Impact of preoperative versus postoperative dialysis on left ventricular assist device outcomes: An analysis from the Society of Thoracic Surgeons Interagency Registry for Mechanically Assisted Circulatory Support database

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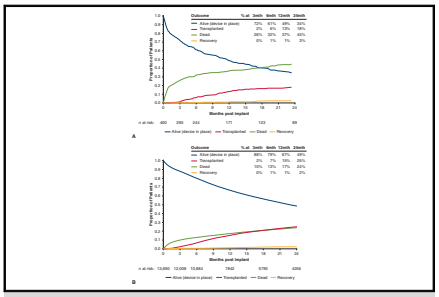
ABSTRACT

Objective: Chronic kidney disease and renal failure are common in patients being considered for left ventricular assist device support. We sought to evaluate the outcomes of patients undergoing left ventricular assist device implantation with preoperative dialysis and those with new-onset postoperative renal failure requiring dialysis.

Methods: All patients (n = 14,090) undergoing primary left ventricular assist device implantation who were listed in the Interagency Registry for Mechanically Assisted Circulatory Support database (2014-2019) were evaluated. Landmark analysis then stratified patients alive at 1 month by preoperative dialysis and at 1 month postoperatively, preoperative dialysis only, postoperative dialysis only, and no dialysis.

Results: Of 14,090 patients undergoing left ventricular assist device implantation, patients on dialysis (400%, 3%) preoperatively had significantly higher mortality at 1 month (18% vs 6%, $P < .0001$). However, of patients on preoperative dialysis, 131 (32.8%) no longer required dialysis at 1 month postoperatively and had long-term survival similar to patients who never required dialysis (no dialysis vs recovered, $P = .13$). Long-term survival was significantly worse in patients with persistent dialysis and new dialysis at 1 month postoperatively ($P < .0001$). Time to first stroke, major nondevice infection, any bleeding event, and gastrointestinal bleeding were all worse in patients on preoperative or postoperative dialysis (all $P < .0001$). Device infection, malfunction, or thrombosis was not associated with dialysis status ($P > .05$). Negative predictors of recovery include biventricular assist device (odds ratio, 0.20) and inotropes 1 week postimplant (odds ratio, 0.19).

Conclusions: Preoperative renal failure is associated with 3 times higher mortality and worse morbidity in patients receiving a left ventricular assist device. However, one-third of patients with preoperative dialysis will recover renal function postimplant with similar long-term survival and quality of life as those without dialysis. (JTCVS Open 2022;9:122-43)



Overall survival in preoperative dialysis versus no preoperative dialysis.

CENTRAL MESSAGE

Preoperative dialysis is associated with 3 times higher mortality during LVAD implant; however, one-third of patients will recover renal function with similar long-term survival and quality of life as those without.

PERSPECTIVE

Few studies evaluate LVAD recipients receiving dialysis, but data vary with some demonstrating diminished renal function as a strong predictor of adverse outcomes after LVAD implantation and other data suggesting that LVAD implantation improves renal function and can be performed with reasonable outcomes in this patient population.

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Given the deidentified nature of this national database study, it was approved by the University of Virginia Health Sciences Institutional Review Board with waiver of consent.

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Abbreviations and Acronyms

BIVAD	= biventricular assist device
CI	= confidence interval
ESRD	= end-stage renal disease
INTERMACS	= interagency registry for mechanically assisted circulatory support
LVAD	= left ventricular assist device
OR	= odds ratio
STS	= Society of Thoracic Surgeons

Left ventricular assist devices (LVADs) have been shown to prolong survival and improve quality of life for appropriately selected patients with advanced heart failure.[1,2] Over the past 20 years, developments in LVAD technology have been correlated with improved patient outcomes and more widespread use of the therapy. However, determining which patients will ultimately benefit from the use of an LVAD remains complicated because patients with medically refractory heart disease are a heterogeneous group and often have other comorbidities.

Kidney disease is often associated with heart disease and can be directly linked as in cardiorenal syndrome or can exist as 2 separate entities. The prevalence of heart failure is approximately 40% among patients with end-stage renal disease (ESRD), with more than one-third (37%) dying of complications related to heart failure.[3] Few studies have evaluated outcomes among LVAD recipients with kidney disease, and these have largely focused on patients with earlier stages of kidney disease not receiving dialysis and those receiving acute dialysis for acute kidney injury, rather than those with ESRD.[4-6] Some groups argue that diminished renal function is a strong predictor of adverse outcomes after LVAD implantation and should be viewed as a contraindication to this therapy.[7] Others argue that LVAD implantation improves renal function and can be performed with reasonable outcomes in this patient subset; therefore, preoperative renal dysfunction should not be an exclusion criterion for LVADs.[8]

In light of recent conflicting data, the purpose of this study was to assess the impact of preoperative ESRD and new postoperative dialysis on patient outcomes after LVAD placement in the Society of Thoracic Surgeons (STS) National Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) database.[9] Specifically, we sought to evaluate the association between preoperative dialysis and survival, complications, and quality of life after LVAD implant. We evaluated major adverse events, survival, and patient-reported quality of life with the hypothesis that patients on dialysis undergoing LVAD implantation would have worse outcomes and those who develop renal failure requiring dialysis after LVAD implantation will have poor long-term survival. Secondary objectives included identification of predictors of renal recovery in patients on dialysis before LVAD implant. Finally, subgroup analysis evaluated the association between outcomes and patient acuity by preoperative dialysis.

MATERIALS AND METHODS

Patient Data

All adult patients (aged >18 years; n = 14,325) undergoing first durable continuous-flow mechanical circulatory support device implant in the STS INTERMACS database between June 2, 2014, and June 30, 2019, were included in the analysis with follow-up through December 31, 2019. Patients receiving total artificial heart and primary isolated right ventricular devices were excluded (Figure E1). Standard STS INTERMACS definitions were used, and longitudinal data were assessed according to customary STS INTERMACS practices. Patients were stratified by preoperative dialysis (n = 400) or no preoperative dialysis (n = 13,690). Landmark analysis then stratified patients alive at 1 month by preoperative dialysis and at 1 month postoperatively (n = 186, persistent dialysis), preoperative dialysis only (n = 131, recovered), postoperative dialysis only (n = 819, new dialysis), and no dialysis (n = 11,047, no dialysis). Recovered was defined as yes dialysis preoperatively and no dialysis at 1-month follow-up. Given the deidentified nature of this national database study, it was exempt from review by the University of Virginia Health Sciences Institutional Review Board with waiver of consent.

Statistical Analysis

Categorical variables are presented as counts and percentages, and continuous variables are shown as mean ± standard deviation or median (25^{th}, 75^{th} percentiles) based on normality. Baseline characteristics and short-term outcomes were assessed by univariate analysis. The Student *t* test or Mann–Whitney *U* test was used for continuous variables, and the chi-square test was used for categorical variables; when appropriate, Tukey's post hoc correction for multiple comparisons was used. Kaplan–Meier survival estimates were calculated, censoring patients at the time of transplantation, device exchange, or explant for recovery. Time to event analysis was performed with standard INTERMACS methodology using Kaplan–Meier censoring for transplant, device exchange, explant, or death. For all time-varying analyses, differences for specific subsets of data were compared with the use of log-rank testing. A logistic regression was fit in the cohort of all patients on preoperative dialysis for the outcome of "no dialysis" at 1 month after implant. Forward stepwise selection was used for all preoperative and 1-week follow-up variables with less than 20% missing. Model fit and performance were assessed with c-statistic. The patients self-reported if they would undergo LVAD placement again, and these data were presented. All analysis was performed using SAS Version 9.4 (SAS Institute).

RESULTS

Patient Characteristics and Competing Risks

After applying exclusion criteria, a final population of 14,090 patients undergoing LVAD implantation were included for analysis (Figure E1). A total of 400 (3%) of these patients were on dialysis preoperatively. Patients on dialysis were younger (55 vs 57 years $P = .001$), with lower rates of bridge to transplant already listed status (18.3% vs 23.1%, $P = .02$) and significantly higher rates of INTERMACS profile level 1 (49% vs 16%, $P < .0001$, Table 1). Patients on preoperative dialysis were also significantly

TABLE 1. Baseline characteristics

Preimplant characteristics	No predialysis (n = 13,690)	Predialysis (n = 400)	*P* value
Alcohol abuse	1029 (7.5%)	30 (7.5%)	.99
Aortic regurgitation (moderate/severe)	521 (4.4%)	12 (3.8%)	.61
Ascites preimplant	436 (4.7%)	26 (9.5%)	.0002
Blood type O	6443 (47.4%)	178 (44.9%)	.33
Cancer	646 (4.7%)	22 (5.5%)	.47
College	5022 (49.9%)	150 (53.6%)	.22
Current smoker	739 (5.4%)	26 (6.5%)	.34
Drug abuse	1208 (8.8%)	30 (7.5%)	.36
Bridge to transplant: listed	3164 (23.1%)	73 (18.3%)	.02
Bridge to transplant: likely to be listed	1746 (12.8%)	37 (9.3%)	.04
Bridge to transplant: moderately likely to be listed	1146 (8.4%)	44 (11.0%)	.06
Bridge to transplant: unlikely to be listed	350 (2.6%)	12 (3.0%)	.58
Destination therapy	7170 (52.4%)	224 (56.0%)	.15
Failure to wean	173 (1.3%)	7 (1.8%)	.39
History of hepatitis	167 (1.2%)	4 (1.0%)	.69
History of CABG	2388 (17.4%)	72 (18.0%)	.77
History of valve surgery	908 (6.6%)	31 (7.8%)	.38
ICD	10,669 (78.4%)	248 (62.9%)	<.0001
INTERMACS Patient Profile Level 1	2172 (15.9%)	196 (49.0%)	<.0001
INTERMACS Patient Profile Level 2	4731 (34.6%)	150 (37.5%)	.22
INTERMACS Patient Profile Level 3	5010 (36.6%)	40 (10.0%)	<.0001
INTERMACS Patient Profile Level 4	1496 (10.9%)	10 (2.5%)	<.0001
INTERMACS Patient Profile Level 5	187 (1.4%)	2 (0.5%)	.14
INTERMACS Patient Profile Level 6	69 (0.5%)	1 (0.3%)	.48
INTERMACS Patient Profile Level 7	25 (0.2%)	1 (0.3%)	.76
Inotropes	11,556 (84.7%)	368 (92.2%)	<.0001
ECMO	398 (2.9%)	53 (13.3%)	<.0001
IABP	2380 (17.4%)	87 (21.8%)	.02
Ventilator	599 (4.4%)	68 (17.0%)	<.0001
LVEF (<20 severe)	9180 (70.0%)	258 (68.3%)	.45
Male	10,630 (77.8%)	334 (83.5%)	.01
Married	8115 (60.6%)	251 (64.0%)	.17
Mitral regurgitation (moderate/severe)	7342 (57.4%)	211 (59.8%)	.38
NYHA = 4	11,155 (84.1%)	364 (95.3%)	<.0001
Peripheral vascular disease	558 (4.1%)	23 (5.8%)	.1
Race: White	8810 (64.4%)	242 (60.5%)	.11
RV dysfunction (severe)	1664 (14.8%)	75 (23.4%)	<.0001
Severe diabetes*	1254 (9.2%)	52 (13.0%)	.01
Temporary cardiac support	3740 (32.1%)	255 (66.9%)	<.0001
Tricuspid regurgitation (moderate/severe)	5341 (42.0%)	177 (49.9%)	.0033
Age (yrs)	56.9 ± 13.0 (n = 13,690)	54.8 ± 12.7 (n = 400)	.0011
Albumin (g/dL)	3.43 ± 0.6 (n = 13,037)	3.07 ± 0.6 (n = 388)	<.0001
Total bilirubin (mg/dL)	1.30 ± 1.6 (n = 13,169)	2.72 ± 4.5 (n = 391)	<.0001
BMI (kg/m^2)	28.63 ± 7.4 (n = 13,635)	28.89 ± 7.3 (n = 399)	.49

