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## Community Health Status and Outcomes after Allogeneic Hematopoietic Cell Transplantation in the United States

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## Abstract

**Background:** The association of community factors and outcomes after hematopoietic cell transplantation (HCT) has not been comprehensively described. We evaluated the impact of community health status on allogeneic HCT outcomes using the County Health Rankings and Roadmaps (CHRR) and the Center for International Blood and Marrow Transplant Research (CIBMTR).

**Methods:** We included 18,544 adult allogeneic HCT recipients reported to CIBMTR by 170 United States centers in 2014–2016. We derived sociodemographic, environmental, and community indicators from the CHRR, created an aggregate community risk score, and assigned them to each patient (PCS) and transplant center (CCS). Higher scores indicate less healthy communities. We studied the impact of PCS and CCS on patient outcomes after allogeneic HCT.

**Results:** The median age was 55 (range 18–83). The median PCS was  $-0.21$  (range,  $-1.37$  to  $2.10$ ; standard deviation [SD]  $0.42$ ) and the median CCS was  $-0.13$  (range  $-1.04$  to  $0.96$ ; SD  $0.40$ ). In multivariable analyses, higher PCS was associated with inferior survival (hazard ratio [HR]/ 1 SD increase  $1.04$ , [99% CI  $1.00$ – $1.08$ ],  $p=0.0089$ ). Among hematologic malignancies, we observed a tendency towards inferior survival (HR  $1.04$ , [ $1.00$ – $1.08$ ],  $p=0.0102$ ) with higher PCS; higher PCS was associated with higher non-relapse mortality (NRM) (HR  $1.08$ , [ $1.02$ – $1.15$ ],  $p=0.0004$ ). CCS was not significantly associated with survival, relapse, or NRM.

**Conclusion:** Patients residing in counties with worse community health status have inferior survival, as a result of an increased risk of NRM after allogeneic HCT. There was no association between community health status of transplant center location and allogeneic HCT outcomes.

## Precis:

We developed a new community risk score for HCT recipients derived from a large publicly available database (the County Health Rankings & Roadmaps) to describe patient and transplant center community health status. Patient community-risk score (PCS) was associated with non-relapse mortality and overall survival, however center community-risk score (CCS) was not associated with transplant outcomes.

## Keywords

Hematopoietic cell transplantation; Allogeneic transplant; Community health; Survival

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## INTRODUCTION

Allogeneic hematopoietic cell transplantation (HCT) access and outcomes can be influenced by several factors contributing to health care disparity.<sup>1–6</sup> Health care disparity is a complex construct; multilevel patient, provider, institutional, community, and societal factors are important in the context of allogeneic HCT.<sup>2,3</sup> These factors may influence patients' choices and behaviors as well as transplant center practices. The role of patient-level factors is easier to understand and evaluate; age, sex, race/ethnicity, and socioeconomic status have been frequently studied as social determinants of HCT access and recipient outcomes.<sup>1–4</sup> The impact of health-disparities as determined by community factors on allogeneic HCT outcomes is less clear and has been only partially described with sociodemographic factors such as race, ethnicity, and income. Community factors may be associated with allogeneic HCT outcomes since transplant centers and providers cannot always identify, address, or mitigate patient-specific community and social issues that may directly or indirectly influence recipient outcomes. Additionally, the health status of the community where a center is located may affect its practices, referral patterns, and care delivery system, which may ultimately be reflected in individual patient outcomes and the aggregate outcomes of all patients transplanted at that center.

As noted above, the literature in HCT has mostly focused on sex, race/ethnicity, and socioeconomic status.<sup>7,8</sup> A significant challenge in comprehensively describing the myriads of healthcare disparity factors in allogeneic HCT was the lack of a tool that can objectively evaluate community and social determinants of health among transplant recipients. The County Health Rankings and Roadmaps (CHRR) project uses the information on sociodemographic, environmental, and community health status from several national data resources and summarizes them into a composite measure of the health status for all counties in the United States (US).<sup>9</sup> County health status using this resource has been associated with access and outcomes in complex surgical procedures and has been investigated in solid organ transplantation.<sup>10–12</sup>

We used data on community health disparity factors from the CHRR and on patient characteristics and transplant outcomes from the Center for International Blood and Marrow Transplant Research (CIBMTR) to test our hypothesis that community health status of the patient and the center are associated with patient outcomes after allogeneic HCT. The primary objective of our study was to evaluate associations of community health status of patient residence and community health status of transplant center location with patient survival, relapse, and non-relapse mortality (NRM).

