HHS Public Access
Author manuscript
Dig Dis Sci. Author manuscript; available in PMC 2021 January 01.

Published in final edited form as:
Dig Dis Sci. 2020 January ; 65(1): 104–110. doi:10.1007/s10620-019-05734-z.

County Rankings Have Limited Utility When Predicting Liver Transplant Outcomes

Clifford Akateh, MD[1,2], **Rebecca Miller, BS**[6], **Eliza W. Beal, MD, MS**[1,2], **Dmitry Tumin, PhD**[3], **Joseph D. Tobias, MD**[6,7], **Don Hayes Jr., MD, MS**[4,5,8], **Sylvester M. Black, MD, PhD**[2]

[1]Division of General and Gastrointestinal Surgery, Department of Surgery, Ohio State University Wexner Medical Center, Columbus, OH 43210, USA

[2]Division of Transplantation, Department of Surgery, Ohio State University Wexner Medical Center, Columbus, OH 43210, USA

[3]Department of Pediatrics, Brody School of Medicine at East Carolina University, Greenville, NC 27834, USA

[4]Division of Pulmonary, Allergy, Critical Care and Sleep Medicine, Department of Internal Medicine, Ohio State University Wexner Medical Center, Columbus, OH 43210, USA

[5]Section of Pulmonary Medicine, Department of Pediatrics, Nationwide Children's Hospital, Columbus, OH 43205, USA

[6]Department of Anesthesiology and Pain Medicine, Nationwide Children's Hospital, Columbus, OH 43205, USA

[7]Department of Anesthesiology and Pain Medicine, Ohio State University Wexner Medical Center, Columbus, OH 43205, USA

[8]Department of Pediatrics, Ohio State University College of Medicine, Columbus, OH 43210

Abstract

Background: Evidence of geographic differences in liver transplantation (LT) outcomes have been proposed as a reason to include community characteristics in risk-adjustment of transplant quality metrics. However, consistency and utility of rankings in LT outcomes for counties has not been demonstrated.

Correspondence: Dr. Clifford Akateh, OSU Wexner Medical Center - Faculty Tower, 395 W 12th Ave, Room 654, Columbus, OH-43210-1267, Phone: (614) 293-8704, Fax: (614) 293-4063, clifford.akateh@osumc.edu.

Disclosure: The authors have no conflicts of interest to disclose.

Aims: We sought to evaluate the utility of county rankings (county socioeconomic status (SES) or county health scores (CHS)) on outcomes after LT.

Methods: Using the United Network for Organ Sharing Registry, adults ≥18 years of age undergoing LT between 2002-2014 were identified. County-specific 1-year survival was calculated using the Kaplan-Meier method for counties with ≥5 LT performed during this period. Agreement between high-risk designation by 1-year mortality rate and county ranking was calculated using the Spearman correlation coefficient.

Results: The analysis included 47,769 LT recipients in 1092 counties. County 1-year mortality rates were not correlated with county CHS (Spearman $\rho=0.01$, $p=0.694$) or county SES (Spearman $\rho=-0.01$, $p=0.734$). After controlling for individual-level covariates, a statistically significant variability in mortality hazards across counties ($p<0.001$) persisted. Although both CHS and SES measures improved the model fit ($p=0.004$ and $p=0.048$ respectively), an unexplained residual variation in mortality hazard across counties continued.

Conclusions: There is poor agreement between county rankings on various socioeconomic indicators and LT outcomes. Although there is variability in outcomes across counties, this appears not to be due to county level socioeconomic indices.

Keywords

Liver Transplantation; Socioeconomic Factors; county health scores; county socioeconomic status; Survival; Risk Adjustment; Human

INTRODUCTION

There is increased awareness of the impact of socioeconomic status (SES) and other social determinants of health on surgical outcomes [1,2]. As such, in 2014 the National Quality Forum (NQF) recommended that quality measures be adjusted for sociodemographic risk factors[3]. In organ transplantation, equitable access to donor organs has been a concern from the outset. In 2005, the Department of Health and Human Services (DHHS) implemented the “final rule ” [4], to ensure equitable distribution and allocation of organs. Nevertheless, concerns remain that access to transplantation and outcomes of transplantation continue to be subject to economic and social disparities. This is particularly true in liver transplantation (LT), where socioeconomic status and geographical location are known to influence listing for transplant, as well as access to transplant centers [5–8].

For patients who successfully undergo FT, the effects of geography (community socioeconomic disadvantage) on outcomes are less clear. While patient-level social and economic factors (race, education, insurance status) have been shown to consistently affect patient outcomes and graft survival, the impact of community factors is less certain [9]. In 2014, Quillin et al. reported significant differences in 2-year survival after LT according to an index of community SES [10]. Community SES was found to be an independent predictor of patient survival, regardless of the donor, recipient and transplant center factors. This result appeared to support the inclusion of community factors in risk adjustment models for evaluating transplant centers [11]. However, a recent publication by Ross et al. 2017, using community health score (calculated at the county level), found no significant difference in post-LT outcomes according to this measure.

