Organization of Living Donor Organ Exchanges as an Economic Design Paradigm

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Kidney Exchange

- One of the most unexpected applications of market design which contributed to the visibility and success of the field is kidney exchange (KE) (Roth, Sönmez, and Ünver, 2004, 2005, 2007).
  - Within a few years after its introduction as a market design application, our formal approach transformed living donor kidney donation in many countries.
  - Within a decade, it started saving more than a thousand lives annually.

Kidney Exchange — Why Unexpected?

- Way outside the traditional domain of economics.
- Help from economists was volunteered as "outsiders" and was not solicited.
- This is a story of aspiring design economists who want to make a difference in how institutions work.

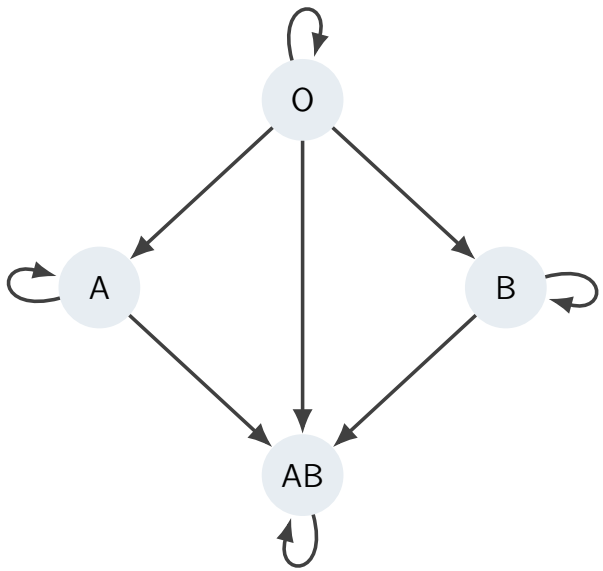
Background

- Transplantation is the preferred treatment for the most serious forms of kidney disease.
- There is a significant transplant organ shortage in almost all countries.
- Buying and selling a body part is illegal in most countries.
- Donation is the only legal source of transplant organs.

Medicine of Donation: Blood-type Compatibility

A donor needs to pass two compatibility tests before transplantation.

- ABO Blood-type Compatibility: There are four blood types: O, A, B, AB.



  - AB can receive from all blood types.
  - A can receive from A and O.
  - B can receive from B and O.
  - O can only receive from O.

Medicine of Donation: Tissue-type Compatibility

- Tissue-type Compatibility:
  - Before the transplantation, the potential recipient is tested for the presence of preformed antibodies against donor DNA.
  - If the level of antibodies is above a threshold, then the transplant cannot be carried out.

Donation Paradigms

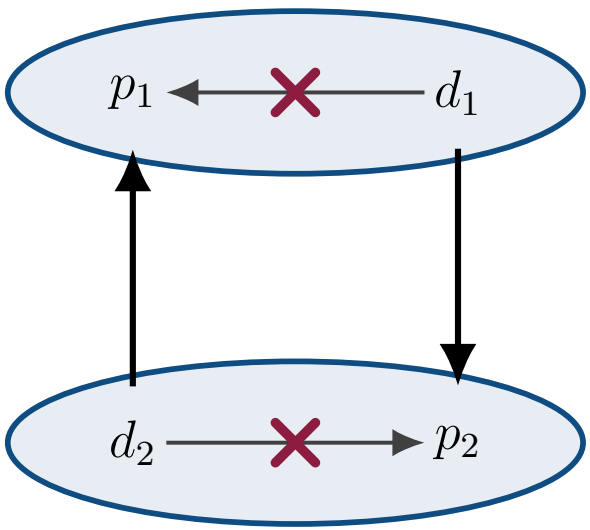
- **Traditional:**
  - Deceased Donation: Centralized priority allocation. Waiting time is always prioritized, however, to different degrees for different organs.
  - Live Donation: Mostly loved ones of the patient come forward, and if one is compatible with the patient, donation is conducted.
- **Newer:**
  - Paired Exchange
  - List Exchange

Early Phases of Kidney Exchange in New England

- Approved by the UNOS Board of Trustees in Fall 2000, the first kidney exchange program in the US was established in New England (UNOS Region 1) in February 2001 (Delmonico et al., 2004).
- In order to overcome barriers to living donation due to biological incompatibilities, the program made two types of arrangements: paired exchange and list exchange.

Paired Kidney Exchange (PKE)

- Paired Exchange: If the live donor who came forward for a patient is not compatible, the donor's organ is swapped with the organ from a similar patient-donor pair to find a compatible match for both patients. (Proposed by Rapaport 1986)

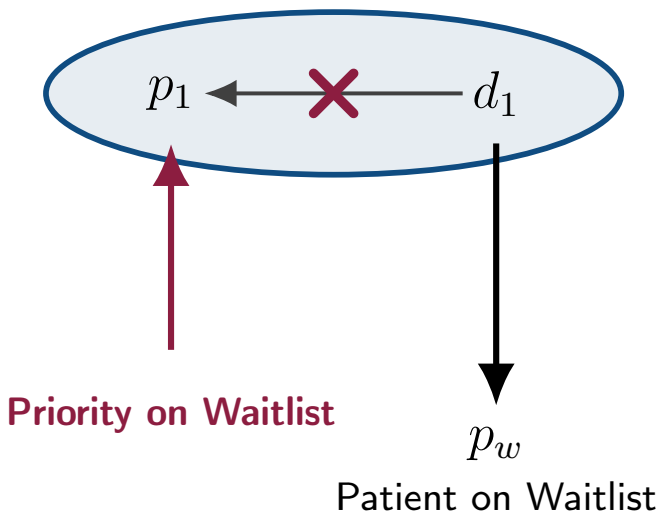


Paired Kidney Exchange (PKE) — Reception

- Transplantation community issued a consensus statement in 2000 declaring it as ethically acceptable (Abecassis et al., 2000).
  - Considered high praise in the medical community.
  - The consensus statement urged all four operations to be carried out simultaneously.
- First carried out in South Korea in 1991 (Park et al., 1999).

List Exchange (LE)

- List Exchange: If the live donor who came forward for a patient is incompatible,
  - the donor's organ is given to a patient on the deceased-donor waitlist;
  - in return, the first patient receives the highest priority on the waitlist to receive the next incoming deceased-donor organ. (Proposed by Ross and Woodle 2000)



List Exchange (LE) — Pros and Cons

- Appeal: Easy to organize.
- Ethically problematic:
  - The patient who goes to the waitlist is usually of blood type O while the organ donated by her donor is A or B.
  - Recall O blood-type patients are naturally disadvantaged.

