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Modelling Of Doctor-Patient Interaction In Kidney Transplantation Consultations Using Game Theory

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Abstract
The rise in the number of end-stage kidney disease (ESKD) patients in Malaysia and the scarcity of kidney resources have made the decision-making process involving the nephrologists and the ESKD patients increasingly essential during their pre-transplantation medical consultations. The purpose of this study is to develop a game theory model of doctor-patient interaction in kidney transplantation consultations to analyze the optimal decisions to be taken by the nephrologists and the patients in the form of sequential games. Backward induction method was adopted to determine the subgame perfect Nash equilibrium in the proposed sequential game theory model that consists of two different scenarios: one with the nephrologist being the first mover of the game and the other with the patient being the first mover instead. It was discovered that the scenario in which the patient plays first in the sequential game can lead to a more cooperative outcome between the nephrologist and the patient in their transplantation consultations process. The analysis of the equilibria solution showed that the proposed game theory model could be used as a decision-making tool for the players to identify the best strategy to be employed as well as to enhance cooperation between nephrologists and patients during their negotiation process in kidney transplantation consultations.

Keywords: Game Theory; Doctor-Patient Interaction; Kidney Transplantation; Sequential Games; Nash Equilibrium; Backward Induction.

1. Introduction

End-stage kidney disease (ESKD), also called end-stage renal disease (ESRD) or kidney failure, is the last stage of chronic kidney disease, where kidney function has declined to the point that the kidneys can no longer work on their own to meet one's body needs in fluid regulation [1]. Every year, the number of ESKD patients in our country is on the rise [2]. Based on the report of Malaysian Dialysis and Transplant Registry (MDTR) in 2018, there are a total of 45,937 ESKD patients in Malaysia and this figure is expected to go up to 106,000 by the year of 2040 [3]. The ever-increasing prevalence of the fatal kidney disease has made it a significant public health problem in Malaysia [2].

Due to the lack of kidney resources, the selection of candidates for kidney transplantation will be a highly complex and hastened process, in which potential recipients will be assessed thoroughly based on several health conditions criteria, including the severity of disease and also the verification of post-transplantation prognosis [3]. Hence, in order to ensure the right decisions regarding the potential treatment for patients are made, the interaction between doctors and ESKD patients during their medical consultations are of paramount significance. When there is an interaction of common and conflicting interests between two players, that is, a doctor and a patient in this case, the situation can be described and modelled by using game theory [4], which appears as a suitable mathematical tool to improve the decision-making process of doctors and patients during pre-transplantation consultations.

Game theory has been considerably used to help make better decisions in healthcare settings. Djulbegovic et al. [4] demonstrated a situation of clinical interaction involving a busy doctor and his patient by means of the Prisoners' Dilemma structure, in which the doctor can decide whether to perform a cursory or a thorough examination before giving the patient the prescription he seeks. The patient can in turn choose to just accept the prescription given or ask for a more detailed discussion of benefits and risks of the treatment. The researchers adopted both pure and mixed strategies of Nash Equilibrium to achieve the most strategic decisions for both the doctor and the patient. However, the study neglects the ethical obligations of the doctors to their patients' well-being without taking into account the element of emotions which is inevitably important in any kind of human interaction, so is in a doctor-patient relationship. Therefore, adding emotions to the game, such as frustration, regret, guilt and trust, will account for the payoffs of the players, which was proven by Mendonca et al. [5] in his research on liver transplantation consultations who incorporated those emotion elements into his game theory model and showed that the emotion variables could have a significant amount of impact on the clinical outcomes. This research extends the model to observe how emotions can be associated with the payoffs of nephrologists and ESKD patients in analyzing the best strategy profile for the players.

This research paper will present literature review on the concept of game theory and Nash equilibrium in Section 2, followed by research methodology in Section 3 which includes model set-up and parameters boundary conditions construction on doctor-patient interaction in kidney transplantation consultations by using game theory as well as solution concept identification using backward induction. The results and discussion of analysis done on the established sequential game model will be presented in Section 4. This paper ends with a conclusion drawn from the game equilibria obtained in Section 5.

2. Literature Review

2.1. Game Theory Concept

Game theory is a mathematical framework for analyzing strategic interactions between two or more decision makers called players, each with two or more ways of acting called strategies, and well-defined preferences among the possible outcomes, represented by numerical payoffs [6]. A game is defined as any set of circumstances with an outcome that depends on the actions or decisions of all players involved. Under the theory, it is assumed that players are rational and will strive to maximize their payoffs in the game. A player need not be an individual; it can be a nation, a corporate body such as a board or a committee, or a team consisting of many people with shared interests [7]. The decisions made by players are said to be interdependent, and this interdependence causes each player to consider other player's possible decisions in formulating a strategy.