(Continued)

TABLE 1. Continued

Preimplant characteristics	No predialysis (n = 13,690)	Predialysis (n = 400)	*P* value
BNP (pg/mL)	1213.27 ± 1116.4 (n = 6059)	1638.28 ± 1273.8 (n = 196)	<.0001
BSA (m^2)	2.07 ± 0.3 (n = 13,635)	2.10 ± 0.3 (n = 399)	.11
BUN (mg/dL)	28.82 ± 16.8 (n = 13,672)	34.51 ± 22.1 (n = 399)	<.0001
Cholesterol (mg/dL)	128.73 ± 42.4 (n = 8319)	108.44 ± 35.5 (n = 241)	<.0001
Cardiac index (L/min per m^2)	2.14 ± 0.8 (n = 11,670)	2.42 ± 1.1 (n = 287)	<.0001
Creatinine (mg/dL)	1.37 ± 0.6 (n = 13,671)	2.25 ± 1.7 (n = 399)	<.0001
Diastolic blood pressure (mm Hg)	66.09 ± 11.5 (n = 13,454)	63.21 ± 12.1 (n = 388)	<.0001
Hemoglobin (mg/dL)	11.22 ± 2.2 (n = 13,654)	9.11 ± 1.7 (n = 400)	<.0001
Heart rate (bpm)	89.78 ± 17.6 (n = 13,636)	95.07 ± 18.0 (n = 398)	<.0001
INR (international units)	1.29 ± 0.5 (n = 13,179)	1.42 ± 0.6 (n = 392)	.0001
LDH	355.76 ± 339.9 (n = 8793)	720.69 ± 1445.6 (n = 304)	<.0001
LVEDD (cm)	6.81 ± 1.1 (n = 11,022)	6.45 ± 1.1 (n = 293)	<.0001
Platelet (K/μL)	198.11 ± 78.8 (n = 13,643)	141.39 ± 78.8 (n = 399)	<.0001
Pre albumin (mg/dL)	18.77 ± 7.3 (n = 7589)	14.85 ± 6.8 (n = 256)	<.0001
Pulmonary diastolic pressure (mm Hg)	24.89 ± 8.9 (n = 12,182)	25.81 ± 8.7 (n = 323)	.07
Pulmonary systolic pressure (mm Hg)	49.61 ± 14.9 (n = 12,246)	50.17 ± 15.3 (n = 326)	.5
Pulmonary wedge pressure (mm Hg)	25.01 ± 9.4 (n = 10,104)	27.51 ± 9.2 (n = 212)	.0001
Pulmonary vascular resistance (PVR) using cardiac output (wood units)	4.22 ± 1.4 (n = 11,643)	4.84 ± 1.6 (n = 285)	<.0001
RA pressure (mm Hg)	12.51 ± 8.1 (n = 9438)	16.91 ± 9.4 (n = 195)	<.0001
AST (μ/L)	49.08 ± 165.4 (n = 13,192)	119.21 ± 538.2 (n = 392)	.01
ALT (μ/L)	57.70 ± 158.6 (n = 13,174)	138.06 ± 464.7 (n = 390)	.0007
Sodium (mmol/L)	135.09 ± 4.8 (n = 13,671)	135.23 ± 4.9 (n = 399)	.56
Systolic blood pressure (mm Hg)	106.55 ± 16.2 (n = 13,484)	100.59 ± 16.3 (n = 392)	<.0001
WBC (K/μL)	8.59 ± 3.9 (n = 13,651)	11.52 ± 5.8 (n = 399)	<.0001

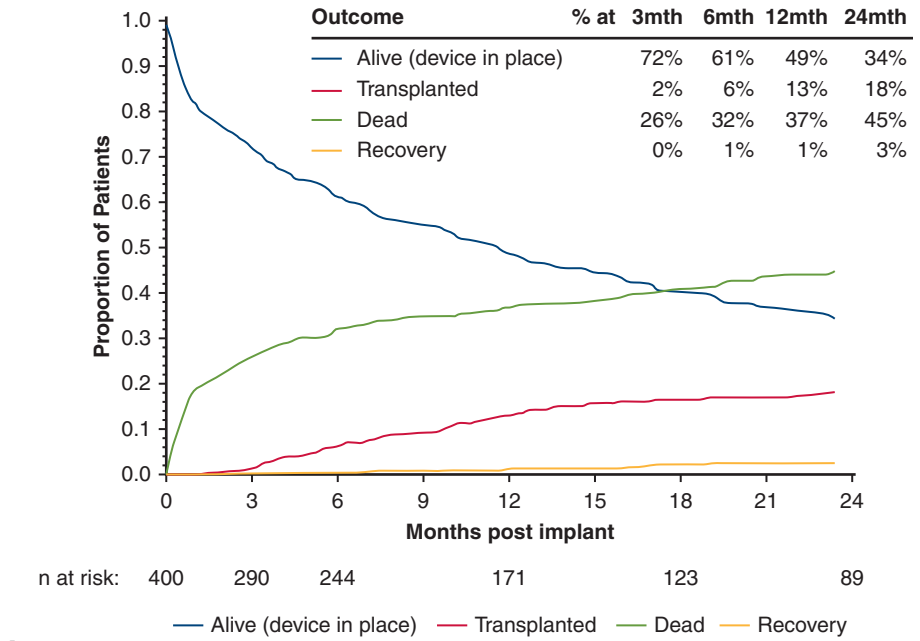
CABG, Coronary artery bypass grafting; *ICD*, implantable cardioverter defibrillator; *INTERMACS*, Interagency Registry for Mechanically Assisted Circulatory Support; *ECMO*, extracorporeal membrane oxygenation; *IABP*, intra-aortic balloon pump; *LVEF*, left ventricular ejection fraction; *NYHA*, New York Heart Association; *BMI*, body mass index; *BNP*, brain natriuretic peptide; *BSA*, body surface area; *BUN*, blood urea nitrogen; *INR*, international normalized ratio; *LDH*, lactate dehydrogenase; *LVEDD*, left ventricular end-diastolic diameter; *RA*, right atrium; *AST*, aspartate aminotransferase; *ALT*, alanine aminotransferase; *RV*, right ventricle; *WBC*, white blood cell. *Severe diabetes defined as hemoglobin A1c greater than 8 mg/dL or associated with diabetic nephropathy, vasculopathy, or oculopathy.

more likely to be on temporary circulatory support (66.9% vs 32.1, $P < .0001$) including extracorporeal membrane oxygenation (13.3% vs 2.9%, $P < .0001$), intra-aortic balloon pump (21.8% vs 17.4%, $P = .02$), and inotropes (92.2% vs 84.7%, $P < .0001$). Additionally, patients on dialysis had more preoperative right ventricular dysfunction (23.4% vs 14.8% severe, $P < .0001$) and pulmonary vascular resistance (4.84 vs 4.22 Wood units, $P < .0001$), and higher brain natriuretic peptide (1638 vs 1213 pg/mL, $P < .0001$) and total bilirubin (2.72 vs 1.30 mg/dL, $P < .0001$). Overall markers of acuity were worse in the preoperative dialysis group, including hemoglobin level (9.1 vs 11.2, $P < .0001$), platelets (141 vs 198, $P < .0001$), albumin (3.1 vs 3.4, $P < .0001$), and ascites (9.5% vs 4.7%, $P = .0002$).

Competing risk of death, transplant, and recovery were assessed for the no preoperative dialysis group (Figure 1, *A*) and the preoperative dialysis group (Figure 2, *B*). There were lower rates of transplantation (18% vs 25%, $P < .0001$) and higher mortality (45% vs 24%, $P < .0001$) over the first 24 months for patients on preoperative dialysis.

Time to Adverse Events and Patient-Reported Quality of Life

The time to first stroke, including hemorrhagic, ischemic, or transient ischemic attack, was worse in the patients with preoperative dialysis ($P < .0001$, Figure 2, *A*). The time to first major nondevice infection was significantly worse for the preoperative dialysis group ($P < .0001$, Figure 2, *B*). When assessing time to first major bleeding event, the preoperative dialysis group performed worse ($P < .0001$, Figure 2, *C*). Additionally, time to first major gastrointestinal bleeding event was worse in the preoperative dialysis group ($P < .0001$, Figure 2, *D*). When assessing time to first adverse device-related event, we saw no statistical association for major pump-related infection (Figure 3, *A*, $P = .99$). The time to first major nonthrombotic device malfunction was not statistically associated with preoperative dialysis



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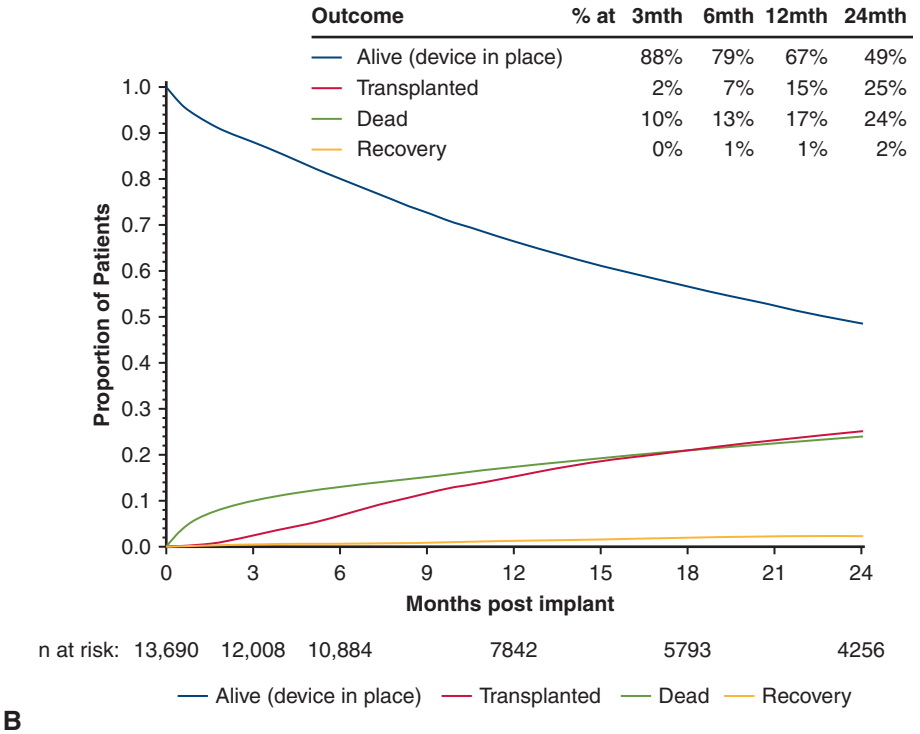
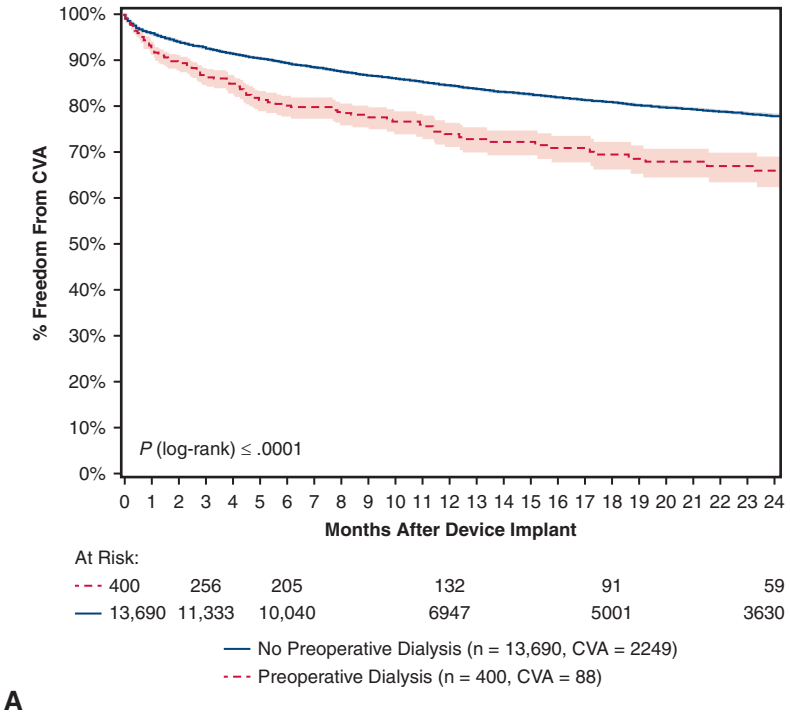


