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The Impact of Redistricting Proposals on Health Care Expenditures for Liver Transplant Candidates and Recipients

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Redistricting, which means sharing organs in novel districts developed through mathematical optimization, has been proposed to reduce pervasive geographic disparities in access to liver transplantation. The economic impact of redistricting was evaluated with two distinct data sources, Medicare claims and the University HealthSystem Consortium (UHC). We estimated total Medicare payments under (i) the current allocation system (Share 35), (ii) full regional sharing, (iii) an eight-district plan, and (iv) a four-district plan for a simulated population of patients listed for liver transplant over 5 years, using the liver simulated allocation model. The model predicted 5-year transplant volumes (Share 35, 29 267; regional sharing, 29 005; eight districts, 29 034; four districts, 28 265) and a reduction in overall mortality, including listed and posttransplant patients, of up to 676 lives. Compared with current allocation, the eight-district plan was estimated to reduce payments for pretransplant care ($1638 million to $1506 million, $p < 0.001$), transplant episode ($5607 million to $5569 million, $p < 0.03$) and posttransplant care ($479 million to $488 million, $p < 0.001$). The eight-district plan was estimated to increase per-patient transportation costs for organs ($8988 to $11 874 per patient, $p < 0.001$) and UHC estimated hospital costs ($4699 per case). In summary, redistricting appears to be potentially cost saving for the health care system but will increase the cost of performing liver transplants for some transplant centers.

Abbreviations: DRG, diagnosis-related group; DSA, donation service area; ESLD, end-stage liver disease; HCC, hepatocellular carcinoma; LSAM, liver simulated allocation model; MELD, Model for End-Stage Liver Disease; OPO, organ procurement organization; OPTN, Organ Procurement and Transplantation Network; SRTR, Scientific Registry of Transplant Recipients; UHC, University HealthSystem Consortium; UNOS, United Network for Organ Sharing; USD, U.S. dollars

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Introduction

Geographic disparity in access to liver transplantation has a profound impact on mortality and morbidity from end-stage liver failure in the United States (1–4). Current policy mandates allocation of liver allografts to local recipients prior to regional or national sharing, provided candidates meet minimum thresholds for severity of illness (Model for End-Stage Liver Disease [MELD] score ≥35 and ≥15). This system of organ allocation contributes to excess waitlist mortality and has been reported to reduce the overall benefit of transplant (5). Using mathematical optimization algorithms, we developed novel, broader sharing districts designed to reduce geographic disparity in MELD at transplant by optimally aggregating existing donation service areas (DSAs) (Figure 1) (5). Implementation of these districts has the potential to reduce disparities in MELD score at transplant, to decrease mortality among waitlist candidates and, consequently, to increase the net benefit of transplant care.

Among the potential barriers to the proposed revision of U.S. liver allocation policy is concern about the impact of broader sharing proposals on spending for end-stage liver disease (ESLD) generally and liver transplantation specifically. In our prior analyses, we clearly demonstrated a strong correlation between severity of ESLD, as assessed by MELD score, and the cost of liver transplantation,

Figure 1: Optimized redistricting plan: (A) eight districts, (B) four districts.

particularly in patients with MELD scores >20 (4,6,7). Using these models of direct medical costs for transplantation, earlier proposals to expand regional sharing were evaluated and appeared to be highly cost effective despite an increase in per-transplant expenditures (4).

Any economic assessment of organ allocation policy proposals should include the impact of the allocation system on the health care spending for waitlisted patients with ESLD and the cost of transportation within larger sharing districts. Pretransplant ESLD care is complex and expensive, particularly the treatment of encephalopathy, variceal bleeding, hepatitis C infection and hepatocellular carcinoma (HCC) (8,9). The cost of pre–liver transplant care increases dramatically with the severity of illness and the development of HCC. In our recent assessment of health care spending among Medicare patients, risk-adjusted monthly Medicare expenditures for patients with a MELD score of 30 was 10-fold higher than for those with a MELD score of 20 ($22 685 vs. $2030) (10). Although pretransplant costs are not currently borne by the transplant centers, public and private payers incur these costs for patients on the waiting list.

We have developed models of health care spending that estimate Medicare payments for pretransplant, transplant and posttransplant services (4,10). We have also modeled the distance and modality of organ transportation to estimate the cost of ground and air transportation under current allocation systems and proposed sharing districts. The current analysis estimates the economic implications of the broader sharing proposals on health care spending for costs of waitlisted patients, organ transport, transplant services and up to 3 years of posttransplant care. We estimated the total cost of ESLD care under (i) the current allocation system (Share 35), (ii) regional sharing, (iii) an eight-district plan, and (iv) a four-district plan for a simulated population of all patients ever listed for liver transplant over a 5-year period. Robust sensitivity analyses were performed to assess the stability of these estimates. To specifically address the cost of transplant care borne by transplant programs, we separately analyzed hospital cost accounting data from the University HealthSystem Consortium (UHC) for the cost of the transplant episode only.