Furthermore, the small number of LT performed complicates the task of demonstrating that patients from disadvantaged counties all share the same elevated risk of poor outcomes. This could make county rankings of transplant outcomes highly unstable over time [12], and uncorrelated with other county-level measures such as county SES and CHS.

To elucidate the utility of county rankings for evaluating LT outcomes, we sought to evaluate the variation across counties in risk-adjusted survival after LT. Persistence of significant variation across counties would support the need for adjusting survival outcomes for county-level characteristics. Therefore, we considered how previously used geographical measures (SES and CHS) performed in explaining the variation across counties after adjustment for individual recipient and donor characteristics[1013,14]. We hypothesized that LT outcomes varied across counties even after adjusting for individual patient characteristics and that this variation would be partially explained by adjusting for specific measures of county SES or CHS. Our secondary aim was to determine whether adjusting for multiple county rankings (SES and CHS) could wholly explain the variation in LT outcomes across counties.

METHODS

The United Network for Organ Sharing Registry was used to identify adults ≥18 years of age undergoing first-time whole LT in February 2002 - December 2014. Patients were excluded from the analysis if their survival time was missing or if their county of residence was not known. In multivariable analysis of overall survival, patients were excluded if they had missing data on individual-level covariates. The primary outcome was overall patient survival, tracked until March 2016. To illustrate geographic variability in unadjusted LT outcomes, county-specific 1-year patient survival was calculated using the Kaplan-Meier method for counties with ≥5 LT performed during the study period, and Spearman correlation coefficients were used to compare county-specific estimated 1-year mortality rates to county measures of SES and CHS, detailed below.

The first county-level measure was the composite SES score as described by Diez Roux et al. [15]. The score was calculated as a sum of z-scores from 6 county-level variables in the 2007-2011 5-year American Community Survey (ACS) [16]. These variables included the log of the median household income; log of the median value of housing units; the percentage of households receiving interest, dividend, or net rental income; the percentage of adults 25 years of age or older who had completed high school; the percentage of adults 25 years of older who had completed college; and the percentage of employed people 16 years of age or older in executive, managerial, or professional specialty occupations (in more recent years: management, business, science, and arts occupations). Counties included in the analysis were then stratified by quintile according to composite SES score [10].

The second county-level measure recently used in an analysis of LT outcomes was the county's CHS, a measure of community health resources and risk. This score was derived from multiple aspects of community health, access to care, social and environmental risk factors: years of potential life lost, proportion of children with low birth weight, proportion of adults with poor or fair reported health, adults' poor reported physical health days, poor reported mental health days, proportion of individuals reporting tobacco use, adult obesity prevalence, physical inactivity prevalence, rate of preventable hospital stays, and median annual household income. A cumulative score (out of 40) was computed for each county, the county CHS [13]. For consistency with the classification of county SES, each county received a score of 0-4 based on quintile ranking (0 points if the county belonged to the 20thpercentile or below for a particular index and 1 point for each subsequent quintile).

We used Cox proportional hazards regression to evaluate county differences in mortality hazard while controlling for individual recipient characteristics, donor characteristics, and transplant center volume. Covariates in this analysis included recipient age, recipient gender, recipient race, recipient insurance coverage at the time of transplant, recipient level of education, recipient body mass index (BMI), recipient's etiology of liver failure, Diabetes and Dialysis, recipient final Laboratory Model for End-stage Liver Disease (MELD) score, Transplant center volume, and the Donor Risk Index (DRI), dichotomized at DRI > 1.9 to indicate high-risk donors [17,18]. In addition to these recipient-, donor-, and center-level characteristics, the Cox model included a shared frailty term to represent any unexplained variation in mortality hazard across counties [19]. The Cox model included all available follow-up time for each respondent, not limited to the first year post-transplant.

The shared frailty Cox model is a type of mixed effects regression model which estimates the overall variation in an outcome (mortality) across aggregate units (counties), without assuming that this variation is explained by a specific observed characteristic [19,20]. Briefly, county-specific mortality hazard is assumed to follow a gamma distribution, with a mean of 1 and a variance parameter θ to be estimated. The "shared frailty" term estimates any observed county characteristics that increase or decrease the mortality hazard of the residents of that county. Therefore, if θ is statistically indistinguishable from 0, we would conclude that residual county-level differences in mortality hazard are negligible, after adjusting for other covariates.[19] The statistical significance of θ was assessed via a likelihood ratio (LR) test comparing the model with shared frailty to a Cox model without shared frailty. We assessed the statistical significance of county-level variation after adjusting for individual and center covariates only, after adding either county SES or CHS scores, and after adding both SES and CHS scores. LR tests were used to determine improvement in model fit with the addition of county-level covariates. Data analysis was performed in Stata/IC 15.1 (College Station, TX: StataCorp LP). Two-tailed $P<0.05$ was considered statistically significant.