The CIBMTR administers the Stem Cell Therapeutic Outcomes Database, a component of the C.W. Bill Young Transplantation Program, through a contract with the Health Resources and Services Administration. Under the purview of this law, transplant centers in the US are required to report data for all allogeneic HCT recipients to the CIBMTR. As part of

this contract, the CIBMTR performs an annual center-specific outcomes analysis (CSA) and reports risk-adjusted one-year survival for first allogeneic HCT of rolling three-year window for each center in the US.<sup>13–15</sup> CSA method reflects recommendations of the 2010 Center-Specific Outcomes Analysis Forum.<sup>16,17</sup> The center-specific outcomes analysis model is a complex statistical model, currently considering over 30 variables. Variables to be adjusted for are determined through model selection procedures. As a secondary objective, we explored whether patient community-risk score (PCS) and center community-risk score (CCS) would be independent predictors of 1-year survival, using the same exact model (pseudo-value logistic regression model) and parameters that are currently analyzed in the CSA model.

## MATERIALS AND METHODS

### Data Source: CIBMTR

The CIBMTR is a voluntary and international working group of transplantation centers that contribute data on their HCT to statistical centers located at the Medical College of Wisconsin, Milwaukee and the National Marrow Donor Program (NMDP), Minneapolis. Participating centers are required to report all transplantations consecutively; patients are followed longitudinally. Computerized checks for discrepancies, physicians' review of submitted data, and on-site audits of participating centers ensure data quality. Observational studies conducted by the CIBMTR are performed in compliance with the Privacy Rule (HIPAA) as a Public Health Authority and with all applicable federal regulations, as determined by continuous review of the Institutional Review Board of the NMDP.

### Data Source: CHRR

The CHRR project is a collaboration between the University of Wisconsin Population Health Institute and the Robert Wood Johnson Foundation. The CHRR provides annually updated information on county-level health factors and outcomes that can serve as surrogate measures of disparities among communities.<sup>9,18</sup> Data on these measures are obtained from a variety of public data sources.<sup>18</sup> The measures are standardized among all counties across the US, combined using scientifically-informed weights and are publicly available at [www.countyhealthrankings.org](http://www.countyhealthrankings.org). Details of the ranking methodology and measures are available through the CHRR website. Briefly, counties in each of the 50 US states are ranked according to summaries of a variety of health measures. The overall "Health Factors" summary score is a weighted composite of four components: health behaviors, clinical care, social and economic environment, and physical environment. For example, the measures included within the health behaviors domain are rates of adult smoking, adult obesity, food environment index, physical inactivity, access to exercise opportunities, excessive drinking, alcohol-impaired driving deaths, sexually transmitted diseases, and teen birth. The clinical care domain consists of rates of uninsured, preventable hospital stays, diabetes monitoring, mammography screening, and availability of primary care physicians, dentists, and mental health providers.

Using the 2018 CHRR data, we created patient- and center-specific composite scores based on "Health Factors" assigned to the ZIP code of patient residence and center

location, allowing calculation of a nationally standardized score for each patient and center, respectively. The Z-scores of thirty variables that constitute “Health Factors” from the CHRR were normalized to bring all measures into the same scale by subtracting the national average of that measure and dividing by the national standard deviation (SD). For most measures, a higher score indicated worse health factors. For the few measures where this was reversed (i.e., diabetes monitoring and mammography screening), the Z-scores were multiplied by  $-1$  to maintain directional consistency. The final PCS was computed by multiplying Z-scores for all measures by their weights and then adding all weighted measures. For PCS, we linked ZIP codes of patient residence at the time of HCT to county information, using the Centers for Disease Control and Prevention (CDC)’s Federal Information Processing Standards (FIPS).<sup>19</sup> Similarly, we assigned CCS by deriving a composite score from ZIP code and FIPS of each transplant center location.

