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ORIGINAL ARTICLE

Geographic variation in utilization of deceased donor livers in the United States in the era of advanced perfusion

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Abstract

Understanding the geographic variation in deceased donor liver utilization can guide allocation policy and technology implementation. Using US transplant registry data, we evaluated geographic differences in utilization by donor quality, policy era, and uptake of advanced perfusion (AP). This retrospective cohort included all liver donors and waitlisted patients from 2010 to September 2024. Donors were aggregated by Hospital Referral Region (HRR) and stratified by quality using the liver Discard Risk Index (DSRI). Exposures included the allocation policy era and increased use of AP technology (July 2022 onward). Observed-to-expected (O:E) ratios of liver non-utilization were calculated by HRR and modeled to reveal geographically contiguous low utilization clusters (LUCs). The proportion of HRRs within LUCs increased from 24% in Share 15 (S15), to 25% in Share 35 (S35), 32% in Acuity Circles (AC), and then decreased to 21% in the AP era ($p = 0.01$). There were 7 distinct LUCs in S15 (median non-utilization = 33%), 7 LUCs in S35 (non-utilization = 32%), 7 LUCs in AC (non-utilization = 41%), and 3 LUCs in the AP era (non-utilization = 46%). Donor quality by HRR decreased over time, with a median DSRI of 2.56 (IQR: 1.25–5.79) in S15 to 5.69 (2.01–35.30) in AP ($p < 0.001$). Accounting for DSRI, odds of non-utilization were highest in AC (*ref. Share 35*, OR = 1.27, $p < 0.001$), which decreased in AP (OR = 1.06, $p = 0.001$). Utilization of normothermic machine perfusion was associated with a markedly lower odds of discard (OR = 0.03, 0.03–0.04; $p < 0.001$). Livers originating from LUCs traveled shorter distances in each era other than S35. The number of net exporter HRRs in LUCs was equivalent to non-LUCs in each era, other than AP, where LUCs contained fewer net exporter HRRs [2 (3.2%) vs. 42 (17.4%), $p = 0.004$]. On

Abbreviations: AC era, Acuity Circles era; AP, advanced perfusion; AP era, Advanced Perfusion era; CHS, Community Health Score; CMS, Centers for Medicare & Medicaid Services; DCD, donation after circulatory death; DSA, Donor Service Area; DSRI, Discard Risk Index; HRR, Hospital Referral Region; HAS, hospital service area; LUS, low utilizationcluster; MMaT, MELD at transplant; NMP, normothermic machine perfusion; O:E, observed-to-expected; OPO, organ procurement organization; SDOH, social determinants of health; STAR, Standard Transplant Analysis and Research; SVI, Social Vulnerability Index; UNOS, United Network for Organ Sharing.

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adjusted analysis, candidates in LUCs had a lower likelihood of transplant (HR = 0.88, $p < 0.001$) but also lower waitlist mortality (HR = 0.95, $p < 0.001$). The advent of advanced perfusion was associated with the utilization of otherwise marginal liver allografts and ameliorating geographic imbalances in discard seen with successive allocation policy eras.

Keywords: advanced perfusion, allocation policy, normothermic machine perfusion, organ procurement organizations, organ utilization

INTRODUCTION

As the standard-of-care treatment for end-stage liver disease, liver transplantation depends upon organ supply. Allocation policy must balance several ethical tenets, including beneficence, equity, utility, and medical urgency, none of which are static in the complex liver transplant ecosystem.[1–5] Historically, geography has played a significant role in liver allocation with the need to minimize cold ischemia time.[6] However, organ sharing has broadened over time, as exemplified in the current allocation system, Acuity Circles.[7,8] In eliminating Donor Service Areas (DSAs), administrative boundaries were replaced by fixed circles around candidates, which widen with increasing MELD score.[7] This has led to unprecedented logistical complexity under a ticking clock of ischemic injury, placing a significant burden on transplant programs and organ procurement organizations (OPOs) while increasing transportation costs and perpetuating geographic differences in access.[9–12]

In response to the ongoing organ shortage, higher numbers of donation after circulatory death (DCD) donors have been pursued, with an increase from 5.2% of transplanted grafts in 2013 to 16.7% in 2023,[13] but not without concerns for additional postoperative risks.[14–16] Novel procurement and preservation strategies hold promise for grafts previously considered marginal or untransplantable, especially those from DCD donors.[15,17–20] Normothermic machine perfusion (NMP) in particular permits longer transport times, alleviating logistical burdens while increasing graft availability, reducing waiting times, and improving outcomes.[21–23] However, the geographic effects of allocation policy, graft quality, and advanced perfusion on graft utilization are unknown.

