Novel linkage of UNOS and PHIS to assess the impact of race and socioeconomic status on pediatric liver transplant outcomes

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Abstract

Background: S Despite the technological advancements made in pediatric liver transplant, concerns remain about the equality of patient care during the peri-operative period. Analyses have consistently shown discrepancies in mortality, graft failure, and waitlist time across race, ethnicity and socioeconomic status. National analyses, however, are lacking as most reported data comes from single-hospital studies without adequate power to account for possible confounding variables. The aim of this study was to evaluate the impact of race, ethnicity, and SES on transplant outcomes and resource utilization on a national level, using a linked administrative database.

Methods: Utilizing a novel linkage of the Scientific Registry of Transplant Recipients and the Pediatric Health Information System administrative databases, we performed a multicenter, retrospective analysis of 3609 children age ≤ 18 years, who received a LT in the US between 2003 and 2017. Proportional hazards models were used to assess effect of race and SES on patient and graft survival. Resource utilization was measured by length of stay (LOS), intensive care unit (ICU) LOS, length of mechanical ventilation (MV) and vasopressors, and total charges.

Results: White recipients had graft survival advantages compared to black patients (p = .007). This difference persisted after adjusting for resource utilization and recipient and donor characteristics (hazard ratio [HR] 1.47; 95% CI 1.08 – 2.00). There was no significant difference in overall survival between races. Resource utilization did not differ significantly between black and white races. Privately insured recipients had advantages in both graft (p = .003) and patient survival (p = .014) compared to publicly insured patients. This difference remained when

adjusted with the multivariate model (graft failure: HR = 1.28, 95% CI 1.01 – 1.62; survival: HR 1.38 (95% CI, 1.07 – 1.77). Publicly insured patients also had increased resource utilization compared to privately insured patients: LOS (16 vs 15 days, $p = .001$), ICU LOS (4 vs. 3 days, $p = .001$), TPN time (2 vs. 1 days, $p = .004$)), and total charge ($145871 vs. $129872, $p < .001$).

Conclusions: In pediatric LT recipients, publicly insured patients showed increased risk of graft failure, death, and resource utilization as compared to privately insured patients; these differences were not as consistent across patient race, but still showed trends towards worse survival and graft failure with minority status.

Introduction

For children with biliary atresia, acute liver failure, inborn errors of metabolism, and other forms of end-stage liver disease, liver transplantation is the only cure. Liver transplantation has been shown to significantly improve the lives of children with these illnesses, and success with the procedure continues to grow each year. In 2008, 1- and 5-year survival rates approached 90%, an increase from 75% in 1980 (1–3). Despite the great advancements made in pediatric liver transplant care, concerns remain regarding inequitable allocation and utilization of grafts across race, ethnicity, and socioeconomic status (SES).

These concerns over pediatric graft distribution and utilization stem primarily from well-documented and long-standing racial and socioeconomic disparities seen in adult literature (4). Before the Model for End-stage Liver Disease (MELD) was introduced in 2002, adult African American patients had significantly lower rates of LT compared to white patients. In this pre-MELD era, African Americans were 25-33% less likely to receive grafts compared to white counterparts (5,6), and in one study of veteran populations African American veterans were 85% less likely to be referred for LT when compared to white veterans (7). Though the introduction of the MELD score has helped improve the rate of African Americans liver transplants (OR = 1.12 compared to white patients, 2018 data) (8), minorities continue to struggle in terms of donor quality and patient outcomes. A 2015 study of the Organ Procurement and Transplantation Network/United Network for Organ Sharing (OPTN/UNOS) database revealed that African Americans were significantly less likely to get live donor organs compared to white patients (OR 0.35, 95% CI, 0.20–0.60) (9). Multiple regional and national studies have also shown that African American transplant recipients are less likely to survive at 1, 5, and 10-year time points when compared to white patients, even in data restricted to the post-MELD era (10–13).

There are few studies addressing how SES impacts the likelihood of receiving a graft, or survival after LT. Challenges exist with how to accurately measure the effect of SES on transplant outcome. While median income may serve as a surrogate for SES, it does not account for measures that encompass access to healthcare such as insurance status or distance to a hospital. From existing data, trends indicate that the best measures of low SES do indeed lead to worse outcomes post-LT. For example, LT recipients in low median income classes have significantly lower 2-year survival rates compared to wealthier counterparts (14). For patients living farther than 25 miles away from a transplant center, mortality is significantly increased compared to patients who live closer (HR 1.08, 95% CI 1.03-1.12) (15). Lastly, patients with Medicare and Medicaid have significantly worse patient survival compared to those with private insurance (16).

