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Increasing heart transplant donor pool by liberalization of size matching

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Abstract

BACKGROUND—The heart transplant (HT) guidelines recommendation to match recipient and donors within 30% of body weight lacks a strong evidence base and is not well established in patients bridged to transplant with left ventricular assist devices (LVAD). In light of the scarcity of donor hearts, we investigated the effect of size mismatch on hemodynamics, one-year survival and length of stay (LOS) following HT.

METHODS—Single-center retrospective analysis of consecutive HT patients from April 2007 to September 2017. Recipients were divided into 3 cohorts based on donor-to-recipient weight ratio (DRWR): (1) undersized (<0.7), (2) size-matched, (0.7–1.3); (3) oversized (>1.3).

RESULTS—288 consecutive patients were identified (mean age 53 ± 11 years; 76% male), 46 were undersized (0.61 ± 0.05), 210 size-matched (0.94 ± 0.16), and 32 oversized (1.65 ± 0.38). There was no significant difference in donor left ventricular end diastolic diameter (LVEDD) between the 3 groups ($p = 0.11$). The donor/recipient (D/R) predicted heart mass (PHM) was lowest in the undersized group (0.92 ± 0.13). There were no significant differences in 1-year survival in the overall and LVAD cohort ($p = 0.65$ and 0.59 , respectively). Neither donor LVEDD nor D/R PHM differed among survivors or non-survivors. LOS was longer in the undersized group than the size-matched cohort ($p = 0.004$). The undersized group had hearts with the highest filling pressures and lowest cardiac index at 1 week among the remaining groups ($p = 0.009$, 0.017 , and $p = 0.05$, respectively). There were no clinically significant differences in hemodynamics at 1 or 6 months.

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Disclosure statement

The authors have no conflicts of interest to disclose.

CONCLUSIONS—HT undersizing affects hemodynamics early but not later in the course and does not impact 1-year survival. The liberalization of size matching may increase the HT donor pool significantly.

Keywords

size mismatch; heart transplantation; left ventricular assist devices; mortality

The definitive treatment for end-stage heart failure is heart transplant (HT). However, the shortage of donor organs, paralleled by a decline in organ utilization, highlights the necessity of effective strategies for donor/recipient (D/R) matching.¹ Donor selection criteria remain controversial, and recommendations are mostly based on expert consensus.^{2,3} Current International Society of Heart and Lung Transplantation (ISHLT) guidelines on size matching rely solely on body weight and assume a direct correlation between body weight and heart size. The guideline recommends using donors with a weight within 30% of the recipient weight (20% if female donor/male recipient) unless the organ is from a male donor weighing >70 kg.²

Significant graft undersizing has been linked to higher mortality,³ and donor size and weight mismatch remains a common explanation for declining a donor heart.⁴ However the current system of weight-based heart size matching functions poorly in terms of optimal organ allocation and may preclude the use of adequately sized hearts.^{5–8} Bodyweight and left ventricular size have been shown to be poorly correlated.⁹ Thus, other parameters may provide additional assessment of cardiac size to permit appropriate D/R matching. In particular donor left ventricular end diastolic diameter (LVEDD) and left ventricular wall thickness may prove helpful in selecting donor organs. Furthermore, predicted heart mass (PHM) had been recently introduced as a matching method, and a D/R ratio of 0.86 has been identified as a cut off enabling safe transplantation in hearts graded as undersized per body weight matching algorithms.¹⁰

We aimed to study the impact of donor/recipient size mismatching on post-transplant survival and cardiac hemodynamics.

Methods

Study design

We performed a retrospective chart analysis of consecutive patients undergoing HT at the University of Chicago between April 2007 and September 2017. The University of Chicago Institutional Review Board approved this retrospective chart review. Heart allocation at the University of Chicago incorporates LVEDD matching and does not exclude donor hearts solely based on weight matching criteria. Pre-transplant donor information, including height, weight, and echocardiographic data, were retrieved from the United Network of Organ Sharing (UNOS) DonorNet database. Post-transplant recipient data, including primary graft dysfunction, hemodynamic measurements, length of stay (LOS), and survival were collected from the Electronic Medical Record.

