Donor Predictors of Allograft Utilization and Recipient Outcomes after Heart Transplantation

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Abstract

Background—Despite a national organ donor shortage and a growing population of patients with end-stage heart disease, the acceptance rate of donor hearts for transplantation is low. We sought to identify donor predictors of allograft non-utilization, and to determine whether these predictors are in fact associated with adverse recipient post-transplant outcomes.

Methods and Results—We studied a cohort of 1,872 potential organ donors managed by the California Transplant Donor Network from 2001–2008. Forty five percent of available allografts were accepted for heart transplantation. Donor predictors of allograft non-utilization included age>50 years, female sex, death due to cerebrovascular accident, hypertension, diabetes, a positive troponin assay, left ventricular dysfunction and regional wall motion abnormalities, and left ventricular hypertrophy. For hearts that were transplanted, only donor cause of death was associated with prolonged recipient hospitalization post-transplant, and only donor diabetes was predictive of increased recipient mortality.

Conclusions—While there are many donor predictors of allograft discard in the current era, these characteristics appear to have little effect on recipient outcomes when the hearts are transplanted. Our results suggest that more liberal use of cardiac allografts with relative contraindications may be warranted.

Keywords

Organ donor; Heart transplantation; Transplant recipients; Transplant outcomes

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INTRODUCTION

Despite the availability of successful medical therapies for end-stage heart failure, and now of mechanical circulatory support,[1] heart transplantation remains the best option for appropriate candidates with end-stage heart disease.[2] The severe and persistent shortage of donor organs, however, considerably limits the availability of heart transplantation. While it is estimated that more than 20,000 patients could benefit from this life-saving procedure each year,[3] only 1,853 heart transplants were performed in the United States in 2009, with a concurrent waiting list mortality of 13.7% (OPTN/SRTR Annual Data Report 2010). These alarming statistics have motivated the search for ways to increase the size of the donor pool and the use of available organs.[4]

In 2003, Sheehy et al estimated the annual number of brain-dead potential organ donors in the United States to be between 10,500 and 13,800; of these potential donors, only 42% donated one or more organs for transplantation.[5] While public health efforts to increase donor identification and consent rates address a major limiting factor in donor availability, the transplant community must also focus on ways to increase the utilization of suitable grafts from available donors. At this time, approximately 60% of currently available cardiac allografts are discarded due to stringent acceptance criteria that have not been rigorously tested in clinical and research settings. In fact, single-center experience using marginal or high-risk donor hearts for transplantation has demonstrated excellent clinical results.[6–9]

Given the discrepancy between the pressing need for donor organs and the low utilization rate of available grafts, we sought to identify current predictors of cardiac allograft non-utilization, and to determine whether these predictors are in fact associated with adverse recipient outcomes.

METHODS

Subjects

We studied a contemporary cohort of 1,872 organ donors between the ages of 14 and 69 years who were managed by the California Transplant Donor Network (CTDN, Oakland, CA) from 2001–2008. This age range was chosen for study based on the observation that allografts from donors less than 14 and greater than 69 years of age were not accepted for transplantation into adult recipients during this time period. CTDN is the largest organ procurement agency in Northern California and supplies donor organs mainly to transplant centers in northern and central California, and occasionally to neighboring regions. Potential brain dead organ donors were identified by treating physicians at hospitals throughout the region, and consent for organ donation was obtained from family members or next-of-kin. Management of the organ donor was subsequently assumed by CTDN staff, and consent was obtained from the donor's family to collect patient data and biological samples. This study was approved by CTDN and by the Stanford University Institutional Review Board.

Donor Management

During the eight year time period studied, all brain dead organ donors at CTDN were managed according to a standardized protocol that included: methylprednisolone administered at the onset of donor management and until organ procurement (15mg/kg every 12 hours); dopamine as the first-line inotropic agent (maximum 20 mcg/kg/min); phenylephrine as the second-line vasoactive agent (maximum 300 mcg/min); intravenous fluid and/or loop diuretic administration to obtain a goal central venous pressure of 5–8 mmHg and a urine output of > 30ml/hour; electrolyte repletion to achieve normalization of potassium, phosphorous, magnesium and calcium levels; empiric antimicrobial therapy with vancomycin and levofloxacin; and inhaled, nebulized albuterol (2.5 mg every four hours).

Vasoactive and inotropic medications were titrated according to pulmonary artery catheter readings to achieve a target systemic vascular resistance of 800–1200 dynes-seconds/cm^5 and cardiac index >2 l/min/m^2. Esmolol infusions were initiated for tachycardia that was deemed unrelated to beta-agonist infusion and were discontinued upon initiation of organ procurement. Thyroid hormone (levothyroxine) was administered when requested by the accepting transplant centers.

Clinical Data

Upon assumption of donor management, comprehensive data on donor-level variables were recorded by CTDN staff in a standardized fashion, including demographic variables, cause of death, health-related behaviors, and past medical history. Data on comprehensive laboratory testing were also recorded, including serologies; hematologic, hepatic, and renal function indices; and cardiac enzyme assays. Standard testing for potential donors who were not immediately ruled-out for cardiac graft donation (due to known coronary artery disease treated with percutaneous stents or bypass surgery, prior cardiac valve surgery, lack of consent for donation, or coroner exclusion) included an electrocardiogram; one or more echocardiograms; and a coronary angiogram for male donors over 40 years and female donors over 45 years. All cardiac testing was performed and interpreted at the donor hospital and results were recorded by CTDN personnel. Data on vital signs, invasive hemodynamics, and medications were also recorded.

Donor data were extracted from the medical records and were entered into the research study database by study personnel. A subsequent quality-assessment review of 5% of the medical records was performed, reviewing 177 fields per donor chart, and demonstrated >95% accuracy of data collection.