### Study Population

For our study, we used data on patients included in the CIBMTR’s 2018 center-specific outcomes analysis dataset. The dataset included 24,141 adult recipients who underwent their first allogeneic HCTs at US centers from 2014 to 2016. We excluded recipients who were  $<18$  years of age at the time of HCT due to the concern that different factors influence their outcomes compared to adults ( $N=3,784$ ). We excluded patients who had missing ZIP code or FIPS ( $N=506$ ) or had not consented for research ( $N=1,166$ ). We also excluded 138 patients residing in counties for whom no data were available in the CHRR. Categories with a very small number of recipients were also excluded (2 with inherited erythrocyte abnormalities and one related cord blood transplant recipient). Hence, our final study cohort consisted of 18,544 patients (Table 1).

The main objective of our study was to evaluate the association of PCS and CCS with patient survival after allogeneic HCT. Since we were also interested in assessing the association between PCS and CCS with relapse and NRM, we conducted a subgroup analysis in patients with hematologic malignancies ( $N=17,793$ ) after excluding 735 patients with nonmalignant diseases and 19 with solid tumors (Table 1).

For our secondary objective, we explored whether patient- and center-level health disparity factors would have a significant contribution to the center-specific analysis focused on 1-year survival. We included our study cohort of 18,544 patients to test whether the addition of PCS or CCS provided any additional information on center-specific survival that is estimated by a validated methodology. For this analysis, we used the exact same model, parameters, and outcome currently used in the CSA model.

### Statistical Analysis

For the primary objective, we used a Cox proportional hazards model to test the association of PCS and CCS with OS, relapse, and NRM. For relapse and NRM analysis, the cohort was further restricted to those with hematologic malignancies ( $N=17,793$ ). Variables included for the analyses were: recipient age/sex, recipient race/ethnicity, donor age/sex, donor race/ethnicity, performance score at HCT, disease indication, HCT comorbidity index,<sup>20</sup> transplant year, recipient and donor cytomegalovirus status, graft sources, donor

types, human leukocyte antigen (HLA) match status, donor parity, history of mechanical ventilation, history of invasive fungal infection, socioeconomic status, disease-specific variables (e.g., time from diagnosis to transplant for acute myeloid leukemia [AML] and acute lymphoblastic leukemia [ALL], therapy related AML or myelodysplastic syndrome [MDS], AML European Leukemia Network risk group,<sup>21</sup> ALL cytogenetic risk group,<sup>22</sup> cell lineage for ALL, MDS risk score,<sup>23</sup> chemotherapy sensitivity for lymphomas, subtype of non-Hodgkin lymphoma, cytogenetic risk group,<sup>24</sup> and International Staging System score for myeloma). Conditioning intensity was additionally considered as a covariate.<sup>25</sup> Given the very large sample size, we used the alpha level of 0.01 as a significance level for this analysis.

For our secondary exploratory analysis, we evaluated whether PCS and CCS provide any additional information on the endpoint used in the annual center-specific analysis of one-year survival. We examined if the addition of PCS and CCS in regression models was significantly associated with the adjusted odds of one-year survival; the center-specific analysis uses a pseudo-value logistic regression model which allows to accommodate censoring. CSA uses an alpha level of 0.05 to declare significance; thus, the same threshold was used for this analysis.<sup>13</sup> As noted above, we included all adult recipients with all disease indications in this analysis (n=18,544).

All analyses were done using SAS 9.4 (Cary, NC). All tests were two-sided.

## RESULTS

### Patient Characteristics and Distribution of PCS and CCS

The median follow-up of survivors for the whole cohort was 24 months (range, 1.5–51.8 months). Median age at HCT was 55 years (range, 18–83 years); 20% were <40 years, and 21% were ≥65 years in age at the time of their HCT (Table 1). The distribution of community health status score is described in Figure 1. Figure 2 represents the distribution of the community health status score of the patients included in the cohort by geographic location in the US. The median PCS was –0.21 (interquartile range [IQR] –0.53 to 0.03), and the median CCS was –0.13 (IQR –0.43 to 0.12). Pearson correlation coefficient between PCS and CCS was  $r=0.3$ . This represented a weakly positive linear relationship between PCS and CCS.

