Influence of heart transplant allocation changes on hospital resource utilization

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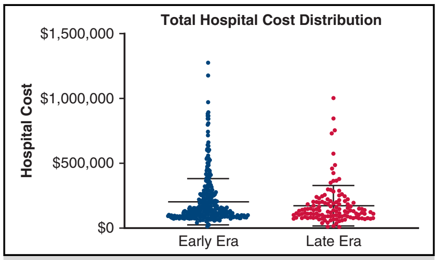
ABSTRACT

Objectives: The 2018 change in the heart transplant allocation system resulted in greater use of temporary mechanical circulatory support. We hypothesized that the allocation change has increased hospital resource utilization, including length of stay and cost.

Methods: All heart transplant patients within a regional Society of Thoracic Surgeons database were included (2012-2020). Patients were stratified before and after the transplant allocation changes into early (January 2012-September 2018) and late eras (November 2018-June 2020). Costs were adjusted for inflation and presented in 2020 dollars.

Results: Of 535 heart transplants, there were 410 early and 125 late era patients. Baseline characteristics were similar, except for greater lung and valvular disease in the late era. Fewer patients in the late era were bridged with durable left ventricular assist devices (69% vs 31%; $P < .0001$), biventricular devices (5% vs 1%; $P = .047$), and more with temporary mechanical circulatory support (4% vs 46%; $P < .0001$). There was no difference in early mortality (6% vs 4%; $P = .33$) or major morbidity (57% vs 61%; $P = .40$). Length of stay was longer preoperatively (1 vs 9 days; $P < .0001$), but not different postoperatively. There was no difference in median total hospital cost ($132,465 vs $128,996; $P = .15$), although there was high variability. On multivariable regression, preoperative extracorporeal membrane oxygenation utilization was the main driver of resource utilization.

Conclusions: The new heart transplant allocation system has resulted in different bridging techniques, with greater reliance on temporary mechanical circulatory support. Although this is associated with an increase in preoperative length of stay, it did not translate into increased hospital cost. (JTCVS Open 2023;13:218-31)



Costs for the transplant index hospitalization.

CENTRAL MESSAGE

The new heart transplant allocation system increased use of temporary MCS. This was associated with an increase in preoperative length of stay. Although costs shifted, they did not clearly increase.

PERSPECTIVE

The heart transplantation allocation system was changed in 2018 and deprioritized patients with durable mechanical circulatory support. Whereas overall fiscal influences on the system may be limited, individual organizations will need to accommodate the increased use of temporary mechanical support devices and the infrastructure needs of longer length of stays.

On October 18, 2018, the United Network for Organ Sharing revised the United States adult heart allocation system with the intention of addressing several problems present in the previous system.[1] These changes were made to prioritize the sickest patients by homogenizing patients grouped within 1 status. The ultimate goal of the new allocation system is to reduce waitlist time for the sickest patients.[2] Before the implementation of the new allocation system, patients treated with temporary, nondischargeable mechanical circulatory support (MCS)

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Abbreviations and Acronyms

- ECMO = extracorporeal membrane oxygenation
- IABP = intra-aortic balloon pump
- ICU = intensive care unit
- LVAD = left ventricular assist device
- LOS = length of stay
- MCS = mechanical circulatory support
- RCC = ratio of cost to charge
- STS = Society of Thoracic Surgeons
- VAD = ventricular assist device
- VCSQI = Virginia Cardiac Services Quality Initiative

had the highest waitlist mortality.[3] Before the change, patients were placed into a 3-tiered system with status 1A, 1B, and 2 (Table E1). A major criticism was that the 1A category was encompassing of a wide range of acuity and included total artificial heart, temporary left ventricular assist devices (LVAD), intra-aortic balloon pump (IABP), and extracorporeal membrane oxygenation (ECMO); LVADs with complications, mechanical ventilation, patients with invasive hemodynamic monitoring and high-dose inotropic support; and patients who had been granted an exemption.[4-6] Within the prior system, all patients who underwent durable LVAD implantation and were listed for transplant received a 30-day window of status 1A time. Most patients who underwent transplant under this system were thus classified as status 1A, with little focus on disease severity or the likelihood of mortality without transplantation. The current allocation system stratifies and groups patients into a 6-tiered system (status 1-6). Status 1A was divided into 3 separate categories (status 1, 2, and 3), whereas status 4 was created to correspond to the previous status 1B. (Table E1).

Since this change in the heart transplant allocation system, fewer patients are bridged with durable ventricular assist devices (VAD) and there has been an increase in the use of temporary MCS.[7] As time has progressed and technologies improved, patients with VADs have experienced fewer complications, thus many of these patients are less acutely ill and are now in the status 4 category in the new allocation system unless deemed nondischargeable, with a complication or during a 30-day discretionary period (Figure E1).[8] Many temporary MCS devices are used as a bridge to heart transplant and include IABP, percutaneous VADs veno-arterial ECMO, and surgically implanted, nondischargeable MCS devices.[9,10] Studies have demonstrated that MCS can be resource intensive with high costs.[11] However, the true influence on hospital resource utilization and cost remains unknown. We hypothesized that the new heart transplant allocation change has increased length of stay (LOS) and total cost.