Methods

Data sources

Medicare payments: A novel database was created by linking clinical and demographic information from the Organ Procurement and Transplant Network (OPTN) with Medicare billing claims for liver transplant candidates and recipients listed or transplanted in the 2002–2008 period. The OPTN registry includes records of all solid organ transplant candidates and recipients in the United States, including complete waitlist and follow-up information about waitlist status change, recertification on the waitlist, historic laboratory values and specific clinical outcomes. Medicare billing claims provided payment information for patients with Medicare fee-for-service primary or secondary insurance. To merge the two databases, beneficiary identifiers from Medicare files (n = 10 528) were linked to OPTN records using Social Security number, gender and date of birth. The merge and data cohort generation for waitlist and transplant analysis was described in previous publications (10).

We combined payments for all services from Medicare Part B: inpatient, outpatient, home health and hospice. Payments for all four services were summed and aggregated based on number of months each candidate spent on the waiting list (pretransplant) and the number of years (first 3 years only) after transplant for liver transplant recipients (posttransplant). Pretransplant costs included a daily estimate of spending adjusted for MELD score and other patient characteristics for the duration of the patient's listing for transplantation. In the posttransplant models, cost per patient was estimated for two time periods: early (3 days before transplant to 1 year after) and late (years 1 to 3 after transplant). The costs were censored at the time of retransplant to capture the cost associated with the first transplant. Medicare payments were minimally adjusted for wage and price differences by region that conform to standard diagnosis-related group (DRG) and evaluation and management code–based fee schedule. In addition, we did not include organ acquisition cost under Medicare claims because that cost is paid via the institutional cost report.

UHC cost accounting data: A second data set was created by merging UHC cost accounting data with OPTN for liver transplants (n = 36 939) performed between 2002 and 2013. Because no unique identifiers were available for this data set, the transplant records were linked using date of transplant, age and gender. The UHC data included patient-level cost data from administrative billing claims submissions adjusted to costs using the transplant hospital's Medicare cost-to-charge ratio and adjusted for geographic differential in wages. Unfortunately, accurate estimates of pre- and posttransplant care expenditures cannot be determined from UHC data.

The UHC and Medicare cohorts were largely similar with the exceptions of the percentage of patients employed and the age distributions (Table S1).

Cost model regression analysis

Multivariable linear regression was used to estimate monthly (for pretransplant models) or total (posttransplant models) person-level spending. For the model predicting average monthly spending on the waiting list, we clustered multivariable linear models on patient identifier. For both waitlist and transplant models, we applied MELD spline terms to adjust for the nonlinear relationship between MELD and cost, with spline knots at biological MELD scores of 20 and 25.

The models were adjusted for recipient and donor factors relevant to waitlist and transplant analysis. Recipient factors included recipient age, race, gender, blood group, diagnosis category, HCC exception status, diabetes, cerebrovascular disease, work status for income and daily MELD or MELD score at transplant. Donor factors included donor age, race, sex, blood group, cause of death and donation after cardiac death. We estimated Medicare spending separately for the early (transplant event up to 1 year after transplant) and late (years 2 and 3 following liver transplant) posttransplant periods. Costs were adjusted for inflation from the median year (2006) of the Medicare claims to 2013 based on consumer price index inflation reported by the U.S. Bureau of Labor Statistics ($1.00 in 2006 was worth $1.16 in 2013).

We completed a separate multivariate regression model for using the UHC cost data assessing the cost of the transplant episode using identical donor and recipient factors. The estimates were adjusted to 2013 dollars using the consumer price index for health care from the median year (2008). Data management and analysis was performed using SAS 9.3 software (SAS Institute, Cary, NC) and R 3.0 (R Foundation for Statistical Computing, Vienna, Austria).

Transportation costs

For each transplant, transport mode of the recovery team to the donor hospital and back to the transplant center was predicted using a transport model that assigns cost and mode of transportation based on estimated travel time (11). The predicted mode of transportation was by ground if driving time was <2 h (or 1.5 h for organ procurement organizations [OPOs] that use helicopters), by helicopter for OPOs that use helicopters if driving would take ≥1.5 h and the distance was ≤100 miles, and by air from the nearest airport for longer distances. Round-trip cost was estimated to be $1108 per team by ground transportation, $4742 per team by helicopter (12) and distance dependent for flights. Flight cost estimates were based on 94 transports for liver transplantation in the Living Legacy Foundation OPO in 2013. Round-trip cost for flights was estimated to be $7767 + $8.40 × round trip miles. This cost includes the cost for aircraft charter, fuel, aircraft crew and airport fees. The modeled flight costs are approximately twice the costs reported in Michigan (12); however, flight costs in Michigan have doubled since the initial report and are now comparable to our model estimates (personal communication, Micheal Englobe, MD, University of Michigan, 2015).

Applying cost models to redistricting alternatives

Four allocation scenarios were simulated in the liver simulated allocation model (LSAM): current allocation under Share 35, full regional sharing within the existing 11 regions and full districtwide sharing under optimized maps dividing the United States into either four or eight districts. The redistricted maps were designed using constraints chosen by the United Network for Organ Sharing (UNOS) Liver and Intestinal Transplantation Committee with the goal of reducing disparity in access to liver organ offers across the United States, as described in previous publications (13). The initial populations of waitlisted candidates and incident candidates through the 5 years of simulation were identical among scenarios and based on actual liver transplant candidates who were listed between 2006 and 2011. LSAM simulations were repeated over 10 iterations for each scenario, and the average cost over the iterations was reported. The impact of the redistricting was separately modeled for each transplant program and DSA to assess the relative impact of these centers on the cost of transplant.

