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The Heartmate Risk Score Predicts Morbidity and Mortality in Unselected Left Ventricular Assist Device Recipients and Risk Stratifies INTERMACS Class 1 Patients

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ABSTRACT

OBJECTIVES This study evaluated the Heartmate Risk Score (HMRS) and its potential benefits in clinical practice.

BACKGROUND The HMRS has been shown to correlate with mortality in the cohort of patients enrolled in the Heartmate II trials, but its validity in unselected, "real world" populations remains unclear.

METHODS This study identified a cohort of 269 consecutive patients who received a Heartmate II left ventricular assist device at our institution, the Barnes-Jewish Hospital in St. Louis, Missouri, between June 2005 and June 2013. Ninety-day and 2-year mortality rates, as well as frequency of several morbid events, were compared by retrospectively assigned HMRS category groups. The analysis was repeated within the subgroup of INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) class 1 patients.

RESULTS Receiver operating curve analysis showed that the HMRS correlated with 90-day mortality with an area under the curve of 0.70. Stratification in low, mid, and high HMRS groups identified patients with increasing hazard of 90-day mortality, increasing long-term mortality, increasing rate of gastrointestinal bleeding events, and increasing median number of days spent in the hospital in the first year post implant. Within INTERMACS class 1 patients, those in the highest HMRS group were found to have a relative risk of 90-day mortality 5.7 times higher than those in the lowest HMRS group (39.1% vs. 6.9%, $p = 0.029$).

CONCLUSIONS HMRS is a valid clinical tool to stratify risk of morbidity and mortality after implant of Heartmate II devices in unselected patients and can be used to predict short-term mortality risk in INTERMACS class 1 patients.
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Left ventricular assist devices (LVADs) have become the standard of care for patients with end-stage heart failure both as a bridge to transplant (BTT) (1) and as destination therapy (DT) (2). Over the past decade, rates of LVAD implants in North America have grown exponentially, with the announcement of the 10,000th LVAD implant in the INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) registry in June 2013 (3). However, LVAD support remains associated with high morbidity and mortality and carries high costs (4). It is therefore critical to risk stratify patients

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ABBREVIATIONS AND ACRONYMS

AUC = area under the curve

GI = gastrointestinal

HMII = Heartmate II

HMRS = Heartmate Risk Score

INTERMACS = Interagency Registry for Mechanically Assisted Circulatory Support

LVAD = left ventricular assist device

ROC = receiver operating curve

effectively to identify patients with the greatest potential to benefit and to avoid futile implants. In addition, accurate risk stratification allows clinicians to inform patients and their families correctly as they consider this invasive therapeutic option.

Several clinical prediction rules have been developed to assess the likelihood of short-term mortality after LVAD implantation (5,6). Among these, the Heartmate Risk Score (HMRS) is a novel, simple, quantitative tool to predict mortality risk at 90 days in recipients of Heartmate II (HMII) (Thoratec Corp., Pleasanton, California) LVADs, independent of the implant strategy (DT vs. BTT) (7). The HMRS was derived from a large cohort of patients enrolled in the HMII trials and was defined as a function of age, international normalized ratio (INR), albumin concentration, creatinine concentration and implant center volume. More than 1,100 patients were evenly split into a derivation cohort and a validation cohort. The association between the HMRS and 90-day mortality was evaluated with the receiver operating curve (ROC) analysis. Overall, stratification into low, mid, and high HMRS categories was shown to identify patient populations with correspondingly low, intermediate, and high 90-day mortality rates. In the derivation cohort, the HMRS was shown to have an area under the curve (AUC) of 0.77, whereas the AUC in the validation cohort was 0.64. Notably, the cohort of patients enrolled in the HMII trials is not well representative of today's LVAD recipients (8). Furthermore, the HMRS was not compared with INTERMACS classification, arguably the most widely used tool to risk stratify LVAD recipients (6). The ability of the HMRS to correlate with mortality in "real world" patients has been questioned (9). We sought to investigate the clinical utility of the HMRS retrospectively in an unselected, consecutive cohort of HMII recipients from our institution, the Barnes-Jewish Hospital (BJH) in St. Louis, Missouri. Additionally, we intended to evaluate the ability of the HMRS to risk stratify INTERMACS class 1 patients, a subgroup of patients in whom mortality is exceedingly high and in whom the utility of durable LVADs is controversial.