PATIENTS AND METHODS

Patient Data and Variable Definitions

The Virginia Cardiac Services Quality Initiative (VCSQI) database was queried for all heart transplant patients from 2012 to 2020. De-identified records were extracted for analysis. Patients were stratified across the heart transplant allocation system change with a 1-month washout period during implementation. The early era was defined from January 2012 through September 2018. The late era was defined from November 2018 through June 2020. All variables utilize Society of Thoracic Surgeons (STS) definitions.[12] Preoperative support was classified into medical-only, durable LVAD, IABP, percutaneous VAD (ie, Tandem Heart; LivaNova, London, United Kingdom or Impella; Abiomed, Danvers, Mass), or veno-arterial ECMO. IABP, percutaneous VAD, and veno-arterial ECMO were together classified as temporary MCS. When mutual exclusivity was required for certain regression analyses, the higher level of support was prioritized (ECMO > percutaneous VAD > IABP), otherwise patients with multiple modalities were treated as such.

The Virginia Cardiac Services Quality Initiative (VCSQI) is a regional quality collaborative that includes 18 centers and practices within the Commonwealth of Virginia. Clinical data from the STS Adult Cardiac Surgery Database is submitted in accordance with the data use agreement between member institutions, VCSQI and the database vendor (ARMUS Corporation). The clinical data are paired with cost data with a 99% match rate. Member institutions submit Universal Billing-04 files and the charges are classified by the International Classification of Diseases revenue codes. Classification details are shown in Table E2. Center for Medicare and Medicaid Services ratios of cost to charge (RCCs) are then used to convert the data into cost estimates based on 20 groupings with corresponding RCCs calculated at the hospital level for each fiscal year. The hospital costs are then adjusted for medical inflation using the market basket for the Medicare inpatient prospective payment system and presented in 2020 dollars. The primary objective of the VCSQI is quality improvement and this manuscript represents a secondary analysis of the VCSQI quality registry without Health Insurance Portability and Accountability Act identifiers and is exempt from institutional review board review (University of Virginia Institutional Review Board protocol 23305).

Statistical Analysis

Continuous variables are presented as median (quartile 1-quartile 3) and compared by Mann Whitney *U* test. Categorical variables are presented as count (%) and compared by χ^2 test or Fisher exact test as appropriate. Patients were stratified by era for univariable analysis. Given the skewed nature of cost data, cost associations were also estimated using a generalized linear mixed model that accounted for clustering at the hospital level. For multivariable analyses the era, mechanical assist devices and patient demographic characteristics and comorbidities were included in the hierarchical generalized linear models as fixed effects, whereas hospital remained a random effect. Additional covariates were chosen a priori based on clinical significance and limited by event rates. Missing data were excluded for corollary univariable statistical tests (Table E3). Simple imputation was utilized due to the low missingness with lower risk or median depending on variable type. Statistical significance was defined as a *P*-value <.05. All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc).

RESULTS

Demographic, Baseline, and Operative Characteristics

A total of 535 patients underwent heart transplant, with 410 performed in the early era and 125 in the late era. Patients across eras were generally similar with no difference in age and gender distributions (Table 1). In the late era there was greater tobacco use (36% vs 52%; *P* = .002) and a higher burden of chronic lung disease (28% vs 43%; $P = .001$). Although there were similar rates of coronary disease, there were higher rates of severe mitral and tricuspid regurgitation in the late era.

As seen in Table 2, fewer patients in the new allocation system (late era) were bridged with durable VADs (69% vs 31%; $P < .0001$) and more with temporary MCS (4% vs 46%; $P < .0001$). There was also a decrease in the number of biventricular VADs and total artificial hearts (5% vs 1%; $P = .047$). For temporary support, the largest increase was seen in preoperative IABP use (2% vs 41%; $P < .0001$). The rate of preoperative medical management only did not change significantly over time (28% vs 23%; $P = .31$). These patient selection changes correlated with fewer VAD explants and shorter median cardiopulmonary bypass times (176 minutes [136-225 minutes] vs 151 minutes [118.5-199 minutes]); $P = .0005$.

Short-Term Outcomes and Resource Utilization

There was no difference in early mortality (6% vs 4%; $P = 0\ .33$) or major morbidity (57% vs 61%; $P = .43$) across eras (Table 3). The preoperative LOS was significantly longer (1 vs 9 days; $P < .0001$) in the late era. This data was highly skewed in the early era, with the mean preoperative LOS being 10.8 ± 30.3 and 11.3 ± 11.0 days, respectively. However, the median postoperative LOS was 16 days in both eras, and there was no difference in median intensive care unit times. After discharge, more patients in the late era were sent to facilities rather than discharged to home (14% vs 23%; $P = .02$).

The median total hospital cost was no different between eras ($132,465 vs $128,996; $P = .15$). Figure 1 demonstrates similar distributions of total cost across eras, with high variability. Indeed, examination of mean hospital cost in the early ($199,906 ± $179,291) versus late eras ($173,000 ± $155,514) reveals standard deviations that are nearly as large as the mean. Generalized linear mixed modeling confirmed the Mann-Whitney univariable results with no significant association between era and total hospital cost (estimate, –26,523; 95% CI, –60,952 to 7906; $P = .131$).