With this in mind, we examined the relationship between allocation policy and the advent of advanced perfusion on spatially defined liver utilization while controlling for donor quality. We then evaluated geographic differences in waitlist outcomes by differences in regional utilization. This knowledge has the potential to aid in the identification of higher-performing areas for the sharing of best practices and lower-performing areas for targeted improvement efforts. Furthermore, this study may identify areas where differences in organ availability result more from regional utilization practices rather than donor quality, while concurrently elucidating potential implications for patients on the liver transplant waitlist.

METHODS

With institutional review board approval and a waiver of informed consent (University of Alabama at Birmingham, IRB-300012017), data on all deceased donors and liver transplant candidates contained within the United Network for Organ Sharing (UNOS) Standard Transplant Analysis and Research (STAR) file supplemented with donor hospital zip code as of September 2024 were obtained. All research was conducted in accordance with both the Declarations of Helsinki and Istanbul.

Definition of eras

Before June 18, 2013, represented the Share 15 era; from June 18, 2013, to February 4, 2020, represented the Share 35 era; from February 4, 2020, to July 1, 2022, represented the Acuity Circles era; while July 1, 2022, onward represents the Advanced Perfusion era. The start of the Advanced Perfusion era was chosen based on the commercial availability of NMP devices and increasing utilization of NMP after this date (Supplemental Figure S1, http://links.lww.com/LVT/A979), as NMP utilization is explicitly recorded within OPTN records.

Donor utilization and aggregation

Deceased donors from 2010 onward with at least one organ procured for the intent of transplantation were included, even if no organs were ultimately transplanted. Notably, DCD donors who were not deceased within the allotted timeframe are not captured in this dataset and were therefore excluded. The primary outcome was the transplant of a liver or liver segment from a given donor. Donor liver quality was assessed utilizing the liver discard risk index (DSRI), which predicts liver non-utilization with a c-statistic of 0.8.[24] As the DSRI is only calculated for donors aged 10 and above, the donor population for analysis of liver non-utilization was restricted to this age group.

Donors were aggregated by hospital referral regions (HRRs). HRRs were created to characterize tertiary care areas within regional healthcare markets by assigning hospital service areas (HSAs) to regions where the highest proportion of major cardiovascular procedures were performed, making minor modifications to achieve a population $>120{,}000$, a high localization index, and geographic continuity.[25] Aggregation into HRR as opposed to administrative boundaries such as donation service area (DSA) has the advantage of reflecting real world patterns of care delivery. The study area was restricted to the contiguous United States.

Determination of low utilization clusters

The unadjusted liver non-utilization rate for each HRR was calculated as $\frac{\textit{number of donors from whom liver was not transplanted}}{\textit{total number of donors in the HRR}}$. The expected number of cases of non-utilization for each HRR was determined using negative binomial regression with DSRI as the independent variable for expected liver non-utilization. Using the spatial statistical software SaTScan,[26,27] clusters of geographically contiguous HRRs with significantly lower observed-to-expected (O:E) utilization rates were revealed, hereafter referred to as "Low Utilization Clusters" (LUCs). Briefly, the spatial scan statistic considers multiple circular windows around each HRR as candidate clusters, with the smallest window containing only the HRR itself, and the largest window containing up to 10% of the population at risk. The number of non-utilized livers within each candidate cluster is assumed to be Poisson distributed, and the total number of donors in the candidate cluster is the population offset. Likelihood ratio tests are then performed to determine the most likely clusters, with significance testing performed through iterative Monte Carlo simulations. HRRs that had their center within a significant circular cluster were considered to be part of the LUC. SaTScan is a trademark of Martin Kulldorff. The SaTScan software was developed under the joint auspices of (i) Martin Kulldorff, (ii) the National Cancer Institute, and (iii) Farzad Mostashari of the New York City Department of Health and Mental Hygiene. The statistical methodology used for cluster detection has been described in detail by Kulldorff.[28]