Early Phases of Kidney Exchange in New England

- Despite the ethical concerns, New England included LE in its program. This decision was defended by its leadership as follows:

> "This exchange program has a clear utilitarian goal: to have more recipients undergo successful transplantation by expanding the pool of compatible live donors."
>
> *Delmonico et al. (2004)*

- Reflecting the concerns, however, much of the discussion in Delmonico et al. (2004) involves the precautions taken to mitigate the adverse impact of LE on type O patients on the DD waiting list.

Early Phases of Kidney Exchange in New England

- Despite being the less preferred type of KE, most transplants arranged by New England's program in its early phases were from LE.
  - # of LE Transplants (Feb. 2001–Dec. 2003): 17
  - # of PKE Transplants (Feb. 2001–Dec. 2003): 8 in 4 PKEs
- No Database: Prior to our involvement in Fall 2004, the program in New England did not collect data on living donors of kidney patients.
  - Explains the small number of transplants from PKE in the early years of the program.
- While arranging a LE does not require a patient-donor database, organizing them also involved operational challenges in New England.

Early Phases of Kidney Exchange in New England

- A prerequisite for eligibility for LE was to assure that no PKE is feasible between the patient and any other patient registered in all 14 transplant centers in the system.

> "[...] the general practice has been to ask such pairs to wait a minimum of one month, in order to avoid flooding the system with 'unnecessary' list exchanges. If no such pair is identified, the center can proceed with the live donor list exchange process."
>
> *Delmonico et al. (2004)*

Timing is Everything!

- Timing is everything! Under these circumstances, we shared the first draft of RSÜ (2004) with Dr. Delmonico in Fall 2003, and conveyed our interest in collaborating with them to improve their KE program.
- But how did this research develop in the first place?

Early Market Design Research in Kidney Exchange

- I visited Alvin Roth at Harvard University for the academic year 2002–2003.
- During my visit, Roth alerted me that the house allocation with existing tenants model (Abdulkadiroğlu and Sönmez, 1999) has an unusual application in kidney transplantation:
  - Patients with living donors are analogous to existing tenants.
  - Paired-donor kidneys are analogous to occupied houses.
  - Patients on DD list are analogous to newcomers.
  - DD kidneys are analogous to vacant houses.

Early Market Design Research in Kidney Exchange

- Consequently, the you request my house — I get your turn (YRMH-IGYT) mechanism (Abdulkadiroğlu and Sönmez, 1999; Sönmez and Ünver, 2005) also had an application.
- Regulating the claims for "unattached" houses (either vacant or vacated during the procedure) with an exogenous priority list, YRMH-IGYT organizes two types of exchanges:
  1. Cycle: existing tenants trade their current houses.
     - PKE corresponds to a cycle with two individuals.
  2. Chain: one individual trades her priority for an "unattached" house and the remaining individuals trade their current houses.
     - LE corresponds to a chain with two individuals.

Early Market Design Research in Kidney Exchange

- While regulating chains through an exogenous priority list (as in YRMH-IGYT) is also a viable policy for KE, we observed that other chain selection rules may mitigate (and even eliminate) the adverse impact of LE on type O patients on the DD list.
- RSÜ (2004): Addressed both goals of the transplantation community with this generalization of the YRMH-IGYT mechanism.

The Birth of a Partnership Between Economists & Doctors

- Our informed and cautious approach resonated with Dr. Delmonico, the Chief Medical Officer at New England Organ Bank.
  Subsequently, he made the following requests:
  1. Given the scale of simulated welfare gains from our system, we should drop the more controversial LE altogether.
  2. Due to logistical constraints, we should only allow for PKE.
  3. To avoid a situation where patients and hospitals may compete for donors with certain characteristics, we must assume that patients are indifferent between all compatible donors.

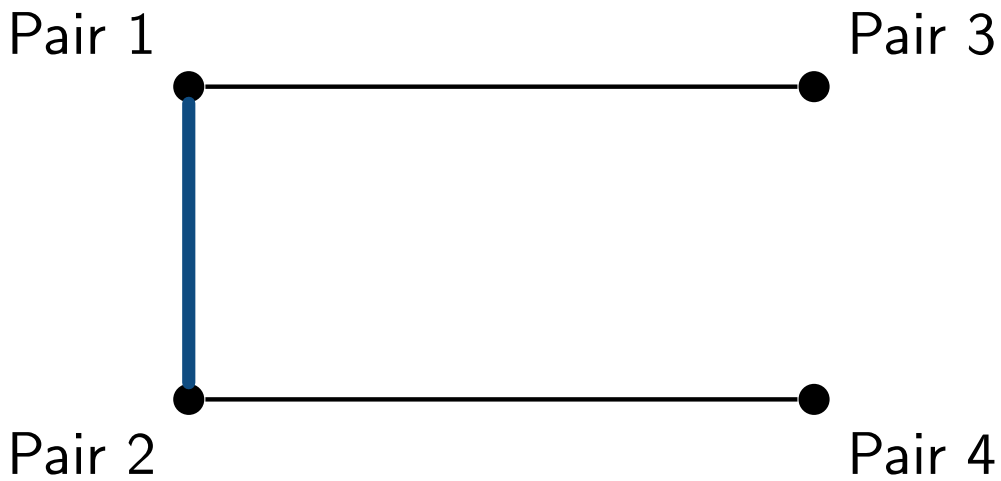
NEPKE: The First Optimized Kidney Exchange System

- We accommodated all requests in RSÜ (2005), which formed the basis of the New England Program for Kidney Exchange (NEPKE).
  - Approved by the Renal Transplant Oversight Committee of New England in September 2004, NEPKE became the first KE system that adapted analytical techniques from market design and optimization.

Optimization is Important

- Our team came up with optimized algorithms, coded and ran NEPKE's software for several years. Our partnership resulted in a number of additional breakthroughs.
- Even in the absence of more elaborate exchanges, merely organizing the two-way exchanges may result in increased efficiency.

