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Evaluation and Prioritizing of Biomaterials for the application of implantation in human body using Fuzzy AHP AND TOPSIS

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ABSTRACT

Biomedical Engineering (BME) is proliferating nowadays due to its vast applications in the human body. It deals with the implementation of engineering principles and design concepts in the biological sciences for the health purposes. In this paper, we have considered seven BME materials, i.e., Polyether ether ketone (PEEK), Polymethyl methacrylate(PMMA), Polyoxymethylene (POM), Ultra-high-molecular-weight polyethylene(UHMWPE), Silicon rubber, Alumina, Bone(Cortical). To evaluate these seven alternative materials, seven common properties, i.e., Ultimate Tensile Strength, Deformation strength, Young's modulus, Density, Thermal conductivity, Dielectric constant, Poisson ratio are considered. The objective of this work to evaluate and prioritize the seven alternative materials under consideration. Hybrid Multi-criteria Decision Making (MCDM) technique, i.e., Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) is adopted to solve the model. From the findings of the research, it is concluded that Polyether ether ketone (PEEK) material is most suitable for biomedical implantations.

Keywords: Biomedical Engineering, Biomaterial, MCDM, Fuzzy AHP, TOPSIS

1. INTRODUCTION

A biomaterial is any substance which has been engineered to meet a biological requirement like medical purpose. The applications of these materials have been proliferating since last fifty years. These materials can be derived either from nature or man-made (Synthetic) using chemical process. A wide range of synthetic materials has been, or still are, utilized as a part of the fabrication of prosthetic gadgets. These incorporate polymers, ceramics, metals, and carbon or its allotropes. The benefits of engineered materials incorporate unsurprising mechanical properties and simplicity of value control. However, none are genuinely biocompatible and much of the time nonstop sedate treatment, for example, anticoagulation, is required to conquer unfavorable host reaction to the embedded gadget.

Same as the biomaterials, implantable materials can likewise be characterized under two noteworthy headings specifically active and non-active. An 'active medical device' is characterized as 'any medicinal device depending for it's working on a source of electrical vitality or any wellspring of force other than that specifically produced by the human body or gravity'. A 'non-active medical device' is characterized as 'any medicinal device other than an active medical device or a device utilized for as a part of the vitro diagnosis.

The application of these materials in the medical engineering is called as Biomedical Engineering (BME) which applies the engineering concepts to the materials. The applications include Joint replacements,

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Bone plates, Bone cement, Dental implants for tooth fixation,Heart valves,Contact lenses,Breast implants,Nerve conduits etc.

2. PROPOSED ALGORITHM

2.1. Fuzzy AHP Method

Step 2.1.1. Construction of fuzzy pair-wise comparison matrix:

The fuzzy judgment matrix A= $\left\{a_{ij}\right\}$ ofn criteria or

alternatives using pair-wise comparison is made by the use of TFNs as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}$$

where a_{ij} is a fuzzy triangular number

Step 2.1.2. Compute the value of Fuzzy Synthetic Extent

Based on the aggregated pair-wise comparison matrix, A =$\left\{a_{ij}\right\}$, the value of fuzzy synthetic extent S w.r.t the i_{th} criterion is calculated as follows

$$S_i = \sum_{j=1}^{n} a_{ij} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij}]^{-1}$$

Where

$$\sum_{j=1}^{m} a_{ij} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \text{ and } \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} = \left(\sum_{i=1}^{n} l_j, \sum_{i=1}^{n} m_j, \sum_{i=1}^{n} u_j \right)$$

Step 2.1.3. Approximation of fuzzy priorities

On the basis of fuzzy synthetic extent values, the non-fuzzy values representing the relative preferences or weight of one criterion over others i.e. the degree of possibility are calculated using Chang's method as expressed below

$$V(S_i \geq S_j) = \begin{cases} 1, & if\ m_i \geq m_j \\ \dfrac{(u_i - l_j)}{(u_i - m_i) + (m_j - l_j)}, & if\ l_j \leq u_i \\ 0, & others \end{cases}$$

where $i, j = 1, \dots\dots\dots, n; j \neq i$

The degree of possibility for a TFN to be greater than the number of n TFNs can be given by $V(S_i \geq S_1, S_2, S_3, \dots\dots S_k) = \min\,(S_i \geq S_{1,} S_i \geq S_2, \dots\dots, S_i \geq S_k) = w(S_i)$ where $k \neq i$ .Each w(S_i) value represents the relative preferences or weight, a non-fuzzy number, of one criterion over others.