Study groups

Transplant recipients were divided into groups based on donor-to-recipient weight ratio (DRWR): (1) undersized donor heart (<0.7), (2) size-matched (0.7–1.3), and (3) oversized donor heart (>1.3).

PHM was calculated as previously described.¹⁰ $PHM = \text{predicted right ventricular mass} + \text{predicted left ventricular mass}$. Predicted right ventricular mass = $a \times \text{age}^{-0.32} \times \text{height}^{1.135} \times \text{weight}^{0.315}$ ($a = 10.59$ for females and 11.25 for males). Predicted left ventricular mass = $a \times \text{height}^{0.54} \times \text{weight}^{0.61}$ ($a = 6.82$ for females and 8.25 for males).

Outcomes

The primary outcome was one-year survival, and secondary outcomes were the LOS during the index hospitalization and intracardiac hemodynamics at 1 week, 1 month, and 6 months after HT. A subgroup analysis using the same DRWR groups was performed in patients with a left ventricular assist device (LVAD) before HT.

Statistical analysis

Continuous variables were expressed as mean $\pm$ standard deviation and compared using the unpaired *t*-test or Mann–Whitney U-test as appropriate. Categorical variables were compared using the chi-square test or Fisher's exact test as appropriate. To evaluate differences in outcome measures between groups, we used an analysis of variance model and pairwise *t*-tests.

Survival was assessed by Kaplan–Meier analyses and compared by log-rank tests. Cox proportional regression analysis was performed to assess the significance of size mismatch as a risk factor for mortality. Multivariate Cox regression models were constructed accounting for recipient age, recipient history of pulmonary hypertension (mean pulmonary artery pressure >25 mm Hg), and recipient creatinine. All statistical analyses were performed using SPSS Statistics (version 22) software.

Results

Patient characteristics

Two hundred eighty-eight consecutive patients comprised the study cohort. The mean age was 53 ± 11 years, and 76% were males (Table 1). Out of the 288 patients, 58 were bridged to transplantation with LVAD.

Based on DRWR, 46 (16%) patients were in the undersized group (0.61 ± 0.05), 210 (73%) patients were in the size-matched group (0.94 ± 0.16), and 32 (11.1%) patients were in the oversized group (1.65 ± 0.38).

There were no significant differences in demographics, gender mismatch, comorbidities, and laboratory values between the 3 groups.

Donor and recipient size matching

Donor and recipient matching parameters are shown in Table 2. Recipient weight was significantly different between the groups with patients in the undersized group weighing the most (104 ± 21 kg), and patients in the oversized group weighing the least (69 ± 18 kg; $p < 0.001$ for comparison across all 3 groups). Conversely, donor weight was lowest in the undersized group (63 ± 12 kg), and highest in the oversized group (105 ± 23 kg; $p < 0.001$). The mean DRWRs were 0.61 ± 0.05 , 0.94 ± 0.16 and 1.65 ± 0.38 , for the undersized, size-matched and oversized groups respectively ($p < 0.001$).

Recipient height was also significantly different between the groups, with the undersized group having the tallest recipients (175.5 ± 9.5 cm) and the oversized group having the shortest recipients (168.3 ± 12.2 cm; $p = 0.001$).

Donor LVEDD was not different between the groups (4.0 ± 0.5 cm in the undersized group, 4.3 ± 0.6 in the size-matched group and 4.2 ± 0.7 in the oversized group; $p = 0.11$).

PHM and the D/R PHM were significantly different between the groups with the lowest D/R PHM found in the undersized group (0.92 ± 0.13) and the highest D/R PHM in the oversized group (1.35 ± 0.17 , $p < 0.001$). The D/R PHM ratio was < 0.86 in 16 patients in the undersized group, 13 patients in the size-matched group, and no patients in the oversized group.

Survival and length of stay

One-year survival for the overall cohort was 90% (30 of 288 patients died during the first year). In the Kaplan-Meier analysis, there was no difference in 1-year survival between the 3 groups ($p = 0.65$; Figure 1 and Table 3).