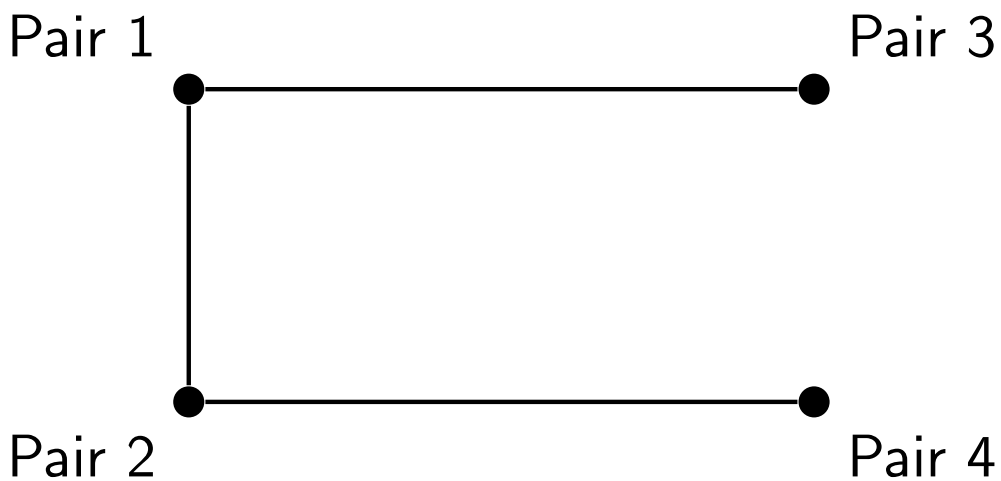
Optimization is Important



Suboptimal Exchange:
2 patients receive transplant

- Even in the absence of more elaborate exchanges, merely organizing the paired-exchanges may result in increased efficiency.

Optimization is Important



- Even in the absence of more elaborate exchanges, merely organizing the paired-exchanges may result in increased efficiency.

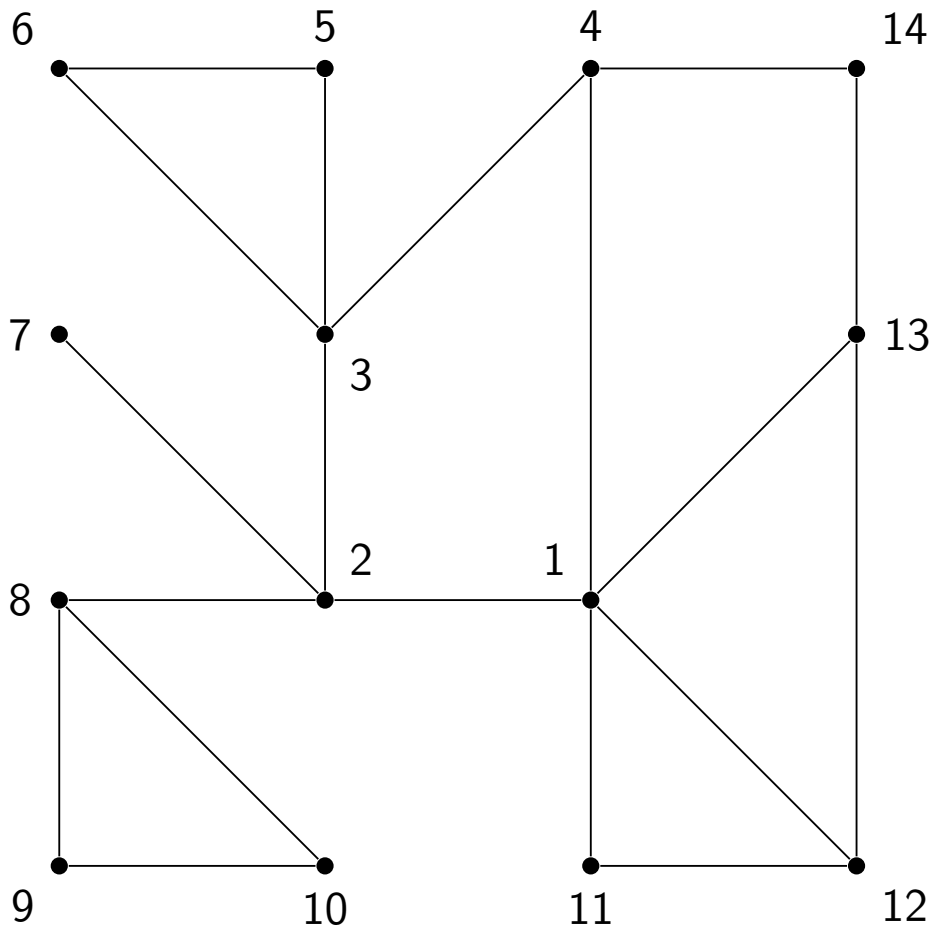
Optimization is Important

Optimal Exchange:
4 patients receive transplant

- Even in the absence of more elaborate exchanges, merely organizing the paired-exchanges may result in increased efficiency.

Optimization is Important

- The 2-way exchange graph can be very complicated because of both blood-type and tissue-type incompatibilities.