B

FIGURE 1. Competing risks outcomes. A, Competing risk outcomes for all patients undergoing LVAD implantation on preoperative dialysis (n = 400). The *red curve* represents patients alive on support. The *blue line* tracks deaths, the *green line* is patients who underwent transplantation, and the *yellow line* is patients who underwent device exchange or explant for recovery. B, Competing risk outcomes for all patients undergoing LVAD implantation not on preoperative dialysis (n = 13,690). The *red curve* represents patients alive on support. The *blue line* tracks deaths, the *green line* is patients who underwent transplantation, and the *yellow line* is patients who underwent device exchange or explant for recovery.

status (Figure 3, *B*, $P = .34$). Finally, time to first device thrombosis did not statistically differ between groups (Figure 3, *C*, $P = .06$).

Patient-reported outcomes were assessed in the STS INTERMACS database and compared by preoperative dialysis status. Responses to the question "Knowing what you



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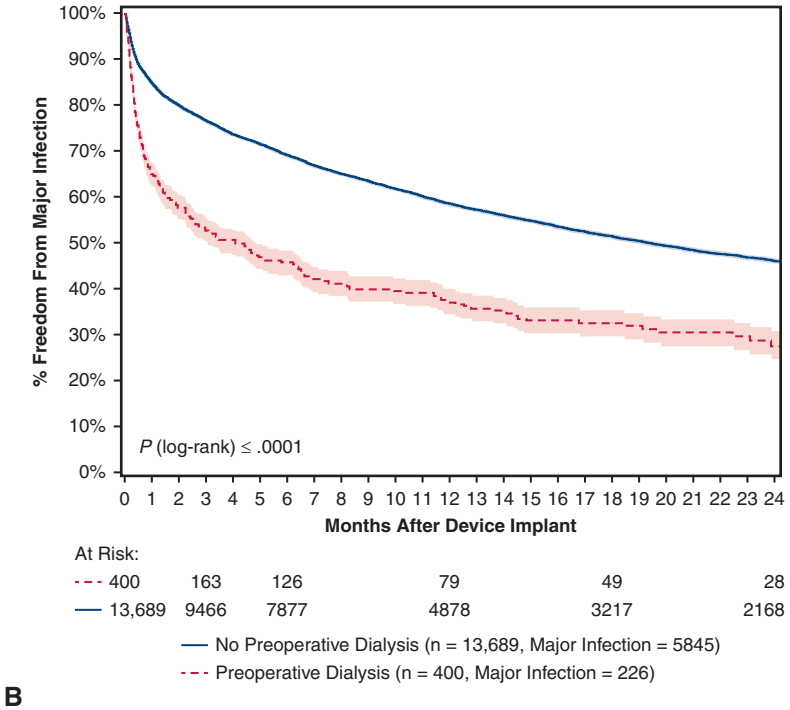
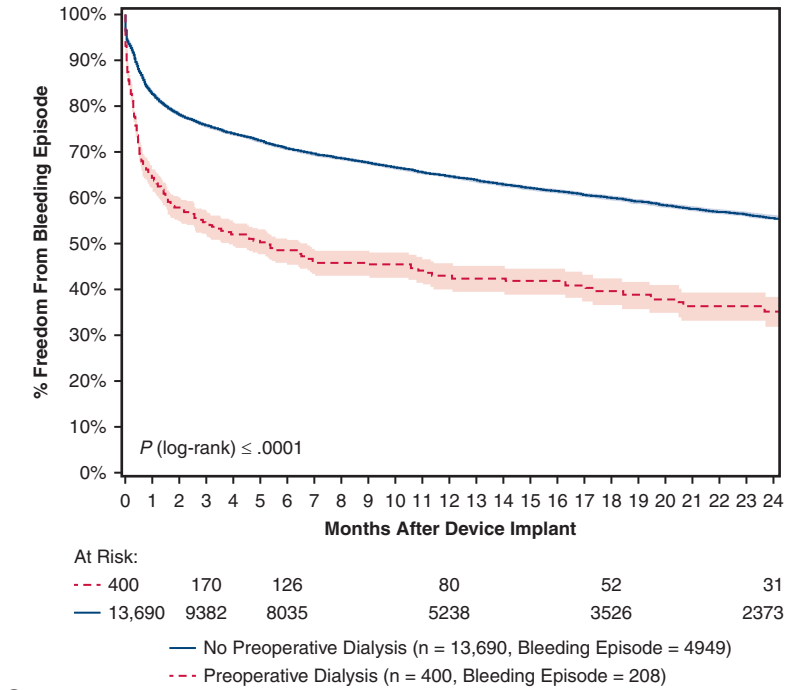


B

FIGURE 2. Time to major adverse event by preoperative dialysis. A, Time to first CVA by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B. Time to first major infection by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. C, Time to first bleeding episode by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. D, Time to first gastrointestinal bleeding by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. *CVA*, Cerebrovascular accident; *GI*, gastrointestinal.



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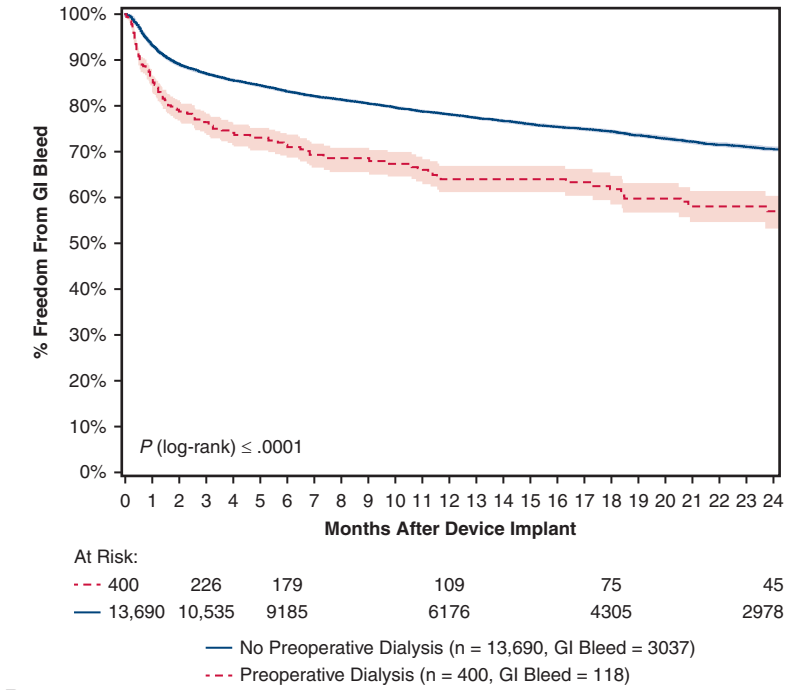

D

FIGURE 2. Continued.

know now would you still have undergone ventricular assist device support?" demonstrated no difference by preoperative dialysis (all $P > .05$, Figure E2, *A*). A majority of patients in both groups at all time points answered positively that they would undergo LVAD implantation again. Response rates for patient-reported outcomes were between 38% and 54% over the first 12 months.

Landmark Analysis and Predictors of Renal Recovery

Subgroup analysis landmark on survival at 30 days demonstrated patients on preoperative dialysis; 131 (32.8%) no longer required dialysis at 1 month postoperatively, and this subset had similar long-term survival to patients who never required dialysis (no dialysis vs recovered,

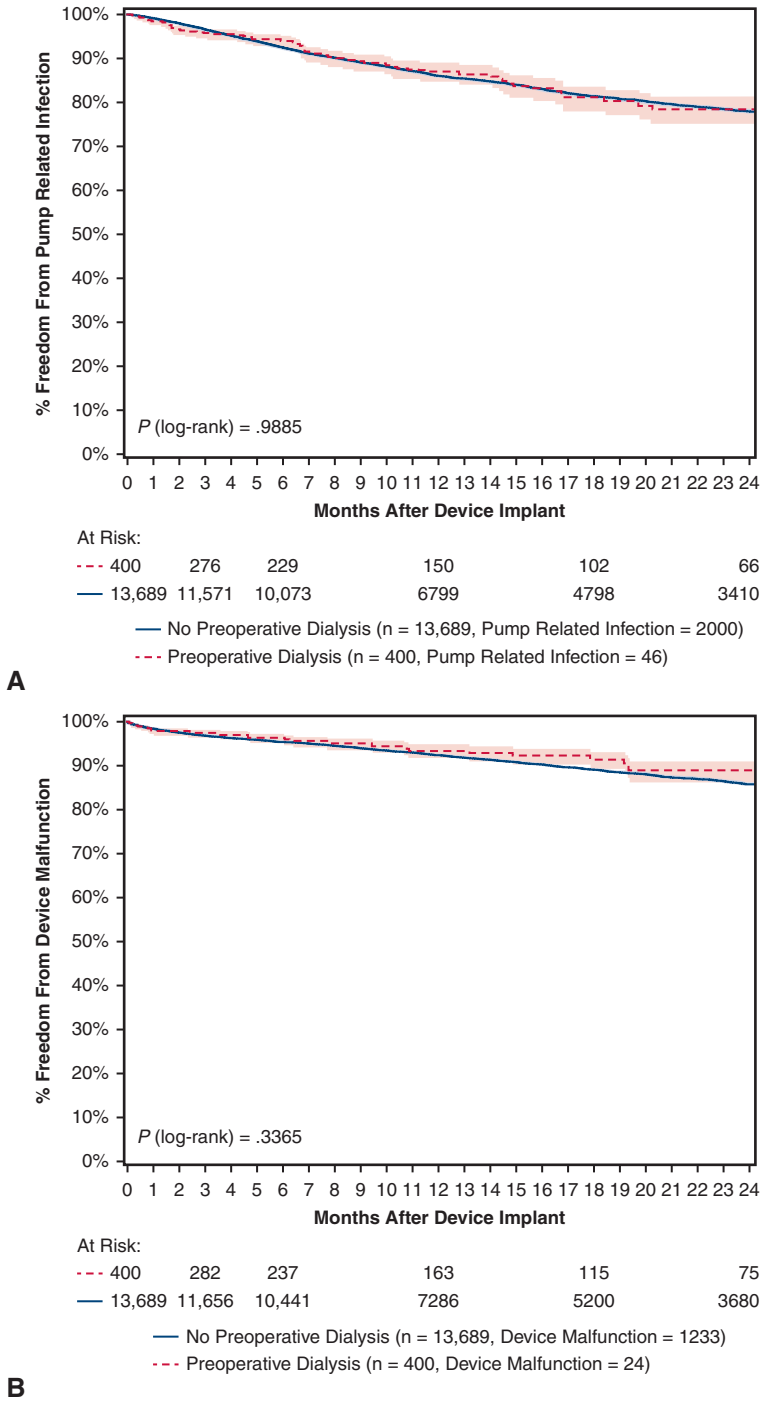

FIGURE 3. Time to pump-related events. A, Time to first pump-related infection by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, Time to first device malfunction (not thrombus) by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. C, Time to first thrombus event by preimplant dialysis status: censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.