### PCS, CCS, and HCT Outcomes

In our first analysis evaluating the relationship of PCS and CCS with recipient outcomes (Table 2), higher PCS was associated with inferior overall survival (OS) in Cox regression multivariable analysis (hazard ratio [HR] 1.04 per one SD increase in PCS, 99% CI [1.00–1.08],  $p=0.0089$ ). On the other hand, CCS was not significantly associated with OS (HR 1.01, 99% CI [0.98–1.04],  $p=0.54$ ).

In patients with hematologic malignancies, higher PCS had a tendency towards with inferior OS (HR 1.04 per 1 SD increase, 99% CI [1.00–1.08],  $p=0.0102$ ; Table 2). This tendency was primarily driven by higher NRM in patients with higher PCS (HR 1.08, 99% CI [1.02–1.15],  $p=0.0004$ ). As in the analysis of all patients, we observed no association of CCS with

OS, NRM, or relapse among HCT recipients with hematologic malignancies (Table 2). Full results of multivariate analysis are included in Supplemental Tables 1–4. Due to the nature of our PCS and CCS calculations, results are not available in each outcome.

### PCS, CCS, and Center-Specific Analysis

For this secondary analysis, we tested PCS and CCS in the pseudo-value logistic regression model from the 2018 CIBMTR center-specific analysis, while adjusting for all patient-, disease- and transplant-related variables considered in that particular model. Neither PCS (odds ratio [OR] 1.03, 95% CI 0.99–1.08,  $p=0.11$ ) nor CCS (OR 1.02, 95% CI 0.99–1.06,  $p=0.24$ ) were significantly associated with 1-year odds of OS.

## DISCUSSION

A complex network of social, physical, and environmental factors influence health care access, delivery, and outcomes in allogeneic HCT.<sup>3,26,27</sup> In our first of its kind study using a comprehensive assessment of patient- and center-related health disparity factors using the CHRR, we demonstrate that allogeneic HCT recipients who reside in counties with poor overall community health status have lower survival and that this is primarily driven by a higher risk of NRM. However, patient survival was not determined by community health status of the county where their transplant center was located. Furthermore, neither patient nor center community health status was associated with one-year odds of OS using the exact same model, parameters, and significance level that are currently used in the CIBMTR center-specific analysis model.<sup>13,15</sup>

The association between community health status of patient residence and their survival and risks of NRM supports our hypothesis that worse community health and healthcare resources surrounding a patient's residence negatively influence post-HCT course. Previous studies have evaluated the relationship of individual sociodemographic variables such as race, ethnicity, and socioeconomic status with post-HCT survival.<sup>1,4,7</sup> This study discovered a need to recognize the patient's community health status as an additional potentially modifiable prognostic factor. Poor community health may be linked to poor mechanisms for follow-up and lack of family or personal resources to address HCT complications. In light of this, HCT centers can develop a strategy to improve close follow-up and check-ins with patients from areas of high community risk. Also, dedicating additional resources to the focused areas can advance the overall community health.

In contrast, the lack of association of community risk of center location with patient survival can be supported by the following: First, many transplant candidates are referred by local physicians to distant transplant centers and return to their residence after alloHCT. Second, there can be other important community health factors not captured by the CHRR. Third, community health status at centers may not influence clinical practice of transplant centers. Fourth, some of the variables assessing the community health status may interact and correlate with covariates in the model that we tested.

Addition of PCS or CCS did not change the 2018 center-specific analysis model. In the current study, neither PCS nor CCS was shown to be independent predictors of one-year



OS considered in the pseudo-value logistic regression model. The latter approach models survival at one-year time point from transplant, which is quite different from the time to event analysis behind the Cox model focused on the instantaneous hazard rate over the entire follow up period. Inherent statistical methodology differences between the pseudo-value logistic regression and Cox regression may be responsible for the difference in prognostic value of PCS.

To our knowledge, this study is the first successful attempt to establish a community score model across the US for HCT. A previous study was limited by small sample size and limited community variation.<sup>28</sup> Otherwise, studying community factors was a new concept in the field of HCT. Outside of the field of HCT, ten variables from CHRR were derived to create a kidney transplant specific community risk score model that had significant associations with waitlist mortality and transplant outcomes.<sup>10,11</sup> Now, we have derived a new scoring system from CHRR that can be used in other studies to describe disparities in the context of HCT comprehensively.