Comparative analyses by LUC status

HRRs within LUCs were then compared to the remaining HRRs to determine factors potentially associated with non-utilization. An association between HRR-level social determinants of health (SDOH) and organ non-utilization was also sought by comparing 2 aggregate measures for SDOH adapted to the HRR level: the Social Vulnerability Index (SVI)[27,29] and Community Health Score (CHS).[30] Higher scores on each measure represent less favorable SDOH.[31]

A number of comparisons were made by HRR to determine whether they were within an LUC. These included the number of active transplant centers within an HRR (>100 liver transplants during the study period), the number of liver transplants performed by centers, and the mean distance (in NM) between donor hospitals to accepting hospitals. In addition, we evaluated whether HRRs were net exporters of livers procured within their jurisdiction; HRRs with a preponderance of exported livers were deemed net exporters. Livers were considered to be local if transplanted within the same DSA as the originating HRR (within eras S15 and S35) or within 250 NM of the donor hospital (within eras AC and AP); otherwise, livers were considered exported.

We evaluated the likelihood of undergoing liver transplantation and death without liver transplantation for patients on the transplant waitlist based upon residence within an LUC at the time of initial listing, utilizing cumulative function estimates. The adjusted relative rate of each event was assessed using multivariable cause-specific Cox proportional hazards models, as the intention of this analysis was to determine if LUC was directly associated with lower rates of transplantation from an etiological point of view.[32,33] Patient-specific factors at the time of transplant, such as lab values and location at time of transplant, were compared based on LUC status. Associations with liver allocation policy eras and the widespread introduction of advanced perfusion technology were also explored with logistic regression.

Normally distributed continuous data are reported as mean (SD) and were compared with independent samples t tests. Non-normally distributed data are reported as median and IQR and were compared using the Mann–Whitney U test. Categorical data were reported as counts and percentages and compared by chi-squared or Fisher exact test, as appropriate. Non-spatial statistical analysis was performed using SAS version 9.4 (SAS Institute). Geographic analysis was performed with ArcGIS Pro (Esri).

RESULTS

There were 163,534 donors during the study period, of whom 10,025 (6.13%) were excluded based on a priori criteria (1357 without authorization for liver donation, 2504 outside the continental United States, and 6164 age <10). Another 1431 (0.93%) donors were excluded based on missing data (1375 without information on liver disposition, 3 with missing zip codes, and 53 who

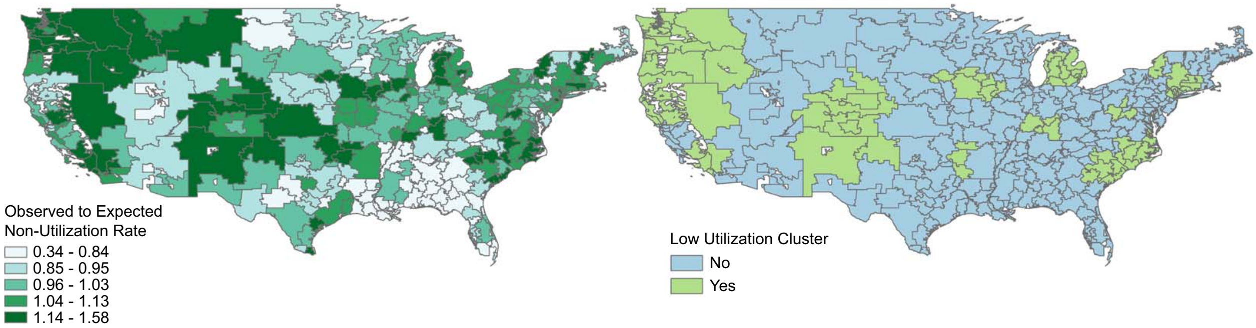

FIGURE 1 Observed-to-expected (O:E) non-utilization and low utilization clusters (LUCs) over the study period. A total of 10 LUCs were seen over the entire study period. Adjusting for donor quality, the risk of non-utilization within LUCs was 1.14 (1.07–1.24) versus 0.95 outside of LUCs (0.83–1.03; $p < 0.001$).

did not map to an HRR), yielding a final study population of 152,078 donors. There were 3573 (2.35%) donors in this cohort missing at least one variable needed to calculate the DSRI; therefore, complete case analysis was performed. The AUROC for the DSRI in predicting non-utilization was 0.84, indicating good discriminatory ability. Donor demographic information is presented in Supplemental Table S1, http://links.lww.com/LVT/A979.

