# A Decision Rule for Transplanting Non-Cadaveric Organs

Amnon Levy

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# A DECISION RULE FOR TRANSPLANTING NON-CADAVERIC ORGANS

by

Amnon Levy

Economics  Discipline

School of Economics and Information Systems

University of Wollongong

## Abstract

*This paper conceptually analyzes the minimum probability of success required for transplanting non-cadaveric organs, its relationship with the initial, and possible rates of change in the, quality-adjusted life-years of the recipient and donor and its relationship with the expected medical knowledge gain.*

**Author's address:** Amnon Levy, Economics Discipline, School of Economics and Information Systems, University of Wollongong, Wollongong, NSW 2522, Australia

**Author's e-mail address:** amnon_levy@uow.edu.au

**Author's telephone:** + 61 2 42213658

**Author's Fax:** + 61 2 42213725

## I. Introduction

This paper was motivated by a recent case of transplantation of lung sections from two young adults to their younger adult sister who was suffering from cystic fibrosis. The transplantation procedure was experimental and involved the removal of the sick sister's damaged lungs and the implantation of a small heart tissue and the lower sections of the right and left lungs of her healthy siblings. Despite the experimental nature of the procedure, the high probability of failure and the expected deterioration of the donors' health, each of the siblings agreed to participate in the triple operation. The recipient died three weeks after the operation from infection, hemorrhage and other complications. The donors lost about twenty percent of their lung capacity and suffered from the pain and trauma that accompanied the incisions. This case demonstrates that family members and friends who are endowed with strong emotions of altruism, solidarity and obligation are inclined, despite their loss of health, to be donors even when the probability of failure is very high, and that surgeons and hospitals perform high-risk transplantations in a quest for gaining experience and knowledge.

Previous analyzes of organ-transplanting decisions have focused on the recipient's perspectives and dealt with the organ accept/reject decision (see Israel and Yechiali, 1985; Ahn and Hornberger, 1996; and Howard, 2002). In the case of experimental non-cadaveric organ transplantation, the well being of the donors and the medical knowledge-gains should also be considered. The objective of this paper is to formulate the non-cadaveric transplantation decision problem and to derive the minimum probability of success required for proceeding with transplantation. The proposed minimum-probability formula may help the various stakeholders to subdue their

individual inclinations and submit their personal emotions and interests to an aggregate, rational decision-making. In transplantations of organs taken from living donors there are many stakeholders – the recipient, the donor(s), the surgeon(s) and the hospital, the family members and friends of the recipient and the donor(s), the medical industry and the public. The proposed analysis is focused on the considerations of the inner circle of the most directly involved and affected stakeholders.

## II. Recipient, donor and surgeon's considerations

The analysis involved the essential stakeholders involved in the transplantation - the recipient ($R$), the donor ($D$) and the surgeon, or more broadly the hospital, ($S$). It is assumed that the medical procedures are transparent and the knowledge gained from a transplantation operation is perfectly disseminated within the medical industry. This assumption ensures best practice, eliminates self-promoting considerations and renders the surgeon a representative of the medical industry. Ex ante, the outcome of the recipient's operation is uncertain due, mainly, to her initial critical condition and the possibility of rejection. In contrast, the level of uncertainty associated with the consequences of the donor's operation for her health is much smaller and assumed, for tractability, to be negligible.

In making a decision on transplantation of a non-cadaveric organ the surgeon is assumed to be concerned with the lifetime well-being of the recipient ($u^R$), with the lifetime well-being of the donor ($u^D$) and with the value of the medical knowledge-gains ($\Delta K^S$) which, as in the case of any asset, is measured as the expected contribution of the medical knowledge gained from the transplantation to the well-being of future potential

recipients and donors. The surgeon's overall concern ($u^S$) is taken to be a weighted sum of these three factors:

$$u^S = u^R + \boldsymbol{g}_1 u^D + \boldsymbol{g}_2 \Delta K^S . \tag{1}$$

Here, $\boldsymbol{g}_1$ is a positive scalar denoting the surgeon's degree of concern for the donor's lifetime well being relative to the surgeon's degree of concern (taken as a numeraire) for the recipient's lifetime well being. No favoritism is reflected by $\boldsymbol{g}_1 = 1$. Similarly, $\boldsymbol{g}_2$ is a positive scalar indicating the surgeon's degree of interest in learning-by-doing relative to the surgeon's degree of concern for the lifetime well-being of the recipient. A $\boldsymbol{g}_2 > 1$ implies that the surgeon has a relatively strong interest in learning-by-doing. It does not reveal opportunism because procedure are transparent and knowledge-gains disseminate within the medical industry, nor does it reflect inadequate consideration for human life due to the potential benefit from the knowledge gained for future patients.