2.2. Nash Equilibrium

Nash Equilibrium is one of the fundamental concepts in game theory that determines the best outcome or the optimal solution in a non-cooperative game, in which each player will continue with their initial strategy without any incentive to deviate from it. Under the Nash equilibrium, each player is assumed to know the equilibrium strategies of other players and neither of them can benefit from a strategy that differs from their initially chosen action. A game may have multiple Nash equilibria or none of them [8].

Nash equilibrium can be distinguished into two types, that is, pure strategy Nash equilibrium and mixed strategy Nash equilibrium. In pure strategy Nash equilibrium, all players in the game are playing pure strategies, whereas in mixed strategy Nash equilibrium, at least one player is playing a mixed strategy. Being an essential theorem within game theory, Nash equilibrium helps players to determine the best payoff in a situation based on both their decisions and also other players'. To find the Nash equilibrium in a game, one would have to model out each of the possible scenarios to obtain the results, then choose what the optimal strategy would be. In a two-person game, the possible strategies that both players can choose are taken into account. If neither player can do better by changing their strategy given the strategy of the other player, a Nash equilibrium is said to have occurred.

3. Methodology

3.1. Model Set-Up

A few imperative elements of the game theory model are defined, namely the players of the game, the strategies used by the players, and also the payoffs of players in the game. Two players are identified in the game, that is, the doctor, commonly a nephrologist, and the ESKD patient who is waiting for a kidney transplant. They are the two decision makers in the game. The strategies of the nephrologist are Keep Patient's Name (on the waiting list) which is denoted by 1, Exclude Patient's Name Temporarily denoted by 2, and Exclude Patient's Name Permanently denoted by 3, whilst the ESKD patient has two strategies that are Follow Advice denoted by 1, and Not Follow Advice that is denoted by 2. By following advice, the patient refrains from taking addictive substances such as illicit drugs; for the latter, the patient do not abstain from active drug use which could jeopardize his or her kidney function even after transplantation is performed. The payoffs of the nephrologist and the patient are assigned with the letter N and letter P respectively, with the action adopted by the nephrologist taking the first subscript and the action by the patient taking the second subscript. The resulting payoffs are given as shown in Table 1.

Table 1: Payoff representation for the nephrologist (N) and the patient (P)

Payoff of Nephrologist	Payoff of Patient	Description
N_{11}	P_{11}	Nephrologist keeps patient's name on the transplant waiting list and patient follows advice.
N_{12}	P_{12}	Nephrologist keeps patient's name on the transplant waiting list and patient does not follow advice.
N_{21}	P_{21}	Nephrologist excludes patient's name temporarily from the transplant waiting list and patient follows advice.
N_{22}	P_{22}	Nephrologist excludes patient's name temporarily from the transplant waiting list and patient does not follow advice.
N_{31}	P_{31}	Nephrologist excludes patient's name permanently from the transplant waiting list and patient follows advice.
N_{32}	P_{32}	Nephrologist excludes patient's name permanently from the transplant waiting list and patient does not follow advice.

With reference to [5], the payoffs of nephrologist and patient take the following order respectively:

$$N_{11} > N_{22} > N_{32} > N_{21} > N_{31} > N_{12} \tag{1}$$

$$P_{11} > P_{12} > P_{21} > P_{22} > P_{31} > P_{32} \tag{2}$$

Under the consultations game model, both utilities and emotions are taken into consideration in the payoffs of players to better model the doctor-patient interaction. Utilities indicate players' preferences for different outcomes they encounter in terms of real numbers. The letter *U* represents the nephrologist's utilities, and the letter *V* refers to the patient's utilities. U_1 and V_1 denote the utility earned by the nephrologist and the patient respectively if the patient's name is kept on the transplant waiting list; U_2 and V_2 are the utilities concern the circumstance where the patient's name is excluded temporarily from the list whereas U_3 and V_3 are the utilities obtained for the case when the patient's name is excluded from the list permanently. In general, the first case is most preferred for both players since the nephrologists will always want to save people's lives in the first place and the ESKD patients will never want to be deprived of the chance to get selected for the receipt of a healthy graft. Hence, $U_1 > U_2 > U_3$ and $V_1 > V_2 > V_3$.

With respect to emotions, both the nephrologist and the patient may feel regret (*R*) or frustration (*F*). The nephrologist may also feel guilt (*G*) when keeping a non-compliant patient on the waiting list.

The emotions arise following the temporary and permanent decisions can be differentiated using the superscript t and m respectively. The patient has two parameters *B* and *H* representing the benefit he or she will obtain for following advice such as quitting substance use and the harm received due to taking drugs, respectively. In addition, parameter β representing the incentive for the nephrologist to exclude patient's name permanently is added to the nephrologist's payoffs, which refers to how much the nephrologist values allocating the kidney transplant to a patient with better adherence to advice or prognosis, whilst parameter γ representing the incentive for the patient to not follow advice, that is, the instant pleasure of drug use experienced by the patient, is added to the patient's payoffs.

