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Hybrid Multi-criteria Decision-Making Model for Kidney Allocation

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Abstract

Background and Objectives: Organ transplantation is an appropriate treatment for patients at the final stage of disease. The most important step in organ transplant is organ allocation. Decision making for organ allocation is a complex and multi-criteria problem. The demand for kidney is more than other organs. Donated kidneys in Iran are allocated by filtering the waiting list. This method is not optimal and efficient. Hence, the purpose of this study is developing a multi-criteria decision-making (MCDM) model for kidney allocation based on a scoring method.

Methods: This study consists of two phases. The goal of the first phase is weighting the effective factors in kidney allocation. In this phase, the factors were extracted from the literature. Next, they were weighted using the analytic hierarchy process (AHP) method. In the second phase, the patients on the waiting list were ranked using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The main contribution of this study is developing an integrated kidney allocation model using AHP and TOPSIS methods. It is the first study that consists of both factors weighting and patients ranking phases.

Findings: Results show that "zero human leukocyte antigen (HLA) mismatches", "high medical urgency", and "identical blood type between donor and recipient" to be the three most important factors for kidney allocation, respectively. "Panel reactive antibodies (PRA) <80%" is the least important.

Conclusions: The proposed model may be used to develop an organ allocation system in countries that do not have an allocation algorithm, or intend to improve their allocation systems. On the other hand, the proposed method can be applied to other organs with little modification.

Keywords: Organ transplant, Kidney allocation, Multi-Criteria Decision Making, AHP, TOPSIS, Iran.

Background and Objectives

The attention to organ transplants has increased in recent years. Advances in surgical techniques and immunosuppressive drugs have made transplantation the most appropriate treatment for many diseases including, end-stage renal disease.[1] One of the challenges in this area is the imbalance between supply and demand.[2] The number of patients requiring transplantation has been increasing, while the number of donated organs does not increase significantly.[3] Therefore, the optimal use of the available organs is vital and decision making for organ allocation is a complex and multi-criteria problem.[4]

The allocation algorithm should be able to maximize the utility of transplantation in addition to ensure equity among patients.[5,6] There are different allocation algorithms in various countries. For example, the algorithm used in the US[7] differs from that used in Europe.[8] Each country has developed an allocation algorithm for different organs based on existing conditions and policies. The organ allocation algorithms can be divided into two categories:

(a) Algorithms that try to select the appropriate recipients by filtering the waiting list based on effective factors.[9]

(b) Algorithms that identify the most appropriate recipients by scoring the various factors and calculating points for each patient.[4]

The current allocation algorithm in Iran is based on a filtering method. For example, about kidney allocation, patients needing kidney transplant must be registered on the waiting list. As soon as a donated kidney is available, the allocator (an expert who is responsible for organ allocation) by filtering the waiting list, identifies the appropriate patient. The first factor to filter the list is the patients' medical condition. Emergency patients are prioritized for allocation. Then, the list is filtered based

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on the identical blood type the donor and the patients. Next, she/he will sort the list by waiting time. Finally, she/he chooses the six high priorities by considering the age difference between the donor and patients and the patient's distance to the transplant center. Two top priorities are kidney recipients, and four next priorities are in reservation mode.

The existing method is largely equity-based. The factors that affect transplant survival and increase the utility are ignored.[10]

There are several reasons for modifying the current kidney allocation system in Iran. The most important reason is that modifying the current system can improve the overall transplant survival. A system that allocates kidneys based on utility criteria would reduce the number of re-transplantation or delay it, and slow down the growth of the waiting list.[11] Therefore, the main purpose of this study is to propose a multi-criteria decision making model that can prioritize patients by identifying and weighting the kidney allocation criteria.

The main question in this study is: " Which is the most appropriate patient for transplantation on the waiting list?" For answering this question, the following items were also explained in this study:

Which are the most important criteria for kidney allocation?

How to balance between equity and utility in kidney allocating?

The only assumption considered in this study is: If the kidney is allocated to the patient, it will be available at the right time.

For this end, the study was conducted in two phases. In the first phase, kidney allocation criteria were extracted from the literature, then their weight was calculated by analytic hierarchy process (AHP) method. In the second phase, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which is one of the conventional methods in multi-criteria decision making, was used to rank the patients.

