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Impact of ABCDE Bundle Implementation in the Intensive Care Unit on Specific Patient Costs

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Abstract

Objectives: To measure the impact of full versus partial ABCDE bundle implementation on specific cost centers and related resource utilization. **Design:** Retrospective cohort study. **Setting:** Two medical ICUs within Montefiore Health System (Bronx, NY). **Patients:** Four hundred and seventy-two mechanically ventilated patients admitted to the medical ICUs during a hospitalization which began and ended between January 1, 2013 and December 31, 2013. **Interventions:** The full (A)wakening, (B)reathing, (C)oordination, (D)elirium Monitoring/Management and (E)arly Mobilization bundle was implemented in the intervention ICU while a portion of the bundle (A, B, and D components) was implemented in the comparison ICU. **Measurements and Main Results:** Relative to the comparison ICU, implementation of the entire bundle in the intervention ICU was associated with a 27.3% (95% CI: 9.9%, 41.3%; $P = 0.004$) decrease in total hospital laboratory costs and a 2,888.6% (95% CI: 77.9%, 50,113.2%; $P = 0.018$) increase in total hospital physical therapy costs. Cost of total hospital medications, diagnostic radiology and respiratory therapy were unchanged. Relative to the comparison ICU, total hospital resource use decreased in the intervention ICU (incidence rate ratio [95% CI], laboratory: 0.68 [0.54, 0.87], $P = 0.002$; diagnostic radiology: 0.75 [0.59, 0.96], $P = 0.020$). **Conclusions:** Full ABCDE bundle implementation resulted in a decrease in total hospital laboratory costs and total hospital laboratory and diagnostic resource utilization while leading to an increase in physical therapy costs.

Keywords

critical care, intensive care units, early ambulation, cost and cost analysis, laboratories, radiology

Introduction

The Awakening and Breathing Coordination, Delirium monitoring and management, and Early mobilization (ABCDE bundle) is an amalgamation of evidence-based, multidisciplinary strategies proposed to reduce the burden of intensive care unit (ICU) acquired delirium and weakness.[1] Up to 75% of ICU patients become delirious during their ICU stay[2] and among critical illness survivors, up to 50% develop disabling muscle weakness.[3] Both comorbidities are independently associated with increased mortality, duration of mechanical ventilation, and length of ICU and hospital stay.[4-7] Persistent cognitive dysfunction and functional decline have been reported in critically ill patients who develop ICU acquired delirium and weakness.[8-10] Furthermore, delirium in critically ill patients results in increased ICU and hospital costs.[11]

We previously demonstrated that ABCDE bundle implementation is associated with a decrease in the incidence of delirium/coma, duration of mechanical ventilation, length of stay and total hospital and ICU costs.[12] Collinsworth et al showed it to be a cost-effective intervention to decrease mortality in critically ill patients.[13] Despite this evidence of benefit, however, only 45% of US ICUs have early mobilization programs.[14,15]

Financial support and staffing are 2 of the main barriers to adoption and implementation of the ABCDE bundle.[15] To overcome the economic barriers, it is important to understand

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how implementation of ABCDE in the ICU is associated with ICU and hospital cost reductions. Specifically, whether cross-the-board cost reductions are at play or, instead, focused savings and/or expenditures are to credit is unclear. Without this information, it may be difficult to (1) secure initial funding and (2) appropriately monitor returns-on-investment. Therefore, we sought to determine the impact of bundle implementation on specific costs (e.g., those related to laboratory testing) and related resource utilization (e.g., the number of specific laboratory tests ordered).

Materials and Methods

We conducted a retrospective cohort study of adults with hospitalization which began and ended between January 1, 2013 and December 31, 2013 at the medical ICU at 2 academic tertiary care hospitals within the Montefiore Health System in the Bronx, NY.

Intervention

The ABCDE bundle was implemented as a quality improvement initiative in 2 medical ICUs in a stepwise manner. At baseline, both ICUs had sedation vacation and spontaneous breathing trials (B) as part of mechanical ventilation order sets. These orders were used without guiding protocols. The Awakening and Delirium Monitoring/Management (AD) components of the bundle were started on July 1, 2012 in both ICUs. On July 1, 2013, the Coordination and Early mobilization components (CE) were introduced only in one ICU (intervention ICU), completing the entire ABCDE bundle. This included the addition of a dedicated ICU early mobilization team that mobilized patients 7 days a week. The other (comparison) ICU did not undergo any further changes related to mechanical ventilation liberation strategies or physiotherapy during this time period. The full details of the stepwise implementation of the components of the ABCDE bundle in the 2 ICUs has been previously described.[12] For the purposes of these analyses, we considered 2 time periods: B-AD (January 1, 2013-June 30, 2013) and B-AD-CE (July 1, 2013-December 31, 2013).