In children, there have been far fewer studies investigating racial and socioeconomic disparities related to liver transplant, and only three publications have specifically studied the impact on pediatric liver transplant rates and post-transplant outcomes. The first, a single center retrospective review published in 2014, showed that African American children had significantly higher hazard rates for both graft failure (HR = 2.59) and for mortality (HR = 4.24) compared to white children (17). Furthermore, these differences were present even when models were controlled for demographic, clinical, and socioeconomic characteristics. However, generalizability of this data to a national scale is limited given patients were recruited from a single hospital. A more recent study in 2018 analyzed racial disparities in children listed for LT using the Scientific Registry of Transplant Recipients (SRTR). The study included 7355 children and found that African Americans had higher Pediatric End-Stage Liver Disease (PELD) scores at first listing, were less likely to be granted exception points, and were half as likely to receive

living donor grafts when compared to their white counterparts (18). Because the SRTR database does not provide zip codes, however, this study could not control for geographic confounding, which has been shown to significantly impact organ allocation (19). Most importantly, this study provided minimal patient and graft survival after transplantation. While the authors found that there was no difference in 1-year mortality by race for waitlisted children, long-term outcomes in children who actually received liver transplants were not addressed. Finally, a retrospective review of 3728 pediatric transplant recipients from the UNOS database addressed the use of exception scores across race and found that African American patients were 13% less likely to have an exemption score submitted as compared to white patients (RR 0.87, 95% CI 0.77-0.98, $p = 0.02$) (20).

Presently, the reason for these stark differences in adult and pediatric liver transplant care is poorly understood, providing ample motivation for ongoing research. Many explanations have been proposed. One is that race and socioeconomic status are intrinsically linked to access to care, which we know is essential for long-term survival after transplant. Without the ability to attend follow-up appointments or and adhere to complex medication regiments, grafts can fail. Unfortunately accounting for access to care in a predictive model is difficult. There is no single number that can represent access to care, and our best surrogate measures like median income, zip code, distance from hospital, medical literacy or insurance status may not be captured by the databases from which we draw conclusions. Furthermore, it is particularly challenging to study these variables in pediatric cohorts, as a single center may not complete enough transplants to produce sample sizes to detect real differences.

Others have proposed that perhaps genetic makeup itself is a contributing factor to the racial disparities seen. Since most donor organs come from white patients, perhaps white patients

have better outcomes than their black counterparts due to better genetic matching. And while efforts are underway to increase donations from minority populations, major strides still need to be made before we can consistently race-match our donor populations. Alternatively, it may be possible that the underlying pathology causing illness in minority patient populations are more severe than those affecting white populations, making it more difficult to survive following transplant. We know black patients have higher rates of biliary atresia, for example, and maybe certain pathologies are more difficult to cure with organ transplant than others.

Lastly, we must consider inherent bias as the source of these differences. Even with equitable distribution of donor organs, and appropriate follow-up care, the unfortunate truth may be that patients from minority races and low socioeconomic statuses simply receive worse medical care than their counterparts, which leads to worse outcomes. This could be due to inherent bias of providers, systemic issues intrinsic the hospital system that make it difficult for certain groups to receive care, or something else entirely that we cannot yet measure.

With so many unknowns, it is incredibly important that we continue to investigate the racial and socioeconomic disparities affecting pediatric liver transplant patients. Learning both the extent of the disparities and the driving factors behind them will allow us to provide better care for patients of all races, ethnicities, and socioeconomic statuses. Furthermore, it will help alleviate the burden of disease that disproportionately affects certain patient populations, ensuring that all children and adults are receiving equitable and robust liver transplant care.

Therefore, we have conducted the present study in an attempt to further explore racial and socioeconomic disparities in pediatric transplant, with the hope that we may provide answers to some of the unknowns discussed above. This study is unique in that it combines the SRTR database with the Pediatric Health Information System (PHIS), an administrative database with

information about resource utilization (21,22). This novel linkage expands the analytical possibilities in pediatric LT recipients and allows for further exploration of the impact that race and SES status have on pediatric liver transplantation. We hope that the conclusions drawn from this undertaking will provide hospitals, administrators, and health care workers with a better understanding of the social landscape that influences transplant care, and may guide new decisions and policies towards a more equitable allocation model of pediatric liver grafts.

Methods

Study population

This study utilized data from the Scientific Registry of Transplant Recipients (SRTR, Hennepin Healthcare Research Institute, Minneapolis, MN) and the Pediatric Health Information System (PHIS, Children's Hospital Association, Lenexa, KS) administrative billing database. SRTR includes data on all donor, wait-listed candidates, and transplant recipients in the United States since October of 1987. This data is submitted by members of the OPTN and has been described elsewhere. The Health Resources and Services Administration, US Department of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors. PHIS is an administrative database that contains inpatient, emergency department, ambulatory surgery and observation encounter-level data from over 50 not-for-profit, tertiary care pediatric hospitals in the United States. It also records detailed billing and charge data for each encounter. Charge data was converted to cost using hospital specific cost-to-charge ratios. Prices were adjusted for inflation to 2016 dollars using the medical component of the Consumer Price Index as described previously (23). Nearly all of these hospitals also submit resource utilization data (e.g. pharmaceuticals, imaging, and laboratory) into PHIS. Data are de-identified

at the time of data submission, and data are subjected to a number of reliability and validity checks before being included in the database.

The two data sets were linked together at the patient level using indirect identifiers in a stepwise approach as described previously, using birth, sex, date of transplant, and hospital if needed (23). Patient data that was unable to be uniquely linked was excluded from the analysis. All pediatric LT recipients <18 years of age who received no more than one transplant from January 1, 2003 to December 31, 2018 were included, a total of 3609 patients, representing 53% of all pediatric transplants in that time period. Demographic characteristics of the donors and recipient of the linked subset were similar to the overall SRTR cohort.

