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Age-based preferences in paired kidney exchange ☆

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ABSTRACT

We consider a Paired Kidney Exchange (PKE) model in which patients' preferences are restricted so that patients prefer kidneys from compatible younger donors to kidneys from older ones. We propose a family of rules, sequential priority rules, that only allow for pairwise exchanges and satisfy individual rationality, efficiency, strategy-proofness, and non-bossiness. These rules allocate kidneys according to a priority algorithm that gives priority to patients with younger donors and assign kidneys from younger donors first. We extend the analysis to rules that allow multiple ways exchanges and to the case of patients who have more than one potential donor.

1. Introduction

Paired Kidney Exchange (PKE) programs seek to overcome any incompatibility (of blood or tissue types)[1] of living donor–patient pairs by arranging swaps of donors among several pairs (Delmonico, 2004; Delmonico et al., 2004; Roth et al., 2004). PKE programs work as clearing houses that periodically search for mutually compatible exchanges of donors in a pool of donor–patient pairs. In order to find such mutually compatible exchanges, PKE programs need to elicit relevant information from patients (and their doctors) and to overcome feasibility constraints that are absent in standard problems of allocation of indivisible goods. Specifically, PKE programs involve the cooperation and the coordination of several transplantation units at different medical centers. Thus, the complexity of the logistics makes exchanges involving too

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[1] A patient and a donor are incompatible if the patient's body will immediately reject the donor's kidney after the graft, and thus the transplantation is deemed not viable.

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many donor–patient pairs unfeasible.[2] For this reason, real-life PKE programs have generally focused on maximizing the number of simultaneous compatible organ exchanges between two donor–patient pairs, although swaps involving more than two pairs are also carried out. To deal with situations where a donor–patient pair may be necessary in more than one compatible exchange of donors, real life PKE programs usually give priority to particular patients in much the same way as it happens in the allocation of kidneys obtained from cadaveric donors.[3]

Living donor kidney transplantation yields excellent results in terms of life expectancy of the graft compared to kidney transplantation from cadaveric organs (Delmonico, 2004; Gjertson and Cecka, 2000). This fact explains the prevalent approach in PKE programs, which assumes that patients only care about receiving a compatible kidney. Recent medical research, however, supports the idea that different compatible kidneys can have substantially different outcomes. The age and the health status of the donor, in fact, have a major impact on the expected survival of the graft (Su et al., 2004; Gentry et al., 2007; Gjertson, 2004; Øien et al., 2007).[4] This observation has important implications for modeling PKE. First, the heterogeneity of transplantation outcomes may affect participants' incentives. Secondly, it provides a justification for the participation in PKE programs of patients with a compatible willing donor. These pairs may have incentives to participate in PKE programs since the patient could obtain a kidney that results in higher life-expectancy than that of her donor's kidney. The participation of compatible pairs can dramatically increase the chances of finding compatible swaps for incompatible pairs, and boost the transplantation rate (Roth et al., 2004, 2005b, 2006; Gentry et al., 2007).[5]

We model PKE clearing houses as rules that assign kidneys to patients through kidney exchanges taking into account patients' preferences over available kidneys. Preferences of patients depend on the donors' characteristics that determine compatibility as well as life expectancy after transplantation. The pool of available kidneys can be partitioned into groups of kidneys of similar quality corresponding to the age of the donors. Patients are interested in receiving a compatible kidney, but they prefer a kidney from a younger donor. This observation suggests the analysis of a restricted domain of preferences: the *age-based preference domain*. In this domain, we study rules that satisfy individual rationality,[6] efficiency restricted by the logistic constraints, and strategy-proofness.[7] Individual rationality is an essential property of a rule for the obvious reason that no patient can be forced to perform a transplant. In our setting, it also aims to guarantee to compatible pairs that they can never regret for enrolling in a PKE program. Strategy-proofness is compelling in our setting, because it implies that patients of compatible pairs truthfully reveal which is the minimum gain in term of higher life-expectancy that persuades them to accept a paired kidney exchange.

We first focus on rules that only allow for pairwise exchanges among two donor–patient pairs.[8] Rules that satisfy the above properties and the auxiliary property of non-bossiness select assignments that maximize the number of pairwise exchanges among pairs with the youngest donors and, sequentially among pairs in different age groups according to an ordering based on donors' age.[9] We call such rules sequential maximizing rules. It results illustrative to describe the intuition behind sequential maximizing rules for the simplest case in which donors are partitioned in two age groups, young and mature donors. A sequential maximizing rule identifies a set of patients who maximizes the number of compatible pairwise exchanges between pairs with a young donor. Having fixed the exchanges performed by these pairs, it proceeds by identifying a set of patients who maximizes the number of compatible pairwise exchanges between unmatched patients with a young donor and patients with a mature donor. Finally, keeping fixed all swaps identified in the previous stages, it identifies a set of patients who maximize the number of compatible pairwise exchanges between unmatched patients with a mature donor.

In addition to the previous necessary condition, we also provide an algorithm that defines a family of rules, sequential priority rules, that satisfy our axioms. Patients are prioritized according to their donor age, and among patients with donors

[2] There is growing interest in the creation of non-simultaneous, extended non-directed altruistic anonymous donor chains that help to avoid such limitations. A donor chain starts with an anonymous altruistic donor willing to donate to anyone needing a kidney transplant without having a related direct recipient (Rees et al., 2009; Ünver, 2010; Ausubel and Morrill, 2014). In some cases, the incompatible donor of the recipient starts a chain as a new anonymous altruistic donor. Based on Organ Procurement and Transplantation Network data as of January 23, 2017; in 2016, 612 living donation kidney transplants have been obtained through standard paired donation and 217 by anonymous donors (https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/ and https://optn.transplant.hrsa.gov/resources/ethics/living-non-directed-organ-donation/).

[3] This is the case of the New England PKE program (Roth et al., 2005a, 2005b). Similar protocols are adopted by other centralized PKE programs implemented in countries like Korea (Park et al., 2004), the Netherlands (Keizer et al., 2005), the United Kingdom (NHS Blood and Transplant, 2016), Spain (Organización Nacional de Transplantes, 2015), and the United States with its UNOS National Pilot Program for Kidney Paired Donation (Ashlagi and Roth, 2012, 2014).

[4] For instance, Øien et al. (2007) confirm that the donor's age and health status have a crucial role in the case of living donations. A donor over 65 years old is associated with a higher risk of graft loss at every time point after transplantation. There is more controversy in the medical literature regarding the effects of other characteristics such as the similarity of tissue types between patients and donors (Delmonico, 2004; Gjertson and Cecka, 2000; Opelz, 1997).

[5] In the most recent updates of the Spanish PKE program (Organización Nacional de Transplantes, 2015), the problem of how to favor compatible pairs' participation is explicitly acknowledged.

[6] A rule satisfies individual rationality if patients never prefer the initial assignment where no kidney swap is performed to the outcome prescribed by the rule.

[7] A rule satisfies strategy-proofness if patients never have incentives to misrepresent their preferences.

[8] While PKE programs perform kidney exchanges involving more than two donor–patient pairs, pairwise exchanges are prevalent. We discuss the possibility of multiple ways exchanges in Section 5.2.

[9] A rule satisfies non-bossiness if, whenever a change in a patient's preferences does not modify her assignment, that is, the kidney she receives, it does not modify any other patient's assignment.