Cohort

Our primary cohort consisted of all mechanically ventilated (MV) adults (age 18 years and older) admitted to either the intervention or comparison ICU for at least 24 consecutive hours during a hospitalization which began and ended between January 1, 2013 and December 31, 2013. Only the first ICU admission of each hospitalization was included. Patients were excluded if they were admitted to the hospital 72 hours before ICU admission, were transferred between the 2 study ICUs or another ICU in the hospital system, or had an ICU stay that was not fully confined within one time period (B-AD or B-AD-CE). Additionally, patients were excluded if their clinical and cost data could not be linked or if their ICU admission extended beyond day 30 of their hospitalization (as daily cost data are available only through hospital day 30).

Patient Data

Clinical data was obtained from health care surveillance software (Clinical Looking Glass; Emerging Health Information Technology, Yonkers, NY) and included information on demographics (age, self-reported race and ethnicity, gender, residence prior to hospitalization), location prior to ICU admission (emergency department versus other), Charlson comorbidity index,[16] and severity of acute illness (Acute Physiology and Chronic Health Evaluation [APACHE] IV).[17]

Cost Data

Cost data were obtained from the Montefiore Health System and were determined from charges using cost-to-charge ratios which are consistent across hospitals, but differ from cost center to cost center and from calendar year to calendar year. Cost-to-charge ratios are used to estimate a hospital's cost of healthcare service from its charges. Costs represent the amount incurred by the hospital to provide a certain service while charges represent the amount the hospital bills the payer for the service provided.[18] Cost centers are functional units in an organization that provide specific services.[19] Cost centers included in our analysis were: blood bank, dialysis, medications, electrocardiography, electroencephalography, laboratory, medical/surgical supplies, physical therapy, radioisotopes, diagnostic radiology, and respiratory therapy; therapeutic radiology was excluded because only 2 patients in the cohort incurred a cost associated with it. Cost centers for cardiac catheterization, clinic, cardiac care unit, delivery and labor, emergency room, and operating/recovery room were excluded as these were reliably accrued outside of the ICU setting. Room and board costs were also excluded as these are determined solely by nursing unit and length of stay; our findings on the association of ABCDE with ICU and hospital lengths of stay has been previously reported.[12]

Resource Use Data

We evaluated resource use for cost centers where core elements of use were identifiable and quantifiable (e.g., individual tests and not use of physical therapy services). Data was available on use of: (1) laboratory tests—including complete blood counts, basic metabolic panels, arterial blood gases, liver function tests, blood cultures and urinalyses; and (2) diagnostic radiology—including chest X-rays and computed tomography scans of the head, chest, or abdomen and pelvis. Each patient's total count of laboratory and, separately, diagnostic radiology tests were combined to measure resource use. We did not look at sedative use as this was already known to decrease with ABCDE implementation.[12]

Table 1. Baseline Characteristics and Unadjusted Outcomes Stratified by ICU.

	A-BD period		A-BD-CE period		Comparison vs intervention ICU
Patient characteristics	Comparison ICU (%)	Intervention ICU (%)	Comparison ICU (%)	Intervention ICU (%)	*P*-value
# of patients, N	134	136	92	123	
Age, median (IQR)	67 (56,79)	68 (53,76)	67 (57,77)	60 (51,72)	0.013
Male gender	46%	44%	48%	54%	0.7
Race					0.005
White	34%	21%	36%	19%	
Black	25%	32%	27%	35%	
Multi-race	31%	36%	27%	37%	
Other	10%	10%	10%	9%	
Hispanic	36%	40%	27%	40%	0.07
From home	83%	76%	73%	76%	0.54
Admit from ER	86%	73%	80%	68%	0.001
Charlson Index,[a] median (IQR)	0 (0,2)	0 (0,2)	0 (0,2)	0 (0,2)	0.36
Apache score					0.46
≤50	29%	21%	12%	19%	
51-100	54%	57%	60%	57%	
101-150	3%	4%	12%	15%	
>150	0%	0%	0%	2%	
Missing	13%	18%	16%	7%	
Admit diagnosis					0.03
ID	56%	44%	50%	41%	
CV	10%	10%	8%	13%	
Respiratory	14%	25%	13%	18%	
GI	4%	5%	13%	5%	
Met/renal/endo	4%	7%	4%	11%	
Other	10%	10%	12%	13%	
Duration (days), median (IQR)					
ICU LOS[b]	7.5 (4.5,12.8)	7.3 (4.5,12.1)	6.8 (4.3,13.0)	5.0 (3.1,9.1)	0.013
Hospital LOS[b]	13.1 (8.3,20.2)	14.9 (8.9,25.2)	14.5 (7.8,23.6)	12.7 (6.7,22.2)	0.64
Ventilation[c]	5 (3,10)	6 (3,10)	5 (3,10)	4 (2,7)	0.23
Hospital mortality	34%	39%	33%	39%	0.22
Disposition for survivors					0.044
Home	52%	41%	47%	44%	
Rehab	5%	4%	3%	3%	
NH, LTAC	34%	51%	44%	41%	
Acute hospital	6%	0%	3%	5%	
Hospice	3%	1%	3%	1%	
AMA, elope	0%	4%	0%	5%	

