nursing salaries or overhead costs (utilities, insurance, administrative costs, etc.), while variable costs include physician labor, diagnostic testing, or medication costs. Direct non-medical costs are those which are incurred by the patient or their family that are not related to care provided by the hospital or physicians. These may include medical transportation, family lodging, and rehabilitation or in-home care after the hospitalization. Indirect costs are often the most difficult to quantify and include lost wages or productivity of the patient or family members.[8] Marginal costs refer to the additive costs of an additional day of hospitalization.[7]

Simply reporting total costs of an intervention is one approach to cost analysis. However, a more worthwhile exercise is examining cost-effectiveness. This compares not only costs between interventions, but also the *effects* of the intervention, i.e. how well does an intervention perform with regard to some outcome. Table 1 shows several commonly utilized methods of economic evaluations.[5,9,10] Cost-minimization analysis refers to a simple practice of comparing how much two interventions with the same effectiveness cost. The less expensive intervention would be superior. Unfortunately, medicine (and especially critical care medicine) rarely compares two interventions with similar efficacy. Cost-benefit analysis takes this one step further, and assigns a monetary benefit to the intervention.

Therefore, cost-benefit analysis yields a dollar spent for dollar gained result. However, much of the benefit in medicine is difficult to monetize, for example, precisely how much is life worth when compared to death? Cost-effectiveness analysis instead examines the ratio of the cost of an intervention to a unit of outcome, for example, dollars per life-year gained. This is an improvement over either cost-minimization and cost-benefit analyses, but does not allow one to compare interventions with different outcomes (e.g. mortality and reduction in days of mechanical ventilation are not equal). Cost-utility analysis (often used interchangeably with cost-effectiveness analysis) improves upon cost-effectiveness by assigning some measure of utility, typically a scale from 0 (death) to 1 (fully healthy) to each life-year gained. The unit of measurement this analysis creates is a ratio of dollars per quality-adjusted life year (QALY). A QALY represents one year of life multiplied by some measure of utility, typically 0 (representing death) to 1 (representing fully healthy).[5]

Therefore a person who survives for 4 years at 0.75 utility gains 3 QALYs. This allows for comparison of a variety of interventions with different outcomes in a standardized way, using an incremental cost-effectiveness ratio (ICER), and also creates a patient-centered outcome, as it takes into account quality of life. Obviously, it is a complicated measure, so a disadvantage is the difficulty understanding the measurement. The generally accepted cutoff for what is considered cost-effective is $50,000 per QALY.[11,12] This point of reference comes from the incremental cost-effectiveness ratio of dialysis, which is a federal entitlement to all citizens under Medicare.[12] By that rationale, any intervention that is as cost-effective as dialysis should also be offered to all. Interventions with ICERs >$100,000 per QALY are considered to be not cost-effective. Some authors believe that this number underestimates the acceptable costs to society, based on inflation and current accepted practices. One study suggested a range of $109,000 to $297,000 per QALY would be more in line with current societal preferences and inflation.[13]

Intensive Care Unit Costs

The intensive care unit consumes a large portion of hospital resources. Patients in the intensive care unit have longer lengths of stay and higher total costs than patients who never require ICU care.[14] Recent estimates show that ICU care is responsible for 13.4% of hospital costs.[1] When limited to Medicare beneficiaries, this number increases to almost one-third, while only 22% of Medicare hospitalizations require an ICU stay.[14] The average ICU patient has a longer length of stay when compared to the hospitalized patient who never requires ICU care (7.8 days vs. 5.0 days). In the same study of Medicare recipients, the average total cost of hospitalization is much higher for patients who require an ICU stay than for those who never require ICU care ($14,135 vs. $5,571).[14] Other studies have found slightly more variable costs, ranging from $14,135 to $32,253.[4,14,15] Average daily costs in the ICU range from $2,278-$3518.[1,14] However, using this analysis can be somewhat misleading, as multiple studies have demonstrated that the first ICU day is significantly more expensive than each subsequent day.[4,7] As shown in Figure 1, the cost of the first ICU day was $7,728, while subsequent day costs were each less than $4,000. Patients who require ICU care also have a significant burden of illness after hospitalization. Another study of Medicare recipients examined patients who required an ICU stay, patients who were hospitalized but never required ICU care, and patients who were never hospitalized.

This study showed that the rate of hospitalization and use of skilled nursing facility (SNF) was slightly higher in the ICU group than in hospital controls, and significantly higher than the general population.[16]