Multivariable Analyses

The complete results of the multivariable regressions are shown in Tables E4 through E7, whereas the limited results focused on era, durable VAD, and temporary MCS are shown in Table 4. Looking at these focused results, the new allocation system was associated with significantly lower total hospital cost (–$41,869; $P = .047$), whereas preoperative percutaneous LVAD ($145,961; $P = .042$) and ECMO ($211,735; $P < .001$) were associated with dramatically higher hospital cost. For preoperative LOS, a preoperative durable LVAD was associated with 18.1 fewer days ($P < .001$), whereas preoperative ECMO trended

TABLE 1. Baseline demographic characteristics and comorbidities

Characteristic or comorbidity	Early era (n = 410)	Late era (n = 125)	*P* value
Age (y)	57 (46-63)	54 (44-62)	.16
Female sex	120 (29.3)	33 (26.4)	.53
Body mass index	29.0 (25.6-32.7)	28.4 (23.9-32.1)	.09
Diabetes	163 (39.8)	52 (41.6)	.71
New York Heart Association functional class IV	252 (64.6)	95 (77.9)	.008
Lung disease (>mild)	114 (27.8)	54 (43.2)	.001
Hypertension	267 (65.1)	73 (58.9)	.20
Prior stroke	56 (13.7)	19 (15.3)	.65
Coronary artery disease	153 (37.3)	46 (36.8)	.98
Peripheral artery disease	24 (5.9)	12 (9.6)	.14
Prior myocardial infarction	132 (32.4)	41 (33.6)	.80
Dialysis	10 (2.4)	5 (4.0)	.35
Aortic insufficiency (>mild)	24 (5.9)	6 (4.8)	.65
Aortic stenosis	2 (0.5)	2 (1.6)	.21
Mitral regurgitation (>mild)	66 (16.1)	59 (47.2)	<.0001
Mitral stenosis	4 (1.0)	1 (0.8)	.87
Tricuspid regurgitation (>mild)	56 (13.7)	49 (39.8)	<.0001
Previous cardiac surgery	324 (79.0)	59 (47.2)	<.0001
Previous cardiac intervention	400 (97.6)	143 (91.2)	.001

Values are median (quartile 1-quartile 3) or n (%).

TABLE 2. Preoperative and intraoperative mechanical circulatory support (MSC) methods

Preoperative MCS use	Early era (n = 410)	Late era (n = 125)	*P* value
Percutaneous RVAD	3 (0.8)	1 (0.8)	.97
Prior durable MCS	282 (68.8)	39 (31.2)	<.0001
Prior BiVAD/TAH	19 (4.6)	1 (0.8)	.047
Preoperative temporary MCS	16 (3.9)	57 (45.6)	<.0001
Preoperative intra-aortic balloon pump	8 (2.0)	51 (40.8)	<.0001
Percutaneous LVAD	2 (0.5)	4 (3.2)	.01
Venoarterial ECMO	6 (1.5)	10 (8.0)	.0002
Neither durable nor temporary MCS	114 (27.8)	29 (23.2)	.31
	Pre	**Post**	
Intraoperative characteristic			
Cardiopulmonary bypass time (min)	176 (138-225)	151 (119-199)	.0002

Values are presented as median (quartile 1-quartile 3) or n (%). *MSC*, Mechanical circulatory support; *RVAD*, right ventricular assist device; *BiVAD*, biventricular assist device; *TAH*, total artificial heart; *LVAD*, left ventricular assist device; *ECMO*, extracorporeal membrane oxygenation.

toward association with longer preoperative stay (11.9 days; $P = .081$). Only preoperative ECMO was significantly associated with postoperative LOS (12.6 days; $P = .014$) and intensive care unit LOS (233 hours; $P = .007$). The results are graphically presented in Figure 2.

DISCUSSION

This analysis of more than 500 heart transplant patients from the Commonwealth of Virginia confirms a dramatic shift in preoperative heart transplant management. There was a 54% reduction in preoperative durable LVAD support and a 1050% increase in temporary MCS utilization. As expected, this was associated with eight additional pretransplant days in the hospital. The most significant cost driver was ECMO utilization, which increased from 1.5% to 8% after the allocation change and was associated with an additional \$210,501 in total hospital cost. Percutaneous LVADs only increased from 0.5% to 3.2%, but were also associated higher hospital costs (\$145,961). Meanwhile, other bridging techniques, including durable LVAD and IABP were not associated with increased cost of the index transplantation hospitalization. The strongest predictor of preoperative LOS was prior durable MCS at –18.1 days, suggesting no large differences between other bridging

TABLE 3. Short-term outcomes, resource utilization, and cost

Clinical outcome	Early era (n = 410)	Late era (n = 125)	*P* value
Operative mortality	26 (6.3)	5 (4.0)	.33
New temporary MCS	28 (6.8)	3 (4.0)	.82
Major morbidity	233 (56.8)	76 (60.8)	.43
Permanent stroke	6 (1.5)	0 (0)	.18
Prolonged ventilation	210 (51.3)	63 (50.4)	.85
Renal failure	67 (16.4)	30 (24.0)	.05
Postoperative dialysis	52 (12.7)	22 (17.6)	.17
Reoperation for any reason	86 (21.0)	39 (31.5)	.02
Red blood cell transfusion	279 (68.2)	77 (61.6)	.17
Resource utilization			
LOS admit to surgery (d)	1 (0-2)	9 (2-17)	<.001
LOS surgery to discharge (d)	16 (12-24)	16 (12-23)	.76
LOS (d)	19 (14-35)	27 (18-39)	.0002
Postoperative ICU LOS (h)	160 (121-276)	165 (118-271)	.98
Discharge to facility	59 (14.4)	29 (23.2)	.02
Total cost (\$)	132,465 (92,344-243,136)	128,996 (86,135-197,885)	.15

Values are presented as median (quartile 1-quartile 3) or n (%). *MCS*, Mechanical circulatory support; *LOS*, length of stay; *ICU*, intensive care unit.