Across all eras, the median HRR level liver non-utilization rate was 30.7% (95% CI: 26.0%–35.3%), and there were 10 geographically distinct low utilization clusters (LUCs) of HRRs with elevated adjusted liver non-utilization rates over the entire study period (Figure 1). The median liver non-utilization rate for HRRs within an LUC was higher (35.0%, 32.0%–38.5%) than those outside an LUC (28.9%, 24.2%–33.6%; $p < 0.001$). The range of DSRI was statistically different for donors within an LUC (3.38, IQR: 1.49–14.81) versus outside an LUC (3.38, 1.52–12.33; $p < 0.001$). Comparison of donor characteristics in LUCs versus outside LUCs is presented in Supplemental Table S1, http://links.lww.com/LVT/A979. Adjusting for donor quality, the median observed-to-expected (O:E) discard rate for HRRs in an LUC (RR = 1.14, 95% CI: 1.07–1.24) was higher than those outside an LUC (0.95, 0.83–1.03; $p < 0.001$; Figure 1). Low utilization clusters had similar SDOH as measured by SVI but poorer SDOH as measured by CHS (Supplemental Table S2, http://links.lww.com/LVT/A979). There was no difference in the number of transplant centers or transplants performed inside of versus outside of LUCs in the overall analysis and in the subgroup analyses by era (Supplemental Table S3, http://links.lww.com/LVT/A979). Furthermore, the percentage of HRRs with a transplant center present for LUCs and non-LUCs was similar across eras (Supplemental Table S4, http://links.lww.com/LVT/A979).

Share 15 era

There were 7 LUCs identified in the Share 15 era, with a median non-utilization rate of 32.7% (IQR: 28.0%–38.0%) compared to 20.5% (14.5%–27.8%; $p < 0.001$) for the remaining HRRs. The DSRI was higher for HRRs within an LUC in the Share 15 era (2.94, 1.45–7.76) than for those outside an LUC (2.45, 1.19–5.20; $p < 0.001$). Adjusting for donor quality, the median O:E discard rate for HRRs in an LUC (RR = 1.33, 95% CI: 1.14–1.51) was higher than for those outside an LUC (0.84, 0.60–1.13; $p < 0.001$). SDOH measures were similar across HRR inside and outside of LUCs as measured by both the SVI and CHS (Supplemental Table 2, http://links.lww.com/LVT/A979).

Share 35 era

There were 7 LUCs identified in the Share 35 era, with a median non-utilization rate of 31.9% (28.2%–36.2%) compared to 23.3% (17.5%–28.8%; $p < 0.001$) for the remaining HRRs. The DSRI was higher for donors within an LUC in the Share 35 era (3.19, 1.44–10.96) than for those outside an LUC (2.86, 1.35–7.40; $p < 0.001$). Adjusting for donor quality, the median O:E discard rate for HRRs in an LUC (RR = 1.22, 95% CI: 1.10–1.40) was higher than for those outside an LUC (0.91, 0.75–1.06; $p < 0.001$). Low utilization clusters had more unfavorable SDOH as measured by both SVI and CHS than areas outside LUCs (Supplemental Table 2, http://links.lww.com/LVT/A979).