METHODS

PATIENT COHORT. We retrospectively identified a cohort of 339 consecutive patients who underwent implantation of a continuous flow LVAD at BJH between June 2005 and June 2013 (Online Figure 1). Within this cohort we identified 305 consecutive patients who received an HMII device. Thirty-six HMII recipients were excluded; 22 had undergone LVAD exchange, and 14 had insufficient data to calculate the pre-operative HMRS. The most common reason for exclusion in this last group was lack of albumin level pre-implant.

Patient characteristics and clinical outcomes were obtained through review of the medical records. All data were collected and managed using REDCap, an electronic data capture tool hosted by our institution (10). The HMRS was calculated by reviewing chart data up to 1 week before the implant day and using the available data closest to the implant day. INTERMACS classification at the time of implant was dictated by the implanting surgeon in the operative note or was assigned by the advanced heart failure team. HMRS was categorized as low (<1.58), mid (1.58 to 2.48), and high (>2.48), as previously described (7). Actuarial survival during mechanical circulatory support was calculated from the date of implant to death, and patients were censored as alive at the time of cardiac transplantation. The study was reviewed and approved by the Washington University in St. Louis Institutional Review Board.

STATISTICAL ANALYSIS. Comparisons of baseline characteristics between patients alive and dead at 90 days and between the BJH cohort and the HMRS derivation sample were conducted with Student 2-sample *t* test and Fisher exact test for continuous and categorical data, respectively. Non-normal and ordinal data were compared using the Kruskal-Wallis test and were summarized by the median (1st quartile, 3rd quartile). An ROC curve to assess the ability of HMRS, as a continuous variable, to predict 90-day mortality, was generated along with the AUC. Additionally, a logistic regression model was built to evaluate all pair-wise comparisons of 90-day mortality between HMRS category levels. Tukey's method for multiple comparisons was used to adjust p values. To account for different length of follow-up time among patients, the number of gastrointestinal (GI) bleeding events, strokes, hemolysis events, and days in the hospital within the first year were evaluated with a Poisson regression model having the log follow-up years as offset and scaled to account for overdispersion. Pair-wise comparisons among HMRS categories were conducted through the model, and Tukey's method for multiple comparison tests was used to adjust p values. Kaplan-Meier survival curves were developed by HMRS category to evaluate long-term (2-year) survival. The log-rank test was used to assess differences between curves.

The results from a logistic model including only HMRS were compared with a model including HMRS,

history of coronary artery disease, and vasopressors to evaluate the ability to improve on HMRS as a predictor of 90-day mortality. The impact of these additional variables on the HMRS was evaluated by comparing the change in the C-statistic and calculating the category-free net reclassification improvement (category-free NRI) (11). Data analysis was performed with SAS (Cary, North Carolina) and GraphPad Prism 6 (GraphPad Software, Inc., San Diego, California).

RESULTS

CHARACTERISTICS OF THE BARNES-JEWISH HOSPITAL COHORT AND HMRS DERIVATION COHORT. Basic characteristics of the BJH cohort are shown in Table 1. The cohort was composed predominantly of Caucasian men. The average age was 55.9 years. Thirty-three percent of the cohort was classified as INTERMACS class 1 at the time of implant. Compared with the HMRS derivation cohort, the baseline characteristics were similar in terms of HMRS variables as well as gender, race, and use of intravenous inotropes or intra-aortic balloon pump before LVAD (Table 2). The BJH cohort was enriched in patients undergoing BTT when compared with the HMRS derivation cohort (67% vs. 42%).