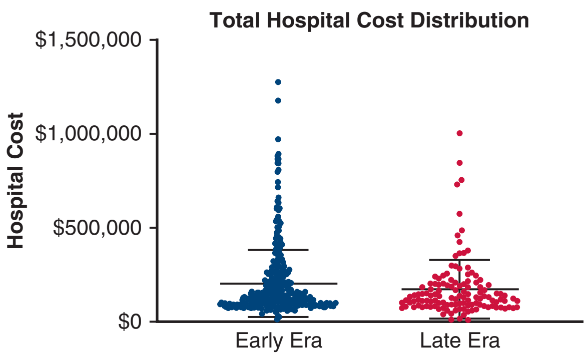

FIGURE 1. Distribution of total cost for the transplant index hospitalization for all patients with bars for median and interquartile range. Era definitions were early for before the transplant allocation changes (January 2012-September 2018) and late for after the allocation changes (November 2018-June 2020).

strategies (medical and other temporary MCS options). Postoperatively, only ECMO was associated with both intensive care unit and postoperative LOSs.

Bridging Strategies

Within VCSQI we found a large increase in IABP (+1852%) and ECMO (+462%) use as a bridge to transplant. This dramatic increase in IABP use is higher than previously shown in early publications after the allocation change.[13,14] Despite the change in utilization, patients utilizing IABP appear to have similar 90-day posttransplant survival in the old versus new allocation system (94.3% vs 93.5%).[13] Additionally, ECMO now accounts for 8% of heart transplant patients' bridging strategies in the new allocation system. Studies have confirmed this trend on a national level with a 4-fold increase in ECMO utilization resulting in ECMO patients being more likely to be transplanted with shorter wait list times.[5,15]

The change in heart failure management has been associated with higher-acuity patients being transplanted in the late era, including more New York Heart Association functional class IV heart failure, severe valve disease, and higher ECMO utilization. Despite these baseline disparities, there were no significant differences found in major complications rates, including operative mortality (6% vs 4%) or major morbidity (57% vs 61%). These findings are in contrast with national data that report an increase in 1-year mortality with a risk adjusted hazard ratio of 1.25 with the new allocation system.[5] However, there are wide differences in 1-year mortality across United Network for Organ Sharing regions. As with any variation in outcomes, this warrants further investigation for possible quality improvement. The low mortality rate in our analysis is also a testament to increasing survival of patients bridged

TABLE 4. Generalized linear regressions for adjusted resource utilization

Variable	Estimate	95% CI	*P* value
Total cost ($)			
New allocation system	–$41,869	–83,217 to –521	.047
Prior durable MCS	–$19,301	–58,667 to 20,065	.336
Preoperative IABP	$9928	–47,902 to 67,758	.736
Preoperative percutaneous LVAD	$145,961	5224 to 286,698	.042
Preoperative ECMO	$210,501	122,342 to 298,660	<.0001
Preoperative length of stay (d)			
New allocation system	–5.6	–11.9 to 0.7	.080
Prior durable MCS	–18.1	–24.1 to –12.2	<.001
Preoperative IABP	–6.7	–15.4 to 2.1	.135
Preoperative percutaneous LVAD	10.2	–11.1 to 31.5	.347
Preoperative ECMO	11.9	–1.5 to 25.3	.081
Postoperative length of stay (d)			
New allocation system	–0.8	–5.5 to 3.9	.736
Prior durable MCS	2.6	–1.9 to 7.1	.257
Preoperative IABP	3.2	–3.4 to 9.7	.344
Preoperative percutaneous LVAD	–7.0	–23.0 to 9.0	.393
Preoperative ECMO	12.6	2.6 to 22.7	.014
ICU length of stay (h)			
New allocation system	–1.5	–80.6 to 77.5	.970
Prior durable MCS	25.4	–50.2 to 100.9	.510
Preoperative IABP	60.7	–48.9 to 170.3	.278
Preoperative percutaneous LVAD	–60.3	–328.3 to 207.7	.659
Preoperative ECMO	232.8	63.9 to 401.7	.007

CI, Confidence interval; *MCS*, mechanical circulatory support; *IABP*, intra-aortic balloon pump; *LVAD*, left ventricular assist device; *ECMO*, extracorporeal membrane oxygenation; *ICU*, intensive care unit.