Pretransplant cost in LSAM

Over the 5-year simulation, candidates began accruing pretransplant care costs from the beginning of the simulation or from the date they listed after the simulation started. The pretransplant period ended when the candidate received a transplant or was removed from the waitlist without receiving a transplant. The cost of pretransplant care was estimated based on the number of days the candidate spent on the waitlist at MELD scores ranging from 6 to 40. Pretransplant monthly cost estimates were interpolated from the cost regression models to a daily cost figure that was applied according to each candidate's daily MELD. Total cost of pretransplant care was summed over the 5-year simulation. A patient's pretransplant care cost per month was calculated by dividing the patient's total pretransplant cost by the cumulative months waiting in the simulation. This was averaged for all patients for the reported pretransplant cost per patient-month.

Transplant and 1-year follow-up cost in LSAM

Over the 5-year simulation, candidates who received a transplant accrued the total cost of the procedure plus 1 year of follow-up care, regardless of survival, to 1 year after transplant. This reflects the fact that a large fraction of the cost was incurred at the transplant event. Total transplant and 1-year cost was summed over the 5-year simulation. Transplant and 1-year cost per patient was calculated by dividing the total transplant and 1-year cost by the number of patients who received transplants.

Posttransplant cost in LSAM

Transplant recipients began accruing late posttransplant care expenditures from 1 year after transplant until the date of the recipient's death, the date of relisting or the end of the 5-year simulation. For recipients who survived beyond 3 years after transplant in the simulation, we assumed that the annual cost of care beyond 3 years was equivalent to the annual cost of care in the second and third years after transplant. Total posttransplant cost was summed over the 5-year simulation. A patient's posttransplant care cost per month was calculated by dividing the cost of their care beyond 1 year after transplant by the number of months the patient survived beyond 1 year after transplant. This was averaged over transplant recipients who survived to 1 year after transplant for the reported posttransplant cost per patient-month.

UHC analysis and geographic variation

For the purpose of assessing transplant center costs, the LSAM results for transplants performed were combined with the UHC estimates of the hospital costs to determine the impact of overall spending and the cost per transplant procedure. These costs are presented separately from the overall cost model and include all hospital costs, including acquisition of the organ.

No adjustment for nonmedical costs or quality of life

The models do not account for working-hour impact on transplant providers. The models do not account for lost income because this cannot be estimated from OPTN data. Only direct medical expenditures are accounted for in LSAM-based models. No adjustments were made for quality of life, including premature death, in the estimates of total expenditures.

Other redistricting impacts

The geographic disparity in access to liver transplantation was measured as the standard deviation of the median allocation MELD score in each DSA. We calculated the median allocation MELD score at transplant for each DSA and then used the standard deviation to measure how the severity of illness at transplant varied among them. We generated maps to illustrate the disparity in median allocation MELD score at transplant across the country. Furthermore, we compared median distances, transport times and expected waiting list deaths and total deaths among the allocation scenarios, as projected by LSAM.

Results

The proposed broader districts were compared with the current allocation system and full regional sharing using the 11 existing allocation regions to assess cost and outcomes for >70 000 listed patients and 30 000 liver transplants (Table 1). The models predict 5-year transplant volumes (Share 35, 29 267; regional sharing, 29 005; eight districts, 29 034; four districts, 28 265) and a reduction in overall mortality, including listed and posttransplant patients, of up to 676 lives.

Geographic disparity in MELD at transplant

The optimized districts are predicted to substantially reduce disparity in the MELD score at transplant across the country, as measured by the decrease in standard deviation of MELD score at transplant from the current 2.74 to 1.90 with eight-district sharing or to 1.61 with four-district sharing ($p = 0.0019$ for each pairwise comparison with the current value; Figure 2). As we have shown previously (13), the disparity in MELD at transplant would actually increase to 3.18 with full regional sharing in the existing regions. The reduction in disparity at transplant with optimized redistricting would result in a more uniform MELD at transplant across the United States, with the exception of California, for both four- and eight-district systems (Figure 3). Because these are simulation results and MELD at transplant has been rising nationally, the MELD scores shown might not reflect current MELDs at transplant but instead should be interpreted only as comparisons among allocation systems.

