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Title

Ventricular arrhythmias in patients with biventricular assist devices.

Permalink

<https://escholarship.org/uc/item/48k0s24k>

Journal

Journal of interventional cardiac electrophysiology : an international journal of arrhythmias and pacing, 58(3)

ISSN

1572-8595

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Publication Date

2020-09-14

Peer reviewed

1 **Ventricular Arrhythmias in Patients With**
2 **Biventricular Assist Devices**

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24 **Running Title:** Ventricular Arrhythmias Associated with Biventricular Assist
25 Device

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39 **ABSTRACT**

40 **Purpose:**

41 Ventricular arrhythmias (VAs) are common in patients after left ventricular assist device
42 (LVAD)n implant and are associated with worse outcomes. However, the prevalence and
43 impact of VA in patients with durable biventricular assist device (BIVAD) is unknown. We
44 performed a retrospective cohort study of patients with BIVADs to evaluate the prevalence
45 of VA and their clinical outcomes.

46

47 **Methods:**

48 Consecutive patients who received a BIVAD between June 2014 to July 2017 at our medical
49 center were included. The prevalence of VA, defined as sustained ventricular tachycardia or
50 fibrillation requiring defibrillation or ICD therapy, was compared between BIVAD patients and
51 a propensity-matched population of patients with LVAD from our center. The occurrence of
52 adverse clinical events was compared between BIVAD patients with and without VA.

53

54 **Results:**

55 Of the 13 patients with BIVADs, 6 patients (46%) experienced clinically significant VA, similar
56 to a propensity-matched LVAD population (38%, $p = 1.00$). There were no differences in
57 baseline characteristics between the two cohorts, except patients in the non-VA group had
58 worse hemodynamics (mitral regurgitation and right-sided indices), less history of VA and
59 were younger. BIVAD patients with VA had a higher incidence of major bleeding (MR 3.05
60 (1.07 - 8.66), $p = 0.036$) and worse composite outcomes (log-rank test, $p = 0.046$). The
61 presence of VA was associated with worse outcomes in both LVAD and BIVAD groups.

62

63 **Conclusion:**

64 Ventricular arrhythmias are common in patients with BIVADs and are associated with worse
65 outcomes. Future work should assess whether therapies such as ablation improve the
66 outcome of BIVAD patients with VA.

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71 **Abbreviations**

72 AF = atrial fibrillation

73 ATP = anti-tachycardia pacing

74 BIVAD = biventricular assist device

75 CVA = cerebrovascular accident

76 EF = ejection fraction

77 EPPY = events per patient year

78 GFR = glomerular filtration rate

79 GI = gastrointestinal

80 HF = heart failure

81 IABP = intra-aortic balloon pump

82 ICD = implanted cardioverter-defibrillator

83 INTERMACS = Interagency Registry for Mechanically Assisted Circulatory Support

84 LA = left atrium

85 LVAD = left ventricular assist device

86 LV-HVAD = left ventricular HeartWare ventricular assist device

87 RA-HVAD = right atrial HeartWare ventricular assist device

88 LVIDd = left ventricle internal diameter diastole

89 PAPI = pulmonary artery pulsatility index

90 PASP = pulmonary artery systolic pressure

91 PCWP = pulmonary capillary wedge pressure

- 92 PVR = pulmonary vascular resistance
- 93 RAP = right atrial pressure
- 94 RV = right ventricle
- 95 RVSP = right ventricular systolic pressure
- 96 RVSWI = right ventricular stroke work index
- 97 RVAD = right ventricular assist device
- 98 TAPSE = tricuspid annular plane systolic excursion
- 99 VA = ventricular arrhythmia
- 100 VT = ventricular tachycardia

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Key words: Ventricular arrhythmia, ventricular tachycardia, biventricular assist device, heart failure

INTRODUCTION

Heart failure is estimated to affect 5.8 million people in the United States and is expected to increase [1]. Despite advances in guideline-directed medical and electronic device therapies, mortality and morbidity remain high in patients with advanced heart failure. Given the shortage of donors available for transplant, the use of ventricular assist devices (VADs) has grown substantially over the years [2].

Ventricular arrhythmias (VAs) are common comorbidities in patients with left ventricular assist devices (LVADs), with rates ranging from 20 - 50% [3-7]. These events have been reported to occur more frequently within the first 30 days of left ventricular assist device (LVAD) placement [8, 9], and early occurrences of VA have been associated with higher mortality [3, 10]. In patients with concomitant right ventricular failure, durable biventricular assist devices (BIVADs) are increasingly implanted with promising results [11-13]. There are currently limited data on the prevalence and outcomes of VAs in patients with BIVADs. Although VAs may be tolerated over the short term due to hemodynamic support provided by the BIVAD, we hypothesize that patients with clinically significant VAs after BIVAD placement may have worse outcomes compared to those without VAs. The purpose of our study is to assess the prevalence of clinically significant VAs after BIVAD placement in comparison to a propensity-matched LVAD population and assess adverse clinical outcomes in BIVAD patients with and without VA.