Clinical Variables

From SRTR, the following demographic and clinical variables were collected: age (in years), sex, ethnicity (non-Hispanic white, black, Hispanic, or other), insurance status (private or public), etiology of end stage liver disease (acute heaptic necrosis, biliary atresia, metabolic disease, malignancy, autoimmune/PSC, and other/unknown), year of transplant, PELD score at first listing, PELD score at time of transplant, time spent on waitlist (days), condition at transplant (ICU, hospital, or home), liver type (split or whole), cadaveric donor, and cold ischemia time (hours). From PHIS, the following utilization variables were collected: hospital length of stay (LOS) (days), intensive care unit (ICU) LOS (days), mechanical ventilation time (days), total parenteral nutrition (TPN) time (days), pressor time (days), and total cost of admission ($USD). Insurance status was considered the primary measure of socioeconomic status in this study. Insurance type was determined from SRTR data, and categorized as public (Medicaid, Medicare, and Children's Health Insurance Program), private, or other (self, charity

care, and unknown). Continuous variables were converted into categories to assist with modeling. Low, medium, and high groups was defined by splitting the overall cohort into roughly equal thirds.

The primary outcome assessed across recipient race and insurance status were overall patient survival, defined as time from transplant to death, and graft failure, defined as time from transplant to death or first re-transplant. Median follow up time was 4 years and 11 months. Between racial groups, comparisons were made against white race (white vs. black, white vs. Hispanic, white vs. Other) and between SES groups, comparisons were made against private insurance (private vs. public, private vs. other).

Statistical Analysis

All demographic, clinical, and utilization variables were compared by race and insurance status. Categorical variables were assessed by chi-square analysis. Univariate analysis of graft failure and patient survival was performed using Kaplan-Meier estimation methods, and the log-rank test was used to assess racial and socioeconomic differences after LT. Separate Cox proportional hazards regression models were then used to assess the effect of race and SES on the rate of graft failure and patient survival, after adjusting for patient demographics and resource utilization. Variables used for adjustment included: sex, age, diagnosis, blood type, year of transplant, PELD score at first listing, PELD score at transplant, waitlist time, condition at transplant, split vs. whole liver, live vs. cadaveric liver, cold ischemia time, hospital LOS, ICU LOS, total ventilation days, total TPN days, total pressor days, and cost of transplant admission. The proportional hazards assumption was assessed using visual inspection. Likelihood ratio tests

were used to assess model significance, and 95% confidence intervals (CIs) for the effects of race and SES were reported for each.

Results

Racial Differences in Patient Characteristics

There were 3609 children who received a LT during the study period. The average age of transplant was <1 and the most common reason for referral was biliary atresia. The majority of patients received cadaveric grafts (87.4%) versus live grafts, and whole organs (59%) versus split livers.

From this cohort, 55% of patients were white, 13% black, 23% Hispanic, and 9% other or unknown. Major clinical and demographic characteristics across race were examined (Table 1). White recipients were significantly more likely to have private insurance (62%) compared to other racial groups (Black: 26%, $p < .001$; Hispanic: 17%, $p < .00$; Other: 56%, $p < .001$). patients. Diagnoses differed significantly amongst groups (white vs. black, $p < .001$; white vs. Hispanic, $p < .001$; white vs. Other, $p < .001$). White patients had the highest rates of metabolic disease (20%), whereas black patients had the highest rates of biliary atresia (43%) and Hispanic patients had the highest rates of acute hepatic necrosis (17%). White patients had significantly lower PELD scores both at first listing (White: 10; black: 15, $p < .001$; Hispanic: 12, $p = .001$; Other: 14, $p < .001$) and at transplant (White: 12; black: 16, $p < .001$; Hispanic: 14, $p = .001$; Other: 16, $p = .003$). White patients were more likely to be at home prior to transplant compared to black ($p = .026$) and Hispanic ($p < .001$) groups. In terms of graft type, white patients were significantly more likely to receive live organs compared to black patients (14% vs. 5%, $p < .001$), more likely to receive split livers compared to black (42% vs. 34%, $p = .002$). No

differences in organ type were seen compared to Hispanic or Other groups. White patients also had lower cold ischemia times compared to black patients (6.2 hr vs. 6.9 hr, p = .001). Of note, white patients had significantly longer waitlist times (60 days) compared to Hispanic (50 days, p = .002) patients.

Racial Differences in Resource Utilization

We next examined racial differences in resource utilization at the index hospitalization for transplant (Table 2). All patient groups had similar total length of stays in the hospital and the ICU, and similar usage of ventilators and TPN. Hispanic patients had significantly more pressor days compared to white patients (2 [1-4] vs. 2 [0-3], p <.001). In terms of cost, white patients had significantly lower total costs compared to Hispanic and Other groups, but no difference compared to black patients (white: $133628; Hispanic: $140717, p = .009; Other: $155159, p = .006; Black: $128519, p = .509).

