MELD is MELD is MELD? Transplant center–level variation in waitlist mortality for candidates with the same biological MELD

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Abstract

Recently, model for end-stage liver disease (MELD)-based liver allocation in the United States has been questioned based on concerns that waitlist mortality for a given biologic MELD (bMELD), calculated using laboratory values alone, might be higher at certain centers in certain locations across the country. Therefore, we aimed to quantify the center-level variation in bMELD-predicted mortality risk. Using Scientific Registry of Transplant Recipients (SRTR) data from January 2015 to December 2019, we modeled mortality risk in 33,260 adult, first-time waitlisted candidates from 120 centers using multilevel Poisson regression, adjusting for sex, and time-varying age and bMELD. We calculated a "MELD correction factor" using each center's random intercept and bMELD coefficient. A MELD correction factor of +1 means that center's candidates have a higher-than-average bMELD-predicted mortality risk equivalent to 1 bMELD point. We found that the “MELD correction factor” median (IQR) was 0.03 (−0.47, 0.52), indicating almost no center-level variation. The number of centers with “MELD correction factors” within ±0.5 points, and between ±0.5–±1, ±1.0–±1.5, and ±1.5–±2.0 points was 62, 41, 13, and 4, respectively. No centers had waitlisted candidates with a higher-than-average bMELD-predicted mortality risk beyond ±2 bMELD points. Given that bMELD similarly predicts waitlist mortality at centers across the country, our results support continued MELD-based prioritization of waitlisted candidates irrespective of center.
1 | INTRODUCTION

For almost 20 years, the Model for End-stage Liver Disease (MELD) score has been considered the objective and measurable medical criterion used to arrange waitlisted candidates with end-stage liver disease in order of medical urgency and to fairly distribute scarce deceased donor livers.\cite{1,2,3} Recent policy changes altering geographic units for liver recovery and allocation,\cite{4,5} however, have invigorated discussions around the fairness of MELD-based prioritization. Specifically, there are concerns that MELD-based liver allocation might unfairly disadvantage transplant centers that disproportionately serve "sicker" populations who have relatively higher waitlist mortality than would be accounted for in their MELD score.\cite{6,7} As such, some have even advocated against broader sharing of livers as it might shift livers out of centers serving vulnerable, disadvantaged, relatively sicker populations to large, urban, relatively wealthier centers where waitlisted candidates may have a higher likelihood of survival at any given MELD score.\cite{7,8}

Prior studies have demonstrated that demographic and social risk factors for waitlist mortality are asymmetrically distributed across the United States,\cite{8,9,10} and these factors are not captured in the biologic MELD (bMELD) that is calculated using laboratory values alone. After accounting for MELD, waitlisted candidates from high-risk communities, defined by individual-level health status and behaviors and community health-related resources, have up to a 16% greater waitlist mortality than those in the lowest risk communities.\cite{9} It might be that if a transplant center were to disproportionally serve waitlisted candidates from these high-risk communities, MELD-based allocation of deceased donor livers would underserve the center's waitlisted population if their true mortality risk were higher than bMELD-predicted. If this is true, it would mean that radical changes are warranted to arrange waitlisted candidates in order of medical urgency or to modulate deceased donor liver supply as to temper mortality risk above bMELD-predicted at certain centers across the country. For wait-listed candidates who are not granted exception points for the inaccuracy of bMELD in reflecting their medical urgency, the degree of variation in excess mortality risk across transplant centers that is not biologic MELD-predicted has not been well described.

Therefore, the goal of this study was to compare the mortality risk of waitlisted candidates with the same MELD across transplant centers in the United States. We used transplant registry data to (i) quantify the unique mortality risk of waitlisted candidates at each transplant center, (ii) calculate a corrected MELD score for each transplant center based on their unique mortality risk, and (iii) characterize the variation in corrected MELD across transplant centers.
METHODS

2.1 Data source

This study used data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donor, wait-listed candidates, and transplant recipients in the US, submitted by the members of the Organ Procurement and Transplant Network (OPTN), and has been described elsewhere. The Health Resources and Services Administration (HRSA), U.S. Department of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors.