In the unadjusted Cox regression model, undersized hearts were not associated with 1-year mortality (hazard ratio [HR], 0.58; 95% confidence interval: 0.18, 1.91; $p = 0.37$). Donor LVEDD was not different among patients who survived the first year after transplantation (4.2 ± 0.6) and patients who did not survive (4.1 ± 0.6 ; $p = 0.52$).

In the overall cohort survival was not different for PHM < 0.86 or ≥ 0.86 with 92% vs 89% one-year survival ($p = 0.63$). PHM was not different between survivors (1.09 ± 0.19) and non-survivors (1.13 ± 0.14 ; $p = 0.39$).

Among the undersized group ($n = 46$), the 16 patients with a PHM < 0.86 had a 100% 1-year survival, which was not statistically different from the 30 patients with a PHM ≥ 0.86 (90% 1-year survival; $p = 0.3$).

LOS was longer in the undersized group (22 days; 95% confidence interval: 14, 34) than the size-matched cohort (18 days; 95% confidence interval: 14, 26; $p = 0.004$; Table 3).

When stratified for recipient pulmonary hypertension, bridge to transplantation (BTT) with LVAD, ischemic time > 240 minutes and gender mismatch, there were no significant differences in LOS and 1-year survival (Table 4). The only detected difference was among

the oversized group in LOS between recipients with prior LVAD and no prior LVAD; this, however, is likely caused by an outlier in LOS of 131 days.

Hemodynamics

Hemodynamic measurements at 1 week, 1 month, and 6 months following HT are shown in Table 5. Central venous pressure (CVP) and pulmonary capillary wedge pressure (PCWP) were higher in the undersized group as compared with the size-matched group at 1 week ($p = 0.009$ and $p = 0.017$, respectively). There were no differences in CVP or PCWP at 1 month. At 6 months, CVP was 6 ± 4 mm Hg in the undersized group as compared with 5 ± 4 mm Hg in the size-matched group, a statistically significant difference ($p = 0.026$) without much clinical relevance. Likewise, Fick cardiac index (CI) was lower in the undersized group at 1 week (2.69 ± 0.54 liter/min/m² vs. 3.01 ± 0.83 liter/min/m²; $p = 0.05$), but was statistically comparable at 1 month and 6 months ($p = 0.82$ and $p = 0.91$, respectively).

LVAD patients

Fifty-eight patients (20.1%) were bridged to transplant with an LVAD. In this subgroup, 8 (13.8 %) patients were in the undersized group, 47 (82.4%) patients were in the size-matched group, and 3 patients were in the oversized group. One-year survival for LVAD patients was similar between the 3 groups ($p = 0.59$; Figure 2). No differences were seen between CVP, PCWP or CI at any of the time points in the LVAD subgroup ($p > 0.05$ for all; Table 6).

Discussion

In the current study, we evaluated the effect of D/R heart size matching on survival and hemodynamics. Our main findings are as follows: (1) Recipients of donor hearts that are undersized according to DRWR have a statistically comparable outcome to recipients of size-matched or oversized hearts. (2) Recipients of donor hearts that are undersized according to DRWR have higher intracardiac filling pressures and lower CI early after transplantation, but the hemodynamic differences resolve with longer follow-up. (3) The subgroup of patients who had LVAD support also did not have any difference in survival based on DRWR.

LOS was longer for the undersized group than the size-matched group during the index hospitalization, which reflects the increased complexity of managing undersized donor hearts and is likely because of a need for more diuresis in the undersized group. Donor shortage remains one of the leading limitations to expanding the utilization of heart transplantation for more advanced heart failure patients. Recent changes in the organ allocation system addressed the growing need for donors' hearts.¹¹ In the US, the opioid epidemic¹² and the acceptance of hepatitis-C positive donors^{13–15} have expanded the donor pool, while the use of donation after circulatory death hearts have had a similar effect in Europe and Australia.^{11,16,17} However, selection criteria remain controversial, and recommendations are mostly based on expert consensus.^{2,3} Current ISHLT guidelines recommend a donor within 30% of the recipient weight (20% if female donor/male recipient)² and significant bodyweight undersizing has been linked to higher post-transplant

mortality.³ To date, several reports on size matching using bodyweight found an adverse outcome with undersizing.^{5,18–20} However the actual correlation between body size and LVEDD in the adult population remains controversial.⁹