HMRS AND 90-DAY MORTALITY. ROC analysis for HMRS as a predictor of 90-day mortality yielded an AUC of 0.70 (95% confidence interval [CI]: 0.60 to 0.79). Patients in the highest HMRS group had a relative risk of 90-day mortality 3.9 times greater than patients in the lowest HMRS group (32.7% vs. 8.3%, p = 0.001) and 2.6 times greater than those in the mid HMRS group (32.7% vs. 12.5%, p = 0.01) (Figure 1). Our center contributed 37 patients to the HMII trials. To avoid any potential bias in our results, we repeated the analysis excluding all patients who

TABLE 1 Baseline Characteristics of Patients in the BJH Cohort of LVAD Recipients (N = 269)

Age (yrs)	55.9 ± 12.1
Caucasian	200 (74%)
Male	217 (81%)
BMI	28.9 ± 6.2
Strategy	
Bridge to transplant	181 (67%)
Destination therapy	86 (32%)
INTERMACS profile	
1	89 (33%)
2	146 (54%)
3	17 (6%)
4 or more	17 (6%)
Ischemic cardiomyopathy	116 (43%)
STEMI in last 30 days	11 (4%)
Vasopressors before LVAD	29 (13%)
Inpatient inotropes before LVAD	184 (85%)
Balloon pump before LVAD	58 (27%)

Values are mean ± SD or n (%).

BJH = Barnes-Jewish Hospital; BMI = body mass index; INTERMACS = Interagency Registry for Mechanically Assisted Circulatory Support; LVAD = left ventricular assist device; STEMI = ST-segment elevation myocardial infarction.

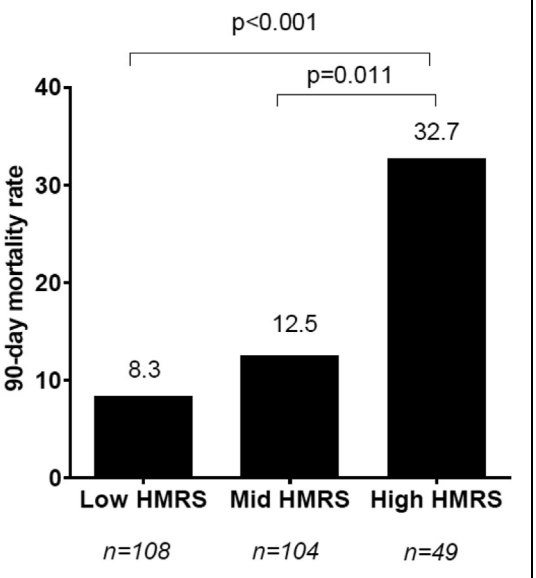
TABLE 2 Comparison of the BJH Cohort and the HMRS Derivation Cohort

Variable	HMRS Derivation Cohort (n = 583)	BJH Cohort (n = 269)	p Values
Age (yrs)	58.3 ± 13.3	55.9 ± 12.1	0.85
Male	450 (77%)	217 (81 %)	0.28
Caucasian	433 (74%)	200 (74%)	1.00
BTT	245 (42%)	181 (67%)	<0.001
Intravenous inotropes before to VAD	495 (85%)	184 (85%)	1.00
IABP before LVAD	177 (30%)	58 (27%)	0.34
Creatinine	1.47 ± 0.55	1.57 ± 0.80	0.88
Albumin	3.44 ± 0.58	3.54 ± 0.54	0.86
INR	1.31 ± 0.33	1.58 ± 0.51	0.50

Values are mean ± SD or n (%).

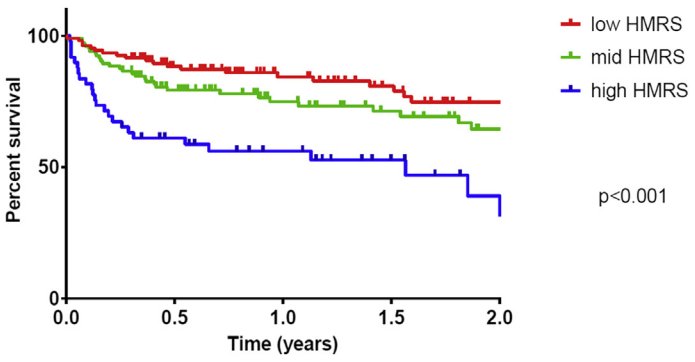
BJH = Barnes-Jewish Hospital; BTT = bridge to transplant; HMRS = Heartmate Risk Score; IABP = intra-aortic balloon pump; INR = international normalized ratio; LVAD = left ventricular assist device; VAD = ventricular assist device.

