Kidney Exchange: Past, Present, and Potential Future

Tayfun Sönmez, Boston College

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Lund University, School of Economics and Management

Kidney Transplants

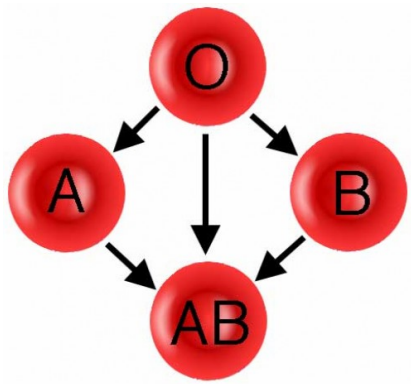
- There are close to 96,000 patients on the waiting list for deceased donor kidneys in the U.S. as of April 2013.
- The shortage of kidney increases by about 3,500 kidneys each year in the U.S.

Kidney Transplants

- In 2012:
  - 34,840 patients were added to waiting list while 28,437 patients were removed;
  - 10,868 transplants of deceased donor kidneys performed; and
  - 4,185 patients died while on the waiting list and 2,667 were removed from the list due to being too sick to receive a transplant.
  - There were also 5,619 transplants of kidneys from living donors.
- Often living donors are incompatible with their intended patient.

Medical Constraint: ABO Blood Type Compatibility

- There are four blood types: A, B, AB and O.

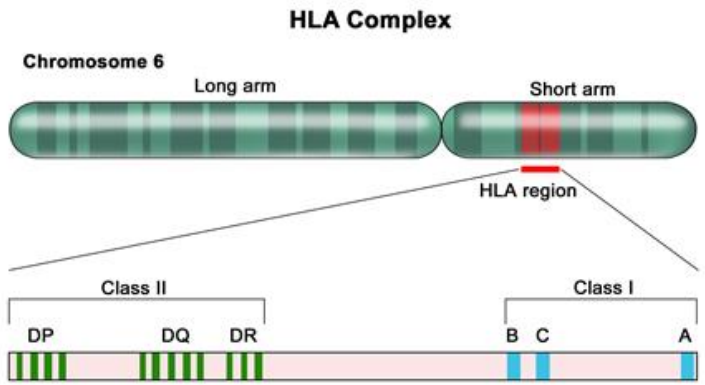


- In the absence of other complications:
  - Type O kidneys can be transplanted into any patient;
  - type A kidneys can be transplanted into type A or type AB patients;
  - type B kidneys can be transplanted into type B or type AB patients;
  - type AB kidneys can only be transplanted into type AB patients.
- Type O patients are disadvantaged because of this "natural injustice."

Medical Constraint: Tissue Type Compatibility

- Tissue type or Human Leukocyte Antigen (HLA) type: Combination of several pairs of antigens on Chromosome 6.

  HLA proteins A, B, and DR are especially important.



- Prior to transplantation, the potential recipient is tested for the presence of preformed antibodies against donor HLA.

  If there is a positive crossmatch, the transplantation cannot be carried out.

Institutional Constraint: No Money

- The 1984 National Organ Transplant Act (NOTA) makes paying for an organ for transplantation a felony:

  "it shall be unlawful for any person to knowingly acquire, receive or otherwise transfer any human organ for valuable consideration for use in human transplantation."

Allocation of Deceased Donor Kidneys in the U.S.

- U.S. Congress views deceased donor kidneys offered for transplantation as a national resource, and the 1984 NOTA established the Organ Procurement and Transplantation Network (OPTN).

UNOS® DONATE LIFE
UNITED NETWORK FOR ORGAN SHARING

- United Network for Organ Sharing (UNOS), as the OPTN contractor, overseas the allocation of deceased donor kidneys.

Live Donor Transplants: Much Less Organized Until 2004

- A patient identifies a willing donor and, if the transplant is feasible, it is carried out.
- Otherwise, the patient remains on the deceased donor queue, while the donor returns home.
- In the period 2000-2004, additional possibilities have been utilized in a few cases through exchanges between two incompatible pairs.

Paired Kidney Exchange

- First proposed by Rapaport (1986).
- The first kidney exchanges were carried out in South Korea in early 1990s.
- Renewed interest in the U.S. with Ross et al. (1997) on "Ethics of Kidney Exchange."