Table 2 presents the payoff matrix with the notations used to represent each player's strategy, whilst Table 3 summarizes the expressions of payoffs for the nephrologist and the patient with respect to utilities.

Table 2: Representation of the game strategies and its payoff matrix

		Nephrologist		
		Keeps patient's name on the waiting list (K)	Excludes patient's name temporarily ($\mathrm{NK_t}$)	Excludes patient's name permanently ($\mathrm{NK_m}$)
Patient	Follow advice (F)	N_{11} , P_{11}	N_{21} , P_{21}	N_{31} , P_{31}
	Not follow advice (NF)	N_{12} , P_{12}	N_{22} , P_{22}	N_{32} , P_{32}

Table 3: Payoff expressions for both players with respect to utilities

Payoff Expressions with respect to Utilities	
Nephrologist	$N_{11} = U_1$
	$N_{12} = U_1 - G$
	$N_{21} = U_2 - R_N^t$
	$N_{22} = U_2 - F_N^t$
	$N_{31} = U_3 - R_N^m + \beta$
	$N_{32} = U_3 - F_N^m + \beta$
Patient	$P_{11} = V_1 + B$
	$P_{12} = V_1 - H + \gamma$
	$P_{21} = V_2 - F_P^t + B$
	$P_{22} = V_2 - R_P^t - H + \gamma$
	$P_{31} = V_3 - F_P^m + B$
	$P_{32} = V_3 - R_P^m - H + \gamma$

In general, there are some assumptions made for the utilities exist in the model. The feeling of guilt (*G*) has the highest value among the emotions since it is associated with a loss of society when the kidney graft is allocated to a patient who ignores medical advice and continues to abuse his or her body. On the other hand, the feeling of regret is assumed to be more intense or greater than that of frustration ($R > F$), and these emotion values are considered higher when the decision made is permanent compared to when it is just a temporary decision ($R^m > R^t$ and $F^m > F^t$). These yield $R^m > R^t > F^m > F^t$. In addition, it is reasonable to assume that the difference between regret and frustration when it is a permanent decision is higher than that when it is a temporary decision, thus, $R^m - F^m > R^t - F^t$ [5]. Next, the harm value of active substance use is greater than the benefit value of quitting it in absolute value, that is, |*H*| > |*B*|, since the continuing habit of drug use will further exacerbate the health condition of ESKD patients whilst quitting it at this point is less likely to do much for the better or cure the kidney condition.

3.2. Parameters Boundary Conditions Construction

Recall the payoff orders stated in equation (1) and (2) that $N_{11} > N_{22} > N_{32} > N_{21} > N_{31} > N_{12}$ and $P_{11} > P_{12} > P_{21} > P_{22} > P_{31} > P_{32}$, but this is only true when the value of parameter β and of γ is small enough to have an influence on the ordering. As these parameter values go up, the payoff orders for both the players could become different. Hence, it is necessary to examine the different boundary conditions for the values of *β* and *γ* that alter the payoff orders.

3.2.1 Boundary Conditions of γ

With reference to the initial payoff order of patient in equation (2) where *γ* value is small enough, it can be easily seen that $P_{11} > P_{12}$, $P_{21} > P_{22}$ and $P_{31} > P_{32}$, indicating that regardless of the strategy taken by the nephrologist, the patient will always prefer following advice than not following advice and thus, following advice (denoted as strategy 1) is a dominant strategy of patient. However, since a higher value of *γ* will contribute to a different result, one must find the boundary conditions of *γ* that will lead to the change in patient's payoff orders by referring to payoff expressions given in Table 3. For example, the boundary condition of *γ* that will change $P_{11} > P_{12}$ to $P_{12} > P_{11}$ can be derived as demonstrated below:

$$\begin{aligned} P_{12} &> P_{11} \\ V_1 - H + \gamma &> V_1 + B \\ \gamma &> B + H \end{aligned}$$

Letting $B + H$ be γ_1 , one will have $\gamma > \gamma_1$. This implies that for any value of $\gamma > \gamma_1$, the patient will prefer not following advice over following advice when the nephrologist chooses keeping patient's name on the waiting list (as indicated by $P_{12} > P_{11}$).

The rest of the boundary conditions are constructed in the same way. All the results of the derivation are summarized in Table 4.