Patel et al., using data from the UNOS registry (1999–2007, total of 15,284 HT recipients; 2,078 categorized as undersized), showed that donor heart undersizing (weight ratio < 0.8) was associated with higher mortality in recipients with elevated pulmonary vascular resistance (pulmonary vascular resistance [PVR] > 4 Wood Units; $p = 0.04$). However, the significance of this finding is limited since transplanting patients with high PVR > 4 Wood Units is associated with higher mortality per se and elevated PVR unresponsive to medical therapy is a relative contraindication to transplantation.²¹

Though there was no absolute difference in survival between the bodyweight matching groups and weight ratio < 0.8 did not predict 5-year mortality after heart transplantation.⁶

A subsequent larger study from the same registry (21,928 patients from 1999–2011) found that donor undersizing, here defined using a weight ratio of < 0.6, only affected mortality in transplants with a female donor and male recipient.²⁰ Thus, both large UNOS registry studies did not identify increased mortality using undersized donor hearts in the overall population.^{6,20}

More recently, a study from the ISHLT registry (1994–2013; 52,455 patients) found that donor heart undersizing (weight ratio < 0.7) was associated with a modest increase in 30-day (12%; odds ratio = 1.89; $p < 0.001$) and overall mortality (1 year: 21%; 5 years: 34%; hazard ratio = 1.27; $p < 0.001$). For the overall study group of non-obese recipients, mortality was 7% at 30 days, 15% at 1 year and 27% at 5 years. Interestingly in the overall cohort recipients with a body mass index [BMI] > 30 has increased mortality but there was no difference in mortality with undersizing, suggesting that size-matching guidelines may be less relevant in the obese population.¹⁸

Body size is a crude method of determining appropriate matching between potential donors and recipients. As a result, many adequate donor organs may go unused. Recently, different approaches to size matching have been proposed. Reed et al. showed that the formula for PHM was more useful in stratifying outcomes than body weight.^{3,5}

This finding was recently confirmed in a UNOS registry analysis consisting of 19,168 transplant recipients between 2007 and 2016.¹⁰ Patients with PHM < 0.86 had increased 1-year-mortality (HR, 1.34; 95% confidence interval: 1.13, 1.59; $p < 0.001$). However, similar to our analysis, conventional measures of donor and recipient matching, such as body weight, height, BMI, and BSA, did not predict mortality.

In our analysis, the average D/R PHM in the undersized group was above 0.86, and the 16 patients with a ratio < 0.86 did not have worse survival (100% at 1 year as compared with 90% for the cohort as a whole). Furthermore, PHM was not different between survivors and non-survivors among the entire cohort. We did not find an increase in mortality in undersized patients who also had a PHM < 0.86, although the small number of patients in this cohort may have limited our ability to detect an actual difference between these groups.

Furthermore, the lack of difference in PHM between the DRWR groups might be a result of our matching algorithm including LVEDD and LPWD and thus assuring adequate heart mass, which is reflected in our finding of an average PHM in the undersized group of 0.92 ± 0.13 and demonstrates the benefits of a matching algorithm exceeding sole bodyweight. Thus, even in our undersized group adequate heart mass has been assured consistent with the recently defined PHM value of >0.86 .¹⁰

In addition, it has previously been hypothesized that undersized hearts can increase myocardial mass over time to adapting to the new hemodynamic environment.^{8,10,22}

These results demonstrate that using body size measures alone are insufficient for optimal organ matching.