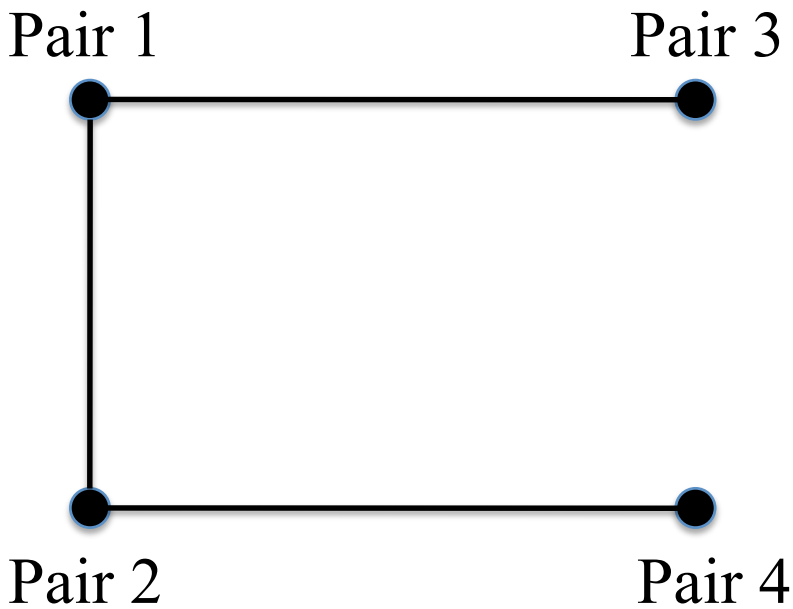
Paired Kidney Exchange

- In 2000 the transplantation community issued a consensus statement declaring it as "ethically acceptable."
- The consensus statement urged all four operations to be carried out simultaneously!
- The first kidney exchange in the U.S. was carried out in Rhode Island in 2000.
- Prior to formal organized kidney exchange clearinghouses, very rare: 5 paired exchanges in New England between 2000-2004.

Kidney Exchange as a Market Design Problem

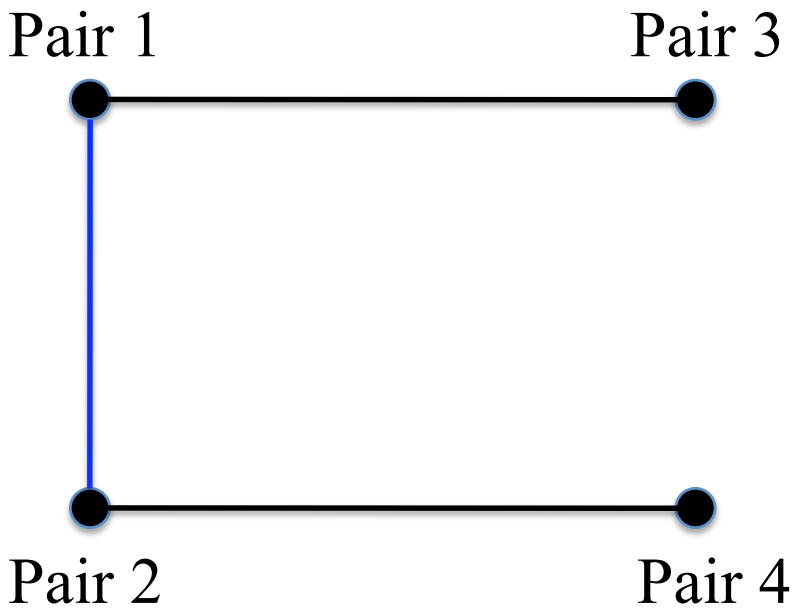
- The emerging field of Market Design applies insights and tools from economic theory to solve real-life resource allocation problems.
- In early 2000s, market designers observed that the two main types of kidney exchanges conducted in the U.S. correspond to the most basic forms of exchanges in house allocation models in matching literature.
- Building on the existing practices in kidney transplantation, Roth, Sönmez, & Ünver (2004, 2005, 2007) analyzed how an efficient and incentive-compatible system of exchanges might be organized, and what its welfare implications might be.
- The methodology and techniques advocated in this research program provided the backbone of several kidney exchange programs in the U.S. and the rest of the world.