RESULTS

We identified 47,769 LT recipients meeting inclusion criteria during the study period, of whom 36,984 had complete data on covariates for multivariable analysis. The characteristics of the study cohort are summarized in Table 1. There were 1,092 counties represented in the analysis (median number of patients per county, 142). The median 1-year mortality rate estimated by the Kaplan-Meier method was 89% (interquartile range [IQR]: 82%, 94%; Figure 1). On Spearman analysis of rank correlation, unadjusted county 1-year mortality was not correlated with the continuous county CHS measure ($\rho = 0.01$; $p = 0.694$), and was not correlated with the continuous county SES measure ($\rho = -0.01$; $p = 0.734$). Counties were classified into quintiles according to CHS and SES for further analysis, as described above.

As shown in Table 2, we initially fit a shared-frailty Cox model adjusted for individual covariates, but no specific county-level covariates. Notable individual characteristics associated with increased mortality hazard included race, educational attainment, insurance status, etiology of liver failure, comorbidities such as diabetes and dialysis, and receiving an organ with an increased donor risk index (DRI>1.9). Transplant center volume, however, was not associated with outcomes. The variance of the shared frailty term was found to be statistically significant ($\theta = 0.009$, $p < 0.001$; Table 3), indicating that mortality hazard varied by county even after controlling for individual characteristics. However, the implied gamma distribution of mortality hazard across counties (Figure 2) revealed that residual differences in mortality hazard between counties might not be clinically significant. For example, Figure 2 shows that without adjusting for any specific county-level measures, the difference in mortality hazard between a county at the 80^{th} percentile of mortality hazard, and a county with median post-transplant mortality, is an HR of 1.08.

Next, we evaluated whether controlling for specific county measures improved model fit and explained the residual variability in post-transplant outcomes across counties. As summarized in Table 3, controlling for county CHS quintile improved model fit over the model shown in Table 2 (LR test $p = 0.004$), as did controlling for county SES quintile (LR test $p = 0.048$). However, the addition of county SES quintile to a model containing individual characteristics and CHS quintile did not lead to improvement in model fit (LR test $p = 0.868$). In both of these models, however, there remained unexplained variability in mortality hazard across counties, as indicated by a statistically significant variance of the county shared frailty term. The inclusion of both county measures did not entirely explain the residual variation in mortality hazard across counties ($\theta = 0.007$, $p = 0.001$). As illustrated in Figure 2, the fully adjusted model implied a narrower gamma distribution of mortality hazard (less residual variation among counties), compared to the model with only individual-level controls. In the fully adjusted model, comparing a county at the 80^{th} percentile of mortality hazard to the county with the median mortality hazard yielded a HR of 1.07.

DISCUSSION

While the mechanisms underlying disparities in survival and outcomes after LT remain unknown, various hospital and patient factors have been implicated. Our results demonstrate that most of the variabilities in outcomes seen after LT are likely driven by patient-level socioeconomic characteristics such as type of insurance, a surrogate of access to care, education/income, race, in addition to patient comorbidities and donor factors. Consistent with previous literature, we found that public insurance (Medicare and Medicaid), as well as black race, are associated with some of the higest hazards of mortality [9,21]. We found inconsistent associations between county characteristics (County SES and CHS scores) and outcomes following LT. Adjusting for individual covariates using the shared-frailty Cox model results in an unexplained residual difference in mortality of about 9% between patients from different counties. However, there was a limited utility in using specific county measures to improve our ability to explain these differences in post-transplant mortality. These findings suggest that further research is needed to validate these geographic measures as predictors of outcome after LT, before incorporating them into risk-adjusted models.

There is a rich amount of social epidemiological data relating the impact of various community socioeconomic factors on the health of the residents [22–25]. These data are easily available and capture a wide range of potentially relevant contextual influences on LT survival. For instance, residence in lower socioeconomic communities may imply poor transportation networks, tertiary care and overall barriers in access to LT. Previous studies have used different geographical measures population including socioeconomic advantage index, economic inequality index, black-white segregation index, county SES score, and county CHS score, but have not specifically reported how the best geographical measure was selected for analyses [10,13,19,26] in our analysis, we found that county CHS might be a more useful measure than county SES, although both variables moderately improved the model fit. By contrast, an earlier analysis by Quillin et al. [10] reported that county SES was significantly associated with LT outcomes, and Ross et al. [13] reported that county CHS was not associated with LT outcomes after adjustment for a more comprehensive range of recipient, donor, and center factors. These mixed findings highlight the fragility of reported associations between county characteristics and LT outcomes and suggest the limited utility of these factors for clinical or regulatory assessment of transplant recipients' expected survival.