Table 4: Boundary conditions for parameter *γ*

Boundary Conditions of γ
$P_{12} > P_{11} \iff \gamma > \gamma_1$; *where* $\gamma_1 = B + H$
$P_{22} > P_{21} \iff \gamma > \gamma_2$; *where* $\gamma_2 = B + H + R_P^t - F_P^t$
$P_{32} > P_{31} \iff \gamma > \gamma_3$; *where* $\gamma_3 = B + H + R_P^m - F_P^m$

Based on Table 4, it is obvious that γ_1 which consists of only two utilities (*B* and *H*) takes the smallest value compared to γ_2 and γ_3. Recall that $(R_P^m - F_P^m) > (R_P^t - F_P^t)$, so γ_3 will have the highest value. Thus, it is justified that $\gamma_1 < \gamma_2 < \gamma_3$.

3.2.2. Boundary Conditions of β

With reference to the initial payoff order of nephrologist in equation (1) where *β* value is small enough, it can be observed that $N_{11} > N_{21} > N_{31}$ and $N_{22} > N_{32} > N_{12}$, indicating that regardless of the strategy chosen by the patient, strategy 3 of nephrologist, that is, permanent exclusion from the list, is always dominated by other strategies. Since a higher value of *β* will contribute to a different result, given that *β* is only associated with N_{31} and N_{32}, one must find the boundary conditions of *β* that will change the nephrologist's payoff orders to $N_{31} > N_{21}$, $N_{31} > N_{11}$ and $N_{32} > N_{22}$. Note than N_{12} is not examined since it is not associated with β and it will always be the worst payoff of the nephrologist no matter how β changes.

By using the same approach, the boundary conditions of β that will lead to a change in the nephrologist's payoff are derived and summarized in Table 5.

Table 5: Boundary conditions for parameter β

Boundary Conditions of *β*
$N_{32} > N_{22} \Leftrightarrow \beta > \beta_1$; *where* $\beta_1 = (U_2 - U_3) + F_N^m - F_N^t$
$N_{31} > N_{21} \Leftrightarrow \beta > \beta_2$; *where* $\beta_2 = (U_2 - U_3) + R_N^m - R_N^t$
$N_{31} > N_{11} \Leftrightarrow \beta > \beta_3$; *where* $\beta_3 = (U_1 - U_3) + R_N^m$

Based on Table 5, since *R* > *F* as previously mentioned and $(R_N^m - R_N^t)$ is greater than $(F_N^m - F_N^t)$, it is said that $\beta_2 > \beta_1$. Next, since $(U_1 - U_3) > (U_2 - U_3)$ and β_3 does not have the additional subtraction term as in β_1 and β_2 , β_3 will take the highest value and hence, it is justified that $\beta_1 < \beta_2 < \beta_3$.

3.3. Solution Concept Identification using Backward Induction

A solution concept is a rule in game theory for predicting how a game will be played [8]. These predictions, also called the solutions, describe which strategies will be taken by players and thus the outcome of the game is determined. In this study, the solution concept applied is subgame perfect Nash equilibrium, a refined Nash equilibrium used in sequential games. A strategy profile is a subgame perfect Nash equilibrium if it is a Nash equilibrium of every subgame in the original game where each strategy chosen by the players is the best response to all other strategies played. A common method used to determine the subgame perfect Nash equilibrium in a finite sequential game is backward induction. Under this method, one will start from the bottom of the game by determining the actions that the final mover or the last player should take in each possible circumstance to maximize his or her own payoff. By eliminating the choices that this player will not choose, one can narrow down the game tree and the best action of the next-to-last mover is identified in the same manner by moving up the tree. This process continues backward until one reaches the top of the tree where the optimal action for every stage is determined.

4. Results and discussion

4.1. Sequential Game Equilibria

In the established sequential game model, the nephrologist and the patient take turns to make their decisions, and so there will be two scenarios to be considered in the study in which the first scenario will have the nephrologist playing first and the patient playing next, whereas the second scenario will have the patient playing first and the nephrologist playing next.

4.1.1. Scenario I : Nephrologist plays first

The sequential game tree representing the scenario is illustrated in Figure 1, with the nephrologist being the first player and the patient being the second player.