Acuity circles era

There were 7 LUCs identified in the Acuity Circles era, with a median non-utilization rate of 40.6% (35.6%–46.6%) compared to 33.3% (27.8%–38.9%; $p < 0.001$) for the remaining HRRs. The DSRI was higher for donors within an LUC in the Acuity Circles era (4.28, 1.73–23.95) than for those outside an LUC (3.91, 1.65–18.25; $p < 0.001$). Adjusting for donor quality, the median O:E discard rate for HRRs in an LUC (RR = 1.10, 95% CI: 0.99–1.19) was higher than for those outside an LUC (0.93, 0.75–1.05; $p < 0.001$). Low

TABLE 1 Percentage of hospital referral regions (HRRs) inside versus outside of low utilization clusters (LUCs) by era

	HRRs inside LUCs	HRRs outside LUCs	
Era			$p=0.01$
Share 15	73 (24.1%)	231 (76.0%)	
Share 35	77 (25.3%)	227 (74.7%)	
Acuity Circles	98 (32.2%)	206 (67.8%)	
Advanced Perfusion	63 (20.7%)	241 (79.3%)	

Note: Percentages may not total 100% due to rounding.

utilization clusters had similar SDOH as measured by SVI but worse SDOH as measured by CHS (Supplemental Table 2, http://links.lww.com/LVT/A979).

Advanced perfusion era

There were 3 LUCs identified in the Advanced Perfusion era, with a median non-utilization rate of 45.8% (41.7%–52.4%) compared to 35.8% (30.4%–40.9%; $p<0.001$) for the remaining HRRs. The DSRI was higher for donors within an LUC in the Advanced Perfusion era (7.96, 2.50–44.08) than for those outside an LUC (5.19, 1.91–32.36; $p<0.001$). Adjusting for donor quality, the median O:E discard rate for HRRs in an LUC (RR = 1.16, 95% CI: 1.09–1.29) was higher than for those outside an LUC (0.94, 0.80–1.07; $p<0.001$). Low utilization clusters had more unfavorable SDOH as measured by SVI and CHS than their counterparts outside LUCs (Supplemental Table 2, http://links.lww.com/LVT/A979).

TABLE 2 Median donor liver discard risk index (DSRI) by hospital referral region (HRR)

Era	DSRI (median, IQR)	O:E discard rate (median, IQR)
Share 15	2.56 (1.25–5.79)	0.94 (0.66–1.26)
Share 35	2.94 (1.37–8.10)	1.00 (0.83–1.16)
Acuity Circles	4.01 (1.69–20.03)	0.99 (0.84–1.12)
Advanced Perfusion	5.69 (2.01–35.30)	0.98 (0.85–1.13)

Abbreviation: O:E, observed-to-expected.

Between-eras comparison

The percentage of HRRs belonging to an LUC was lowest in the Advanced Perfusion era and highest in the Acuity Circles era (Table 1, Figure 2). The median DSRI progressively increased with each era (Table 2, $p<0.001$). At the donor level, odds of liver non-utilization adjusted for DSRI were lowest in the Share 35 era, followed by the Advanced Perfusion era. Compared to Share 35, the highest odds of donor liver being discarded were in the Acuity Circles era and the lowest in the Advanced Perfusion era, after adjusting for DSRI (Table 3). In the Advanced Perfusion era, 11.9% of donor livers in HRRs located outside LUCs were placed on NMP