Abbreviations: AMA, against medical advice; CV, cardiovascular; ER, emergency room; GI, gastrointestinal; ICU, intensive care unit; ID, infectious disease; IQR, interquartile range; LOS, length of stay; LTAC, long-term acute care; met/renal/endo, metabolic/renal/endocrine; NH, nursing home.
[a]Calculated without points for age.
[b]Non-integer values calculated using dates and times.
[c]Integer values calculated using calendar days only.

Outcomes

Our primary outcome was total hospital cost for each cost center. Secondary cost outcomes included total ICU cost and average daily ICU cost for each cost center. We also evaluated resource utilization outcomes including total hospital, total ICU and average daily number of ICU laboratory tests and diagnostic radiology used; we had a priori planned to evaluate blood product usage, but due to low utilization rates, this evaluation was abandoned post-hoc.

Statistical Analysis

Baseline characteristics and cost per cost center were compared between ICUs (including data from both time periods) using Kruskal-Wallis tests for continuous variables and chi-square tests for categorical variables. We then conducted a series of multivariable difference-in-difference analyses[20-23] to identify whether there were significant changes in outcomes associated with complete ABCDE bundle (B-AD-CE) implementation. For each model, all available patient covariates were included

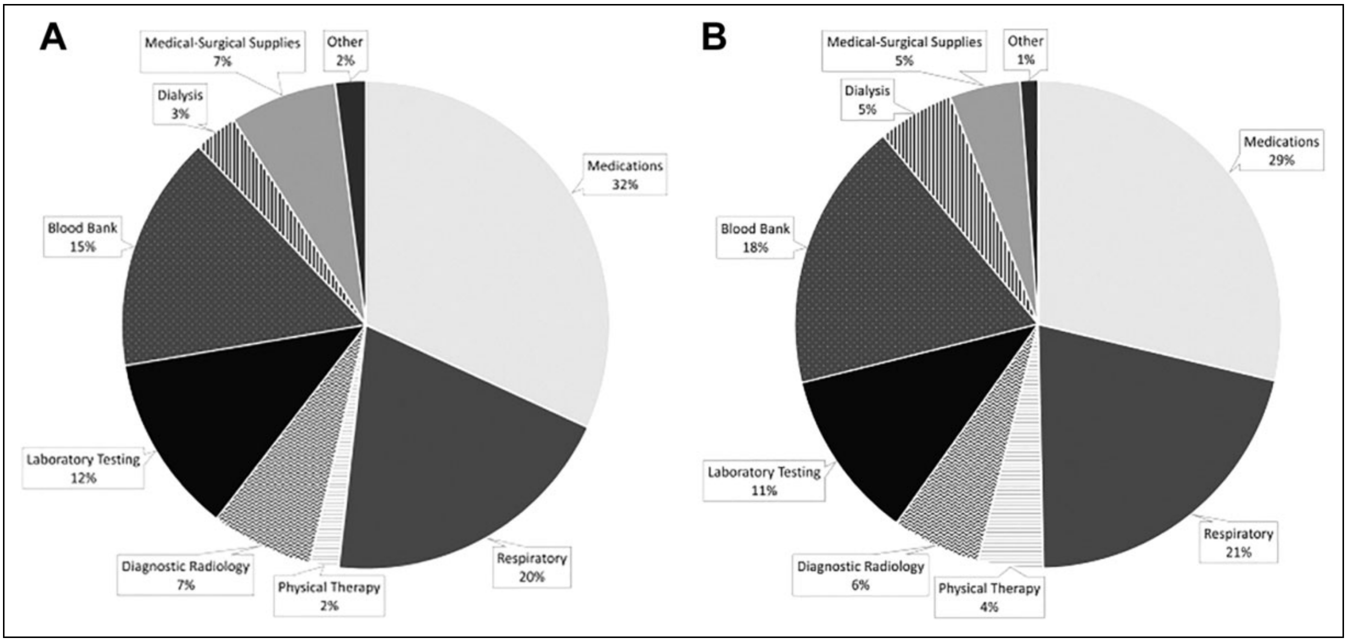

Figure 1. Breakdown of total hospital costs by ICU (all of 2013). (A) Comparison hospital, (B) intervention hospital. ICU indicates intensive care unit.