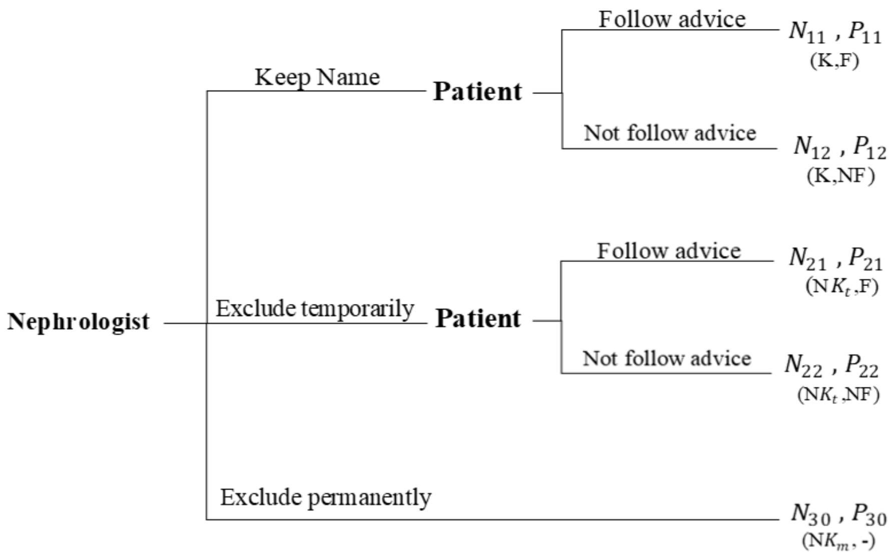

Figure 1: Tree representation of the sequential game of doctor-patient interaction in kidney transplantation consultations, with the nephrologist playing first followed by the patient.

Referring to the game tree established in Figure 1, notice that if the nephrologist decides to exclude the patient's name permanently from the transplant waiting list, then there will be no game afterwards. The nephrologist will end up getting N_{30}= β as payoff gained and the patient will get P_{30} = 0. This situation can be explained as the case when the patient's health condition is already too critical to be considered for receiving a kidney transplant. As a result, the nephrologist has to save the graft for another patient with better prognosis, thus being rewarded with incentive β.

As previously mentioned, by applying backward induction, the subgame perfect Nash equilibria of the sequential game for each different value of parameter γ and β can be determined considering all the possible interval combinations of γ and β across $\gamma_1 < \gamma_2 < \gamma_3$ and $\beta_1 < \beta_2 < \beta_3$.

Case I : $\gamma < \gamma_1 < \gamma_2 < \gamma_3$

Starting off both parameters with their lowest values where $\gamma < \gamma_1 < \gamma_2 < \gamma_3$ and $\beta < \beta_1 < \beta_2 < \beta_3$, since $P_{11} > P_{12}$, $P_{21} > P_{22}$ and $P_{31} > P_{32}$, the patient will always choose to follow advice. Referring to the branches of strategy 'Follow advice' in the game tree presented in Figure 1, the nephrologist will decide by comparing N_{11} and N_{21}. Since N_{11} is the highest payoff of nephrologist as mentioned in Equation (1), the nephrologist will choose keeping name. Hence, the subgame perfect Nash equilibrium obtained is (K,F). Increasing β to a point where $\beta_1 < \beta < \beta_2 < \beta_3$, the same result is obtained because of the same reason ($P_{11} > P_{12}$, $P_{21} > P_{22}$, $P_{31} > P_{32}$ and N_{11} being the highest payoff of nephrologist), therefore, the subgame perfect Nash equilibrium is (K,F). For the interval $\beta_1 < \beta_2 < \beta < \beta_3$, according to Table 5, $N_{31} > N_{21}$ and $N_{11} > N_{31}$, which is equivalent to $N_{11} > N_{31} > N_{21}$. However, N_{31} does not exist in the game tree, so one needs to examine N_{30} instead. Since $N_{11} = U_1$ (based on Table 3) and $N_{30} = \beta$, if $\beta < U_1$, which also means $N_{30} < N_{11}$, the nephrologist will still choose keeping name and the resulting subgame perfect Nash equilibrium is again (K,F). If $\beta > U_1$, this time $N_{30} > N_{11}$, the nephrologist will choose permanent exclusion and there will be no game. The subgame perfect Nash equilibrium is ($\mathrm{NK_m}$, -). Next, increasing β further to the highest point where $\beta_1 < \beta_2 < \beta_3 < \beta$, the nephrologist will always choose permanent exclusion which yields the highest payoff for the nephrologist and there will be no game afterwards. The subgame perfect Nash equilibrium is ($\mathrm{NK_m}$, -).

Case II : $\gamma_1 < \gamma < \gamma_2 < \gamma_3$

Increasing γ to a point where $\gamma_1 < \gamma < \gamma_2 < \gamma_3$, one will see $P_{12} > P_{11}$ which implies that the patient tends to not follow advice when the nephrologist chooses keeping name, and $P_{21} > P_{22}$ which implies that the patient tends to follow advice when the nephrologist chooses temporary exclusion. However, the nephrologist will not want to choose keeping name when the patient chooses not following advice since N_{12} is the worst payoff for the nephrologist. Instead, the nephrologist will choose between temporary and permanent exclusion. By examining only the branches of strategy 'Exclude temporarily' and 'Exclude permanently' in the game tree presented in Figure 1, if the nephrologist chooses to exclude temporarily, the patient will respond by following advice which yields a better payoff since $P_{21} > P_{22}$. If the nephrologist chooses to exclude permanently, there will be no game and the nephrologist will end up getting $N_{30}= \beta$ as payoff. Comparing N_{21} and N_{30} , if N_{21} > N_{30}, which also means N_{21} > β, the nephrologist will choose temporary exclusion that offers a better payoff and the resulting subgame perfect Nash equilibrium is again ($\mathrm{NK_t}$,F). If N_{21} < β, the nephrologist will choose permanent exclusion and there will be no game. The subgame perfect Nash equilibrium is ($\mathrm{NK_m}$, -).