FIGURE 1 Predicting 90-Day Mortality on the Basis of HMRS



Ninety-day mortality rate in the Barnes-Jewish Hospital left ventricular assist device cohort stratified by Heartmate Risk Score (HMRS) group. The number of patients in each group (n) is indicated **below each bar**.

FIGURE 2 Long-Term Mortality on the Basis of HMRS

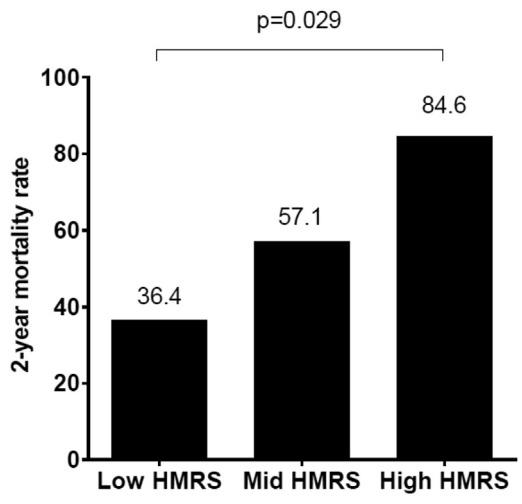


Kaplan-Meier Survival of Heartmate II recipients in the Barnes-Jewish Hospital cohort stratified by Heartmate Risk Score (HMRS) group. Log-rank test p = 0.001.

underwent LVAD implantation during the time of recruitment in the HMII landmark studies, and we obtained very similar results (AUC of 0.68).

HMRS AND LONG-TERM OUTCOMES AFTER LVAD IMPLANT. Kaplan-Meier survival analysis censoring patients as alive at the time of heart transplantation showed a statistically significant difference in long-term survival among the high, mid, and low HMRS groups (log-rank p < 0.001) (Figure 2). To assess the ability of the HMRS to predict life span during mechanical support, we assessed long-term survival in patients who received LVAD as DT. We found that the 2-year mortality of patients who received DT in the high HMRS category was 84.6% as compared with 36.4% in the low HMRS group (relative risk: 2.32, p = 0.029) (Figure 3).

FIGURE 3 Long-Term Mortality in Destination Therapy Patients on the Basis of HMRS



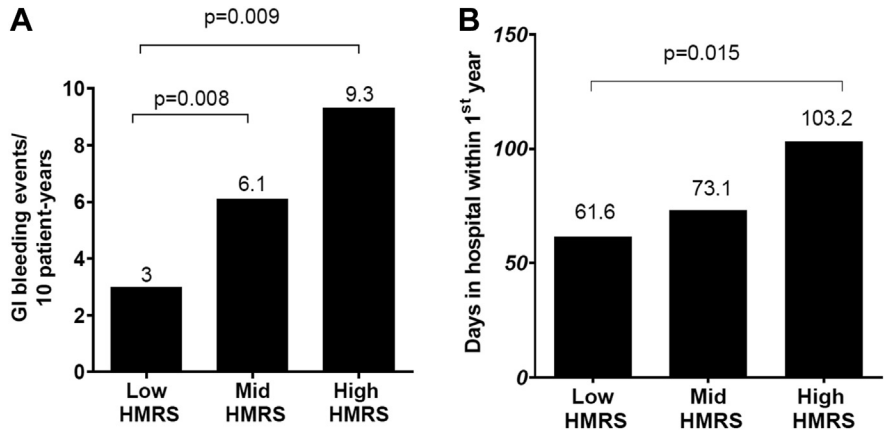
Two-year mortality rate in patients who received a left ventricular assist device as destination therapy stratified by Heartmate Risk Score (HMRS) group.