$P = .13$, Figure 4). Long-term survival was significantly worse in patients with persistent dialysis and new dialysis at 1 month postoperatively ($P < .0001$, Figure 4).

Two logistic regressions were fit to identify independent predictors of renal recovery, with the first only including preoperative factors and the second including preoperative

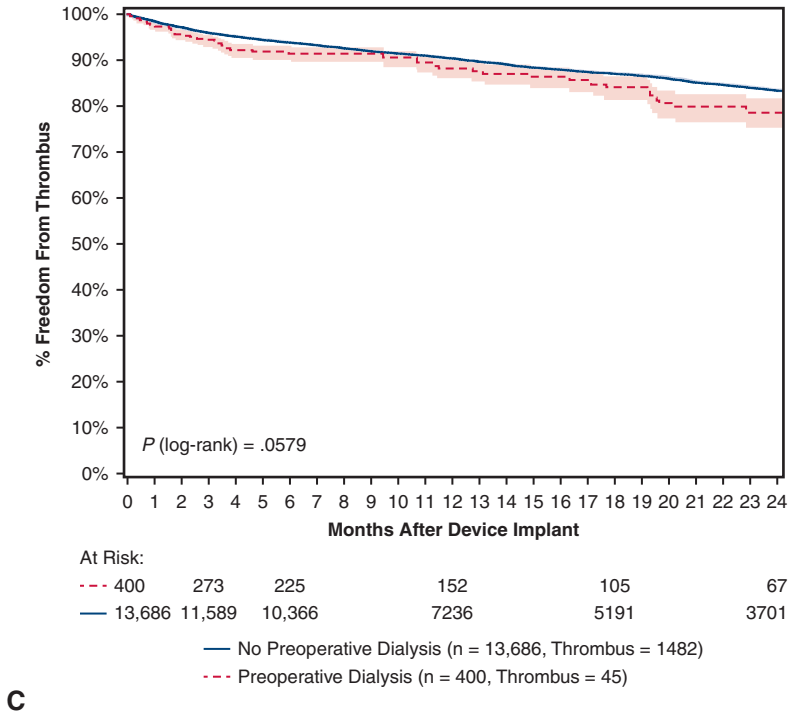

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FIGURE 3. Continued.

and 1-week postoperative variables. A total of 131 patients no longer required dialysis at 1 month for the model. In the preoperatively only model, several independent predictors were identified with higher preoperative sodium (odds ratio [OR], 0.93; 95% confidence interval [CI], 0.89-0.98), creatinine (OR, 0.47; 95% CI, 0.35-0.63), and white blood cell count (OR, 0.93; 95% CI, 0.88-0.98) were associated with lower rates of recovery. However, higher blood urea nitrogen (OR, 1.02; 95% CI, 1.01-1.03) was associated with higher rates of renal recovery (Table 2).

In a model including preoperative and 1-week postoperative variables, preimplant dialysis within 48 hours (OR, 0.52; 95% CI, 0.29-0.93), previous cardiac surgery (OR, 0.53; 95% CI, 0.30-0.94), biventricular assist device (BIVAD) implant (OR, 0.20; 95% CI, 0.08-0.53), and higher preoperative sodium (OR, 0.93; 95% CI, 0.88-0.98) and creatinine (OR, 0.67; 95% CI, 0.49-0.90) were independently associated with a lower chance of recovery. One-week postimplant variables independently associated with renal recovery included higher blood urea nitrogen (OR, 1.04; 95% CI, 1.03-1.06), whereas higher creatinine (OR, 0.43; 95% CI, 0.27-0.67), albumin (OR, 0.33; 95% CI, 0.19-0.58), and white blood cell count (OR, 0.90; 95% CI, 0.86-0.95) were associated with lower renal recovery (Table 3). Finally, the strongest negative predictor of renal recovery was requirement of inotropic support 1 week after implant (OR, 0.19; 95% CI, 0.08-0.48).

Subgroup Analysis by Acuity

To account for the disproportional number of high-acuity patients in the preoperative dialysis group, we performed a subgroup analysis stratified by INTERMACS level (1-2 and 3-7). All-cause survival was significantly higher in patients not requiring preoperative dialysis regardless of INTERMACS level (Figure 5, *A* and *B*). When looking at time to adverse event, contrary to the primary analysis, cerebrovascular accident was significantly worse in patients on preoperative dialysis in the INTERMACS 1-2 subgroups with no statistical difference in the INTERMACS 3-7 subgroup (Figure E3). However, the remainder of the subgroup time to adverse event analysis was similar to the primary analysis with patients on preoperative dialysis having significantly worse time to event for major infection (Figure E4), major bleed (Figure E5), and gastrointestinal bleed (Figure E6) in both the high-acuity (INTERMACS 1-2) and lower-acuity (INTERMACS 3-7) groups. Likewise, the device-related time to adverse events did not differ by dialysis status for pump-related infection (Figure E7) or device malfunction (Figure E8) in the INTERMACS 1-2 or INTERMACS 3-7 cohorts. However, freedom from device thrombus was significantly worse for patients on preoperative dialysis in the INTERMACS 1-2 cohort but not in the INTERMACS 3-7 cohort (Figure E9).

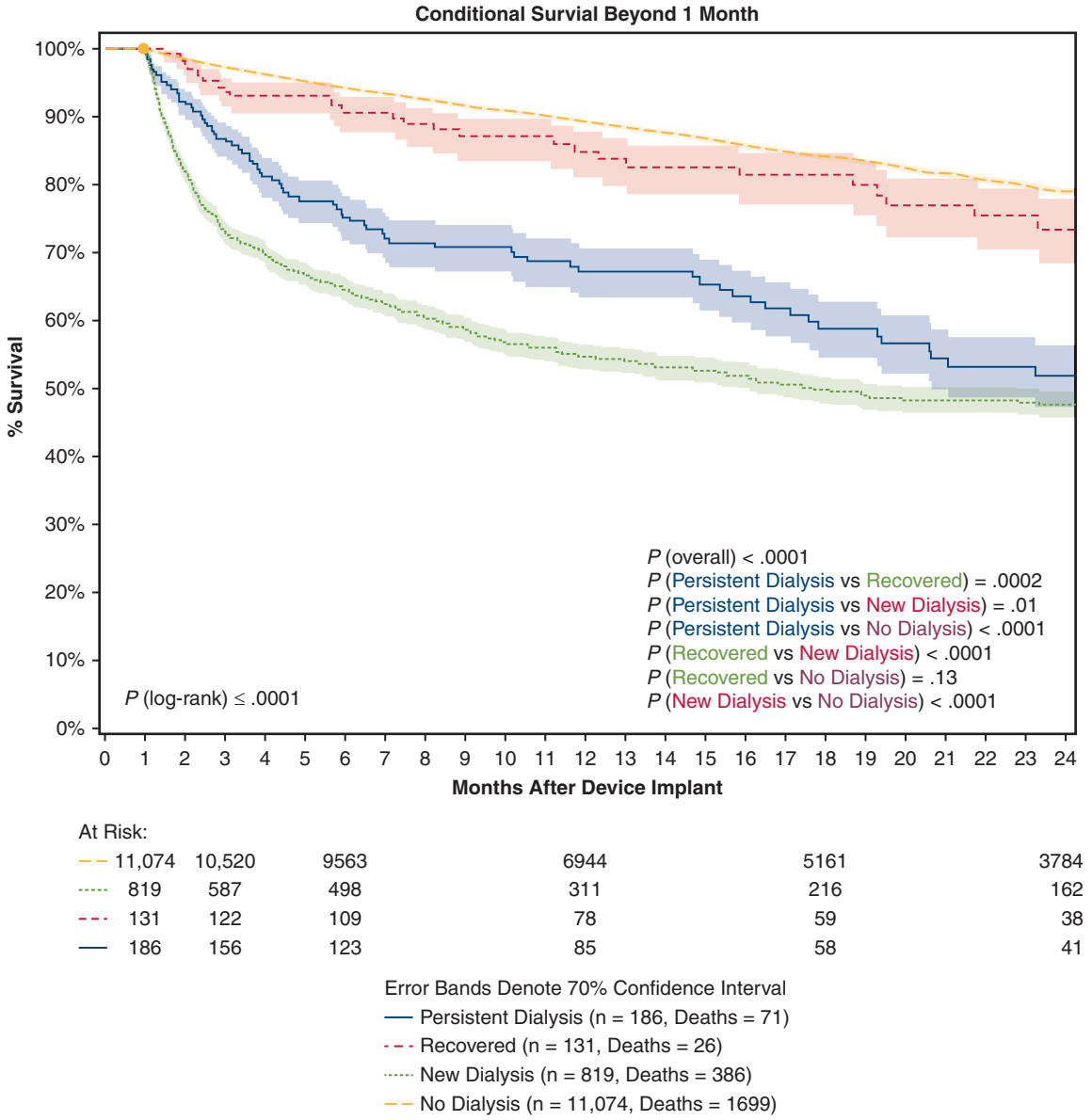

FIGURE 4. The 1-month landmark survival for persistent dialysis (*blue*), preoperative dialysis that recovered (*red*), new postoperative dialysis (*green*), and no preoperative or postoperative dialysis (*yellow*). Number at risk listed across the bottom. Log-rank comparison of each group listed in the right top corner.

DISCUSSION

This study demonstrates that a minority of patients undergoing LVAD implantation in the STS INTERMACS database required preoperative dialysis. These patients had significantly higher acuity and worse baseline right heart function. As hypothesized, patients requiring preoperative dialysis before LVAD implantation had significantly higher mortality with worse long-term survival and freedom from adverse events. However, there was a subset of patients who recovered renal function and had similar long-term outcomes similar to patients not on dialysis preoperatively. We identify several preoperative and 1-week postoperative predictors of renal recovery, with BIVAD implant and remaining on inotropes at 1 week being the strongest predictors of no renal recovery. The subgroup analysis demonstrated similar findings when accounting for acuity by analyzing INTERMACS 1-2 and INTERMACS 3-7 patients separately (Figure 6).

TABLE 2. Predictors of renal recovery in patients on preimplant dialysis including preimplant risk factors

Predictor	Odds ratio	95% CI	*P* value
Preimplant sodium (mmol/L)	0.93	0.89-0.98	.01
Preimplant BUN (mg/dL)	1.02	1.01-1.03	.006
Preimplant creatinine (mg/dL)	0.47	0.35-0.63	<.0001
Preimplant WBC ($\times 10^9$L)	0.93	0.88-0.98	.005

CI, Confidence interval; *BUN*, blood urea nitrogen; *WBC*, white blood cell.