Case III : $\gamma_1 < \gamma_2 < \gamma < \gamma_3$

For a higher value of γ such that $\gamma_1 < \gamma_2 < \gamma < \gamma_3$, one will have $P_{12} > P_{11}$, $P_{22} > P_{21}$ and $P_{31} > P_{32}$. Hence, the patient will choose to get either P_{12} , P_{22} or P_{30} in this case. Anticipating these three possible choices that may be adopted by the patient, the nephologist will decide by comparing N_{12} , N_{22} and N_{30} to see which strategy will give him or her the best payoff. Recall that N_{12} is the worst payoff of nephrologist, he or she will never choose keeping name for patients with such a high level of γ. Thus, the nephrologist must choose between temporary and permanent exclusion, that is, getting either N_{22} or N_{30} as payoff. By comparing these two payoffs, if N_{22} > N_{30}, which also means N_{22} > β, the nephrologist will choose temporary exclusion that offers a better payoff and the patient will respond by choosing to not follow advice. Hence, the subgame perfect Nash equilibrium is ($\mathrm{NK_t}$,NF). If N_{22} < β, the nephrologist will choose permanent exclusion and there will be no game. The subgame perfect Nash equilibrium is (NK_m , -).

Case IV : $\gamma_1 < \gamma_2 < \gamma_3 < \gamma$

Increasing γ to its highest value such that $\gamma_1 < \gamma_2 < \gamma_3 < \gamma$, the patient will never choose to follow advice since $P_{12} > P_{11}$, $P_{22} > P_{21}$ and $P_{32} > P_{31}$ as indicated by the boundary conditions derived. The result is the same as the previous case. Table 6 summarizes the overall results obtained for the 4 cases.

Table 6: Sequential game equilibria obtained with their corresponding payoffs gained for each interval of γ and β in which the nephrologist plays first.

Equilibria of The Sequential Game where Nephrologist Plays First			
γ	β	Subgame Perfect Nash Equilibrium	Payoffs gained
$\gamma < \gamma_1 < \gamma_2 < \gamma_3$	$\beta < \beta_1 < \beta_2 < \beta_3$	(K , F)	(N_{11}, P_{11})
	$\beta_1 < \beta < \beta_2 < \beta_3$	(K , F)	(N_{11}, P_{11})
	$\beta_1 < \beta_2 < \beta < U_1 < \beta_3$	(K , F)	(N_{11}, P_{11})
	$\beta_1 < \beta_2 < U_1 < \beta < \beta_3$	($\mathrm{NK_m}$, -)	(β , 0)
	$\beta_1 < \beta_2 < \beta_3 < \beta$	($\mathrm{NK_m}$, -)	(β , 0)
$\gamma_1 < \gamma < \gamma_2 < \gamma_3$	$\beta < N_{21}$	($\mathrm{NK_t}$, F)	(N_{21}, P_{21})
	$\beta > N_{21}$	($\mathrm{NK_m}$, -)	(β , 0)
$\gamma_1 < \gamma_2 < \gamma < \gamma_3$	$\beta < N_{22}$	($\mathrm{NK_t}$, NF)	(N_{22}, P_{22})
	$\beta > N_{22}$	($\mathrm{NK_m}$, -)	(β , 0)
$\gamma_1 < \gamma_2 < \gamma_3 < \gamma$	$\beta < N_{22}$	($\mathrm{NK_t}$, NF)	(N_{22}, P_{22})
	$\beta > N_{22}$	($\mathrm{NK_m}$, -)	(β , 0)

4.1.2. Scenario II : Patient plays first

The sequential game tree representing the scenario is illustrated in Figure 2, with the patient being the first player and the nephrologist being the second player.