Socioeconomic Differences in Patient Characteristics

Demographic and clinical characteristics across socioeconomic status were examined (Table 3). Privately insured patients were more likely to be older (p < .001) than publicly insured patients. Diagnoses differed significantly amongst groups (public vs. private, p < .001; public vs. other, p < .001). Publicly patients had the highest rates of biliary atresia (39%) whereas other or uninsured patients had the highest rates of metabolic disease (35%). There were no differences in PELD scores between privately and publicly insured patients, but patients without insurance ("Other") had significantly lower PELD scores compared to privately insured patients, both at first listing (7 vs. 12, p = .036) and at transplant (7 vs. 13, p = .008). There were no differences

across groups in terms of waitlist time. Privately insured patients were more likely to be at home prior to transplant compared to publicly insured ($p = .006$) and uninsured patients ($p < .001$). Privately insured patients were more likely to have live donors compared to publicly insured patients (16% vs. 8%, $p <.001$) and less cold ischemia time (6.3 hr vs. 6.7 hr, $p < .001$). There was no difference in split vs. whole liver distribution across groups.

Socioeconomic Differences in Resource Utilization

Socioeconomic differences in resource utilization were examined (Table 4). Publicly insured patients had significantly more resource utilization compared to privately insured patients, revealing a longer median length of stay (16 [11-26] vs. 15 [10-23] days, $p = .001$), longer median ICU stay (4 [0-10] vs. 3 [0-8] days, $p = .001$), longer ventilation time (2 [1-6] vs. 2 [0-6], $p = .007$), longer median TPN time (2 [0-12] vs. 1 [0-9] days, $p = .004$), longer median pressor time (2 [1-3] vs. 2 [1-3], $p = .001$) and higher total cost ($145871 [$96434 – $238545] vs. $129872 [$89608 – $208223], $p = .004$).

Patient and Graft Survival after LT

We next performed a univariate Kaplan-Meier survival to assess differences in survival across race and SES. There was no difference in overall survival between the various racial groups (Figure 1A). However, white patients had a graft survival advantage compared to black patients ($p = .007$, Figure 1B). As for SES, privately insured patients demonstrated improved overall survival over publicly insured patients ($p = .003$, Figure 2A), and improved graft survival ($p = .014$, Figure 2B).

To fully investigate the effect of race and SES on patient and graft survival, we then performed a Cox proportional hazards analysis. Univariate analyses only revealed differences between white vs. black patients and publicly insured vs. privately insured patients, thus Cox analysis was limited to these subgroups (Table 5). The crude hazard ratio (HR) comparing white patients to black patients ranged from 1.31 (95% CI 0.96 – 1.78, p = .085) for patient survival to 1.47 (95% CI 1.11 – 1.95, p = .008) for graft survival. When accounting for the clinical and utilization variables described in Tables 1 and 2, these HRs adjusted to 1.33 (95% CI 0.96 – 1.86, p = .091) and 1.47 (95% CI 1.08 – 200, p = .014) respectively, indicating that the survival advantage of white patients was no longer statistically significant.

For SES, the crude hazard ratio (HR) comparing privately insured patients to publicly insured patients ranged from 1.41 (95% CI 1.127 – 1.765, p = .003) for patient survival to 1.31 (95% CI 1.056– 1.616, p = .014) for graft survival. When adjusted for the clinical and utilization variables described in Tables 1 and 2, these HRs fell to 1.38 (95% CI 1.07 – 1.77, p = .012) and 1.28 (95% CI 1.01 – 1.62, p = .043) respectively, but continued to show statistically significant patient survival and graft survival advantages in favor of privately insured patients.

Discussion

As the demand for pediatric liver grafts continues to outpace the availability of organ donors, an emphasis on the equitable allocation of grafts is essential. Unfortunately, few studies have investigated how social factors like race, ethnicity and SES affect LT allocation, with most work limited to local or regional analyses. In this study, we assessed how race and SES affect patient and graft survival on a national level, by combining two large multi-center databases. The incorporation of administrative data into our model enabled us to assess, for the first time, if

resource utilization during the transplant admission differs by race and SES, and how these differences affect long-term outcomes.

Our findings revealed that both race and SES strongly predict patient and graft survival. Privately insured patients had statistically higher rates of patient and graft survival compared to publicly insured patients, even after adjusting for relevant clinical factors. The inclusion of resource utilization variables into the model did not affect this trend, further strengthening the rigor of this finding. Minority status had a similar effect on outcomes. Black patients had significantly worse graft survival than their white counterparts, even after adjustments were included in the model. However, differences in survival were only apparent at the crude level, as adjustments to the model made this finding insignificant.

These conclusions are not surprising, given the wealth of adult literature that supports race and SES as independent drivers for long-term outcomes in liver transplant care (4–13). Our data also agrees with prior pediatric studies which, though limited to regional analyses, have shown that minority status and lower SES lead to worse patient and graft survival (17). By including resource utilization variables into our analyses, however, we have created an even more rigorous model for determining how race and SES affect outcomes compared to prior studies. This added rigor can also explain why minority status became insignificant after fully adjusting for all the variables included in the model – the dataset became underpowered to continue to detect differences in mortality after so many covariates were included. Nevertheless, the use of two large, multi-center databases has enabled us to increase the external validity of our results compared to prior pediatric literature.