Step 2.1.4. Determination of Normalized Weights

The normalized weights $W(S_i)$ will be formed in terms of a weights vector as follows:

$$W = (w(S_1), w(S_2), ... w(S_n))^T$$

Step 2.1.5. Establish final global weights

2.2. TOPSIS Method

In this technique two artificial choices are estimated:

1. Ideal alternative: the one which has the best level for all traits considered.
2. Negative ideal option: the one which has the most noticeably awful trait values.

TOPSIS chooses the option that is the nearest to the perfect arrangement and most remote from the negative perfect option. TOPSIS accepts that we have m options (choices) and n properties/criteria and we have the score of every alternative as for every criteria.

TOPSIS has gotten much considerations from scientists and experts, and was broadly utilized as a part of eight ranges: (1) Supply Chain Management and Logistics, (2) Water Resources Management, (3) Energy Management, (4) Management Chemical Engineering, (5) Human Resources Management, (6) Design, Engineering and Manufacturing Systems, (7) Health, Safety and Environment, (8) Business and Marketing Management.

Step 2.2.1:

Decision matrix needs to be established for the ranking. The structure of the matrix is as follows

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_J \end{array} \begin{array}{c} \begin{array}{cccccc} F_1 & F_2 & \cdots & F_j & \cdots & F_n \end{array} \\ \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1j} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2j} & \cdots & f_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{i1} & f_{i2} & \cdots & f_{ij} & \cdots & f_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{J1} & f_{J2} & \cdots & f_{Jj} & \cdots & f_{Jn} \end{bmatrix} \end{array}$$

Where A_j denotes the alternatives j, j = 1,2,…,J; F_i represents i_{th} attribute or criterion, i= 1,2,…,n, related to the i_{th} alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion $F_{j.}$

Step 2.2.2: Normalized decision matrix $R(=[r_{ij}])$ are calculated .It is calculated as:

$$r_{ij} = \frac{fij}{\sqrt{\sum_{j=1}^{J} f_{ij}^2}} \qquad j = 1, 2, ..., J;\ i = 1, 2, ..., n.$$

Step 2.2.3: Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value vij is calculated as:

$$V_{ij} = w_i \times r_{ij}, \quad j = 1,2,....,J; i = 1,2,...,n.$$

Where w_i represents the weight of the i_{th} attribute or criterion

Step 2.2.4: Determine the positiveideal and negative-ideal solutions

$$A^* = \{v_1^*, v_2^*,...., v_i^*\} = \left\{ \left(\max_j v_{ij} \mid i \in I' \right), \left(\min_j v_{ij} \mid i \in I'' \right) \right\},$$

$$A^- = \{v_1^-, v_2^-,...., v_i^-\} = \left\{ \left(\min_j v_{ij} \mid i \in I' \right), \left(\max_j v_{ij} \mid i \in I'' \right) \right\},$$

Where I' is associated with the benefit criteria, and I'' is associated with the cost criteria.

Step 2.2.5: Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the positive -ideal solution (D_j^*) is given as

$$D_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^*\right)^2} \quad \text{j=1,2,….,J.}$$

Similarly, the separation of each alternative from the negative ideal solution (D_j^-) is as follows:

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2} \quad \text{j=1, 2,…,J.}$$

Step 6: Calculate the relative closeness to the ideal solution and rank the performance order. The relative closeness of the alternative A_j can be expressed as

$$CC_j^* = \frac{D_j^-}{D_j^* + D_j^-}, \text{ j= 1,2,….,J.}$$

Where CC_j^* the index value lies between 0 and 1. The larger the index value means the better the performance of the alternatives.