as were independent variables for ICU (comparison vs intervention), "time period of admission" (B-AD vs B-AD-CE), and an interaction term for "ICU of admission" and "time period of admission." This interaction term reflects the association of being admitted to the intervention ICU after implementation of the intervention after adjusting for historical trends in outcomes using the comparison ICU as a control.

Because many of the costs for each cost center had "excess zeros" (because many patients never accrued those costs), we used 2-part regression models for these cost centers (blood bank, dialysis, electrocardiography, electroencephalography, medical/surgical supplies, physical therapy, radioisotopes, respiratory therapy); this technique allows for the determination of both (1) the odds of having a cost other than zero (using logistic regression) and, separately, (2) the percentage change in non-zero costs (using log-linear regression) associated with each covariate. We used standard log-linear regression models for those cost centers in which there was not an "excess of zeros" (medications, laboratory, diagnostic radiology). Our main analysis was focused, post-hoc, on 5 primary cost centers (medications, laboratory, diagnostic radiology, physical therapy, and respiratory therapy) based on their relative contributions to the overall cost for each patient and their expected association with ABCDE bundle implementation; separate log-linear regression models were, thus, created for physical therapy and respiratory therapy to allow for more direct comparison of these 5 main cost centers. Finally, we created negative binomial regression models for the resource outcomes (total number of hospital and total number ICU laboratory and, separately, diagnostic radiology tests) and log-linear regression models for average daily ICU resource outcomes.

The statistical level of significance was set at less than a 2-sided alpha of 0.05. STATA 15 (Statacorp, College Station, TX) and Microsoft Excel (Microsoft, Redmond, WA) were used for all analyses. The Albert Einstein College of Medicine Institutional Review Board approved a waiver of informed consent for this study (IRB number 2014-3466).

Results

Our cohort consisted of 472 patients (259 admitted to the intervention ICU and 226 to the comparison ICU). Gender, comorbidities, and severity of acute illness were similar between the intervention and comparison ICU patients (Table 1). Relative to the comparison ICU, intervention ICU patients were younger (median [interquartile range, IQR]—intervention ICU: 63 [53-75] vs comparison: 67 [56-78], $P = 0.013$) and more often non-white (79.9% vs 65.0%, $P = 0.005$). Fewer were admitted to the ICU from the emergency department (70.7% vs 83.6%, $P = 0.001$). Hospital mortality (39.0% vs 33.6%, $P = 0.22$) and length of stay (13.9 [8.0-23.6] vs 13.6 [7.9-21.8] days, $P = 0.64$) were similar in both ICUs, but ICU length of stay was shorter in the intervention ICU (6.1 [3.8-10.5] vs 7.2 [4.4-12.8] days, $P = 0.013$).

Cost centers that accounted for the largest proportion of hospital costs in both ICUs (Figure 1A, B and Online Appendix Table 1) were, in descending order: medications (32% in the comparison ICU and 29% in the intervention hospital), respiratory therapy (20% and 21%), blood bank (15% and 18%), laboratory (12% and 11%), and diagnostic radiology (7% and 6%). Resource utilization during the hospital stay was lower in the intervention ICU: (51 [33-81] vs 65.5 [36-92] laboratory