Even with these improvements, it is still difficult to determine why race and SES affect outcomes in pediatric liver transplant. One explanation is that the true driving factor of patient

and graft survival is access to care, and that minority status and low SES are both surrogates for worse access to care. A close look at our patient and resource variables may support this hypothesis. For example, Black, Hispanic, and publicly insured patients were more often in the ICU/hospital prior to LT, had higher PELD scored prior to LT, and utilized more resources during their transplant hospitalization. Taken together, these findings may insinuate that these groups were sicker on average prior to transplant, and so had worse access to care before receiving a LT. Having worse access to care could certainly lead to worse survival following transplant, as these patients would have more difficulty making follow-up appointments, taking appropriate medications and seeking medical care when needed. Another explanation is that minorities and publicly insured patients are more likely to receive organs of worse quality, leading to earlier death and graft failure. On average, these groups had grafts with longer cold ischemia time, were more likely to receive grafts from cadaveric donors, and less often received split livers. Having worse organs would lead to sooner graft failure and death. Determining why these groups are at risk for worse quality organs remains to be understood.

There were several limitations to our study. First, our study is retrospective. By requiring a successful linkage of PHIS and SRTR for inclusion in the study, we effectively limited our sample to only those hospitals who report data to PHIS, accounting for only half of the total LTs performed in the United States over this time period. Pruning our sample in this way introduces selection bias, but we expect the effect has been minimal and therefore does not detract from our overall conclusions. Second, based on the limitations of our dataset, there were many covariates we were unable to account for. These include recipient comorbidities, such as cardiovascular disease, hypertension, or diabetes, and long-term LT care, like patient compliance, episodes of rejection, and readmission after LT. Perhaps most important, we were unable to include many

components that make up access to care, like health literacy, distance to the hospital, and median income, which may help explain some of the differences across race and insurance status that we found. Including these terms in our model may further reduce the effect modification we are seeing across social factors, if access to care is truly the driving factor of disparities in long-term outcomes. Lastly, we could not account for the cause of death or graft failure, which can heavily depend on underlying social factors like race and ethnicity. A more careful analysis of cause of death may help us tease out which morbidity can be attributed to social causes versus medical care.

Certainly, the interactions between SES, race, and access to care is complicated, and determining how these factors affect patient mortality is nontrivial. By trying to address the limitations discussed above, we hope it will be possible to further elucidate these relationships. The use of linked, large datasets is essential to this process – it provides added rigor to survival models by incorporating possible confounding variables and increases the power to detect small differences in long-term outcomes. We hope to use this methodology moving forward, combining more sources of data to allow for a more robust exploration of race and socioeconomic status, with a focus on access to care. We believe that understanding how access to care is essential to maintaining the equitable distribution of organs, and necessary given the limited amount of grafts available for transplant. While we have shown an independent effect of race and SES on patient survival and mortality, the exact mechanisms behind this process remain to be understood, and so more work must be done.

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Tables and Figures

Table 1: Demographic and clinical characteristics by racial group

	White (n=1987)		Black (n=475)			Hispanic (n=819)			Other (n=328)		
	n/*median*	%/IQR	n/*median*	%/IQR	p	n/*median*	%/IQR	P *value*	n/*median*	%/IQR	p
Male sex	1043	52%	215	45%	0.005	395	48%	0.040	155	47%	0.079
Age at transplant	2	0 - 9	2	1 - 10	0.215	2	0 - 7	0.002	1	0 - 5	0.000
<1yr	528	27%	114	24%		252	31%		127	39%	
1-5 yr	734	37%	193	41%		322	39%		121	37%	
6 to 11	346	17%	70	15%		133	16%		50	15%	
12 to 17	379	19%	98	21%		112	14%		30	9%	
Diagnosis											
acute hepatic necrosis	184	9%	66	14%	0.000	137	17%	0.000	36	11%	0.000
biliary atresia	680	34%	204	43%		294	36%		164	50%	
cholestatic disease	218	11%	55	12%		91	11%		30	9%	
metabolic disease	400	20%	41	9%		103	13%		33	10%	
malignancy	216	11%	27	6%		85	10%		30	9%	
autoimmune / PSC	78	4%	29	6%		18	2%		8	2%	
other/unknown	211	11%	53	11%		91	11%		27	8%	
Blood Type											
A	781	39%	112	24%	0.001	217	26%	0.000	100	30%	0.000
B	215	11%	102	21%		82	10%		76	23%	
AB	83	4%	31	7%		25	3%		15	5%	
O	908	46%	230	48%		495	60%		137	42%	
Year of transplant											
2003-2007	521	26%	130	27%	0.852	203	25%	0.55	63	19%	0.005
2008-2012	669	34%	160	34%		270	33%		106	32%	
2013-2017	797	40%	185	39%		346	42%		159	48%	
PELD score											
at listing	10	-1 - 20	15	7 - 23	0.000	12	1 - 23	0.001	14	1 - 25	0.000
low	728	37%	93	20%		257	31%		98	30%	
medium	654	33%	186	39%		253	31%		93	28%	
high	605	30%	196	41%		309	38%		137	42%	
at transplant	12	0 - 23	16	6 - 24	0.000	14	2 - 25	0.000	16	4 - 26	0.003
low	702	35%	108	23%		243	30%		91	28%	
medium	686	35%	188	40%		270	33%		110	34%	
high	599	30%	179	38%		306	37%		127	39%	

