Valuing Prearranged Paired Kidney Exchanges: A Stochastic Game Approach

Abstract:

End-stage renal disease (ESRD) is the ninth-leading cause of death in the U.S. Transplantation is the most viable renal replacement therapy for ESRD patients, but there is a severe disparity between the demand for kidneys for transplantation and the supply. This shortage is further complicated by incompatibilities in blood-type and antigen matching between patient-donor pairs. Paired kidney exchange (PKE), a cross-exchange of kidneys among incompatible patient-donor pairs, overcomes many difficulties in matching patients with incompatible donors. In a typical PKE, transplantation surgeries take place simultaneously so that no donor may renge after her intended recipient receives the kidney. Therefore, in a PKE, the occurrence of a transplantation requires compatibility among the pairs' willingnesses to exchange. We consider an arbitrary number of autonomous patients with probabilistically evolving health statuses in a prearranged PKE, and model their transplant timing decisions as a discrete-time non-zero-sum noncooperative stochastic game. We explore necessary and sufficient conditions for patients' decisions to be a stationary-perfect equilibrium, and formulate a mixed-integer linear programming representation of equilibrium constraints, which provides a characterization of the socially optimal stationary-perfect equilibria. We carefully calibrate our model using large scale nationally representative clinical data, and empirically confirm that randomized strategies, which are less consistent with clinical practice and rationality of the patients, do not yield a significant social welfare gain over pure strategies. We also quantify the social welfare loss due to patient autonomy and demonstrate that maximizing the number of transplants may be undesirable. Our results highlight the importance of the timing of an exchange and the disease severity on matching patient-donor pairs.

Keywords: medical decision making, paired kidney exchange, game theory, Markov decision processes, integer programming