Costs of Mechanical Ventilation

Patients requiring mechanical ventilation utilize an even larger portion of critical care medicine and hospital resources. Nearly 3% of hospitalized patients require mechanical ventilation, with an incidence of 2.7 episodes per 1000 population.[3] At an estimated national cost of $27 billion, this represents nearly one-third of ICU costs. Mechanically ventilated patients accrue higher total costs than their non-ventilated counterparts. In 2005, a study conducted to determine the attributable costs of mechanical ventilation revealed longer mean lengths of stay (6.9 days vs. 2.9 days), higher total ICU costs ($31,574 vs. $12,931) and hospital costs ($47,158 vs. $23,707) and an incremental cost of $1,522 per patient per day.[4] However, this incremental cost reflected average daily total costs, rather than marginal or variable costs. Median costs were significantly lower than average costs for all patients in this same study, again demonstrating that ICU costs, including those of mechanically ventilated patients, are not likely to be normalized, but skewed by higher initial costs (Figure 1). Moreover, it is important to remember that much of the cost associated with mechanical ventilation is reflective of their higher severity of illness when compared to their non-ventilated counterparts. Comparing the cost of an ICU day liberated from mechanical ventilation to an ICU day of a patient who never required mechanical ventilation may not be a realistic comparison. Additionally, another study to evaluate the marginal costs of an ICU stay confirmed that over 80% of costs in the ICU are fixed hospital costs, which are incurred regardless of patient throughput.[7] The contribution of direct-variable costs (i.e. costs that could potentially be reduced by a shorter length of stay or fewer interventions) was much smaller (see Table 2). For example, the direct-variable cost-reduction of liberating a patient from the ventilator was only $106. Transferring a patient from the ICU to the ward saved only $118.

Several studies have evaluated the cost-effectiveness of mechanical ventilation.[15,17-20] Incremental costs per QALY range from $11,970 to $110,000. Variations in costs can be variably ascribed to adjustments for age, comorbidities and prognosis. For example, the cost of providing mechanical ventilation to a patient with acute respiratory failure *without* pre-existing lung disease was $11,970 per QALY, while the same provision to a patient *with* pre-existing lung disease was $14,365 per QALY.[15]

Prolonged mechanical ventilation (PMV) accounts for 5-10% of patients who require mechanical ventilation. PMV patients have a 1-year mortality of 50 to 60% in most studies.[8,21,22] Economic evaluation of prolonged mechanical ventilation has been complicated in the past, given a wide variety of definitions for PMV. One study compared the costs of prolonged acute mechanical ventilation (PAMV), defined as 96 hours or greater, with mechanical ventilation for less than 96 hours (acute MV).[23] Of over 750,000 patients requiring mechanical ventilation in 2003, 61% received it for less than 96 hours, while 39% received PAMV. Patients with PAMV, when compared to patients with acute MV, experienced longer length of stay (17 vs. 6 days) and higher median costs ($40,903 vs.

$13,434). Average daily costs were not statistically different between the groups ($2,666 for PAMV vs. $3,228 for MV). Total aggregate costs were over $16 billion for PAMV patients compared to only $9 billion for the acute MV group. Therefore, 39% of patients requiring mechanical ventilation account for 64% of hospital costs for mechanically ventilated patients. In-hospital mortality was similar in the two groups. PMV also contributes significantly to post-hospital costs. One study revealed that recipients of PMV spent nearly 75% of the first year either in an LTAC, SNF, or receiving home health care.[24] Two-thirds of these patients were readmitted to the hospital at least once after discharge. Mean costs per patient in this study were $306,135.

Fewer studies have analyzed the cost-effectiveness of prolonged mechanical ventilation. One study demonstrated even wider variation in cost-effectiveness in PMV than is seen during mechanical ventilation in general.[18] This study utilized a base case patient, and defined PMV as mechanical ventilation for ≥21 days with placement of a tracheostomy. The comparison was the alternative of withdrawal of mechanical ventilation at some point between 7 and 21 days of mechanical ventilation. This study also examined post-hospital costs, which are typically much higher for patients that require mechanical ventilation. Total costs for care were $196,077 for PMV, compared to $52,269 for withdrawal of mechanical ventilation. Hospitalization accounted for $120,370 of this total for the PMV patient. Obviously, the withdrawal comparator incurred no post-hospital costs. Incremental costs were considerably higher for PMV compared to mechanical ventilation in general, with an overall ICER of $82,411 per QALY. The same increased costs held up when utilizing an alternative definition of PMV (mechanical ventilation for ≥4 days plus tracheostomy placement) with ICER of $73,629 per QALY. Using the same modeling, provision of mechanical ventilation for ≥2 days but <7 days incurred only $28,517 per QALY. Further broken down by age, providing PMV for an 18-year-old was associated with an ICER of only $14,289 per QALY, while the same provision for a 75-year-old incurred $127,589 per QALY, and an 85-year-old >$206,000 per QALY. When adjusted based on estimated 1-year survival, those with >50% survival would incur $60,967 per QALY, while those with <50% 1-year survival incurred $101,787 per QALY.

Cost Differences Between ARDS and Other Critical Illness

Outcomes and costs of ARDS have been well-studied in a large cohort of patients. A series of articles has reported on one-, two-, and 5-year outcomes of hospital survivors of ARDS.[25-27] The cohort was composed of 109 patients identified with ARDS, between 1998-2002. Patients were followed prospectively for 1 year, then consented for further follow-up. The authors examined costs, including post-hospital costs, functional status, and work status. Average total hospital costs were $128,860 (2002 Canadian $), with the majority of this cost born in the ICU ($97,810). Of these costs, the largest contributor was nursing care, which accounted for over 75% of the costs incurred. Of survivors at 2 years, 39% had been hospitalized, 20% more than once. Post-discharge costs were $28,350 by year two (2002 Can$), and totaled $49,572 by year 5 (2009 Can$). Figure 2 shows the post-discharge costs. The first year after discharge was the most expensive, responsible for nearly half the 5-year total. Post-discharge costs varied significantly based on the number of coexisting illnesses. Patients with ≤1 coexisting illness incurred less than $40,000 by year 5, while those with ≥2 coexisting illnesses incurred over $80,000. Average yearly post-hospital costs by year 5 were $5,566, which was fairly stable from the two years prior. This remains higher than the expected costs for healthy workers of between $1,100 and $3,200.