Waitlist time (days)	60	18 - 177	57	14 - 180	0.323	50	11 - 126	0.002	47	12 - 121	0.052
low	620	31%	161	34%		296	36%		115	35%	
medium	661	33%	142	30%		287	35%		119	36%	
high	706	36%	172	36%		236	29%		94	29%	
Condition at transplant											
ICU	342	17%	99	21%	0.026	188	23%	0.000	63	19%	0.103
Hospital	306	15%	89	19%		166	20%		64	20%	
Home	1332	67%	284	60%		457	56%		201	61%	
Unknown	7	0%	3	1%		8	1%		0	0%	
Split liver (vs. whole)	828	42%	161	34%	0.002	342	42%	0.966	147	45%	0.285
Live donor (vs. cadaveric)	283	14%	24	5%	<.001	101	12%	0.181	45	14%	0.801
Cold ischemia time (hr)	6.2	4.5 - 8.4	6.9	5.2 - 8.3	0.001	6.6	5.0 - 8.3	0.156	6.9	5.1 - 9.0	0.001
low	680	34%	255	31%		255	31%		87	27%	
medium	604	30%	267	33%		267	33%		108	33%	
high	601	30%	265	33%		265	32%		125	38%	
Unknown	102	5%	27	3%		32	4%		8	2%	
Insurance											
Private	1239	62%	124	26%	<.001	138	17%	0.000	184	56%	0.000
Public	645	32%	342	72%		638	78%		141	43%	
Other/unknown	103	5%	9	2%		43	5%		3	1%	

P values are comparison of racial groups against whites.

IQR, inter-quartile range; *PSC,* primary sclerosing cholangitis; *PELD,* pediatric end-stage liver disease; *ICU*, intensive care unit;

Table 2: Resource utilization by racial group

	White (n=1987)		Black (n=475)			Hispanic (n=819)			Other (n=328)		
	n/*median*	%/IQR	n/*median*	%/IQR	P *value*	n/*median*	%/IQR	P *value*	n/*median*	%/IQR	P *value*
Hospital LOS (days)	15	10 - 24	16	10 - 26	0.119	15	10 - 26	0.129	15	10 - 24	0.752
low	620	31%	154	32%		275	34%		102	31%	
medium	707	36%	146	31%		259	32%		123	38%	
high	660	33%	175	37%		285	35%		103	31%	
ICU LOS (days)	3	0 - 8	3	0 - 9	0.527	3	0 - 9	0.400	5	1.5 - 10	0.003
low	619	31%	150	32%		254	31%		73	22%	
medium	666	34%	147	31%		256	31%		117	36%	
high	702	35%	178	37%		309	38%		138	42%	
Mechanical ventilation days	2	0 - 5	2	1 - 6	0.597	2	0 - 6	0.113	2	1 - 5	0.005
low	520	26%	115	24%		221	27%		59	18%	
medium	789	40%	199	42%		292	36%		152	46%	
high	678	34%	161	34%		306	37%		117	36%	
TPN Days	2	0 - 10	0	0 - 10	0.167	1	0 - 11	0.444	3	0 - 10.5	0.511
low	926	47%	244	51%		390	48%		142	43%	
medium	347	17%	78	16%		154	19%		63	19%	
high	714	36%	153	32%		275	34%		123	38%	
Pressor Days	2	1 - 3	2	1 - 3	0.488	2	1 - 4	0.000	2	1 - 3	0.028
low	341	17%	71	15%		101	12%		37	11%	
medium	1003	50%	243	51%		392	48%		178	54%	
high	643	32%	161	34%		326	40%		113	34%	
Cost of Transplant Admission	133628	92434-21117	128519	89900-226913	0.509	140717	88658-229627	0.009	155159	103611-244070	0.006
low	632	32%	165	35%		273	33%		80	24%	
medium	655	33%	141	30%		241	29%		114	35%	
high	603	30%	145	31%		282	34%		124	38%	
Unknown	97	5%	24	5%		23	3%		10	3%	

P values are comparison of racial groups against whites.

IQR, inter-quartile range; *ICU*, intensive care unit; *LOS*, length of stay; *TPN*, total parenteral nutrition