Allograft Utilization—All donor hearts transplanted in the United States were considered "utilized" and followed for recipient outcomes. Data on heart transplant recipient characteristics and post-transplant outcomes were obtained from the United Network for Organ Sharing (UNOS) provided by way of Standard Transplant Analysis and Research (STAR) files. Any hearts that were part of a multi-organ transplant were excluded from further follow up.

Donor Predictors of Cardiac Allograft Non-Utilization—Eleven donor "risk factors" for allograft non-utilization were selected *a priori*, based on prior literature. These included (1) donor age>50 years,[2, 10–12] (2) female sex,[13–17] (3) cerebrovascular accident/stroke as the cause of death,[12, 18–20] (4) hypertension,[11, 12] (5) diabetes,[10, 11] (6) history of cocaine or methamphetamine use,[21–23] (7) high inotrope requirement (dopamine>10 mcg/kg/min) during donor management,[10–12, 24] (8) cardiac troponin I >1.0 mcg/L,[25–27] (9) left ventricular dysfunction (defined as left ventricular ejection fraction<50%),[12, 28] (10) left ventricular regional wall motion abnormalities,[10] and (11) left ventricular hypertrophy (defined as septal or posterior wall thickness>1.1 cm).[6, 12, 29, 30] A cut-off of 1.0 mcg/L was used to define an elevated troponin level based on the knowledge that donor hospitals used a variety of assays from multiple manufacturers to perform this test, and reference values for a positive troponin level varied from 0.04–1.0 mcg/L depending on the specific assay used. We therefore selected the upper boundary to ensure specificity in capturing abnormal troponin values, albeit with a recognized loss of sensitivity.

Recipient Outcomes—Based on the assumption that donor characteristics would preferentially influence short-term post-transplant outcomes (rather than long-term outcomes such as overall survival), we examined the following three recipient outcomes: delayed hospital discharge (hospital discharge after 21 days post-transplant), 30-day graft

survival, and 1-year graft survival. A cut-off of 21 days for recipient post-transplant hospitalization was chosen prior to data analysis based on the authors' clinical experience. Recipients were classified as having a length of stay less than 21 days if they were discharged within 21 days after the heart transplant procedure and did not die (or were not retransplanted) prior to discharge. Graft failure was defined as death or retransplantation within the specified time period.

Recipient covariates included age, sex, etiology of heart disease, serum creatinine and total bilirubin at transplant, presence of diabetes, most recent panel of reactive antibodies, pulmonary artery systolic pressure, use of inotropic support, medical condition at time of transplantation, wait list priority status (1A, 1B, or 2), requirement for mechanical ventilation, and allograft cold ischemic time.

Statistical Analysis

Allograft Utilization—Time trends of rates of graft utilization and prevalence of donor risk factors were calculated. Odds ratios were calculated to study associations between these eleven donor risk factors and cardiac allograft non-utilization.

An allograft utilization score was then derived using all available donor predictors in our research database. These included demographic factors (race, weight, height), clinical factors (use of cardiopulmonary resuscitation, history of coronary artery disease, diabetes, hypertension), laboratory values (hemoglobin, creatinine), hemodynamics (heart rate, central venous pressure, systolic and diastolic blood pressure), use of vasoactive medications (phenylephrine, norepinephrine, and esmolol), and hormonal therapy (corticosteroids and levothyroxine). To combine these donor characteristics into a single utilization score, the predicted probability of allograft utilization was calculated. To predict allograft utilization we used the Random Forest algorithm[31]—a robust extension of decision trees that has been used extensively in other biomedical studies. Two notable features of the Random Forest model are that it can handle missing values and it validates internally, alleviating the need for cross-validation. To compare the utility of these scores in predicting actual allograft utilization, ROC curves and the associated c-statistics were calculated.

Recipient Outcomes—Logistic regression models were used to examine associations between donor predictors and recipient outcomes. We first examined the 11 donor risk factors identified *a priori*, and then assessed the relationship between the total number of donor risk factors present and recipient outcomes. To examine the *utilization choice* hearts were dichotomized based on the predicted probability of utilization (<50% vs >50%) from the Random Forest scores and were then compared. Finally, Random Forest models were then generated for the three recipient outcomes of interest, using all available donor predictors. All reported p-values are two-tailed. Analyses were performed using R version 2.15 with the Random Forest package

RESULTS

From 2001–2008, 1,872 potential organ donors were managed by CTDN. Allografts from 808 (43%) of these donors were accepted for heart transplantation. Demographic characteristics of the donors whose hearts were and were not transplanted are presented in Table 1. Donors whose hearts were not accepted for transplantation were more likely to be older, female, and had cerebrovascular accident/stroke as a cause of death. These donors had a higher incidence of smoking, hypertension, diabetes, and coronary artery disease, and were more likely to have a positive cardiac troponin assay. These donors had a slightly higher dopamine requirement during the donor management period and were less likely to have received corticosteroids and thyroxine supplementation. Finally, non-utilized grafts were

less likely to have had an echocardiogram, had a lower mean left ventricular ejection fraction and a higher incidence of left ventricular regional wall motion abnormalities and left ventricular hypertrophy. These results confirmed our initial assumption that the donor "risk factors" selected *a priori* for analytic purposes were significant predictors of cardiac allograft non-utilization, except for high donor dopamine requirement (>10 mcg/kg/min) during the donor management period and donor history of cocaine or methamphetamine use.