PHM is an attractive parameter to achieve better matching since it incorporates important factors: gender, age, height, and weight of D/R. However it uses an extrapolated value rather than direct heart size and is not readily available.¹⁰ We used donor LVEDD as an adjunct variable to achieve optimal donor and recipient matching. A significant advantage of LVEDD is its ready availability and ease of use. The use of LVEDD as a matching tool in transplantation has been described in pediatric heart transplantation, but no reports have evaluated its usefulness in the adult population.²³ Importantly, donor LVEDD was the same across all 3 groups in our study and did not differ among survivors and non-survivors. However, when incorporating LVEDD in decision making for donor matching, the most critical component is to avoid hearts with excessively large LVEDDs that can jeopardize chest closure—this is especially important in patients undergoing repeat sternotomy.

Size matching may take on increased importance in LVAD patients because of a more challenging operation with re-sternotomy. A previous study showed significantly lower graft survival after LVAD explant when the donor-to-recipient BMI ratio was <0.8 compared with a ratio of $>1.2 \text{ kg/m}^2$.¹⁹ In our analysis, we did not see any increase in one-year mortality in the subgroup of patients bridged to transplant with LVAD. However, our analysis for the LVAD subgroup is limited by the small sample size of only 11 size-mismatched patients. Nevertheless, BTT is a unique patient population, and our data should be followed up with more extensive studies investigating D/R size matching.

Also, in the non-LVAD population transplanting an undersized heart does impose surgical challenges. Our surgeons use stay stitches to prevent vessel twitching with more considerable distances on bigger vessels and shorter distances on smaller vessels allowing for safe stretching of the smaller caliber vessel. Furthermore in case of ample empty pleural space, the pleura is taken down and collapsed on the pericardium to allow for lung expansion.

Gender Mismatch and compound risk

It is widely accepted that female to male transplantation does bear a higher risk for adverse outcomes^{24,25} Interestingly, Bergenfeldt et al., however, reported increased cumulative mortality for both gender-mismatched transplants compared with gender-matched transplants. Importantly this relationship was not modified by BMI or weight mismatch

questioning the sole role of size mismatch.¹⁸ It, however, remains controversial if this is a sole consequence of heart size mismatch since it has been suggested that females have less heart mass per kilogram of body weight compared with males or if additional immunologic factors play a role.⁵

In our study, we had an inadequate number of such transplants (total of 22) to draw significant conclusions about the effect of gender-mismatched transplants fully.

However beyond the consideration of gender mismatch when using undersized hearts, the concern is for potential adverse outcomes with additive factors such as long ischemic time and recipient pulmonary hypertension, known risk factors of adverse outcome and primary graft failure.^{21,26,27} Resternotomy and LVAD explant further complicate graft implantation. In our analysis, however we did not find an effect on LOS during the index hospitalization and 1-year survival when stratified for long ischemic time and recipient pulmonary hypertension. Also, the case of gender mismatch (combined female-male and male-female) and BTT with LVAD did not affect both outcomes, however as previously stated the absolute numbers of gender mismatch and BTT per subgroup are likely underpowered to draw meaningful conclusion for the analysis of compound risk. In general, when considering use of an undersized donor heart per DRWR careful evaluation is crucial especially in the setting of compound risk including expected long ischemic time, gender mismatch, recipient PH, and BTT LVAD candidates. Our institution's approach to D/R matching including considerations for undersized donor hearts is detailed below.

University of Chicago size matching transplant algorithm

Our single-center experience did not show inferior outcomes when using undersized donor hearts, in contrast to the extensive registry analyses that have shown increased mortality associated with undersizing. The importance of our study is to demonstrate the potential to achieve excellent outcomes despite undersizing when these hearts are accepted in a protocolized manner, and meticulous attention is paid to both surgical and medical management. We hope that this report will encourage other centers to consider the use of undersized hearts in a selective manner, which may increase overall organ utilization. However, it is essential to emphasize that widespread use of undersized hearts without incorporating additional donor and recipient factors will likely lead to increased mortality.

In general, we incorporate in our institutional matching algorithm several concepts of transplant size matching, which are outlined in Figure 3. The algorithm is intended to describe how our institution determines when undersized or oversized hearts can be accepted. This size-matching algorithm is incorporated into an overall assessment of the donor hearts, which also evaluates multiple additional features including donor age, donor heart function, ischemic time and donor/recipient comorbidities.