Organized Exchange & Optimization is Important



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

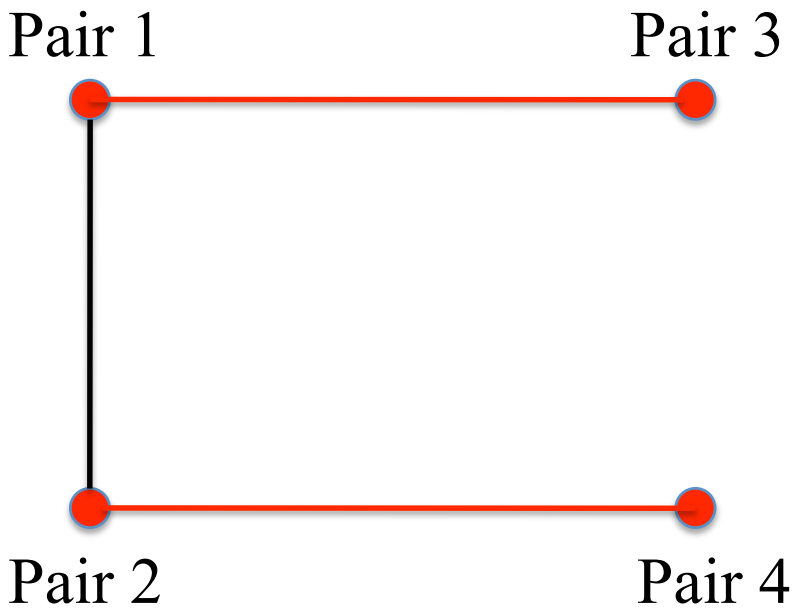
Optimization is Important



Suboptimal Exchange:
2 patients receive transplant

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

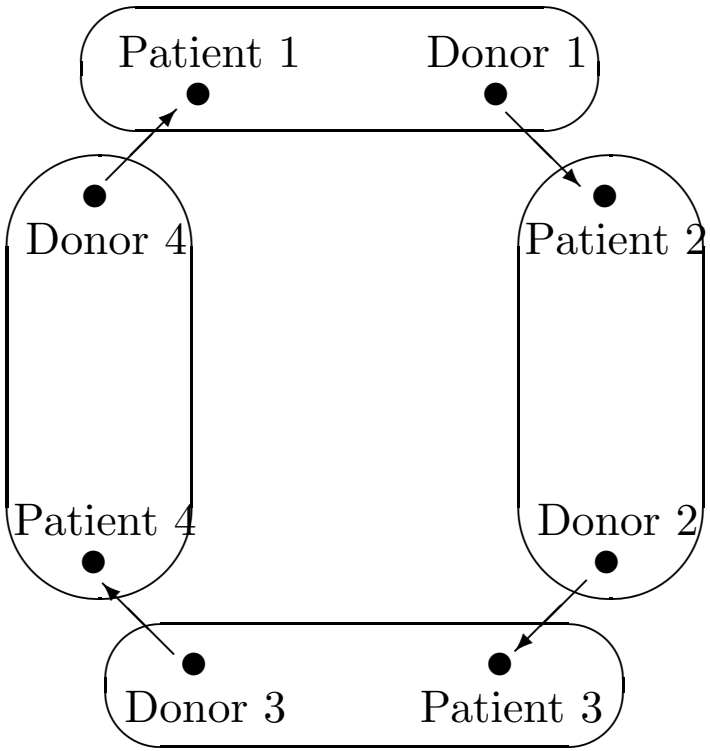
Optimization is Important



Optimal Exchange:
4 patients receive transplant

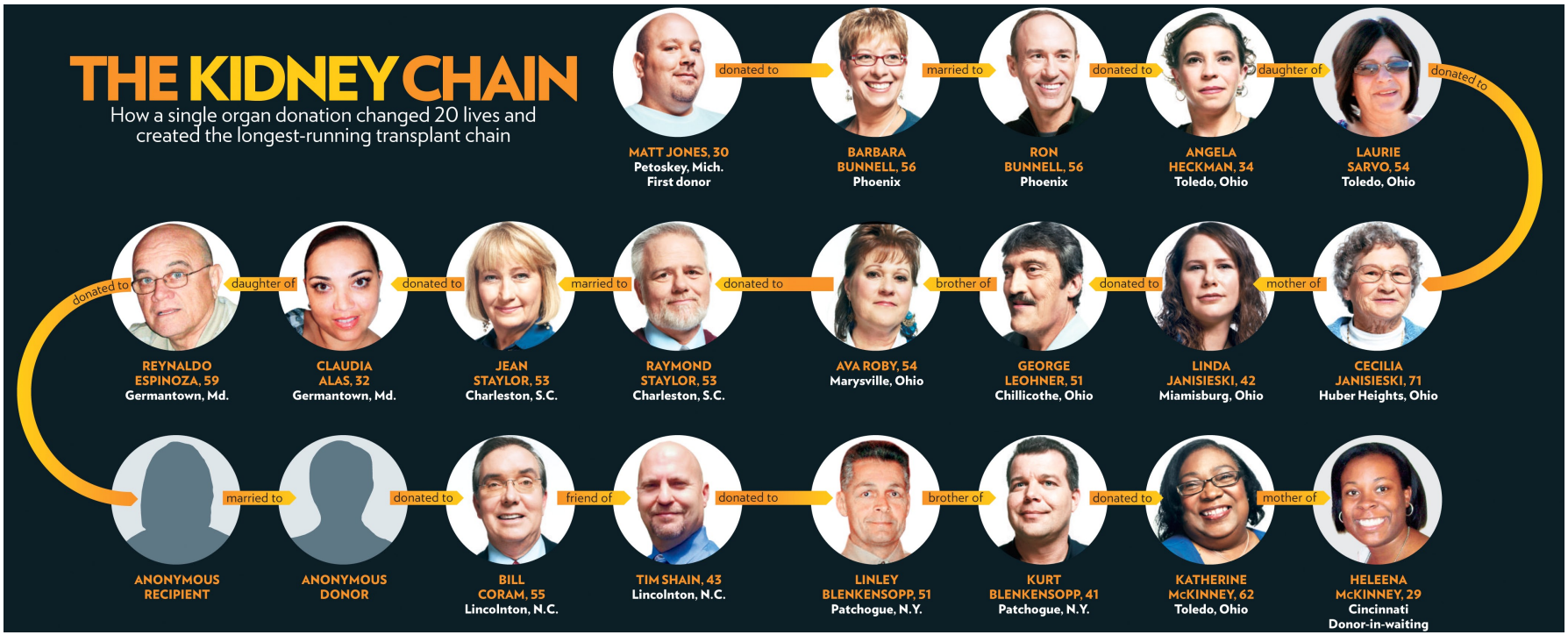
- Even in the absence of more elaborate exchanges, merely organizing the paired-exchanges may result in increased efficiency.

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!

Gifts of Altruistic Donors Can Be Multiplied via Chains



- Simultaneity is not critical when a kidney-chain starts with a donation from an altruistic donor. Hence large kidney-chains can be utilized!

Inclusion of Compatible Pairs 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.k.a. positive crossmatch).
- This is a relatively rare event: Zenios, Woodle & Ross (2001) reports the positive crossmatch frequency as
  - 33.3 % between female patients and their husbands, and
  - 11.1 % between other types of pairs.
- In contrast, 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!

$$\Longrightarrow \quad \#\ \text{O Patients} >> \#\ \text{O Donors}$$

- This disparity can be minimized if compatible pairs can also be included in kidney exchange.