During the study period, cardiac allograft utilization decreased by an average of 4.2% per year (95% CI 1.9%–6.4%), from a high of 56% utilization in 2002 to a low of 37% utilization in 2007. This decrease in utilization was independent of changes in donor risk factors with a 4.3% (2.3%–6.3%) annual decrease in allograft acceptance for transplantation after adjusting for other covariates. Of the 11 pre-identified donor risk factors, only the incidence of diabetes increased during this time period (p<0.0054). In fact, the following donor risk factors decreased in incidence: donor age>50 years (p<0.03), death due to cerebrovascular accident (p<0.0004), and high dopamine requirement (p<1×10^{-8}).

We then studied associations between the eleven donor risk factors selected *a priori* and cardiac allograft acceptance for transplantation. Figure 1 demonstrates the distribution of these donor risk factors in grafts that were and were not accepted. All of the risk factors were highly associated with allograft utilization (p<0.001) except for the amount of dopamine administered during donor management and donor history of cocaine or methamphetamine use. The total number of donor risk factors was also strongly associated with allograft utilization (p< 1×10^{-8}) with accepted grafts having a median of 2 (IQR 1, 3) risk factors and discarded grafts having a median of 3 (IQR 2, 5) risk factors.

Finally, all available donor variables were used to predict allograft utilization using the Random Forest algorithm. A total of 59 covariates were used and 2000 trees were grown. The most important predictors in the Random Forest models were donor age, cause of death, left ventricular ejection fraction, and history of hypertension. The Random Forest model demonstrated excellent predictive ability with an overall c-statistic of 0.86.

Donor Predictors of Recipient Outcomes

Recipient outcomes data were available for 806 of the 808 cardiac allografts accepted for transplantation. Of the recipients, 29 were excluded from analysis as they had received multi-organ transplants. Table 2 demonstrates recipient characteristics at the time of transplantation, stratified by those who received an allograft with greater than 50% probability of acceptance, based on the Random Forest predictions. Not surprisingly, 64% of the allografts were those that had a greater than 50% probability of utilization. The recipients who received the "less desirable" grafts were more likely to be female, had better clinical status and were less likely to be on life support; no other significant clinical differences were identified.

The primary outcomes examined were time to hospital discharge and recipient 30-day and 1-year survival. Overall, the outcomes were generally positive and consistent with national heart transplant statistics[2] with 75% of recipients discharged within 21 days, and only 3.9% and 11.4% dying within 30 days and one year, respectively. Kaplan-Meier curves stratified by the probability of graft acceptance (based on the Random Forest predictions) are presented in Figure 2. Overall, recipients of allografts that were more likely to be accepted were discharged earlier from the hospital (log rank p<0.035). However, there was minimal difference in overall survival (p=0.067).

Associations between the eleven donor risk factors identified *a priori*, and the recipient outcomes of interest were then examined and the odds ratios are presented in Table 3. While

most donor risk factors appeared associated with prolonged hospital stay post-transplant, only CVA/stroke as the donor cause of death was marginally significantly associated [OR 1.41 (95% CI 1.00, 2.00)] with prolonged recipient hospitalization. Similarly, while many donor risk factors appeared to increase recipient risk of death, left ventricular hypertrophy and history of diabetes were the only donor characteristics significantly associated with recipient 30-day and 1-year mortality. After adjustment for recipient characteristics, diabetes remained the only donor predictor of recipient mortality [OR 3.58 (95% CI 1.18–10.84) for 1-year mortality]. A notable finding was that the presence of multiple donor risk factors did not increase the occurrence of adverse recipient outcomes (Figure 3).

Finally, we used all of the available donor characteristics to predict the three outcomes of interest using Random Forest models. The ROC curves, along with the ROC curve for allograft utilization, are shown in Figure 4. While the donor characteristics were highly predictive of graft utilization, those same characteristics were not predictive of recipient outcomes.

DISCUSSION

National transplant data collected by the Association of Organ Procurement Organizations (www.aopo.org, accessed June 21, 2012) reveals a cardiac allograft utilization rate (number of hearts accepted for transplantation/total number of donors) of 28.2%-30.1% from 2009–2011. Many reasons exist for discarding donor hearts, including older donor age, small size, co-morbidities, logistical issues, left ventricular hypertrophy, and donor left ventricular dysfunction. Unfortunately, the current criteria for acceptance of donor hearts are poorly standardized and are often based on retrospective single-center studies and anecdotal experience. Indeed, large registry analyses have shown that very few donor characteristics have significant impact on recipient outcomes,[32, 33] suggesting that recipient factors figure more prominently toward the risk of death after heart transplantation.

Our aim in conducting this study was to closely examine current practices with respect to cardiac allograft acceptance in a contemporary cohort of potential organ donors. During the eight year time period examined, we found that utilization rates decreased by an average of 4.2% per year, from a high of 56% in 2002 to a low of 37% in 2007. This decline in allograft acceptance occurred despite a *decreased* incidence of donor risk factors for non-utilization, such as death due to cerebrovascular accident and older age. While utilization rates in our donation service area are higher than the national average, the significant decline over time suggests increasing avoidance of risk—a practice that could potentially lead to longer waiting list times and increasing waiting list mortality. One explanation for the trend towards avoidance of "high risk" donors could be related to advances in mechanical circulatory support (particularly ventricular assist devices, VADs) as a bridge to transplantation. Improvements in VAD design and a reduction in size of the devices has allowed for predictable clinical stabilization of a growing population of end-stage heart failure patients,[1, 34] even those who are critically ill. The concern with adopting this approach indiscriminately is that bridging devices are expensive and can double the cost of an already expensive procedure. VAD implantation also exposes patients to the risk of additional surgical procedures, infections, and development of HLA antibodies,[35] which may contribute to poorer outcomes after heart transplantation.[36, 37]

We first examined the associations between the eleven donor risk factors identified *a priori*, based on our review of the literature, and allograft utilization. Almost all of these risk factors, except for high dopamine requirement and cocaine/methamphetamine use, significantly predicted non-utilization. The total number of donor risk factors was also strongly associated with non-utilization.