For size matching, we use age, gender, and heart size as the best reflections of left ventricular mass. Age and gender are incorporated by the newly introduced parameter of PHM, which we will include in our algorithm in the future. The introduced value of 0.86, allowing for safe transplantation in case of bodyweight undersizing is especially relevant.

When choosing a donor undersized per body weight definition, we adjust by incorporating 2 additional factors: a donor LVEDD of at least 4 cm and left posterior ventricular wall >0.9 cm but <1.2 cm. Avoiding smaller donor LVEDD is especially important in patients bridged with LVAD and in female to male gender mismatch transplantation. In contrast, as stated when transplanting oversized hearts per DRWR, it is crucial to avoid donor hearts with a large LVEDD to avoid restrictive physiology and difficult chest wall closure. For all hearts, we try to avoid prolonged ischemic times but do not apply separate ischemic time criteria to hearts based on size matching.

Size matching and hemodynamics

Previous studies have not addressed the impact of weight-based size mismatching on post-transplant hemodynamics. Early after transplant, hearts are typically stiff and can have restrictive hemodynamics with a greater dependence on heart rate to maintain cardiac output.^{5,28} This problem may be exacerbated in undersized hearts with smaller stroke volumes and has been proposed as one of the mechanisms by which undersized donor hearts develop graft dysfunction and result in mortality. In this study, we confirm that undersized donor hearts have mildly worse hemodynamics one week after transplant. Importantly, these abnormalities resolved within a month. A previous study showed that undersized hearts increased in left ventricular mass and diameter over 10 weeks, suggesting that undersized transplanted hearts adapt appropriately to their new hemodynamic burden.⁸

Reed et al. implied that this adaption actually represents pathological hypertrophy since it is not associated with exercise and thus might in itself be the cause of adverse outcomes.⁵ However we believe that hypertrophy as a response to higher circulatory needs of a larger recipient body is indeed comparable to hypertrophy seen in athletes and represents a physiological adaptive process.

Limitations

Our study is a single-center analysis with limitations related to retrospective data collection. However, the UNOS DonorNet Database is prospectively maintained, increasing the accuracy of the data abstracted for our study. The study covered 10 years, during which time post-transplant management protocols have changed significantly. Because of a small number of deaths, we cannot analyze factors related to survival within each subgroup. The LVAD subgroup is underpowered to detect differences among the size match groups.

Conclusions

The current policy of matching HT donors and recipients based on weight may lead to the underutilization of donor organs. We did not find an effect on outcomes with the use of undersized donors in our cohort and believed that other approaches to match patients, such as LVEDD or PHM, may allow programs to expand their donor pool. Further prospective studies are needed to confirm the benefits of matching PHM and LVEDD when performing donor selection.

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Figure 1.

Analyzed for bodyweight matching there were no significant differences in 1-year survival between the groups. One-year survival was 88% for in range, 89% for oversize and 94% for undersized hearts ($p = 0.65$).

Figure 2.
As seen in the overall cohort, there were no significant differences in survival for bodyweight matching in the subgroup analysis of left-ventricular-assist-devices bridging.

Figure 3.

University of Chicago Transplant Size Matching Algorithm as part of an overall assessment of the donor's heart. Our size matching starts with bodyweight matching. In case of an undersized donor per body weight definition we adjust by incorporating 2 additional factors: a donor left ventricular end diastolic diameter (LVEDD) of at least 4 cm and left posterior ventricular wall >0.9 cm but <1.2 cm. Especially in left-ventricular-assist-devices patients and female-male gender mismatch smaller donor LVEDDs should be avoided. In case of oversized hearts, it is essential to avoid donor hearts with a large LVEDD to avoid restrictive physiology and difficult chest wall closure. DRWR, donor-to-recipient weight ratio; LVEDD, left ventricular end diastolic diameter; PHM, predicted heart mass; LVPW, left ventricular posterior wall.

