The Society of Thoracic Surgeons Intermacs 2019 Annual Report: The Changing Landscape of Devices and Indications

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Background. **The field of mechanical circulatory support has been impacted by the approval of new continuous-flow left ventricular assist devices (LVADs) and changes to the United States heart allocation system.**

Methods. **Primary isolated continuous-flow LVAD implants in The Society of Thoracic Surgeons Intermacs registry from January 2014 through September 2019 were evaluated. Survival and freedom from major adverse events were compared between axial-flow, centrifugal-flow with hybrid levitation (CF-HL), and centrifugal-flow with full magnetic levitation (CF-FML) devices.**

Results. **Of 2603 devices implanted in 2014, 1824 (70.1%) were axial flow and 1213 (46.6%) were destination therapy (DT); through September 2019, 1752 devices were implanted, but only 37 (2.1%) were axial flow and 1230 (70.2%) were DT. Implants were performed in 13,016 patients between 2014 and 2018. Patients receiving implants in 2017-2018 compared with 2014-2016 were more likely to be at Intermacs profile 1 (17.1% vs 14.3%, $P < .001$) and to have preimplant temporary mechanical circulatory support (34.8% vs 29.3%, $P < .001$). Overall survival and freedom from major adverse events were higher with CF-FML devices. In multivariable analysis of survival between CF-HL and CF-FML, device type was not a significant early hazard, but the use of CF-HL devices had a late hazard ratio for death of 3.01 ($P < .001$).**

Conclusions. **Over the past 5 years, centrifugal-flow LVADs have become the dominant technology and DT the most common implant strategy. While outcomes with CF-FML devices are promising, comparisons with other devices from nonrandomized registry studies should be made with caution.**

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Progress in the field of mechanical circulatory support (MCS) continues apace. In the past year, the United States (US) Food and Drug Administration (FDA) approved the HeartMate 3 (HM3), a centrifugal-flow fully magnetically levitated (CF-FML) device (Abbott Laboratories, Abbott Park, IL), for both short- and long-term support and recently granted breakthrough device designation for a totally implantable platform currently under development (Medtronic Inc, Minneapolis, MN). Additional prototypes from numerous other innovators

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Abbreviations and Acronyms

BTC = bridge to candidacy
BTT = bridge to transplant
CF-FML = centrifugal flow with full magnetic levitation
CF-HF = centrifugal flow with hybrid levitation
DT = destination therapy
ECMO = extracorporeal membrane oxygenation
FDA = Food and Drug Administration
GI = gastrointestinal
HM3 = HeartMate 3
IABP = intraaortic balloon pump
LVAD = left ventricular assist device
MCS = mechanical circulatory support
STS = The Society of Thoracic Surgeons
tMCS = temporary mechanical circulatory support
UNOS = United Network for Organ Sharing
US = United States

and companies hold promise as the next generation of devices. Although excellent postimplant survival has been achieved, regulatory agencies are no longer assessing device outcomes by survival alone but rather by survival free of major adverse events, typically defined as freedom from reoperation for pump replacement and debilitating stroke. Such a high bar for success is necessary to drive innovation and make durable MCS increasingly attractive to patients, families, health care systems, and payers alike, particularly when the devices are intended for long-term support.

A major restructuring of the United Network for Organ Sharing (UNOS) allocation system for cardiac allografts was recently instituted, which undoubtedly will impact implantation strategy and potentially the number of durable left ventricular assist device (LVAD) implants. The change in October 2018 prioritized patients who were the most ill with a stated goal to minimize heart transplant waitlist mortality by assigning higher statuses to those patients supported with extracorporeal membrane oxygenation (ECMO) and nondischargeable temporary (t) MCS. As a result of these changes, those who are stable outpatients on durable continuous-flow devices are now at a relatively lower urgency status. Furthermore, those with complications of MCS are required to meet more stringent criteria and are not assigned to the highest statuses, potentially limiting the access to organs for patients on durable VAD support.

A recently published UNOS registry analysis comparing transplant outcomes before and after the new heart allocation system demonstrated that fewer patients had a durable LVAD before transplant and an increased use of intraaortic balloon pump (IABP), ECMO, or other tMCS devices.[1] This Society of Thoracic Surgeons (STS) Intermacs annual report presents the first opportunity to glean the impact of the new allocation system on the overall number of devices implanted and the proportion implanted as a bridge to transplantation (BTT). In addition, survival, adverse event rates, and composite outcomes will be evaluated for the newest generation of durable VADs.

Patients and Methods

This STS Intermacs annual report analyzed 2 cohorts. The first comprised all adult (aged $\geq$19 years) patients who underwent implantation of an isolated primary continuous-flow LVAD between 2014 and September 30, 2019, and were included in the STS Intermacs Database. This cohort was used to assess the impact of the changes to the UNOS heart allocation system and the approval of a CF-FML LVAD on the number of devices implanted, both overall and by device type, and implant indication.

Between June 2006 and December 2018, 24,354 adult (aged $\geq$19 years) patients received an FDA-approved durable MCS device and were entered into the STS Intermacs Database (Figure 1). Given the evolution of devices, implant techniques, and patient selection and management, the second cohort focused on the most contemporary portion of the overall STS Intermacs Database, namely, the 13,787 patients who underwent implantation between January 2014 and December 2018, with follow-up through September 30, 2019. Excluded were 771 patients who received a total artificial heart, a pulsatile left ventricular or biventricular assist device, or a continuous-flow device as an isolated right ventricular assist device or as biventricular support, resulting in 13,016 patients who received an isolated primary continuous-flow LVAD, who were used to compare baseline patient characteristics over time, survival, freedom from major adverse events, and cumulative hospitalizations.

For descriptive purposes, categorical variables are expressed as frequencies and percentages. Continuous variables are expressed as means $\pm$ SD or median as appropriate for data distribution. Discrete variables were compared with the use of χ^2 test. Kaplan-Meier survival estimates were calculated, censoring patients at the time of transplantation or explant for recovery. For all survival analyses, differences for specific subsets of data were compared with the use of log-rank testing. Outcomes associated with specified strategies at the time of implant (BTT, bridge to decision, and destination therapy [DT]) were examined using the competing outcomes analytic, in which multiple mutually exclusive outcomes are tracked over time. At any point in time, the sum of the proportion (percentage) of patients in each outcome category equals 100%. Risk factors for death after implant were explored using multiphase hazard function modeling. Risk factors with a P value of less than .05 were retained in the final model. Multivariable analysis was performed with a 3-phase hazard model with parametric modeling. Statistical analysis was quantified with SAS 9.4 software (SAS Institute, Inc, Cary, NC).