2.2 Study population

We identified 33,260 adult, first-time, liver-only waitlist candidates from 120 transplant centers listed between January 1, 2015 and December 31, 2019. To assess the medical urgency for liver transplantation, waitlist candidates were assigned with bMELD score, a numerical score ranging from 6 to 40 using serum creatinine, bilirubin, INR, and serum sodium values. Biologic MELD is distinct from allocation MELD, which includes the combination of bMELD and exception scores, scores granted after regional board review according to liver allocation policy for candidates with disease severity that is not accurately represented by bMELD alone. We excluded candidates who were granted exception scores given that exception scores are influenced by policy era or geography. We also excluded candidates who were never active on the waitlist and patients who ever received exception points or were ever listed as Status 1, if information about listing center was missing (n = 8). In addition, we also excluded all registrants from transplant centers with fewer than five waitlisted candidates. We characterized candidates’ age, sex, race/ethnicity (characterized as White, Black, Hispanic, Asian, or other race), primary indication for transplant, bMELD at listing, and insurance status.

2.3 Waitlist mortality risk

Waitlist mortality was defined as candidate’s removal from the waitlist due to death, deteriorating condition, or medical unsuitability. To estimate center-level variation in mortality risk among candidates with similar bMELD, we modeled waitlist mortality for each transplant center using multivariable, multilevel Poisson regression adjusting for candidate time-varying age (per 10 years), bMELD (per point), and sex. Race/ethnicity was not found to be a confounder, and not included in the model. In our model, we used the latest MELD score in all censoring events. Censoring events included transplantation, removal for other reasons, and administrative censoring at study duration end on December 31, 2019. We modeled fixed effects to describe the average mortality risk across all transplant centers and allowed each transplant center to have its own y-intercept (i.e., unique mortality risk). The center-level random intercept represented the relative waitlist mortality risk at each center compared to the national average, after adjusting for bMELD and other covariates.
2.4 | Center-level MELD correction factor

To estimate whether candidates with the same bMELD at different centers had the same mortality risk, we estimated a novel metric, the “MELD correction factor,” dividing the center-level random intercept as described above by the coefficient for bMELD from the same model. The MELD correction factor illustrates relative wait-list mortality risk at each center compared to the national average, scaled to MELD points. For example, A MELD correction factor of 0 would mean that candidates at that center have MELD-adjusted mortality risk equivalent to the national average; a MELD correction factor of +1 would mean that candidates at that center have a higher-than-average MELD-adjusted mortality risk (e.g., candidates with bMELD of 17 at that center have mortality risk equivalent to patients with a bMELD of 18 elsewhere). A MELD correction factor of −1 would mean that candidates at that center have a lower-than-average MELD-adjusted mortality risk (e.g., candidates with bMELD of 17 at that center have risk equivalent to bMELD of 16 elsewhere). We plotted MELD correction factors using a caterpillar plot to show the center-level variation in MELD adjusted mortality risk. To illustrate the geographic pattern of MELD-adjusted waitlist mortality risk, we plotted MELD correction factors for transplant centers on color-scaled maps.

2.5 | MELD correction factors within MELD strata

If there is variation in center-level mortality risk that is not adequately captured by bMELD, it may vary depending on the patient's severity of illness; for example, it may be present only among patients with the highest bMELD scores. To check whether this is the case, we estimated center-level MELD correction factors specific to different strata of bMELD score: 16–20, 21–25, 26–30, 31–35, and 36–40.

2.6 | Sensitivity analysis

It is possible that waitlisted candidates bMELD progression might differ across different transplant centers, and our analysis adjusting for time-varying MELD would not capture this difference. Therefore, we performed a sensitivity analysis in which we selected one day at random from each candidate's time on the waitlist and followed each candidate from that day until mortality, transplant, other waitlist removal, or censorship at 90 days. We repeated our calculation of the MELD correction factor, adjusting for MELD on that random day, but not censoring for or adjusting for a change in MELD. In this analysis, if candidates at some centers have a swifter increase in MELD and subsequent increased mortality risk, it would be reflected in an increased MELD correction factor.