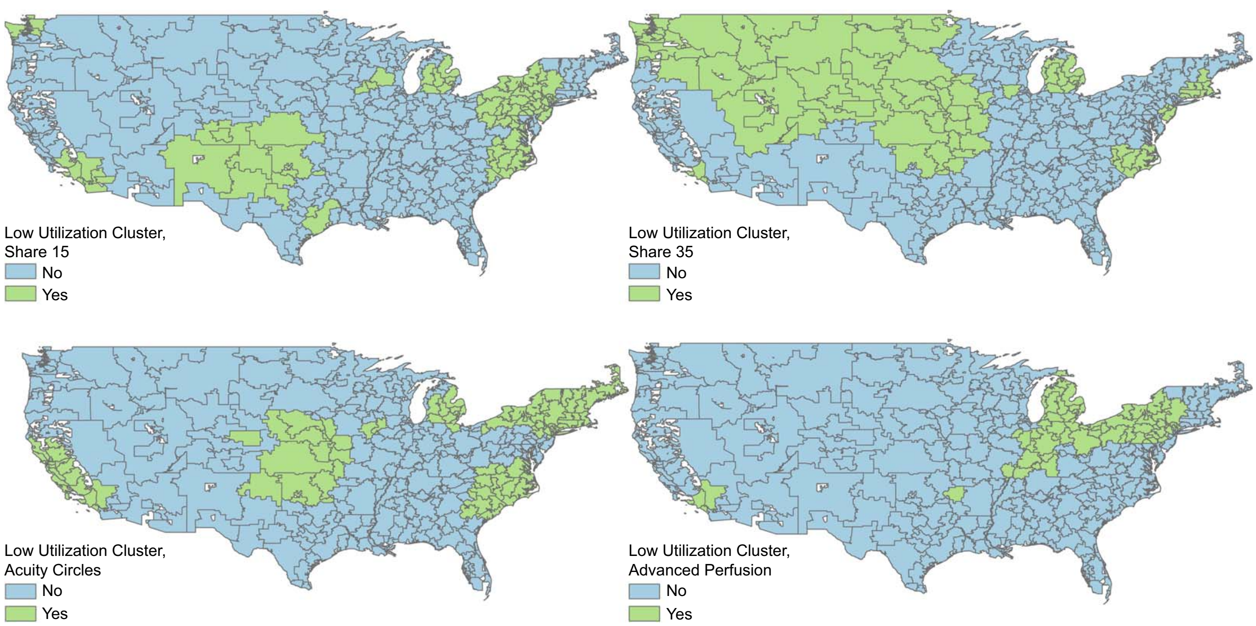

FIGURE 2 Low utilization clusters (LUCs) by policy era and implementation of advanced perfusion. There were 7 LUCs from Share 15 to Acuity Circles and 3 in the Advanced Perfusion era. However, the number of hospital referral regions (HRRs) within LUCs increased until the widespread implementation of advanced perfusion, with 73 in Share 15, 77 in Share 35, 98 in Acuity Circles, then 63 in the Advanced Perfusion era ($p=0.011$).

TABLE 3 Logistic regression analysis of liver non-utilization by era, adjusted for donor liver discard risk index (DSRI)

	OR for non-utilization	p
Liver DSRI	1.05 (1.05–1.05)	**< 0.001**
Era		
Share 15	1.09 (1.05–1.13)	**< 0.001**
Share 35	*Reference*	—
Acuity Circles	1.27 (1.23–1.31)	**< 0.001**
Advanced Perfusion	1.06 (1.02–1.09)	**0.001**

Statistical significance ($P < 0.05$) values are in bold.

compared to 9.13% of donors in LUCs ($p < 0.001$). Utilization of NMP in the AP era was associated with a markedly lower odds of discard (OR = 0.03, 0.03–0.04; $p < 0.001$) when controlling for DSRI. Subgroup analysis limited only to transplanted livers demonstrated a nearly 7-fold higher median DSRI in livers undergoing NMP (14.86, IQR: 3.26–38.86) vs. those using other preservation modalities (2.51, 1.23–5.28; $p < 0.001$). In each era other than S35, livers originating outside of LUCs traveled on average further than those within LUCs (Table 4). The proportion of net exporter HRRs was equivalent by LUC status until the AP era, at which point fewer HRRs within LUCs were net exporters (3.2% in LUCs vs. 17.4% outside of LUCs, $p = 0.004$; Table 5).

Waitlist outcomes

Candidate information by LUC residence can be found in Supplemental Table S5, http://links.lww.com/LVT/A979. The cumulative incidence of transplant was lower for candidates residing within an LUC at 1, 3, 6, and 12 months (22.7%, 32.3%, 39.6%, and 50.8%) versus those outside an LUC (24.2%, 35.1%, 43.7%, and 55.9%; $p < 0.001$). The cumulative incidence of death on the waitlist for candidates residing within an LUC was slightly higher at 1, 3, 6, and 12 months (3.0%, 5.1%, 7.1%, and 10.3%) compared to candidates outside an LUC (3.0%, 5.0%, 7.2%, and 10.3%; $p < 0.001$). However, this difference was small and likely not clinically meaningful. After adjusting for recipient factors, candidates residing within an LUC had a lower rate of transplant (HR = 0.88, 0.87–0.89; $p < 0.001$, Supplemental Table S6, http://links.lww.com/LVT/A979) and a lower rate of death without transplant (HR = 0.95, 0.93–0.98; $p < 0.001$ and Supplemental Table S7, http://links.lww.com/LVT/A979) compared to those residing outside LUC.