148 **METHODS**

149 **Patient population and study design**

150 This retrospective study consisted of 13 consecutive patients who received durable
151 biventricular support between June 2014 to July 2017 at University of California, San Diego.
152 Twelve patients underwent implantation of HeartWare device (HVAD, Medtronic, Minnesota,
153 MN) in a left ventricular (LV-HVAD) and right atrial (RA-HVAD) configuration. One patient
154 received a HeartMate II (HM2, Abbott, Pleasanton, CA) LVAD and a RA-HVAD. In all patients,
155 the right ventricular assist device (RVAD) cannula was placed in the anterior wall of the right
156 atrium to improve flow dynamics and reduce the incidence of suction events, as described
157 previously [12, 13]. The occurrence of clinically significant VA, defined as sustained
158 ventricular tachycardia (VT) or ventricular fibrillation lasting ≥ 30 seconds, requiring
159 external defibrillation or appropriate ICD therapy (anti-tachycardic pacing (ATP) or shock),
160 were recorded over time. VAs occurring in rapid succession were considered as a single
161 event.

162 Patients were divided into two groups, those with clinically significant VAs after
163 BIVAD placement (VA group) and those without (non-VA group). Relevant baseline
164 characteristics prior to biventricular support including age, gender, duration of heart failure,
165 medical comorbidities, echocardiogram, right heart catheterization, and laboratory data
166 were compared between the two groups. VA and ICD events were obtained via ICD
167 interrogation reports and thorough chart review of telemetry and ECG criteria. Patients were
168 followed until occurrence of death, transplant, or RVAD decommissioning. Adverse events
169 defined by the Interagency Registry for Mechanically Assisted Circulatory Support
170 (INTERMACS) criteria [14] were recorded, including death, heart failure hospitalization, total
171 hospitalization, RVAD thrombosis, major bleeding, infection, renal failure, respiratory, and
172 neurologic dysfunction. Additionally, propensity score analysis was performed to compare
173 prevalence of VA and composite outcome between LVAD and BIVAD patients.

174

175 **Statistical analysis**

176 Categorical baseline variables were presented as numbers with proportions and
177 compared using Fisher's exact test. Continuous variables were presented as median with
178 interquartile range (Q1-Q3) and compared with the Mann-Whitney test. Poisson regression
179 analysis was used to compare incidence rates of adverse events, presented as mean ratios
180 (MR). The Poisson model was adjusted for patient age at the time of BIVAD placement, with
181 the logarithm of follow up time (one-patient year) used as an offset. The Poisson over-
182 dispersion model was used in the presence of over-dispersion. Kaplan-Meier estimate of
183 composite outcome (death, heart failure hospitalization, major bleeding, and RVAD
184 thrombosis) was performed for both groups, censoring for transplant. Survival curves were
185 compared using the log-rank test. Statistical analysis was performed using SPSS for
186 Windows Version 25 (SPSS Inc. Chicago, IL, USA). For all analyses, $p < 0.05$ (two tailed) was
187 considered statistically significant.

188 Propensity score analysis was performed using a logistic regression model in patients
189 who had LVAD placement at our medical center from August 2011 to August 2018 ($n = 181$).
190 Covariates included in propensity score calculation were selected based on prior studies [15]
191 and included demographic (age, sex, ethnicity) and clinical (body mass index, bridge to
192 transplant, HVAD, INTERMACS profile, non-ischemic heart failure, prior history of VA,
193 hypertension, diabetes, atrial fibrillation, renal function, platelet count, international
194 normalized ratio, ejection fraction, use of class three anti-arrhythmic drugs, and angiotensin-
195 converting enzyme inhibitors) characteristics. BIVAD and LVAD patients were matched in a
196 1:1 manner based on the propensity score of each patient. A caliper width of 20% of the
197 standard deviation of the logit of the propensity score was used, which eliminates 99% of
198 the bias owing to measured confounding variables [16].

199

200 **RESULTS**

201 **Patient population**

202 A total of 13 patients received BIVADs as bridge-to-transplant. 10 patients (77%) had
203 contemporaneous BIVAD placement and 3 patients had conversion from LVAD alone to

204 BIVAD due to progressive right ventricular failure and hemodynamic instability at post-LVAD
205 day 1, 4, and 13, respectively. Baseline characteristics of all patients are presented in Table
206 1. Notable differences between the VA and non-VA groups were observed in age (53.5 [47 -
207 57] vs 29 [20 - 49], $p = 0.035$), presence of moderate or severe mitral regurgitation (33% vs
208 100%, $p = 0.021$), right atrial pressure (13 [11 - 19] vs 21 [20 - 23], $p = 0.04$, and
209 pulmonary artery pulsatility index (1.8 [1.6 - 2.2] vs 1.0 [0.8 - 1.3], $p = 0.016$). Additionally,
210 all 6 patients in the VA group had a history of VAs prior to BIVAD placement, compared to 2
211 patients in the non-VA group (100.0% vs 29%, $p = 0.021$). Etiology of heart failure is listed in
212 Table 2. Of the 13 patients, 2 (15%) had ischemic cardiomyopathy and the remaining 11
213 patients (85%) had nonischemic cardiomyopathy. Patients were followed for median of 263
214 [47 - 519] days.

