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Evaluating Kidney Failure in Age Groups with Cubic Neutrosophic Sets

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Abstract. This study presents a multi criteria decision making (MCDM) approach based on the cubic neutrosophic TOPSIS method with a score function to evaluate kidney failure across different age groups. Patients are assessed based on symptoms and these symptoms are linked to diseases to form a complete patient disease relationship. The cubic neutrosophic framework handles uncertainty and imprecision in medical data, and the score function ensures accurate ranking of alternatives. Real patient data are analyzed to determine the level of susceptibility to kidney failure among children (0 - 17), adults (18 - 49), and the elderly (50 +). The findings show that the elderly group is the most susceptible to kidney failure, emphasizing the importance of early diagnosis and preventive measures in this population.

Keywords: Cubic Neutrosophic Set, Kidney Failure, Age Groups, Topsis Method, Score Function.

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1. Introduction

In 1965, Zadeh [25] introduced fuzzy sets (FS), assigning each element a membership value between 0 and 1 to represent uncertainty. Later, in 1975, he extended this to interval-valued fuzzy sets (IVFS), where elements are given intervals instead of single values, offering a more flexible way to capture imprecision.

Jun et al. [15] proposed cubic sets (CS), which use cubic functions for membership grades, building on FS and IVFS to better model uncertainty. Smarandache [21] introduced neutrosophic sets (NS), incorporating truth, indeterminacy, and falsity. Wang et al. [23] extended this to interval-valued neutrosophic sets (IVNS), allowing interval representation for all three components. Y. B. Jun et al. [15] later defined neutrosophic cubic sets, with further applications researched by Ajay et al. [2] and M. Ali et al. [3]. Inspired by this, we propose cubic neutrosophic sets, which differ from neutrosophic cubic sets but share a common foundation.

TOPSIS has been widely extended under fuzzy and neutrosophic environments for multi-criteria decision-making (MCDM). Wang et al. [23] developed fuzzy TOPSIS with subjective and objective weights, while Nadaban et al. [18] introduced neutrosophic TOPSIS for indeterminate data. Simplifications were offered by Elhassouny et al. [10], and further extensions were made by Imtaz et al. [13], Li et al. [17], and Sindhu et al. [20]. Applications in medical diagnosis include works by Broumi et al. [8], Guleria et al. [12], and Farooq et al. [11].

This paper evaluates the risk of kidney failure among children, adults, and the elderly. The TOPSIS approach based on cubic neutrosophic sets is applied to manage uncertainty in medical data and to rank age groups according to their susceptibility.

2. Preliminaries

Definition 2.1. Let X be a non-empty set. A Cubic Set(CS) $\mathcal{C}$ in X is a structure of the form $\mathcal{C} = \{\grave{n}, \tilde{\varrho}(\grave{n}), \varrho(\grave{n})/\grave{n} \in X)\}$ and denoted by $\mathcal{C} =< \tilde{\varrho}, \varrho >$, where $\tilde{\varrho} = [\varrho^L, \varrho^U]$ is an IVFS in X and ϱ is a FS in X.

Definition 2.2. Let X be a universe set. Then a Neutrosophic Set(NS) N on X $\mathsf{N} = \{\grave{n}, \zeta(\grave{n}), \varrho(\grave{n}), \varsigma(\grave{n})/\grave{n} \in X\}$, with $\zeta, \varrho, \varsigma \in [0, 1]$.

Definition 2.3. An Interval Valued Neutrosophic Set(IVNS) of X is denoted as $\tilde{\mathsf{N}} = \{\grave{n}, \tilde{\zeta}(\grave{n}), \tilde{\varrho}(\grave{n}), \tilde{\varsigma}(\grave{n})/\grave{n} \in X\}$ where $\tilde{\zeta}, \tilde{\varrho}, \tilde{\varsigma} \in [0, 1]$.

3. Topsis Method for cubic neutrosophic set(CNS)

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a method used to make decisions involving multiple criteria. It evaluates alternatives by comparing their affinity with the best solution and their deviation from the least advantageous solution. Each criterion is assigned a weight, and a relative closeness score determines the final ranking.