The reason for selecting AHP and TOPSIS methods from various multi-criteria decision-making (MCDM) methods was their wide use in the literature. Besides, these methods are user-friendly and easy to both understand and implement.

The drawback of AHP for patients ranking is the high number of pairwise comparison that could result in a tiresome comparison process.[12] Therefore, we used TOPSIS to rank the patients.

According to aforementioned, in this study we develop a comprehensive kidney allocation framework for the countries including Iran that use the filtering approach for organ allocation and need to modify or improve their organ allocation algorithm. To the best of our knowledge, there is no study in the literature for organ allocation which proposes an integrated framework that consists of all steps for developing an organ allocation system (identifying the factors, weighting the factors, and ranking the patients). The main contribution of this study is proposing an appropriate framework for kidney allocation, which integrates AHP with TOPSIS methods together for the first time. The proposed framework is usable for other organs allocation.

The rest of paper is organized as follows: Next section includes a literature review of MCDM methods in healthcare systems, especially organ allocation. In the following, the proposed methodology and the empirical results and discussion are detailed. Finally, we present our conclusion in the last section.

Related Works

MCDM methods have received much attention from researchers in diverse industries, including healthcare systems.[13] Decision making in healthcare sector is difficult due to its complexity and critical effects on the life quality of individuals.[14] Several fuzzy and classic MCDM methods are supporting healthcare decision making processes.[15] In this section, we attempt to review how other researchers have employed MCDM methods to evaluate the healthcare industries. We have classified previous studies into 5 different areas, including: service quality, risk assessment, healthcare technology, hospital healthcare service, and organ transplant. We summarized the literature review in this area in Table 1. It shows the application area, year of publication, authors, techniques and methods, and study purpose.

In the literature, there was little research employing MCDM methods for organ allocation. The application of MCDM methods to organ allocation was studied in the 1990s. For the first time, Ryan Cook et al used AHP to develop a ranking system for allocation of cadaver liver.[34] Later, further research was conducted in this area. Koch et al used AHP method to organ allocation. They considered quantitative and qualitative criteria.[35] In Saha et al study, AHP was applied to rank the patients for an available kidney. They considered four criteria of matching, transplant status, selection, and location.[36]

The detailed literature review shows there is little research in the application of MCDM methods to organ allocation. On the other hands, the existing studies employed one of the MCDM methods to allocate an organ without clearly developing a comprehensive framework that consists of all step for organ allocation (identifying and

Table 1: Literature review about application of MCDM methods on healthcare industry

Areas	Reference/ Year	Author(s)	Technique and Method	Study Purpose
Service quality	(16) / 2019	La Fata et al	Fuzzy ELECTRE III	Evaluate the service quality in the public healthcare.
	(17)/2016	Shafii et al	TOPSIS and fuzzy AHP	Evaluate the service quality factors in the teaching hospitals.
	(18)/ 2019	Torkzad and Beheshtinia	AHP	Evaluate the criteria that effect hospital service quality.
	(19)/2015	Moslehi et al	AHP and Delphi methods	Explore the most important factors that can be used for quality measurement of the Iranian health centers.
	(20)/2019	Tuzkaya et al	IVIF_PROMETHEE	Present a methodology that can be used in the healthcare service quality evaluation.
Risk assessment	(21)/2017	Samuel et al	Fuzzy AHP and ANN	Propose the novel MCDM approach for the predicting of heart failure risk.
	(22)/2008	Dolan and Iadarola	AHP	Discover the prospective efficacy of several new small-risk graphic communication formats.
	(23)/2012	Yucel et al.	FIS and ANP	Assessment of risk factors in hospital to implement information systems.
Healthcare technology	(24)/2016	Nilashi et al	Fuzzy ANP	Understand the important factors which driving the decision in the adoption of hospital information system
	(25)/ 2019	Liu et al	VIKOR	Examine the influential factors for customers' adoption of mobile health.
	(26)/2013	Lu et al	ANP, DEMATEL, and VIKOR	Assess the factors affecting the adoption of RFID in healthcare industry.
Hospital healthcare service	(27)/2019	Rouyendegh et al.	DEA and fuzzy AHP	Develop a new method using the integration of DEA and fuzzy AHP for performance evaluation in the healthcare industry.
	(28)/ 2017	Ajmera	TOPSIS	Rank the best strategy for medical tourism sectors based on SWOT analysis.
	(29)/ 2017	Asadi et al	Fuzzy AHP	Develop a novel MCDM model to determine and prioritize factors affecting outsourcing of services in the hospital.
	(30)/2019	Hatefi and Haeri	Balanced scorecard and fuzzy DEA	Evaluation of hospital performance.
	(31)/2014	Leaven	ANP	Optimize performance of a clinical laboratory inside a local hospital system.
	(32)/ 2018	Ghatreh et al	Grey theory and TOPSIS	Proposed a novel MCDM method to location supplementary blood centers.
	(33)/2010	Tsai et al	Fuzzy AHP and Delphi method	Assess hospital performances measurements
Organ transplant	(34)/1990	Ryan Cook et al	AHP	Develop a ranking system for allocation of cadaver liver.
	(35)/ 1996	Koch et al	AHP	Develop a model for Organ allocation.
	(36)/ 2012	Saha et al	AHP	Rank the patients for an available kidney.
	(37)/ 2013	Lin et al	AHP	Propose a multi-criterion decision-making model for liver allocation.