Deaths on waitlist, deaths after waitlist removal, retransplantation, and posttransplant deaths

Compared with the existing Share 35 system, the four-district plan reduced waitlist deaths by 490, reduced deaths after waitlist removal by 218 and slightly increased posttransplant deaths by 32, for a net change of 676 fewer deaths over 5 years (Table 1). Compared with the existing Share 35 system, the eight-district plan reduced waitlist deaths by 276, reduced deaths after waitlist removal by 143 and slightly increased posttransplant deaths by 56, for a net

Table 1: Impact of allocation scenarios, 5-year liver simulated allocation model

	Current allocation (Share 35)	Fully regional sharing	Eight-district regional sharing	Four-district regional sharing
Regions/districts	11	11	8	4
Number of pretransplant patients	72 043	71 888	71 910	71 902
Number of transplants	29 967	29 005	29 034	28 965
Modality of transportation, %				
Drive (if <2 h)	47	33	27	16
Airplane	53	66	73	84
Helicopter (if ≤100 miles)	0.35	0.44	0.24	0.15
Patient-months on waitlist, n				
MELD 6–20	628 338	660 580	674 691	671 506
MELD 20–29	97 261	100 882	97 557	101 538
MELD 30–40	8747	7725	6113	4509
Months on waitlist (average per patient)	10.2	10.7	10.8	10.8
MELD score at transplant, n				
6–15	7004	7691	7761	7498
16–25	11 754	9667	8595	7387
25–30	2800	3142	3798	4631
30–35	3868	4228	4480	4859
>35	4508	4284	4411	4546
Distance (median)	122	194	243	419
Transport time (median)	1.75	1.89	2.00	2.31
Lives saved (net)				
Waitlist	0	−96	276	490
Removed	0	−103	143	218
Posttransplant	0	220	−56	−32
Standard deviation of median MELD score at transplant (per OPO)	2.75	3.18	1.90	1.61

MELD, Model for End-Stage Liver Disease; OPO, organ procurement organization.

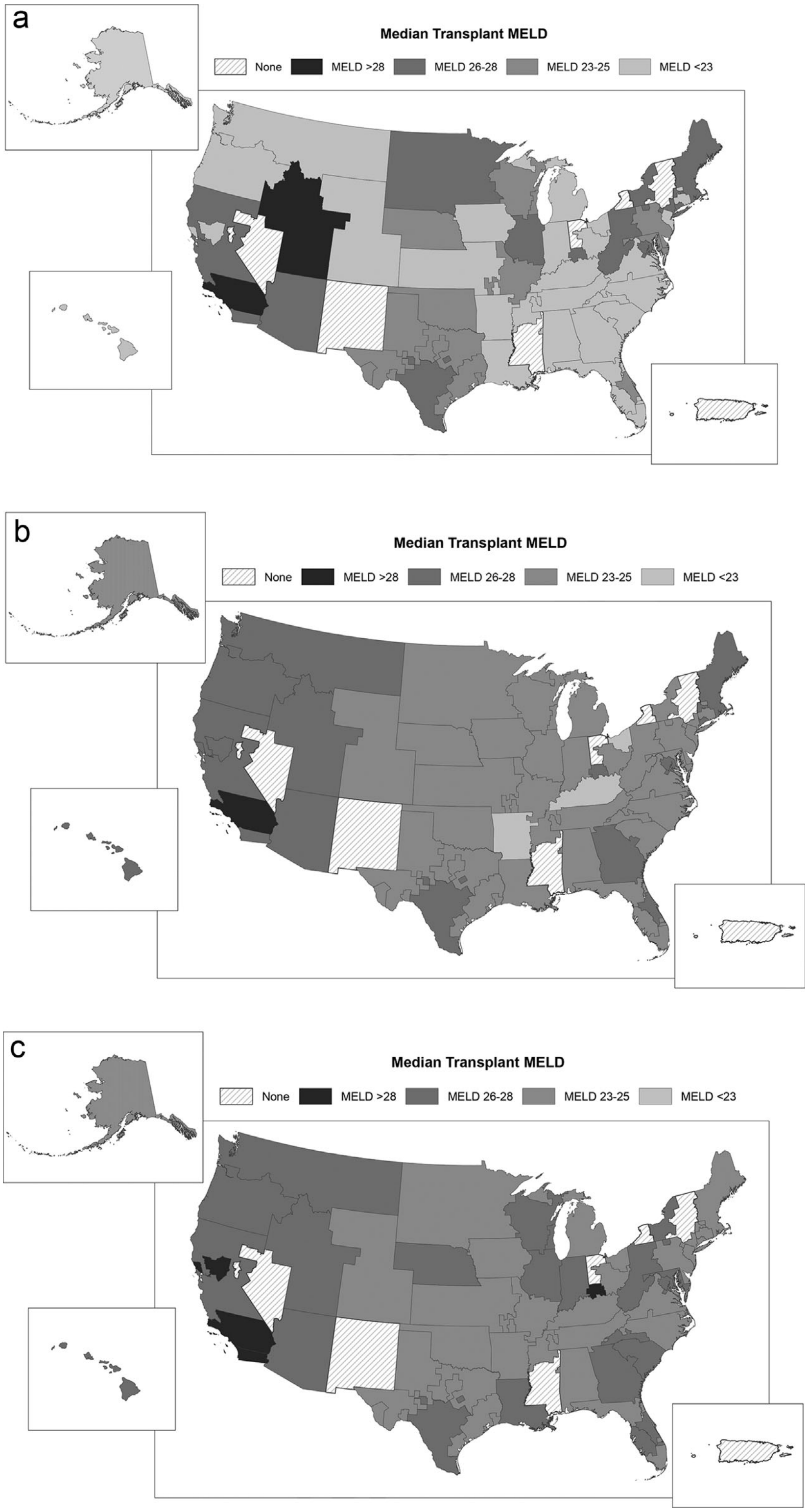

Figure 2: Simulated median MELD at transplant. (A) Current share 35 allocation, (B) eight districts, (C) four districts. MELD, Model for End-Stage Liver Disease.

change of 362 fewer deaths over 5 years (Table 1). There was no significant increase in the rate of retransplantation (current system, 5.7%; four districts, 5.6%; eight districts, 5.8%; regional sharing, 5.9%; $p = 0.45$).