Definition 3.1. Let $\mathcal{X}$ be a nonempty set. A cubic neutrosophic set (CNS) on $\mathcal{X}$ is represented as $\mathfrak{C} = \{\grave{n}, \zeta^\bigstar(\grave{n}), \varrho^\bigstar(\grave{n}), \varsigma^\bigstar(\grave{n})/\grave{n} \in \mathcal{X}\}$

Where, $\zeta^\bigstar =< \tilde{\zeta}, \zeta >\in [0, 1], \tilde{\zeta}$ is an i-v truth membership function and ζ is a truth membership funtion,

$\varrho^\bigstar =< \tilde{\varrho}, \varrho >\in [0, 1], \tilde{\varrho}$ is an i-v indeterminacy membership function and ϱ is a indeterminacy membership funtion,

$\varsigma^\bigstar =< \tilde{\varsigma}, \varsigma >\in [0, 1], \tilde{\varsigma}$ is an i-v falsity membership function and ς is a falsity membership funtion,

with the condition that $0 \leq \tilde{\zeta} + \tilde{\varrho} + \tilde{\varsigma} \leq 3$ and $0 \leq \zeta + \varrho + \varsigma \leq 3$.

Definition 3.2. Let $\mathfrak{C} = \{(\zeta^-, \zeta^+), \zeta, (\varrho^-, \varrho^+), \varrho, (\varsigma^-, \varsigma^+), \varsigma\}$ be a cubic neutrosophic number. Its score function is defined as follows

$$S(\mathfrak{C}) = \frac{\frac{(\zeta^-+\zeta^+)+\zeta}{3} + \frac{[3-(\varrho^-+\varrho^+)+\varrho]}{3} + \frac{[3-(\varsigma^-+\varsigma^+)+\varsigma]}{3}}{3}$$

Definition 3.3. Let $\mathcal{N}$ and $\mathcal{K}$ be two cubic neutrosophic numbers. The maxmin composition between them is defined as follows

$$\mathcal{N} * \mathcal{K} = \left\{ \begin{array}{l} \{\max(\min(\tilde{\zeta}_N, \tilde{\zeta}_K)), \min(\max(\zeta_N, \zeta_K))\}, \\ \\ \{\min(\max(\tilde{\varrho}_N, \tilde{\varrho}_K)), \max(\min(\varrho_N, \varrho_K))\}, \\ \\ \{\min(\max(\tilde{\varsigma}_N, \tilde{\varsigma}_K)), \max(\min(\varsigma_N, \zeta_K))\} \end{array} \right\}$$

Topsis Algorithm

Step:1 Create a table values

The alternatives and criteria are structured in a table value to evaluate their performance under each criterion. In this table, rows represent alternatives and columns represent criteria. This table value serves as the foundation for further analysis and comparison.

$$\begin{pmatrix} (\zeta^\star_{11}, \varrho^\star_{11}, \varsigma^\star_{11}) & (\zeta^\star_{12}, \varrho^\star_{12}, \varsigma^\star_{12}) & \cdots & (\zeta^\star_{1n}, \varrho^\star_{1n}, \varsigma^\star_{1n}) \\ (\zeta^\star_{21}, \varrho^\star_{21}, \varsigma^\star_{21}) & (\zeta^\star_{22}, \varrho^\star_{22}, \varsigma^\star_{22}) & \cdots & (\zeta^\star_{2n}, \varrho^\star_{2n}, \varsigma^\star_{2n}) \\ \vdots & \vdots & & \vdots \\ (\zeta^\star_{m1}, \varrho^\star_{m1}, \varsigma^\star_{m1}) & (\zeta^\star_{m2}, \varrho^\star_{m2}, \varsigma^\star_{m2}) & \cdots & (\zeta^\star_{mn}, \varrho^\star_{mn}, \varsigma^\star_{mn}) \end{pmatrix}$$

Step:2 Score the table values

Using the definition 3.2 to create score table value.

Step:3 Construct the weighted score values

Each criterion is assigned a weight according to its importance. The performance of each alternative is multiplied by these weights to compute the weighted scores.

$$W_j = \frac{1-E_j}{\sum_{j=1}^{m}(1-E_j)}$$

Here, $j = 1, 2, ..., m$ and $\sum W_j = 1$

Step:4 Determaine the PIS and NIS

Positive Ideal Solution: $N_j^+ = \mathcal{D}_1^+, \mathcal{D}_2^+, \ldots, \mathcal{D}_n^+$

where $\mathcal{D}_i^+ = \{\max(\mathcal{D}_{ij}); j \in J^+, \min(\mathcal{D}_{ij}); j \in J^+\}$