The analyses reported here were approved by the Intermacs/PediMACS Committee of the STS Access and Publications Task Force under the Workforce on Research

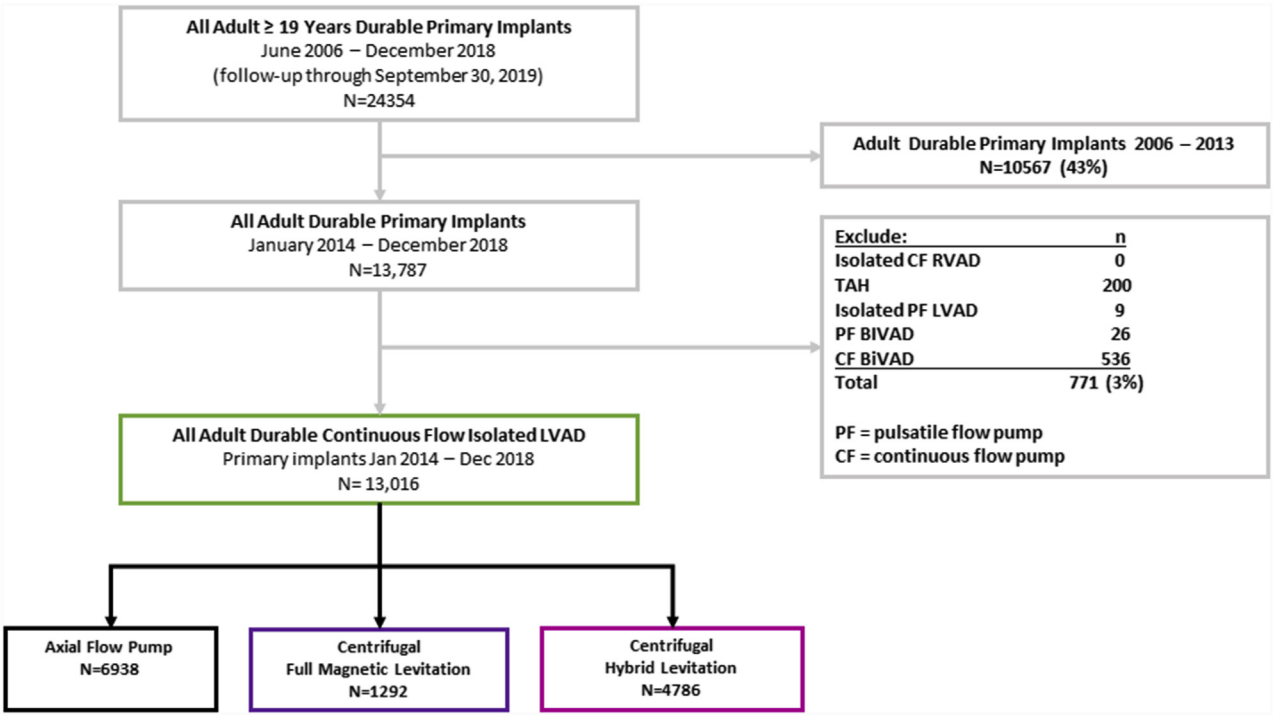

Figure 1. Consolidated Standards of Reporting Trials diagram indicating the device implants registered in The Society of Thoracic Surgeons Intermacs Database and the final cohort for this analysis: adult isolated primary left ventricular assist device (LVAD) implants, January 2014-December 2018. (BiVAD, biventricular assist device; RVAD, right ventricular assist device; TAH, total artificial heart.)

Development. Patient consent for STS Intermacs data collection was obtained at enrolling centers according to local Institutional Review Board requirements.

Results

Implants and Indications Over Time

When examining all adult patients who received an isolated primary continuous-flow LVAD from 2014 through September of 2019, the total yearly implants in the registry decreased from 2015 through 2017, likely as a consequence of the 1028 implants (516 HM3, 512 HeartMate II [Abbott Laboratories, Abbott Park, IL]) that were part of the contemporaneous MOMENTUM 3 (Multicenter Study of MagLev Technology in Patients Undergoing Mechanical Circulatory Support Therapy with HeartMate 3) trial[2-4] (Figure 2A) and another 1000 patients that received implants as part of the continued access protocol, and hence not a part of the commercial devices included in the STS Intermacs registry. Another potential reason for a decline in the number of registered implants was the transfer of the STS Intermacs Database to the STS. This transfer required a new contract from each contributing center. By the start of 2018, not all centers had completed their contract, and thus, for variable periods, some participating centers were not contributing data to STS Intermacs. Total implants subsequently increased in 2018 after the approval of the HM3 as short-term support, although the total number of implants was still somewhat less than in 2015. The impact of the ENDURANCE (Clinical Trial to Evaluate the HeartWare® Ventricular Assist System) Supplemental[5] and MOMENTUM 3 trials can also be seen with the substantial decrease in the implantation of axial-flow devices in 2018 and their virtual absence in 2019. Compared with 2018, there has also been a decline in the total number of centrifugal-flow with hybrid levitation (CF-HL) devices implanted in 2019 (Figure 2B) even after annualization (Supplemental Figure 1).

The effect of the new US heart allocation system was manifested in the dramatic change in the distribution of implant strategies over time (Figure 3). Before 2018, approximately 25% of patients received the LVAD as bridge-to-transplant candidacy (BTC), 25% as BTT, and about half as DT. However, since the introduction of the new heart allocation system in October of 2018, less than 10% of the implants were BTT and more than 70% were DT in 2019.

Evolution of Patient Characteristics Over Time

The second cohort comprised 13,016 patients (Figure 1). Of this group 53% (n = 6938) received an axial-flow device, 37% (n = 4786) received a CF-HL, and 10% (n = 1292) received a CF-FML device. The patients were separated into 2 groups, those whose LVAD was implanted from 2014-2016 and 2017-2018 to assess the evolution of patient characteristics over time (Table 1). For the more recent group, patients were more likely to be nonwhite and unmarried. Interestingly, there were fewer patients with an implantable cardioverter defibrillator before implant, a history of peripheral vascular