Optimization is Important

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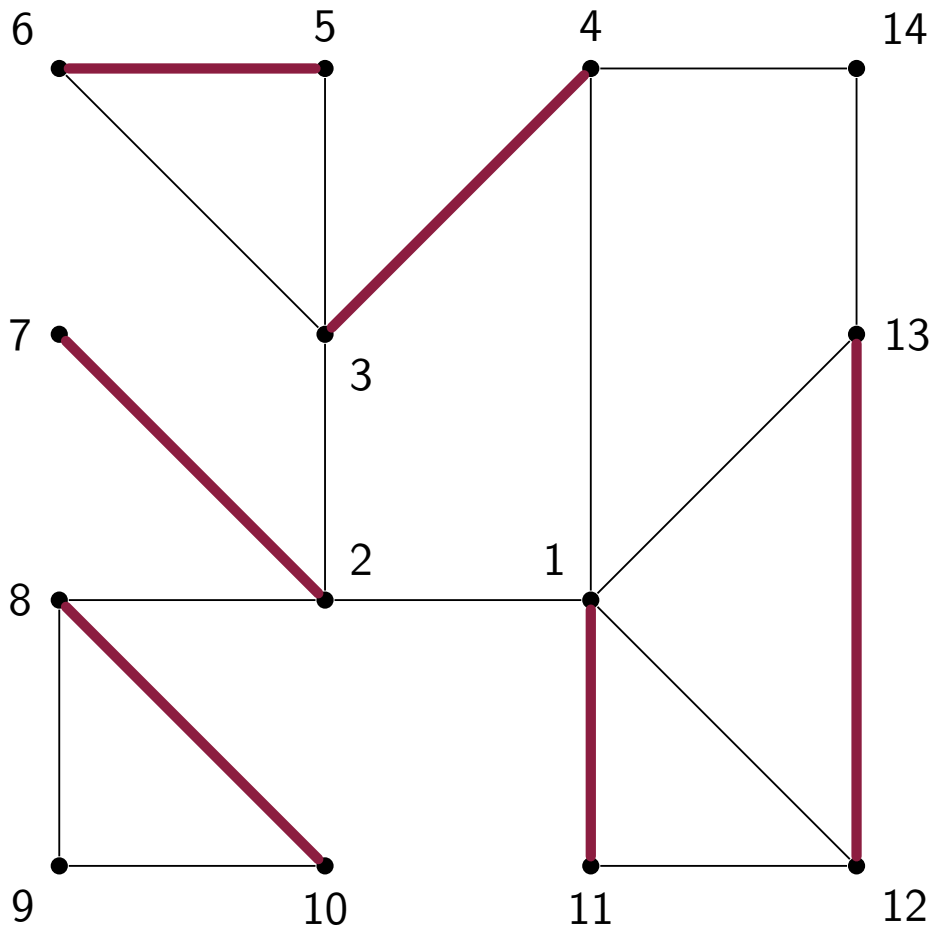
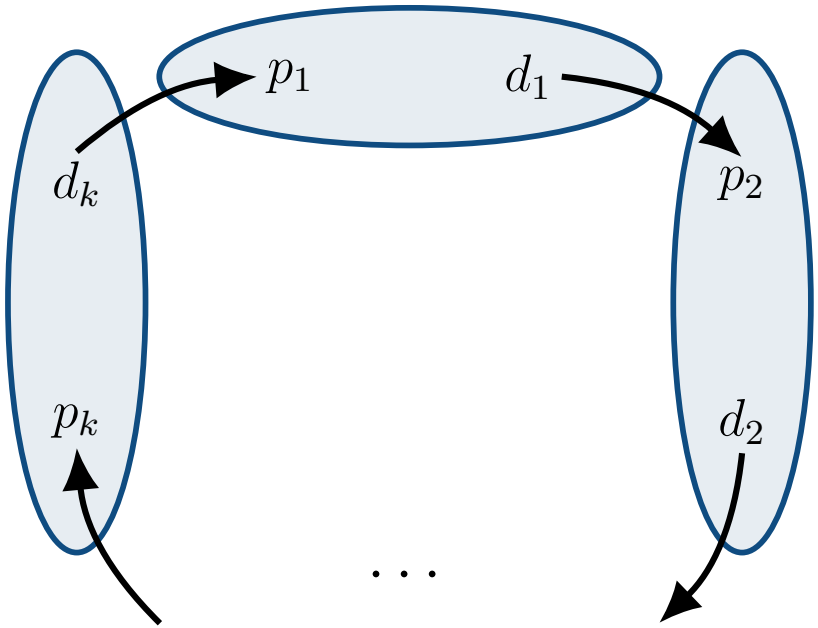


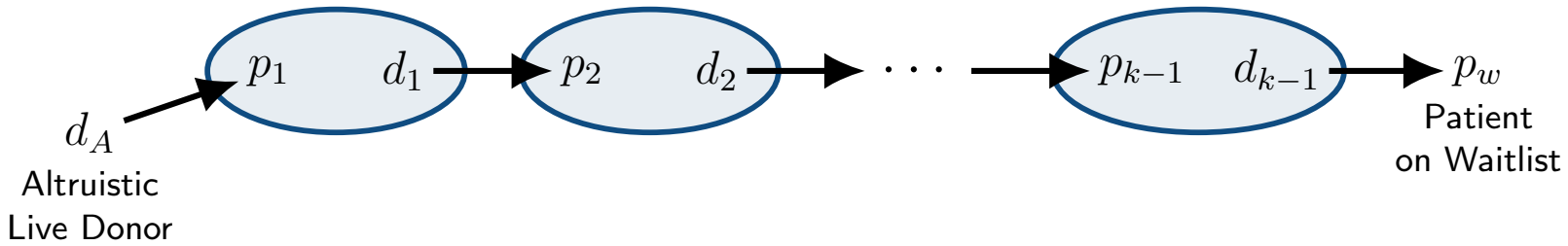
Gains from Larger Exchanges are Considerable



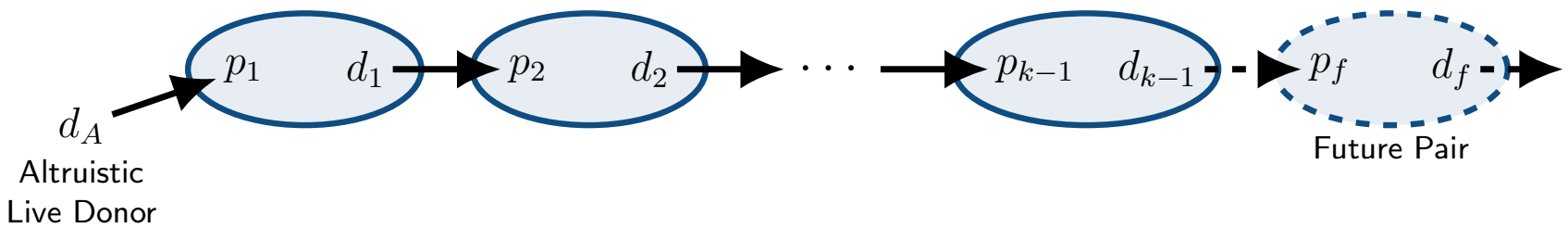
- Additional live-donor transplants may be possible through three-way, four-way, . . . , exchanges.
- Three-way exchange is especially important! (RSÜ, 2007, Saidman, Roth, Sönmez, Ünver, and Delmonico, 2006)
- NEPKE incorporated 3-way exchanges.

Non-Directed Donor (NDD) Chains

- NDD-chains: Together with our NEPKE partners, we introduced and advocated for non-simultaneous implementation of chains, when they initiate with a non-directed living donor kidney (Roth et al., 2006).



- Open NDD-chains: The last pair can donate to a future pair, continuing the chain (Rees et al., 2009):