Recognizing the fact that other donor characteristics may influence allograft acceptance decisions, we used all available donor covariate data to construct a Random Forest algorithm. Random Forest models confer several advantages: they can handle a large number of input variables, they can give an estimate of which variables are important in the classification, and they can produce a highly accurate classifier. In addition, they internally validate, thereby obviating the need for cross-validation. This model had excellent discrimination, with a c-statistic of 0.86.

After identifying donor predictors of allograft non-utilization, we examined the associations between these predictors and recipient outcomes. Only cerebrovascular accident as the donor cause of death marginally predicted prolonged recipient post-transplant hospitalization, and diabetes was the only donor predictor of increased recipient mortality. These findings concur with prior studies demonstrating the relatively small contribution of donor characteristics to post-transplant adverse events.[4, 38, 39]

One criticism of studies examining the influence of donor characteristics on recipient outcomes is that of selection bias. Allografts with many undesirable features are rarely accepted for transplantation, making it difficult to determine whether the recipient outcomes would have been acceptable. On the other hand, grafts with one or two unfavorable characteristics (such as reduced left ventricular systolic function) may be accepted if the graft is otherwise favorable (e.g. from a young and healthy male donor). Thus, it is difficult, if not impossible, to determine the relative contributions of unfavorable characteristics to recipient events. In other words, the grafts with undesirable characteristics are very carefully chosen to minimize the risk of adverse events. This phenomenon, combined with the relatively low mortality within 30-days to 1-year post-transplant, may paradoxically make it seem as though unfavorable characteristics are associated with improved recipient outcomes.

We used the excellent discriminative ability of our Random Forest model to predict which allografts in our cohort "would" and "would not" have been accepted for transplantation, based on a threshold of >50% predicted probability of utilization. Based on this model, 36% of the allografts accepted for transplantation had a <50% probability of utilization, based on donor characteristics. We once again examined recipient post-transplant outcomes, this time based on the predicted probability of allograft acceptance, and were unable to identify any significant differences in recipient survival. Thus, receipt of an allograft that was unlikely to be used for transplantation, based on combinations of unfavorable donor characteristics, did not result in adverse recipient events. Finally, donor characteristics in aggregate did not prove to be a reliable predictor of recipient outcomes.

This study has significant strengths and limitations. First and foremost, this represents the largest existing research database of detailed, rigorously adjudicated clinical data on over 1,800 potential organ donors managed in a standardized fashion in the current era. The recipient outcomes selected for analysis are robust, as all heart transplant centers in the United States are required to report metrics such as length of post-transplant hospitalization and recipient survival to UNOS. The primary limitation is the observational nature of the data. We are reluctant to make any causal statements about the relationship between donor characteristics and recipient outcomes. There are likely selection effects that may explain the relatively positive outcomes among recipients of the less desirable allografts. Also, reasons for allograft discard were not documented in the donor medical record. Thus, it is possible that reasons other than donor characteristics (lack of a suitable recipient, time considerations, donor family preference) could have accounted for some cases of non-utilization. Nonetheless, we were still able to identify a number of strong donor predictors of allograft non-utilization. Several important predictors were based on echocardiography: reduced left ventricular systolic function, left ventricular regional wall motion abnormalities,

and left ventricular hypertrophy. However, donor echocardiograms were interpreted at local hospitals and were not centrally reviewed; we therefore cannot verify the accuracy of echocardiogram interpretation and measurements. Another limitation lies in the fact that relatively few recipients died within the first year post-transplant; this study may therefore have been underpowered to detect subtle influences of donor characteristics on post-transplant outcomes. Finally, this study was limited to donors managed by CTDN and may not be generalizable to heart transplant procedures performed throughout the United States or worldwide.

In conclusion, we have demonstrated the persistent low utilization of available cardiac allografts for transplantation in the face of a national organ donor shortage and a growing number of patients with end-stage heart disease. We identified predictors of allograft non-utilization and demonstrated that the anticipated relationship between these donor predictors and adverse recipient outcomes was not seen in our heart transplant cohort. These findings support the following statement recently put forth by the National Heart, Lung, and Blood Institute regarding the next decade of heart transplantation research: "Without clear evidence about the outcomes associated with different donor characteristics informing the donor selection process, it is probable that many potentially useful organs are currently being discarded. Because an important rate limiting factor in [heart transplantation] is the number of available donor organs, studies that define how to optimize donor use and develop biomarkers to define organ utility might increase the donor pool by providing evidence that would support the use of those organs deemed to be less than perfect."[40] The field of heart transplantation would therefore benefit greatly from prospective, multi-center trials studying the effects of liberalizing allograft acceptance criteria.