Consistent with the high costs of caring for ARDS survivors were their high degree of functional limitations. At one year, only 49% had returned to work.[25] At two years, this number had increased to 65%.[26] However, at 5 years, only 77% had ultimately returned to work.[27] Of survivors with complete follow-up, 83% had been working prior to their critical illness. This study was not able to measure indirect costs (as discussed earlier, quite difficult to measure) but the increased costs of their health-care after their illness coupled with the lost wages of the patients and their families only serves to increase the burden of critical illness in these patients.

Another study evaluated the cost-effectiveness of mechanical ventilation for ARDS based on the SUPPORT trial. [20,28] In this study, they developed a model to determine the likelihood of survival, and stratified patients to low-risk (>70% estimated 2-month survival), medium-risk (51-70% estimated 2-month survival), and high-risk (≤50% estimated 2-month survival). Total costs and cost-effectiveness both varied by likelihood of survival. Total costs were higher for medium-risk patient ($70,130) than for low-risk ($59,096) or high-risk, $59,310. However, cost-effectiveness was directly proportional to risk. For low-risk ARDS patients, the ICER was $29,000 per QALY, for medium-risk patients, the ICER rose to $44,000 per QALY, and for high-risk patients, the ICER increased to $110,000 per QALY, beyond what is considered cost-effective. Such a small change in prognosis and survival had a tremendous impact on expected costs.

So how do these costs compare with other accepted medical treatments? Table 3 summarizes the incremental costs associated with various interventions, both in and out of the ICU. Mechanical ventilation for acute respiratory failure is as cost-effective as many other medical interventions. For example, mechanical ventilation for ARDS has similar cost-effectiveness to the use of recombinant tissue plasminogen activator for acute stroke, therapeutic hypothermia for out-of-hospital cardiac arrest, percutaneous coronary intervention for stable angina, and cardiac resynchronization therapy for heart failure.[29-32] Prolonged mechanical ventilation may be cost effective when provided to younger patients with fewer comorbidities, and those whose expected survival is >50%. Prolonged mechanical ventilation is not cost-effective when provided to a patient with less than a 50% chance of survival. However, PMV still is less costly than CPR for in-hospital cardiac arrest, which boasts an ICER of $225,892 per QALY.[33]

Factors driving costs

There are many factors that contribute to the costs of ICU care and ARDS. Patients who require mechanical ventilation have higher severity of illness and a higher number of comorbidities than their non-mechanically ventilated counterparts.[16] These patients also have higher lengths of stay, thus driving up total costs regardless of stable daily costs after the first two days.[3,16,34,35] These patient factors are generally not modifiable, but do have a significant impact on costs.[36] Insurance status, or more specifically the lack thereof, seems to result in decreased utilization of common ICU resources, e.g. tracheostomy, hemodialysis, and central venous catheters.[37] This seemingly decreases costs, but is also associated with an increased risk of mortality. Unfortunately, the largest contributor to healthcare costs is hospital costs, and direct fixed costs comprise over 80% of these costs.[7] Changes in ICU length of stay will only modify these costs if the discharged patient is not replaced with a new patient in their stead. Over time, reductions in ICU length of stay could lead to a reduction in staffing needs, which could reduce costs, but this could have a negative impact on workforce. With the increasing utilization of ICU beds, it is unlikely that meaningful reduction in workforce costs could be achieved.

Implications for Practitioners and Policy-makers

What can be done about the costs of critical care? Quality improvement initiatives have demonstrated reductions in hospital acquired complications, which can reduce costs.[38,39] Multiple studies have demonstrated an improvement in catheter-related blood-stream infection rate when simple protocols were implemented.[38-40] A recent study demonstrated that even potentially costly interventions to improve adherence to lung protective ventilation from 50 to 90% would be cost-effective, with an ICER of $11,690 per QALY.[17] A hospital could spend over $9,000 per patient to implement better adherence, and this intervention remained cost-effective. Yet, despite these interventions, it remains true that the majority of costs in the intensive care unit remain fixed, and are resistant to such interventions. Modest reductions in days of mechanical ventilation, ICU length of stay, and even hospitalization are unlikely to yield significant cost reductions.

Despite this, many interventions in critical care have aimed at decreasing ICU and hospital length of stay. As an example of the potential flaws in this approach, one study demonstrated that the true cost reduction accomplished by reducing ICU length of stay by one day was only $118.[7] This analysis may have underestimated attributable costs, though, as each day in the hospital increases the risk of hospital acquired complications, and nosocomial complications are more common in the ICU. Approximately 90% of nosocomial blood stream infections are associated with central venous catheters, which are more commonly placed in the intensive care unit.[41] These complications incur additional costs and increase both ICU and hospital length of stay.[42] In one study, adverse events were associated with an increase in ICU costs of $3,961.[43] While reducing ICU length of stay may have an impact on the rate of complications, it is unclear what length of stay reduction translates into clinically meaningful reduction in these complications.