215

216 **Prevalence of VA after BIVAD placement**

217 Overall, 6 of the 13 patients (46%) experienced clinically significant VAs after BIVAD
218 placement. A total of 62 interventions (33 ICD shocks, 3 ATP, 26 external defibrillations)
219 were delivered for 41 episodes of VA. Among the 41 episodes of VA, 56% were associated
220 with inotrope use ($n = 23$), 12% were associated with suction event ($n = 5$), 7% were
221 associated with electrolyte derangement ($n = 3$; serum potassium ≤ 3.0 mmol/L), and 5%
222 were associated with RVAD thrombosis ($n = 2$). Twenty percent ($n = 8$) of the VA episodes
223 were not associated with any clear identifiable triggers. VAs more commonly occurred in the
224 first month after BIVAD placement (Figure 1). Median days to first VA event was 14 [2 - 28]
225 days.

226

227 **Outcomes of patients with VA after BIVAD placement**

228 Of the six patients in the VA group, one expired while on BIVAD support and two
229 received transplant. Three patients experienced recurrent RVAD thrombosis, two of whom
230 had their RVADs decommissioned and later expired, and one was transitioned to destination
231 therapy due to his co-morbidities. In comparison, six of the seven patients in the non-VA

232 group received transplant. One patient experienced recurrent RVAD thrombosis leading to
233 RVAD decommissioning.

234 The most common adverse events after BIVAD placement were major bleeding and
235 hospital readmission (Table 3). Poisson regression analysis, adjusting for age, was used to
236 compare the incidence of adverse events (events per patient-year). The VA group had a
237 higher rate of major bleeding compared to the non-VA group (MR 3.049, 95% CI [1.073 -
238 8.664], $p = 0.036$), but there was no difference in incidence of heart failure hospitalization,
239 total hospitalization, RVAD thrombosis, driveline or VAD infection, renal failure, respiratory
240 failure, and cerebrovascular accidents when analyzed individually. Kaplan Meier curve of
241 composite outcome revealed rapid separation of the curves for event-free survival favoring
242 the non-VA group ($p = 0.046$) (Figure 2A).

243

244 **Comparison between patients with BIVADs and LVADs**

245 There was no difference in baseline characteristics between patients with BIVADs and
246 LVADs after propensity score matching (Table 4). Prevalence of VA was similar between the
247 two groups (46% vs 38%, $p = 1.00$). Kaplan Meier analysis of composite outcomes is shown
248 in Figure 2. Event-free survival favored the non-VA group in both BIVAD ($p = 0.046$) and
249 LVAD patients ($p = 0.009$). However, there was no statistical difference in composite
250 outcomes of the VA groups when comparing BIVAD vs LVAD patients (log-rank $p = 0.470$).

251

252 **DISCUSSION**

253 There are three key findings in this study. First, the prevalence of VAs during BIVAD
254 therapy was high, but similar to a propensity-matched LVAD population. Second, BIVAD
255 patients with VAs experienced more major bleeding and had worse composite post-
256 operative cardiovascular morbidity compared to BIVAD patients without VAs. Third, the
257 presence of VA was associated with worse outcomes, irrespective of BIVAD or LVAD therapy.

258

259 **Prevalence of VA in Patients with BIVADs**

260 To our knowledge, this was the first study to specifically evaluate the prevalence and
261 outcomes of VAs in patients with BIVADs with right-sided inflow cannula placed in the right
262 atrial position. In our study, 46% of patients experienced clinically significant VAs after
263 BIVAD placement. Although this is high, this is comparable to prior studies reported in the
264 LVAD population [3, 4, 17] and not significantly different from our propensity-matched LVAD
265 group. One explanation may be that RA placement of the RVAD is more favorable
266 hemodynamically compared to RV placement. Prior studies have suggested RV placement of
267 RVAD is associated with increased suction events and RVAD thrombosis [12, 18], both of
268 which could precipitate VAs. In addition, RA placement avoids scarring of the RV, further
269 decreasing the risk of VA by preventing scar formation.. While RA-HVAD does carry the
270 theoretical risk of increased atrial arrhythmias due to scarring, none of our patients
271 developed new onset atrial arrhythmia after BIVAD placement. The clinical significance and
272 burden of atrial tachyarrhythmias after BIVAD placement was beyond the scope of this study
273 and is an area for future research.