Table 3: Demographic and clinical characteristics by SES

	Private (n=1685)		Public (n=1766)			Other (n=158)		
Variable	n/*median*	%/IQR	n/*median*	%/IQR	P *value*	n/*median*	%/IQR	P *value*
Male sex	853	51%	879	50%	0.618	76	48%	0.544
Age at transplant	2	0 - 10	2	0 - 7	0.000	3	1 - 10	0.008
<1yr	479	28%	512	29%		30	19%	
1-5 yr	541	32%	760	43%		69	44%	
6 to 11	310	18%	266	15%		23	15%	
12 to 17	355	21%	228	13%		36	23%	
Diagnosis								
acute hepatic necrosis	193	11%	217	12%	0.000	13	8%	0.000
biliary atresia	623	37%	689	39%		30	19%	
cholestatic disease	158	9%	218	12%		18	11%	
metabolic disease	284	17%	238	13%		55	35%	
malignancy	161	10%	183	10%		14	9%	
autoimmune / PSC	87	5%	44	2%		2	1%	
other/unknown	179	11%	177	10%		26	16%	
Blood Type								
A	612	36%	548	31%	0.000	50	32%	0.569
B	224	13%	231	13%		20	13%	
AB	82	5%	65	4%		7	4%	
O	767	46%	922	52%		81	51%	
Year of transplant								
2003-2007	483	29%	397	22%	0.000	37	23%	0.003
2008-2012	567	34%	598	34%		40	25%	
2013-2017	635	38%	771	44%		81	51%	
PELD score								
at listing	12	0 - 21	12	1 - 22	0.419	7	-5 - 18	0.036
low	553	33%	557	32%		66	42%	
med	561	33%	573	32%		52	33%	
high	571	34%	636	36%		40	25%	
at transplant	13	2 - 24	14	2 - 24	0.118	7	-4 - 20	0.008
low	522	31%	556	31%		66	42%	
med	612	36%	586	33%		56	35%	
high	551	33%	624	35%		36	23%	
Waitlist time (days)	55	14-162	56	16-152	0.821	63	17-155	0.913
low	560	33%	582	33%		50	32%	
med	570	34%	585	33%		54	34%	

high	555	33%	599	34%		54	34%	
Condition at transplant								
ICU	312	19%	361	20%	0.006	19	12%	0.000
Hospital	270	16%	340	19%		15	9%	
Home	1103	65%	1065	60%		106	67%	
Unknown	0	0%	0	0%		18	11%	
Split liver (vs. whole)	707	42%	703	40%	0.199	68	43%	0.793
Live donor (vs. cadaveric)	277	16%	147	8%	0.000	29	18%	0.536
Cold ischemia time	6.3	4.5-8.3	6.7	5.0-8.5	0.000	6.0	4.0-8.0	0.913
low	578	34%	503	28%		58	37%	
med	499	30%	612	35%		40	25%	
high	521	31%	593	34%		36	23%	
Unknown	87	5%	58	3%		24	15%	

P values are comparison of insurance groups against privately insured patients.
IQR, inter-quartile range; *PSC,* primary sclerosing cholangitis; *PELD,* pediatric end-stage liver disease; *ICU*, intensive care unit;

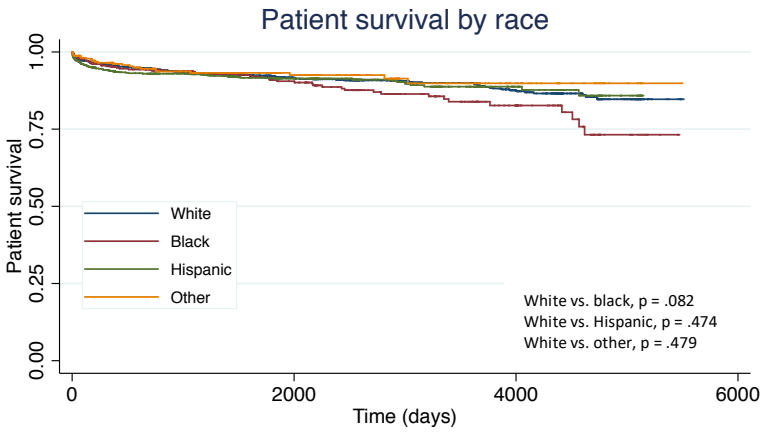
Table 4: Resource utilization by SES

	Private (n=1685)		Public (n=1766)			Other (n=158)		
	n/*median*	%/IQR	n/*median*	%/IQR	P *value*	n/*median*	%/IQR	P *value*
Hospital LOS (days)	15	10 - 23	16	11 - 26	0.001	16	11 - 24	0.243
low	585	35%	520	29%		46	29%	
medium	578	34%	603	34%		54	34%	
high	522	31%	643	36%		58	37%	
ICU LOS (days)	3	0 - 8	4	0 - 10	0.001	3	0 - 7	
low	553	33%	490	28%		53	34%	0.757
medium	551	33%	580	33%		55	35%	
high	581	34%	696	39%		50	32%	
Mechanical ventilation days	2	0 - 5	2	1 - 6	0.007	1.5	0 - 6	0.005
low	451	27%	406	23%		58	37%	
medium	683	41%	704	40%		45	28%	
high	551	33%	656	37%		55	35%	
TPN Days	1	0 - 9	2	0 - 12	0.004	0	0 - 9	0.412
low	841	50%	781	44%		80	51%	
medium	290	17%	331	19%		21	13%	
high	554	33%	654	37%		57	36%	
Pressor Days	2	1 - 3	2	1 - 3	0.001	1	0 - 3	0.002
low	271	16%	236	13%		43	27%	
medium	880	52%	866	49%		70	44%	
high	534	32%	664	38%		45	28%	
Cost of Transplant Admission	129872	89608 - 208223	145871	96434 - 238545	0.004	109435	79193 - 173560	0.000
low	562	33%	518	29%		70	44%	
medium	553	33%	559	32%		39	25%	
high	499	30%	622	35%		33	21%	
Unknown	71	4%	67	4%		16	10%	

P values are comparison of racial groups against whites.