On the other hand, one method that many hospitals utilize to reduce length of stay and perhaps *hospital costs* is to discharge patients to long-term acute care hospitals (LTACs). There is significant incentive for hospitals to reduce length of stay, and therefore utilization of long-term acute care hospitals (LTACs) has been increasing.[44,45] The Center for Medicaid and Medicare Services (CMS) stipulates that LTACs are required to have an average length of stay greater than 25 days for its Medicare recipients.[46] LTACs are paid less for patients who stay < 5/6 of their average length-of-stay. This practice is likely to result in cost-shifting as opposed to true cost reduction, however. In fact, one study recently noted that the costs *of total episode of illness* for patients referred to LTACs were nearly

50% higher than costs for similar patients not referred.[47] This remained true regardless of the reason for initial admission. In patients requiring mechanical ventilation, the mean cost of care was $32,930. Length of stay was at least 20 days longer for the patients referred to an LTAC than for their matched counterparts. Reforming the payment structure for these typically for-profit post-acute care institutions represents a priority for cost-reduction measures.

The utilization of critical care services is increasing, and will continue to increase. The complexity of the patients cared for in the ICU is also increasing.[35,44] Both the Leapfrog group and the Society of Critical Care Medicine have made recommendations regarding intensivist physician staffing of the ICU.[48,49] Despite this, there remains a difficulty finding sufficient intensivist physicians to adequately meet these recommendations.[50] Additionally, the possible benefit of 24-hour staffing of ICUs by intensivists remains unclear. One study has shown that there is no impact on mortality if the ICU is already staffed by an intensivist during the day.[51] Another study demonstrated no impact on long-term survival or quality of life with the addition of a nighttime intensivist to an ICU in a teaching hospital.[52] There remains inadequate data regarding the optimal number of ICU patients a single intensivist should provide care for or what is the best balance of intensivists and lower-cost physician extenders. Future studies identifying optimal staffing levels could aid in cost reduction through improved delivery of critical care.

Prolonged mechanical ventilation appears to be more costly than the provision of short-term mechanical ventilation, and appears to be a reasonable target for cost-reduction. The number of patients receiving PMV increased from around 250,000 in 2000 to over 375,000 in 2008, and is expected to be greater than 625,000 by the year 2020.[53] Future interventions in the provision of prolonged mechanical ventilation, or the avoidance of PMV could lead to significant reductions in the costs of critical care. Yet, despite the high costs of PMV, a study of survivors of PMV found that 75.9% would choose to undergo mechanical ventilation based on their experiences.[54] Recipients of Medicare were less likely to choose mechanical ventilation in this study. However, another study of surrogates found that an overwhelming majority reported receiving no information regarding aspects of PMV that they felt was important, including expected functional status (80%), quality of life (72%), cognitive status (65%), and services that might be needed after hospitalization (82%).[55] Another study demonstrated that there is significant discordance between clinicians and patients or their surrogates regarding expected outcomes of PMV.[8] Both physicians and surrogates tended to be overly optimistic regarding potential outcomes. In that same study, only 11% of patients were alive and independently functioning at one year. A recently developed prognostic model can aid physicians in discussing potential outcomes with patients and their families.[56] Further development of useful, timely, and broadly applicable prognostication tools and communication interventions, particularly when it comes to prolonged mechanical ventilation would be a potential method to reduce utilization of this costly intervention. Effective communication remains the ICU clinician's best tool in addressing the appropriateness of ICU care.

Summary

Evaluation of costs in the intensive care unit is a complicated endeavor. A variety of factors affect the costs of care. The provision of short-term mechanical ventilation for acute respiratory failure and ARDS is cost-effective by current societal standards. Continued focus on interventions to reduce duration of mechanical ventilation and ICU length of stay are clinically important, but may not yield significant cost reductions for the healthcare system. Prolonged mechanical ventilation may not be cost-effective, particularly when provided to those with worse prognoses. Improved development of prognostication models and increased effectiveness of communication between clinicians and patients or their surrogates could help avoid costly interventions with poor outcomes.