Simulated time on waitlist

The average time spent on the waitlist in the simulation ranged from 10.2 mo per patient in the current allocation system to 10.8 mo per patient in the four-district plan (Table 1). The

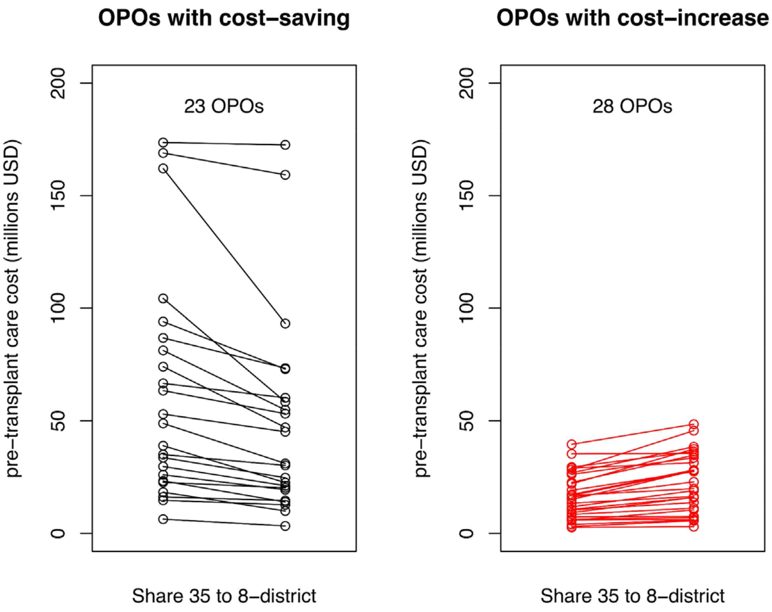

Figure 3: Pretransplant care cost totals per OPO, for OPOs in which pretransplant costs decrease and for OPOs in which pretransplant costs increase, comparing current Share 35 allocation with eight-district redistricting. OPO, organ procurement organization; USD, U.S. dollars.

proportion of total wait time spent at biological MELD scores >30 was 0.6% in the four-district plan versus 1.2% with the current allocation. Compared with the existing system, redistricting with four districts reduces the national prevalence of waitlisted patients with biological MELD >30 by 57% (current system, 10 398 patient-months; regional sharing, 7725 patient-months; eight districts, 6113 patient-months; four districts, 4509 patient-months). This decrease was statistically significant ($p < 0.001$, chi-square test) and is seen in all allocation plans that have broader sharing than the current Share 35 plan with 11 regions.

Spending on pretransplant care

Medicare spending on pretransplant care over the 5-year period was evaluated using the models by integrating daily cost over the total time on the waiting list (Table 2). Total spending for pretransplant care actually increased from $1638 million under the current Share 35 allocation to $1647 million with full regional sharing but was reduced in both of the redistricting models ($1506 million for the eight-district plan and $1461 million for the four-district plan, $p < 0.001$ for both). Average monthly pretransplant costs per waitlist patient were reduced from $6038 to $5934 in the eight-district plan because patients with high MELD scores spent less time on the waiting list. The reductions in pretransplant care costs accrued mostly within OPOs that had very high pretransplant costs (Figure 3). Only OPOs that currently have low pretransplant care costs might see increased pretransplant care costs, but these increases would be slight.

Table 2: Estimated 5-year Medicare spending for following redistricting

	Current allocation (Share 35)	Fully regional sharing	Eight-district sharing	Four-district sharing
Medicare spending				
Pretransplant care, $ (per patient-month)	1638 million (6038)	1647 million (5998)	1506 million (5934)†	1461 million (5928)†
Transplant and 1 year (without organ acquisition), $ (per patient)	5607 million (187 120)	5485 million (189 099)†	5569 million (191 811)*	5655 million (195 228)*
Posttransplant care, $ (per patient-month)	488 million (1214)	472 million (1222)†	479 million (1235)†	483 million (1248)†
Transportation (total), $ (per patient)	269 million (8988)	297 million (10 243)†	345 million (11 874)†	422 million (14 552)†
Total cost (care and transportation), $	8003 million	7901 million†	7899 million†	8020 million

Reported costs are averages over 10 iterations of a 5-year liver simulated allocation model from 2006 to 2011. Transplant and 1-year care includes cost for the entire year, regardless of whether the patient survived 1 year after transplant. Transportation (round-trip) costs were estimated by $1108 by driving, $4742 by helicopter, and $8.40 multiplied by round-trip distance plus $7767 by plane. Costs were adjusted to 2013.

†$p < 0.001$ vs. Share 35.

*$p < 0.03$ vs. Share 35.