There are "Economies of Scale" in Kidney Exchange

- Larger kidney exchange programs (such as national programs) provide a more efficient system than several smaller ones.
- Larger programs are especially beneficial for hard to match patients such as those who have positive crossmatch with a large fraction of donor population (a.k.a. high PRA or highly sensitized patients).

Number of Kidney Exchanges

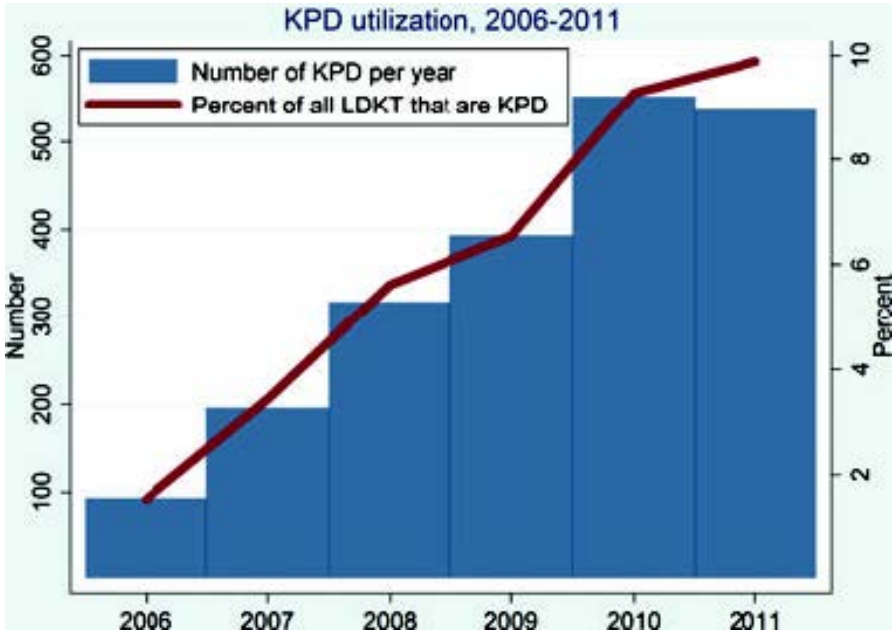


Figure from Massie et al AJT 2013

- A handful of kidney exchanges in the U.S. prior to 2004, increased to 93 in 2006 and to 553 in 2010.
- Currently kidney exchanges in the U.S. account for about 10% of all live donor kidney transplants.

The Progress of Kidney Exchange in the Last Decade

1. Organization & Optimization of Kidney Exchange
2. Utilizing Gains from Larger Exchanges
3. Integration of Altruistic Donors via Kidney Chains
4. Inclusion of Compatible Pairs for Increased Efficiency
5. Higher Efficiency via Larger Kidney Exchange Programs

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To what extent these insights have been utilized so far?

New England Program For Kidney Exchange

A transplant option for patients with an incompatible living donor

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Welcome

A Life-Saving Option

The New England Program for Kidney Exchange offers new life-saving options to those seeking a kidney transplant, but whose potential living donor is not a good biological "match" due to either blood type incompatibility or cross-match incompatibility. This option is known as kidney exchange, kidney paired donation, or kidney swap.

NEPKE uses a computer program to find cases where the donor in an incompatible pair can be matched to a recipient in another pair. By exchanging donors, a compatible match for both recipients may be found. You can learn more about the program HERE and read our newsletter here.

NEPKE can also find potential kidney recipients for those generous people who seek to become non-directed living donors (otherwise known as Good Samaritan Donors or Altruistic Donors). Information about that process is available HERE .

NEWS: Transplant centers are being provided with brochures to provide information about this program to their kidney patients.
More News

NEPKE
Transplants to Date
83

Notes: There are many good websites on the Internet that help kidney patients learn more about transplant options.
Links

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Kidney Donor Exchange Progra

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For research and clinical trials: UW Division of Transplantation

UW Health Transplant Kidney Exchange Program

UW Health surgeons perform transplant procedures working with living donors for kidney transplants. Advantages to living donation include a scheduled procedure, better conditions for the surgery, improved patient survival and better long-term function of the transplanted organ.

The Paired Exchange Program

Paired kidney exchange.
View full image

In the past, a recipient candidate of an incompatible living donor had to opt only for a deceased donor kidney. Through a national kidney exchange program, the UW Health Transplant Program offers options for patients who have an incompatible donor, making it possible for them to receive a living donor kidney transplant. The exchange program helps the deceased organ donor organ shortage by using organs from living donors who may otherwise be unable to donate, and helps patients who may have difficulty finding an appropriately-matched living donor.

With more than 50 transplant centers participating in this national program, the donor pool is greatly expanded which significantly increases the opportunity to find a compatible donor for a recipient.

How the Process Works

Video
UW Health Transplant Kidney Exchange

Living Kidney Donor Program
Living Donor Advocate
Living Donor Mentor Program
Living Kidney Donation Frequently Asked Questions
Ten Reasons Why Recipients Should Want a Living Kidney Donor
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UW Health Transplant Kidney Exchange Program

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UCLA Kidney Exchange Program

UCLA Kidney Exchange - An option for patients with incompatible living donors

What is a kidney exchange?