We acknowledge several limitations in this study. The disparity related factors were evaluated at the county level (vs. zip code level), which can be a rather broad geographic unit to describe an individual patient's situation. However, the county-level community health status has been used and validated in many other studies.<sup>10,11,29</sup> The current results are only applicable to the US. Also, due to the nature of the CIBMTR registry, we did not study access to HCT. Also, a small number of recipients may have relocated from their residence during the post-HCT period.

While revealing the presence of community risk in HCT, this study raises more important questions to be answered. Disparities in access to HCT has been well described in the literature.<sup>2,3,8,26,27,30–32</sup> However, we could not study the association of community health factors with access since our dataset only included information on patients who were able to receive transplantation. It is possible that the relatively low median/range of PCS indirectly reflects lower rates of referral for patients from “less healthy” communities. We also recognize that the interaction between socio-demographic factors and health status is complex. For example, it is possible that patients residing in less healthy communities may be more likely to have comorbidities that makes them less favorable candidates for transplantation. It is important to continue to better understand these barriers to access to HCT and a detailed data source such as CHRR may facilitate future studies in this area. Furthermore, while the CHRR data reflect health factors and outcomes for the general population, not all health factor measures may influence HCT outcomes. Creating a HCT-specific community risk score model by assessing individual community factors is another important next step.