TABLE 3. Predictors of renal recovery in patients on preimplant dialysis including preimplant and 1-week follow-up risk factors

Predictor	Odds ratio	95% CI	*P* value
Preimplant sodium (mmol/L)	0.93	0.88-0.98	.012
Preimplant creatinine (mg/dL)	0.67	0.49-0.90	.009
Preimplant dialysis within 48 h of implant	0.52	0.29-0.93	.026
Previous cardiac surgery	0.53	0.30-0.94	.031
BIVAD	0.20	0.08-0.53	.001
1 wk BUN (mg/dL)	1.04	1.03-1.06	<.0001
1 wk creatinine (mg/dL)	0.43	0.27-0.67	.001
1 wk albumin (g/dL)	0.33	0.19-0.58	<.0001
1 wk WBC ($\times 10^9$L)	0.90	0.86-0.95	<.0001
1 wk inotrope	0.19	0.08-0.48	.001

CI, Confidence interval; *BIVAD*, biventricular assist device; *BUN*, blood urea nitrogen; *WBC*, white blood cell.

These data support the hypothesis that preoperative dialysis before LVAD implantation is a major risk factor for death and adverse events. A recent study by Bansal and colleagues[7] also examined this question using Medicare claims data 2003-2013 and demonstrated a median survival of 16 days with 51.6% of patients with ESRD dying during the index hospitalization for LVAD implantation. A more recent study by Kilic and colleagues[8] reports outcomes of 18 patients requiring preoperative dialysis with a 1-year survival of 55%. However, the contemporary data in the present study are more encouraging with a 55% 2-year survival. In addition to improved patient selection and expanded device options, the experience in providing multidisciplinary care for these complex patients has improved over time.[10,11] Despite these advancements, it is still appropriate to consider dialysis dependence a major risk for patients undergoing consideration for LVAD implant, and we would highlight the importance of etiology of renal dysfunction in patient selection.[12] Mohamedali and colleagues[13] further highlighted the relationship between preoperative renal dysfunction (glomerular filtration rate $\leq$60) and postimplant survival, which was strongly associated with recovery of renal function postoperatively.

These data demonstrate that preoperative dialysis was associated with postimplant complications including stroke, infection, and bleeding but not device-specific complications. These findings are important when considering LVAD implantation in patients on dialysis because the inherent risks can be overcome if the patient has renal recovery with no persistent risk from the device. However, if patients do not recover renal function, the early morbidity will contribute significantly to early mortality. These issues further highlight the importance of defining etiology of preoperative renal dysfunction to determine the likelihood of renal recovery after LVAD implantation.[4] Despite the associations between postoperative morbidity and mortality, an overwhelming majority of patients said they would undergo LVAD implantation again given their experience.

We identify a subset of patients on preoperative dialysis (32.8%) who recover renal function after LVAD implant. This cohort of patients did very well long term and had equivalent outcomes to those who do not require dialysis preoperatively or postoperatively. The single-center study by Kilic and colleagues[8] showed similar findings examining patients with preoperative renal dysfunction or dialysis. In their series of 273 patients undergoing LVAD implant, they demonstrate that approximately 50% of patients with preoperative renal dysfunction ultimately recover renal function by 1 year.[8] Another series by Franz and colleagues[14] reports 50% renal recovery or progression to heart/kidney transplant in 11 patients requiring maintenance hemodialysis after LVAD implant. The present study goes one step further to identify predictors of renal recovery for preoperative patient selection with negative predictors including BIVAD implants, prior cardiac surgery, and higher sodium or creatinine. We also include 1-week postimplant characteristics for the purpose of patient counseling and decision making for postimplant. Most important, we demonstrate that patients still requiring inotropes 1 week postimplant are more than 5 times less likely to have renal recovery by 1 month postimplant (OR, 0.19).

Several studies have evaluated the incidence and impact of postoperative renal failure after LVAD implant.[9,12,15] The present data from the STS INTERMACS database demonstrate a 6.9% rate of new postoperative renal failure, with these patients having the lowest survival, which was comparable to patients with preoperative and persistent dialysis. These data are further supported by the study from Seese and colleagues[16] identifying 2 pathways to multisystem organ failure after LVAD implantation, with postoperative renal failure highlighting the early-death cluster pathway. According to the authors, the early-death pathway was characterized by renal failure-to-respiratory failure-to-death with a median survival of less than 1 month. Additionally, data from Walther and colleagues[17] highlight the significant association between new-onset renal dysfunction and hospital readmission after LVAD implant. Given the high morbidity and mortality associated with postoperative renal failure, a clinical risk prediction tool would be beneficial for patient selection. Current data support preoperative renal function as one of the strongest predictors of postoperative renal failure, with other predictors likely similar to those used in survival models given the strong association between renal failure and death.[15,18,19]

Study Limitations

The limitations of this study include the retrospective nature precluding demonstration of causality. Additionally,

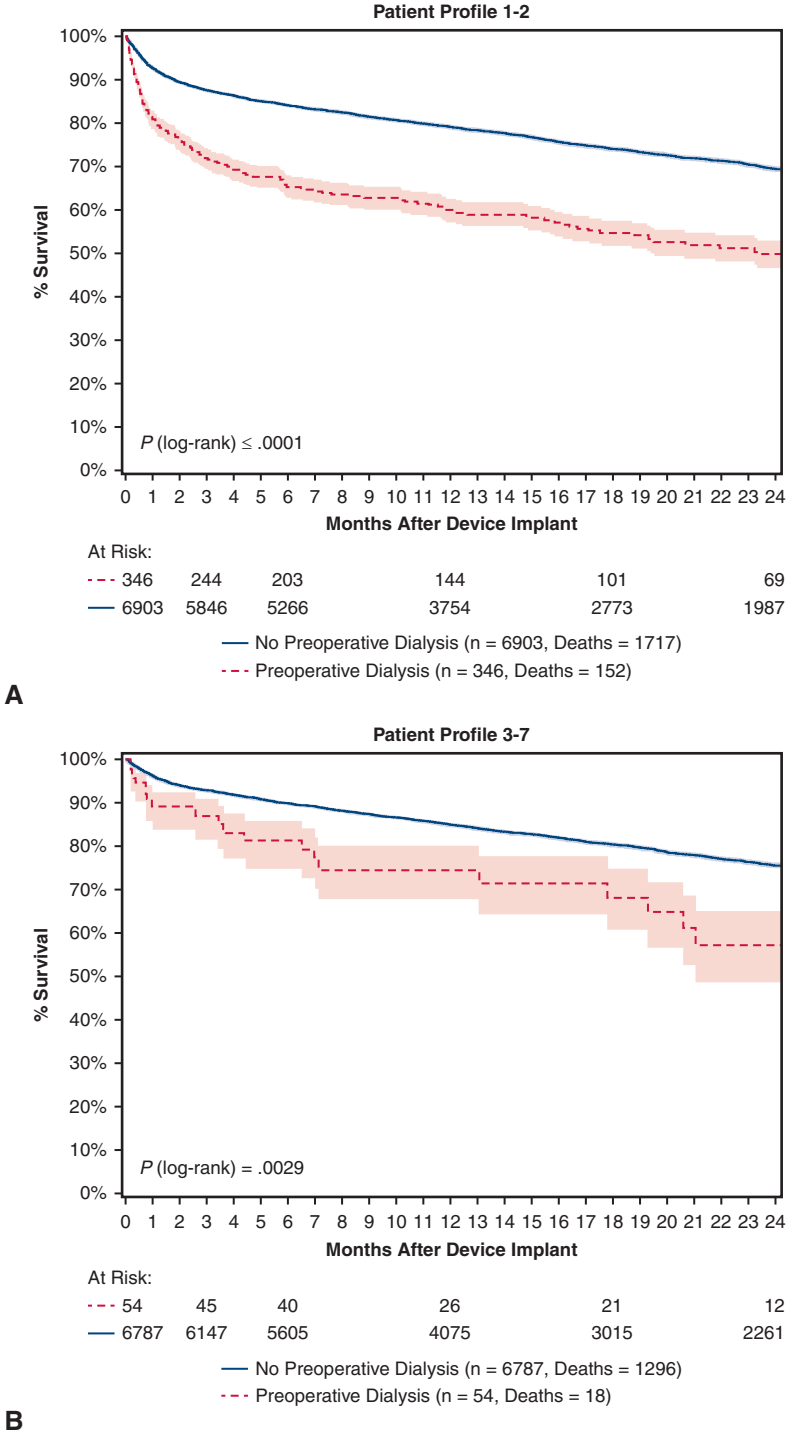

FIGURE 5. Kaplan–Meier survival curves by patient profile stratified by preoperative dialysis. A, INTERMACS profile 1-2 Kaplan–Meier survival curves for preoperative dialysis (*red*) and no preoperative dialysis (*blue*) censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B. INTERMACS Profile 3-7. Kaplan–Meier survival curves for preoperative dialysis (*red*) and no preoperative dialysis (*blue*) censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.

we do not have specific data on the nature of preoperative dialysis including chronicity, frequency, or duration. Furthermore, we are unable to control for clinical decision making pertaining to device implantation or management of renal failure. Finally, the patient-reported outcomes represent data available for a minority of patients in each group and may be biased toward patients with optimal outcomes.[20,21]