There is now robust evidence to suggest that various socioeconomic and demographic factors such as insurance coverage, race, educational attainment, and income influence patients' outcomes following LT[9,21,27–29]. For instance, patients with public insurance consistently have poor outcomes after LT [9] Additionally, transition from private to public insurance, especially the transition to Medicaid insurance has been associated with worse survival and graft failure [21]. While the underlying mechanisms of these disparities are poorly understood, their impact on outcomes is evident. As such, the inclusion of these adverse socioeconomic factors into risk models of LT outcome is necessary. This, however, raises the concern about which of these measures are appropriate for inclusion into risk adjustment. Given the instability in some of these SES measures, it is necessary to validate the variables and demonstrate their stability over time, including factors that have been shown to impact outcomes across a wide range of disease states and pathologies, such as income, educational attainment, employment status, insurance status, and sociodemographic factors such as race and ethnicity. Additionally, other measures with strong correlation to SES such as language and health literacy, and marital status may be worth tracking in the transplant registry.

Despite the implementation of the MELD allocation system, geographical differences in LT outcomes persist, largely driven by large regional differences in organ availability and access to LT. However, some variabilities in outcomes are observed in different donor service areas (DSA) within the same UNOS region [30]. Distance from the nearest transplant center is a predictor of outcomes after transplantation [31]. Although we did not specifically adjust for these influences in our analysis, these factors would have been captured as part of the residual variability in LT outcomes across counties, estimated in the shared-frailty Cox model. The shared-frailty Cox model allows for characterization of both the impact of explicitly measured geographic characteristics, as well as residual differences in outcomes across geographical units, providing information on whether additional geographical measures should be considered for inclusion in the model. In our analysis, the addition of additional county measures (CHS and county SES) did not explain the residual variability across counties.

Our conclusions are constrained by limitations of data from the UNOS Registry and our analytic approach. We used the zip code at the time of transplantation, which does not account for relocation and changes in zip code post-transplantation. Secondly, although education and insurance status are good correlates of income, individual income is not captured in the database and could potentially explain the residual variability in outcomes that continue to be detected by the model. Additionally, exclusion of counties that contained fewer than 5 patients limits the generalizability of the findings to transplant recipients and centers in rural counties. Lastly, calculation of county CHS and SES scores utilized on variables employed Quillin et al. and Ross et al., which is not a comprehensive list of community factors captured by the County Health Rankings from the Robert Wood Johnson Foundation or American Community Survey.

CONCLUSION:

In summary, our findings show that while residual county differences in LT outcomes persist after adjusting for patient-level socioeconomic indices, they do not appear to be related to county SES or county health scores. Therefore, the inclusion of these geographic measures of community disadvantage into risk-adjusted models of LT outcome will require further validation. In addressing disparities in outcomes, more effort should be focused on addressing individual/patient level barriers to access to care.

Acknowledgments

Funding Sources: This research was supported by the NIH T32AI 106704-05 training grant.

Abbreviations:

LT	liver transplantation
SES	socioeconomic status
CHS	county health scores
NQF	National Quality Forum
DHHS	Department of Health and Human Services
ACS	American Community Survey
ESLD	end-stage liver disease
MELD	model for end-stage liver disease
US	United States of America

UNOS	United Network for Organ Sharing
DRI	donor risk index
LOS	length of stay
HR	hazard ratios
CI	confidence interval