Negative Ideal Solution: $N_j^- = \mathcal{D}_1^-, \mathcal{D}_2^-, \ldots, \mathcal{D}_n^-$

where $\mathcal{D}_i^- = \{\max(\mathcal{D}_{ij}); j \in J^-, \min(\mathcal{D}_{ij}); j \in J^-\}$

Here, $j = 1, 2, ..., n$

Step:5 Compute the separation distances for the alternatives

Seperation measure of each alternatives is to be measured from PIS and NIS respectively.

$$\mathcal{P}_i^+ = \sqrt{\sum_{j=1}^{m} (\mathcal{D}_j^+ - \mathcal{D}_{ij})^2}$$

$$\mathcal{P}_i^- = \sqrt{\sum_{j=1}^{m} (\mathcal{D}_j^- - \mathcal{D}_{ij})^2}$$

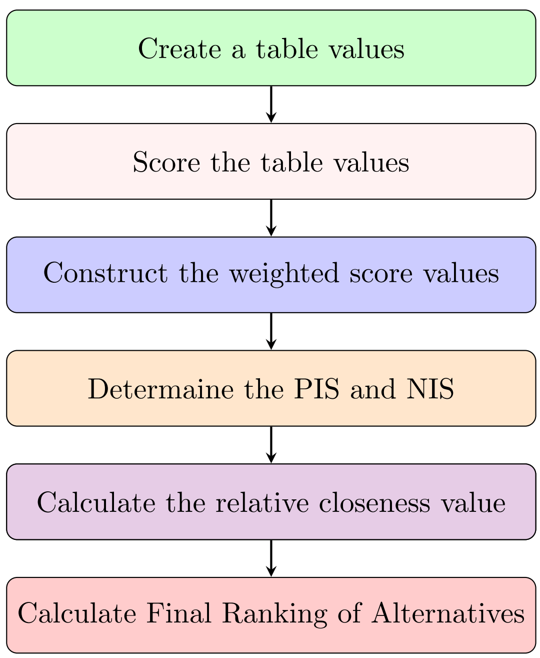
Step:6 Calculate the relative similarity to the ideal solution

For each alternatives, closeness coefficient is calculated by

$$\mathcal{S}_i = \frac{\mathcal{P}_i^-}{\mathcal{P}_i^+ + \mathcal{P}_i^-}$$

Step:7 Result Alternatives are ordered based on their closeness coefficient, and the one attaining the maximum value is regarded as optimal.

The algorithm is represented in the form of a flow chart. It shows the step-by-step process of TOPSIS from constructing the table of values to ranking the alternatives.



Numerical Example

Kidney failure can affect individuals of all age groups, though the underlying causes may vary. Lifestyle factors such as an unhealthy diet, physical inactivity, irregular daily routines, and insufficient hydration can gradually impair renal function. Chronic stress and prolonged exposure to harmful substances, including certain medications and environmental toxins, further increase the risk of kidney damage. In addition to these lifestyle-related factors, medical conditions such as diabetes mellitus, hypertension and recurrent or chronic infections can progressively injure the renal structures over time. Genetic predisposition and inherited disorders may also contribute, with some conditions presenting symptoms during childhood. Understanding these risk factors is essential for early detection, effective prevention, and the improvement of long-term renal health outcomes.

Chronic kidney disease develops gradually, often as a consequence of diabetes, hypertension, chronic infections or prolonged use of nephrotoxic drugs. These factors damage the glomeruli and other renal filtering structures, leading to progressive loss of kidney function. Patients commonly present with fatigue, edema in the extremities or face, nausea, decreased appetite, reduced urine output and pruritus caused by accumulation of toxins in the blood.

Nephrotic syndrome arises from damage to the glomeruli, resulting in significant protein loss in the urine. It may develop due to primary kidney disorders, systemic conditions such as diabetes and lupus or infections. Clinical manifestations include puffiness around the eyes, generalized edema, frothy urine, fatigue and hyperlipidemia.

Glomerulonephritis is characterized by inflammation of the glomerular structures, often triggered by immune responses following infections or due to autoimmune diseases such as lupus. Patients typically present with hematuria, edema, elevated blood pressure and decreased urine output, reflecting impaired renal filtration.

Acute kidney injury is a sudden decline in renal function, commonly caused by dehydration, severe infections, blood loss, exposure to nephrotoxic agents or urinary obstruction. Clinical features include rapid reduction in urine output, edema, fatigue, confusion, shortness of breath and in severe cases, cardiovascular complications due to fluid overload.