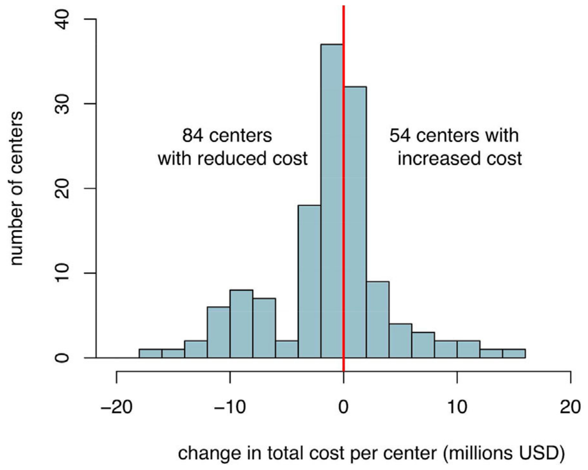

Figure 4: Distribution of the change in total cost per center under redistricting with eight districts. USD, U.S. dollars.

Spending for transplant episode and posttransplant care

The distribution of the predicted MELD score at transplant varied within the models. Compared with the current system, the novel districts had a minimal impact on the transplantation of patients with very high MELD scores (>35; 1–2% shift). There was, however, a substantial reduction in the transplantation of patients with biological MELD scores of 16–25 and with corresponding increases in the transplantation of patients with biological MELD scores of 6–15, 25–30, and 30–35. Compared with the current Share 35 system, the eight-district plan would increase the average cost per transplant by $4691, although overall spending was predicted to fall by $38 million over 5 years ($p = 0.032$), principally because of the projected reduction in total number of transplants (29 034 vs. 29 967). The four-district plan would increase per-transplant spending by $8108 per transplant, resulting a $58 million increase over 5 years ($p < 0.01$). Posttransplant costs were statistically significantly lower with the eight-district plan versus Share 35 (Student's t-test, $p < 0.01$); however, the impact was modest, with an estimated difference of $9 million over 5 years.

Cost of transportation

Transportation cost increased significantly as the districts increased in size. Sharing from DSA of origin would increase from 34.6% under the Share 35 system to 81.7% under a four-district system. The use of aircraft for organ transplant was expected to increase substantially with broader sharing, from 53% under the current Share 35 system to 66% for full regional sharing in the existing regions, to 73% in an eight-district system and to 84% in a four-district system. Consequently, transportation costs would be expected to increase from $269 million under the current system of liver allocation to $345 million for the eight-district system and $483 million for the four-district system. The average transport cost would be expected to increase from $8988 to $11 874 per transplant with an eight-district system or to $14 552 per transplant with a four-district system.

Total Medicare spending

The total cost of care for waitlisted and transplanted patients was generally similar following redistricting. The eight-district plan reduced expected spending by $104 million ($p < 0.001$), whereas the four-district plan increased estimated spending by $17 million (p-value not significant) over 5 years. In these models, increased transportation and transplant costs were largely offset by reductions in pretransplant spending and a reduction in the total number of transplants performed. The impact of redistricting varied by center and DSA (Figure 4). Total spending was expected to increase for patients cared for in 54 (39%) of the transplant centers.

Change in hospital cost

The shift to patients with higher biological MELD scores was predicted to increase the estimated cost of performing transplants, as modeled using hospital cost accounting data from UHC. The results were similar to the Medicare data and suggest that the eight-district plan would increase the cost of the transplant episode by $4980 per transplant and that the four-district plan would increase those costs by $8906. Compared with Share 35, the eight-district plan would decrease the national cost of liver transplant by $64 million over 5 years, and the four-district plan would increase costs by $34 million over 5 years, given the predicted number of transplants performed (Table 3).

Discussion

Redistricting and broader sharing of allografts is being considered to address long-standing concerns about equity

Table 3: Estimated hospital cost of transplantation over 5 years

	Current allocation (Share 35)	Fully regional sharing	Eight-district sharing	Four-district sharing
Total hospital cost for transplant care, $	6706 million	6550 million	6643 million	6740 million
Cost per liver transplant, $	223 809	225 814	228 790	232 715

Reported costs are averages over 10 iterations of a 5-year liver simulated allocation model from 2006 to 2011. Reported costs using models were derived from hospital accounting data for the initial transplant hospitalization based on donor and recipient characteristics for projected transplants under each proposed redistricting plan. Costs were adjusted to 2013. Costs include organ acquisition.

and efficiency in the liver allocation system. Under the existing allocation rules, patient survival is directly tied to geography, and that appears to violate the Final Rule (14). The UNOS Liver and Intestinal Transplantation Committee has proposed a redistricting approach to broader sharing that uses optimized districts within which organs are shared based on allocation MELD score (15). Simulations predict that redistricting will reduce waitlist mortality and decrease geographic disparity in allocation MELD score at transplant without decreasing posttransplant survival. By redirecting allografts to patients with the greatest likelihood of death on the waiting list, a four-district plan would save 676 lives over a 5-year period. The economic implications of redistricting are predicted to be reduced spending for pretransplant care and increased spending for transplant care and organ transportation.

