Mathematical Methods to Reduce Geographic Disparities in Organ Availability
Balancing supply and demand

• Geographic disparities in organ availability are caused by uneven distribution of liver disease, listings, and eligible deaths
• Eligible deaths vary 4-fold among DSAs
• Listings for liver transplant vary 14-fold among DSAs
• Deaths due to liver disease vary 19-fold among DSAs
OPO performance

• OPO performance metrics vary by less than 2-fold across DSAs
• Geographic disparities are not correlated with organ procurement organization performance
  [Gentry et al. Liver sharing and organ procurement organization performance. Liver Transplantation 21(3) 2015]
• OPO performance improvements can increase transplants but can not resolve geographic imbalance in supply and demand
Liver committee efforts to reduce disparity

- June 2009: Evaluation of Allocation Systems using Regional Sharing or Concentric Circle Sharing above various MELD/PELD Thresholds
- February 2010: Data request models multiple allocation systems
- June 2010: LSAM evaluation of organ distance traveled for 27 proposed allocation systems
- October 2010: Simulated waiting list deaths by MELD/PELD for various allocation systems
- March 2011: Analysis of Region 8 Alternative Allocation System
Percent Shared vs. Decrease in Total Deaths

Decrease in deaths vs. Percent shared outside of local
Broader sharing not sufficient to reduce disparity -- actually worse with existing regions

• Fully regional sharing is not predicted to reduce disparity in MELD at transplant; paradoxically, fully regional sharing increases disparity [Gentry et al. Am J Trans 2013]

• Share-35 is a partial step toward regional sharing in the existing regions. Actual data from Share-35 shows increase in disparity of median MELD at transplant.
Percent Shared vs. Decrease in Total Deaths

Decrease in deaths

Percent shared outside of local
Geographic disparity metrics

• Total number of waitlist deaths is not a disparity metric. The aim of redistricting is not to reduce total waitlist deaths, it is to reduce disparity in availability of organs to candidates waiting in different parts of the country.

• Supply and demand: Our redistricting optimization minimizes the absolute difference between supply (livers transplanted in 2010) and demand (high-priority incident listings in 2010) in each district
  ▪ Note that changes to MELD exception points would not change the redistricting optimization

• Variance in median MELD at transplant: The OPTN’s liver committee was tasked by the Board to choose a metric of geographic disparity in liver allocation, and this was the metric it chose. (March 2013)
Liver committee alternatives considered

• The liver committee decided in 2013, after examining many alternatives, to undertake an extensive study of redistricting
  ▪ Optimization is a simple, transparent, parsimonious solution understandable to the entire transplant community
  ▪ Redistricting retains existing DSA boundaries and only reorganizes at the regional level
  ▪ Plan was to use optimization to design the district maps, and then use simulation modeling (LSAM) to perform detailed analysis of redistricting impacts – disparities as measured by MELD at transplant, transport, cost,
Liver Committee’s design constraints

• Districts should respect the existing DSA boundaries and should be contiguous.*
• The number of districts should be at least 4 and no more than 8.
• The maximum median transplant-volume-weighted transport time between DSAs is 3 hours.
• Each district must contain at least 6 transplant centers.
• Districts should be designed to minimize geographic disparity, and must not increase waitlist death.
\( I = \mathcal{K} \{1, 2, 3, \ldots, 57\} \) DSAs

\( w_{ik} = 1 \) if DSA \( i \) is in the district with center at DSA \( k \), and 0 if not

\( Y_k = 1 \) if DSA \( k \) is selected as the center of a district, and 0 if not

\( c_k = \) active liver transplant centers in DSA \( k \)

\( \delta_{ij} = \) volume-weighted distance from DSA \( i \) to \( j \)

\( \tau_{ij} = \) volume-weighted transport time between DSAs \( i \) and \( j \)

\( d_k = \) livers available in DSA \( k \)

\( p_k = \) number of livers that should go to DSA \( k \) if geography were not a factor in allocation

[Gentry, Chow, Massie, Segev. To appear, Interfaces, 2015.]
Objective: minimize geographic disparity in liver availability by minimizing the sum of misdirected livers.
subject to: \[ \sum_{k \in \mathcal{K}} W_{ik} = 1 \quad \text{for all } i \in \mathcal{I} \]
\[ W_{ik} - Y_k \leq 0 \quad \text{for all } i \in \mathcal{I} \text{ and } k \in \mathcal{K} \]

Each DSA is assigned to one district

If a DSA \( k \) is assigned as the center of the district containing DSA \( i \),

\[ Y_k \text{ should be } 1 \]
Number of districts is $N$

Require at least $\bar{h}$ transplant centers in each district
Maximum transport time from each district to its district center is
\[ \sum_{k \in \mathcal{K}} \alpha_{ijk} W_{ik} \leq 1 - Y_j \text{ for all } i \in \mathcal{I} \text{ and } j \in \mathcal{K} \]

\( \delta_{ij} = \text{volume-weighted distance from DSA } i \text{ to } j \)

\( \alpha_{ijk} = \{1 \text{ if } \delta_{ik} > \delta_{ij}, 0 \text{ if not}\} \)

Every DSA is assigned to its nearest district center

(Daskin, Service Science, 2010)
Mathematical optimization for redistricting

- The only data used for designing the sharing districts are the # donors per OPO and # new liver transplant candidates at various MELDs (supply/demand per OPO)
  - Maps under consideration were designed using 2010 data
  - These counts are stable: maps designed using 2006 data also significantly reduced geographic disparity and reduced waiting list and total deaths when applied to 2010 simulations (Gentry et al., AJT 2013)
  - These counts seem to be stable even since Share-35
Optimized 8 District Map
Optimized 4 District Map
Summary

• The mathematical optimization that designed the redistricting alternatives shown is transparent and parsimonious, representing exactly the limits of feasibility in allocation as selected by the liver committee.
• Redistricting design considers only geography, supply, demand.
• Under redistricting, livers flow from areas with greater-than-expected eligible deaths and fewer-than-expected listings toward areas with fewer-than-expected eligible deaths and greater-than-expected listings.
• Full sharing in optimized districts is predicted by the Liver Simulated Allocation Model to greatly reduce geographic disparity and reduce waitlist deaths and total deaths.
Thank You

Contact the Scientific Registry of Transplant Recipients:

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