REFERENCES

1. Bennett KM, Scarborough JE, Pappas TN, Kepler TB. Patient Socioeconomic Status Is an Independent Predictor of Operative Mortality. Annals of Surgery. 2010;252(3).
2. Haider AH, Scott VK, Rehman KA, et al. Racial Disparities in Surgical Care and Outcomes in the United States: A Comprehensive Review of Patient, Provider, and Systemic Factors. Journal of the American College of Surgeons. 2013;216(3): 482–492.e412. [PubMed: 23318117]
3. Risk Adjustment for Socioeconomic Status or Other Sociodemographic Factors. National Quality Forum;2014.
4. Duda L National Organ Allocation Policy: The Final Rule. Virtual Mentor: Ethics Journal of the American Medical Association. 2005;7(9).
5. Ellison MD, Edwards LB, Edwards EB, Barker CF. Geographic differences in access to transplantation in the United States. Transplantation. 2003;76(9).
6. Adler JT, Yeh H. Social determinants in liver transplantation. Clinical Liver Disease. 2016;7(1): 15–17. [PubMed: 31041019]
7. Adler JT, Bababekov YJ, Markmann JF, Chang DC, Yeh H. Distance is associated with mortality on the waitlist in pediatric liver transplantation. Pediatric Transplantation. 2017;21(2): el2842-n/a.
8. Yeh H, Smoot E, Schoenfeld DA, Markmann JF. Geographic Inequity in Access to Livers for Transplantation. Transplantation. 2011;91(4): 479–486. [PubMed: 21200366]
9. Yoo HY, Thuluvath PJ. Outcome of liver transplantation in adult recipients: Influence of neighborhood income, education, and insurance. 2004;10(2): 235–243.
10. Quillin RC III, Wilson GC, Wima K, et al. Neighborhood Level Effects of Socioeconomic Status on Liver Transplant Selection and Recipient Survival. Clinical Gastroenterology and Hepatology. 2014;12(11): 1934–1941. [PubMed: 24907503]
11. Schold JD, Phelan MP, Buccini LD. Utility of Ecological Risk Factors for Evaluation of Transplant Center Performance. American Journal of Transplantation. 2017;17(3): 617–621. [PubMed: 27696682]
12. Miller R, Akateh C, Thompson N, et al. County socioeconomic characteristics and pediatric renal transplantation outcomes. Pediatr Nephrol. 2018.
13. Ross K, Patzer RE, Goldberg DS, Lynch RJ. Sociodemographic Determinants of Waitlist and Posttransplant Survival Among End-Stage Liver Disease Patients. American Journal of Transplantation. 2017.
14. County Health Rankings and Roadmaps, <http://www.countyhealthrankings.org/rankings/data> Published 2017.
15. Roux AVD, Merkin SS, Arnett D, et al. Neighborhood of Residence and Incidence of Coronary Heart Disease. New England Journal of Medicine. 2001;345(2): 99–106. [PubMed: 11450679]
16. Bureau UC. American Community Survey Data Releases. 2017.
17. Feng S, Goodrich NP, Bragg-Gresham JL, et al. Characteristics Associated with Liver Graft Failure: The Concept of a Donor Risk Index. American Journal of Transplantation. 2006;6(4): 783–790. [PubMed: 16539636]
18. Beal EW, Black SM, Mumtaz K, et al. High Center Volume Does Not Mitigate Risk Associated with Using High Donor Risk Organs in Liver Transplantation. Digestive Diseases and Sciences. 2017.

19. Tumin D, Horan J, Shrider EA, et al. County socioeconomic characteristics and heart transplant outcomes in the United States. American Heart Journal. 2017;190: 104–112. [PubMed: 28760203]
20. Singh TP, Gauvreau K. Center Effect on Post-Transplant Survival among Currently Active United States Pediatric Heart Transplant Centers. Am J Transplant. 2018;18:2914–2923. [PubMed: 29806728]
21. DuBay DA, MacLennan PA, Reed RD, et al. Insurance Type and Solid Organ Transplantation Outcomes: A Historical Perspective on How Medicaid Expansion Might Impact Transplantation Outcomes. Journal of the American College of Surgeons. 2016;223(4): 611–620.e614. [PubMed: 27457252]
22. Johnson AM, Johnson A, Hines RB, Bayakly R. The Effects of Residential Segregation and Neighborhood Characteristics on Surgery and Survival in Patients with Early-Stage Non–Small Cell Lung Cancer. Cancer Epidemiology Biomarkers & Prevention. 2016;25(5): 750.
23. Dwyer-Lindgren L, Bertozzi-Villa A, Stubbs RW, et al. Us county-level trends in mortality rates for major causes of death, 1980-2014. JAMA. 2016;316(22): 2385–2401. [PubMed: 27959996]
24. Dwyer-Lindgren L, Bertozzi-Villa A, Stubbs R, et al. Inequalities in Life Expectancy Among US Counties, 1980 to 2014 Temporal Trends and Key Drivers. Jama Internal Medicine. 2017;177(7): 1003–1011. [PubMed: 28492829]
25. Foraker RE, Rose KM, Kucharska-Newton AM, Ni H, Suchindran CM, Whitsel EA. Variation in Rates of Fatal Coronary Heart Disease by Neighborhood Socioeconomic Status: The Atherosclerosis Risk in Communities Surveillance (1992–2002). Annals of Epidemiology. 2011;21(8): 580–588. [PubMed: 21524592]
26. Schold JD, Heaphy ELG, Buccini LD, et al. Prominent Impact of Community Risk Factors on Kidney Transplant Candidate Processes and Outcomes. American Journal of Transplantation. 2013;13(9): 2374–2383. [PubMed: 24034708]
27. Akateh C, Tumin D, Beal EW, et al. Change in Health Insurance Coverage After Liver Transplantation Can Be Associated with Worse Outcomes. Digestive Diseases and Sciences. 2018;63(6): 1463–1472. [PubMed: 29574563]
28. Beal EW, Tumin D, Mumtaz K, et al. Factors contributing to employment patterns after liver transplantation. Clinical Transplantation. 2017;31(6): el2967-n/a.
29. Kemmer N, Zacharias V, Kaiser TE, Neff GW. Access to Liver Transplantation in the MELD Era: Role of Ethnicity and Insurance. Digestive Diseases and Sciences. 2008;54(8): 1794. [PubMed: 19051029]
30. Barshes NR, Becker NS, Washburn WK, Halff GA, Aloia TA, Goss JA. Geographic disparities in deceased donor liver transplantation within a single UNOS region. Liver Transplantation. 2007;13(5): 747–751. [PubMed: 17457866]
31. Goldberg DS, French B, Forde KA, et al. Association of distance from a transplant center with access to waitlist placement, receipt of liver transplantation, and survival among us veterans. JAMA. 2014;311(12): 1234–1243. [PubMed: 24668105]