Currently, practices in post-transplant care are varied among transplant centers depending on community health care models in the US.<sup>33</sup> Patients from communities with inadequate resources, reflected by worse PCS, likely need resources and attention to overcome this additional risk. In conclusion, as community health of patient residence is associated with post-alloHCT overall and non-relapse mortalities, more studies are needed to understand and mitigate these disparities.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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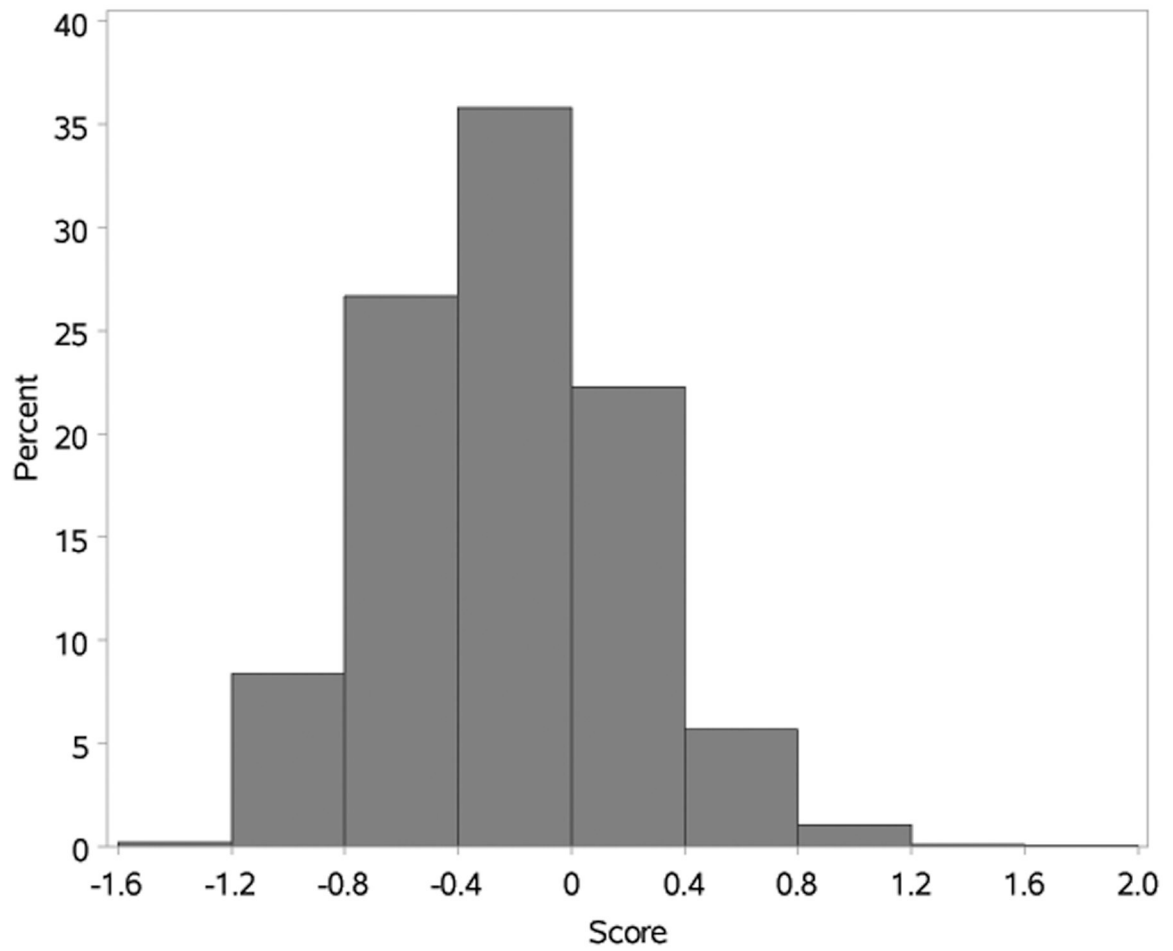
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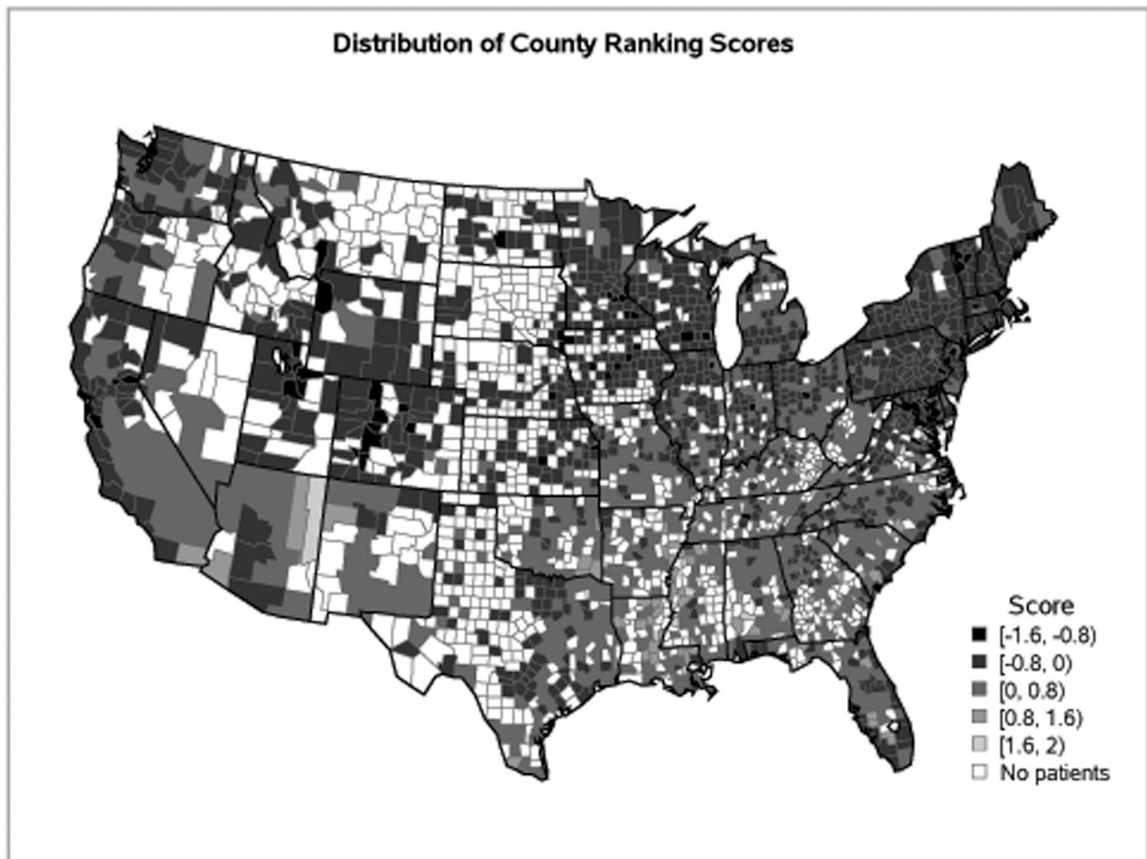
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### Histogram of County Health Ranking Scores



**Figure 1. Numerical Distribution of County Ranking Scores on Adult Allogeneic Transplant Patient Residence in the United States**

\*Note: lower scores are better health factor rankings, while higher scores are worse health factor rankings. Z-score of 0 was the normalized average for all US counties.