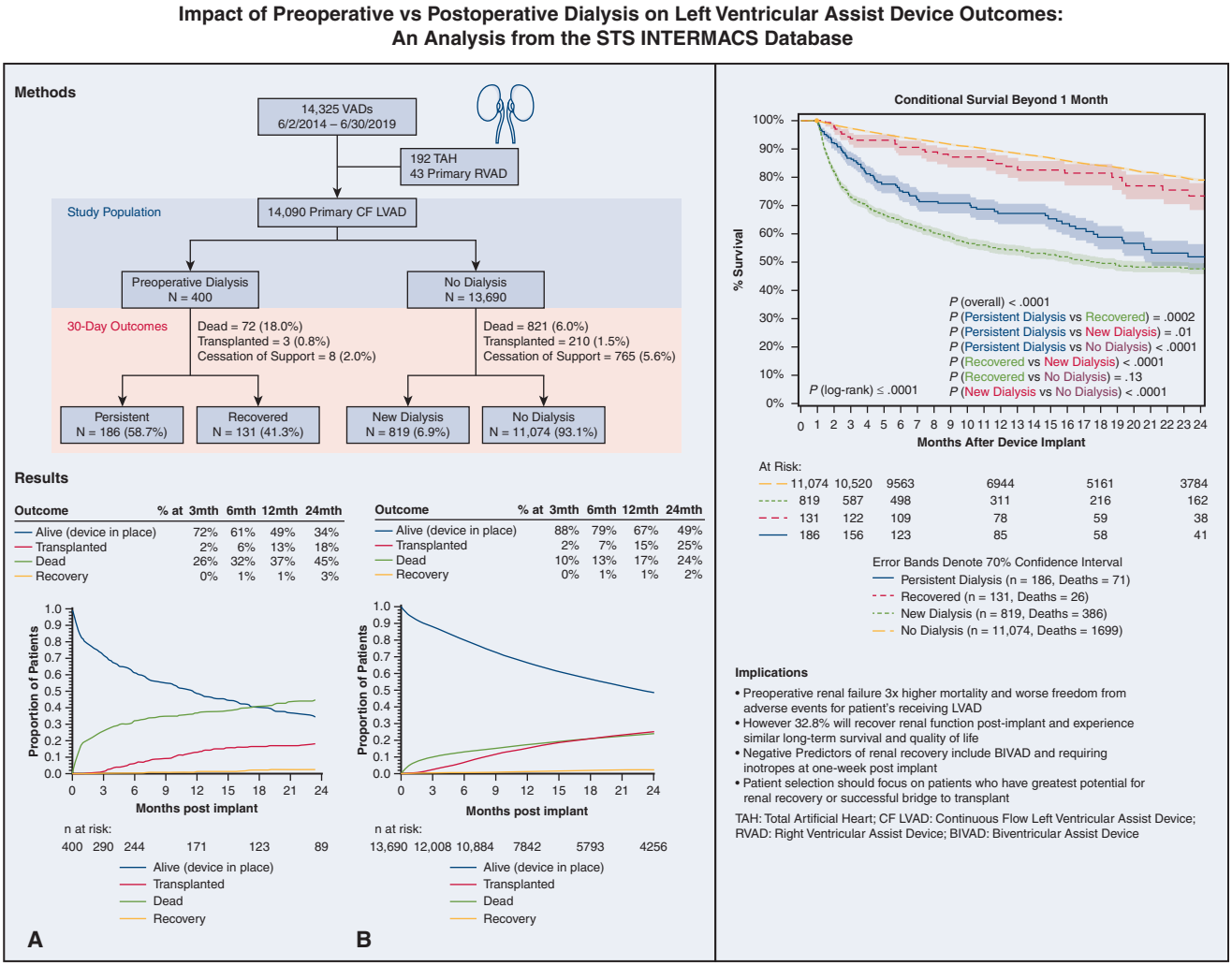

FIGURE 6. The patient population with 30-day outcomes as well as time to event curves with competing risks for patients on preoperative dialysis (n = 400) and those not on preoperative dialysis (n = 13,690). Overall survivals for each cohort censored for death, transplant, and device explant with the take home points are highlighted. Bands represent 70% CIs. Number at risk listed across the bottom. *STS*, Society of Thoracic Surgeons; *VAD*, ventricular assist device; *TAH*, total artificial heart; *CF LVAD*, continuous flow left ventricular assist device; *RVAD*, right ventricular assist device; *LVAD*, continuous flow left ventricular assist device; *BIVAD*, biventricular assist device.

CONCLUSIONS

Preoperative renal failure is associated with 3 times higher mortality and worse freedom from adverse events for patients receiving LVADs. However, a subset of patients (32.8%) will recover renal function postimplant and experience long-term survival and quality of life similar to those without dialysis. However, patients undergoing BIVAD and requiring inotropes at 1 week postimplant are significantly less likely to have renal recovery. Patient selection in the presence of dialysis dependence should focus on identifying these patients who have the greatest potential for renal recovery or successful bridge to heart/kidney transplant to benefit from LVAD implantation.

Conflict of Interest Statement

Dr Yarboro is proctor and consultant for Medtronic. Dr Yount is a proctor and consultant for Edwards Life Science. Dr Kirklin is Director of the Data Center for STS INTERMACS and receives partial salary support paid to his institution. Dr Ailawadi is a consultant for Abbott, Edwards, Medtronic, Anteris, Atricure, and Gore. All other authors reported no conflicts of interest.

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

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Key Words: dialysis, INTERMACS, LVAD, outcomes, renal failure

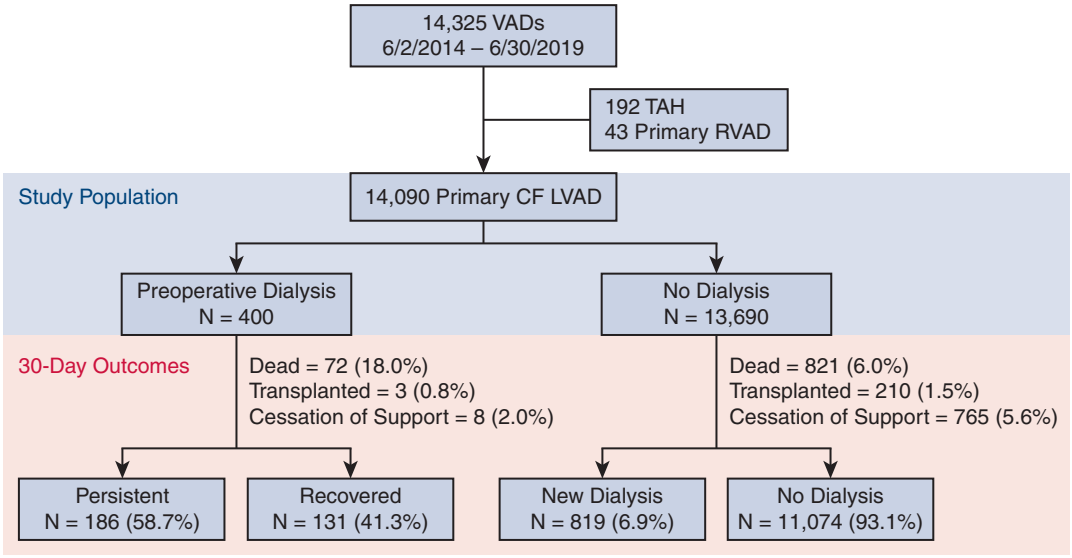


FIGURE E1. Consort diagram of the study population and 30-day outcomes for each group. *VAD*, Ventricular assist device; *TAH*, total artificial heart; *RVAD*, right ventricular assist device; *LVAD*, left ventricular assist device.

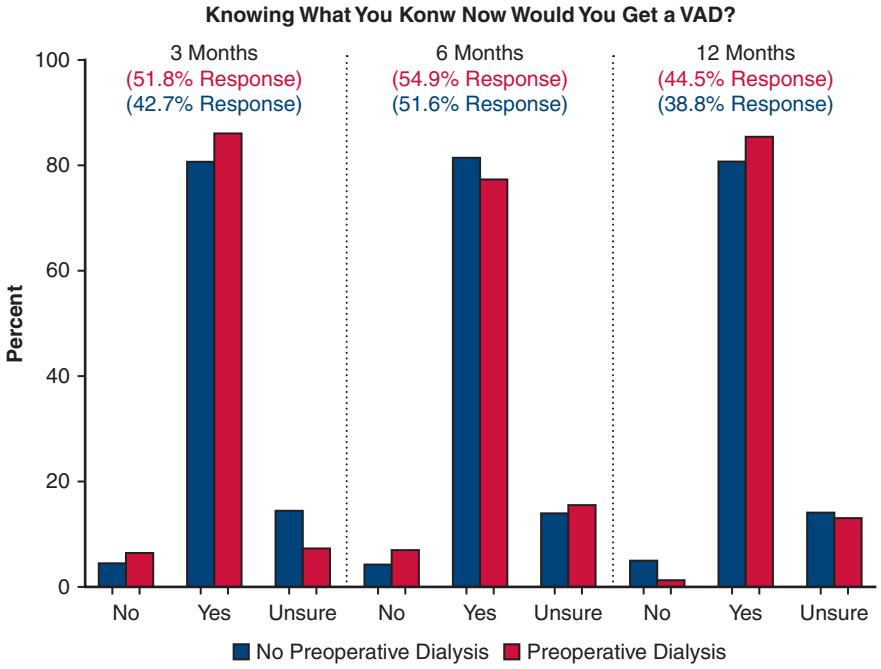
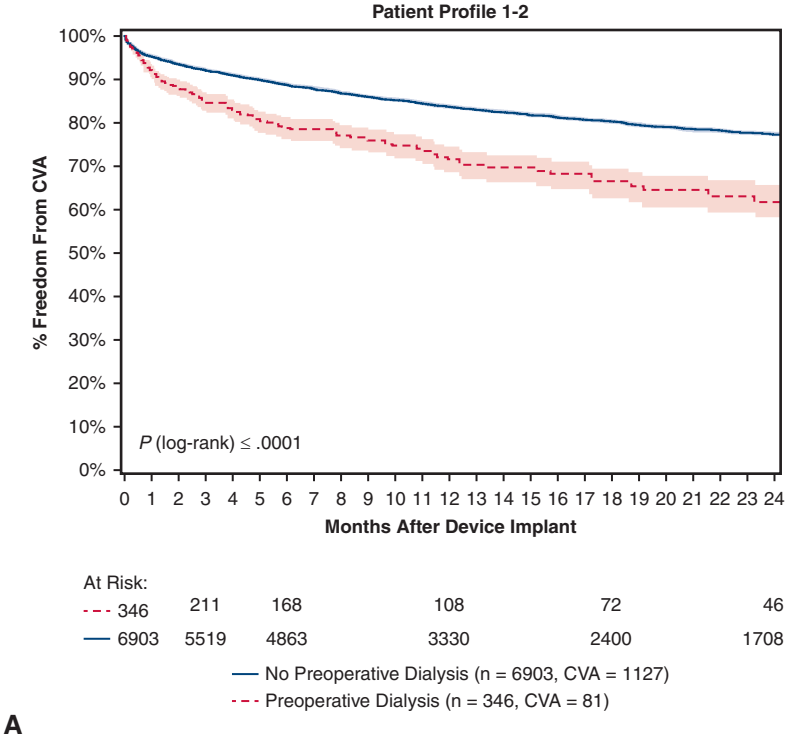


FIGURE E2. Patient-reported response to the question "Knowing what you know now would you get a VAD?" for preoperative dialysis (*red*) and no preoperative dialysis (*blue*) at 3, 6, and 12 months with response rate. *VAD*, Ventricular assist device.



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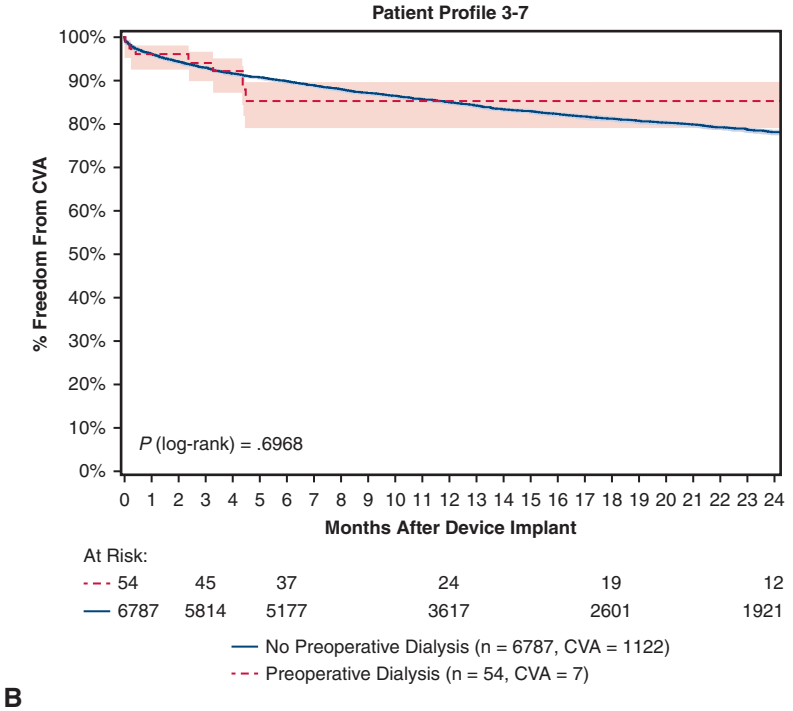