Table 1
Baseline Characteristics

	Undersize (n = 46)	Size matched (n = 210)	Oversize (n = 32)	p-value
Recipient Age, years $\pm$ SD	51.9 $\pm$ 11.5	52.7 $\pm$ 12.5	54.4 $\pm$ 14.0	0.68
Recipient male, n (%)	32 (69.6)	166 (79)	22 (68.8)	0.22
Donor Age, years $\pm$ SD	30.7 $\pm$ 8.9	32.2 $\pm$ 10.9	35.7 $\pm$ 11.9	0.12
Donor male, n (%)	31 (69)	160 (76.2)	18 (56.3)	0.07
Gender mismatch, n (%)	4 (8.59)	14 (6.7)	4 (12.5)	0.49
Female donor, n (%)	1 (2.2)	4 (1.9)	0 (0)	0.48
Male donor, n (%)	3 (6.5)	10 (4.8)	4 (12.5)	0.48
Prior sternotomy, n (%)	23 (50)	98 (47)	10 (31.3)	0.21
Prior LVAD implantation, n (%)	9 (19.5)	50 (23.8)	4 (12.5)	0.33
Recipient total bilirubin, mg/dl $\pm$ SD	0.7 $\pm$ 0.5	0.9 $\pm$ 0.8	0.7 $\pm$ 0.4	0.20
Recipient creatinine, mg/dl $\pm$ SD	1.8 $\pm$ 2.0	1.5 $\pm$ 1.0	1.3 $\pm$ 0.6	0.17
Recipient PH, n (%)	26 (56.5)	136 (64.8)	22 (68.75)	0.71
Recipient DM, n (%)	15 (32.6)	46 (21.9)	8 (25)	0.30
Ischemic Time > 240 min (%)	48	32	46	0.08

DM, diabetes mellitus; LVAD, left ventricular assist device; PH, pulmonary hypertension; SD, standard deviation.

Table 2

Size Matching Parameters

	<i>p</i> -value				
	Undersize (n = 46)	Size matched (n = 210)	Oversize (n = 32)	Overall	Undersize vs size matched
Recipient weight, kg	104 ± 21	86 ± 17	69 ± 18	<0.001	<0.001
Donor weight, kg	63 ± 12	80 ± 16	105 ± 23	<0.001	<0.001
<i>D/R weight</i>	0.61 ± 0.05	0.94 ± 0.16	1.65 ± 0.38	<0.001	<0.001
Recipient height, cm	175.5 ± 9.5	174.6 ± 8.9	168.3 ± 12.2	0.001	0.001
Donor height, cm	164.3 ± 11.8	171.6 ± 9.0	169.9 ± 15.7	0.087	0.83
<i>D/R height</i>	0.95 ± 0.07	0.99 ± 0.07	1.02 ± 0.10	<0.001	0.004
Recipient LVEDD	7.0 ± 1.3	7.0 ± 1.3	6.4 ± 1.5	0.083	
Donor LVEDD	4.0 ± 0.5	4.3 ± 0.6	4.2 ± 0.7	0.11	0.089
Recipient PHM	6671 ± 956	6405 ± 870	5644 ± 811	<0.001	0.15
Donor PHM	6102 ± 1001	6971 ± 1065	7582 ± 1320	<0.001	<0.001
D/R PHM	0.92 ± 0.13	1.10 ± 0.15	1.35 ± 0.17	<0.001	<0.001

D/R, donor/recipient; LVEDD, left ventricular end diastolic diameter; PHM-predicted heart mass.

All values are expressed as mean ± standard deviation.

Table 3

One-Year- Survival and Length of Stay

		<i>p</i> -value		
	Undersize (n = 46)	Size matched (n = 210)	Oversize (n = 32)	Overall
LOS, days (95% CI)	22 (14, 34)	18 (14, 26)	22 (15, 31)	0.004
1-year survival, %	94	88	89	0.65
				Size matched vs oversized
				0.043

CI, confidence interval; LOS, length of stay.