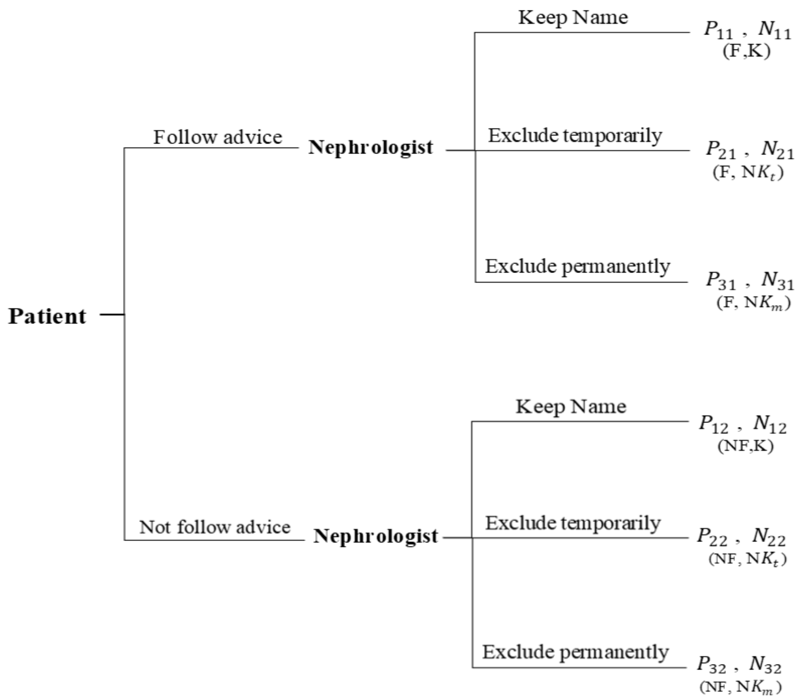

Figure 2: Tree representation of the sequential game of doctor-patient interaction in kidney transplantation consultations, with the patient playing first followed by the nephrologist.

Case I : $\gamma < \gamma_1 < \gamma_2 < \gamma_3$

When $\gamma < \gamma_1$, one will have $P_{11} > P_{12}$, $P_{21} > P_{22}$ and $P_{31} > P_{32}$, indicating that the patient will always choose to follow advice. Referring to the branches of strategy 'Follow advice' in the game tree presented in Figure 2, the 3 possible choices of the nephrologist are compared in terms of their corresponding payoffs (N_{11} , N_{21} and N_{31}). Based on the boundary conditions of β, for any $\beta < \beta_3$, N_{11} is always the highest payoff of nephrologist. Hence, the nephrologist will choose 'Keep Name' and the subgame perfect Nash equilibrium obtained is (F,K). When $\beta > \beta_3$, one will now see $N_{31} > N_{11}$ as derived in Table 5. Under this circumstance, the nephrologist will choose 'Exclude permanently' instead which yields a better payoff than 'Keep Name'. Therefore, the subgame perfect Nash equilibrium is (F, $\mathrm{NK_m}$).

Case II : $\gamma_1 < \gamma < \gamma_2 < \gamma_3$

When γ value is higher such that $\gamma_1 < \gamma < \gamma_2 < \gamma_3$, the patient tends to not follow advice. However, if the patient as the first mover chooses to not follow advice, the nephrologist will respond by choosing either temporary or permanent exclusion since the nephrologist will not want to consider strategy 'Keep Name' which is going to give him or her the lowest payoff, N_{12} . Hence, the patient will get either P_{22} or P_{32} as payoff. On the other hand, for any value of $\beta < \beta_3$, N_{11} is always the best payoff of nephrologist. As a result, if the patient as the first mover chooses to follow advice, the nephrologist must respond by choosing 'Keep Name' to gain the highest benefit and the patient will get P_{11} as payoff. Hence, this leaves the patient with a total of 3 possible choices which are getting either P_{22} , P_{32} or P_{11} as payoff after anticipating the decisions likely to be made by the nephrologist. Since $P_{11} > P_{22}$ and $P_{11} > P_{32}$, the patient will choose to follow advice and the nephrologist will choose keeping name. The subgame perfect Nash equilibrium is (F, K). Conversely, if $\beta > \beta_3$, one will have $N_{31} > N_{11}$, the nephrologist will choose permanent exclusion. This time, the patient will need to compare P_{31} , P_{22} and P_{32} . If the patient chooses 'Not follow advice', the nephrologist will respond by choosing 'Exclude permanently' since $N_{32} > N_{22}$ and this will then bring a lower payoff of P_{32} to the patient. Therefore, the patient will rather choose "Follow advice' since $P_{31} > P_{32}$. The subgame perfect Nash equilibrium is (F, $\mathrm{NK_m}$).

Case III : $\gamma_1 < \gamma_2 < \gamma < \gamma_3$

Increasing γ further to a point where $\gamma_1 < \gamma_2 < \gamma < \gamma_3$, the exact same results as the previous case are obtained with the same reasoning.

Case IV : $\gamma_1 < \gamma_2 < \gamma_3 < \gamma$

Increasing γ to its highest value such that $\gamma_1 < \gamma_2 < \gamma_3 < \gamma$, when $\beta < \beta_3$, the same reasoning as the previous case is applied and the resulting subgame perfect Nash equilibrium is again (F, K). The difference in results is observed when $\beta > \beta_3$, the nephrologist will always choose permanent exclusion as indicated by the boundary conditions derived in Table 5. Therefore, the patient must decide by comparing P_{31} and P_{32} . Since $P_{32} > P_{31}$ when $\gamma > \gamma_3$, the patient will choose 'Not follow advice' and the subgame perfect Nash equilibrium obtained is (NF, $\mathrm{NK_m}$). The overall results obtained for the 4 cases are summarized in Table 7.