A kidney exchange is an innovative twist on efforts aimed at **increasing the donor pool** by giving people who are unable to receive a kidney from a loved one or friend the opportunity to still receive a kidney through **an exchange between incompatible donor-recipient pairs**. Approximately one-third of patients who have a willing living kidney donor will not be able to receive the donor kidney because of an incompatible blood type or incompatible crossmatch. In the past, that would mean that patients often would have for years on dialysis until a deceased donor kidney became available.

Now, with this exciting new program, you can exchange donors with another pair(s) in a similar situation as you, **making transplantation possible**. Learn more about kidney swap and kidney chain »

Two types of kidney exchanges are possible:

- Kidney swap »
- Kidney chain »

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KIDNEY EXCHANGE PROGRAM

Blood Type Compatibility

Blood type	Can receive from	Can donate to
O	O	O,A,B,AB
A	A,O	A,AB
B	B,O	B,AB
AB	O,A,B,AB	AB

ALLIANCE FOR PAIRED DONATION

Serving Kidney Patients through Technology, Education, a

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We have alliance partners in many locations
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Also visit www.thenead.com

Click here to view the People Magazine story on NEAD chains.

I NEED A KIDNEY TRANSPLANT

I WOULD LIKE TO DONATE A KIDNEY

I WANT TO DONATE FINANCIALLY

Alliance for Paired Donation – Saving Lives through Kidney Paired Donation

More than 84,000 people in America are waiting for a kidney transplant; sadly, about 12 of these patients die every day because there aren't enough donors. Many kidney patients have someone who is willing to donate, but because of immune system or blood type incompatibilities, they are not able to give a kidney to their loved one.

The Alliance for Paired Donation can help. Kidney paired donation matches one incompatible donor/recipient pair to another pair in the same situation, so that the donor of

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Paying Saving Lives Kidney Watch

2009 Annual Re

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Paired Kidney Exchange

- What is a paired kidney exchange?
- How are donor/recipient pairs matched?

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Incredible 3-way kidney swap

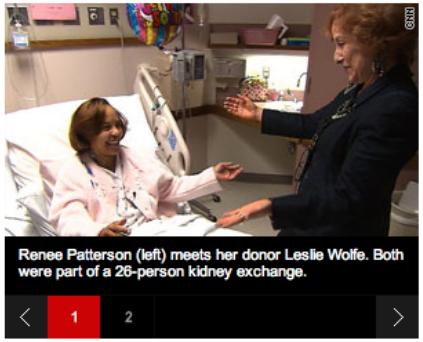
Mike and Susan Williams of Banton

By DAVID GRAHAM
Published on **Friday 5 August 2011 14:00**

TOP STORIES
Tower strategy aims

Massive transplant effort pairs 13 kidneys to 13 patients

By Val Willingham, CNN
December 14, 2009 8:40 a.m. EST



Renee Patterson (left) meets her donor Leslie Wolfe. Both were part of a 26-person kidney exchange.

1 2

Washington (CNN) -- Renee Patterson's most precious present this Christmas won't be under her tree, and it didn't come from a store. This holiday, she said, she got her life back.

The Upper Marlboro, Maryland, resident learned nine years ago she had kidney disease. One of her kidneys began to deteriorate, and she had to begin regular dialysis. Because she couldn't find a family match, her former colleague and friend, Michael Williams, offered to donate one of his kidneys. Problem was, Patterson and Williams didn't match either. But Patterson's doctor suggested they look into the paired kidney donation program at Washington Hospital Center in Washington, D.C.

She became part a massive mix-and-match transplant effort in the U.S., involving more than a dozen kidneys.

STORY HIGHLIGHTS

- **NEW:** Renee Patterson met her donor, Leslie Wolfe, on Monday
- Patterson joined program that connects patients with willing donors
- Patterson's friend donated kidney to compatible recipient;

DENVER AND THE WEST

Selflessness, to the third power

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0 COMMENTS

3 kidney transplants to occur simultaneously across country

By Brian Maines
The Denver Post

POSTED: 07/30/2008 12:30:00 AM MDT

With clocks synchronized, three kidney transplants will happen simultaneously at three hospitals in three time zones around the country this morning.

At 7:30 a.m. Denver time, the three-state kidney exchange will begin with patients in North Carolina, in Alabama and at the University of Colorado Hospital in Aurora.

"It's the first time in U.S. history that three transplants will be happening at the same time," said Vonnie Bagwell, the living donor coordinator at CU Denver Health Center.

Maggie Mrva, foreground, is to receive a kidney today from Martha Hansen, rear, at the CU Hospital in Aurora. All three transplant operations are to begin at 7:30 a.m. Denver time. (Brian Lehmann, Pool)

World's Largest Kidney Exchange Gives 14 People New Chance at Life

ABC WORLD NEWS WITH DIANE SAWYER

By LISA STARK (@LisaStark) and BRADLEY BLACKBURN
June 15, 2010

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182 1

In the nation's capital, a circle of strangers is now connected for life.

Beginning last month, 14 donors gave their kidneys to 14 people who desperately needed them in the largest kidney exchange in history.

Washington kidney exchange is largest ever

By Melanie D.G. Kaplan | December 1, 2009, 4:00 AM PST

The largest-ever single-city kidney exchange took place this summer in Washington. The seven-way exchange, which involved 14 patients, occurred at **Georgetown University Hospital** and **Washington Hospital Center** over four days in July. It was the brainchild of **Dr. Keith Melancon**, director of **Georgetown's Kidney and Pancreas Transplant Surgery**, who used a procedure called ***plasmapheresis*** to address not only donor compatibility but racial disparity.