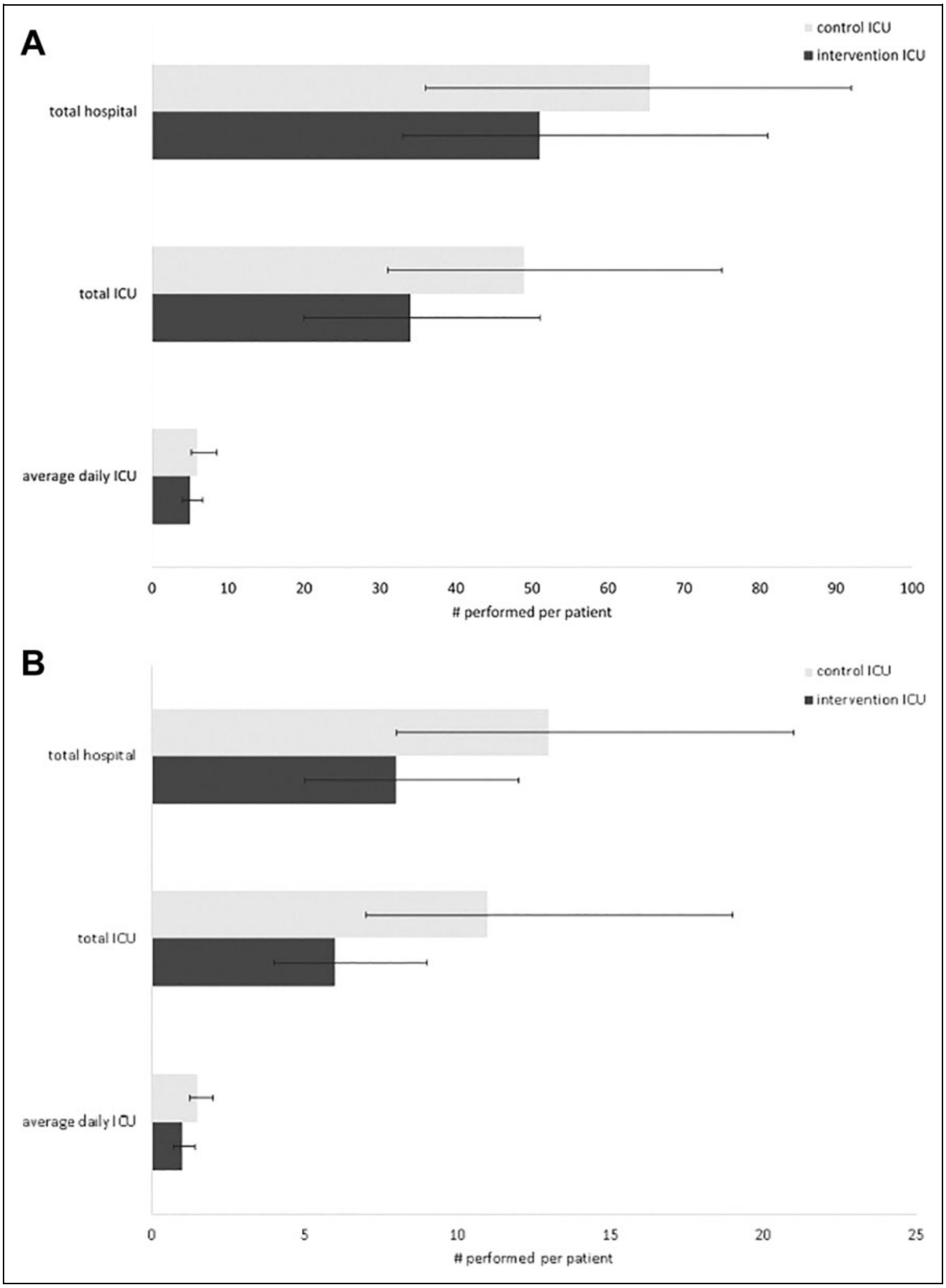

Figure 2. Resource use by ICU (all of 2013).* (A) Laboratory tests, (B) diagnostic radiology tests. *For all comparisons between ICUs, $P < 0.001$. ICU indicates intensive care unit; bars: medians; interquartile range represented by |—|

tests per patient, $P < 0.001$; 8 [5-12] vs 13 [8-21] diagnostic radiology tests per patient, $P < 0.001$; Figure 2A and B).

Primary Outcome

Following completion of the ABCDE bundle (B-AD-CE vs B-AD), total hospital laboratory costs decreased by 27.3% (95% confidence interval, CI [9.9%, 41.3%], $P = 0.004$) while total hospital physical therapy costs increased by 2,888.6% (95% CI [77.9%, 50,113.2%], $P = 0.018$; Figure 3; Online Appendix Table 2). There were no significant changes in costs of total hospital medications, diagnostic radiology and respiratory therapy.