2.7 | Statistical analysis

Confidence intervals are reported as per the method of Louis and Zeger. All analyses were performed using Stata 14.1/MP for Linux (College Station, TX).
3 | RESULTS

3.1 | Study population

We identified 33,260 waitlist candidates (Table 1). The median age was 56, 39.2% were female, 73.8% were Caucasian, 6.3% were African American, 15.2% were Hispanic/Latino, 3% were Asian, and 53.9% had private insurance. Median (IQR) bMELD at listing was 18 (14–25). Primary causes of liver failure were alcoholic cirrhosis (35%), cirrhosis due to Hepatitis C virus (10.2%), non-alcoholic steatohepatitis (21.1%), and hepatocellular carcinoma (2.3%).

3.2 | Waitlist mortality risk

For each bMELD point, there was a 26% increase in the relative rate of waitlist mortality (IRR = $1.25$ to $1.26$) (Table 2, Table S1). The relative waitlist mortality risk at each center compared to the national average was 0.21.

3.3 | Center-level MELD correction factor

Across transplant centers, the median MELD correction factor (IQR) was 0.03 (IQR: −0.47 to 0.52) (Figure 1B). Only eight centers had a MELD correction factor less than −1.0, and nine centers had a MELD correction factor greater than 1.0 (Figure 1A). Only three transplant centers had a MELD correction factor greater than 1.5, and only 1 center had MELD correction factor less than −1.5. All centers had MELD correction factors between −2 and 2, indicating little variation in mortality risk for candidates with similar MELD at different centers. There was no clear geographic pattern of MELD correction factors (Figure 2).

3.4 | MELD correction factors within MELD strata

There was mild center-level variation in MELD-adjusted mortality risk after stratified analysis. Median (IQR) MELD correction factors for strata 16–20, 21–25, 26–30, 31–35, and 36–40 were −0.01 (−0.10 to 0.09), −0.02 (−0.16 to 0.16), −0.01 (−0.24 to 0.24), 0.01 (−0.71 to 0.69), and −0.09 (−0.53 to 0.52), respectively. In other words, even at the very highest bMELD ranges, there were almost no differences in mortality across transplant centers for patients with the same bMELD. There was more variation in the higher MELD strata; nine transplant centers in MELD stratum 31–35 and five transplant centers in MELD stratum 36–40 had MELD correction factors beyond ±2 (Figure 3).

3.5 | Sensitivity analysis

The median (IQR) MELD correction factor was −0.09 (−0.38, 0.56) MELD points with a range of −1.68 to 1.46 MELD points, broadly consistent with our main findings.

4 | DISCUSSION

In this national study of 33,260 liver transplant candidates at 120 centers, we found that the MELD correction factor median (IQR) was 0.03 (−0.47 to 0.52), indicating almost no center-level variation in bMELD-predicted mortality risk. The number of centers with MELD correction factors within ±0.5 points and between ±0.5 to ±1, ±1.0 to ±1.5, and
±1.5 to ±2.0 points was 62, 41, 13, and 4, respectively. There were no centers with MELD correction factors ±2 points greater than the national average mortality risk.

Our finding that bMELD similarly predicts mortality risk across transplant centers indicates that bMELD is operating as anticipated and accurately predicting mortality risk in patients with end-stage liver disease,\textsuperscript{13,14} independent of transplant center. In prior studies, the \( c \) statistic,\textsuperscript{15} a widely used marker of predictive discrimination, ranged from 0.83 to 0.88,\textsuperscript{16-18} indicating excellent predictive accuracy. Early results following MELD-based allocation in 2002 demonstrated a decrease in overall waitlist mortality risk\textsuperscript{19} with minimal variation across demographics (i.e., age, sex, and race/ethnicity).\textsuperscript{20} MELD-based allocation actually decreased racial disparities in mortality risk.\textsuperscript{21} However, prior studies have not directly addressed the question of whether some transplant centers serve relatively sicker waitlisted candidates as compared to others. Our finding of minimal center-level variation in actual mortality risk for waitlisted candidates at different transplant centers with the same bMELD augments what is already known about bMELD's predictive and discrimination ability.