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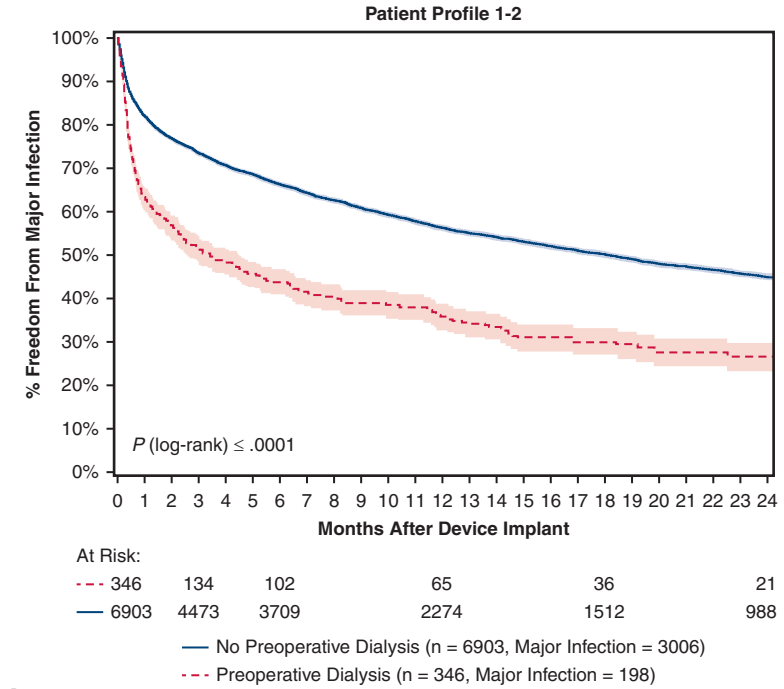
FIGURE E3. Time to first CVA by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first CVA by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B. INTERMACS Profile 3-7 time to first CVA by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. *CVA*, Cerebrovascular accident.



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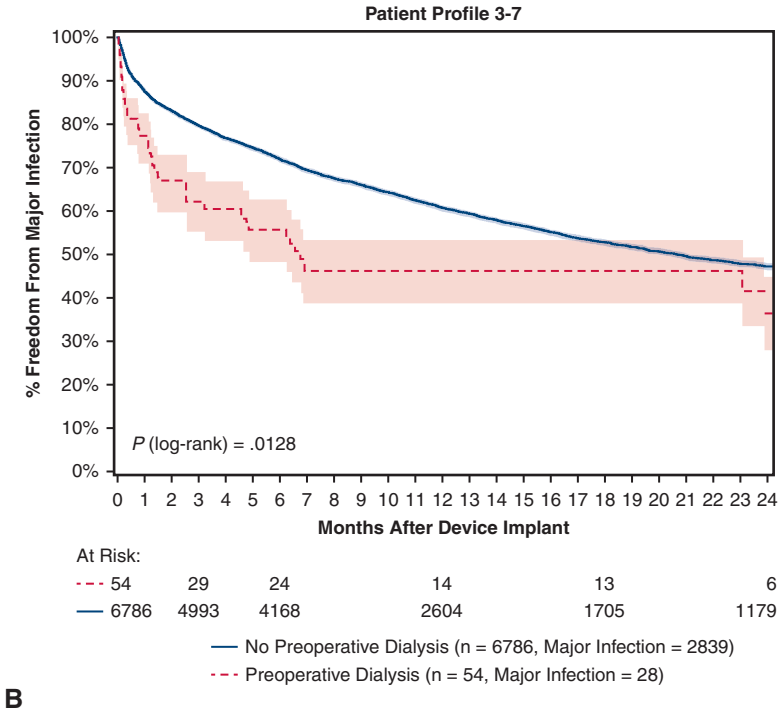

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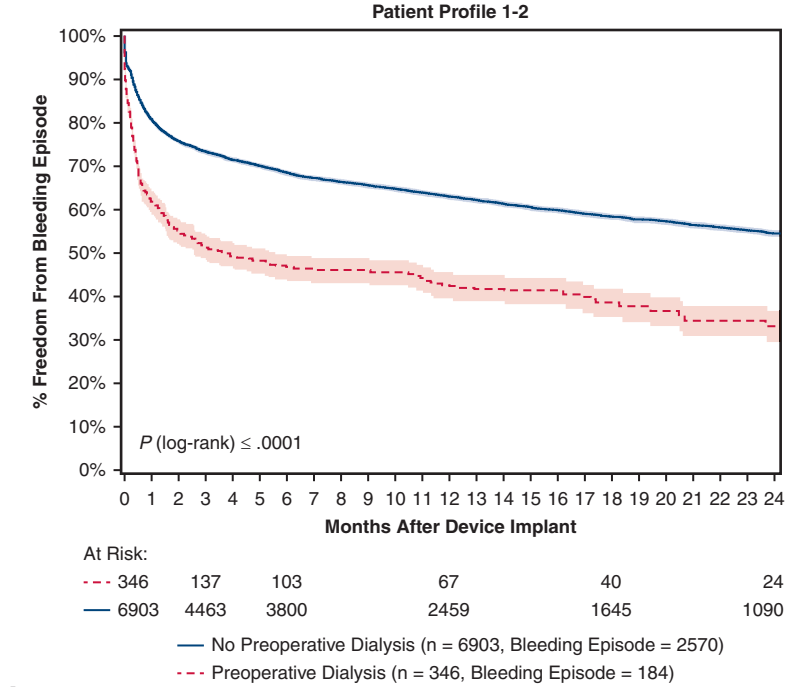
FIGURE E4. Time to first major infection by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first major infection by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, INTERMACS Profile 3-7 time to first Major Infection by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.



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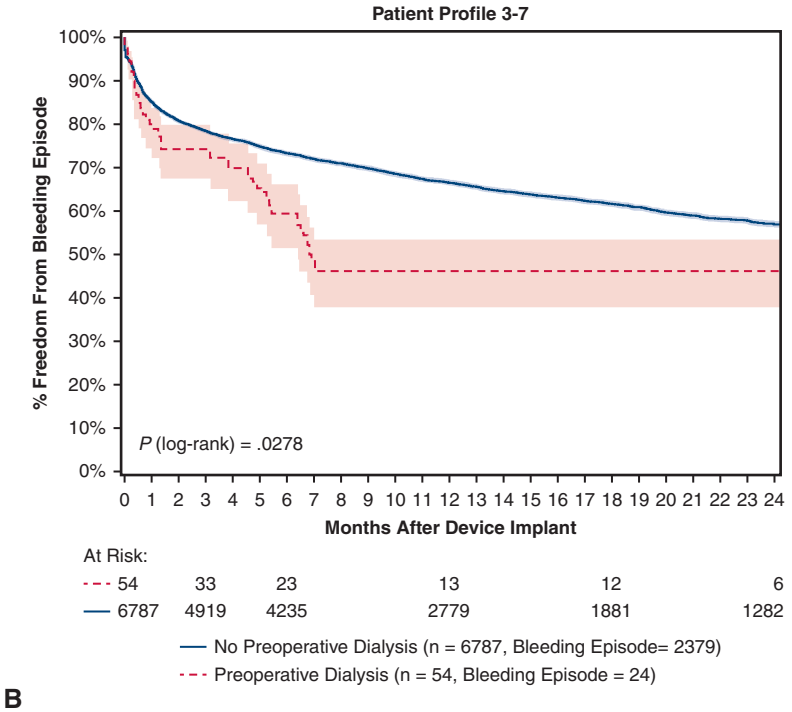

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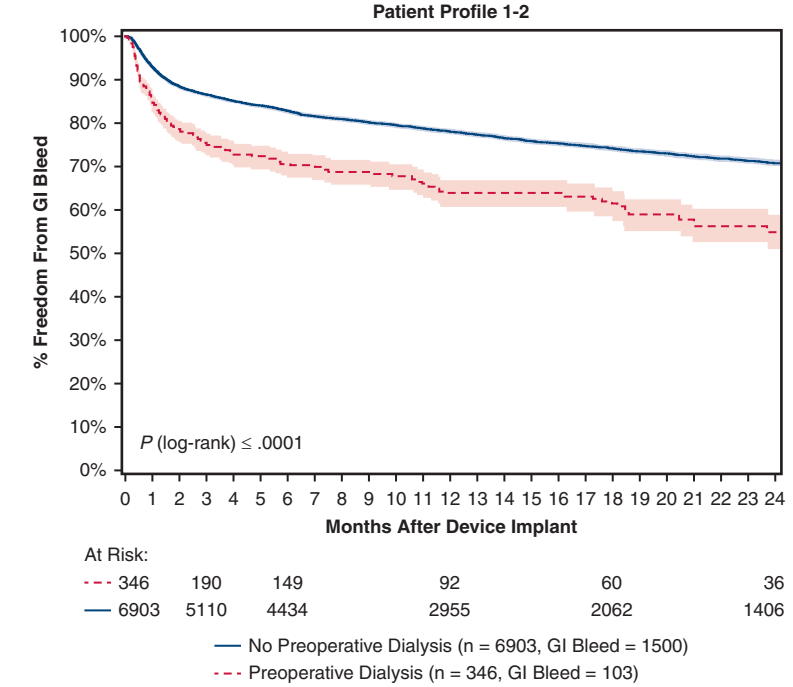
FIGURE E5. Time to first bleeding episode by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first bleeding episode by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, INTERMACS Profile 3-7 time to first Bleeding episode by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.



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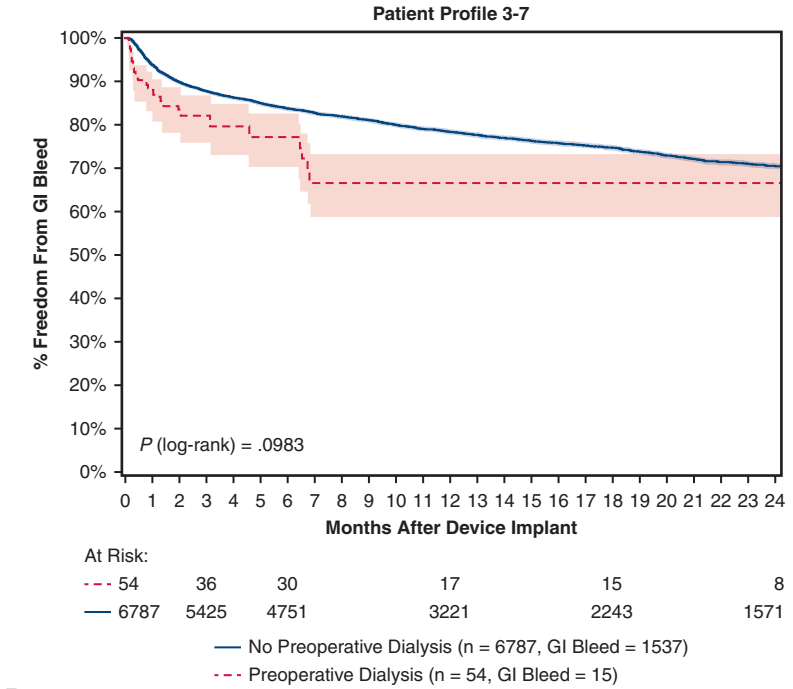

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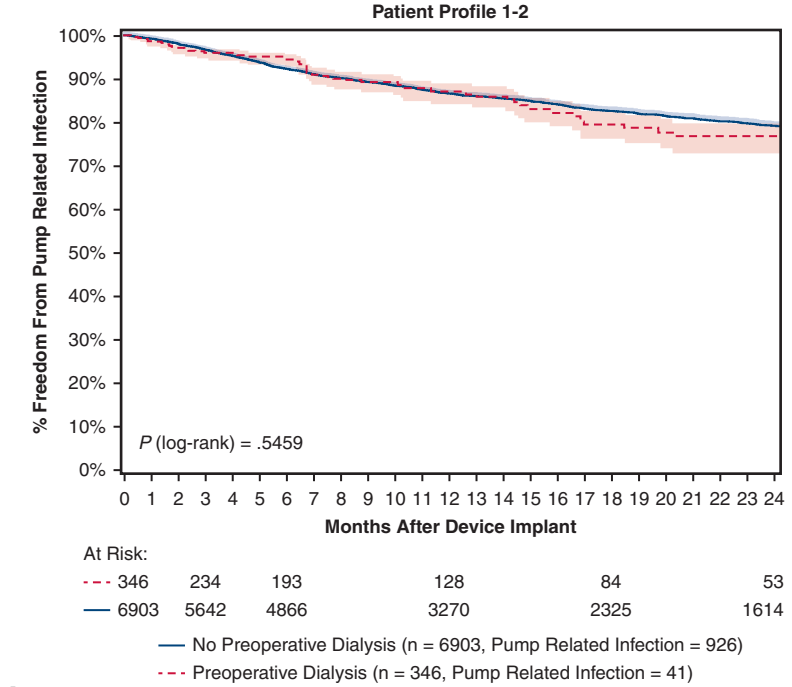
FIGURE E6. Time to first GI bleeding by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first GI bleeding by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, INTERMACS Profile 3-7 time to first GI bleeding by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. *GI*, Gastrointestinal.