Non-Directed Donor (NDD) Chains — Impact

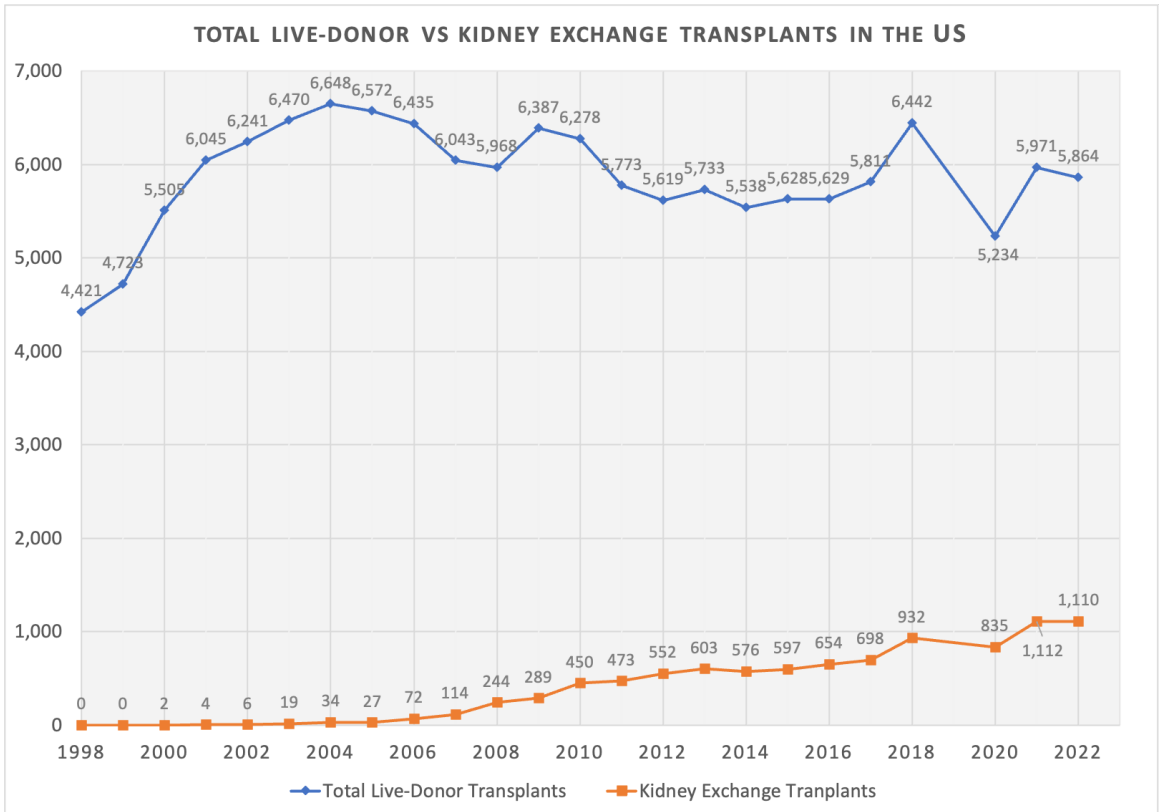
- While NEPKE did not adopt NDD-chains, a second KE program we supported in its early years, Alliance for Paired Donation (APD), did.
- Today, a sizable part of the welfare gains from KE are due to NDD-chains (Agarwal et al., 2019).

Non-Directed Donor (NDD) Chains

Current US Situation

- NEPKE and APD were the first optimized kidney exchange programs (we ran both for many years).
  - NEPKE dissolved to become the (public) National UNOS Exchange Program.
  - APD still exists.
- Now, the National Kidney Registry (a private non-profit) is the largest kidney exchange program in the world.
- Kidney Exchange accounts for almost 20% of all living-donor kidney transplants in the US.

Current US Situation — Transplant Numbers



Kidney Exchange Receives Global Interest and Recognition

- These innovations attracted global interest, increasing the annual number of KPE transplants to over 1,000 in the US alone within a decade, nearly a 100-fold increase.
- In 2012, our co-author Alvin Roth received the Nobel Prize in Economics, in large part due to the success and visibility of KPE.

U.S. National Science Foundation

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Home / News / Kidney Exchange: A Life-Saving Application of Matching Theory

Discovery Files

Kidney Exchange: A Life-Saving Application of Matching Theory

Economists help build a kidney exchange system that saves lives.

October 5, 2005

Editor's note: On March 28, 2007, the Justice Department issued a legal memo stating that paired kidney donations do not violate a provision of the National Organ Transplant Act that makes it illegal to acquire an organ for transplant in exchange for "valuable consideration." The Justice opinion, issued in response to a question from the Department of Health and Human Services, is expected to increase the number transplants resulting from paired donations.

One Major Setback: Compatible Pairs

- Despite all these breakthroughs, we faced one major setback: with rare exceptions (e.g., San Antonio, Texas), limited ability to convince the medical community to include compatible pairs in KPE.
  - Potential to increase KPE transplants by as much as 160% (Sönmez, Ünver, and Yenmez, 2020).

Inclusion of Compatible Pairs in Exchange is Important

- Typically, a blood-type compatible pair participates in kidney exchange only when the donor is tissue-type incompatible with the intended recipient.
  A blood-type incompatible pair is automatically referred to a kidney exchange program.
- Hence, there are many more blood-type incompatible pairs in kidney exchange programs than blood-type compatible pairs.

$$\#\ \textbf{O Patients} \gg \#\ \textbf{O Donors}$$

From Kidney to Liver Paired Exchange

- Initially, due to Dr. Delmonico's wishes, we modeled preferences as compatible or incompatible only, with no fine-graining.
- Our progress to include compatible pairs in organ exchange came from an unexpected modality: liver paired exchange.

Institutions: Living-Donor Liver Donation

- Living-donor liver transplants are more common in Middle Eastern and Asian countries, where deceased donation is at a minimum due to cultural reasons and legal non-recognition of "brain death".
- Riskier than living-donor kidney transplants for the donors.