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60 Lives, 30 Kidneys, All Linked

FROM START TO FINISH A donation by a Good Samaritan, Rick Ruzzamenti, upper left, set in motion a 60-person chain of transplants that ended with a kidney for Donald C. Terry Jr., bottom right.

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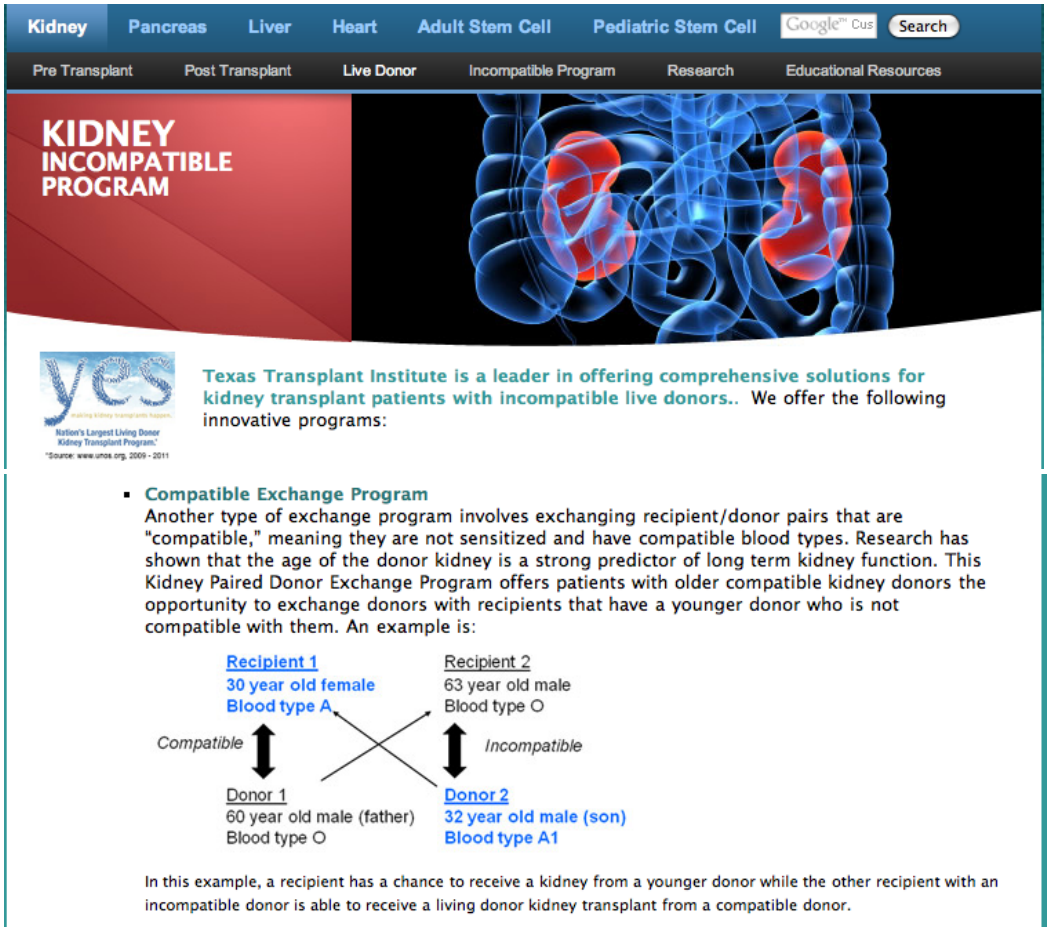

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KIDNEY INCOMPATIBLE PROGRAM

Texas Transplant Institute is a leader in offering comprehensive solutions for kidney transplant patients with incompatible live donors.. We offer the following innovative programs:

- **Compatible Exchange Program**
  Another type of exchange program involves exchanging recipient/donor pairs that are "compatible," meaning they are not sensitized and have compatible blood types. Research has shown that the age of the donor kidney is a strong predictor of long term kidney function. This Kidney Paired Donor Exchange Program offers patients with older compatible kidney donors the opportunity to exchange donors with recipients that have a younger donor who is not compatible with them. An example is:

In this example, a recipient has a chance to receive a kidney from a younger donor while the other recipient with an incompatible donor is able to receive a living donor kidney transplant from a compatible donor.

- Very limited implementation of this idea.
- Limited or no incentives for compatible pairs to participate in kidney exchange.

Modeling Choice and Evolution of Kidney Exchange Pools

- The first market design paper on kidney exchange, Roth, Sönmez, & Ünver (2004), presented considerably larger potential efficiency gains from kidney exchange than we observe in practice today.
- Part of the difference is due to larger exchanges along with more elaborate list exchanges allowed in RSÜ (2004).
- However, by far the biggest factor in this difference is the prominent presence of compatible pairs in RSÜ (2004).
- Patients are assumed have strict preferences over compatible kidneys in RSÜ (2004).

  As such, patients have valid reasons to participate in kidney exchange even if they have a compatible donor.
- Hence, the disparity between numbers of O patients and O donors is minimal in RSÜ (2004) as an implication of its modeling choice.