Redistricting and broader sharing will increase logistical complexity and transport costs for transplant centers and OPOs (16). The use of air transport was predicted to increase from 53% of liver transplant procedures to 84% in a four-district system, adding nearly $169 million to transport costs over 5 years. Although substantial, this additional spending is predicted to be offset by a reduction in health care expenditures for patients with advanced ESLD who are on transplant waiting lists. The four-district plan was predicted reduce the number of patient-months on the waiting list for patients with a biological MELD score >30 by 49% compared with current allocation, reducing pretransplant spending by $177 million. The cost of the transplant episode is estimated to increase, using both Medicare claims and UHC hospital accounting data. Transplant center cost per transplant is estimated to increase by approximately $5000 per transplant with the eight-district system and $9000 with the four-district system. These increased costs reflect the shift to transplanting higher MELD patients. The overall cost of transplant care over 5 years was estimated to remain relatively stable. These costs do not include the cost of organ acquisition, which is assumed to remain constant across allocation proposals with the exception of transportation costs. In general, organ acquisition includes the standard acquisition cost assigned to the OPO, which does not vary by accepting center, listing and staff costs, and pretransplant costs, all of which do not vary by allocation systems. Consequently, although the Medicare estimates may not capture the total cost of care, they identify the relative changes accurately. The UHC data include the organ acquisition costs and demonstrate a similar relative increase in transplant spending associated with the transplantation of higher MELD patients nationally.

A cost analysis of liver allocation policy alternatives is crucial in assessing the feasibility of allocation changes. Although prior assessments have focused exclusively on the cost of the transplant procedure itself, a complete assessment must address the impact of allocation on the cost of pretransplant care. The high cost of pre-ESLD care reflects expenditures for hepatitis C and obesity-related liver disease (8,9,17). ELSD expenses are highly correlated with severity of liver failure; spending for patients with biological MELD scores >30 was >10 times greater than for patients with MELD scores <20 (10). This cost differential reflects the expenses resulting from hepatic encephalopathy, portal hypertensive bleeding and HCC that must be stabilized while waiting for liver transplant. National charges for inpatient care for hepatic encephalopathy have increased from $4.7 billion to $7.2 billion from 2005 to 2009 as a result of the increasing incidence of advanced ESLD (18). Portal hypertension management includes a variety of high-cost procedures such as therapeutic endoscopy, intensive care unit admissions and interventional radiological procedures such as transjugular intrahepatic portosystemic shunts. Similarly, surgical and interventional procedures are used to manage patients with HCC.

The existing geographic disparity in organ availability increases spending for pretransplant care in certain regions as a result of both the prevalence of high MELD patients and the cost associated with supporting patients with advanced cirrhosis for prolonged periods. In prior analyses, ESLD costs for waitlisted patients varied by nearly 100% between regions (10). Patients living in regions with higher median allocation MELD scores at transplant require procedures to treat and stabilize their HCC to prevent spread prior to transplant. Using claims data from a large managed care plan, McAdam-Marx et al compared annual spending for HCC patients ($43 671 per person) and ESLD without HCC ($27 845) (19). Although patients with HCC in low-MELD regions can frequently be transplanted rapidly, those in competitive regions must wait for several cycles of HCC-related upgrades prior to transplant and thus require locoregional therapy to maintain their candidacy (20). The proposed redistricting directly addresses these issues by mitigating disparity in MELD at transplant and in waiting times. In addition, broader sharing may reduce the need for some repeated locoregional therapy in high-MELD regions through timely access to available allografts.

The cost of the transplant procedure itself also differs significantly between geographic areas, likely as a result of both biological MELD score at transplant and more widespread use of marginal donor organs to meet clinical demand. Patients transplanted in high-MELD regions have higher costs, longer lengths of stay and worse outcomes, on average, than patients transplanted in less competitive regions with lower MELD scores at transplant (4,7,21–24). Consequently, the costs and benefits of the new districts are likely to be experienced differently by transplant centers across the United States. Total spending is expected to be lower for patients cared for in 84 (60.8%) of the transplant programs that are currently transplanting patients with very high biological MELD scores. Unfortunately, under current episode-based payment systems, transplant centers are unlikely to benefit from cost savings for pretransplant patients but are likely to bear the additional costs of organ transport and initial posttransplant care resulting from the redistricting proposals. Nevertheless, as health care reimbursement shifts toward accountable care models with capitated payments, health systems might derive both economic and clinical benefits from a more efficient allocation system (25,26). In addition, some of the increase in transplant costs will be offset through higher transplant volumes and outlier payments and through the Medicare Organ Acquisition cost center to which the transportation costs will be assigned. In the interim, support of higher payments at the time of transplant may be needed because the payer community will directly benefit from lower pretransplant spending and improved patient outcomes.