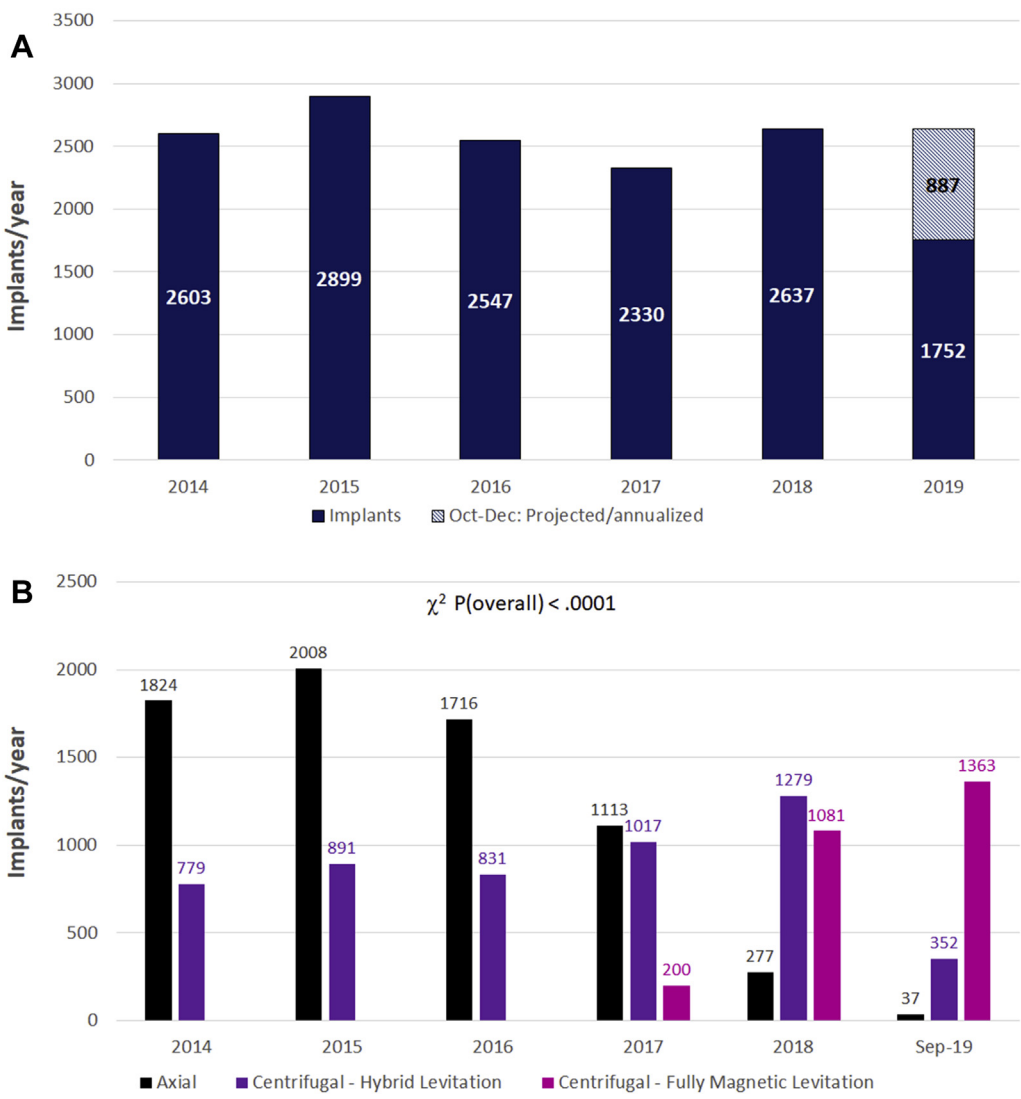

Figure 2. Isolated primary continuous flow LVAD implants, January 2014-September 30, 2019 (A) by year and (B) by pump and by year.

disease, or prior bypass surgery. The distribution of Intermacs profiles remained predominantly 2 to 3; however, there were significantly more profile 1 patients (17.1% vs 14.3%, $P < .001$) in the 2017-2018 group. Implants into patients who were Intermacs profiles 4 to 7 continued to be uncommon and comprised less than 15% of the total implants.

The other notable change in preimplant severity of illness was an increasing use of tMCS (34.8% vs 29.3%, $P < .001$) in the more recent group. Although some statistically significant differences were noted in preimplant laboratory, echocardiographic, and hemodynamic data between the 2 cohorts, few were clinically meaningful.

Outcomes After Implantation

Survival with current-generation continuous-flow LVADs continues to be favorable, with a 30-day mortality of only 5% and 1-year survival of 82% (Figure 4). Although slightly more than half of the patients are alive at 4 years after implant, only 29% of patients remain supported on MCS, and 33% have undergone cardiac transplantation (Figure 5). Explant of devices for myocardial recovery continues to be rare in the STS Intermacs population, occurring in less than 5% of the implants by 5 years.

In STS Intermacs, implant intent is associated with survival, particularly early survival. Those whose LVAD was implanted as BTT have superior survival compared with BTC and DT patients (Figure 6). The improved survival with the current generation of devices is now comparable to survival after cardiac transplantation for the first year, but afterward, transplant survival is superior to MCS, regardless of indication.[6] The various competing outcomes differ across implant indications (Supplemental Figure 2A-D). For those who received the LVAD as BTT, 33% received a transplant by 1 year, 50% by 2 years, and 61% by 5 years. In contrast, for those whose LVAD was implanted as BTC, only 19% received a transplant by 1 year, 30% by 2 years, and 41% by 5 years. Fewer than 20% of patients whose LVAD was implanted as DT receive a transplant by 5 years, and only 30% remain supported on

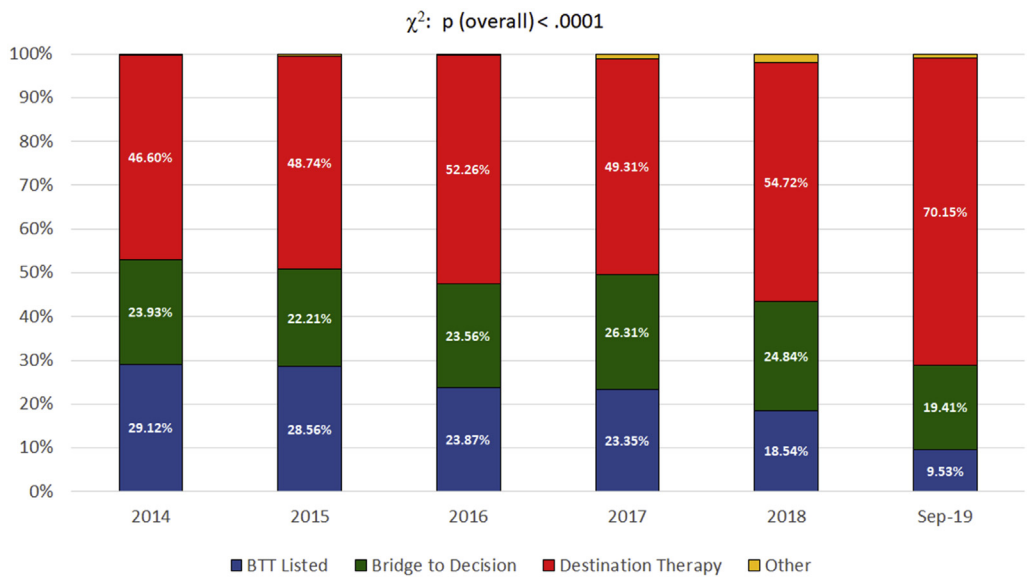

Figure 3. Implant strategies by year. (BTT, bridge to transplant.)

LVAD past 5 years. Importantly, the risk of death on device exceeds survival between 36 and 48 months after implant, regardless of implant strategy.