Acknowledgments

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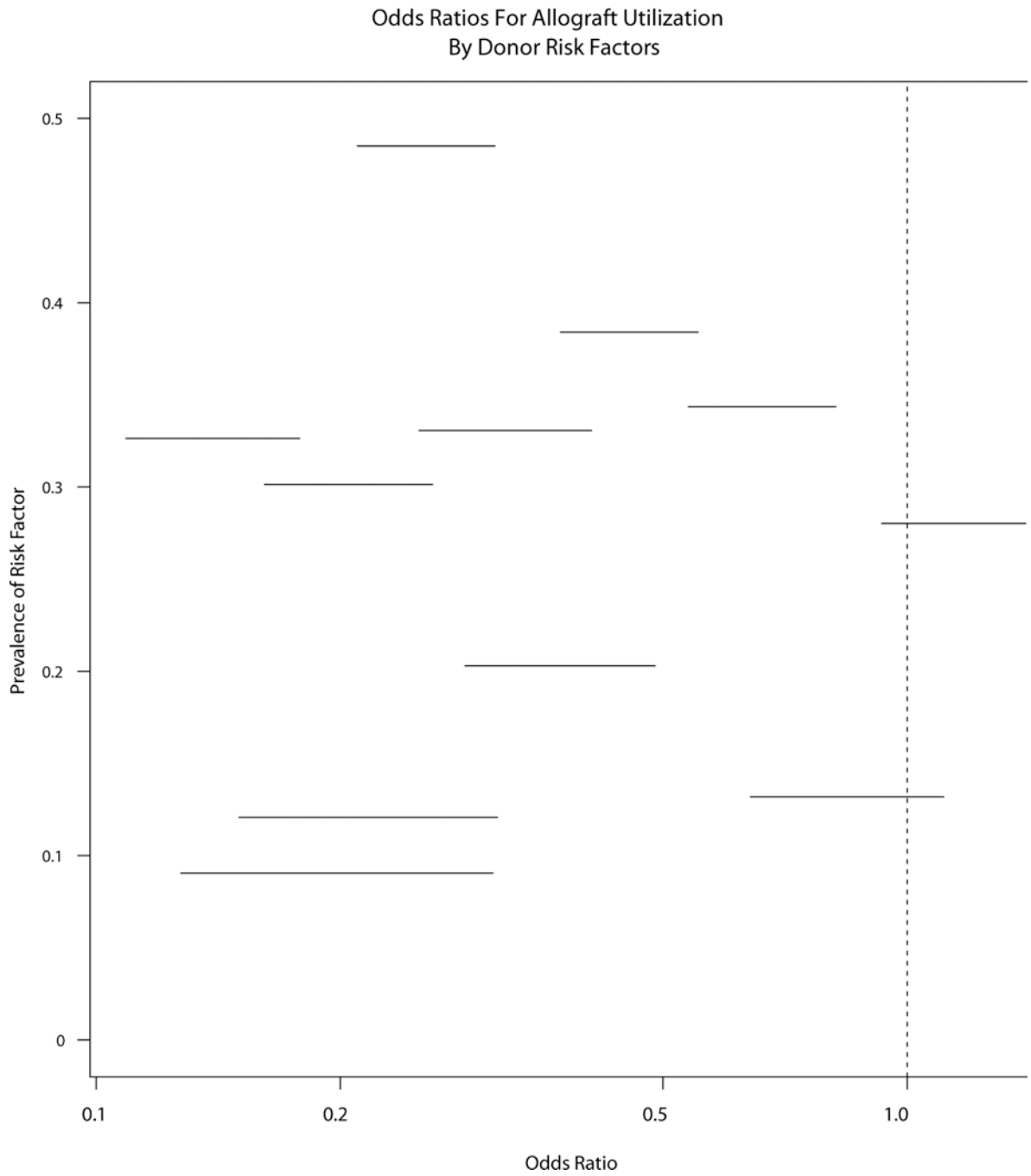
Figure 1.
Odds ratios for cardiac allograft acceptance for transplantation, by donor risk factors
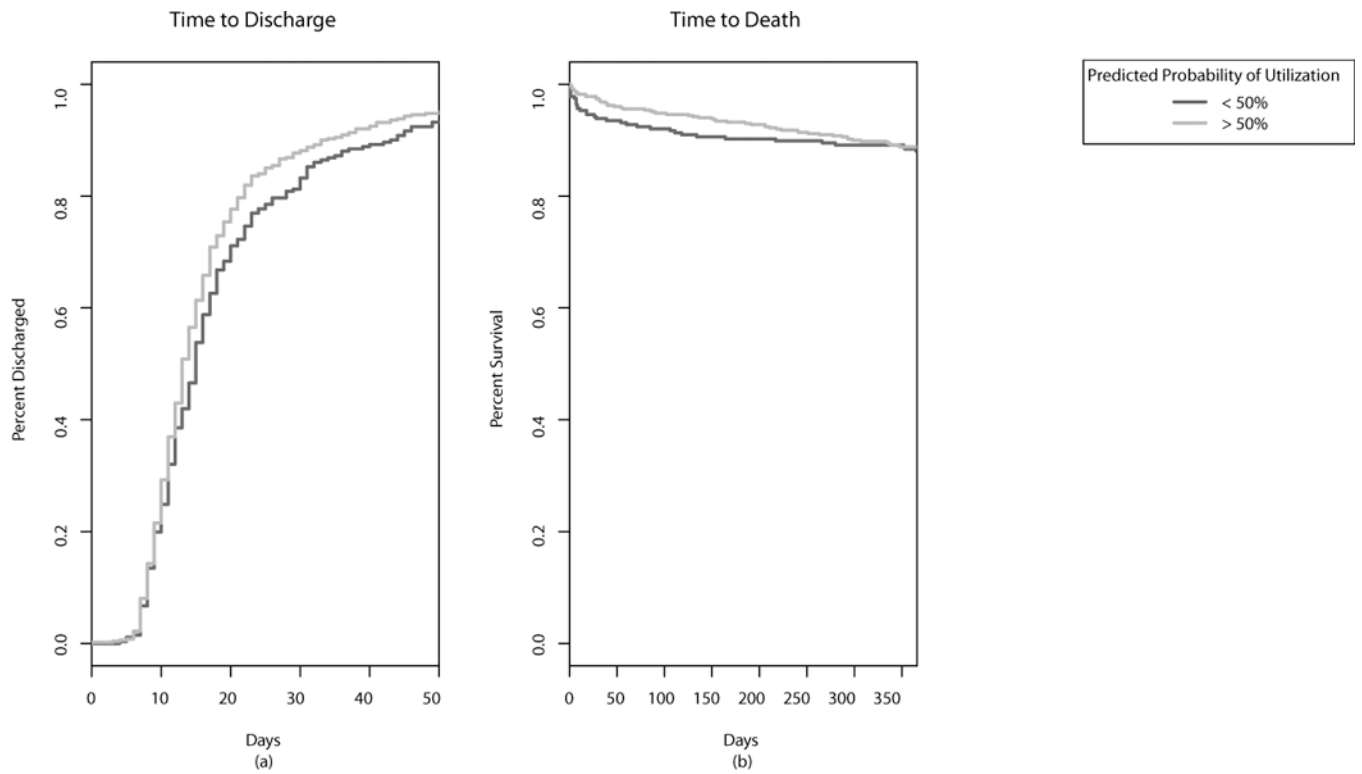
Figure 2.
Effect of allograft predicted probability of utilization (< or >50%) on (a) time to hospital discharge after heart transplantation, and (b) 1 year graft survival.
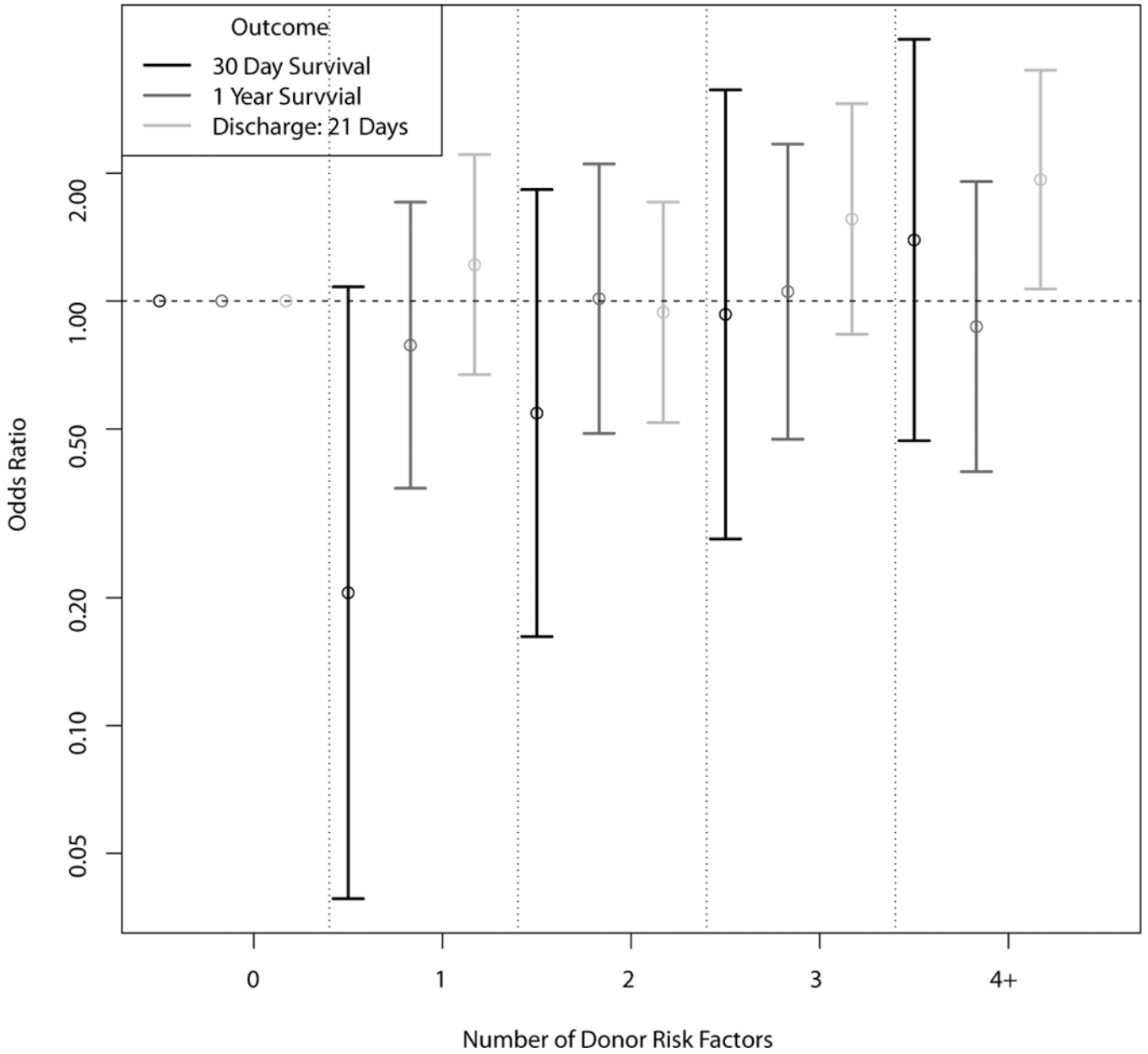
Figure 3.
Associations between number of donor risk factors and heart transplant recipient outcomes
(discharge within 21 days post-transplant, 30 day graft survival, and 1 year graft survival)