Table 7: Sequential game equilibria obtained with their corresponding payoffs gained for each interval of γ and β in which the patient plays first.

Equilibria of The Sequential Game where Patient Plays First			
γ	β	Subgame Perfect Nash Equilibrium	Payoffs gained
$\gamma < \gamma_1 < \gamma_2 < \gamma_3$	$\beta < \beta_3$	(F , K)	(P_{11}, N_{11})
	$\beta > \beta_3$	(F , $\mathrm{NK_m}$)	(P_{31}, N_{31})
$\gamma_1 < \gamma < \gamma_2 < \gamma_3$	$\beta < \beta_3$	(F , K)	(P_{11}, N_{11})
	$\beta > \beta_3$	(F , $\mathrm{NK_m}$)	(P_{31}, N_{31})
$\gamma_1 < \gamma_2 < \gamma < \gamma_3$	$\beta < \beta_3$	(F , K)	(P_{11}, N_{11})
	$\beta > \beta_3$	(F , $\mathrm{NK_m}$)	(P_{31}, N_{31})
$\gamma_1 < \gamma_2 < \gamma_3 < \gamma$	$\beta < \beta_3$	(F , K)	(P_{11}, N_{11})
	$\beta > \beta_3$	(NF , $\mathrm{NK_m}$)	(P_{32}, N_{32})

5. Conclusion

It was shown that a change in the first mover of the game can bring about a significant difference in the results obtained in terms of the game equilibrium. The game scenario where the nephrologist plays first can only give rise to a win-win situation (Keeping Name, Follow Advice) when the γ value is very low ($\gamma < \gamma_1$). Conversely, when the patient becomes the first mover of the game instead, the game equilibria are always (F,K) for all values of γ (except when the β value is very high such that $\beta > \beta_3$). This concludes that having the patient as the first mover of the sequential game will yield more cooperation between the nephrologist and the patient in their transplantation consultations process. This could serve as a basis for any medical encounter involving transplant doctors and patients by letting the patients to take the lead so the patients will know that they are responsible for their own survival resulting from their own decisions whether to cooperate with their doctors since the doctors will act according to the patients' behaviours, and not the other way around. Patient's adherence to medical advice is also proven to be more likely to happen when the γ value is low. Hence, it is vital to help lower this parameter of patient to encourage more cooperative equilibria. This could be done by establishing treatment or addiction recovery programs for drug or active substance users in order to embrace a higher chance to be placed on the kidney transplant waiting list.

As a recommendation for future work, this study can be leveraged and extended for modelling other types of diseases other than ESKD by using game theory in extensive forms such as diabetes, obesity, cancers, and psychological disorders which also involves doctor-patient interaction in medical consultations but with different set of strategies that could be possibly employed by the players.

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References

[1] Dimaria, C. (2019) What You Need to Know About End-Stage Kidney Disease (ESRD). Retrieved on October 28, 2021 from https://www. healthline.com/health/end-stage-kidney-disease.

[2] Bujang, M. A., Adnan, T. H., Hashim, N. H., Mohan, K., Kim, L. A., Ahmad G., Bak, L. G., Bavanandan, S. and Haniff, J. (2017). Forecasting the Incidence and Prevalence of Patients with End-Stage Renal Disease in Malaysia up to the Year 2040. *Int J Nephrol*. 1: 5-8.

[3] Msn. org. (2018) 26th Report of the Malaysian Dialysis and Transplant Registry 2018. Retrieved on October 29, 2021 from https://www.msn.org.my/nrr/mdtr2018.jsp.

[4] Djulbegovic, B., Hozo, I. and Ioannidis, J. P. (2015). Modern health care as a game theory problem. *Eur J Clin Invest*. 45: 1-12.

[5] Mendonca, F. V., Catalao-Lopes, M., Marinho, R. T. and Figueira, J. R. (2018). Improving medical decision-making with a management science game theory approach to liver transplantation. *Omega*. 1: 34–71.

[6] Colman, A. M. *Game Theory and Experimental Games: The Study of Strategic Interaction.* New York: Pergamon Press Inc. 1982.

[7] Bhuiyan, B. A. (2018). An Overview of Game Theory and Some Applications. *Philosophy and Progress*. 59(1): 45-60.

[8] Munoz-Garcia, F. and Toro-Gonzalez, D. (2016). Pure Strategy Nash Equilibrium and Simultaneous-Move Games. *Strategy and Game Theory*. 2: 25-60.