**Figure 2. Map of County Ranking Scores on Adult Allogeneic Transplant Patient Residence in the United States**

\*Note: Lower scores, represented by lighter grey colors, are better health factor rankings, while higher scores, represented by darker grey colors, are worse health factor rankings. White areas did not have transplant recipients.

**Table 1.**

## Patient Characteristics

Variable	All diagnoses N (%)	Hematologic malignancies N (%)
Number of patients	18,544	17,793
Number of transplant centers	170	167
Male	10,707 (58)	10,290 (58)
Age, median (years, range)	55 (18–83)	56 (18–83)
Recipient race		
White	15,732 (85)	15,205 (85)
Black/African American	1,398 (8)	1,250 (7)
Asian	721 (4)	685 (4)
Others/ Unknown	696 (3)	653 (4)
Karnofsky Score at transplant, 70–100	17,961 (97)	17,253 (97)
Positive recipient CMV status	11,790 (64)	11,295 (63)
Sorrer HCT-Comorbidity Index <sup>14</sup> †		
0	3,750 (20)	3,575 (20)
1–2	5,535 (30)	5,343 (30)
3–4	5,936 (32)	5,692 (32)
5	3,325 (18)	3,183 (18)
Estimated household income in USD, median (range)	57,573 (7,500->200,000)	57,640 (7,500->200,000)
Disease indication and status for HCT		
Acute Myelogenous Leukemia (AML)	7,471 (40)	7,471 (42)
CR-1	4,724	4,724
CR-2	1,148	1,148
CR-3+ or relapse/ refractory	1,599	1,599
Acute Lymphoblastic Leukemia (ALL)	2,492 (13)	2,491 (14)
CR-1	1,723	1,723
CR-2	482	482
CR-3+ or relapse/ refractory	286	286
Chronic Myelogenous Leukemia	609 (3)	609 (3)
Early	75	75
Intermediate	264	264
Advanced	240	240
Very advanced	30	30
Other acute leukemia	212 (1)	212 (1)
Other chronic leukemia	389 (2)	389 (2)
CR or PR	298	298
Stable disease	57	57
Progression/ relapse	34	34

Variable	All diagnoses N (%)	Hematologic malignancies N (%)
Myelodysplastic Syndrome	3,086 (17)	3,086 (17)
Myeloproliferative Diseases	723 (4)	723 (4)
Non-Hodgkin Lymphoma	1,892 (10)	1,892 (11)
Hodgkin Lymphoma	382 (2)	382 (2)
Plasma Cell Disorders	538 (3)	538 (3)
Other Malignancy (Solid Tumors)	19 (<1)	--
Total nonmalignant diseases	735 (4)	--
Product type		
BM	2,808 (15)	2,295 (13)
PBSC	14,549 (78)	14,335 (81)
PBSC + BM	16 (<1)	15 (<1)
Cord blood ± Others	1,174 (6)	1,148 (6)
Donor type		
Unrelated donor	10,685 (58)	10,318 (58)
Matched sibling	5,417 (29)	5,166 (29)
Greater than one locus mismatched relative	1,945 (10)	1,841 (10)
Other	500 (3)	468 (3)
Unrelated BM or PBSC donor human leukocyte antigen match		
8/8	7,734 (81)	7,462 (81)
7/8	1,282 (13)	1,234 (13)
6/8 or not specified	496 (6)	474 (3)
Age of unrelated BM or PBSC donor, median (years, range)	28 (18–64)	28 (18–64)
BM or PBSC donor/recipient sex match		
Male-male	6,722 (39)	6,454 (39)
Male-female	4,259 (25)	4,075 (24)
Female-male	3,361 (19)	3,228 (19)
Female-female	3,000 (17)	2,859 (17)
Unknown	31 (<1)	29 (<1)
Unrelated BM or PBSC donor age at transplant, years		
Under 30	5,641 (59)	5,435 (59)
30 to 39	2,214 (23)	2,139 (23)
40 to 49	1,148 (12)	1,102 (12)
50 and above	446 (5)	434 (5)
Unknown	63 (<1)	60 (1)
Unrelated BM or PBSC donor ethnicity		
Hispanic or Latino	535 (6)	505 (6)
Not Hispanic or Latino	4,314 (45)	4,153 (45)
Unknown	4,663 (49)	4,512 (49)
Unrelated BM or PBSC donor race		