Secondary Outcomes

Completion of the ABCDE bundle (B-AD-CE vs B-AD) was associated with a decrease in costs of ICU respiratory therapy (total: 94.4% [52.4%,99.3%], $P = 0.008$; average daily: 91.9% [43.9%,98.8%], $P = 0.011$), medication (total: 87.2%

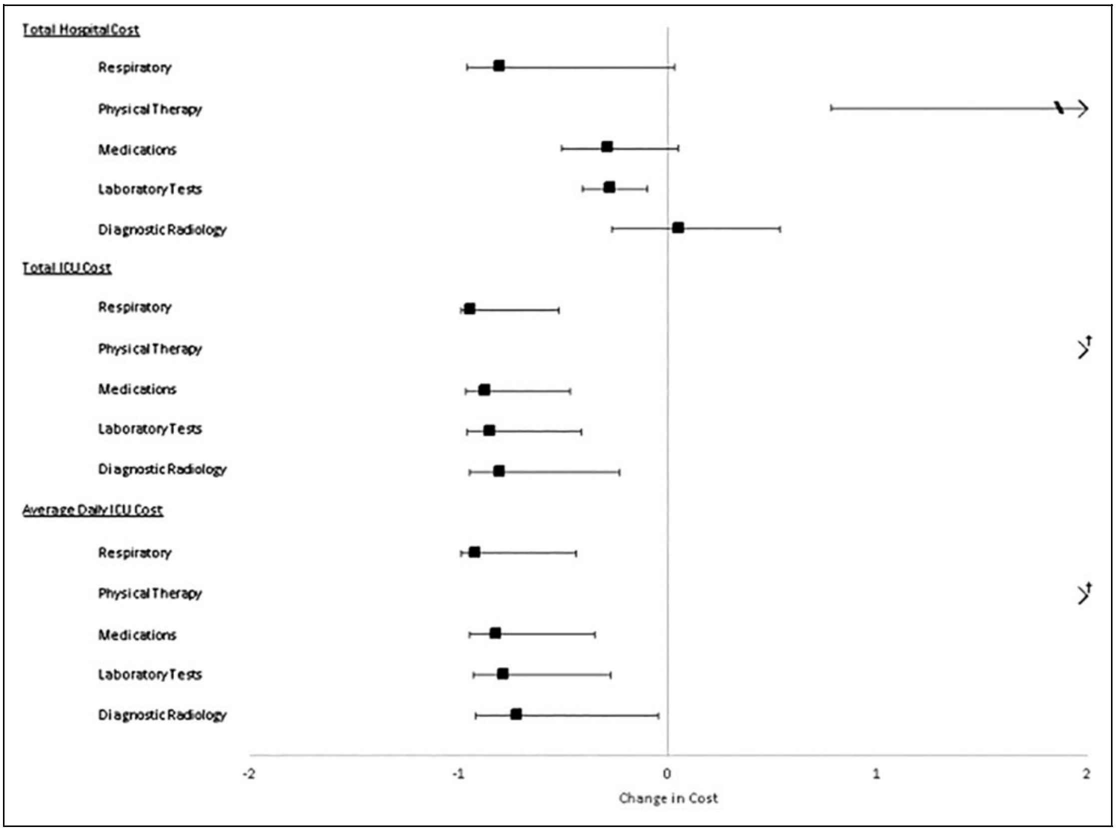

Figure 3. Adjusted associations of ABCDE bundle implementation and costs. *All outcomes are log-transformed and modeled using multivariable linear regression. † Physical therapy costs are outside the scale of the graph with % change in cost for: total hospital—2,889% (95% CI: 78%-50,113%); total ICU—700,715% (77,688%-6,313,775%); and average daily ICU—297,823% (43,291%-2,045,423%). ICU indicates intensive care unit.

[46.9%,96.9%], $P = 0.005$; average daily: 81.9% [35.5%,94.9%] $P = 0.009$), laboratory (total: 84.7% [41.9%,96.0%], $P = 0.006$; average daily: 78.4% [27.9%,93.5%], $P = 0.013$), and diagnostic radiology (total: 80.4% [23.5%,95.0%], $P = 0.019$; average daily: 72.2% [5.1%,91.9%], $P = 0.041$). As expected, ICU physical therapy costs increased notably following completion of the ABCDE bundle (total: 700,715.0% (95% CI, [77,687.7%, 6,313,775.2%], $P < 0.001$; average daily: 297,823.3% [43,291.5%, 2,045,423.3%], $P < 0.001$).

Total hospital resource use decreased in the intervention ICU more than the comparison ICU after ABCDE bundle completion (incidence rate ratio [95% CI], laboratory: 0.68 [0.54, 0.87], $P = 0.002$; diagnostic radiology: 0.75 [0.59, 0.96], $P = 0.020$; Figure 4; Online Appendix Table 3). A similar decline in total ICU resource use (laboratory: 0.70 [0.56, 0.87], $P = 0.001$); diagnostic radiology: 0.78 [0.62, 0.99], $P = 0.044$) was seen. Average daily ICU resource utilization was unchanged.