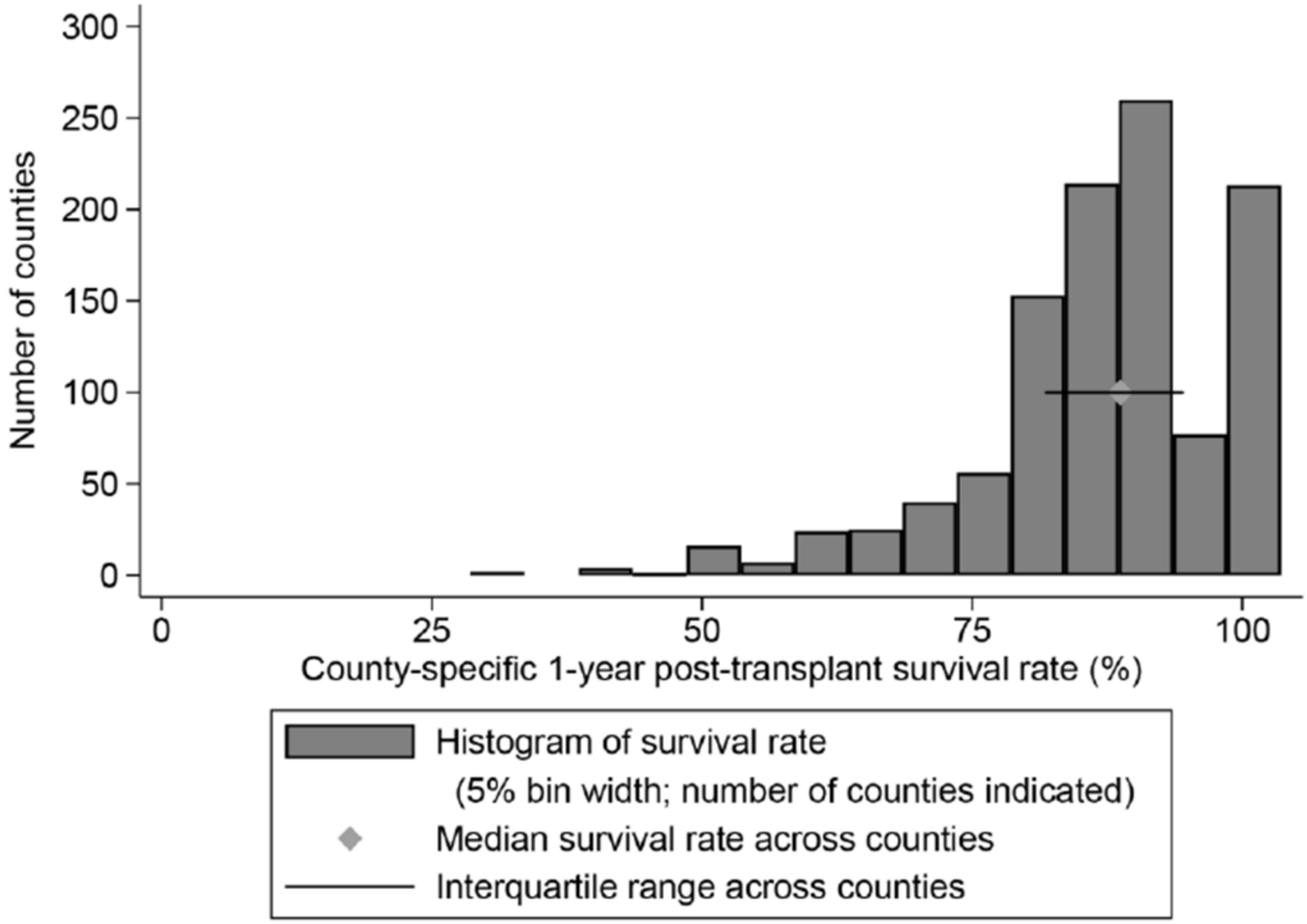

Figure 1.
Distribution of county-level 1–year survival rates after liver transplantation across US counties (N = 1,092).