weighting the factors, ranking the patients). In this study, we propose the framework that employed two MCDM methods (AHP for weighting the factors and TOPSIS for ranking the patients).

Methods

In this section, the proposed method is discussed in detail. Figure 1 shows the steps of the proposed methodology for developing a kidney allocation model.

Phase 1: Weighting of Kidney Allocation Criteria Using AHP

At this phase, the kidney allocation criteria were extracted from the literature. Then, their weights were determined by AHP method.

AHP is a MCDM approach and was introduced by Saaty.[38] The AHP technique is user-friendly and easy to understand and implement.[39] AHP can handle both tangible and intangible factors.[40] Peniwati has shown that when comparing AHP with other MCDM decision making

Table 2: A list of kidney allocation criteria

Factors	Description	Source
ABO matching	Compatibility of the recipient and the donor blood type The kidney with blood type A can only be allocated to the patient with blood type A or AB.	7, 8, 36
Age difference	Age difference between the recipient and the donor The lower age difference between the recipient and the donor will result in better transplant outcome.	36, 43, 44
A prior donor	The patients having donated one of their kidneys or a piece of other organs.	7, 8
HLA mismatching	The number of incompatibility HLA-A, -B, and -DR between the donor and the recipient. HLA: Antigens in the human tissue cells that vary from person to person. Zero HLA mismatches means a high degree of compatibility, and six HLA mismatches mean complete incompatibility.	7, 8, 36, 43
Transplant status	Has the patient been transplanted before?	36
Patient age	Patient age for pediatric patients under 18 years These patients have priority.	7, 8, 36
PRA	PRA: The level of sensitivity of a patient to human leukocyte antigens. Finding a compatible kidney for patients with high PRA value takes a long time. So these patients are prioritized to those with low PRA values.	7, 8, 36, 44
Predicted Survival	Predicted survival rate after transplant. Patients with higher graft survival have higher priority for selection.	7
Medical Urgency	Medical condition of a patient A patient who has a very urgent condition, would have high priority to transplant.	7, 8
Waiting time	The length of time that a patient is on the waiting list	7, 8, 36, 44

methods, AHP is actually more effective.[41]

The various steps involved in the AHP are described as follows[42]:

Step 1: Identifying a list of kidney allocation criteria from the literature review, experts' opinion, and allocation models in other countries (Table 2).

Step 2: Constructing the hierarchy at all level.

In this study, ten factors presumed to affect kidney allocation were extracted from literature and several kidney allocation models in other countries (Table 2). These factors were grouped into two main criteria. Table 3 shows the hierarchy at all levels. The main objective is selection the appropriate recipient, and the two main criteria are equity and utility. In the next columns, sub-criteria are shown.[10]

Step 3: Designing the questionnaire to collect the data for making a pairwise comparison.