Discussion

In this retrospective study, we sought to unpack the drivers of the total hospital and ICU cost reductions we had demonstrated previously after ABCDE bundle implementation which, in total, were largely driven by length of stay reductions.[12] Full implementation of the ABCDE bundle was associated with a decrease in total hospital laboratory costs and an increase in physical therapy cost but no significant change across other cost centers. ICU-based costs decreased for laboratory, respiratory, medications and diagnostic radiology, however; not surprisingly, there was a substantial increase in ICU-based physical therapy costs associated with full implementation of the ABCDE bundle. Fewer laboratory tests and radiographic exams were ordered following full ABCDE bundle implementation suggesting that overall use of diagnostic testing (rather than simply a transition to less expensive testing) may have driven the observed cost savings.

As an ICU-based intervention, it may not be surprising that cost savings associated with ABCDE bundle implementation are more widespread within the ICU setting than when costs of the entire hospital stay (including pre-and post-ICU costs) are considered. Although cost savings within the ICU were reduced for 4 of the 5 major cost drivers—respiratory therapy, medications, laboratory tests, and diagnostic radiology—cost reductions across the hospital stay were only evident for laboratory testing. One possible explanation for this is that the ICU-based cost savings were not large enough in the

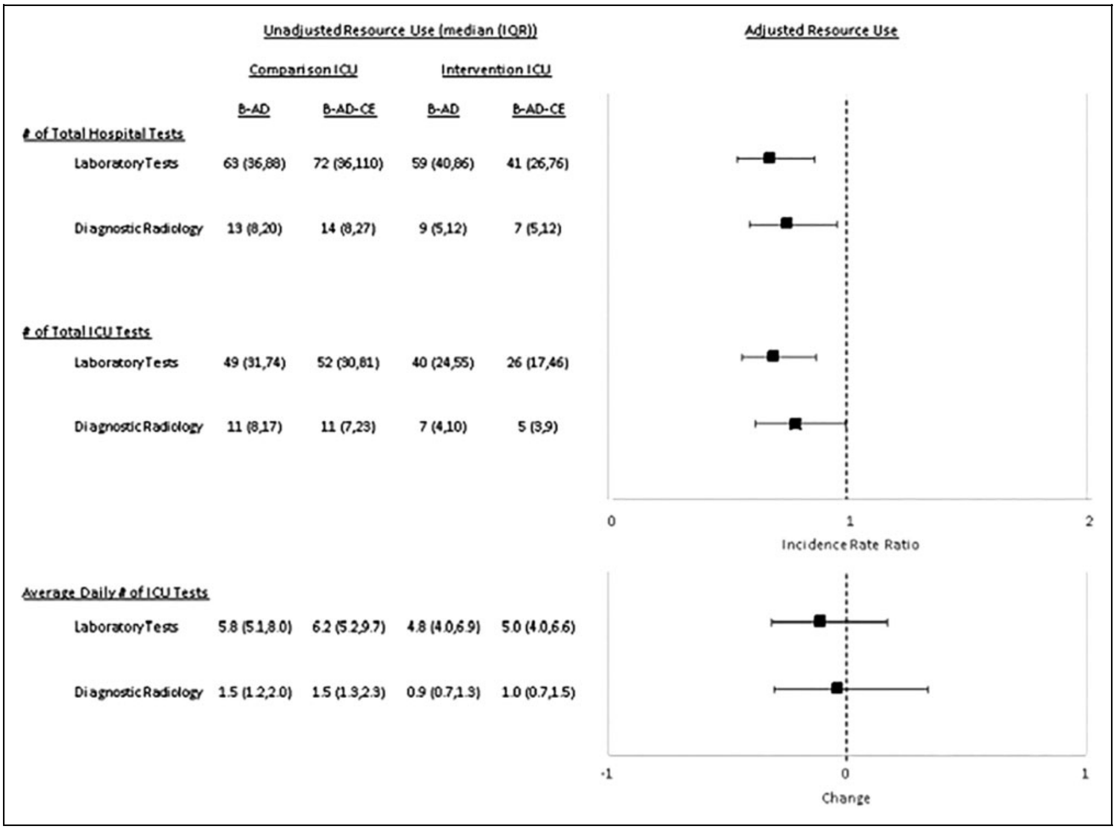

Figure 4. Adjusted associations of ABCDE bundle implementation and resource use.* Using multivariable negative binomial regression models for the total hospital and ICU resource use outcomes and multivariable log-linear regression models for average daily ICU use. ICU indicates intensive care unit; IQR: interquartile range.

