Market Competition and Density in Liver Transplantation: Relationship to Volume and Outcomes

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BACKGROUND: Liver transplantation centers are unevenly distributed within the Donor Service Areas (DSAs) of the United States. This study assessed how market competition and liver transplantation center density are associated with liver transplantation volume within individual DSAs.

STUDY DESIGN: We conducted a retrospective cohort study of 53,156 adult liver transplants in 45 DSAs with 110 transplantation centers identified from the Scientific Registry of Transplant Recipients between 2003 and 2012. The following measures were derived annually for each DSA: market competition using the Herfindahl Hirschman Index, transplantation center density by the Average Nearest Neighbor method, liver quality by the Liver Donor Risk Index, and patient risk by the Model for End-Stage Liver Disease. A hierarchical mixed effects negative binomial regression model of the relationship between liver transplants and market factors was created annually. Patient and graft survival were investigated with a Cox proportional hazards model.

RESULTS: Transplantation center density was associated with market competition ($p < 0.0001$), listings for organ transplantation ($p < 0.0001$), and Model for End-Stage Liver Disease at transplantation ($p = 0.0005$). More liver transplantation centers (incidence rate ratio [IRR] = 1.03; $p = 0.04$), greater market competition (IRR = 1.36; $p = 0.02$), increased listings (IRR = 1.14; $p < 0.0001$), more donors (IRR = 1.24; $p < 0.0001$), and higher Liver Donor Risk Index (IRR = 3.35; $p < 0.0001$) were associated with more transplants. No market variables were associated with increased mortality after transplantation.

CONCLUSIONS: After controlling for demographic and market factors, a greater concentration of centers was associated with more liver transplants without impacting overall survival. These results warrant additional investigation into the relationship between geospatial factors and liver transplantation volume with consideration for the optimization of scarce resources. (J Am Coll Surg 2015;221:524−531. © 2015 by the American College of Surgeons)

Liver transplantation is a profound and life-saving intervention for patients with end-stage liver disease, but geographic disparities in access to transplantation exist in the United States.[1-4] Across the country, liver transplantation centers are distributed unevenly throughout the 58 legislatively defined Donor Service Areas (DSAs), which generally serve as the first geographic border for organ allocation and distribution. Coupled with the current organ allocation system, this geographic variation in transplantation center distribution leads to disparities in access to organ transplantation and graft outcomes.[1-4] As organs are initially allocated within a DSA, considering each DSA as an individual market can be a useful method for understanding transplantation practices and outcomes in the United States.

Earlier work in transplantation has used the Herfindahl Hirschman Index (HHI),[5] a measure of market competition used frequently in describing health care markets, to describe competition within a DSA. In kidney transplantation, increased market competition is associated with increased patient mortality and graft failure due to the use of riskier kidneys.[6] Similarly, increased market competition in liver transplantation is associated with variability in listing rates, risk of graft failure, and risk of death.[7] However, this definition of "market" suffers from the large geographic area covered by the DSAs. As yet, the spatial relationship of transplantation centers has not yet been explored. Although market entry is often regulated by certificates of need, it is also true that competition can exist in heavily regulated markets. Increasing market competition and transplantation center density can encourage the use of more marginal organs; as outcomes continue to improve, this might increase access to transplantation.

Studying transplantation centers relative to their spatial organization and density could provide a useful model to better understand the market forces that shape liver transplantation access and outcomes, which in turn could present useful guidance for decisions about either opening new centers or the consolidation of centers. The specific aims of this study were first to determine if there is an association among market competition, transplantation center density, and the number of liver transplants performed; secondarily, we aimed to measure patient and allograft survival in the context of changing transplantation markets. To do this, we used the HHI and the Average Nearest Neighbor (ANN),[8] a measure of spatial density in Geographic Information Systems.

METHODS
Liver transplantation markets and characteristics
Data for all adult liver transplants performed in the United States were retrieved between January 1, 2003 and December 31, 2012 from the Scientific Registry of Transplant Recipients (SRTR). Transplantation markets were defined initially as the 58 DSAs in the United States;

to better approximate the DSAs with preexisting sharing agreements, DSAs were combined for the years that sharing agreements were in effect in New York, Florida, Tennessee, and Ohio. Centers were included if at least one adult deceased donor liver transplantation was performed in a given calendar year. Pediatric hospitals that performed liver transplants in patients older than 18 years of age, who would otherwise be considered adults, were excluded due to relatively small volume and inconsistent practices (some years there would be no transplants, and these centers would appear to "close and open" randomly despite actually being open). Years in which DSAs did not have liver transplantation centers were excluded from the final analysis.

Market characteristics (number of transplantation centers, new listings, deceased organ donors, and the number of liver transplants) were then abstracted for each DSA on an annual basis. The number of donors was counted from all individuals who donated organs, whether or not a liver was actually transplanted from a particular donor. The HHI,[9] a standard measure of market competition, was calculated on an annual basis for each DSA as described in our previous work.[6] In brief, the HHI ranges from 0 to 1. For a monopoly (one transplantation center in a DSA), the HHI = 1, and the more competitive DSAs (with multiple transplantation centers performing a relatively equal number of transplants) have an HHI closer to 1. For modeling, the HHI was inverted such that 0 represents no competition and that 1 is perfect competition; this facilitates interpretation of the regression coefficients as an increased (inverse) HHI translating to "higher competition." When the inverse is presented in models, it is indicated as "inverse HHI."

The Liver Donor Risk Index (LDRI) was calculated for each liver transplanted.[10] An adjusted LDRI was created with the removal of cold ischemia time and organ sharing status to equalize the overall quality number for exported livers, but both measures were used to ensure validity. Annual population for each DSA was obtained by aggregating the US Census intercensal estimates (http://www.census.gov) on an annual basis by counties within a DSA as reported by the SRTR.[11]

Market density, mixed effects model, and survival analyses
To measure spatial organization of transplantation centers, the ANN method in ArcGIS software, version 10.2 (ESRI) was used; this has been used in Geographic Information Systems applications in health care and epidemiology.[8,12] First, liver transplantation centers were geocoded with BatchGeo (http://www.batchgeo.com).