274 Similar to prior LVAD studies [19-23], we found that a prior history of VAs was
275 associated with development of clinically significant VAs after BIVAD placement. This
276 supports the theory that pre-existing substrate due to underlying cardiomyopathy play an
277 important role in arrhythmogenesis. Multiple studies of LVAD patients who underwent VT
278 ablation showed that the majority of VTs originate in previously diseased substrate
279 distributed throughout the left ventricle [24-27].

280 The majority of VAs occurred within the first month after BIVAD placement, as has
281 been observed in previous LVAD studies [7, 8]. This was not unexpected, as patients are
282 more likely to require inotropic agents post-operatively and are more prone to large fluid
283 shifts, which can cause electrolyte derangement, suction events, or ventricular distension.
284 Interestingly, there was significant variation in the time to first VA event in our patient
285 cohort and two patients experienced occurrence of VAs throughout ventricular support. One
286 explanation is that the timing of these VAs is dependent on their underlying mechanism. In a
287 study by Sacher et al., VAs originating from prior diseased substrates occurred a median of

288 eight days after LVAD placement, whereas VAs originating from the LVAD cannula site can
289 occur as many as 187 days post-procedure [24]. In addition, several studies have
290 demonstrated changes in gene expression involved in arrhythmogenesis with prolonged
291 VAD therapy [5, 28, 29]. Cardiac remodeling may play a role in continued VAs during
292 mechanical support.

293

294

295 **Sustained VA Associated with Adverse Outcomes**

296 It has been shown in prior work that patients with VAs after LVAD placement have higher
297 rates of right ventricular failure [31], a decrease in cardiac output during episodes of VA
298 [32], , and a higher mortality in the presence of early postoperative VAs [3, 10, 21].
299 However, the clinical outcomes of patients with BIVADs who experience VAs is less clear. In
300 our study, we found that BIVAD patients with post-operative VAs had worse composite
301 outcomes and a higher incidence of major bleeding after adjusting for age. This may be
302 partly attributed to the larger number of patients in the VA group treated with amiodarone,
303 which is an inhibitor of warfarin metabolism. Although not statistically significant, more
304 patients in the VA group experienced recurrent RVAD thrombosis which causes elevated
305 right heart pressure, a known association with GI bleeding [34-36]. Similar to prior LVAD
306 studies and our BIVAD cohort, LVAD patients with VA in our propensity-matched analysis
307 also demonstrated worse composite outcomes compared to patients without VA. However,
308 there was no difference in composite outcomes between BIVAD and LVAD patients
309 experiencing VA, suggesting that the presence of VA is an important risk factor associated
310 with worse outcomes.

311 It is worth noting that there were a few differences in baseline comorbidities between
312 the two groups, without favoring a specific group. The non-VA cohort were younger but had
313 worse hemodynamics on pre-VAD right heart catheterization and echocardiogram (more
314 moderate-severe mitral regurgitation, higher right atrial pressures and worse pulmonary
315 artery pulsatility). This is likely reflective of the severity and complexity of illness in the

316 BIVAD patient population. Previous studies have shown varying effects of age on outcome
317 after BIVAD [37, 38] and LVAD placement [39]. In the patients with moderate-severe mitral
318 regurgitation, all patients improved to mild regurgitation, except one patient who improved
319 from severe to moderate disease on follow up echocardiogram. None of these patients
320 underwent concomitant mitral valve repair or replacement during their BIVAD surgery,
321 Residual mitral regurgitation after LVAD placement is not associated with higher risk of VA
322 [30]. Finally, more patients in the VA group had a prior history of VA, which is a known
323 predictor of worse outcomes in LVAD patients, likely due to its close association with
324 development of VA after VAD implantation. We cannot conclude that prior history of VA is an
325 independent risk factor for worse outcome in BIVAD patients, given all patients with prior
326 history of VA in the VA group had occurrence of VA after BIVAD placement.

327

328 **Role of ICD in patients with BIVADs**

329 There was no statistical difference in the prevalence of implanted ICDs between the
330 two groups in this study population (67% vs 86%, $p=0.56$), and was similar to the
331 prevalence reported in studies of VAD patients. However, only one study to date has
332 assessed the survival of these patients with BIVADs [41]. On the other hand, several studies
333 have reported improved survival in patients with concurrent ICD and LVAD implants [22, 41].
334 In more recent studies involving patients with continuous LVADs, the survival benefit of an
335 ICD is less certain [15, 23, 31]. Regardless, both 2017 ACC/AHA/HRS and 2013 International
336 Society for Heart and Lung Transplant (ISHLT) guidelines recommend ICD placement in
337 patients with LVADs who experience sustained VAs (Class IIA) [42, 43]. Further research is
338 required to assess survival benefit of an ICD in patients with BIVADs. Based on this study, it
339 is possible that patients with VAs may benefit from ICD implantation, but most of these
340 patients are bridge to transplant.