Modeling Choice and Evolution of Kidney Exchange Pools

- As a "prerequisite" of collaboration with members of New England transplantation community, we were asked to develop a model that is limited to two-way exchanges where patients are indifferent between compatible kidneys (i.e. dichotomous preferences).
- Doctors were worried that the strict preference assumption might lead to patients or hospitals competing over "better" kidneys, potentially hurting the system.
- This request resulted in RSÜ (2005) which became the starting point of a series of fruitful interactions between market designers and members of the transplantation community.
- However, this alternative modeling choice also removed the primary reason of compatible pairs to participate in kidney exchange!
- The practice of kidney exchange mostly adopted this approach based on dichotomous patient preferences, even though this assumption is in part reflection of some "transplantation politics."

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- Higher Efficiency via Larger Kidney Exchange Programs

Amendment of the National Organ Transplant Act

- When we initially helped found New England Program for Kidney Exchange (NEPKE), it was unclear whether kidney exchange is in violation of NOTA.
- In particular, it was unclear whether kidney exchange was considered to involve transfer of a human organ for valuable consideration.
- In Dec 2007, an amendment of NOTA has passed in the Senate, clarifying that kidney exchange is legal and removing the barrier from establishment of national kidney exchange.

One Hundred Tenth Congress
of the
United States of America

AT THE FIRST SESSION

Begun and held at the City of Washington on Thursday, the fourth day of January, two thousand and seven

An Act

To amend the National Organ Transplant Act to provide that criminal penalties do not apply to human organ paired donation, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Charlie W. Norwood Living Organ Donation Act".

SEC. 2. AMENDMENTS TO THE NATIONAL ORGAN TRANSPLANT ACT.

Section 301 of the National Organ Transplant Act (42 U.S.C. 274e) is amended—

(1) in subsection (a), by adding at the end the following: "The preceding sentence does not apply with respect to human organ paired donation."; and

(2) in subsection (c), by adding at the end the following:

"(4) The term 'human organ paired donation' means the donation and receipt of human organs under the following circumstances:

"(A) An individual (referred to in this paragraph as the 'first donor') desires to make a living donation of a human organ specifically to a particular patient (referred to in this paragraph as the 'first patient'), but such donor is biologically incompatible as a donor for such patient.

"(B) A second individual (referred to in this paragraph as the 'second donor') desires to make a living donation of a human organ specifically to a second particular patient (referred to in this paragraph as the 'second patient'), but such donor is biologically incompatible as a donor for such patient.

"(C) Subject to subparagraph (D), the first donor is biologically compatible as a donor of a human organ for the second patient, and the second donor is biologically compatible as a donor of a human organ for the first patient.

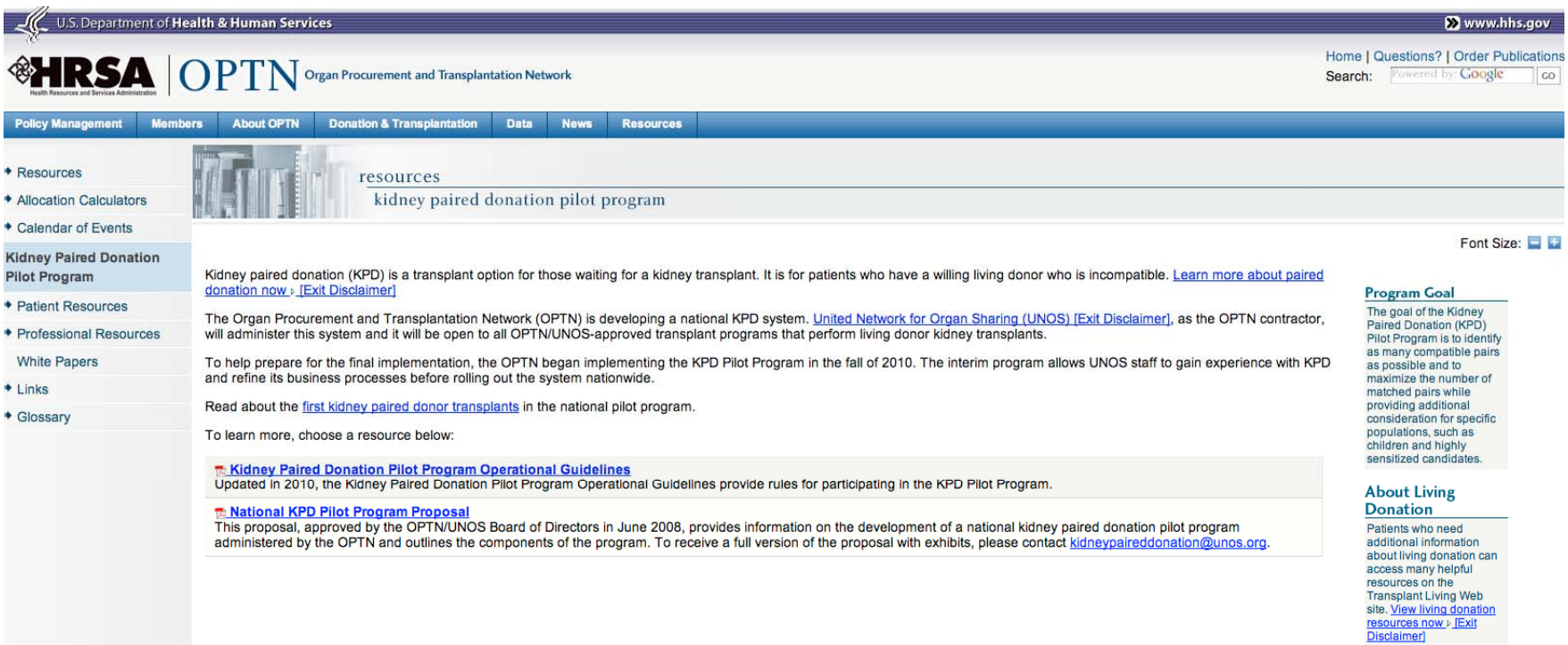
"(D) If there is any additional donor-patient pair as described in subparagraph (A) or (B), each donor in the group of donor-patient pairs is biologically compatible as a donor of a human organ for a patient in such group.