The questionnaires were answered by 13 experts, who were mainly decision makers and policy makers in organ allocation in Iran. The questionnaire first was tested for its content validity. In the next step, data were collected from experts. The Cronbach's alpha coefficient is used to verify reliability. This coefficient is calculated for the item under each of the categories. The Cronbach's alpha coefficient was above 0.8 for all categories. Therefore the reliability of questionnaire items can be verified [(45)]. In this study, we used the nine-point scale developed by Saaty.[38] This scale indicates the level of relative importance (preference) from equal, moderate, strong, very strong, to extreme, by assigning a 1, 3, 5, 7 and 9, respectively.

The AHP uses the pairwise comparison method to determine the relative importance of the criteria.[37] An n*n matrix is obtained at each level of the hierarchy, where n is the number of elements of the level.[46] The components in the matrix, a_{ij} $(i.j = 1.2.3 \ldots n)$ represents the weight of the criterion given by the decision maker. Equation (1) represents the matrix of pairwise comparison.[47]

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}. \; a_{ii} = 1. \; a_{ji} = \frac{1}{a_{ij}}. \; a_{ij} \neq 0 \quad (1)$$

Step 4: Determining the relative weight and check for consistency using consistency ratio (CR).

After the pairwise comparison, mathematical computation is carried out to establish the relative weights of criteria. Computation includes the calculation of normalized principle Eigen vector (w) corresponding to the largest eigenvalue (λ_{max}), as

$$Aw = \lambda_{max} * w \quad (2)$$

The relative weights are obtained by normalizing any of the rows or columns of A.[47]

One advantage of AHP is that it can measure the degree to which the pairwise are consistent with CR.[46] If CR less

Table 3: Weights of the Criteria and Sub-criteria

Global Weight	Local Weight	Sub-criteria Level 2	Local Weight	Sub-criteria Level 1	Local Weight	Criteria
Utility	0.694	HLA mismatch	0.427	Zero	0.514	**0.152**
				1-2	0.260	0.077
				3-4	0.142	0.042
				5-6	0.084	0.025
		Predicted Survival	0.224	<1 year	0.078	0.012
				1-5 years	0.231	0.036
				>5 years	0.691	0.107
		ABO matching	0.239	Identical	0.660	0.109
				Compatible	0.340	0.056
		Age Difference	0.110	<5 years	0.519	0.040
				5-15 years	0.284	0.022
				>15 years	0.196	0.015
Equity	0.306	A Prior Donor	0.043			0.013
		Medical Urgency	0.492	High	0.861	0.130
				Low	0.139	0.021
		Transplant status	0.033			0.010
		Waiting time	0.068			0.021
		PRA	0.1	>80%	0.837	0.026
				<80%	0.163	0.005
		Patient age	0.265	<11 years	0.526	0.043
				11-15 years	0.300	0.024
				15-18 years	0.174	0.014

than 0.1, it indicates that the evaluation within the matrix is acceptable, otherwise, it is not acceptable, and the values should be revised.[48] For checking the consistency of the comparison matrix, a consistency index (CI) is calculated.[47]

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

RI is random index suggested by Saaty.[38]

Step 5: Determining the global weight of criteria.

The global weights were obtained by multiplying the local weights of the criteria with the local weights of sub-criteria.[42]

Phase 2: Ranking the Patients Using TOPSIS

When the weight of the variables is obtained, TOPSIS was used to rank the patients. TOPSIS a simple ranking method in conception and application, was developed by Hwang and Yoon in 1981.[49] TOPSIS ranks alternatives based on the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The positive ideal solution maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria.[13] The optimal alternative is closest to the positive ideal solution and farthest to the negative ideal solution.

TOPSIS method consists of the following steps[13]:

Step 1: Creating an evaluation matrix consisting of m alternatives and n criteria.

Intersection of each alternative and criteria given as x_{ij} . Therefore, we have a matrix $X = \left(x_{ij}\right)_{m\times n}$

Step 2: Constructing normalized decision matrix.

The matrix X is then normalized to from the matrix $= \left(r_{ij}\right)_{m\times n}$, using the normalization method.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\left(\sum_{k=1}^{m} x_{kj}^2\right)}} . \quad i = 1.2.\dots.m. \quad j = 1.2.\dots.n \quad (5)$$

Step 3: Constructing the weighted normalized decision matrix.

$$v_{ij} = w_j r_{ij}. \quad i = 1.2.\dots.m. \quad j = 1.2.\dots.n \quad (6)$$

Where w_j is the original weight given to the indicator v_j .