IQR, inter-quartile range; *ICU*, intensive care unit; *LOS*, length of stay; *TPN*, total parenteral nutrition

Figure 1: Patient and Graft survival by Race



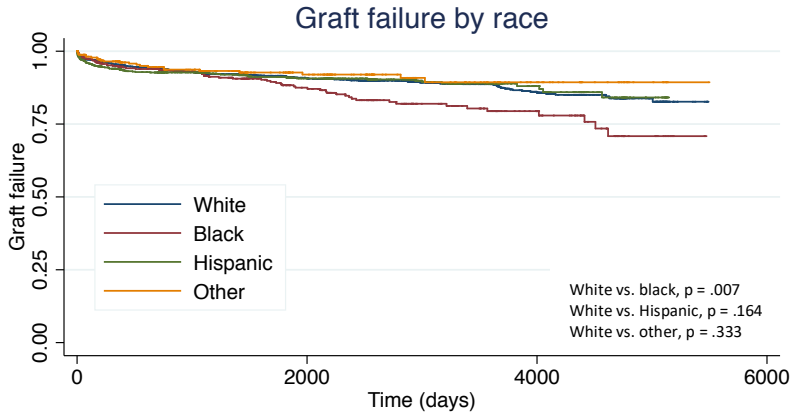
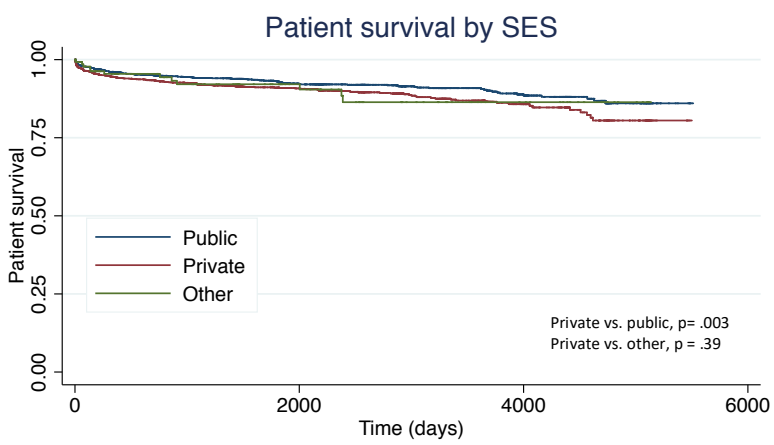


Figure 1: Recipient race predicts patient and graft survival. (A) Black patients have worse survival than white counterparts, but this difference is non-significant (log-rank P = .082). White recipient survival is equivalent to Hispanic survival (p = .474). (B) White patients have significantly worse graft survival compared to white recipients (P = .007), but no difference compared to Hispanic patients.

Figure 2: Patient and Graft survival by SES



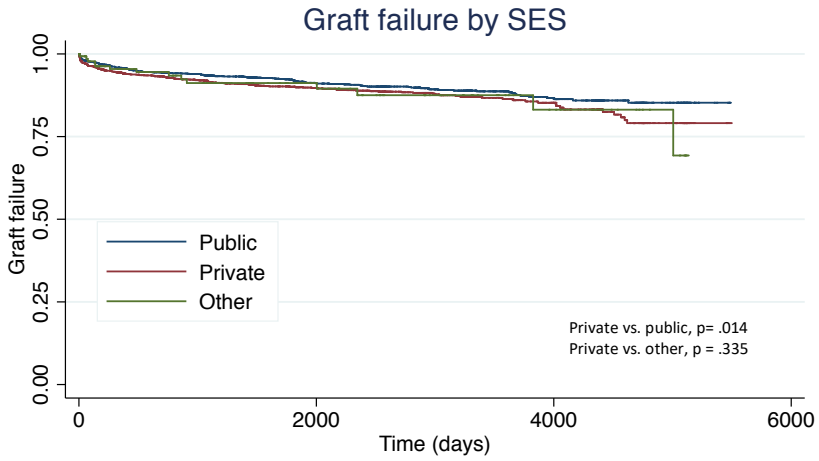


Figure 2: Recipient insurance status predicts patient and graft survival. (A) Publicly insured have worse survival than white counterparts (log-rank P = .003). (B) Publicly insured patients also have significantly worse graft survival compared to white recipients (P = .014).

Table 5: Hazard ratios for Cox regression analysis of relevang subgroups

	HR Patient Survival (95% CI)	P *value*	*HR Graft Failure (95% CI)*	P *value*
White vs. black race				
Crude	1.31 (.96 - 1.78)	0.085	1.47 (1.11 - 1.95)	0.008
Adjusted*	1.33 (.96 - 1.86)	0.091	1.47 (1.08 - 2.00)	0.014
Private vs. public insurance				
Crude	1.41 (1.13 - 1.77)	0.003	1.31 (1.06 - 1.62)	0.014
Adjusted*	1.38 (1.07 - 1.77)	0.012	1.28 (1.01 - 1.62)	0.043

Patient and graft survival adjusted for sex, age, diagnosis, blood type, year of transplant, PELD score at first listing, PELD score at transplant, waitlist time, condition at transplant, split vs. whole liver, live vs. cadaveric donor, cold ischemia time, insurance status, race, hospital LOS, ICU LOS, mechanical ventilation time, TPN time, pressor time, and cost of admission.