HMRS AND MORBIDITY AFTER LVAD IMPLANT. The association between pre-operative HMRS and stroke rate, hemolysis/pump thrombosis rate, implant hospitalization length of stay, GI bleeding events rate, and cumulative days hospitalized in the first year post implant were evaluated. Although HMRS did not correlate with stroke rate, hemolysis/pump thrombosis rate, or implant hospitalization length of stay (data not shown), patients in the high HMRS category had a significantly higher rate of GI bleeding events than did patients in the low HMRS category (9.3 per 10 patient-years vs. 3 per 10 patient-years, p = 0.009) (Figure 4A). Additionally, when compared with patients with low HMRS, subjects in the high HMRS category spent a greater number of days in the hospital in the first year post LVAD (103.2 vs. 61.6 days, p = 0.015) (Figure 4B).

HMRS IN INTERMACS CLASS 1 PATIENTS. One-third of the BJH cohort was classified as INTERMACS class 1 before LVAD implant (n = 89, 33%) (Table 1, Online Table 1). As shown in Figure 5, HMRS categorization effectively stratified mortality risk among INTERMACS class 1 patients, in terms of both 90-day mortality (Figure 5A) and long-term mortality (Figure 5B). The AUC for the HMRS ability to predict 90-day mortality among INTERMACS class 1 patients was 0.75, and INTERMACS class 1 patients in the high HMRS group had a relative risk of mortality at 90-day that was 5.7 times higher than those in the lowest HMRS group (39.1% vs. 6.9%, p = 0.029). Kaplan-Meier survival analysis censoring patients as alive at the time of heart transplantation showed a significant difference in long-term survival across the 3 HMRS levels (log-rank p = 0.039).

HMRS AND OTHER COMMON CLINICAL VARIABLES. We investigated the association with 90-day mortality of a number of variables not included in the HMRS. In univariate analysis, 2 variables not included in the HMRS were significantly associated with 90-day mortality (Table 3): history of coronary artery disease (odds ratio [OR]: 1.38, p = 0.05) and use of vasopressors before implant (OR: 3.2, p = 0.002) (Table 3). However, in multivariate analysis with the HMRS, only pre-operative use of vasopressors maintained a statistically significant association with mortality. Addition of the variable "preoperative use

FIGURE 4 GI Bleeding Events and Days Spent in the Hospital on the Basis of HMRS



(A) Median rate of gastrointestinal (GI) bleeding events per 10 patient-years stratified by Heartmate Risk Score (HMRS) group. **(B)** Median number of days spent in the hospital in the first 365 days post left ventricular assist device implant stratified by HMRS group.

of vasopressors" to the HMRS provided only marginal improvement in the ability of the score to predict 90-day mortality, as shown by a modest, non-statistically significant change in the category-free NRI (Online Table 2). We tested all the variables listed in **Table 3** for association with 90-day mortality with a focus only on the subgroup of INTERMACS class 1 patients and found similar results (Online Table 3).