Step 4: Determining the positive ideal and negative ideal solutions.

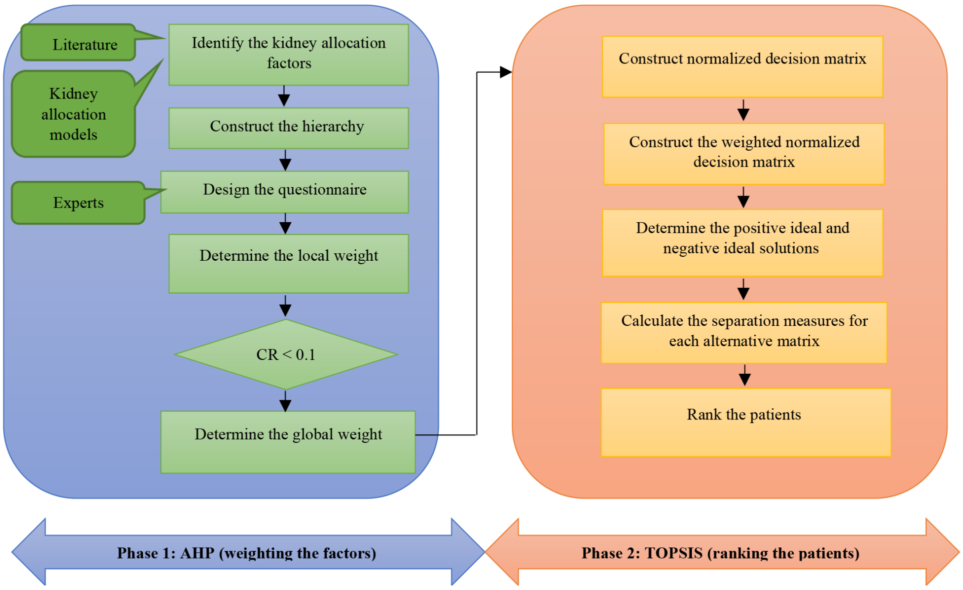

Figure 1. The Proposed Methodology for Developing a Kidney Allocation Model

$A^* = \{v_1^* \ldots . v_n^*\}$: positive ideal solution. (7)

Where $v_i^* = \{\max(v_{ij})\, if\ j \in J_+ ; \min(v_{ij})\, if\ j \in J_-\}$

$A' = \{v_1' \ldots . v_n'\}$: negative ideal solution. (8)

Where $v_i' = \{\min(v_{ij})\, if\ j \in J_+ ; \max(v_{ij})\, if\ j \in J_-\}$

Where,

$J_+ = \{j = 1.2 \ldots . n \mid j\ associated\ with\ the\ criteria\ having\ a\ positive\ impact\}$

$J_- = \{j = 1.2 \ldots . n \mid j\ associated\ with\ the\ criteria\ having\ a\ negative\ impact\}$

Step 5: Calculating the separation measures for each alternative.
The separation from positive ideal alternative is:

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_i^* - v_{ij}\right)^2}. \qquad i = 1 \ldots . m \qquad (9)$$

Similarity, the separation from the negative ideal alternative is:

$$S_i' = \sqrt{\sum_{j=1}^{n} \left(v_i' - v_{ij}\right)^2}. \qquad i = 1 \ldots . m. \qquad (10)$$

Step 6: Calculating the relative closeness to the ideal solution.

$$C_i^* = S_i' / \left(S_i^* + S_i'\right). \quad 0 < C_i^* < 1. \quad i = 1.2 \ldots . m \qquad (11)$$

Rank the alternative with C_i^* closest to 1.

Results and Discussion

This study aimed to develop a hybrid multi-criteria decision making model for kidney allocation that consists of 2 phases. In the first phase, weight of the factors was determined by AHP method. In the second phase, patients were ranked using TOPSIS method. The results of the 2 phases are presented in detail below.