"(E) All donors and patients in the group of donor-patient pairs (whether 2 pairs or more than 2 pairs) enter into a single agreement to donate and receive such human organs, respectively, according to such biological compatibility in the group.

U.S. National Kidney Paired Donation Pilot Program

- In 2010, a pilot national kidney exchange program in U.S. (UNOS-KPD) is launched.

  As of December 2011, NEPKE became part of UNOS-KPD.
- However, in part because of its late establishment, activity in the UNOS-KPD is relatively modest compared to major programs.



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Incentivizing Compatible Pairs

- On the one hand countless blood-type O patients with non-O donors are waiting for a potential exchange, on the other hand many O blood-type donors directly donate to their non-O recipients.
- How can we incentivize participation of these compatible pairs to kidney exchange?

  Some potential paths:

  - Cash incentives: Currently a taboo in much of the world...
  - Giving up the dichotomous preference paradigm as in RSÜ (2004) and Nicoló & Rodríguez-Álvarez (2012): More promising than cash incentives but so far restricted to a few small programs.
- In Sönmez & Ünver (2013) we propose an alternative policy that might potentially be more compatible with the current paradigm.

A New Proposal

- Policy Proposal (Sönmez & Ünver 2013): If an O donor with a compatible non-O patient (or if an AB patient with a compatible non-AB donor) participates in exchange, even though they do not need to, the patient is given priority in the deceased donor wait list in case he needs another kidney in the future due to a second failure.
  - Altruism is incentivized with an "insurance" for a potential future failure.
  - About 15% of kidney transplants are repeat transplants.
  - Such priority is already given to living donors!
- If adopted, this incentive scheme will give a major advantage to UNOS-KPD, since UNOS is in charge of the deceased donor wait list.

Hitting Two Birds with One Stone

- Given a fixed patient-donor pool, patients of all groups benefit from the above-described incentive scheme.

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- Moreover, having an edge over other programs, only the national kidney exchange program survives under our incentive scheme.

  Theorem (Sönmez & Ünver 2013): Consider the game where patient-donor pairs choose among multiple kidney exchange programs based on the expected patient "utility." All pairs list themselves at the national exchange program that has adopted the above described incentive scheme, and thus no pair list themselves in any other program under the unique Nash equilibrium.

Potential Future of Kidney Exchange

1. Organization & Optimization of Kidney Exchange ✓
2. Utilizing Gains from Larger Exchanges ✓
3. Integration of Altruistic Donors via Kidney Chains ✓
4. Inclusion of Compatible Pairs for Increased Efficiency 
5. Higher Efficiency via Larger Kidney Exchange Programs 

Tissue Type Compatibility and Kidney Exchange Pools

- In the absence of compatible pairs, the only blood-type O donors in kidney exchange pools are those with positive crossmatch with their intended patients.
- In other words, we would not see any O donors in kidney exchange pools in the absence of tissue type incompatibility!
- Thus, the only viable exchange would be between
  - blood-type A patients with B donors, and
  - blood-type B patients with A donors.
- Ironically, the presence of tissue type incompatibility considerably increases the scope of kidney exchange in the absence of compatible pairs.

ABO and HLA Desensitization Protocols

- For some patients with "moderate" antibody levels for ABO (blood-type) or HLA (tissue-type) antigens, it may be possible to reduce their level of antibodies with medication below levels that preclude transplantation.

  This process is known as desensitization in transplantation.
- While this medical modality is expensive and inferior to donation from compatible donors, in some cases it may be the only option for some "hard to match" patient-donor groups.
- In the absence of kidney exchange, both ABO-desensitization and HLA-desensitization increases the number of patients who can receive transplants.

  After all, that is the intention of the desensitization protocols!

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- Theorem (Sönmez & Ünver in preparation): While ABO-desensitization increases the number of patients who receive transplants from live donors (either directly or via exchange), HLA-desensitization decreases the number of patients who receive transplants from live donors in the presence of kidney exchange.
- Just as tissue-type incompatibility increases the scope of kidney exchange by increasing the supply of much needed O donors in the pool, HLA-desensitization reduces it via the opposite effect!

Conclusion

- The share of transplants from kidney exchanges have increased dramatically over the last decade with the introduction of organized kidney exchange programs that embraced optimization techniques and certain innovations by market designers.
- However a number of factors including
  - the presence of too many small programs,
  - the disparity between blood-type distributions of donors and patients due to lack of participation of compatible pairs

  limit the real life benefits from kidney exchange considerably below its potential.
- While current kidney exchange programs are fairly successful in optimizing transplants within static kidney exchange pools, there are still considerable gains in adopting policies that will result in more favorable patient-donors pools.

Conclusion

- Insight from several branches of economic theory, including
  - Incentives,
  - Adverse Selection,
  - Externalities

  provide guidance on achieving such favorable patient-donor pools.