Polycystic kidney disease is an inherited disorder characterized by the progressive formation of multiple fluid filled cysts within the kidneys, which gradually replace normal renal tissue. It is associated with flank or back pain, hypertension, hematuria, abdominal enlargement and frequent urination. Over time, these changes can culminate in significant renal impairment and eventual kidney failure.

Let P = $\{\mathcal{P}_1, \mathcal{P}_2, \mathcal{P}_3\}$ represent the age groups of patients in the hospital, where

$\mathcal{P}_1-$ Children(0 - 17),

$\mathcal{P}_2-$ Adults(18 - 49), and

$\mathcal{P}_3-$ Elderly(50+).

Consider a set of symptoms $S = \{\mathcal{S}_1, \mathcal{S}_2, \mathcal{S}_3, \mathcal{S}_4, \mathcal{S}_5\}$, where

$\mathcal{S}_1-$ Edema,

$\mathcal{S}_2-$ Low urine output,

$\mathcal{S}_3-$ High blood pressure,

$\mathcal{S}_4-$ Protein in urine, and

$\mathcal{S}_5-$ Flank/Back pain.

Similarly, let the set of diseases be $D = \{\mathcal{D}_1, \mathcal{D}_2, \mathcal{D}_3, \mathcal{D}_4, \mathcal{D}_5\}$, where

$\mathcal{D}_1-$ Chronic kidney disease,

$\mathcal{D}_2-$ Nephrotic syndrome,

$\mathcal{D}_3-$ Glomerulonephritis,

$\mathcal{D}_4-$ Acute kidney injury, and

$\mathcal{D}_5-$ Polycystic kidney disease.

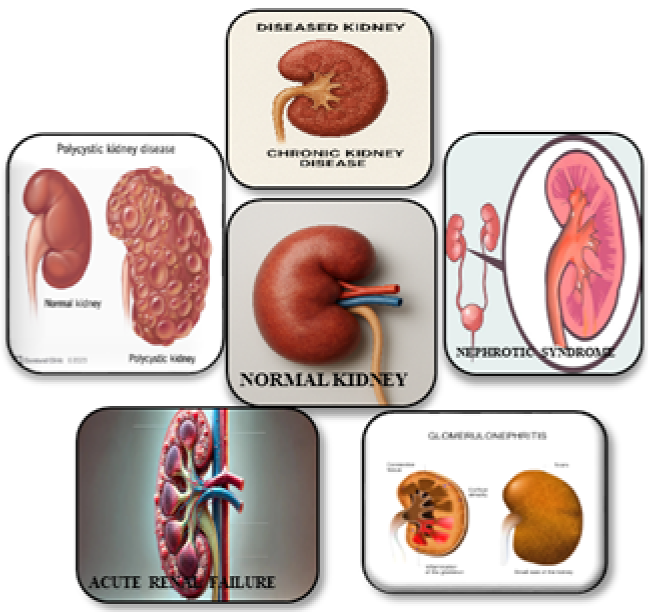


FIGURE 1. Types of Kidney Disease

TABLE 1. Cubic Neutrosophic table value = $\mathcal{N}$

$*$	$\mathcal{S}_1$	$\mathcal{S}_2$
$\mathcal{P}_1$	([.3, .5].7, [.4, .6].8, [.4, .7].9)	([.7, .9].2, [.5, .7].3, [.6, .8].4)
$\mathcal{P}_2$	([.4, .7].8, [.3, .5].7, [.6, .9].2)	([.3, .5].7, [.4, .6].8, [.4, .7].9)
$\mathcal{P}_3$	([.7, .9].2, [.5, .7].3, [.6, .8].4)	([.1, .3].5, [.6, .8].7, [.3, .5].6)

$*$	$\mathcal{S}_3$	$\mathcal{S}_4$
$\mathcal{P}_1$	([.3, .7].2, [.1, .4].8, [.4, .5].5)	([.4, .8].2, [.2, .4].5, [.6, .7].8)
$\mathcal{P}_2$	([.4, .7].3, [.2, .8].5, [.3, .4].6)	([.6, .7].1, [.7, .9].4, [.2, .3].6)
$\mathcal{P}_3$	([.6, .8].7, [.3,.5].2, [.4, .6].8)	([.5, .7].3, [.7, .9].2, [.3, .4].6)