We found a minority of centers had MELD correction factors ±1.5. This observed higher-than-average waitlist mortality risk may not be a failure of bMELD prediction, but a result of unmeasured and/or unadjusted differences in patient case-mix and ESLD care and interventional resources across the country.\textsuperscript{22-24} In a study using National Inpatient Sample data of hospital admissions, patients with cirrhosis admitted to rural hospitals had higher in-hospital mortality and less frequently underwent liver disease-specific procedures, such as paracentesis or endoscopy.\textsuperscript{25} Alternatively, it may be the result of differences in laboratory measurement, as centers testing identical blood samples have been found to report MELD differences up to 6 points.\textsuperscript{26} Similar to prior studies, we found that the greatest variation in bMELD-predicted mortality risk was observed among candidates with MELD 26–30. In an analysis that followed transplant recipients from the time of listing, the variation in 1-year waitlist mortality across transplant centers was 20.6%–28.8%, greater than post-transplant mortality variation, and more varied (53%–72.1%) among candidates with MELD ≥25.\textsuperscript{27} The rare transplant centers and circumstances that have a relatively higher-than-average wait-list mortality risk likely warrants targeted investigation rather than radical changes to MELD-based allocation.

Due to our methods, our findings are different than OPTN/SRTR Annual Data Reports and SRTR’s Liver Transplant Waitlist Outcomes Tool (version 1.4),\textsuperscript{28,29} which predicts that two liver transplant programs in New York within the same geographic unit of allocation can have a 2%–14% waitlist mortality or removal for candidates with same MELDs of 25–29. In contrast to SRTR tools that incorporates transplant as a competing risk with death, we used a censoring model to evaluate bMELD alone. By design, competing risk frameworks are sensitive to changes in allocation and availability of deceased donor livers,\textsuperscript{30} and substantial differences in mortality due to access to liver transplantation have been previously reported.\textsuperscript{31,32} In contrast, our study aim was to determine whether some transplant centers have more severely ill-waitlisted candidates as compared to others after accounting bMELD. As such, we used a censoring model to estimate mortality risk that is not influenced by deceased donor liver allocation. Given that our aim was to address potential differences in mortality risk that are not accounted for by bMELD, we also
excluded waitlisted candidates who were granted exception points. Inclusion of waitlisted candidates who are granted exception points affects waitlist mortality estimation. There is well described geographic variation in both exception point use and potential misuse, and variation in exception point practice has been cited to inaccurately describe geographic disparities. While SRTR tools and competing risk frameworks reflect how the liver allocation system is functioning overall, it does not address variation in bMELD-predicted mortality risk as we have.

Recent policy has altered geographic units of liver allocation from donor service areas to fixed-distance, acuity circles. Deceased donor liver allocation to waitlisted candidates is still MELD-based, meaning that understanding geographic variation in MELD-predicted mortality risk is important irrespective of the geographic unit of allocation. Using a censoring model insensitive to allocation policy changes, we have created a novel metric that can be used to describe differences in bMELD and mortality risk, which is critical to the discussions around fairness of current bMELD-based allocation of deceased donor livers across transplant centers. The metric is easy to calculate using standard programming packages, and we present it as a scaled measurement with incremental point changes that are intuitive and equivalent to well accepted bMELD scoring.