Annual liver transplant activity per million population

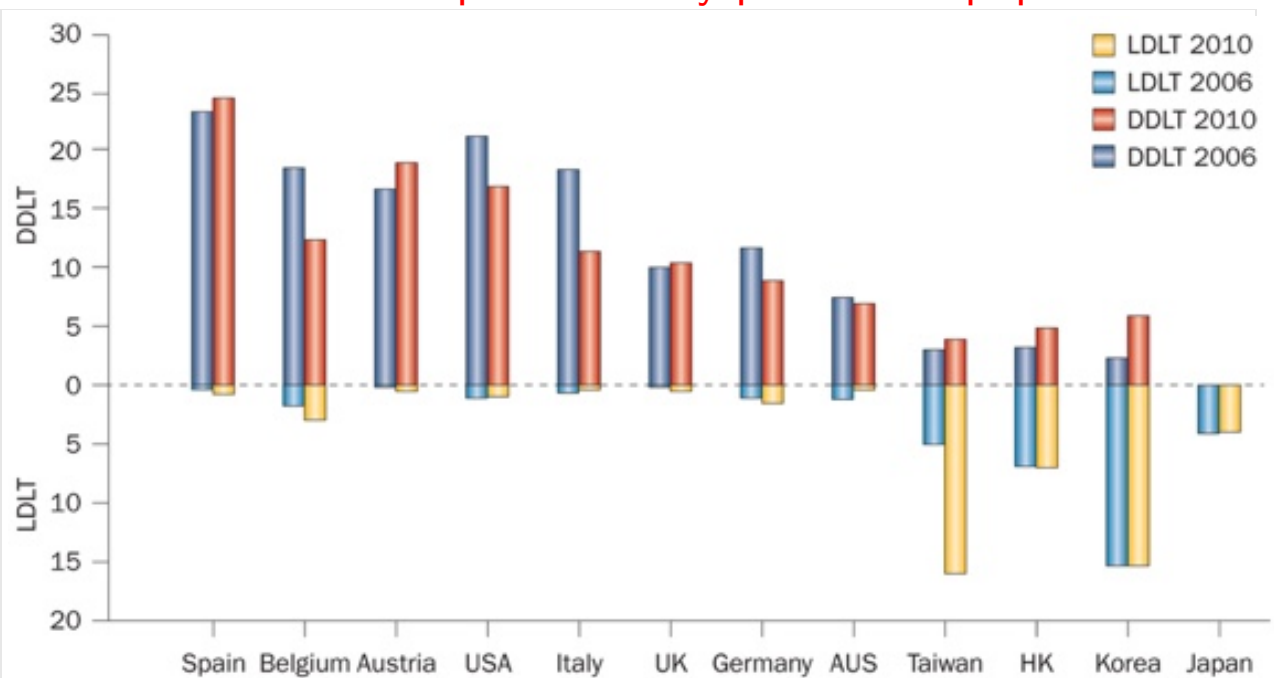
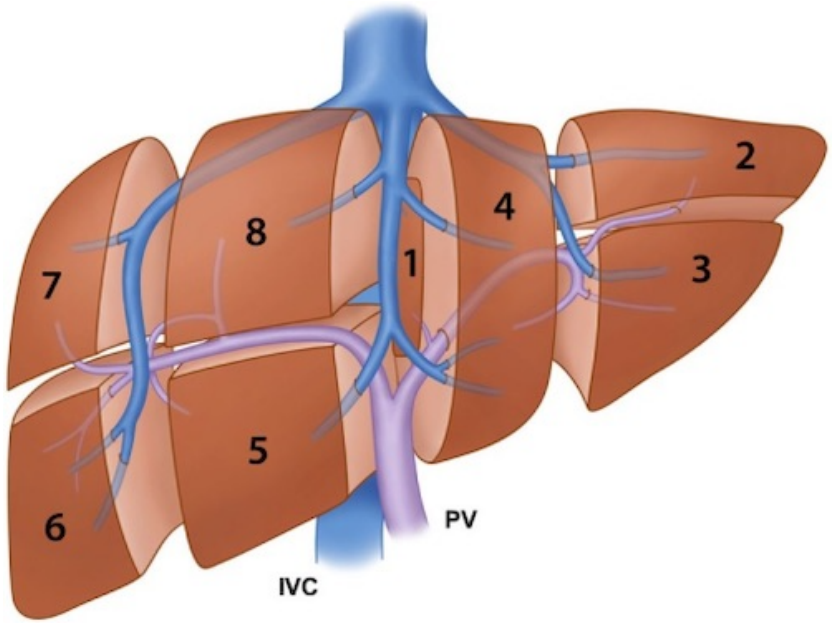


Figure from Chen et al Nature Reviews Gastroenterology & Hepatology 2013

Medical Background: Living-Donor Liver Transplantation

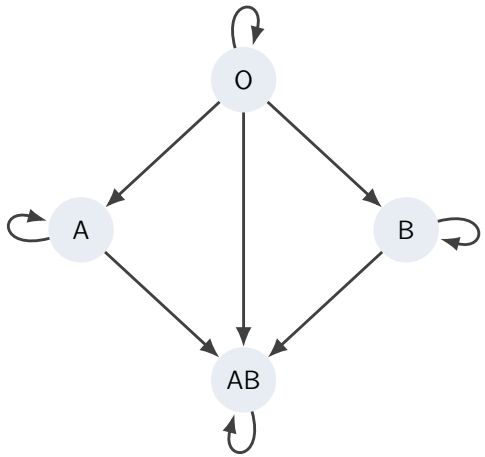


Feasible transplant grafts:

- Segments 2 and 3: for infants.
- Left lobe (Segments 1, 2, 3, 4) — ≈ 30–40% of liver volume; anatomically more difficult; mostly for children.
- Right lobe (Segments 5, 6, 7, 8) — ≈ 60–70% of liver volume; mostly for adults.

Medical Background: Compatibility

- Blood-type compatibility is required.



- Size compatibility is required — unlike kidneys:
  - A patient requires a graft relatively large to survive, but not too large: 0.8%–2% of body weight.
  - A donor requires a remnant relatively large to be safe: $> 30\%$ of liver size, about 0.6% of body weight.
- Tissue-type compatibility is **not** required — unlike kidneys.

Liver Exchange Practice

- Hwang et al. (2010) proposed the idea and documented the practice of liver paired exchange in South Korea since 2003, in very small numbers.
- Chan et al. (2010) documented a liver exchange program in Hong Kong.
- Mishra et al. (2018) advocated for the establishment of liver exchange clearinghouses in the US.
- Dual-Donor Organ Exchange:
  - Ergin, Sönmez, and Ünver (2017) proposed and modeled exchange for transplants that each need two living donors — lung, simultaneous liver+kidney, dual-graft liver.

Our Interest Shifts to Liver Paired Exchange

- In the mid-2010s, as kidney paired exchange systems matured worldwide, our interest shifted to liver paired exchange (LPE).
  - Some LPEs were reported from South Korea, but in very small numbers.
  - Due to several biological incentive mechanisms inherent to LPE (e.g., size constraints), we, along with Haluk Ergin, discovered that the inclusion of blood-type compatible pairs can be much easier in LPE (Ergin, Sönmez, and Ünver, 2020).
  - Consequently, by including compatible pairs, much larger welfare gains could be obtained for LPE than KPE.

Searching for an LPE Partner

ECONOMETRICA: MAY, 2020, **VOLUME 88, ISSUE 3**

Efficient and Incentive-Compatible Liver Exchange

https://doi.org/10.3982/ECTA16400
p. 965-1005

Haluk Ergin, Tayfun Sönmez, M. Utku Ünver

- Starting in the late 2010s, we began searching for liver transplant programs interested in collaborating to establish what we envisioned as the best LPE program globally.

Discovering the Outstanding LT Team at Malatya

- In 2019, we discovered that İnönü University in Malatya is home to the largest liver transplant center in Europe, capable of performing five simultaneous transplants.
  - We communicated with the group's leader, Prof. Dr. Sezai Yilmaz, to see whether they might be interested in a potential collaboration.
  - As we always do, we offered to support and run the program on a pro-bono basis.
  - In July 2019, we were invited to Malatya and, with the strong support of Rector Ahmet Kizilay, reached an agreement to establish a joint LPE program.
- After a three-year delay due to COVID-19, we launched the BBS-LPE system in July 2022 and officially announced it in July 2023.