Results of Weighting the Criteria

After extracting variables from the literature and constructing the hierarchy, a questionnaire was designed to collect the data for making a pairwise comparison. The questionnaire was completed by 13 experts. To aggregate the group decision arithmetic mean operation was used. Table 3 shows the local weights and global weights for each criterion. Figure 2 shows the results of prioritization of two main criteria (equity and utility). As can be seen, utility has gained the higher score. It indicates that the optimal use of donated kidney is more important than equity, according to Iranian experts. Figure 3 presents the utility sub-criteria and their priority scores determined by AHP. As seen, HLA matching gained the highest score. Six equity sub-criteria were evaluated, and it was observed that the medical urgency has the maximum impact on kidney allocation. Almost all organ allocation models give high priority to emergency patients, and it is perfectly reasonable (Figure 4).

By multiplying the local weights of the criteria with the local weights of sub-criteria, the global weights were obtained. Of the 22 sub-criteria, “Zero HLA mismatches”, “High Medical Urgency”, and “Identical blood type between donor and recipient” appear to be the three most important factors for kidney allocation with weights of 0.152, 0.130, and 0.109, respectively. The “PRA < 80%” received the lowest weights of 0.005. All calculated CRs were less than 0.1. It indicates that the evaluation within the matrix is acceptable.

The results show that the most important factor is “Zero HLA mismatches”. This means that the patients with high degree of HLA matching to the donated kidney should be given high priority. HLA matching is one of the utility sub-criteria. Zero HLA mismatches lead to suitable transplant outcome, and it increases transplant survival. In Iran, HLA matching is not considered for kidney allocation. The second important factor is “High Medical Urgency”. It is one of the equity sub-criteria. In Iran, urgency patients have the highest priority for allocation.

The calculated weights of criteria show that the developed model simultaneously attentions to the sub-criteria of utility and equity. This model is suggested to be used by policy makers and decision makers in organ allocation area. The model can be a guideline to improve and modify the current model.

Results of Ranking the Patients

We used calculated weights by AHP method to rank the patients using TOPSIS method. We created a random sample of 20 patients. Then they were sorted based on the method described in the methodology section using TOPSIS method. The results are presented in Table 4. The results of patient rankings were validated by 2 experts.

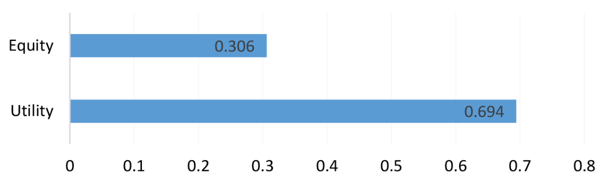

Figure 2. The Weights of Main Kidney Allocation Criteria.

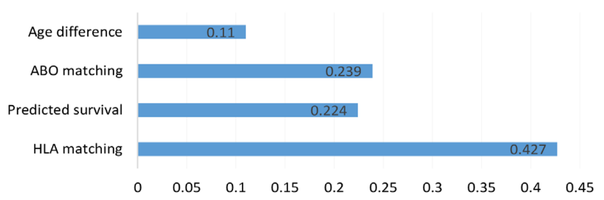

Figure 3. The Weights of Utility Sub-criteria.

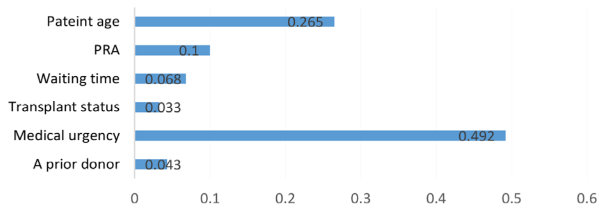

Figure 4. The Weights of Equity Sub-criteria.

Two priorities for allocation are patients 19 and 1 that in addition to their suitable matching with the donor (HLA mismatch=1, ABO matching= Identical, Age difference with donor <5), their graft survival has been predicted more than 5 years. Graft survival is one of the utility sub-criteria. Therefore, the proposed model allocates organs aiming to increase the utility. Three patients are high urgency (patients 1, 5, 11). All of them are in high priority (2, 6, 3). The results show that the proposed model not only focuses on increasing the utility but also aims to increase the equity.