Our study is not without limitations. First, national registry data limits our modeling of the mortality risk. Sociodemographic characteristics have been found to be associated with waitlist mortality but are narrowly ascertained in transplant registry data, with prior studies defaulting to area-level surrogates. However, our finding that there is little variation after accounting for demographic factors (e.g., sex and age) suggests that additional sociodemographic factors are not major contributors to differences in waitlist mortality across transplant centers. We and others have previously demonstrated the value of serial bMELD measurements and how rapid changes in MELD score predict waitlist mortality better than a single time-invariant MELD score. While we did incorporate bMELD as a time-varying covariate, we did not model the change in bMELD score because the current prioritization model does not do so. Lastly, while delayed reporting of MELD changes would affect estimation of mortality risk, this data limitation is unlikely to bias our results given that reporting timeliness is likely not differential across transplant centers. Further, if there are systematic differences in reporting or MELD measurement across transplant centers that is related to center-level variation in MELD-based mortality risk, it would result in a bias towards larger MELD correction factors.

We found that the mortality risk of waitlisted candidates with similar bMELD varies very little across transplant centers in the United States, suggesting that bMELD-based allocation does not favor or penalize some transplant centers over others.

**Supplementary Material**

Refer to Web version on PubMed Central for supplementary material.
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Abbreviations:

- MELD: Model for End-stage Liver Disease
- OPTN: Organ Procurement and Transplant Network
- SRTR: Scientific Registry of Transplant Recipients
- UNOS: United Network for Organ Sharing

REFERENCES

1. Staff IoM. Organ procurement and transplantation: assessing current policies and the potential impact of the DHHS final rule. National Academies Press; 1900.
2. Freeman RB Jr, Wiesner RH, Harper A, et al. The new liver allocation system: moving toward evidence-based transplantation policy. Liver Transpl. 2002;8(9):851–858. [PubMed: 12200791]
3. Freeman RB Jr, Edwards EB. Liver transplant waiting time does not correlate with waiting list mortality: implications for liver allocation policy. Liver Transpl. 2000;6(5):543–552. [PubMed: 10980052]
4. Organ Procurement and Transplantation Network. OPTN policy notice: liver and intestine distribution using distance from donor hospital. https://optn.transplant.hrsa.gov/media/2788/liver_policynotice_201901.pdf. Accessed April 28, 2021.
5. Organ procurement and transplantation network: liver: liver policy: overview. 2018. https://optn.transplant.hrsa.gov/governance/policy-initiatives/liver/. Accessed March 12, 2020, 2020.
6. OPTN. Liver and intestine distribution using distance from donor hospital. 2018; https://optn.transplant.hrsa.gov/governance/public-comment/liver-and-intestine-distribution-using-distance-from-donor-hospital/. Accessed April 30, 2020.
7. Baliga P, Sade RM. New liver allocation policy: flawed moral and empirical foundations. J Law Med Ethics. 2019;47(2):320–322. [PubMed: 31298109]
8. Lynch RJ, Ye F, Sheng Q, Zhao Z, Karp SJ. State-based liver distribution: broad sharing with less harm to vulnerable and under-served communities compared with concentric circles. Liver Transpl. 2019;25(4):588–597. [PubMed: 3087361]
9. Ross K, Patzer RE, Goldberg DS, Lynch RJ. Sociodemographic determinants of waitlist and posttransplant survival among end-stage liver disease patients. Am J Transplant. 2017;17(11):2879–2889. [PubMed: 28695615]
10. Lynch RJ, Magliocca JF, Hundley JC, Karp SJ. Moving past "think local, act global": a perspective on geographic disparity. Am J Transplant. 2019;19(7):1907–1911. [PubMed: 30125467]
11. Massie AB, Kucirka LM, Segev DL. Big data in organ transplantation: registries and administrative claims. Am J Transplant. 2014;14(8):1723–1730. [PubMed: 25040084]
12. Louis TA, Zeger SL. Effective communication of standard errors and confidence intervals. Biostat. 2009;1:1–2.

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13. Malinchoc M, Kamath PS, Gordon FD, Peine CJ, Rank J, ter Borg PC. A model to predict poor survival in patients undergoing transjugular intrahepatic portosystemic shunts. Hepatol. 2000;31(4):864–871.