References

1. Halpern NA, Pastores SM. Critical care medicine in the United States 2000-2005: an analysis of bed numbers, occupancy rates, payer mix, and costs. Critical care medicine. 2010; 38:65–71. [PubMed: 19730257]
2. Rubenfeld GD, Caldwell E, Peabody E, et al. Incidence and outcomes of acute lung injury. The New England journal of medicine. 2005; 353:1685–93. [PubMed: 16236739]
3. Wunsch H, Linde-Zwirble WT, Angus DC, Hartman ME, Milbrandt EB, Kahn JM. The epidemiology of mechanical ventilation use in the United States. Critical care medicine. 2010; 38:1947–53. [PubMed: 20639743]
4. Dasta JF, McLaughlin TP, Mody SH, Piech CT. Daily cost of an intensive care unit day: The contribution of mechanical ventilation*. Critical care medicine. 2005; 33:1266–71. [PubMed: 15942342]
5. Jegers M, Edbrooke DL, Hibbert CL, Chalfin DB, Burchardi H. Definitions and methods of cost assessment: an intensivist's guide. ESICM section on health research and outcome working group on cost effectiveness. Intensive care medicine. 2002; 28:680–5. [PubMed: 12107670]
6. Kahn JM. Understanding economic outcomes in critical care. Curr Opin Crit Care. 2006; 12:399–404. [PubMed: 16943716]
7. Kahn JM, Rubenfeld GD, Rohrbach J, Fuchs BD. Cost savings attributable to reductions in intensive care unit length of stay for mechanically ventilated patients. Medical care. 2008; 46:1226–33. [PubMed: 19300312]
8. Cox CE, Martinu T, Sathy SJ, et al. Expectations and outcomes of prolonged mechanical ventilation. Critical care medicine. 2009; 37:2888–94. quiz 904. [PubMed: 19770733]
9. Gold, MR. Cost-effectiveness in health and medicine. Oxford University Press; New York: 1996.
10. Understanding costs and cost-effectiveness in critical care: report from the second American Thoracic Society workshop on outcomes research. American journal of respiratory and critical care medicine. 2002; 165:540–50. [PubMed: 11850349]
11. Hirth RA, Chernew ME, Miller E, Fendrick AM, Weissert WG. Willingness to pay for a quality-adjusted life year: in search of a standard. Medical decision making: an international journal of the Society for Medical Decision Making. 2000; 20:332–42. [PubMed: 10929856]
12. Ubel PA, Hirth RA, Chernew ME, Fendrick AM. What is the price of life and why doesn't it increase at the rate of inflation? Archives of Internal Medicine. 2003; 163:1637–41. [PubMed: 12885677]
13. Braithwaite RS, Meltzer DO, King JT, Leslie D, Roberts MS. What does the value of modern medicine say about the $50,000 per Quality-Adjusted Life-Year decision rule? Medical care. 2008; 46:349–56. [PubMed: 18362813]
14. Cooper LM, Linde-Zwirble WT. Medicare intensive care unit use: Analysis of incidence, cost, and payment. Critical care medicine. 2004; 32:2247–53. [PubMed: 15640637]
15. Sznajder M, Aegerter P, Launois R, Merliere Y, Guidet B, CubRea A. cost-effectiveness analysis of stays in intensive care units. Intensive care medicine. 2001; 27:146–53. [PubMed: 11280626]

16. Wunsch H, Guerra C, Barnato AE, Angus DC, Li G, Linde-Zwirble WT. Three-year outcomes for Medicare beneficiaries who survive intensive care. JAMA: the journal of the American Medical Association. 2010; 303:849–56.
17. 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; 136:79–88. [PubMed: 19318673]
18. Cox CE, Carson SS, Govert JA, Chelluri L, Sanders GD. An economic evaluation of prolonged mechanical ventilation. Critical care medicine. 2007; 35:1918–27. [PubMed: 17581479]
19. Linko R, Suojaranta-Ylinen R, Karlsson S, Ruokonen E, Varpula T, Pettila V. One-year mortality, quality of life and predicted life-time cost-utility in critically ill patients with acute respiratory failure. Crit Care. 2010; 14:R60. [PubMed: 20384998]
20. Hamel MB, Phillips RS, Davis RB, 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. American Journal of Medicine. 2000; 109:614–20. [PubMed: 11099680]
21. Carson SS. Outcomes of prolonged mechanical ventilation. Curr Opin Crit Care. 2006; 12:405–11. [PubMed: 16943717]
22. Cox CE, Carson SS, Lindquist JH, Olsen MK, Govert JA, Chelluri L. Differences in one-year health outcomes and resource utilization by definition of prolonged mechanical ventilation: a prospective cohort study. Crit Care. 2007; 11:R9. [PubMed: 17244364]
23. Zilberberg MD, Luippold RS, Sulsky S, Shorr AF. Prolonged acute mechanical ventilation, hospital resource utilization, and mortality in the United States. Critical care medicine. 2008; 36:724–30. [PubMed: 18209667]
24. Unroe M, Kahn JM, Carson SS, et al. One-year trajectories of care and resource utilization for recipients of prolonged mechanical ventilation: a cohort study. Annals of internal medicine. 2010; 153:167–75. [PubMed: 20679561]
25. Herridge MS, Cheung AM, Tansey CM, et al. One-year outcomes in survivors of the acute respiratory distress syndrome. The New England journal of medicine. 2003; 348:683–93. [PubMed: 12594312]
26. Cheung AM, Tansey CM, Tomlinson G, et al. Two-year outcomes, health care use, and costs of survivors of acute respiratory distress syndrome. American journal of respiratory and critical care medicine. 2006; 174:538–44. [PubMed: 16763220]
27. Herridge MS, Tansey CM, Matte A, et al. Functional disability 5 years after acute respiratory distress syndrome. The New England journal of medicine. 2011; 364:1293–304. [PubMed: 21470008]
28. Knaus WA, Harrell FE Jr. Lynn J, et al. The SUPPORT prognostic model. Objective estimates of survival for seriously ill hospitalized adults. Study to understand prognoses and preferences for outcomes and risks of treatments. Annals of internal medicine. 1995; 122:191–203. [PubMed: 7810938]
29. Jung KT, Shin DW, Lee KJ, Oh M. Cost-effectiveness of recombinant tissue plasminogen activator in the management of acute ischemic stroke: a systematic review. J Clin Neurol. 2010; 6:117–26. [PubMed: 20944812]
30. Merchant RM, Becker LB, Abella BS, Asch DA, Groeneveld PW. Cost-effectiveness of therapeutic hypothermia after cardiac arrest. Circulation Cardiovascular quality and outcomes. 2009; 2:421–8. [PubMed: 20031872]
31. Gorenoi V, Schonermark MP, Hagen A. Percutaneous coronary intervention with optimal medical therapy vs. optimal medical therapy alone for patients with stable angina pectoris. GMS health technology assessment. 2011; 7:Doc07. [PubMed: 22205918]
32. Noyes K, Veazie P, Hall WJ, et al. Cost-Effectiveness of Cardiac Resynchronization Therapy in the MADIT-CRT Trial. Journal of cardiovascular electrophysiology. 2013; 24:66–74. [PubMed: 22913474]
33. Lee KH, Angus DC, Abramson NS. Cardiopulmonary resuscitation: what cost to cheat death? Critical care medicine. 1996; 24:2046–52. [PubMed: 8968275]