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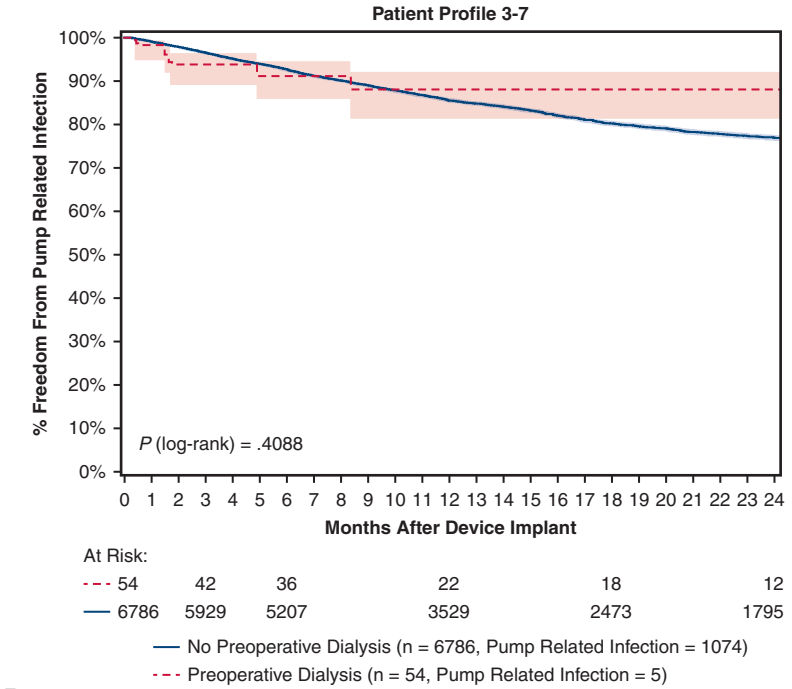

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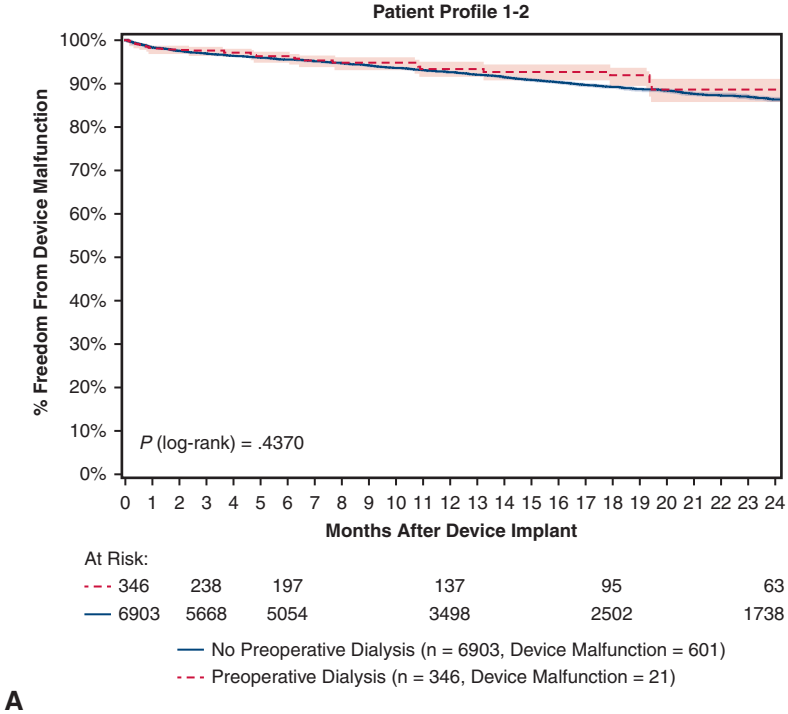
FIGURE E7. Time to first pump-related infection by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first pump-related infection by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, INTERMACS Profile 3-7 time to first pump-related infection by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.



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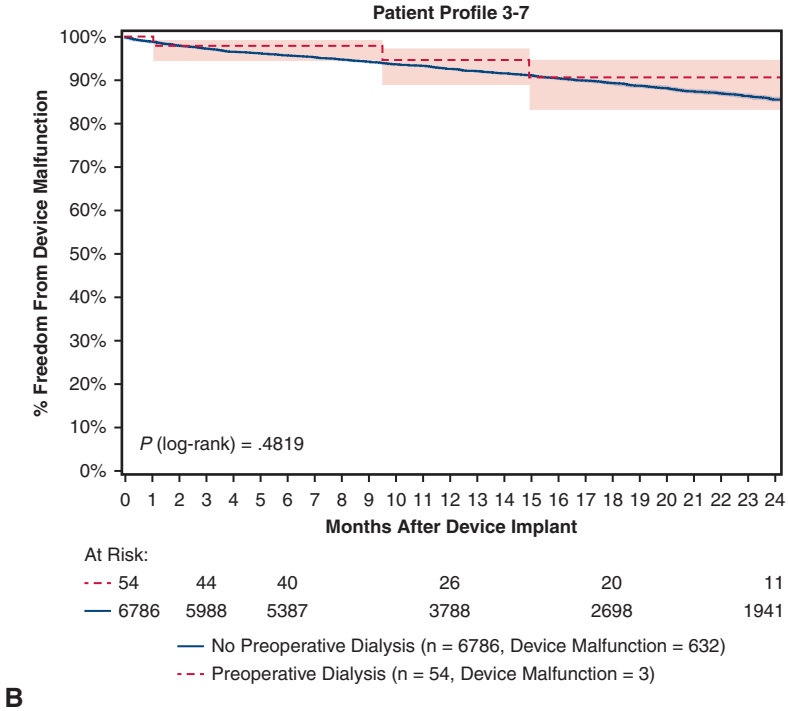

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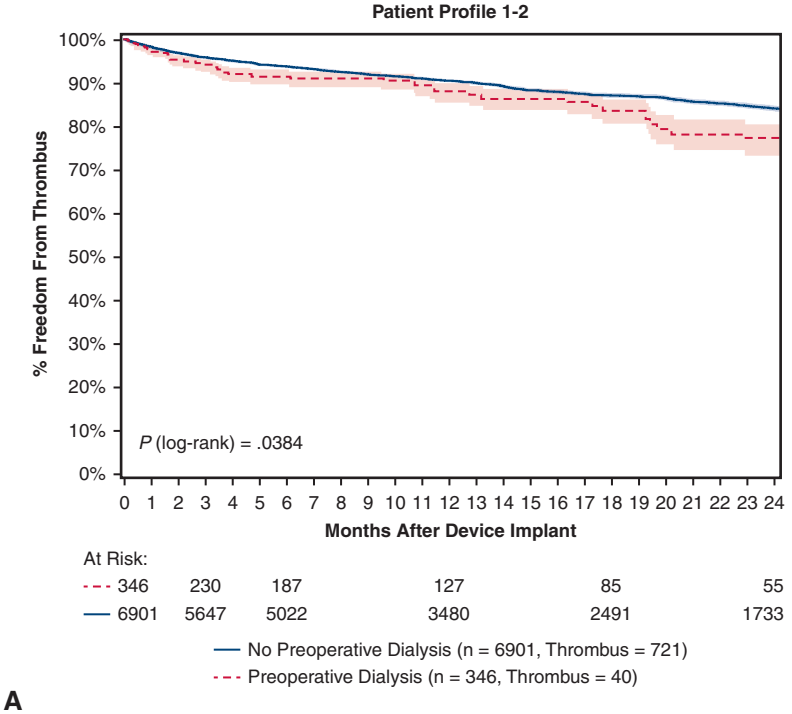
FIGURE E8. Time to first device malfunction (not thrombus) by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first device malfunction (not thrombus) by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, INTERMACS Profile 3-7 time to first device malfunction (not thrombus) by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.



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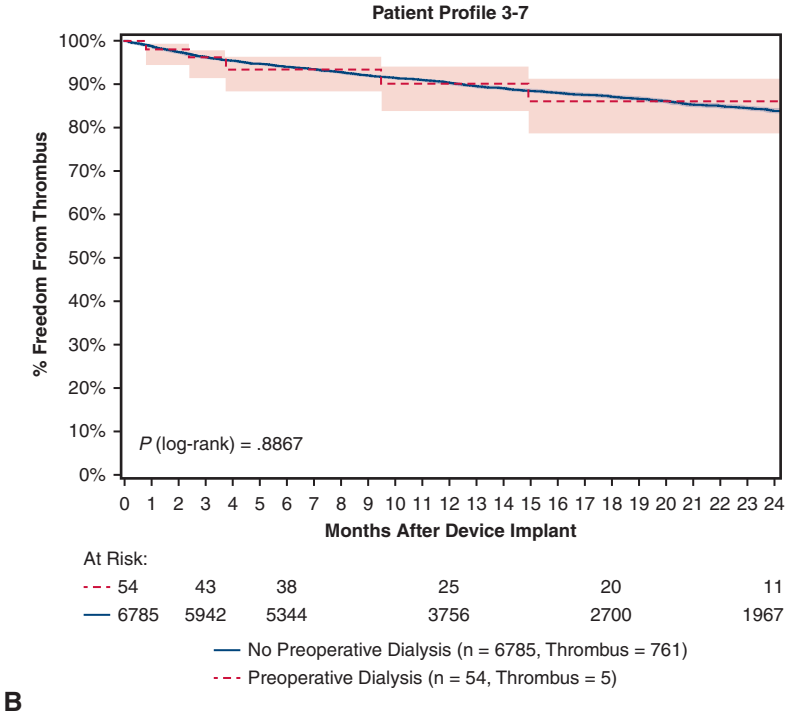

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FIGURE E9. Time to first thrombus event by preimplant dialysis groups. A, INTERMACS Profile 1-2 time to first thrombus event by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom. B, INTERMACS Profile 3-7 time to first thrombus event by preimplant dialysis status. Censored at transplant, cessation of support, or study close. Bands represent 70% CIs. Number at risk listed across the bottom.