These results should be interpreted within the limitations inherent to analysis of registry and claims data. This overall economic analysis was derived exclusively from a cohort of Medicare-insured patients cared for between 2002 and 2008 and adjusted to 2013 costs. Medicare patients with evaluable claims data constituted 27% of the liver transplant population (10). Because the majority of patients with ESLD become eligible for Medicare on the basis of disability rather than age, this cohort is minimally older and has characteristics largely similar to the general population with ESLD. This cohort was chosen because Medicare claims provide the only longitudinal source of data from listing through posttransplant care. Furthermore, estimates of the impact of MELD on cost are similar to those in a previous analysis using data from a large private insurance firm (22). Variation in Medicare payments may not accurately capture differences in the true cost of delivering transplant services as a result of DRG-based reimbursements. Consequently, we analyzed UHC hospital cost accounting data through 2013 for the transplant episode. The differences in the cost of care among liver allocation alternatives using these data were similar to the Medicare estimates, although the total costs included the standard acquisition cost for the organ. Costs included only those costs associated with the transplant procedure and postoperative care. The UHC data confirm an increase in the cost of the transplant episode that may significantly increase the cost of liver transplant care if transplant volumes remain the same or increase. UHC data do not capture the pretransplant care of patients because this care may occur at a variety of medical facilities; however, these data add to the robust nature of the analysis by validating cost estimates from Medicare data though an independent data source.

Despite our attempts to provide robust estimates of both pre- and posttransplant cost, there are several key limitations. The cost of pretransplant care was censored when waitlisted patients were delisted or died; therefore, this analysis results in a conservative estimate of the true cost of ESLD care because it does not include spending for patients who were never listed or who became too sick for transplant prior to death. Although the daily pretransplant costs were adjusted for last reported MELD score, the models did not adjust the cost estimates for the total time at or above the current the MELD score.

The simulation results reflect the limitations of LSAM. The MELD values in the maps in Figure 3 are simulation outputs based on the most recently available (2006–2011) LSAM inputs. LSAM does not account for possible changes in acceptance patterns or listing patterns under revised allocation rules. In addition, LSAM does not fully account for differences in acceptance practices between centers within a given DSA. In current practice, for example, only livers that have been rejected repeatedly at the local level are offered regionally, and thus regionally shared livers have traditionally been associated with higher discard rates. The estimated reduction in total transplants under redistricting is an artifact of simulation and is not expected to occur in reality. Under redistricting, better quality livers would be offered to distant centers earlier in the allocation process for appropriate recipients, and local centers would have incentive to use organs that are currently being discarded. Discard rates for regionally shared livers would likely decrease, consistent with the actual transplant outcomes following the implementation of the Share 35 allocation system (27). The number of lives saved and the economic adjustments with redistricting may be even greater than predicted with this model if organ acceptance practices increased with redistricting. LSAM is also limited in its ability to predict the incidence of graft failure requiring retransplantation under different allocation scenarios; however, there was no predicted increase in the number of retransplants required under each scenario.

These cost estimates may not capture the increased complexity of broader sharing for transplant programs, OPOs and patients. Broader sharing will increase surgeon travel time and risk unless local teams are empowered to recover livers. OPOs will need to develop standard operating procedures with distant transplant programs, including development of protocols to place livers that are declined intraoperatively by the primary transplant center. Finally, local backup of organs will be needed to ensure that accepted allografts are not lost as a result of a recipient issue. Many of these issues are already encountered by transplant programs and OPOs as a result of Share 35. Preliminary analysis of Share 35 demonstrated that despite an increase in regional sharing from 18.9% to 30.4% ($p < 0.001$) of liver transplants, there was a 14% decline in discard rates and no significant impact of cold ischemic time or posttransplant outcome. These results suggest that centers and OPOs can successfully implement measures to address the increased complexity inherent to broader sharing of organs. As a result of this increased work, some OPOs are now charging a surcharge for organs imported and exported among DSAs. If this fee were $10 000 per transplant, the annual cost of liver transplant would increase by an additional $13.7 million to $26.6 million compared with allocation under Share 35. The UNOS Liver and Intestinal Transplantation Committee is considering strategies that reduce air transportation for minimal differences in allocation MELD scores, such as the recently proposed concentric circle plan in which local centers receive some priority for available allografts. In addition, the community should consider the impact of increased demand for private aircraft and consider the use of alternative methods of organ transplant including use of commercial aircraft if this can be done without increasing cold ischemic times significantly.

Redistricting and broader sharing of available allografts have been suggested to reduce geographic disparities in access to liver transplantation. Shifting organs from patients with lower MELD scores to patients with higher MELD scores increases the net benefit of transplantation, as demonstrated by Shaubel et al (28). Mathematically optimized districts are predicted to substantially increase the net benefit of liver transplant care by reducing waiting list deaths with minimal reduction in posttransplant survival. The current data suggest that redistricting will have a modest effect on health care spending and hospital costs with the eight-district plan. Although broader sharing will increase the cost of transporting organs and, potentially, the cost of transplantation in regions with lower MELD scores, the savings achieved through the reduction in care for high-MELD patients are expected to offset these expenditures. Transplant centers, however, will likely face increased costs, particularly in regions currently transplanting lower MELD patients. Although economic concerns should not preclude liver allocation policy changes to save lives and reduce geographic disparity, changes in the allocation system need to be carefully implemented to ensure that transplant centers are not forced to absorb higher costs for transplantation care without sharing in the benefits of lower waitlist costs.

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Disclaimer

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Disclosure

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Table S1: Donor and recipient characteristics (percentage) for the overall cohort of liver transplant patients from the Organ Procurement and Transplantation Network, the University HealthSystem Consortium and Medicare; because these cohorts are not independent, no formal statistical testing can be applied.