34. Rossi C, Simini B, Brazzi L, et al. Variable costs of ICU patients: a multicenter prospective study. Intensive care medicine. 2006; 32:545–52. [PubMed: 16501946]

35. Carson SS, Cox CE, Holmes GM, Howard A, Carey TS. The changing epidemiology of mechanical ventilation: a population-based study. Journal of intensive care medicine. 2006; 21:173–82. [PubMed: 16672639]

36. Shwartz M, Iezzoni LI, Moskowitz MA, Ash AS, Sawitz E. The importance of comorbidities in explaining differences in patient costs. Medical care. 1996; 34:767–82. [PubMed: 8709659]

37. Lyon SM, Benson NM, Cooke CR, Iwashyna TJ, Ratcliffe SJ, Kahn JM. The effect of insurance status on mortality and procedural use in critically ill patients. American journal of respiratory and critical care medicine. 2011; 184:809–15. [PubMed: 21700910]

38. Berenholtz SM, Pronovost PJ, Lipsett PA, et al. Eliminating catheter-related bloodstream infections in the intensive care unit*. Critical care medicine. 2004; 32:2014–20. [PubMed: 15483409]

39. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. The New England journal of medicine. 2006; 355:2725–32. [PubMed: 17192537]

40. Schwebel C, Lucet JC, Vesin A, et al. Economic evaluation of chlorhexidine-impregnated sponges for preventing catheter-related infections in critically ill adults in the Dressing Study. Critical care medicine. 2012; 40:11–7. [PubMed: 21926570]

41. Chalupka AN, Talmor D. The economics of sepsis. Critical care clinics. 2012; 28:57–76. vi. [PubMed: 22123099]

42. Saleh SS, Callan M, Therriault M, Landor N. The Cost Impact of Hospital-Acquired Conditions Among Critical Care Patients. Medical care. 2010; 48:518–26. [PubMed: 20473198]

43. Kaushal R, Bates DW, Franz C, Soukup JR, Rothschild JM. Costs of adverse events in intensive care units. Critical care medicine. 2007; 35:2479–83. [PubMed: 17828035]

44. Kahn JM, Benson NM, Appleby D, Carson SS, Iwashyna TJ. Long-term acute care hospital utilization after critical illness. JAMA: the journal of the American Medical Association. 2010; 303:2253–9.

45. Hall WB, Willis LE, Medvedev S, Carson SS. The implications of long-term acute care hospital transfer practices for measures of in-hospital mortality and length of stay. American journal of respiratory and critical care medicine. 2012; 185:53–7. [PubMed: 21940788]

46. Long-term care hospitals payment system. 2012. Accessed at http://www.medpac.gov/documents/MedPAC_Payment_Basics_12_LTCH.pdf

47. Utilization and Payment Effects of Medicare Referrals to Long-Term Care Hospitals. 2011. Accessed at http://http://www.rti.org/reports/cms/kennell/CMS_LTCH_Referral_Effects.pdf

48. Gasperino J. The Leapfrog initiative for intensive care unit physician staffing and its impact on intensive care unit performance: a narrative review. Health policy. 2011; 102:223–8. [PubMed: 21439669]

49. Ward NS, Afessa B, Kleinpell R, et al. Intensivist/Patient Ratios in Closed ICUs: A Statement From the Society of Critical Care Medicine Taskforce on ICU Staffing. Critical care medicine. 2013; 41:638–45. [PubMed: 23263586]

50. Moran J, Scanlon D. Slow Progress On Meeting Hospital Safety Standards: Learning From The Leapfrog Group's Efforts. Health affairs. 2013; 32:27–35. [PubMed: 23297268]

51. Wallace DJ, Angus DC, Barnato AE, Kramer AA, Kahn JM. Nighttime intensivist staffing and mortality among critically ill patients. The New England journal of medicine. 2012; 366:2093–101. [PubMed: 22612639]

52. Reriani M, Biehl M, Sloan JA, Malinchoc M, Gajic O. Effect of 24-hour mandatory vs on-demand critical care specialist presence on long-term survival and quality of life of critically ill patients in the intensive care unit of a teaching hospital. Journal of critical care. 2012; 27:421–e1-7. [PubMed: 22172796]