3. EXPERIMENT AND RESULT

In this section, fuzzy AHP method is proposed to calculate the weights and then rank the alternatives using TOPSIS. The scaled used in this research is mentioned in Table 1.

The main objective of this research is to rank the BME materials for the use of human purpose. The main input parameters to be considered are Ultimate Tensile Strength (UTS), Deformation strength(Def), Young's modulus (E), Density (ñ), Thermal conductivity (K), Dielectric constant (DC), Poisson ratio (í) for the seven alternatives which are to be ranked based on these criteria. The seven alternatives that are to be considered are Polyether ether ketone (PEEK), Polymethyl methacrylate (PMMA), Polyoxymethylene (POM), Ultra-high-molecular-weight polyethylene(UHMWPE), Silicon rubber (SR), Alumina (Al), Bone(Cortical)(B).Table 2 shows the criteria values for seven alternatives.

All these criteria taken for ranking the BME materials have different units and dimensions need to be normalized by using step 2.2.2 and mentioned in Table 3.

Table 1
Linguistic variables

Linguistic Variables	*Triangular Fuzzy Numbers*
equal	(0,0,0)
extremely low priority	(0,0.1,0.2)
very low priority	(0.1,0.2,0.3)
low priority	(0.2,0.3,0.4)
medium low priority	(0.3,0.4,0.5)
medium priority	(0.4,0.5,0.6)
medium high priority	(0.5,0.6,0.7)
high priority	(0.6,0.7,0.8)
very high priority	(0.7,0.8,0.9)
extremely high priority	(0.8,0.9,1)

Table 2
Quantitative information for seven alternatives

	UTS(Mpa)	Def	E(Gpa)	ρ(g/cm³)	K(w/mk)	DC	v
PEEK	93	50	3.6	1.32	0.25	3.2	0.38
PMMA	60	1.3	2.3	1.17	0.167	3.3	0.76
POM	65	40	3.1	1.47	0.36	3.8	0.35
UHMWPE	30	200	0.5	0.945	0.48	2.3	0.46
SR	7	800	0.08	1.9	0.14	2.9	0.48
Al	400	0.1	380	3.95	30	9.43	0.54
B	105	1.5	19	1.19	0.465	6	0.6

Table 3
Normalized decision matrix

	UTS(Mpa)	Def	E(Gpa)	ρ(g/cm³)	K(w/mk)	DC	v
PEEK	0.2142	0.0605	0.0095	0.2550	0.0083	0.2425	0.2730
PMMA	0.1382	0.0016	0.0060	0.2260	0.0056	0.2500	0.5459
POM	0.1497	0.0484	0.0081	0.2840	0.0120	0.2879	0.2514
UHMWPE	0.0691	0.2418	0.0013	0.1826	0.0160	0.1743	0.3304
SR	0.0161	0.9672	0.0002	0.3671	0.0047	0.2197	0.3448
Al	0.9214	0.0001	0.9987	0.7631	0.9996	0.7145	0.3879
B	0.2419	0.0018	0.0499	0.2299	0.0155	0.4546	0.4310

In order to establish normalized weights, we implemented Fuzzy AHP method. In this process first pair-wise comparison matrix is determined as shown in Table 4.The criteria weights obtained are W_{uts}= 0.1283, W_{def}= 0.0136, W_E= 0.0036, $W_ñ$= 0.0990, W_k= 0.3281,W_{dc}= 0.175,W_i= 0.2524. The sum of these weights is 1.00 which shows that the values in the comparison matrix taken by the decision maker are consistent.

Now,the criteria values are converted into normalized weighted values by multiplying with weights using the formula as shown in step 2.2.3.This normalized weighted matrix is shown in Table 5.