Despite advances in patient selection, operative techniques and perioperative and long-term management, no differences occurred in 2-year survival (72% vs 74%) between those who received LVADs from 2014-2016 compared with 2017-2018 (Supplemental Figure 3). There was no significant difference in survival between axial and CF-HL devices, but the more recently approved CF-FML device had a 1-year survival of 87%, which was significantly higher in an unadjusted comparison compared with axial and CF-HL devices and comparable to a contemporaneous international cohort that underwent cardiac transplantation[6] (Figure 7). Further, given the limited follow-up for the CF-CML devices, comparisons beyond 1 year are limited.

Adverse Events

The unadjusted freedom from several of the most common adverse events, including gastrointestinal (GI) bleeding, stroke, infection, and right heart failure, was assessed for the overall population (Supplemental Figure 4A-D) and by pump type (Figure 8A-D). Apart from right heart failure, the CF-FML devices had a significantly superior freedom from these adverse events compared with the CF-HL and axial-flow devices. GI bleeding remains common in the first year after implant with 25%, 20%, and 12% of patients having a GI bleed for axial, CF-HL, and CF-FML devices, respectively (Figure 8A). Beyond the first-year, centrifugal-flow devices have a greater freedom from GI bleeding than axial-flow devices. The freedom from first stroke, regardless of severity, at 1 year was 88% for axial, 84% for CF-HL, and 93% for CF-FML devices (Figure 8B). Major infection was the most common adverse event, with only 60% of axial, 57% of CF-HL and 67% of CF-FML devices free of a major infection at 1 year (Figure 8C). Lastly, right heart failure overwhelmingly occurred in the first month after implant, and the freedom from right heart failure was higher in axial-flow devices at 1 year (71%) than the CF-HL (62%) or CF-FML (66%) devices (Figure 8D). Similar findings were demonstrated when adverse event-free survival was analyzed by pump type (Supplemental Figure 5A-D).

Multivariable Analysis of Survival

Given the near elimination of new HeartMate II implants in the US after publication of the MOMENTUM 3 clinical trial and the lack of robust comparisons of outcomes between centrifugal technologies in the literature to date, we chose to focus the multivariable survival analysis on risk factors for death in those supported with the CF-HL or CF-FML device. To eliminate temporal differences in patient selection and management, we also restricted the analysis to the period during which both devices were available for FDA-approved implant (August 23, 2017-December 31, 2018). During this interval, 2964 index centrifugal-flow LVADs (1697 CF-HL and 1267 CF-FML) were implanted. There were significant differences in the risk reflected in the baseline characteristics between CF-HL and CF-FML devices (Supplemental Table 1). For this analysis of centrifugal-flow devices, the overall survival was 89% at 3 months and 82% at 1 year, with the greatest hazard for mortality in the first 3 months after implant (Supplemental Figure 6). Factors associated with an increased early hazard (first 90 days postoperatively) of death include age, Intermacs profile 1, use of tMCS, and a prior cardiac operation (Table 2). The type of centrifugal pump was not associated with an early risk of death. In contrast, the strongest risk factor for death in the longer-term (constant phase) was the presence of a CF-HL device. When the multivariable model was repeated with an additional 2 months of follow-up, the strongest risk factor for death in the constant phase remained the

Table 1. Baseline Characteristics

Preimplant Characteristics	2014-2016 (n = 8049)	2017-2018 (n = 4967)	*P* Value
Demographics			
Age, y	57.0	57.1	.59
Female	21.4	22.3	.22
White race	65.7	63.8	.03
Body mass index, kg/m^2	28.64	28.58	.64
Body surface area, m^2	2.08	2.07	.08
Married	62.6	59.9	.002
College	49.5	51.0	.14
Blood type			
O	46.7	48.3	.07
A	36.5	35.1	.11
B	13.1	13.3	.71
AB	3.7	3.3	.17
Medical history			
Alcohol abuse	7.5	7.4	.80
Ascites	5.0	4.9	.75
Cancer	4.9	4.7	.60
Diabetes, severe	9.7	8.8	.09
Dialysis	1.3	1.3	.92
Drug abuse	7.7	8.9	.02
Hepatitis	1.4	1.0	.10
Implantable cardioverter defibrillator	80.3	76.7	<.001
Peripheral vascular disease	4.6	3.7	.01
Prior CABG	18.8	16.7	.003
Prior valve surgery	6.8	6.9	.78
Prior cardiac surgery – other	6.3	5.0	.003
Smoker, current	4.8	5.8	.01
Severity of illness			
Intermacs profile			
1	14.3	17.1	<.001
2	34.7	35.7	.21
3	37.1	35.4	.05
4	11.9	10.0	<.001
5	1.5	1.2	.14
6	0.4	0.4	.84
7	0.2	0.2	.31
Extracorporeal membrane oxygenation	2.9	2.3	.05
Intraaortic balloon pump	18.5	16.9	.02
Inotropes	83.7	85.6	.005
Temporary mechanical support	29.3	34.8	<.001
Ventilator	5.1	3.5	<.001
Cardiac primary diagnoses			
Coronary artery disease	4.8	5.6	.04
Nonischemic cardiomyopathy	51.2	51.4	.81
Ischemic cardiomyopathy	38.5	36.0	.004
Postpartum cardiomyopathy	1.5	1.7	.47
Hypertrophic cardiomyopathy	0.6	0.7	.51
Restrictive cardiomyopathy	1.2	1.4	.28
Congenital heart disease	0.5	0.7	.04
Valvular heart disease	0.7	1.0	.12
None listed	0.2	0.1	.54
Unknown	0.7	1.3	.001

(*Continued*)

Table 1. Continued

Preimplant Characteristics	2014-2016 (n = 8049)	2017-2018 (n = 4967)	*P* Value
Laboratory values			
Albumin, g/dL	3.43	3.43	>.99
Brain natriuretic peptide, pg/mL	1124.13	1299.32	<.001
Blood urea nitrogen, mg/dL	28.59	29.42	.01
Cholesterol, mg/dL	132.91	127.42	.01
Creatinine, mg/dL	1.39	1.40	.55
Hemoglobin, g/dL	11.31	11.06	<.001
International normalized ratio, IU	1.30	1.29	.42
Lactate dehydrogenase, U/L	351.10	368.35	.06
Platelets, K/μL	197.74	197.02	.62
Prealbumin, mg/dL	18.91	18.47	.01
SGOT/AST, U/L	49.61	48.50	.73
SGPT/ALT, U/L	59.54	57.65	.55
Sodium, mmol/L	134.97	135.27	<.001
Total bilirubin, mg/dL	1.33	1.31	.46
White blood cells, K/μL	8.56	8.76	.01
Echocardiography			
LVEDD, cm	6.84	6.76	<.001
LVEF <0.20	69.4	69.5	.97
RVEF, severe	13.8	15.3	.04
Regurgitation (moderate/severe)			
Aortic	4.4	4.1	.45
Mitral	57.4	57.5	.91
Tricuspid	41.8	41.8	>.99
Hemodynamics			
Heart rate	89.09	90.30	<.001
Systolic blood pressure, mm Hg	106.31	106.47	.59
Diastolic blood pressure, mm Hg	65.35	66.38	<.001
Right atrial pressure, mm Hg	12.74	12.42	.07
Pulmonary systolic pressure, mm Hg	49.99	49.49	.08
Pulmonary diastolic pressure, mm Hg	24.88	24.94	.75
Pulmonary wedge pressure, mm Hg	25.04	25.04	>.99
Cardiac index, L/min^2	2.18	2.13	.01
Pulmonary vascular resistance, Wood units	4.24	4.23	.84
Indication			
Bridge to transplant			
Listed	27.3	20.8	<.001
Likely to be listed	13.3	13.1	.83
Moderately likely to be listed	7.7	9.6	<.001
Unlikely to be listed	2.2	2.8	.05
Destination therapy	49.2	52.2	<.001
Failure to wean from CPB	0.6	1.9	<.001
Postcardiac surgery	1	1	.30