TABLE 5 Net exporter hospital referral regions (HRRs) inside versus outside of low utilization clusters (LUCs) by era

Era	Net exporter HRRs within LUCs	Net exporter HRRs outside of LUCs	p
Share 15	10 (14.1%)	29 (12.6%)	0.74
Share 35	12 (15.6%)	45 (19.8%)	0.41
Acuity Circles	12 (12.2%)	32 (15.5%)	0.45
Advanced Perfusion	2 (3.2%)	42 (17.4%)	**0.004**

Statistical significance ($P < 0.05$) values are in bold.

DISCUSSION

Overall, we saw a significant decrease in donor quality with a concurrent rise in low-utilizing HRRs with each successive allocation era, followed by a reversal of these trends with the widespread use of advanced perfusion. Our results demonstrate the impact that advanced perfusion techniques have on decreasing geographic imbalances in utilization, likely through the transplantation of grafts that were previously considered marginable or unusable. Our results suggest that the increased graft availability facilitated by advanced perfusion techniques may mitigate geographic differences in access, ultimately allowing transplant to occur earlier in disease progression, and thereby reducing liver-related mortality.

There are 2 sides to organ utilization: OPO-level recovery rates and center-level acceptance practices. It is important to remember, however, that an increase in non-utilization is the natural byproduct of more aggressive donor pursuit, and that uniformly high utilization may indicate a laxity in OPO-level donor pursuit. An analysis by Lynch et al[34] showed that low-performing

TABLE 4 Distance traveled for livers inside versus outside of low utilization clusters (LUCs) by era

Era	Distance traveled for livers originating within LUCs (NM)	Distance traveled for livers originating outside of LUCs (NM)	p
Share 15	96.2 (166.2)	122.6 (186.6)	**< 0.001**
Share 35	148.7 (216.6)	144.6 (189.9)	0.08
Acuity Circles	180.7 (172.5)	198.7 (200.7)	**< 0.001**
Advanced Perfusion	172.8 (181.1)	203.9 (213.0)	**< 0.001**

Note: Data are presented as mean (SD) and were compared with *t* tests.
Statistical significance ($P < 0.05$) values are in bold.

OPOs tended to recover fewer donors, regardless of donor candidate race, ethnicity, and rurality, suggesting that OPO performance relies upon authorization practices and operational aggressiveness, rather than donor factors. In 2020, OPO quality metrics tied to reimbursement were amended, such that OPOs risked decertification for substandard donation and transplant rates.[35] Since that time, the number of donors pursued has continued to increase,[36] yet we found that the quality-adjusted likelihood of nonuse remains higher than in previous eras. While our results showed that advanced perfusion was associated with a reversal of this trend, it was not fully obviated. It remains to be seen whether more widespread implementation of perfusion technology could finally decrease the liver nonuse rate.

The across-eras decline in donor "quality" is reflective of the intersection of policy and technology within liver transplantation, representing the ongoing effort to push the boundaries of which organs are transplantable.[37] Thus, the increase in DSRI is the expected (and appropriate) result of the pursuit of all potential donors. While efforts to maximize the deceased donor pool largely began within the realm of kidney transplantation,[38,39] marginal liver grafts have been more frequently utilized without sacrificing recipient outcomes,[40–42] in part facilitated with improvements in perioperative care and the commercial availability of advanced perfusion technologies.[23,43] Changes to OPO performance metrics by Centers for Medicare & Medicaid Services (CMS) in 2020 have likely contributed to the pursuit of more marginal donors in recent years as well.[35] Notably, as the DSRI incorporates donor factors such as DCD status, the increased utilization of DCD livers alone is likely a significant contributor to the decline in quality over time, considering DCD utilization has increased over 3-fold in the last decade.[13]