Conclusions

This study aimed to develop a hybrid MCDM model for kidney allocation in Iran by the scoring method. The study consisted of two phases: weighting the kidney allocation criteria and ranking the patients on the waiting list. In the first phase, the factors influencing kidney allocation were identified by literature review. Then weighting of each factor was calculated using AHP method with the participation of 13 experts. The results showed that “zero HLA mismatches”, “high medical urgency”, and “identical blood type between donor and recipient” had the highest weights and “PRA<80%” had the lowest weight. In the second phase, using the calculated weights in the previous phase, TOPSIS method was used to rank the patients. In this phase, a randomized dataset containing information of 20 patients was used. Patients 19, 1, 11, 4, 10, and 5 were ranked the first six priorities, respectively. The results were validated by 2 experts.

In this study, AHP and TOPSIS methods were employed. The combination of AHP and TOPSIS methods was employed by many studies in literature, but the main contribution of this study is proposing an appropriate framework for kidney allocation, which integrates AHP with TOPSIS methods together for the first time. To the best of our knowledge, there is no study in the literature of organ allocation which proposes an integrated framework that

Table 4. Ranking the Patients Using TOPSIS Method

Patient ID	HLA MISMATCHING	Survivability	ABO Matching	Age Difference	A Prior Donor	Urgency	Transplant Status	Waiting Time	PRA	Patient Age	Similarity of Ideal Solution (C*)	Rank
1	1	>5	I	<5	No	High	1	2	>80	<11	0.516	2
2	3	1-5	C	5-15	No	No	1	7	<80	11-15	0.214	20
3	6	<1	C	>15	No	Low	2	9	<80	>18	0.300	15
4	2	1-5	C	<5	Yes	No	1	12	>80	>18	0.452	4
5	0	<1	I	5-15	No	High	1	4	<80	>18	0.379	6
6	1	1-5	C	>15	No	No	1	17	<80	>18	0.235	17
7	4	1-5	C	5-15	No	Low	3	12	<80	15-18	0.350	10
8	5	<1	I	<5	No	No	1	14	<80	>18	0.227	18
9	2	<1	C	>15	No	No	1	12	>80	>18	0.275	16
10	6	1-5	I	5-15	Yes	Low	1	8	<80	>18	0.383	5
11	2	1-5	C	5-15	No	High	2	1	<80	<11	0.486	3
12	3	1-5	I	<5	No	No	1	16	<80	11-15	0.304	14
13	1	>5	I	>15	No	Low	1	6	>80	>18	0.356	8
14	0	>5	C	5-15	No	Low	1	11	<80	>18	0.360	7
15	4	1-5	C	<5	No	No	1	15	<80	<11	0.351	9
16	5	<1	C	5-15	No	No	2	16	<80	>18	0.321	13
17	3	1-5	I	>15	No	No	1	3	<80	15-18	0.342	11
18	2	1-5	C	5-15	No	No	1	21	>80	>18	0.334	12
19	1	>5	I	<5	Yes	Low	2	7	<80	<11	0.610	1
20	6	<1	C	>15	No	No	1	20	<80	>18	0.225	19

consists of all steps for developing an organ allocation system (identifying the factors, weighting the factors, and ranking the patients). The main contribution of this study is proposing an appropriate framework for kidney allocation, which integrates AHP with TOPSIS methods together for the first time. The proposed framework is usable for other organs allocation.

Our study can contribute to the organ allocation literature. On the other hands, the proposed model may be used to develop an organ allocation system in countries such as Iran that do not have an allocation algorithm or intend to improve and modify their allocation systems. The countries can be used the framework presented in this study as a guideline to improve and modify their existing model.

One of the limitations of this study was the unavailability of a real dataset of kidney allocation in Iran, and lack of registering some of effective factors in kidney allocation such as HLA matching and PRA. In this study, traditional methods of AHP and TOPSIS were used. It is suggested that future researches to employ fuzzy AHP and fuzzy TOPSIS, or other MCDM methods for kidney allocation, then compare their results with the proposed model. In this study, a small randomized dataset was used to evaluate the model. Future research could be conducted using a real and larger dataset.

Competing Interests

The authors declare no competing interest.

Authors' Contributions

The authors made equal contributions to this study.

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