Continuous data are reported as the mean and categorical data as the percentage of patients.

ALT, alanine aminotransferase; AST, aspartate transaminase; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; LVEDD, left ventricular end diastolic dimension; LVEF, left ventricular ejection fraction; RVEF, right ventricular ejection fraction; SGOT, serum glutamic oxaloacetic transaminase; SGPT, serum glutamate-pyruvate transaminase.

presence of a CF-HL device (Supplemental Table 2). When the baseline differences between CF-HL and CF-FML were incorporated into the model, no additional significant independent predictors of death were found. Survival at 1-year was significantly higher for CF-FML devices than for CF-HL devices (87% vs 79%, $P < .001$). For those whose LVAD was implanted as BTT, there was no difference in 1-year survival between the 2 devices, but for DT recipients, the CF-FML devices had significantly higher 1-year survival (Supplemental Figure 7A-F).

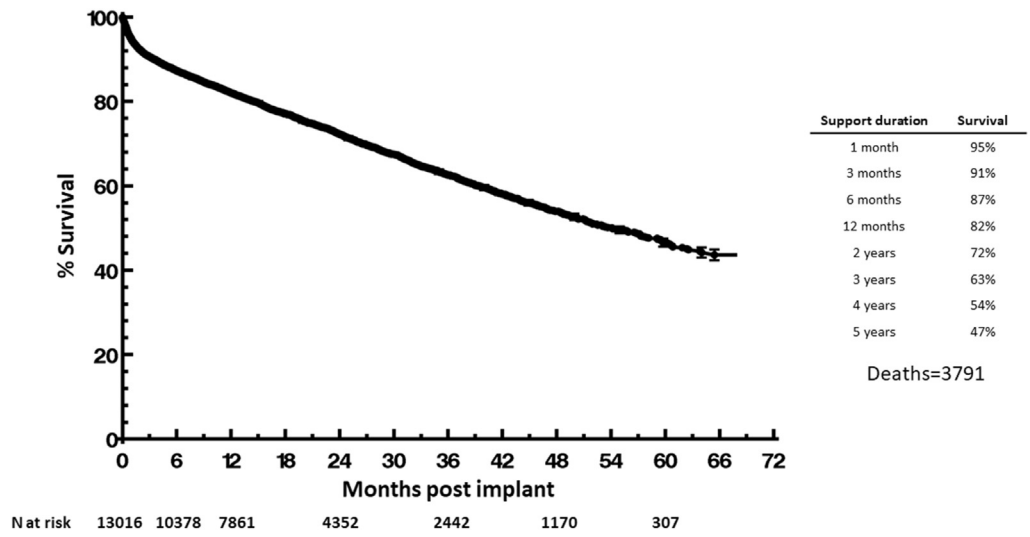

Figure 4. Kaplan-Meier survival curve for isolated primary left ventricular assist device implants, January 2014-December 2018.

Freedom from GI bleeding, stroke, major infection, and right heart failure were significantly higher for CF-FML than CF-HL devices for the population who underwent implantation from August 23, 2017, to December 31, 2018 (Supplemental Figure 8A-D).

Hospitalizations

Rehospitalizations remain a burden after MCS. The cumulative number of rehospitalizations per 100 patients is 59.0 at 3 months and is 218.0 by 12 months (Supplemental Figure 9A-F and Supplemental Figure 10). The most common reasons for rehospitalizations include bleeding, infection, neurologic dysfunction, and right heart failure-related adverse events (Figure 9). Of these reasons for rehospitalizations, major infection was the most common, with 3- and 12-month cumulative rehospitalizations per 100 patients of 4.4 and 24.0, respectively. The cumulative readmissions for planned rehospitalizations were relatively uncommon, at 2.4 and 11.5 per 100 patients at 3 and 12 months, respectively.

Comment

In the current era of continuous-flow LVADs, few changes have occurred in the baseline demographic, laboratory, hemodynamic, or echocardiographic features of patients undergoing durable isolated primary device implantation. The most notable difference when

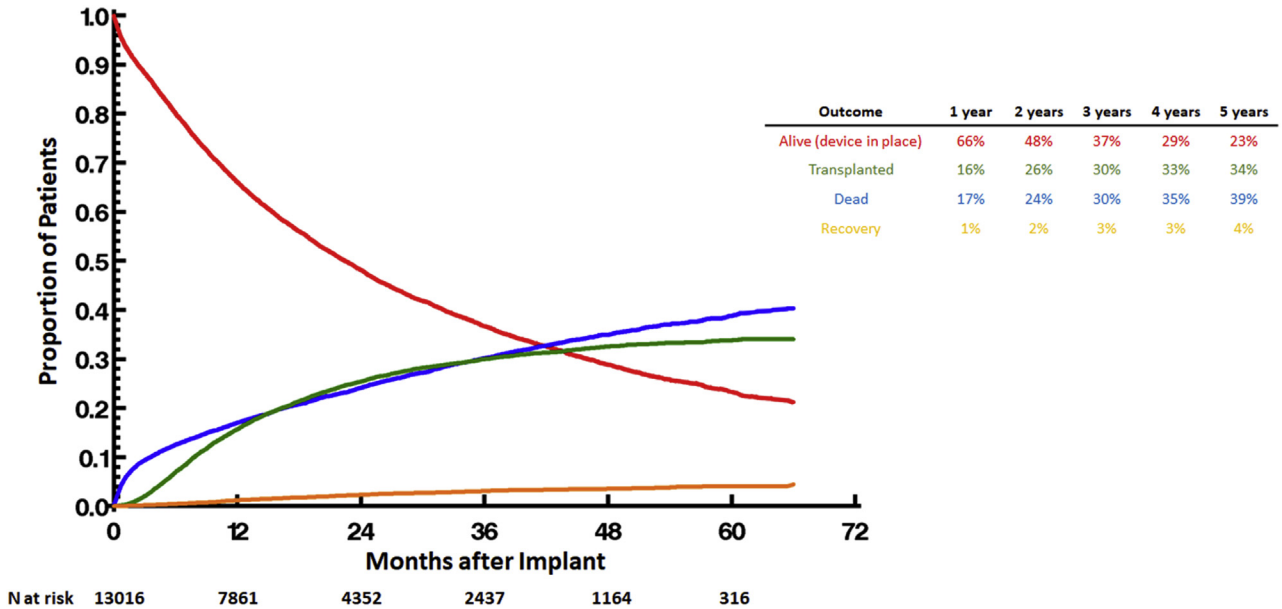

Figure 5. Competing outcomes depiction for isolated primary left ventricular assist device implants, January 2014-December 2018. All outcome events are mutually exclusive. At any point in time, the proportion (percentage) of patients in each category sums to 100%.