53. Zilberberg MD, de Wit M, Shorr AF. Accuracy of previous estimates for adult prolonged acute mechanical ventilation volume in 2020: update using 2000-2008 data. Critical care medicine. 2012; 40:18–20. [PubMed: 21926594]

54. Guentner K, Hoffman LA, Happ MB, et al. Preferences for mechanical ventilation among survivors of prolonged mechanical ventilation and tracheostomy. American Journal of Critical Care. 2006; 15:65–77. [PubMed: 16391316]

55. Nelson JE, Mercado AF, Camhi SL, et al. Communication about chronic critical illness. Archives of Internal Medicine. 2007; 167:2509–15. [PubMed: 18071175]

56. Carson SS, Kahn JM, Hough CL, et al. A multicenter mortality prediction model for patients receiving prolonged mechanical ventilation. Critical care medicine. 2012; 40:1171–6. [PubMed: 22080643]

57. Talmor D, Greenberg D, Howell MD, Lisbon A, Novack V, Shapiro N. The costs and cost-effectiveness of an integrated sepsis treatment protocol. Critical care medicine. 2008; 36:1168–74. [PubMed: 18379243]

58. Boudreau DM, Guzauskas G, Villa KF, Fagan SC, Veenstra DL. A Model of Cost-effectiveness of Tissue Plasminogen Activator in Patient Subgroups 3 to 4.5 Hours After Onset of Acute Ischemic Stroke. Annals of emergency medicine. 2013; 61:46–55. [PubMed: 22633340]

59. Ramsey SD, Patrick DL, Albert RK, Larson EB, Wood DE, Raghu G. The cost-effectiveness of lung transplantation. A pilot study. University of Washington Medical Center Lung Transplant Study Group. Chest. 1995; 108:1594–601. [PubMed: 7497767]

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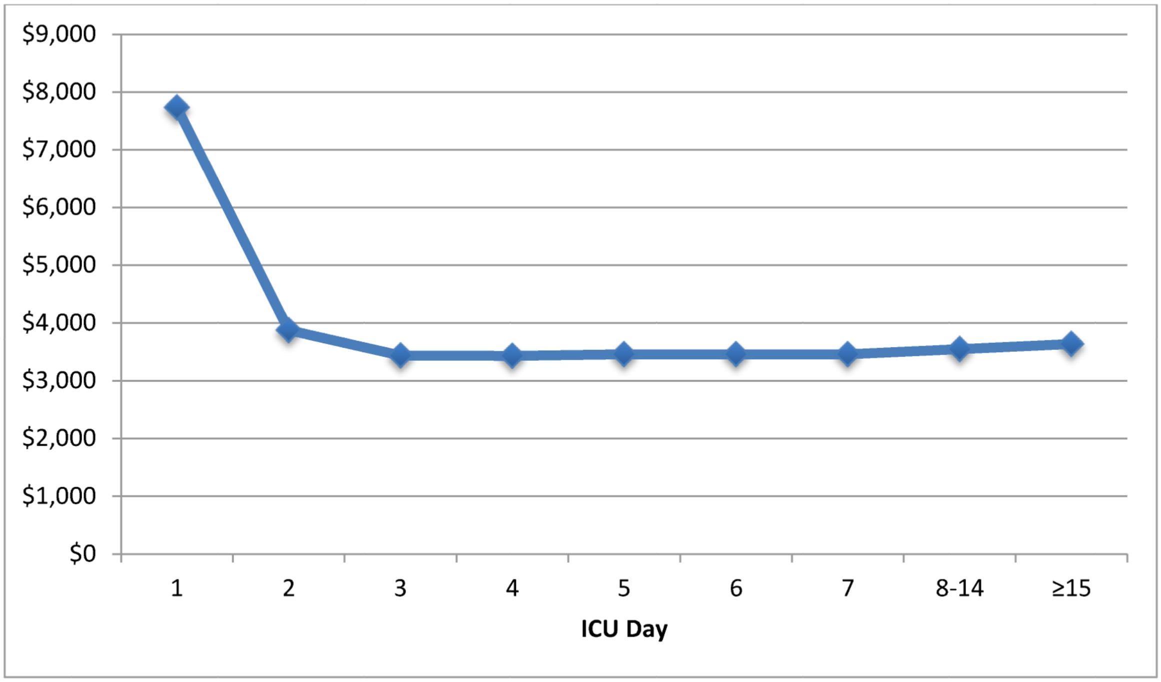

Figure 1. Mean Daily ICU Cost
Adapted from Dasta et al[4]