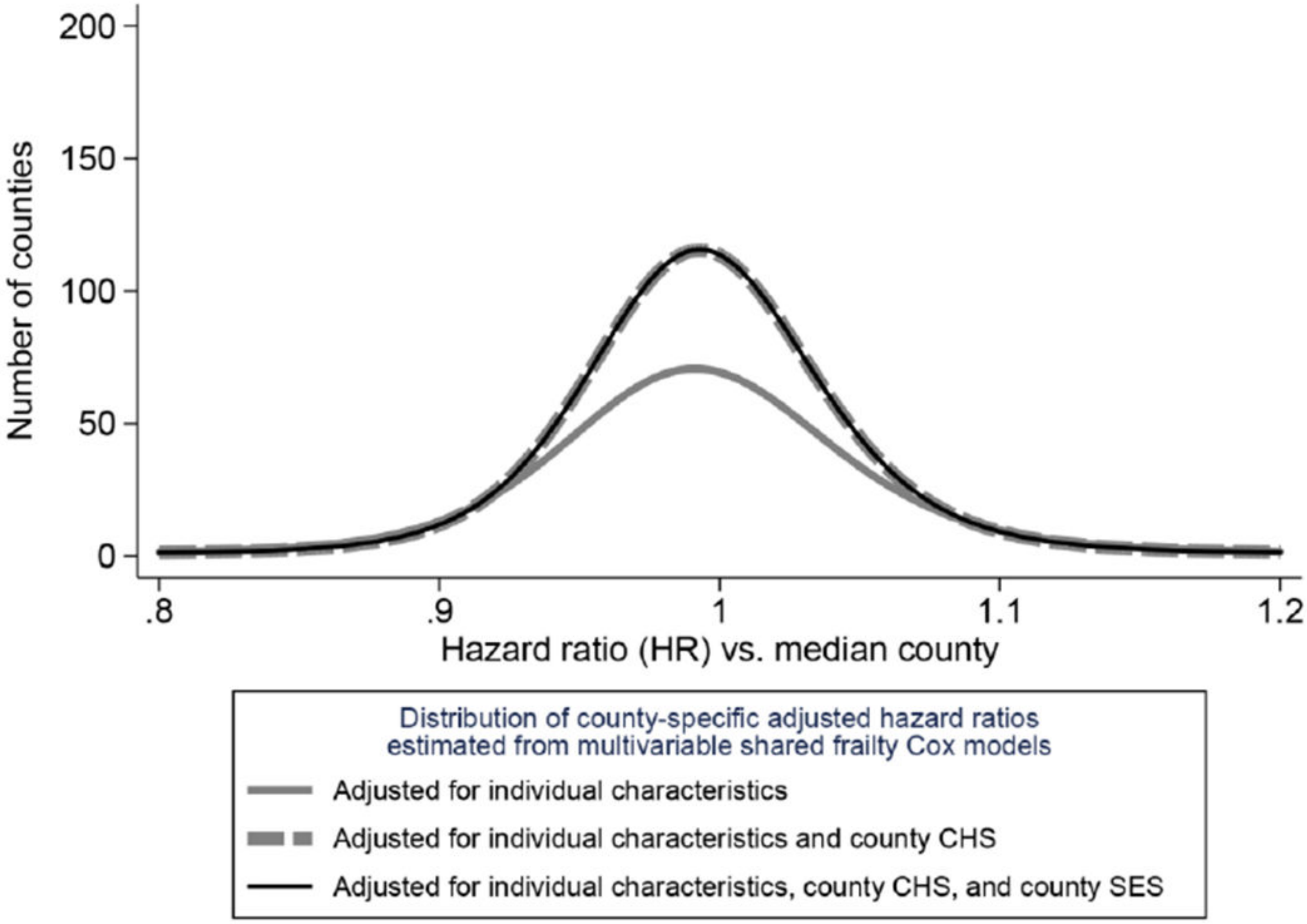

Figure 2.
Distribution of county-specific adjusted hazard ratios estimated from multivariable shared frailty Cox models (N = 1,092).

Table 1:

Recipient and Donor Characteristics (n, %, or mean, standard deviation).