341

342 **Ablation of VA in patients with BIVADs**

343 Catheter ablation of VAs may be effective in patients who experience refractory VT
344 despite medical treatment. We had previously reported a case of refractory unstable VT in a
345 patient with a BIVAD who was successfully treated with catheter ablation [44], as has been
346 shown in another case report [45]. There are also five small observational studies of
347 successful VT ablation in patients with LVADs [24-27, 46]. These studies suggest that
348 ablation is feasible and decreases VA burden. The majority of VTs originated from previous
349 intrinsic myocardial scar, while approximately 30% of VTs originating from the apical LVAD
350 inflow cannula site [24, 25, 27, 46].

351 Since the presence of VAs after VAD implantation is associated with poor outcome, it
352 raises the question of whether VT ablation will have an effect on improved survival. In a
353 retrospective study involving 34 LVAD patients who underwent VT ablation, 10 (29%)
354 expired at a mean follow up of 25 months [24]. In another work involving 7 LVAD patients
355 who underwent VT ablation, 3 (43%) expired [27]. In a study involving 5 patients who
356 received prophylactic epicardial ablation during LVAD placement, 3 had acute procedural
357 success, but only 1 survived at the end of 1 year follow up [47]. Despite the high mortality
358 rates reported in the above studies, their sample sizes were small which limits
359 generalizability, and survival was not the primary endpoint. The mortality benefit of VT
360 ablation for patients with BIVADs is still unclear and is a subject of ongoing investigation.

361

362 **LIMITATIONS**

363 We acknowledge several limitations to our study. First, this was a small study which
364 may limit the generalizability and may appear to be underpowered to detect difference in
365 individual adverse outcomes and prevalence of VA between BIVAD and LVAD groups.
366 However, propensity matching was performed to control for confounding covariates to
367 improve the sensitivity of this analysis. Additionally, the sample sizes for both groups were
368 sufficient to detect differences in adverse outcomes. Second, given this was a retrospective
369 study, programming of ICDs was based on clinical judgement of the attending physicians as
370 opposed to a defined protocol (e.g. patients who have more aggressive ATP and shock

371 protocols may have more ICD therapies as a result)C. However, practice variations are
372 minimized given this is a single center study. Third, ICD interrogation data may not be
373 complete, and three patients did not have ICDs implanted. We attempted to overcome this
374 by reviewing all inpatient documentation, outside hospital records, ECGs, and telemetry
375 tracings. Finally, ventricular origin of VA was not able to be performed for all patients due to
376 lack of 12 lead ECG for most VA events. Despite these limitations, our study provides
377 important findings in an area with very limited data.

378

379 **CONCLUSION**

380 Ventricular arrhythmias in patients with BIVADs are common but comparable to a
381 similar LVAD population and are associated with worse outcomes despite RV support. Future
382 work should assess whether therapies such as ablation improve the outcome of BIVAD
383 patients with VA.

384

385 **COMPLIANCE WITH ETHICAL STANDARDS**

386 The study protocol was approved by the institutional review board at University of California
387 San Diego and adhered to the principles of the Declaration of Helsinki. Informed consent was
388 obtained from all individual participants included in the study.

389

390 **FUNDING**

391 This work was partially supported by research grants from the National Institutes of Health
392 (1KL2TR001444) and the American Heart Association (19CDA34760021).

393

394 **DISCLOSURE STATEMENT**

395 Drs. Lin, Tran, Brambatti, Pretorius, Pollema, Hoffmayer, and Han have no disclosures. Dr.
396 Adler is a consultant for Medtronic and Abbott. Dr. Feld is Director of the Cardiac
397 Electrophysiology Fellowship Training Program which receives fellowship stipend support
398 from Medtronic, Abbott, Boston Scientific, Biosense Webster, and Biotronik. Dr. Krummen

399 reports fellowship support from Medtronic, Boston Scientific, Abbott, and Biotronik. Dr. Ho
400 has received research grants from the National Institutes of Health (1KL2TR001444) and the
401 American Heart Association (19CDA34760021) for work related to this project, grant support
402 from Abbott for work unrelated to this project, fellowship support from Medtronic, Boston
403 Scientific, Abbott, and Biotronik, and has equity in Vektor Medical Inc which is unrelated to
404 this project.

405

406

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559 **Table 1.** Baseline characteristics of patients with BIVADs.