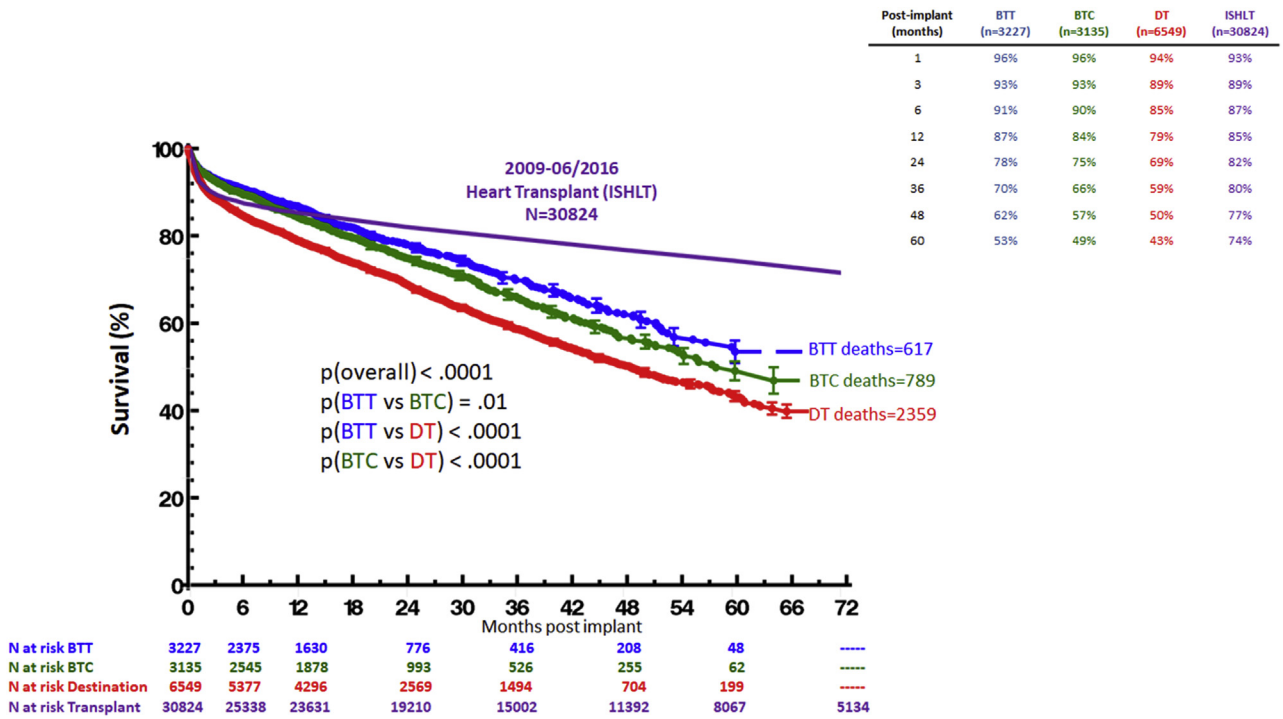

Figure 6. Survival by implant strategy for isolated primary left ventricular assist device implants, January 2014-December 2018, compared with survival after heart transplantation. (BTC, bridge to candidacy; BTT, bridge to transplant; DT, destination therapy; ISHLT, International Society for Heart and Lung Transplantation.)

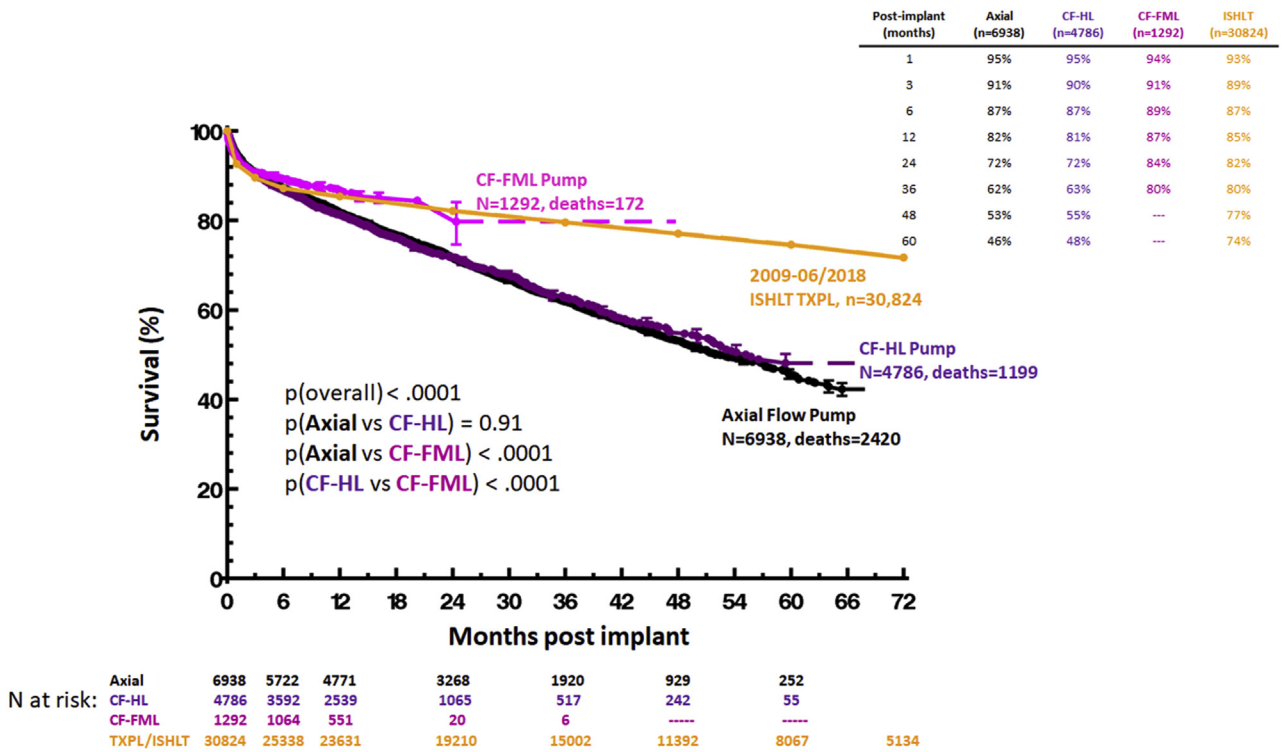

Figure 7. Survival by pump type after isolated primary continuous-flow left ventricular assist device implant, January 2014-December 2018, compared with survival after heart transplantation. (CF-FML, centrifugal flow with full magnetic levitation; CF-HL, centrifugal flow with hybrid levitation; ISHLT, International Society for Heart and Lung Transplantation; TXPL, transplant.)