$*$	$\mathcal{S}_5$
$\mathcal{P}_1$	([.4, .6].2, [.3, .4].5, [.1, .2].9)
$\mathcal{P}_2$	([.8, .9].1, [.7, .8].2, [.6, .8].4)
$\mathcal{P}_3$	([.3, .5].7, [.4, .6].8, [.3, .6].5)

TABLE 2. Cubic Neutrosophic table value = $\mathcal{K}$

$*$	$\mathcal{D}_1$	$\mathcal{D}_2$
$\mathcal{S}_1$	([.2, .4].6, [.3, .4].5, [.6, .7].1)	([.3, .5].4, [.1, .2].1, [.2, .6].4)
$\mathcal{S}_2$	([.4, .6].2, [.3, .4].5, [.1, .2].9)	([.2, .4].6, [.3, .4].5, [.6, .7].1)
$\mathcal{S}_3$	([.4, .7].3, [.2, .8].5, [.3, .4].6)	([.6, .8].7, [.3, .5].2, [.4, .6].8)
$\mathcal{S}_4$	([.1, .2].4, [.4, .5].3, [.6, .7].2)	([.3, .5].7, [.4, .6].8, [.4, .7].9)
$\mathcal{S}_5$	([.8, .9].2, [.7, .9].1, [.6, .8].3)	([.7, .9].2, [.5, .7].3, [.6, .8].4)

*	$\mathcal{D}_3$	$\mathcal{D}_4$
$\mathcal{S}_1$	([.3, .5].7, [.4, .6].8, [.3, .6].5)	([.7, .9].2, [.5, .7].3, [.6, .8].4)
$\mathcal{S}_2$	([.4, .7].3, [.2, .8].5, [.3, .4].6)	([.6, .7].1, [.7, .9].4, [.2, .3].6)
$\mathcal{S}_3$	([.2, .4].6, [.3, .4].5, [.6, .7].1)	([.2, .4].6, [.3, .4].5, [.6, .7].1)
$\mathcal{S}_4$	([.3, .7].2, [.1, .4].8, [.4, .5].5)	([.3, .7].2, [.1, .4].8, [.4, .5].2)
$\mathcal{S}_5$	([.4, .8].2, [.2, .4].5, [.6, .7].8)	([.8, .9].2, [.7, .9].1, [.6, .8].3)

*	$\mathcal{D}_5$
$\mathcal{S}_1$	([.6, .8].7, [.3, .5].2, [.2, .6].4)
$\mathcal{S}_2$	([.4, .7].3, [.2, .8].5, [.3, .4].6)
$\mathcal{S}_3$	([.1, .2].4, [.4, .5].3, [.6, .7].2)
$\mathcal{S}_4$	([.4, .8].6, [.2, .4].7, [.6, .7].2)
$\mathcal{S}_5$	([.3, .5].7, [.4, .6].8, [.3, .6].5)

Step 1 Prepare a cubic neutrosophic table of values

TABLE 3. $\mathcal{N} * \mathcal{K}$ Cubic Neutrosophic table value

$*$	$\mathcal{D}_1$	$\mathcal{D}_2$
$\mathcal{P}_1$	([.4, .7].2, [.2, .5].5, [.4, .5].5)	([.4, .7].2, [.3, .5].5, [.4, .8].8)
$\mathcal{P}_2$	([.8, .9].2, [.2, .5].5, [.3, .4].9)	([.7, .9].2, [.3, .5].5, [.4, .6].6)
$\mathcal{P}_3$	([.4, .7].4, [.3, .7].5, [.3, .5].6)	([.6, .8].4, [.3, .5].5, [.4, .6].8)

$*$	$\mathcal{D}_3$	$\mathcal{D}_4$
$\mathcal{P}_1$	([.4, .7].2, [.2, .4].8, [.4, .7].8)	([.6, .7].2, [0.2, .4].5, [.6, .7].4)
$\mathcal{P}_2$	([.4, .8].2, [.3, .6].7, [.4, .5].6)	([.8, .9].2, [.3, .7].5, [.4, .5].6)
$\mathcal{P}_3$	([.3, .7].3, [.3, .5].5, [.3, .5].6)	([.7, .9].2, [.3, .5].4, [.3, .5].6)

$*$	$\mathcal{D}_5$
$\mathcal{P}_1$	([.4, .8].3, [.2, .4].5, [.3, .6].5)
$\mathcal{P}_2$	([.4, .7].4, [.3, .5].5, [.4, .7].6)
$\mathcal{P}_3$	([.6, .8].5, [.4, .5].8, [.3, .5].6)

Step 2: By applying the score function, construct the corresponding score table.