Baseline characteristics	VA Group (n = 6)	NonVA Group (n = 7)	P value
Age - yr.	54 [47 - 57]	29 [20 - 49]	0.035
Male sex	6 (100)	5 (71)	0.462
Ethnicity			0.629
White	2 (33)	2 (29)	
Black	2 (33)	1 (14)	
Other	2 (33)	4 (57)	
Body mass index - kg/m ²	29.7 [26.0 - 33.9]	23.5 [19.6 - 34.2]	0.313
Indication			
Bridge to transplant	6 (100)	7 (100)	1.000
HF etiology			
Non-ischemic	4 (67)	7 (100)	0.192
INTERMACS profile			0.724
1	4 (67)	4 (57)	
2	2 (33)	3 (43)	
Home inotrope use	1 (17)	3 (43)	0.559
ICD present	4 (67)	6 (86)	0.559
HF duration - mo.	35 [8 - 120]	66 [5 - 96]	1.000
HF hospitalizations pre-BIVAD - no.	6 [1 - 7]	4 [2 - 6]	0.914
Comorbidities			
History of ventricular arrhythmia	6 (100)	2 (29)	0.021
Diabetes	3 (50)	2 (29)	0.592
Hypertension	3 (50)	3 (43)	1.000
Hyperlipidemia	5 (83)	0 (0)	0.005
Atrial fibrillation	3 (50)	5 (71)	0.592
Chronic kidney disease ≥ Stage 3	2 (33)	1 (14)	0.559
End-stage renal disease	0 (0)	0 (0)	-
Echocardiogram			
EF - %			
LVIDd - cm	15 [9 - 17]	15 [14 - 23]	0.657
LA diam - cm	7.7 [4.9 - 7.9]	6.9 [6.7 - 8.4]	0.945
LA vol - ml/m ²	5.0 [3.8 - 6.3]	5.3 [4.0 - 6.0]	1.000
RVSP - mmHg	43 [29 - 50]	56 [47 - 79]	0.138
TAPSE - cm	38 [31 - 44]	44 [19 - 56]	0.595
RV dilation ≥ moderate	1.3 [0.9 - 2.1]	1.6 [1.2 - 1.7]	0.876
Mitral regurgitation, ≥ moderate	0 (0)	3 (43)	0.192
Tricuspid regurgitation, ≥ moderate	2 (33)	7 (100)	0.021
Tricuspid regurgitation, ≥ moderate	2 (33)	6 (86)	0.103
Pre-operative support			
IABP/Impella	3 (50)	1 (14)	0.266
Intubated	1 (17)	2 (29)	1.000
Inotropes	6 (100)	7 (100)	-

> 1 Inotrope	3 (50)	5 (71)	0.592
Vasopressors	2 (33)	1 (14)	0.559
Hemodialysis	1 (17)	1 (14)	1.000
Length of stay pre-implant - days	11 [6 - 15]	13 [7 - 37]	0.628
Hemodynamic parameters			
Heart rate - beats/min			
Systolic blood pressure - mmHg	96 [71 - 110]	111 [89 - 118]	0.276
RAP - mmHg	13 [11 - 19]	21 [20 - 23]	0.040
PASP - mmHg	56 [49 - 68]	50 [47 - 53]	0.465
PCWP - mmHg	29 [26 - 31]	31 [30 - 35]	0.466
Pulmonary artery saturation - %	48.5 [37 - 51]	34 [30 - 38]	0.110
Cardiac output - L/min	3.8 [3.2 - 4.7]	2.6 [2.2 - 3.3]	0.277
Cardiac index - L/min/m ²	1.6 [1.3 - 2.2]	1.3 [1.2 - 1.7]	0.558
PVR - Wood unit	4.4 [2.4 - 5.2]	3.0 [1.8 - 5.6]	0.755
RAP/PCWP	0.5 [0.4 - 0.6]	0.6 [0.5 - 0.8]	0.159
PAPI	1.8 [1.6 - 2.2]	1.0 [0.8 - 1.3]	0.016
RVSWI - mmHg*ml/m ²	5.2 [3.0 - 6.3]	2.5 [2.1 - 3.6]	0.286
Laboratory parameters			
White blood cells - 10 ³ /ul			
Hemoglobin - g/dl	7.7 [7.0 - 10.3]	9.4 [7.9 - 10.6]	0.508
Platelets - 10 ³ /mm ³	10.9 [10.5 - 12.0]	9.2 [7.8 - 11.0]	0.181
Sodium - mmol/L	161 [121 - 224]	150 [130 - 197]	1.000
Blood urea nitrogen - mg/dl	129 [126 - 133]	124 [121 - 128]	0.149
Creatinine - mg/dl	26 [16 - 43]	29 [27 - 34]	0.510
GFR - ml/min/m ²	1.5 [1.3 - 1.7]	1.4 [1.3 - 1.8]	0.342
Alanine aminotransferase - U/L	49 [41 - 53]	50 [47 - 53]	0.557
Aspartate aminotransferase - U/L	26 [16 - 42]	25 [14 - 149]	0.916
Albumin - g/dl	31 [21 - 49]	31 [20 - 71]	0.945
Total bilirubin - mg/dl	3.3 [3.1 - 3.6]	3.6 [3.5 - 3.8]	0.119
International normalized ratio	2.2 [0.5 - 3.4]	1.7 [1.4 - 2.2]	0.731
Pro-brain natriuretic peptide	1.4 [1.3 - 1.7]	1.7 [1.3 - 1.9]	0.534
Anti-arrhythmic therapy	7412 [4006 - 22727]	10198 [4432 - 14897]	0.937
Mexiletine	1 (17)	0 (0)	0.462
Beta-blocker	0 (0)	0 (0)	-
Amiodarone	4 (67)	4 (57)	1.000
Prior ablation procedure	0 (0)	0 (0)	-

Values are presented as median [interquartile range] for continuous variables and number (percentage) for categorical variables.