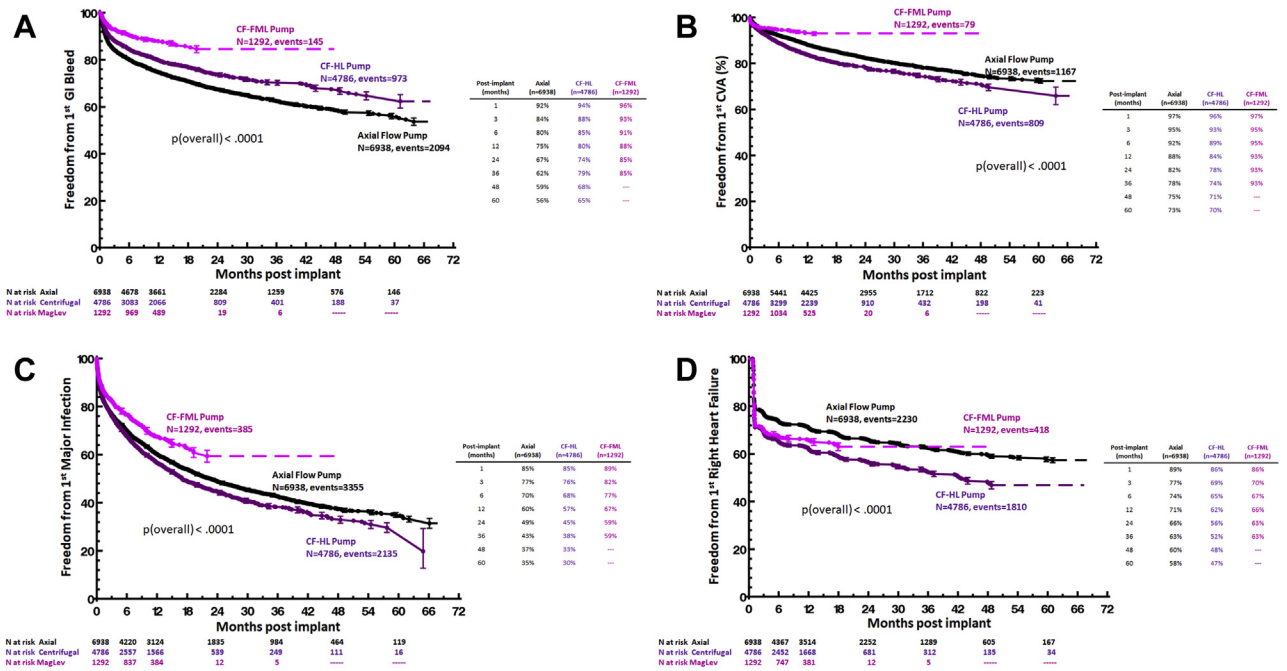

Figure 8. Freedom from adverse events by pump type for isolated primary left ventricular assist device implants, January 2014-December 2018. Freedom from (A) first gastrointestinal (GI) bleed, (B) first cerebrovascular accident (CVA), (C) first major infection, and (D) first right heart failure. (CF-FML, centrifugal flow with full magnetic levitation; CF-HL, centrifugal flow with hybrid levitation.)

comparing the 2014-2016 group to the 2017-2018 group was the increasing presence of tMCS before durable MCS, with a slight decrease in the presence of an IABP and no change in the proportion of patients supported with ECMO before implant. This was accompanied by a slight increase in the number of patients who underwent implantation as Intermacs profile 1, despite being long recognized as a poor prognostic marker compared with other Intermacs profiles.[7] The reason for the increasing prevalence of preoperative tMCS is uncertain, but this

Table 2. Multivariable Model for Contemporary Era for Centrifugal-Flow Left Ventricular Assist Devices: Hybrid vs Fully Magnetically Levitated (August 23, 2017-December 31, 2018)

	Early Hazard		Constant Hazard	
Preimplant Risk Factors for Death	Hazard Ratio	*P* Value	Hazard Ratio	*P* Value
Demographics				
Age[2] (older)	1.31	<.001	1.48	<.001
Clinical status				
Intermacs profile 1	1.76	<.001		
Modifier: temporary circulatory support	1.61	.004		
Device strategy: bridge to decision			1.60	.01
Cardiac/hemodynamics				
Central venous pressure (mm Hg) higher	1.04	.001		
LVEDD (cm) smaller	.80	.001		
Laboratory values				
Blood urea nitrogen (mg/dL) higher	1.08	<.001		
Creatinine (mg/dL) higher			1.42	<.001
International normalized ratio			1.26	.002
Sodium (mmol/L) lower			.95	.003
Total bilirubin (mg/dL) higher	1.08	<.001		
Surgical				
Centrifugal flow-hybrid levitation			3.01	<.001
Previous cardiac operation	1.66	<.001		

LVEDD, left ventricular end-diastolic dimension.

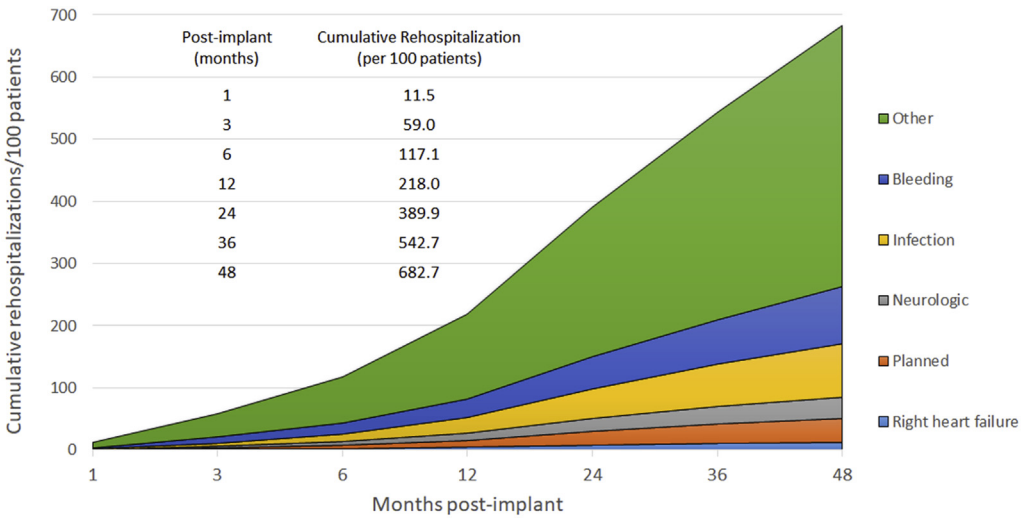

Figure 9. Cumulative rehospitalizations by type for isolated primary left ventricular assist device implants, January 2014-December 2018.

observation mirrors the increased use of tMCS in patients with cardiogenic shock, both in the community and in the LVAD implanting centers.