As is commonly done in the health-economics literature, the lifetime well-beings of the recipient and donor are measured in quality-adjusted life-years (QALYs).[1] Similarly, the value of the medical knowledge gained from the transplantation ($\Delta K^S$) is measured as the expected contribution to the QALYs of future potential patients (recipients and donors). The recipient is considered to be generating lifetime well-being ($u^R$) from her own and the donor's quality-adjusted life-years. For simplicity, her operation can be either successful or a failure. Thus, the ex-ante distribution of her post-

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[1] See Bleichrodt and Quiggin (1999) for the conditions under which lifetime-utility maximization over consumption is consistent with QALYs maximization.

transplantation lifetime well-being ($u_{post}^R$) is given by the following binomial

distribution:

$$u_{post}^R = \begin{cases} (1+g_R)QALYs_0^R + b_R(1-d_D)QALYs_0^D & p \\ \\ (1-d_R)QALYs_0^R + b_R(1-d_D)QALYs_0^D & 1\text{-}p \end{cases} \qquad (2)$$

where,

$p$ = the probability of successful operation, $0 < p < 1$,

$1-p$ = the probability of failure,

$QALYs_0^R$ = the recipient's pre-transplantation QALYs,

$QALYs_0^D$ = the donor's pre-transplantation QALYs,

$g_R$ = the rate of increase in the recipient's QALYs following a successful operation,

$d_R$ = the rate of decrease in the recipient's QALYs in the case of failure,

$d_D$ = the rate of decrease in the donor's QALYs due to the operation, and

$b_R$ = the recipient's degree of concern for the donor's QALYs relative to her own,

$b_R \geq 0$ with $b_R = 0$ indicating strict selfishness and $b_R = 1$ equal care for the donor.

Consequently, the recipient's expected post-operation lifetime well-being is

$$E(u_{post}^R) = [1 + (g_R + d_R)p - d_R]QALYs_0^R + b_R(1 - d_D)QALYs_0^D. \tag{3}$$

In other words, the expected improvement in the recipient's lifetime well-being from the transplantation ($E\Delta u^R$) is

$$E\Delta u^R = E(u_{post}^R) - \underbrace{(QALYs_0^R + b_R QALYs_0^D)}_{u_0^R} = [(g_R + d_R)p - d_R]QALYs_0^R - b_R d_D QALYs_0^D \tag{4}$$

where $u_0^R$ denotes the recipient's pre-operation level of lifetime well-being – a combination of her own and the donor's pre-operation quality-adjusted life-years.

The donor, caring about the recipient's quality-adjusted life-years to a degree $b_D$ relative to her own (so that $b_D > 1$ reflects an extreme degree of altruism), also faces a binomial distribution of her post-operation lifetime well-being:

$$u_{post}^D = \begin{cases} (1 - d_D)QALYs_0^D + b_D(1 + g_R)QALYs_0^R & p \\ \\ (1 - d_D)QALYs_0^D + b_D(1 - d_R)QALYs_0^R & 1\text{-}p. \end{cases} \tag{5}$$

Consequently, the expected change in the donor's lifetime well-being induced by the transplantation is

$$E(u_{post}^D) - \underbrace{(QALYs_0^D + b_D QALYs_0^R)}_{u_0^D} = b_D[(g_R + d_R)p - d_R]QALYs_0^R - d_D QALYs_0^D$$

(6)

where $u_0^D$ denotes the donor's pre-operation level of well-being – a combination of her own and the recipient's pre-operation quality-adjusted life-years.

### III. Decision rule and critical probability of success

From a strictly medical point of view, a risk-averse (loving) surgeon might be excessively conservative (adventurous) in making a decision in favor, or against, transplantation. For this reason, and due to the assumed binomial distribution of the transplantation outcome, risk neutrality is considered in constructing the transplantation decision rule.[2]

A risk-neutral, rational surgeon favors transplantation and seeks the consent of the potential donor and recipient if

$$E(u_{post}^S) - u_0^S > 0.$$

(7)

In view of this condition and in recalling equations (1), (4) and (6), a decision in favor of an experimental transplantation of a non-cadaveric organ is collectively reached by the recipient, donor and surgeon if

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[2] The analysis can be modified for the case of risk-aversion by assuming that the costs of risk-bearing rise with the variance of the transplantation outcome.

$$\{[(g_R + d_R)p - d_R]QALYs_0^R - b_R d_D QALYs_0^D\}$$

$$+ g_1\{b_D[(g_R + d_R)p - d_R]QALYs_0^R - d_D QALYs_0^D\} + g_2\Delta K^S > 0 \qquad (8)$$

or, equivalently, if

$$p > \frac{(b_R + g_1)d_D QALYs_0^D + (1 + g_1 b_D)d_R QALYs_0^R - g_2\Delta K^S}{(1 + g_1 b_D)(g_R + d_R)QALYs_0^R}. \qquad (9)$$

The term on the right-hand-side of inequality (9) is the critical level of $p$: if the probability of success is assessed to be higher (lower) than this critical level, a decision in favor of (against) an experimental transplantation of a non-cadaveric organ is reached. This critical level is, therefore, referred to as the minimum probability of success ($p_{\min}$) required for an experimental transplantation of a non-cadaveric organ.