Table 4
Pair-wise comparison matrix

	C1	C2	C3	C4	C5	C6	C7
C1	(0,0,0)	(3.33,5,10)	(0.4,0.5,0.6)	(0.3,0.4,0.5)	(0.2,0.3,0.4)	(0.7,0.8,0.9)	(0.2,0.3,0.4)
C2	-	(0,0,0)	(2,2.5,3.33)	(1.667,2,2.5)	(0,0.1,0.2)	(0.4,0.5,0.6)	(0.3,0.4,0.5)
C3	-	-	(0,0,0)	(0.2,0.3,0.4)	(1.667,2,2.5)	(0.4,0.5,0.6)	(0.4,0.5,0.6)
C4	-	-	-	(0,0,0)	(0.1,0.2,0.3)	(0.4,0.5,0.6)	(0.7,0.8,0.9)
C5	-	-	-	-	(0,0,0)	(0.2,0.3,0.4)	(0.4,0.5,0.6)
C6	-	-	-	-	-	(0,0,0)	(0.2,0.3,0.4)
C7	-	-	-	-	-	-	(0,0,0)

Table 5
Normalized weighted matrix

	UTS(Mpa)	Def	E (Gpa)	ρ(g/cm³)	K (w/mk)	DC	v
PEEK	0.0275000	0.0008000	0.0000342	0.0252000	0.0027000	0.0424000	0.0689000
PMMA	0.0177000	0.0000218	0.0000216	0.0224000	0.0018000	0.0438000	0.1378000
POM	0.0192000	0.0006582	0.0000292	0.0281000	0.0039000	0.0504000	0.0635000
UHMWPE	0.0089000	0.0032885	0.0000047	0.0181000	0.0052000	0.0305000	0.0834000
SR	0.0021000	0.0131539	0.0000007	0.0363000	0.0015000	0.0385000	0.0870000
Al	0.1182000	0.0000014	0.0035953	0.0755000	0.32800000	0.1250000	0.0979000
B	0.0310000	0.0000245	0.0001796	0.0228000	0.0051000	0.0796000	0.1088000

After the calculation of these normalized weighted values, separation measures, relative closeness values are calculated using steps 2.2.4,2.2.5 and 2.2.6. From these relative closeness values, theranking has been given and these alternative are prioritized.These values are shown in Table 6.

Table 6
Ranking of alternatives

	$\sum_{i=1}^{n}(v_{ij}-v_i^*)^2$	$\sum_{i=1}^{n}\left(v_{ij}-v_i^-\right)^2$	$D^*{}_j$	$D^-{}_j$	CC_j^*	Rank
PEEK	0.0086	0.1205	0.0928	0.3472	0.7891	1
PMMA	0.016	0.1161	0.1265	0.3407	0.7293	6
POM	0.0105	0.1187	0.1023	0.3445	0.7711	2
UHMWPE	0.0125	0.1194	0.1117	0.3456	0.7558	3
SR	0.0144	0.1184	0.1202	0.3440	0.7411	5
Al	0.1202	0.0151	0.3467	0.1228	0.2616	7
B	0.0123	0.1108	0.1108	0.3329	0.7503	4

4. CONCLUSION

It is quite clear that numerous factors are to be considered while selecting a biomaterial for the applications of health purposes. From the research findings, it is implied that the Polyether ether ketone (PEEK) is the best suitable material for the biomedical implantations. The ranking of the biomaterials can be stated as PEEK, POM, UHMWPE, B, SR, PMMA, Al. The use of hybrid technique i.e., Fuzzy AHP and TOPSIS is more accurate and more reliable than to go for a single method. It is computationally easy to evaluate and select the biomaterial based on the seven criteria's. This process includes the quantitative values of the considered criteria with relative importance to conclude the rankings of the alternatives and can be used in any field for the ranking purpose based on the related criteria. Thus, Hybrid Multi-criteria Decision Making (MCDM) technique can be successfully used to for solving various types of decision-making problems with high reliability.

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