Liver Paired Exchange (LPE) News from Türkiye

- About three years ago, on July 28, 2023, İnönü University announced the BBS–Liver Paired Exchange System (BBS-LPE) to the public.

- World-first 4-way LPE in July 2022 (Yilmaz et al., 2023).
- 15 LPE transplants in the first year (July 2022–July 2023), despite the catastrophic magnitude 7.8 earthquake that hit the region.

American Journal of Transplantation
Volume 23, Issue 10, October 2023, Pages 1612-1621

Brief Communication

The first 4-way liver paired exchange from an interdisciplinary collaboration between health care professionals and design economists

Sezai Yilmaz [1], Tayfun Sönmez [2], M. Utku Ünver [2 3], Volkan Ince [1], Sami Akbulut [1], Burak Isik [1], Sukru Emre [1]

For Reference: Prior to the BBS-LPE System

- No other system ever reported $10+$ LPE transplants in any year.
- Reported world total in 20 years was less than 250.
- Two other 3-way exchanges are reported (the first one in Pakistan).

What Happened Since the July 2023 Announcement?

- With the public announcement, the interest in the BBS-LPE system significantly increased.
- World-first 5-way LPE in October 2023 (Yilmaz et al., 2024).
- World-first 6-way LPE in January 2024 (Yilmaz et al., 2024).

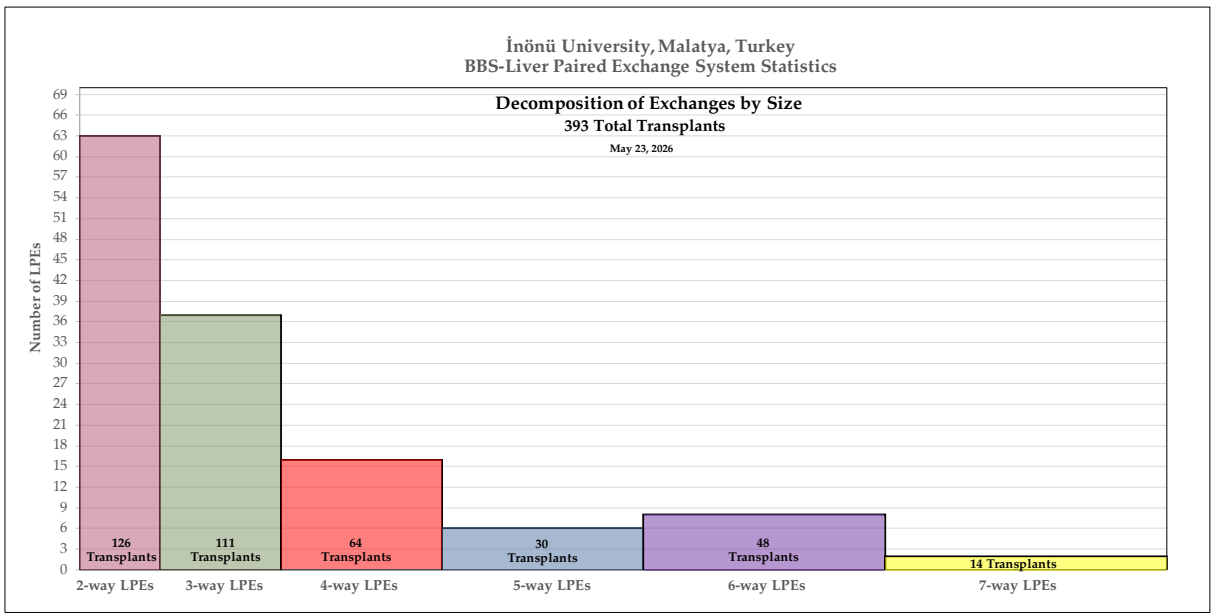
Transplant Milestones

- First system in the world to pass:
  - 100 LPE transplants in March 2024;
  - 150 LPE transplants in September 2024;
  - 200 LPE transplants in January 2025.

- World-first 7-way LPE in July 2024.

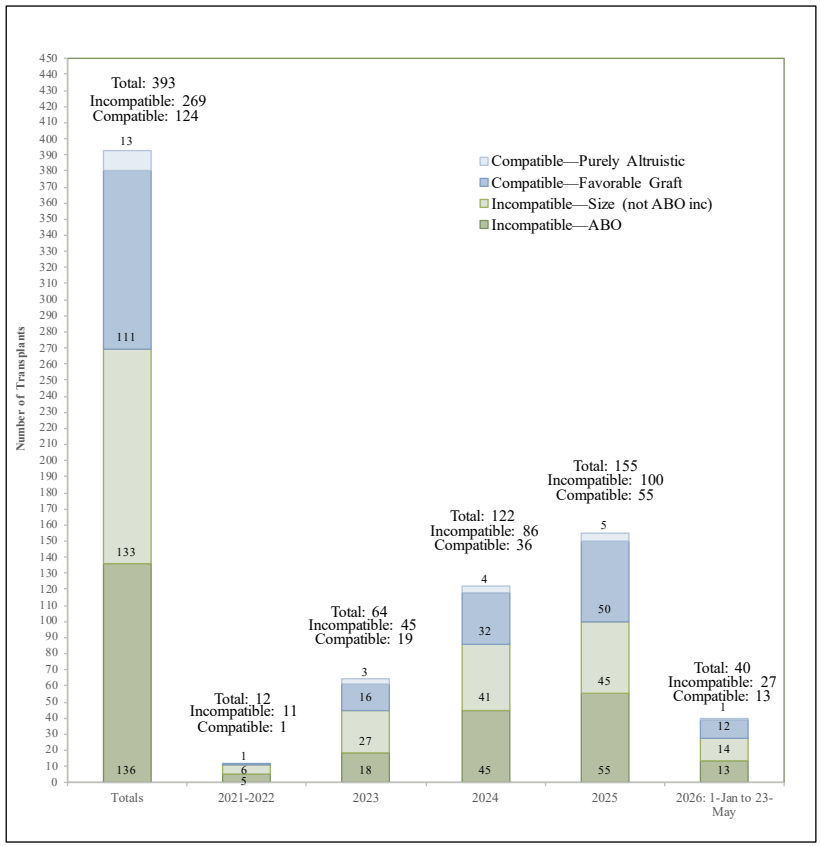
What Happened Since the July 2023 Announcement?