ROC Curves for Donor Prediction of Utilization and Outcomes

Figure 4.
Receiver operating characteristic curves, based on Random Forest models, for donor prediction of (1) cardiac allograft utilization for transplantation, (2) discharge within 21 days post-transplant, (3) 30 day graft survival, (4) 1 year graft survival.

Table 1

Donor characteristics, stratified by cardiac allograft acceptance for transplantation

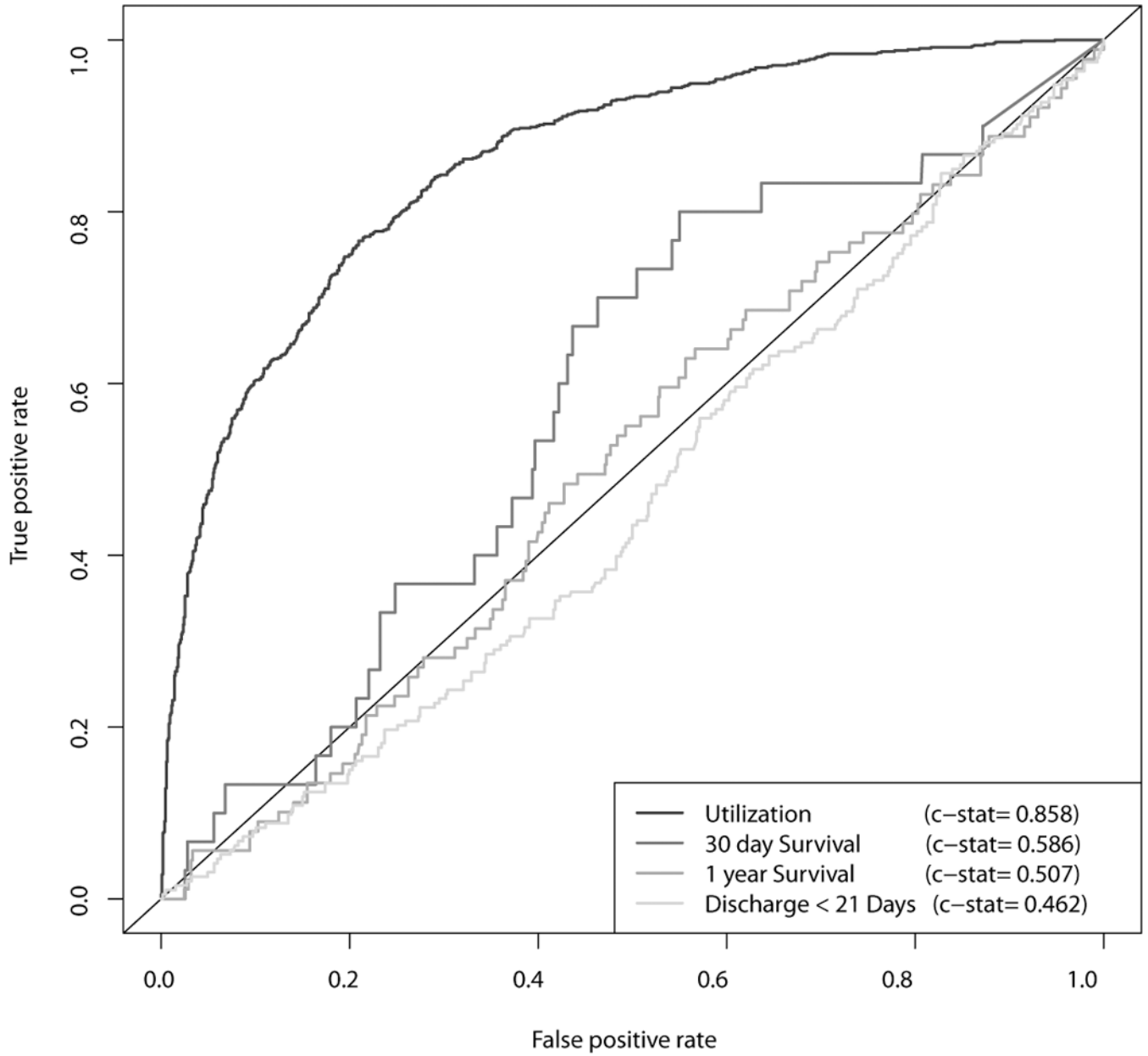|	Not Transplanted	Transplanted	p-value
	N=1064 (57%)	N=808 (43%)	
Demographics			
Age (years)	49 (40, 56)	30 (20, 43)	$< 1 \times 10^{-8}$
Sex (Male)	572 (54%)	581 (72%)	$< 1 \times 10^{-8}$
Cause of death			$< 1 \times 10^{-8}$
Anoxia	151 (14%)	70 (9%)	
Cerebrovascular accident/stroke	665 (63%)	242 (30%)	
Head Trauma	237 (22%)	489 (61%)	
Central nervous system tumor	4 (< 1%)	4 (< 1%)	
Other	5 (< 1%)	3 (< 1%)	
Race			$< 1 \times 10^{-8}$
African American	105 (10%)	815 (10%)	
Asian	118 (11%)	38 (5%)	
Caucasian	621 (58%)	427 (53%)	
Hispanic	200 (19%)	246 (30%)	
Other	20 (2%)	16 (2%)	
Body-mass index (kg/m^2)	26.3 (23.0, 30.9)	25.6 (22.7, 29.0)	2.08×10^{-3}
Blood type			$< 1 \times 10^{-8}$
A	374 (36%)	265 (33%)	
B	147 (14%)	81 (10%)	
AB	63 (6%)	11 (1%)	
O	468 (44%)	447 (56%)	
Clinical			
Cardiopulmonary resuscitation	241 (57%)	168 (53%)	0.360
Smoking	596 (57%)	418 (53%)	0.069
Cocaine/Methamphetamines	281 (27%)	236 (21%)	0.225
Hypertension	447 (38%)	106 (29%)	$< 1 \times 10^{-8}$
Diabetes	142 (14%)	24 (3%)	$< 1 \times 10^{-8}$
Coronary artery disease	91 (9%)	9 (1%)	$< 1 \times 10^{-8}$
Laboratory Values			
Troponin > 1.0 mgcl/L	346 (38%)	211 (29%)	1.36×10^{-4}
CPK-MB (IU/L)	6.9 (2.9, 20.0)	7.7 (3.2, 22.0)	0.204
Vasoactive medications			
Dopamine	822 (77%)	658 (81%)	0.035
Peak dopamine dose (mcg/kg/min)	6.0 (4.0,10.0)	5.3 (4.0, 9.6)	0.183