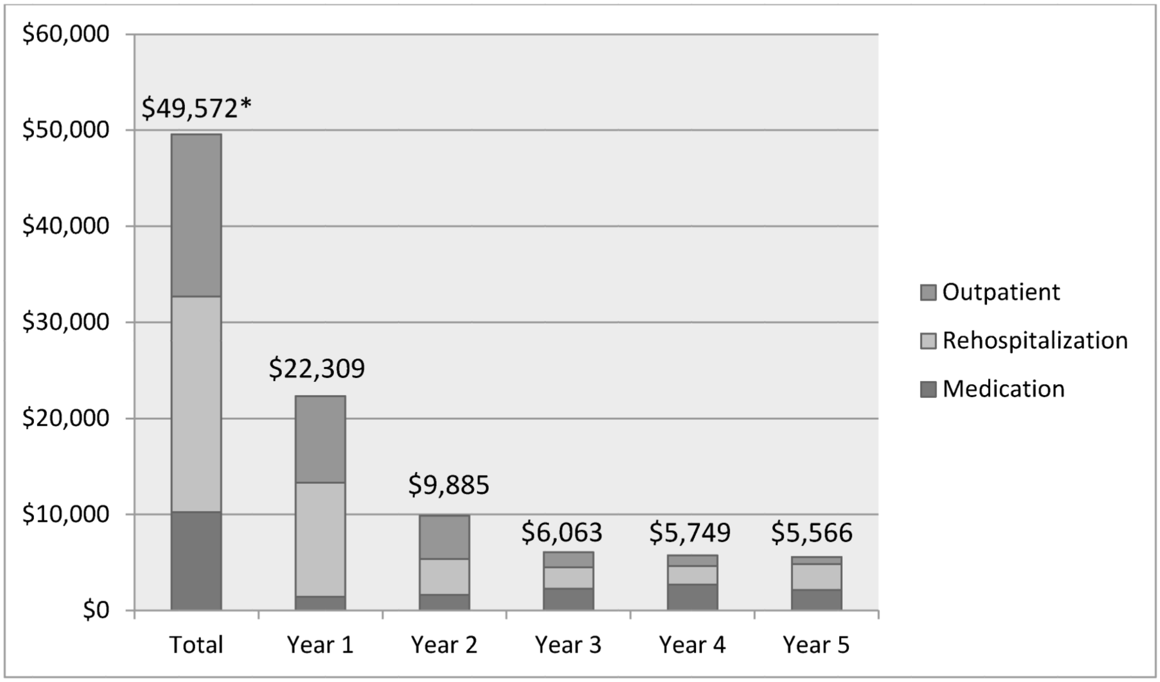

Figure 2. Post-discharge Costs of ARDS
*Costs in 2009 Canadian dollars
Adapted from Herridge et al[27]

Table 1

Types of economic evaluations

Evaluation type	Benefit Measurement	Result	Advantages/Disadvantages
Cost-minimization analysis	None	Cost Difference	Typically difficult to compare outcomes between therapies
Cost-benefit analysis	Dollars	Cost per monetary benefit	- Dissimilar therapies and outcomes can be compared - Monetary value of some outcomes (death, life) difficult to assess
Cost-effectiveness analysis	Clinical outcome	Cost per clinical outcome (e.g. per life saved)	- Evaluates for specific outcomes - Cannot compare analyses between outcomes
Cost-utility analysis	Healthy	Cost per QALY	- Can compare different therapies with different outcome assessments, evaluates patient centered outcomes (e.g. quality of life) - Can be challenging to understand

Table 2

Costs associated with mechanical ventilation

	Cost
Total Hospital	$69,472
Variable*	$28,971
Direct-Variable†	$12,773 (18.4% of total)
Average Daily Direct-Variable	$1751
Marginal Direct-Variable‡	$649-$839
Direct-Variable difference	
-- Last ICU day to first ward day	$118
-- Last ventilator day and first non-ventilator day	$106
-- Last ward day	$109

Adapted from Kahn et al[7]

*Total costs excluding overhead, but including staff salaries and equipment costs

†Variable costs excluding staff salaries and equipment costs

‡Cost of each additional day after day 2

Table 3
Cost-Effectiveness of Selected Medical Interventions

Intervention	Cost/QALY
Mechanical ventilation for respiratory failure related to pneumonia or ARDS (1998 US$)[20]	$29,000 (estimated 2-month survival >70%) $44,000 (estimated 2-month survival 51%-70%) $110,000 (estimated 2-month survival ≤50%)
ICU care for patients with acute respiratory failure without chronic lung disease (1996 US$)[15]	$11,970
ICU care for patients with acute respiratory failure *with* chronic lung disease (1996 US$)[15]	$14,365
Integrated Sepsis treatment protocol for septic shock(2004 US$)[57]	$16,309
Recombinant Tissue Plasminogen Activator in Acute Stroke[29,58]	$29,148 to 55,591 (Short-term costs) (2009 US$) −$41,137 to $4,662 (Long-term Health-care benefits/costs) (2009 US$) $6,255 (Patients between 3-4.5 hours) (2011 US$)
Lung transplantation compared to standard care (1994 US$)[59]	$44,000 (assuming 10-year survival) $204,000 (assuming 5-year survival)
Therapeutic hypothermia for out-of-hospital V-fib arrest (2008 US$)[30]	$47,168
PCI plus OMT compared with OMT alone for stable angina (2010)[31]	€24,805
CRT vs. ICD for heart failure (2008 US$)[32]	$58,330 $16,640 (subgroup with LBBB)
Prolonged mechanical ventilation (>21 days) after acute illness (2005 US$)[18]	$82,411 $60,967 (estimated 1-year survival >50%) $101,787 (estimated 1-year survival ≤50%)
In-hospital cardiopulmonary resuscitation (1995 US$)[33]	$225,892

PCI = Percutaneous coronary intervention, OMT = Optimal medical therapy, CRT = Cardiac resynchronization therapy, ICD = Implantable cardiac defibrillator, LBBB = Left bundle branch block