Our finding that livers arising from non-LUCs traveled further than those within LUCs supports the theory that non-LUCs may compensate for less aggressive donor pursuit practices within LUCs. Work by Doby et al[44] has affirmed that organ recovery at the OPO-level—rather than center-level acceptance practices—likely drives organ utilization practices and overall donor supply. In their study of donor and organ utilization in the context of OPO recovery, high-performing OPOs recovered 80% more donors than low-performing OPOs, yet the rate of kidney discards per donor was similar across OPO performance quartiles.[44] In the context of our investigation, however, the proportion of HRRs that were net exporters by LUC status was equivalent by allocation policy—until the AP era. This suggests that the adoption of advanced perfusion may have disrupted prior geographic patterns of donor utilization and organ distribution, as patterns of in-region non-utilization have likely been mitigated by the ability to place livers further away with the aid of NMP. In addition, Doby et al[44] found that transplant centers within the lowest quartile of OPO performance had higher kidney acceptance rates and were more likely to import kidneys from other DSAs, suggesting that centers compensate for poor organ recovery practices through more liberal acceptance practices. Our study suggests this applies to liver acceptance practices as well, as the number of liver transplants performed was the same between LUCs and non-LUCs, suggesting that increased rates of non-utilization are not from a paucity of local transplant centers.

In this investigation, there were no consistent associations between community-level SDOH measures and access to transplant by donor utilization across eras. While intriguing, these inconsistencies could be from differences in metric composition, poorly-captured individual-level SDOH measures, or the waitlisting of patients with minimal individual-level SDOH risk among those residing in disadvantaged communities.[45,46] However, SDOH metrics including the SVI are notably inconsistent when applied to transplant populations to quantify barriers to access.[46] Additional studies are necessary to delineate known SDOH and geographic differences in access to liver transplant.[47,48]

The impact of allocation policy on center-level liver utilization can be viewed within the context of risks versus benefits. When allocation policy promotes broader sharing, centers that derive the most benefit from these changes have historically tightened donor acceptance criteria, thereby undermining efforts to increase transplantation. For example, Chan et al[49] demonstrated that following Acuity Circles centers with a higher overall median MELD at transplant (MMaT) were more likely to utilize higher quality donors while accepting fewer donor offers as compared to lower MMaT centers, thereby perpetuating geographic inequities. An investigation by Sheetz et al[8] showed that despite an overall increase in liver imports by 310% and exports by 344% with the implementation of Acuity Circles, the rates of transplants and deceased donors pursued were relatively static. Our results showed that broader sharing increased geographic differences in utilization, as evidenced by the increased number of HRRs in LUCs with successive allocation policies, while we showed a promising reversal of this impact with perfusion technologies.

The strengths of this study include the use of spatial epidemiologic techniques to quantify the interrelations of utilization with geography and the modernity, scope, and geographic granularity of these data. Such techniques permit risk adjustment concurrent with the identification of low utilization clusters. However, limitations remain. The liver discard risk index,[24] although previously validated to correlate with non-utilization risk, does not account for all the factors that go into an offer acceptance decision, such as recipient characteristics. In addition, differences in utilization and waitlist outcomes cannot be fully attributed to advanced perfusion due to dynamic changes within the transplant system, such as improvements in pretransplant care and known geographic variation in waitlist mortality.[13] In addition, we selectively used NMP to mark the beginning of the Advanced Perfusion era; we acknowledge that NRP likely followed a similar utilization trajectory, though national estimates of NRP use are not as granular.[13,36,50–53]

In summary, utilization practices are strongly influenced by policy decisions and the adoption of novel technology. Aggressive utilization with the aid of novel perfusion strategies has expanded the donor pool by enabling the pursuit of grafts that were previously considered marginal or untransplantable while diminishing geographic differences in utilization. For the first time in the history of liver transplantation, we are at the precipice of broad and timely access to liver transplantation.[54] However, success depends on aggressive donor pursuit, consideration of utilization practices, and incorporation of innovative technology.[49] With this, the data we offer here allows for assessment of which areas are performing best in organ utilization and which areas would be apt targets for improvement. Translational implementation science and continuous sharing of best practices should be leveraged to increase transplantation through these technologies.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available via request from the OPTN.

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CONFLICTS OF INTEREST

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