14. Kamath PS, Wiesner RH, Malinchoc M, et al. A model to predict survival in patients with end-stage liver disease. Hepatol. 2001;33(2):464–470.

15. Pencina MJ, D’Agostino RB Sr. Evaluating discrimination of risk prediction models: the C statistic. JAMA. 2015;314(10):1063–1064. [PubMed: 26348755]

16. Wiesner R, Edwards E, Freeman R, et al. Model for end-stage liver disease (MELD) and allocation of donor livers. Gastroenterol. 2003;124(1):91–96.

17. Said A, Williams J, Holden J, et al. Model for end stage liver disease score predicts mortality across a broad spectrum of liver disease. J Hepatol. 2004;40(6):897–903. [PubMed: 15158328]

18. Leise MD, Kim WR, Kremers WK, Larson JJ, Benson JT, Therneau TM. A revised model for end-stage liver disease optimizes prediction of mortality among patients awaiting liver transplantation. Gastroenterol. 2011;140(7):1952–1960.

19. Austin MT, Poulose BK, Ray WA, Arborgast PG, Feurer ID, Pinson CW. Model for end-stage liver disease: did the new liver allocation policy affect waiting list mortality? Arch Surg. 2007;142(11):1079–1085. [PubMed: 18025337]

20. Freeman RB, Wiesner RH, Edwards E, Harper A, Merion R, Wolfe R. Results of the first year of the new liver allocation plan. Liver Transpl. 2004;10(1):7–15. [PubMed: 14755772]

21. Moylan CA, Brady CW, Johnson JL, Smith AD, Tuttle-Newhall JE, Muir AJ. Disparities in liver transplantation before and after introduction of the MELD score. JAMA. 2008;300(20):2371–2378. [PubMed: 19033587]

22. Mathur AK, Chakrabarti AK, Mellinger JL, et al. Hospital resource intensity and cirrhosis mortality in United States. World J Gastroenterol. 2017;23(10):1857–1865. [PubMed: 28348492]

23. Mellinger JL, Richardson CR, Mathur AK, Volk ML. Variation among United States hospitals in inpatient mortality for cirrhosis. Clin Gastroenterol Hepatol. 2015;13(3):577–584. [PubMed: 25264271]

24. Chakrabarti A, Osborne NH, Rangnekar AS, Mathur AK. The Effect of hospital characteristics on racial/ethnic variation in cirrhosis mortality. J Racial Ethn Health Disparities. 2017;4(2):243–251. [PubMed: 27068660]

25. Ross KH, Patzer RE, Goldberg D, Osborne NH, Lynch RJ. Rural-Urban differences in in-hospital mortality among admissions for end-stage liver disease in the United States. Liver Transplant. 2019;25(9):1321–1332.

26. Verna EC, Connelly C, Dove LM, et al. Center-related bias in MELD scores within a liver transplant UNOS region: a call for standardization. Transplant. 2020;104(7):1396–1402.

27. Kwong AJ, Flores A, Saracino G, et al. Center variation in intention-to-treat survival among patients listed for liver transplant. Liver Transplant. 2020;26(12):1582–1593.

28. Kwong A, Kim WR, Lake JR, et al. OPTN/SRTR 2018 annual data report: liver. Am J Transplant. 2020;20(s1):193–299. [PubMed: 31898413]

29. Scientific Registry of Transplant Recipients. Liver Transplant Waiting List Outcomes Tool. https://www.srtr.org/reports/waiting-list-calculator/. Accessed April 28, 2021.

30. Kim WR, Therneau TM, Benson JT, et al. Deaths on the liver transplant waiting list: an analysis of competing risks. Hepatol. 2006;43(2):345–351.