BIVAD = biventricular assist device; EF = ejection fraction; GFR = glomerular filtration rate; HF = heart failure; IABP = intra-aortic balloon pump; ICD = implanted cardioverter-defibrillator; INTERMACS = Interagency Registry for Mechanically Assisted Circulatory Support; LA = left atrial; LVIDd = left ventricle internal diameter diastole; PAPI = pulmonary artery pulsatility index; PASP = pulmonary artery systolic pressure; PCWP = pulmonary capillary wedge pressure;

PVR = pulmonary vascular resistance; RAP = right atrial pressure; RV = right ventricle; RVSP = right ventricular systolic pressure; RVSWI = right ventricular stroke work index; TAPSE = tricuspid annular plane systolic excursion

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566 **Table 2.** Etiology of heart failure.

Patient	Etiology of heart failure
1	Ischemic
2	Idiopathic
3	Hypertrophic cardiomyopathy
4	Idiopathic
5	Ischemic
6	Rheumatic heart disease
7	Anabolic steroid abuse
8	Sarcoidosis
9	Idiopathic
10	Myocarditis
11	Idiopathic
12	Idiopathic
13	Myocarditis

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584 **Table 3.** Incidence of adverse events between the VA and NonVA group.

Adverse events	VA group (n = 6)		NonVA group (n = 7)		Mean ratio (MR) (95% CI)	P value
	Events	EPPY	Events	EPPY		
HF hospitalization	2	0.604	3	0.690	1.246 (0.174 - 8.903)	0.827
Total	9	3.019	12	2.762	1.313 (0.543 - 3.177)	0.546
hospitalization						
Major bleeding	18	3.175	6	1.198	3.049 (1.073 - 8.664)	0.036
RVAD thrombosis	5	0.882	4	0.798	2.089 (0.394 - 11.084)	0.387
Infection	8	1.411	7	1.397	0.823 (0.278 - 2.440)	0.823
Renal failure	3	0.705	1	0.200	2.205 (0.225 - 21.600)	0.497
Respiratory failure	6	1.235	4	0.798	1.916 (0.226 - 16.258)	0.551
CVA	1	0.353	1	0.200	1.836 (0.170 - 191.785)	0.616

Mean ratio is adjusted for age. CVA = cerebrovascular accident; EPPY = events per patient-year; HF = heart failure; RVAD = right ventricular assist device

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596 **Table 4.** Propensity score matched cohort baseline characteristics.

Baseline characteristics	BIVAD (n = 13)	LVAD (n = 13)	P value
Age - yr.	47 [28 - 54]	52 [41 - 59]	0.304
Male sex	11 (85)	10 (77)	1.000
Ethnicity			1.000
White	4 (31)	4 (31)	
Non-white	9 (69)	9 (69)	
Body mass index - kg/m ²	26.5 [21.6 - 34.1]	26.9 [25.7 - 29.8]	0.990
Indication			1.000
Bridge to transplant	13 (100)	13 (100)	
VAD type	HeartWare*	HeartWare	-
INTERMACS profile			1.000
1	8 (62)	8 (62)	
2	5 (38)	4 (31)	
3	0 (0)	1 (7)	
HF etiology			1.000
Non-ischemic	11 (85)	11 (85)	
History of ventricular arrhythmia	8 (62)	9 (69)	1.000
Diabetes	5 (38)	4 (31)	1.000
Hypertension	6 (46)	6 (46)	1.000
Atrial fibrillation	8 (62)	8 (62)	1.000
Creatinine - mg/dl	1.39 [1.34 - 1.72]	1.29 [1.04 - 2.06]	0.553
GFR - ml/min/m ²	50 [45 - 53]	61 [31 - 75]	0.787
Platelet - 10 ³ /mm ³	150 [127 - 210]	199 [130 - 218]	0.830
International normalized ratio	1.5 [1.3 - 1.8]	1.3 [1.2 - 1.6]	0.110
Ejection fraction - %	15 [14 - 21]	15 [11 - 20]	0.712

Values are presented as median [interquartile range] for continuous variables and number (percentage) for categorical variables.