	TOTAL = 65,484	
Covariate	**Missing**	**Mean (SD) or N (%)**
Age (y)	0	54 (10)
Sex	0	
Male		44,311 (68%)
Female		21,173 (32%)
Race	0	
White		47,045 (72%)
Black		6,261 (10%)
Other		12,178 (18%)
Education	11,290	
High School or less		28,324 (52%)
Some College		13,220 (25%)
College degree		12,650 (23%)
Insurance Status	2	
Private Insurance		38,760 (59%)
Medicaid		9,132 (14%)
Medicare		14,968 (23%)
Other insurance		2,622 (4%)
BMI (kg/m^2)	62	28 (6)
MELD at Transplant	306	22 (10)
Etiology	0	
Viral		17,324 (27%)
Cryptogenic		3,817 (6%)
Autoimmune		6,180 (9%)
NASH		3,890 (6%)
Alcoholic		11,376 (17%)
HCC		13,303 (20%)
Other		9,594 (15%)
Comorbid conditions		
Diabetes	1,153	15,536 (24%)
Dialysis	0	8,056 (12%)
DRI >1.9	4,635	28,938 (48%)
Transplant center volume (cases)	0	1060 (591)

BMI, body mass index; MELD, Model For End-Stage Liver Disease; NASH, nonalcoholic steatohepatitis; HCC, hepatocellular carcinoma; DRI, donor risk index.

Table 2.

Multivariable Cox proportional hazards model of overall mortality after liver transplantation, with county-level shared frailty term (N = 47,769)

Covariate	HR	95% CI	P
Age (y)	1.02	(1.01 – 1.02)	<0.001
Sex			
Male	Ref.		
Female	0.99	(0.94 – 1.03)	0.559
Race			
White	Ref.		
Black	1.19	(1.12 – 1.27)	<0.001
Other	0.79	(0.75 – 0.84)	<0.001
Education			
High School or less	Ref.		
Some College	0.94	(0.89 – 0.98)	0.010
College degree	0.90	(0.86 – 0.95)	<0.001
Insurance Status			
Private Insurance	Ref.		
Medicaid	1.21	(1.14 – 1.28)	<0.001
Medicare	1.19	(1.14 – 1.25)	<0.001
Other insurance	1.08	(0.96 – 1.21)	0.193
BMI (kg/m^2)	0.99	(0.99 – 1.00)	<0.001
MELD at Transplant	1.01	(1.00 – 1.01)	<0.001
Etiology			
Viral	Ref.		
Cryptogenic	0.75	(0.68 – 0.82)	<0.001
Autoimmune	0.63	(0.58 – 0.69)	<0.001
NASH	0.75	(0.67 – 0.83)	<0.001
Alcoholic	0.90	(0.85 – 0.95)	<0.001
HCC	1.10	(1.04 – 1.16)	0.001
Other	0.90	(0.84 – 0.96)	0.003
Comorbid conditions			
Diabetes	1.27	(1.21 – 1.32)	<0.001
Dialysis	1.25	(1.17 – 1.33)	<0.001
DRI >1.9	1.31	(1.27 – 1.37)	<0.001
Transplant center volume (cases)	1.00	(0.99 – 1.00)	0.539

HR, hazard ratio; CI, confidence interval; BMI, body mass index; MELD, Model For End-Stage Liver Disease; NASH, nonalcoholic steatohepatitis; HCC, hepatocellular carcinoma; DRI, donor risk index.

Table 3.

Comparison of multivariable Cox proportional hazards models of overall mortality after liver transplantation, adjusted for recipient, donor, and county covariates (N= 36,984)

Estimate*	Model 1: Recipient and donor covariates only	Model 2: Model 1 + County CHS	Model 3: Model 1 + Count y SES
County-level covariate quintile†			
Q1 (lowest) HR (95% CI; p)	--	ref.	ref.
Q2 HR (95% CI; p)	--	0.99 (0.91, 1.07; p=0.733)	1.03 (0.97, 1.09; p=0.368)
Q3 HR (95% CI; p)	--	1.02 (0.94, 1.11; p=0.619)	1.04 (0.97, 1.11; p=0.235)
Q4 HR (95% CI; p)	--	0.94 (0.87, 1.02; p=0.143)	1.10 (1.02, 1.18; p=0.013)
Q5 (highest) HR (95% CI; p)	--	0.92 (0.84, 0.99; p=0.032)	1.00 (0.92, 1.10; p=0.923)
Variance of county-level shared frailty (SE; LR test p) ‡	0.009 (0.003; p<0.001)	0.007 (0.003; p=0.007)	0.007 (0.003; p=0.001)
Improvement over model without county-level covariates (LR test p)		p=0.004	p=0.0.048

*All models include a county-level shared frailty term, representing residual variation in mortality hazard across United States counties, after adjustment for model covariates. Results for individual-level covariates are not shown. Full results of Model 1 are presented in Table 2.

†County-level covariates are CHS in Model 2 and SES in Model 3.

‡P<0.05 indicates statistically significant residual difference in outcomes across counties.

CI, confidence interval, HR, hazard ratio, LR, likelihood ratio, SE, standard error.