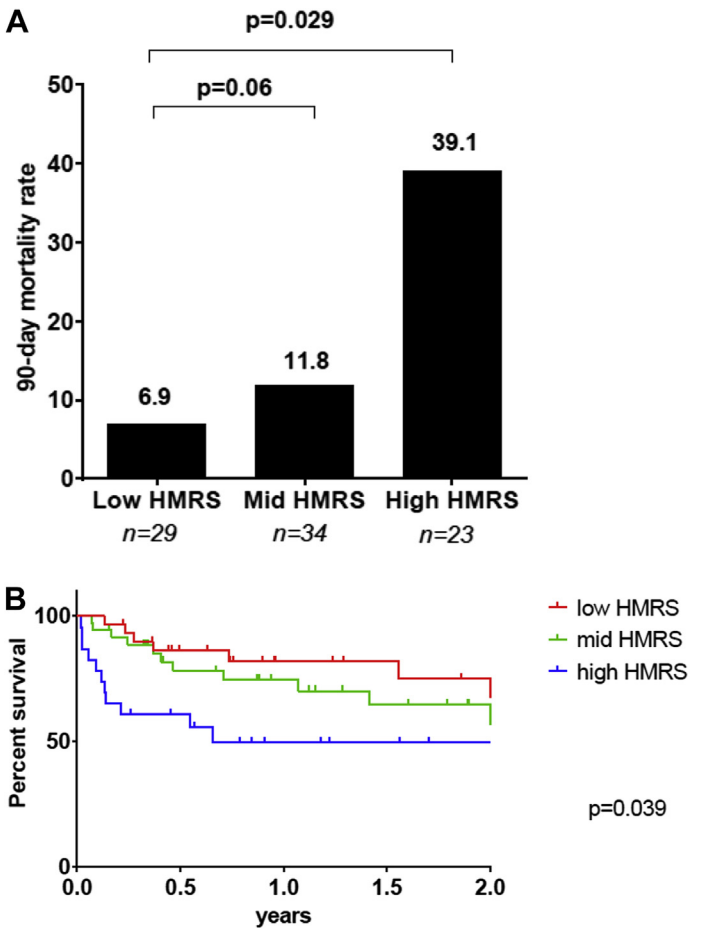
DISCUSSION

HMRS CORRELATES WITH SHORT-TERM AND LONG-TERM SURVIVAL POST LVAD IMPLANT. The HMRS was derived from a large, multicenter trial population and was proposed as a novel and accurate risk predictive model for short-term survival after LVAD implantation (7), but to date its applicability to real world patients remains controversial (9). The current study demonstrates that the HMRS correlates with 90-day mortality (AUC of 0.70) in an unselected cohort of HMII LVAD recipients from a single, large-volume center and can identify patients with low (≈8%), medium (≈12%), and high (≈32%) risk of 90-day mortality for implant of an HMII device. This correlation is very similar to that described in the HMRS derivation paper that found an AUC of 0.71 and in the validation cohort found mortality rates of approximately 8%, 12%, and 26% in low, mid, and high HMRS groups, respectively (7). Importantly, although our center was involved in the HMII trials and contributed some patients to the cohort used to derive the HMRS, the overlap between the 2 cohorts is minimal, and exclusion of all the patients potentially included in the HMRS derivation cohort did not significantly change our results.

In addition to confirming what was previously described, we observed that the HMRS significantly discriminates patient groups with respect to survival at 2 years. Further, by stratifying the DT subgroup by HMRS, DT-treated patients in the high HMRS group were observed to have a 2-year mortality rate almost 2.5 times higher than patients in the low HMRS category. These observations suggest that the correlation between HMRS and long-term outcomes reflects a correlation between pre-operative HMRS category and ability to tolerate long-term mechanical circulatory support independent of receiving a heart transplant.

HMRS RISK STRATIFIES INTERMACS CLASS 1 PATIENTS. Patients with INTERMACS 1 classification are defined as "crashing and burning" subjects, with cardiogenic shock refractory to inotropes. In-hospital mortality in this subgroup remains exceedingly high, and current recommendations are unclear about the utility of durable LVADs in this subgroup (6,12). This observation has led some investigators to use alternative strategies to durable LVADs in INTERMACS class 1 patients, and the number of implants in this population recorded in the INTERMACS registry correspondingly decreased from 41% in 2006 to 14% to 16% in 2011 to 2012 (13,14). However, INTERMACS classification provides a snapshot of hemodynamic status, and in the presence of severe hemodynamic

FIGURE 5 Short-Term and Long-Term Mortality in INTERMACS Class 1 Patients on the Basis of HMRS



(A) Ninety-day mortality rate in INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) class 1 left ventricular assist device (LVAD) recipients stratified by Heartmate Risk Score (HMRS) group. The number of patients in each group (n) is indicated **below each bar**. **(B)** Kaplan-Meier survival stratified by HMRS group among INTERMACS class 1 LVAD recipients. Log-rank test p = 0.039. Three patients were excluded from this analysis because they were censored before 90 days.

compromise, it does not invariably discriminate between patients with preserved organ function and patients with long-standing multiorgan dysfunction. Here we show that within this most acutely ill INTERMACS stratum, the HMRS provides the ability to discriminate between patient groups with a risk of 90-day mortality ranging from as low as 6.9% to as high as 39%. This observation suggests that quantitative risk models such as the HMRS may help clinicians better identify those critically ill patients who are more likely to benefit from durable mechanical circulatory support, as well as identify those patients who are unlikely to benefit from mechanical circulatory support.