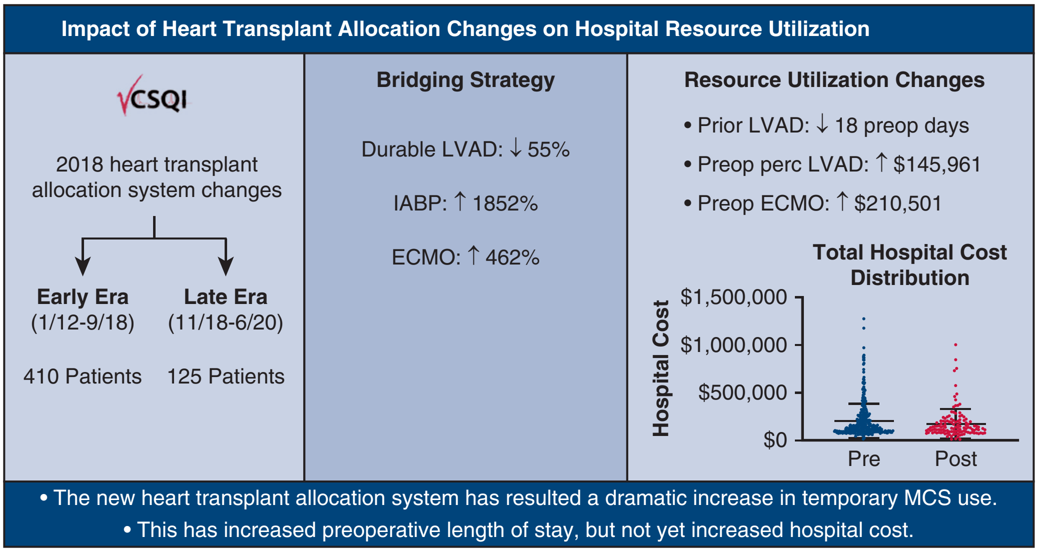

FIGURE 2. Graphical abstract for influence of the heart transplant allocation changes. The methodology for categorization by era on the *left*, changes to the bridging strategy in the *middle*, and resource changes on the *right*. *VCSQI*, Virginia Cardiac Services Quality Initiative; *LVAD*, left ventricular assist device; *IABP*, intra-aortic balloon pump; *ECMO*, extracorporeal membrane oxygenation; *MCS*, mechanical circulatory support.

with ECMO. These patients have traditionally had higher early mortality rates with survival curves that return to other posttransplant levels around 6 months.[16] However, the new allocation system has been associated with improved survival for these patients, likely due to faster transplantation.[17] With the new system, 6-month survival is 90.6%, up from 74.6% previously.[17]

Resource Utilization

There was a clear increase in LOS within this cohort, driven by the preoperative phase increasing 8 days. The early era data had large variation in preoperative LOS and so this difference comes largely from a reduced number of patients with very short preoperative LOS in the late era. There is some evidence this may not be a universal trend; Kilic and colleagues[5] note no difference in overall LOS before and after the allocation change (21.2 vs 21.4 days). The most obvious explanation for the increase LOS is the increase in temporary MCS, which was not as dramatic in the earlier study by Kilic and colleagues[5] and may explain the lack of difference. A finding as large as ours suggests hospitals will need to plan for and accommodate the increased census, which typically requires intensive care unit level of care with some flexibility in either a cardiology or cardiac surgery unit depending on the MCS type. The largest driver of increased preoperative LOS was ECMO at 13.5 days, which also was associated with 11 more postoperative days by multivariable analysis. The decrease in patients utilizing an LVAD undergoing transplantation may also prompt changes in the composition of the heart failure team, with a relative decrease in need for total artificial heart and LVAD patient management.

Despite the increase in LOS, the overall hospital cost remained relatively stable over time. Although overall costs remained stable, we suspect large cost shifts are occurring with the new allocation system. The high variability as seen in Figure 1, also has the potential to obscure potential overall differences. This also highlights the importance of analyzing cost drivers that can lead to high-cost outliers. Multivariable regression shows that ECMO was associated with high additional hospital cost at $210,501. Some hospitals are also increasing use of percutaneous LVADs, which were also associated with significantly higher costs ($145,961). Any trend away from IABP use could result in major cost increases. One aspect that could not be analyzed due to low numbers is the shift away from total artificial hearts, which can be associated with long and expensive hospital stays.[18]

After adjusting for the different bridging methods, the late era was associated with significantly lower hospital costs. This may be due improved care processes over time, improved outcomes for patients not utilizing ECMO/LVAD requiring fewer resources, or other unknown cost savings from the allocation changes unrelated to bridging strategy. In addition, the new allocation system has resulted in shorter waitlist times and thus there is a theoretically lower cost per ECMO patient with the new allocation system (even if overall costs increase). Finally, the last cost driver to highlight is postoperative complications.[19] A single major complication after coronary bypass surgery is associated with an additional $27,000. With such high rates of major morbidity, any potential increase in hospital stay cost due to the LOS will be outdone by the cost of complications in this cohort.

Finally, there was an increase in the number of discharges to a facility in the new era. Although not unexpected given higher-acuity patients, this finding will have implications should a move be made to 90-day bundled payments. This trend in discharges extends beyond just heart transplantation with increased utilization of postacute care facilities throughout postoperative care.[20] There is also wide variation in use across hospitals, which represents an opportunity for improvement and global cost containment in any future alternative payment models.[21,22]

Although data for prior LVAD implantations were not available for this study, the obvious question is whether cost and LOS changes have been reduced by going from 2 operations and hospitalizations down to 1. In our study, we found that prior durable LVAD was associated with 18 fewer preoperative days in the hospital. Meanwhile, in the Multicenter Study of MagLev Technology in Patients Undergoing Mechanical Circulatory Support Therapy with HeartMate 3 clinical trial the median LOS for the HeartMate 3 (Abbott) was 19 days.[23] Although this would suggest the allocation change may not have a large influence on overall LOS, the HeartMate 3 patients also had 2.26 rehospitalizations per patient-year with a median of 13 rehospitalization days in the first 6 months. Whereas a patient-level analysis is needed to answer questions on LOS, there are likely large cost implications of this change. Given the overall hospital cost did not change with the new allocation system, societal cost savings likely occur by omitting the LVAD implantation. Although directly relevant cost data are limited, LVAD implantation estimates for Medicare beneficiaries was a median of $176,825 and for HeartMate 3 destination-therapy patients was £141,598.[24,25] Further research is needed with patient-level, longitudinal data in the modern centrifugal LVAD era to fully understand the cost and overall resource utilization implications of the transplant allocation changes.