Table 4

Compounded Risk of IT, PH, and LVAD

		Undersized (n = 46)			Size matched (n = 210)			Oversized (n = 32)		
		IT >240	IT <240	p	IT >240	IT <240	p	IT >240	IT <240	p
LOS, days (95% CI)		22 (15, 30)	22 (14, 33)	0.74	18 (14, 29)	18 (14, 25)	0.79	22 (16, 31)	22 (14, 31)	0.88
1-year survival, %		89	95	0.49	90	88	0.47	85	93	0.46
		PH	No PH	p	PH	No PH	p	PH	No PH	p
LOS, day (95% CI)		22 (15, 34)	23 (14, 35)	0.99	18 (14, 25)	17 (13, 28)	0.81	21 (15, 29)	24 (18, 70)	0.17
1-year survival, %		92	95	0.71	89	89	0.58	91	80	0.39
		LVAD	No LVAD	p	LVAD	No LVAD	p	LVAD	No LVAD	p
LOS, days (95% CI)		25 (20, 72)	22 (14, 34)	0.28	18 (14, 29)	17 (13, 25)	0.34	59 (33, 131)	21 (15, 25)	0.003*
1-year survival, %		89	95	0.53	92	88	0.32	75	89	0.42
		GM	No GM	p	GM	No GM	p	GM	No GM	p
LOS, day (95% CI)		30 (23, 76)	22 (14, 52)	0.091	16 (19, 24)	18 (13, 34)	0.62	18 (14, 22)	23 (15, 31)	0.22
1-year survival, %		100	93	0.58	100	88	0.17	100	86	0.42

CI, confidence interval; GM, gender mismatch; IT, ischemic time; LOS, length of stay; LVAD, left ventricular assist device; PH, pulmonary hypertension.

Table 5

Hemodynamics

	Undersize (n = 46)	Size matched (n = 210)	Oversize (n = 32)	p-value		
				Overall	Undersize vs size matched	Size matched vs oversized
1 week						
CVP mm Hg	10 ± 4	7 ± 5	6 ± 4	0.002	0.009	0.31
PCWP mm Hg	17 ± 6	15 ± 6	13 ± 4	0.003	0.017	0.26
CI l/min/m ²	2.69 ± 0.54	3.01 ± 0.83	3.29 ± 0.78	0.007	0.052	0.18
1 month						
CVP mm Hg	8 ± 5	6 ± 4	8 ± 6	0.11		
PCWP mm Hg	17 ± 7	15 ± 7	21 ± 12	0.006	0.18	0.012
CI l/min/m ²	3.49 ± 1.43	3.64 ± 1.30	4.85 ± 2.12	0.001	0.82	0.001
6 months						
CVP mm Hg	6 ± 4	5 ± 4	5 ± 4	0.035	0.026	0.98
PCWP mm Hg	13 ± 6	11 ± 6	11 ± 5	0.36		
CI liter/min/m ²	3.01 ± 0.49	2.97 ± 0.53	3.27 ± 0.79	0.048	0.91	0.036

CI, cardiac index; CVP, central venous pressure; PCWP, pulmonary capillary wedge pressure.

All values are expressed as mean ± standard deviation.

Table 6**Hemodynamics LVAD Cohort**

	Undersize (n = 8)	Size matched (n = 47)	Oversize (n = 3)	p-value(undersize vs size matched)
1 week				
CVP mm Hg	9 ± 3	8 ± 4	6 ± 1	0.92
PCWP mm Hg	15 ± 4	15 ± 6	13 ± 1	0.99
CI l/min/m ²	2.49 ± 0.39	2.74 ± 0.44	3.36 ± 0.99	0.29
1 month				
CVP mm Hg	9 ± 5	9 ± 6	13 ± 10	0.90
PCWP mm Hg	19 ± 8	16 ± 7	26 ± 15	0.52
CI l/min/m ²	3.36 ± 1.10	3.25 ± 0.77	6.61 ± 3.18	0.96
6 months				
CVP mm Hg	8 ± 4	6 ± 4	9 ± 1	0.45
PCWP mm Hg	13 ± 4	12 ± 7	15 ± 1	0.83
CI l/min/m ²	2.93 ± 0.53	2.83 ± 0.46	2.86 ± 0.46	0.87

CI, cardiac index; CVP, central venous pressure; PCWP, pulmonary capillary wedge pressure.

All values are expressed as mean ± standard deviation.