THE HMRS CORRELATES WITH MORBIDITY POST LVAD IMPLANT. The current study also describes a previously unrecognized correlation between HMRS and morbid events post LVAD implant. In fact, we found a statistically significant difference in post-LVAD GI bleeding event rates and number of days spent in the hospital in the first year post implant among HMRS groups. Patients in the mid HMRS group had a 2-fold increase, and those in the high HMRS group had 3-fold increase in GI bleeding events per 10 patient-years of follow-up compared with the patients in the low HMRS group. Moreover, the patients in the high HMRS group spent 67% more days in the hospital in the first year post implant when compared with the low HMRS group. This stands to reason because the HMRS incorporates patient age, an identified risk factor for GI bleeding (15), and INR, an indicator of preoperative coagulopathy and liver dysfunction. This observed large difference in rates of GI bleeding, which generally results in prolonged hospitalization, may alone explain the increased in-hospital days within the first year that we found for high HMRS versus low HMRS subjects because we identified no difference in length of hospital stay at the time of LVAD implantation across HMRS groups (data not shown). The ability of the HMRS to predict these and other life-style-limiting post-LVAD complications merits further study, given that this information may provide important background for both clinician and patients when considering an LVAD implant.

THE HMRS CAPTURES MOST OF THE PREDICTIVE POWER OF COMMONLY MEASURED CLINICAL VARIABLES. Although our data validate the predictive accuracy of the HMRS in a real world cohort of HMII recipients, it bears emphasis that both in our cohort and in the HMII trials cohort, the HMRS has a modest discriminative ability for predicting 90-day mortality with an AUC of 0.70. Because the original HMRS score was limited to data available in the clinical trials, we sought additional variables that could improve its discriminative ability. In contrast to what was observed in the HMRS derivation cohort, we found that use of vasopressors before LVAD implant correlated with 90-day mortality in multivariate analysis with the HMRS. However, the addition of this variable did not significantly improve the ability to predict 90-day mortality. Overall, our findings suggest that the HMRS captures most of the predictive power of commonly measured clinical variables and that further work on significantly larger cohorts or the

analysis of novel variables would be needed to generate an improved risk model that could enhance risk stratification of LVAD recipients.

DISCREPANCY WITH OTHER PUBLISHED WORK. Our data are in line with what was observed in the trial cohort of approximately 1,100 patients used to derive and validate the HMRS. Interestingly, another large-volume center applied the HMRS retrospectively to their continuous-flow LVAD cohort and did not find a correlation between HMRS and 90-day mortality (9). The reason for the difference between findings in real world patients at this center and at our institution remains unclear. In comparison, our cohort was larger (261 implants vs. 201), had a similar annual implant volume, had fewer patients with low HMRS (41% vs. 50%), and had a lower prevalence of BTT (67% vs. 76%), although 90-day mortality was essentially the same (14.5% vs. 15.1%). None of these differences appear sufficient to account clearly for the discrepant results. Additionally, our analysis excluded ventricular assist device exchange implants and included a relatively high number of INTERMACs class 1 patients. These data are not available in the published analysis, but there is a potential difference between the two. Ultimately, both retrospective analyses have limited power, and thus the observed discrepancy could represent random variability. Further analysis in other cohorts and larger databases are needed to understand the value of the HMRS in real world patients and to identify better the possible basis of the observed discrepancies.