Limitations

This study is limited by its retrospective nature that precludes determinations of causality and may be influenced by selection bias. A limited number of patients may have crossed over between eras despite the washout period, although we do not expect this to have significant influence. The study period includes the very beginning of the COVID-19 pandemic, which could introduce some confounding, although the time and number of patients is small. The use of the VCSQI dataset is limited to STS variables and misses some transplant-related metrics. Additionally, although all transplant centers in Virginia are included, this represents a small subset of the transplant practices nationwide. The cost data available to VCSQI are imperfect in that they convert charge data into cost estimates. However, health care cost estimation is particularly difficult and RCCs are among only a few reliable methods. Although categorization of specific charges can vary among hospitals and obscures our ability to qualify the cost shifts, on aggregate total hospital cost are consistent and reliable. Finally, this analysis does not incorporate the resource utilization associated with durable LVAD implantation or postdischarge care. The change in LVAD utilization and the implications for resource utilization will require further investigation, but relative cost savings from omission of LVAD implantation will depend on use of percutaneous LVAD and ECMO devices because these have been shown to be large cost drivers.

CONCLUSIONS

The new heart transplant allocation system has resulted in different bridging techniques for patients with heart failure, with greater reliance on temporary MCS. Although this is associated with a large 8-day increase in preoperative LOS, there is no strong evidence to suggest a commensurate increase in total hospital cost. There is evidence that cost drivers are shifting, where although IABP use was not associated with higher costs, percutaneous LVADs and ECMO increased hospital cost $145,000 and $210,000, respectively. Although due to currently low utilization rates in this cohort there was no change in total cost, future increased utilization of these devices can be expected to result in higher transplant-related hospital costs. Health systems should allocate additional infrastructure to accommodate the increase in LOS and may need to shift resources to accommodate the increase in preoperative care requirements, but should not at this time expect significantly higher total expenditures with the new allocation system and current bridging strategies.

Conflict of Interest Statement

Dr Speir is a consultant on the Medtronic Cardiac Surgery Advisory Board. Dr Yarboro has received honoraria for consulting and proctoring for Medtronic. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline reviewing manuscripts for which they have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: heart transplant, mechanical circulatory support, cost, resource utilization

Criteria Requirements in Adult Heart Allocation Policy
See policy for extensive criteria requirements

Status	Criteria	Admitted to hospital that registered candidate	Cardiogenic Shock	Primary Mechanical Circulatory Support Devices						Requires time spent at previous status	Use of Inotropes	V-Tach or V-Fib	Eligible for extension
				VA ECMO	Discharge-able VAD	Non-Discharge-able VAD	Percu-taneous Device	TAH	IABP				
Status 1	VA ECMO	*	*	*									RRB
	Non-dischargeable, surgically implanted, non-endovascular biventricular support device	*				*							Y
	MCSD with life threatening ventricular arrhythmia	*		*	*	*	*	*	*			*	Y
Status 2	Non-dischargeable, surgically implanted, non-endovascular left ventricular support device (LVAD)	*				*							RRB
	TAH, BiVAD, RVAD, or VAD for single ventricle patients				*	*		*					Y
	MCSD with malfunction	*		*	*	*	*	*	*				Y
	Percutaneous endovascular MCSD	*	*										RRB
	Intra-Aortic Balloon Pump (IABP)	*	*				*		*				RRB
	Ventricular Tachycardia (VT) or Ventricular Fibrillation (VF)	*										*	Y
Status 3	Dischargeable LVAD for discretionary 30 days				*								N
	Multiple inotropes or a single high dose inotrope and hemodynamic monitoring	*	*								*		Y
	MCSD with Hemolysis			*	*	*	*	*	*				Y
	MCSD with Pump Thrombosis			*	*	*	*	*	*				Y
	MCSD with Right Heart Failure			*	*	*	*	*	*		*		Y
	MCSD with Device Infection			*	*	*	*	*	*				Y
	MCSD with Mucosal Bleeding	*		*	*	*	*	*	*				Y
	MCSD with Aortic Insufficiency (AI)			*	*	*	*	*	*				Y
	VA ECMO after 7 Days	*		*						*			Y
	Non-dischargeable, surgically implanted, non-endovascular LVAD after 14 Days	*				*				*			Y
	Percutaneous Endovascular Circulatory Support Device after 14 Days	*					*			*			Y
	IABP after 14 Days	*							*	*			Y
Status 4	Dischargeable LVAD without discretionary 30 days				*								Y
	Inotropes without Hemodynamic Monitoring										*		Y
	Congenital Heart Disease												Y
	Ischemic Heart Disease with Intractable Angina												Y
	Amyloidosis, or Hypertrophic or Restrictive Cardiomyopathy												Y
	Heart Re-transplant												Y
Status 5	On the Waitlist for at least one other organ at the same hospital												Y
Status 6	Adult Candidate Suitable for Transplant												Y