- Cumulative Exchange Breakdown (as of May 23, 2026)



- Two 7-ways
- Eleven 4-ways
- Seven 6-ways
- Thirty-seven 3-ways
- Six 5-ways
- Sixty-three 2-ways

Decomposition of Transplant Types



- As of May 23, 2026, the BBS-LPE system performed 393 LPE transplants since its launch in July 2022.
- 155 in 2025 (48% of all LDLTs); 122 in 2024 (47%); 64 in 2023 (27%) — no center has come close to 5%.

Outstanding LT Team, Facilities, and Experience

- DDLT since 2002, LDLT since 2005.
- $4500+$ LT to date ($3400+$ from LDLT).
- At present, 19 LT surgeons.
- 12 Operating rooms at the Liver Transplant Institute, more at the Medical Center.
- Highest volume center in Europe, one of the highest in the world.
- Capacity to perform 6 simultaneous LTs at the Institute, 7 using two rooms at the Medical Center.

- An unusual level of public trust garnered by the LT team, owing to their exceptional dedication and the high-quality care they provide at this renowned institution.

Adopting Nearly All Best Practices for BBS-LPE

Here are some of the technical reasons for İnönü University's success:

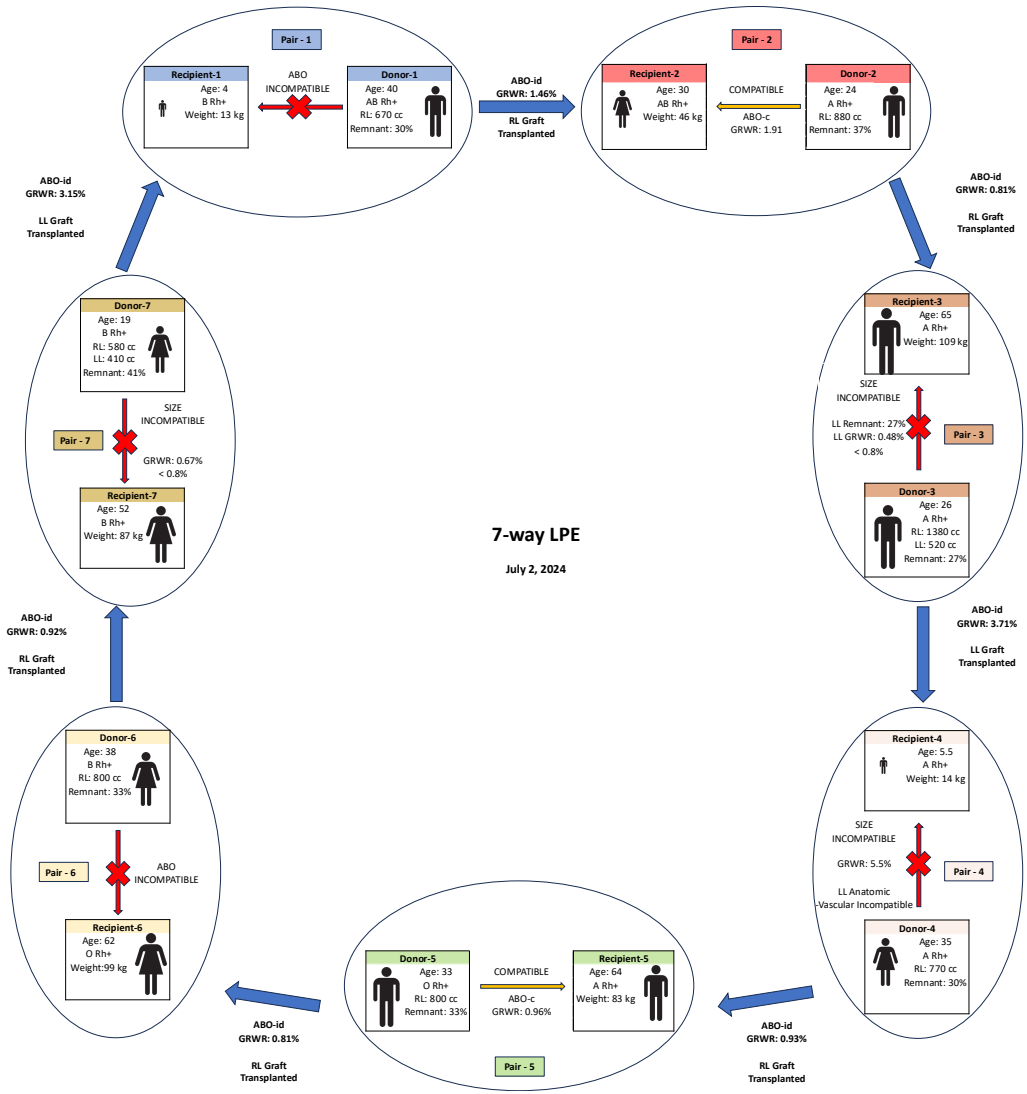
- Implementation of an optimal matching algorithm.
- The capacity to perform up to 7-way LPEs.
  - Larger LPEs are chosen only when there is a clear benefit, such as increasing the number of LTs or matching a patient with urgency.
  - Due to size-incompatibility, larger size exchanges are especially important for LPE.

Adopting Nearly All Best Practices for BBS-LPE (continued)

- Inclusion of compatible pairs, by providing patients with better liver grafts:
  - ABO-identical graft rather than ABO-compatible graft;
  - better size match for the need of the patient.
  - 31.5% of all exchange recipients had a compatible donor (as of May 23, 2026): 111 received better grafts and 13 were purely altruistic.
- Built-in plausible deniability system to avoid coercion.
  - Backing out is less common than reported in some Asian programs.

Illustrating the Merits: Our 7-Way LPE

- Let's illustrate the merits of these policies through our 7-way LPE:



In Progress on Liver Exchange

- Sönmez, Ünver, S. Yilmaz (in progress): Given the amount of data accumulated over the years, what has been the marginal effect of each of the tools we have used on the overall success of liver exchanges?
  - Inclusion of compatible pairs;
  - the availability of multi-way and larger exchanges; and
  - efficiently utilizing size incompatibility.

In Progress on Liver Exchange (continued)

- Şahin, Sönmez, Ünver, Ö. Yılmaz (in progress): Facilitation of dynamically optimal liver exchange mechanisms (one of the first dynamic matching papers was on kidney exchange; Ünver 2010; also Şahin, Sili, Ünver, and Yılmaz 2025).
  - We use "approximate dynamic programming" techniques.
  - Question: Can we come up with a score of optimality for each matching encountered, taking into account how far it is from an "empirically optimal" liver exchange?

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