STUDY LIMITATIONS. Some of our findings may not be applicable in low-volume centers that implant LVADs, insofar the HMRS gives a large "penalty" to patients who received their LVAD in an institution that implants <15 LVADs per year. In our population, this penalty was not applied, and therefore our findings may not apply to the HMRS calculated for patients who receive LVAD implants in lower-volume centers. Further, the ability of the HMRS to predict GI bleeding, as well as days spent in the hospital within the first year post LVAD implant, and its ability to risk stratify INTERMACS class 1 patients have not been described previously and therefore will require evaluation in additional patient populations. Finally, we have performed a retrospective analysis and have therefore shown correlation between HMRS and clinically relevant events. Although this type of analysis suggests predictive value, a prospective study would be required to assess more definitively the ability of the HMRS to predict clinical outcomes.

TABLE 3 Univariable Correlates of 90-Day Mortality in the BJH Cohort*

Variable	Overall (N = 303)	Alive at 90 days (N = 249)	Dead at 90 days (N = 45)	p Value
Caucasian	227 (75%)	189 (76%)	32 (71%)	0.57
Male	239 (79%)	198 (80%)	33 (73%)	0.43
Age (yrs)	56.19 ± 11.91	55.94 ± 11.99	58.98 ± 9.94	0.11
BMI (kg/m^2)	28.93 ± 6.19	28.79 ± 6.12	29.81 ± 6.27	0.31
Strategy				0.020
Bridge to transplant	204 (67%)	176 (71%)	23 (51%)	
Destination therapy	95 (31%)	71 (29%)	21 (47%)	
History of atrial fibrillation	130 (43%)	107 (43%)	21 (47%)	0.74
Smoking within 3 months	29 (10%)	22 (9%)	6 (14%)	0.41
History of CAD	155 (51%)	121 (49%)	30 (67%)	0.034
STEMI in past 30 days	12 (4%)	11 (4%)	0 (0%)	0.23
History of DM	126 (42%)	99 (40%)	23 (51%)	0.19
COPD	40 (13%)	34 (14%)	6 (13%)	1.00
History of ethanol abuse	2 (13%)	2 (18%)	0 (0%)	1.00
History of hypertension	145 (48%)	119 (48%)	22 (49%)	1.00
Ischemic cardiomyopathy	136 (45%)	109 (44%)	22 (49%)	0.63
CABG at time of implant	14 (6%)	9 (5%)	4 (11%)	0.12
Redo sternotomy	67 (28%)	56 (28%)	10 (29%)	1.00
Vasopressors before VAD	35 (14%)	22 (11%)	11 (29%)	0.008
Inpatient inotropes before VAD	214 (86%)	171 (84%)	34 (89%)	0.62
IABP before VAD	64 (25%)	50 (25%)	12 (31%)	0.43

Values are n (%) or mean ± SD. *Comparisons of patients alive and dead at 90 days were conducted with Student 2-sample *t* test and Fisher exact test for continuous and categorical data, respectively. The p value for the difference between the 2 groups is indicated.

BMI = body mass index; CABG = coronary artery bypass grafting; CAD = coronary artery disease; COPD = chronic obstructive pulmonary disease; DM = diabetes mellitus; IABP = intra-aortic balloon pump; STEMI = ST-segment elevation myocardial infarction; VAD = ventricular assist device.

CONCLUSIONS

In summary, we validated the HMRS in a large, unselected cohort of HMII recipients from a single, high-volume center. We demonstrated that the HMRS correlates with short-term and long-term survival, as well as with rates of future GI bleeding and days spent in the hospital in the first year post implant. We also showed that the HMRS can effectively risk stratify INTERMACS class 1 patients, by identifying individuals with high and low risk of 90-day mortality. These findings confirm the performance of the HMRS as a risk stratification tool for pre-operative assessment of LVAD candidates and suggest that the HMRS may be useful in patient selection, especially among the most critically ill patients. Further work in other cohorts or in larger multicenter databases is needed to confirm our findings and to clarify discrepancies in the performance of the HMRS observed across different centers.

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APPENDIX For supplemental tables and a figure, please see the online version of this article.