* indicates a criteria requirement
RRB indicates RRB submission required for extension

FIGURE E1. Organ Procurement and Transplantation Network adult heart allocation policy table. Obtained from the Organ Procurement and Transplantation Network. https://optn.transplant.hrsa.gov/professionals/by-organ/heart-lung/adult-heart-allocation/. Accessed July 12, 2022. *VA-ECMO*, Veno-arterial extracorporeal membrane oxygenation; *VAD*, ventricular assist device; *TAH*, total artificial heart; *MCSD*, mechanical circulatory support device; *Bi-VAD*, biventricular assist device; *RVAD*, right ventricular assist device.

TABLE E1. Heart transplant status definitions before and after the allocation changes*

Preallocation change tier	Postallocation change tier	Requirement
1a	1	VA-ECMO
		Nondischargeable BiVAD
		MCS with life-threatening ventricular arrhythmia
	2	Nondischargeable, surgically implanted, nonendovascular LVAD
		TAH, BiVAD, RVAD, or VAD for patients with single ventricle anatomy
		MCS with malfunction
		Percutaneous endovascular MCS
		Intra-aortic balloon pump
		Ventricular tachycardia or ventricular fibrillation
	3	Dischargeable LVAD for discretionary 30 d
		Multiple inotropes or a single high dose inotrope and hemodynamic monitoring
		MCS with hemolysis, pump thrombosis, right heart failure, device infection, mucosal bleeding, or aortic insufficiency
		VA ECMO after 7 d
		Nondischargeable, surgically implanted, non-endovascular LVAD after 14 d
		Percutaneous endovascular circulatory support device after 14 d
		IABP after 14 d
1b	4	Dischargeable LVAD without discretionary 30 d
		Inotropes without hemodynamic monitoring
		Congenital heart disease
		Ischemic heart disease with intractable angina
		Amyloidosis, or hypertrophic or restrictive cardiomyopathy
		Heart re-transplant
	5	On the waitlist for at least 1 other organ at the same hospital
2	6	Adult candidate suitable for transplant

VA-ECMO, Veno-arterial extracorporeal membrane oxygenation *Bi-VAD*, biventricular assist device; *MCS*, mechanical circulatory support; *LVAD*, left ventricular assist device; *TAH*, total artificial heart; *RVAD*, right ventricular assist device; *VAD*, ventricular assist device; *IABP*, intra-aortic balloon pump. *Table E1 adapted from the Organ Procurement and Transplantation Network adult heart policy table update. https://optn.transplant.hrsa.gov/learn/professional-education/adult-heart-allocation/.

TABLE E2. Cost categories and International Classification of Diseases, Ninth Edition ICD-9 revenue codes

Cost category	Cost subcategory	Revenue codes
Total Stay	Emergency room	450-459
	ICU/CCU	200-219
	Regular room	100-179
Diagnostics	Radiology	320-359, 400-409
	Laboratory	300-319
	Cardiac diagnostics	480, 482-489, 730-731, 739
	Peripheral vascular laboratory	921
Intervention	Anesthesia	370-379
	Operating room	360-369, 490-499
	Recovery room	710-719
	Blood products	380-399
	Implants (pacers, ICD, valve)	275, 278
	General supplies	270-274, 276-277, 279
General care	Pharmacy	250-259
	Intravenous	260-269
	Respiratory therapy	410-419
	Cardiac catheterization laboratory	481
	Therapies, including PT and OT	420-449
	Dialysis	800-809, 820-859, 880-889
Other	Other	180-199, 220-249, 280-299, 470-479, 500-679, 700-709, 740-799, 901-920, 922-942, 944-999

ICU, Intensive care unit; *CCU*, cardiac care unit; *ICD*, implantable cardioverter defibrillator; *PT*, physiotherapy; *OT*, occupational therapy.

TABLE E3. Data missingness

Data point	Sample size
Age (y)	535 (0)
Female sex	535 (0)
Body mass index	532 (0.6)
Diabetes	535 (0)
New York Heart Association functional class IV	512 (4.3)
Lung disease (>mild)	535 (0)
Hypertension	534 (0.2)
Prior stroke	532 (0.6)
Coronary artery disease	531 (0.7)
Peripheral artery disease	535 (0)
Prior myocardial infarction	530 (0.9)
Dialysis	535 (0)
Aortic insufficiency (>mild)	535 (0)
Aortic stenosis	532 (0.6)
Mitral regurgitation (>mild)	535 (0)
Mitral stenosis	531 (0.7)
Tricuspid regurgitation (>mild)	532 (0.6)
Previous cardiac surgery	535 (0)
Previous cardiac intervention	535 (0)

Values are presented as n (%).