	Not Transplanted	Transplanted	p-value
	N=1064 (57%)	**N=808 (43%)**	
Final dopamine dose (mcg/kg/min)	2.4 (0, 4.0)	2.0 (0, 3.5)	0.056
Neosynephrine	766 (72%)	668 (83%)	1.11×10^{-7}
Peak neosynephrine dose (mcg/min)	100 (50, 190)	100 (50, 160)	0.100
Final neosynephrine dose (mcg/min)	20 (0, 50)	15 (0, 40)	8.98×10^{-4}
Epinephrine	40 (4%)	32 (4%)	0.947
Norepinephrine	37 (6%)	43 (8%)	0.208
Esmolol	169 (17%)	143 19%)	0.355
Hormones			
Corticosteriods	1010 (95%)	808 (100%)	$< 1 \times 10^{-8}$
Methylprednisolone dose (g/24 hours)	2.0 (1.5, 3.0)	2.0 (1.7, 3.0)	0.758
Thyroxine	222 (22%)	207 (27%)	0.022
Echocardiogram			
Echocardiogram performed	573 (54%)	785 (97%)	$< 1 \times 10^{-8}$
Left ventricular ejection fraction (%)	60% (50, 70)	65% (60, 70)	$< 1 \times 10^{-8}$
Regional wall motion abnormalities	173 (29%)	107 (13%)	$< 1 \times 10^{-8}$
Left ventricular hypertrophy	246 (48%)	166 (23%)	$< 1 \times 10^{-8}$

Results presented as percentages or median values with interquartile range

CPK-MB: creatine phosphokinase, muscle band

Table 2

Heart transplant recipient characteristics, stratified by probability of allograft utilization

	Predicted probability of utilization		
	< 50% N=277 (36%)	> 50% N=502 (64%)	p-value
Demographics			
Age (years)	53 (42, 60)	52 (38, 60)	0.109
Sex (male)	174 (63%)	395 (79%)	2.68×10^{-6}
Diagnosis			0.932
Dilated cardiomyopathy	125 (45%)	233 (46%)	
Ischemic cardiomyopathy	91 (33%)	163 (32%)	
Other	61 (22%)	106 (21%)	
Medical Condition			0.222
Not hospitalized	144 (52%)	229 (46%)	
Hospitalized, not in ICU	33 (12%)	72 (14%)	
Hospitalized, in ICU	100 (36%)	201 (40%)	
Waiting list status			0.018
1A	74 (27%)	148 (29%)	
1B	86 (31%)	192 (38%)	
2	117 (42%)	162 (32%)	
Cardiopulmonary support			
Inotropic support	108 (39%)	228 (45%)	0.097
Life support	136 (49%)	287 (57%)	0.037
Mechanical ventilation	5 (2%)	8 (2%)	0.942
Clinical variables			
Serum creatinine (mg/dl)	1.2 (1.0, 1.5)	1.2 (1.0, 1.6)	0.195
Mean pulmonary artery systolic pressure (mmHg)	41 (31, 52)	42 (35, 50)	0.372
Diabetes	37 (14%)	74 (15%)	0.932
Total bilirubin (mg/dl)	1.0 (0.7, 1.6)	1.0 (0.7, 1.6)	0.685
Allograft cold ischemic time (hours)	3.7 (3.3, 4.3)	3.7 (3.1, 4.2)	0.971

Probability of allograft utilization based on Random Forest models.

Results presented as percentages or median values with interquartile range.

ICU: intensive care unit

Table 3

Unadjusted odds ratios for associations between donor risk factors and recipient post-transplant outcomes

Donor characteristic	Not discharged within 21 days	p-value	30-day mortality	p-value	1-year mortality	p-value
Age > 50 years	1.43 (0.88, 2.31)	0.145	1.97 (0.78, 4.96)	0.150	1.23 (0.64, 2.36)	0.540
Sex (female)	1.25 (0.87, 1.78)	0.224	1.28 (0.59, 2.79)	0.527	1.07 (0.66, 1.74)	0.783
Cause of death (CVA/Stroke)	**1.41 (1.00, 2.00)**	0.050	1.17 (0.54, 2.53)	0.699	1.02 (0.63, 1.64)	0.950
Hypertension	1.26 (0.79, 2.03)	0.330	1.42 (0.53, 3.81)	0.488	0.76 (0.37, 1.56)	0.449
Diabetes	1.56 (0.62, 3.92)	0.346	**6.35 (2.00, 20.13)**	0.002	**3.07 (1.17, 8.07)**	0.023
Cocaine/methamphetime use	0.85 (0.59, 1.22)	0.375	0.91 (0.40, 2.09)	0.825	0.85 (0.51, 1.40)	0.513
Peak dopamine dose>10 mcg/kg/min	1.12 (0.68, 1.82)	0.662	0.79 (0.24, 2.66)	0.707	0.82 (0.40, 1.69)	0.586
Troponin I > 1.0 mcg/L	0.97 (0.66, 1.41)	0.855	0.68 (0.27, 1.71)	0.414	0.63 (0.36, 1.11)	0.109
Left Ventricular Hypertrophy	1.05 (0.70, 1.59)	0.798	2.23 (1.02, 4.86)	0.044	0.96 (0.56, 1.65)	0.884
Left ventricular ejection fraction < 50%	1.69 (0.86, 3.29)	0.126	1.41 (0.32, 6.17)	0.647	0.60 (0.18, 2.00)	0.409
Regional wall motion abnormalities	1.09 (0.68, 1.75)	0.722	1.02 (0.35, 3.00)	0.967	1.36 (0.75, 2.47)	0.318

CVA, cerebrovascular accident