31. Massie AB, Caffo B, Gentry SE, et al. MELD exceptions and rates of waiting list outcomes. Am J Transplant. 2011;11(11):2362–2371. [PubMed: 21920019]

32. Gentry SE, Massie AB, Cheek SW, et al. Addressing geographic disparities in liver transplantation through redistricting. Am J Transplant. 2013;13(8):2052–2058. [PubMed: 23837931]

33. Ishaque T, Massie AB, Bowring MG, et al. Liver transplantation and waitlist mortality for HCC and non-HCC candidates following the 2015 HCC exception policy change. Am J Transplant. 2019;19(2):564–572. [PubMed: 30312530]

34. Goldberg DS, Makar G, Bittermann T, French B. Center variation in the use of nonstandardized model for end-stage liver disease exception points. Liver Transpl. 2013;19(12):1330–1342. [PubMed: 24039090]
35. Cannon RM, Davis EG, Goldberg DS, et al. Regional variation in appropriateness of non-hepatocellular carcinoma model for end-stage liver disease exception. J Am Coll Surg. 2020;230(4):503–512.e8. [PubMed: 32007535]

36. Merion RM, Wolfe RA, Dykstra DM, Leichtman AB, Gillespie B, Held PJ. Longitudinal assessment of mortality risk among candidates for liver transplantation. Liver Transpl. 2003;9(1):12–18. [PubMed: 12514767]

37. Massie AB, Luo X, Alejo JL, Poon AK, Cameron AM, Segev DL. Higher mortality in registrants with sudden model for end-stage liver disease increase: disadvantaged by the current allocation policy. Liver Transpl. 2015;21(5):683–689. [PubMed: 25762287]
FIGURE 1.
(A) Estimates of MELD correction factors for each transplant center. (B) Distribution of MELD correction factor across transplant centers. A positive MELD correction factor indicates that patients at that center have higher than average waitlist mortality risk after adjusting for MELD (e.g., a value of +1.0 indicates that candidates with MELD of 17 at that center had risk equivalent to MELD of 18 elsewhere). The different shadings represent MELD corrections factors less than −1, −1 to +1; and +1 to +2, more than +2, respectively.
FIGURE 2.
Geographic distribution of MELD correction factors
FIGURE 3.
Distribution of MELD correction factors across transplant centers by MELD stratum. The median (IQR) of MELD correction factors for each MELD stratum were within ±1. MELD correction factors for all transplant centers, represented by violin plot of MELD 6–40, were within ±2. When stratified by MELD score, MELD strat a 31–35 and 36–40, composed of nine and five transplant centers, respectively, had MELD correction factors > ±2
**TABLE 1**
Characteristics of the adult, first-time, liver-only waitlist candidates from 118 transplant centers listed between 01/2013 and 06/2017

| Characteristics                        | Percent (%) |
|----------------------------------------|-------------|
| N                                      | 33,260      |
| Age at listing (median, IQR)           | 56 (48–62)  |
| Female (%)                             | 39.2        |
| Race/ethnicity (%)                     |             |
| Caucasian                              | 73.8        |
| African American                       | 6.3         |
| Hispanic/Latino                        | 15.2        |
| Asian                                  | 3.0         |
| Others                                 | 1.7         |
| Insurance status (%)                   |             |
| Public                                 | 45.5        |
| Private                                | 53.9        |
| Others                                 | 0.6         |
| Primary diagnosis (%)                  |             |
| Hepatitis C virus                      | 10.2        |
| Alcoholic cirrhosis                    | 35.0        |
| Non-alcoholic steatohepatitis          | 21.1        |
| Hepatocellular carcinoma               | 2.3         |
| Others                                 | 31.5        |
| Biologic MELD at listing (median, IQR) | 18 (14–25)  |
### TABLE 2

Adjusted relative rate of waitlist mortality from multivariable, multilevel Poisson regression model

| Characteristic                  | Adjusted relative rate |
|---------------------------------|------------------------|
| Biologic MELD (per point)       | 1.251.26               |
| Age decade                      | 1.571.61               |
| Sex                             |                        |
| Male                            | Reference              |
| Female                          | 1.031.09               |
| Random effect parameters for transplant center | 0.21 |

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