TABLE E4. Generalized linear regressions models for total cost

Total cost ($)	Estimate	95% CI	*P* value
New allocation system	–41,869	–83,217 to –521	.047
Prior durable MCS	–19,301	–58,667 to 20,065	.336
Preoperative IABP	9928	–47,902 to 67,758	.736
Preoperative percutaneous LVAD	145,961	5224 to 286,698	.042
Preoperative ECMO	210,501	122,342 to 298,660	<.0001
Patient age	–629	–1852 to 595	.313
Female sex	1572	–31,101 to 34,245	.925
BMI	444	–1925 to 2813	.713
Diabetes mellitus	24,996	–5586 to 55,579	.109
NYHA functional class IV	–25,951	–60,648 to 8746	.142
Chronic lung disease	9157	–23,125 to 41,439	.578
Coronary artery disease	16,870	–14,709 to 48,449	.294
Prior cardiac surgery	17,271	–24,108 to 58,650	.413
Prior cardiac intervention	77,442	–2170 to 157,053	.057
Smoker, any history	–17,664	–48,701 to 13,372	.264

CI, Confidence interval; *MCS*, mechanical circulatory support; *IABP*, intra-aortic balloon pump; *LVAD*, left ventricular assist device; *ECMO*, extracorporeal membrane oxygenation; *BMI*, body mass index; *NYHA*, New York Heart Association.

TABLE E5. Generalized linear regressions models for preoperative length of stay

Preoperative length of stay (Days)	Estimate	95% CI	*P* value
New allocation system	–5.6	–11.9 to 0.7	.080
Prior durable MCS	–18.1	–24.1 to –12.2	<.001
Preoperative IABP	–6.7	–15.4 to 2.1	.135
Preoperative percutaneous LVAD	10.2	–11.1 to 31.5	.347
Preoperative ECMO	11.9	–1.5 to 25.3	.081
Patient age	–0.2	–0.4 to –0.0	.050
Female sex	–2.6	–7.6 to 2.3	.302
BMI	–0.1	-0.5 to 0.3	.585
Diabetes mellitus	3.9	–0.7 to 8.5	.098
NYHA functional class IV	1.2	–3.9 to 6.3	.641
Chronic lung disease	5.4	0.6 to 10.3	.027
Coronary artery disease	–2.8	–7.6 to 2.0	.255
Prior cardiac surgery	–1.9	–8.2 to 4.3	.547
Prior cardiac intervention	12.4	0.4 to 24.5	.043
Smoker, any history	–3.1	–7.8 to 1.6	.196

CI, Confidence interval; *MCS*, mechanical circulatory support; *IABP*, intra-aortic balloon pump; *LVAD*, left ventricular assist device; *ECMO*, extracorporeal membrane oxygenation; *BMI*, body mass index; *NYHA*, New York Heart Association.

TABLE E6. Generalized linear regressions models for postoperative length of stay

Postoperative length of stay (Days)	Estimate	95% CI	*P* value
New allocation system	–0.8	–5.5 to 3.9	.736
Prior durable MCS	2.6	–1.9 to 7.1	.257
Preoperative IABP	3.2	–3.4 to 9.7	.344
Preoperative percutaneous LVAD	–7.0	–23.0 to 9.0	.393
Preoperative ECMO	12.6	2.6 to 22.7	.014
Patient age	0.0	–0.2 to 0.1	.803
Female sex	1.5	–2.2 to 5.2	.437
BMI	–0.2	–0.4 to 0.1	.249
Diabetes mellitus	4.0	0.5 to 7.5	.025
NYHA functional class IV	–4.7	–8.5 to –0.8	.017
Chronic lung disease	–1.0	–4.6 to 2.6	.577
Coronary artery disease	4.1	0.5 to 7.7	.024
Prior cardiac surgery	–0.2	–4.9 to 4.5	.921
Prior cardiac intervention	3.9	–5.2 to 12.9	.404
Smoker, any history	–1.3	–4.8 to 2.3	.477

CI, Confidence interval; *MCS*, mechanical circulatory support; *IABP*, intra-aortic balloon pump; *LVAD*, left ventricular assist device; *ECMO*, extracorporeal membrane oxygenation; *BMI*, body mass index; *NYHA*, New York Heart Association.

TABLE E7. Generalized linear regressions models for intensive care unit (ICU) length of stay

ICU length of stay (h)	Estimate	95% CI	*P* value
New allocation system	–1.5	–80.6 to 77.5	.970
Prior durable MCS	25.4	–50.2 to 100.9	.510
Preoperative IABP	60.7	–48.9 to 170.3	.278
Preoperative percutaneous LVAD	–60.3	–328.3 to 207.7	.659
Preoperative ECMO	232.8	63.9 to 401.7	.007
Patient age	0.4	–1.9 to 2.7	.716
Sex (female)	25.7	–37.1 to 88.5	.421
BMI	–1.1	–5.6 to 3.5	.641
Diabetes mellitus	42.9	–15.7 to 101.5	.151
NYHA functional class IV	–75.2	–136.8 to -13.6	.017
Chronic lung disease	–1.2	–61.4 to 59.0	.969
Coronary artery disease	42.0	–18.3 to 102.3	.172
Prior cardiac surgery	23.3	–56.6 to 103.2	.567
Prior cardiac intervention	59.2	–92.9 to 211.3	.445
Smoker, any history	–14.0	–73.5 to 45.6	.645

ICU, Intensive care unit; *CI*, confidence interval; *MCS*, mechanical circulatory support; *IABP*, intra-aortic balloon pump; *LVAD*, left ventricular assist device; *ECMO*, extracorporeal membrane oxygenation; *BMI*, body mass index; *NYHA*, New York Heart Association.