HF = heart failure; INTERMACS = Interagency Registry for Mechanically Assisted Circulatory Support; VAD = ventricular assist device

*one patient had a HeartMate II left ventricular assist device

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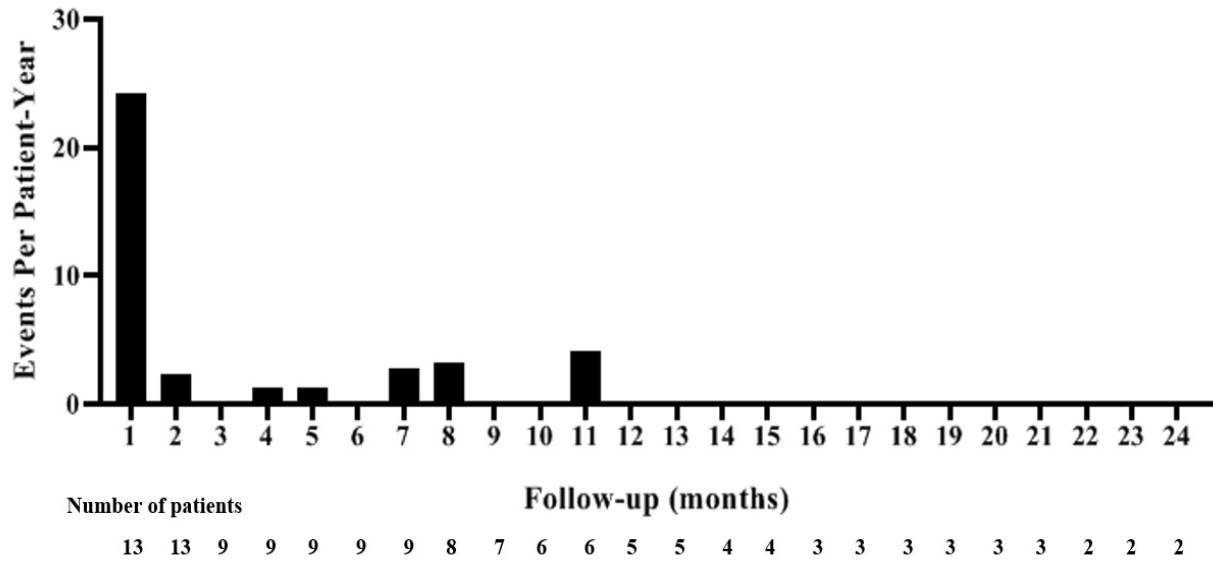
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608 **Figure 1.** Monthly incidence of ventricular arrhythmia per patient-year.



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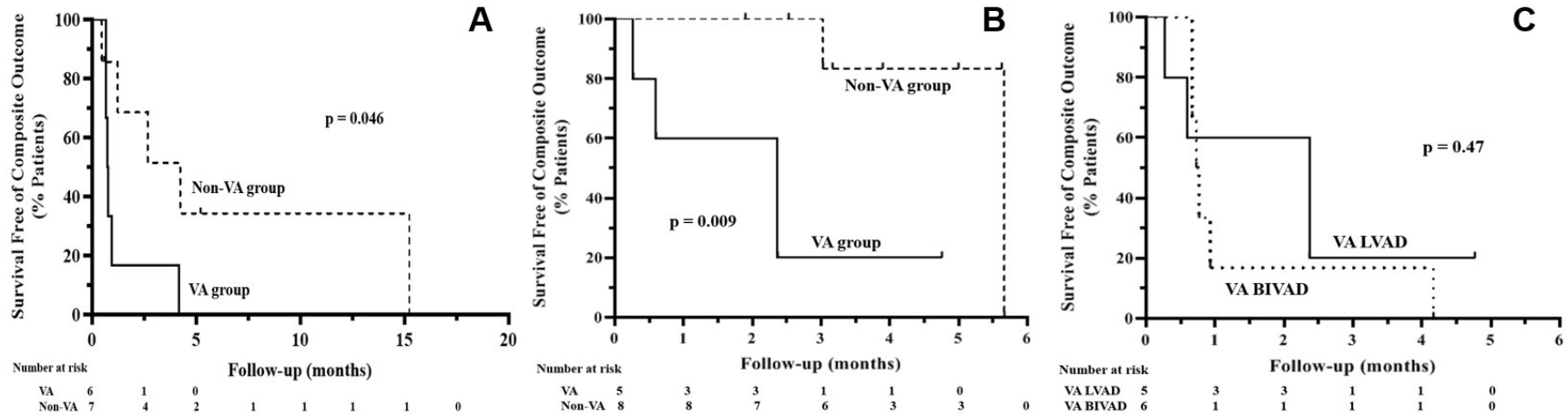
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626 **Figure 2.** Kaplan Meier curve of composite outcome between groups, censored for transplant. A)
 627 Comparison of VA and non-VA patients with BIVADs. B) Comparison of VA and non-VA patients with LVADs.
 628 C) Comparison of VA group in BIVAD and VA group in LVAD patients.



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