respiratory, medication and diagnostic radiology cost centers to result in total hospital cost savings as ICU stay may be only a small fraction of overall hospitalization. Moreover, as was expected, total hospital physical therapy costs increased significantly after ABCDE implementation. Because laboratory testing constituted a significantly higher proportion of total hospital costs than did physical therapy (among patients with both laboratory and physical therapy costs, laboratory costs were 6.7 times higher in the comparison ICU and 2.9 times higher in the intervention ICU), these cost effects contributed to a net hospital cost savings of 30.2% (95% CI: 9.5%-46.1%, $P < 0.007$).[12]

Our ICU-based cost findings have face validity. ICU-based physical therapy costs increased following implementation of the ABCDE bundle. Implementation of an early mobilization program requires a financial investment.[12] Not long ago, over half of US ICUs had no mobilization program,[14,15] so the upfront financial investment to get started may be substantial. This was the case in our institution as prior to the implementation of the bundle, our intervention ICU did not have a mobilization program. ICUs with some existing physical therapy services may not experience the same magnitude of increased physical therapy costs following coordinated bundle implementation. Even in the extreme circumstances of starting from scratch, however, the cost of introducing an early mobilization program will likely be offset by the cost savings from the entire bundle implementation.[12] The ICU-based respiratory therapy cost reductions can be explained by the known decrease in mechanical ventilation duration associated with ABCDE bundle implementation.[12,24]

Our findings that there were ICU cost savings from medications, laboratory tests, and diagnostic radiology with ABCDE implementation is novel. Such cost reductions could, theoretically, be attributable to (1) a decrease in the volume of testing and medication use and/or (2) a reduction in the per-test/per-medication cost. Our results demonstrate that the absolute number of in-ICU diagnostic studies undertaken decreased after ABCDE implementation. While we cannot rule out that clinicians also opted for less costly analyses (e.g., a chest x-ray as opposed to a chest cat-scan), we can say for certain that they "investigated less often." The decrease in mechanical ventilation days following full ABCDE implementation[12] may have reduced the risk for ventilator associated complications (e.g., pneumonia) thereby decreasing the need for diagnostic testing. In addition, ABCDE implementation is known to reduce rates of coma and delirium.[12,24] As many diagnostic tests in the ICU are ordered to work-up delirium[11,25] the reduced volume of diagnostic testing we found may be mediated by the ABCDE-associated reduction in delirium incidence. Similarly, medications are frequently administered in the ICU setting for patients with agitated delirium to protect against self-harm[11,26,27]; our prior work demonstrated a reduction in sedative usage with ABCDE implementation which may be a driver for the medication cost reduction we see in this study.[12]

Our study has several strengths. Firstly, to our knowledge, this is the first study to evaluate the impact of ABCDE implementation on specific patient costs. Secondly, we used patient-level cost data to accurately assign each patients' cost; other studies evaluating the cost associated with early mobilization extrapolated average costs to all patients.[28,29] Thirdly, we used a difference-in-difference methodology which allowed us to adjust for trends in case-mix and outcomes using a comparison unit.

Our study also, however, has several limitations. As a retrospective study, despite attempts to adjust for relevant confounders, residual confounding may persist. Also, as a single center study (2 ICUs within 1 hospital system), the external validity of our findings may be limited. Current guidelines have expanded the ABCDE bundle to include additional A and F components which are Assessment of pain and Family engagement respectively.[30] Subsequent studies will need to assess the impact of the new ABCDEF bundle on the cost centers. Finally, because costs are calculated from charges using a ratio which varies by calendar year, we were unable to evaluate the impact of ABCDE on costs in a larger cohort spanning more than 1 year. Moreover, some staffing (e.g., nursing) costs were not assessed as these are bundled into room and board and allocated to each patient as a daily average cost (not specific to the patient) for their unit.

Conclusions

Cost center-specific cost reductions associated with ABCDE implementation were widespread in the ICU; however, only laboratory costs were reduced when the full hospitalization was considered. Financial sustainability of the ABCDE bundle, therefore, appears to rely not on its impact on specific cost centers but, rather, on the reductions in length of mechanical ventilation and ICU and hospital lengths of stay seen with ABCDE implementation previously.[12] Monitoring the financial health of an ABCDE program through consideration of its impact on specific cost centers is not needed; rather, assessment of total hospital or ICU costs is sufficient.

Authors' Note

This work was performed at Montefiore Health System. Research materials related to our paper can be obtained by contacting the corresponding author via email: ootusanya@gmail.com.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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