Regardless of the type of support used before implant, no differences were noted in the overall preimplant hemodynamics for 2014-2016 compared with 2017-18. Despite the excellent overall outcomes with current devices and consistent with prior STS Intermacs reports, less than 15% of the implants are in preinotrope-dependent Intermacs profiles 4 to 7.[8]

Factors external to the field of MCS, namely the recent changes in the UNOS heart allocation policy, have majorly impacted the use of devices in the US. With nondischargeable tMCS and ECMO comprising the highest statuses in the new allocation system, it has relegated those with MCS complications or who are stable on MCS to lower statuses, potentially impacting the use of durable LVAD support as BTT. Consistent with this, the overall number of implants has remained somewhat static, while the frequency of BTT as a strategy has fallen from approximately one-quarter to one-tenth of all implants. Whether this trend will continue or potentially even reverse as there are more patients being supported with tMCS remains unclear.

As a consequence of the change in the allocation system and reduction of BTT, and to a lesser extent BTC, the field has moved toward DT as the predominant preimplant strategy. With less than 20% of DT patients receiving an allograft at 5 years, a greater percentage of the MCS population will be supported for longer durations. This phenomenon will place increasing importance on survival free of major adverse events to ensure that these longer durations of support are accompanied by a good quality of life.

With the increasing proportion of devices being implanted as DT, the impact of more patients being supported for longer periods of time will be seen on programs, hospitals, and payers. Rehospitalization continues to be a major contributor to cost but can also result in substantial burdens to patients, caregivers, and programs. Prior STS Intermacs reports have demonstrated a very low 1-year freedom from rehospitalization from a composite of major adverse events.[9] Unfortunately, many of the reasons for readmission are recurrent, particularly over long periods of support, as seen in the analysis of cumulative rehospitalizations per 100 patients in this report. Although many of the common adverse events, such as bleeding, infection, right heart failure, and neurologic events, make up a large proportion of the overall readmissions, in sum they are still the minority of all-cause rehospitalizations. To make MCS technology broadly appealing and cost-effective, the MCS field needs to improve its understanding of the risk factors for these readmissions and, more importantly, to develop more effective strategies for their prevention.

Since the prior STS Intermacs report, new MCS technology has been approved and widely adopted. The MOMENTUM 3 trial randomized more than 1000 patients to a HeartMate II or HM3 for short- or long-term support indications. Survival was similar for the 2 devices, but the composite end point of survival free of device replacement and disabling stroke favored the HM3.[4] As a result of these trial findings, the use of axial-flow devices in STS Intermacs decreased from 67% of all continuous-flow LVADs in 2016 to just 2.1% for the first 9 months of 2019.

The 2-year survival for continuous-flow LVADs has not improved significantly for those who underwent implantation between 2014-2016 and 2017-2018. However, survival with the CF-FML device is higher compared with the CF-HL device in an unadjusted analysis and approaches the results of cardiac transplantation in the short-term. The CF-FML device also has a greater freedom from first stroke, GI bleeding, and major infection in unadjusted analyses. When contemporary cohorts of patients with CF-HL and CF-FML were compared in a multivariable analysis, the early hazard for death was similar, but CF-HL support was the strongest risk factor

for death in the longer-term. However, there are important baseline differences in the CF-HL and CF-FML populations. Those implanted with CF-HL devices had a greater burden of important co-morbidities, larger percentage of Intermacs profile 1 patients, higher use of tMCS, greater prevalence of severe RV dysfunction and moderate or greater tricuspid regurgitation, and nearly twice the proportion of DT implants.

The field of durable MCS is now dominated by 2 centrifugal-flow devices. In the absence of a head-to-head comparison in a randomized clinical trial, the community has tried to extrapolate differences in outcomes through comparisons across existing clinical trials. However, such efforts are confounded by differences in trial eras, leading to differences in patient populations, device indication, patient selection, and practice patterns. Importantly, inconsistent adverse event definitions have been used across clinical trials, most notably for neurologic events. A large national postapproval registry, such as STS Intermacs, affords the opportunity to initiate such head-to-head comparisons; however, these comparisons should be interpreted with caution and with important caveats.

STS Intermacs patients within the period of comparison who were not BTT intent did not initially have access to both CF-FML and CF-HL devices. This potential bias occurred because CF-FML approval was initially restricted to those undergoing short-term support, whereas the CF-HL was approved for both BTT and DT. This may have favored outcomes with the CF-CML because DT outcomes tend to be worse than BTT outcomes. After October 2018, the CF-FML device had both BTT and DT approval.

Although many baseline characteristics were assessed in the multivariate analysis, differences likely exist in patient selection, operative technique, and postoperative management that have evolved over time. Moreover, device selection may have also been influenced by ongoing continued access protocol criteria, with potentially sicker and higher-risk patients undergoing implantation of an approved device rather than being enrolled into a clinical trial. Implanting centers that have both devices available may have other protocols or means to determine pump selection that may also affect baseline risk and outcomes.

Furthermore, although adverse event definitions have been more consistent over the period of this analysis, all adverse events for patients entered into the STS Intermacs Database are determined by the implanting center and not subject to central adjudication. For an understanding of the outcome differences between commercially available devices, only a randomized, prospective, multiinstitutional trial will provide the most valid comparison. Importantly, starting in 2021, STS Intermacs will begin using adverse event definitions as redefined under the auspices of the Academic Research Consortium. These new definitions will serve to clarify adverse events and become the recommend nomenclature for use in all future MCS clinical trials.

In conclusion, this STS Intermacs annual report has characterized the continued evolution of the field of durable MCS. The recent changes in the heart allocation system have resulted in a substantial shift in implant strategy toward DT and away from BTT. Evolution of continuous-flow LVAD technology and recent trials have led to the widespread adoption of centrifugal-flow devices as the dominant technology. Longer-term follow-up of larger cohorts of patients in Intermacs is warranted to examine whether, as experience continues, any of the survival differences may be attributable to a somewhat sicker patient population implanted with CF-HL devices. Although the short-term survival and freedom from major adverse events with the CF-FML device appear promising, direct comparisons between centrifugal-flow devices are premature.

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