The right-hand-side of inequality (9) can be rearranged and equivalently rendered as linearly increasing in the donor-recipient pre-operation QALYs ratio and in the ratio of the value of the medical knowledge-gains (measured as the expected contribution to future patients' QALYs) to the recipient's pre-operation QALYs:

$$p_{\min} = \frac{d_R}{(g_R + d_R)} + \left(\frac{(b_R + g_1)d_D}{(1 + g_1 b_D)(g_R + d_R)}\right)\frac{QALYs_0^D}{QALYs_0^R} - \left(\frac{g_2}{(1 + g_1 b_D)(g_R + d_R)}\right)\frac{\Delta K^S}{QALYs_0^R}. \qquad (10)$$

The first term on the right-hand side of equation (10) indicates the minimum probability of success required for an experimental non-cadaveric organ transplantation when the

expected decrease in the donor's QALYs is negligible (i.e., $d_D = 0$, as in the case of cadaveric organ transplantation) and when, for ethical reasons, learning by experimenting on human patients is not admissible and prohibited (i.e., $g_2 = 0$). In this case, the minimum probability of success required for experimental transplantation is also independent of the recipient's pre-operation QALYs and exclusively dependent on the expected rate of change in the recipient's QALYs. It declines with the expected rate of increase ($g_R$) in the recipient's QALYs following a successful operation, and increases with the expected rate of decrease ($d_R$) in the recipient's QALYs following an unsuccessful operation.

The second term on the right-hand side of equation (10) indicates that the minimum probability of success required for an experimental transplantation of a non-cadaveric organ rises with the ratio of the donor's and recipient's pre-operation QALYs. The term in the parentheses reveals that this (mathematically) positive effect of the donor-recipient pre-operation QALYs ratio on the minimum probability required for transplanting a non-cadaveric organ is amplified by: 1. the recipient's degree of concern for the donor's QALYs ($b_R$), 2. the expected rate of decrease in the donor's QALYs due to the operation ($d_D$), and 3. the surgeon's degree of concern for the donor's well being ($g_1$) if $b_D b_R < 1$ (i.e. if the concerns of both the donor and recipient for their own, self QALYs are greater than their concerns for each other QALYs, or, more generally put, if at least one of them is selfish or very moderately altruist towards the other).

However, the positive effect of the donor-recipient pre-operation QALYs ratio on the minimum probability required for transplanting a non-cadaveric organ is moderated by: 1. the expected rate of increase in the recipient's QALYs in the case of success ($g_R$),

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2. the rate of decrease in the recipient's QALYs in the case of failure ($d_R$), 3. the donor's degree of concern for the recipient's QALYs ($b_D$), and 4. the surgeon's degree of concern for the donor's lifetime well-being ($g_1$) if $b_D b_R > 1$ (i.e., if the concerns of both the donor and recipient for their own, self QALYs are smaller than their concerns for each other QALYs - extreme degrees of altruism - or, more generally put, if at least one of them is extremely altruist while the other is not completely selfish).

The third term on the right-hand side of equation (10) suggests that the minimum probability of success required for transplanting a non-cadaveric organ is lowered by the ratio of the value of the expected knowledge-gains stemming from the operation to the recipient's pre-operation QALYs. An inspection of the term in the parentheses reveals that the moderating effect of the ratio of the value of the expected knowledge gains to the recipient's pre-operation QALYs on the minimum probability required for the transplantation is increased by the surgeon's degree of interest in learning-by-doing ($g_2$), but lowered by: 1. the rate of increase in the recipient's QALYs in the case of success ($g_R$), 2. the rate of decrease in the recipient's QALYs in the case of failure ($d_R$), 3. the donor's degree of concern for the recipient's QALYs ($b_D$), and 4. the surgeon's degree of concern for the donor's lifetime well-being ($g_1$).

Knowledge-gains might diminish with practice. In this case, the minimum probability of success required for transplanting a non-cadaveric organ is lower in the early stage of development of the transplantation procedure than in later stages.

## IV. Conclusion

A decision rule for transplanting non-cadaveric organs was developed by taking into account a range of factors affecting the well being and interests of the three most intimately and directly involved stakeholders: the recipient, the donor and the surgeon (the hospital, more broadly). The well beings of the recipient and the donor were assumed to increase with their own quality-adjusted life-years, and were also allowed, as should be expected in the case of the donor at least, to rise with the quality-adjusted life-years of each other. The Surgeon was taken to be solely concerned with the well being of the recipient and the donor and interested in gaining experience and knowledge that can benefit future patients. The cooperative integration of the concerns of the surgeon with the expected changes in the well beings of the recipient and donor led to a transplantation decision rule that indicated the minimum probability of success required for non-cadaveric-organ transplantation. The minimum probability formula included the pre-operation quality-adjusted life-years of the recipient and donor, the perceived value of the knowledge gains, the expected rates of change in the recipient's and donor's quality-adjusted life-years, the degrees of altruism of the donor and recipient towards one another, and the relative weights given by the surgeon to the well beings of the recipient and donor and to the value of knowledge gains. If the expected knowledge-gain diminishes with practice, the minimum probability of success required for transplanting a non-cadaveric organ is lower in the early stage of development of the transplantation procedure than in later stages. Diminishing knowledge-gain from practice may provide an explanation to the high risk taken by surgeons and hospitals in performing experimental transplantations of non-cadaveric organs.

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