Variable	All diagnoses N (%)	Hematologic malignancies N (%)
White	5,242 (55)	5,045 (55)
Black/African American	212 (2)	193 (2)
Asian	175 (2)	164 (2)
Others/ Unknown	3,883 (41)	3,768 (21)
Positive Donor CMV status among BM or PBSC grafts	7,903 (45)	7,547 (45)
History of parity among BM or PBSC donor	2,209 (13)	2,123 (13)
Year of transplant		
2014	6,062 (33)	5,835 (33)
2015	6,213 (33)	5,937 (33)
2016	6,272 (34)	6,021 (34)
Prior autologous stem cell transplant	1,683 (9)	1,675 (9)
Median follow-up of survivors, months (range)	24 (1.5–51.8)	24 (1.5–51.8)

<sup>†</sup> 1 case with unknown HCT-comorbidity index at the time of transplantation

Abbreviations: ALL = Acute Lymphoblastic Leukemia; AML = Acute Myelogenous Leukemia; BM = Bone Marrow; CB = Cord Blood; CMV = Cytomegalovirus; CR= complete remission; HCT = Hematopoietic Cell Transplantation; PBSC = Peripheral blood Stem Cells; PR= partial remission.

**Table 2.**

Multivariable Analysis of Community Health Status and Transplant Outcomes in Adult Recipients of Allogeneic Hematopoietic Cell Transplantation

Population	Outcome	Variable	HR (99% CI)	p-value
All patients (n=18,544)	Overall mortality	<b>PCS</b>	<b>1.04 (1.00 – 1.08)</b>	<b>0.0089</b>
		CCS	1.01 (0.98 – 1.04)	0.5379
Patients with hematologic malignancies (n=17,793)	Overall mortality	<b>PCS</b>	<b>1.04 (1.00 – 1.08)</b>	<b>0.0102</b>
		CCS	1.01 (0.97 – 1.04)	0.6658
	Relapse	PCS	0.97 (0.94 – 1.01)	0.0441
		CCS	1.00 (0.96 – 1.04)	0.9310
	Non-relapse mortality	<b>PCS</b>	<b>1.08 (1.02 – 1.15)</b>	<b>0.0004</b>
		CCS	1.02 (0.97 – 1.07)	0.3106

CCS = center community-risk score; PCS= patient community-risk score.

Hazard ratio (HR) quantifies risk change corresponding to one standard deviation increase in continuous covariate.

Bolded variables indicate a significant association defined by  $p < 0.01$ . All models included the following significant co-variables: diagnosis, disease status/ stage, donor type, HCT-comorbidity index, HLA matching, recipient age, donor age for unrelated BM or PBSC donors, recipient and donor gender, recipient and donor CMV serologies, recipient's self-reported race and ethnicity, donor race, donor ethnicity, donor parity, recipient's performance status score at transplant, prior autologous transplant, resistant disease in lymphoma only, NHL subtype, time from diagnosis to transplant for AML or ALL not in CR1 or PIF, AML transformed from MDS or MPN disease, therapy related AML or MDS, AML ELN risk group, number of induction cycles to achieve latest CR before HCT for AML and ALL patients, year of transplant, T-cell lineage in ALL, Philadelphia chromosome in ALL, ALL cytogenetic risk group, ALL molecular marker (BR/ABL at any time between diagnosis and HCT), MDS with predisposing conditions, MDS IPSS-R prognostic risk category/ score at HCT, deletion 17p in CLL, MM cytogenetics risk group, MM ISS at diagnosis, plasma cell disorder disease status at HCT, plasma cell leukemia, history of mechanical ventilation, history of invasive fungal infection, and median household income based on ZIP Code of residence of recipient.