TABLE 4. Scored table value

$*$	$\mathcal{D}_1$	$\mathcal{D}_2$	$\mathcal{D}_3$	$\mathcal{D}_4$	$\mathcal{D}_5$
$\mathcal{P}_1$	.52	.44	.44	.52	.56
$\mathcal{P}_2$	.57	.54	.48	.54	.5
$\mathcal{P}_3$	.51	.52	.51	.58	.53

Step:3 Weights assigned by scored table value

$$\begin{pmatrix} .52 & .44 & .44 & .52 & .56 \\ .57 & .54 & .48 & .54 & .5 \\ .51 & .52 & .51 & .58 & .53 \end{pmatrix} \begin{pmatrix} .199 \\ .201 \\ .2026 \\ .1982 \\ .1992 \end{pmatrix}$$

TABLE 5. weighted score table value

$*$	$\mathcal{D}_1$	$\mathcal{D}_2$	$\mathcal{D}_3$	$\mathcal{D}_4$	$\mathcal{D}_5$
$\mathcal{P}_1$	.1035	.0884	.0891	.1031	.1116
$\mathcal{P}_2$	.1134	.1085	.0972	.107	.0996
$\mathcal{P}_3$	.1015	.1045	.1033	.115	.1056

Step 4 Calculasion of PIS (positive ideal solution) and NIS (Negative ideal solution)
$\mathcal{P}_j^+ = \{.1134, .1085, .1033, .115, .1116\}$ and
$\mathcal{P}_j^- = \{.1015, .0884, .0891, .1031, .0996\}$

Step 5 Determaination of separation measure given below table

*	$\mathcal{D}_j^+$
$\mathcal{P}_1$	$= .2828$
$\mathcal{P}_2$	$= .0155$
$\mathcal{P}_3$	$= .0126$

*	$\mathcal{D}_j^-$
$\mathcal{P}_1$	$= .0122$
$\mathcal{P}_2$	$= .0251$
$\mathcal{P}_3$	$= .0253$

Step 6 Determaination of relative closeness to ideal solution

	$\mathcal{S}_j$
$\mathcal{P}_1$	$= .0414$
$\mathcal{P}_2$	$= .6182$
$\mathcal{P}_3$	$= .6675$

Step 7 Result $\mathcal{P}_3 > \mathcal{P}_2 > \mathcal{P}_1$.
Hence, it can be concluded that the elderly age group is the most affected by kidney failure.

4. Conclusions

This study applied a cubic neutrosophic TOPSIS approach with a score function to analyze kidney failure across different age groups using real patient data. The results indicate that among children (0 - 18), adults (19 - 49), and the elderly (50 +), the elderly group is the most affected. These findings demonstrate the practical effectiveness of the proposed MCDM model in supporting medical decision making under uncertain and imprecise conditions.

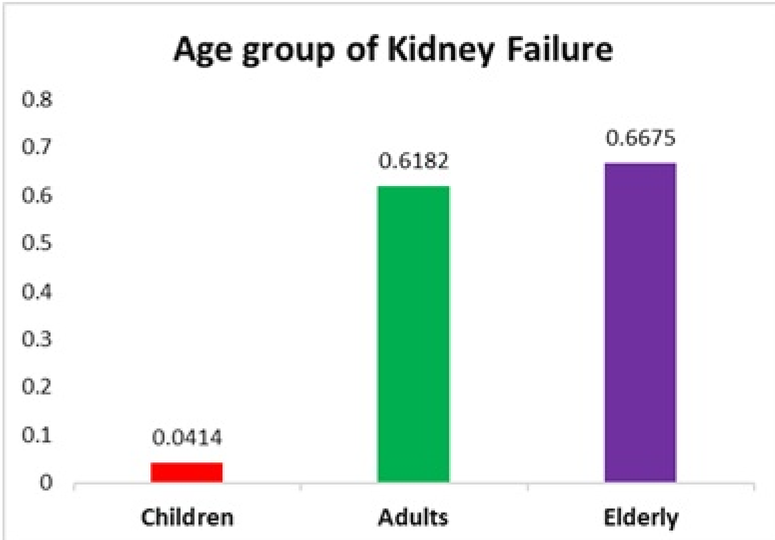


FIGURE 2. $\mathcal{P}_3 > \mathcal{P}_2 > \mathcal{P}_1$.

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