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The Selection of Clinical Orthodontic Implant Materials by Entropy Weight Methods through Hybrid Multi criteria Decision making Techniques

M. Amareswari Reddy

Assistant professor, Dr.L.B.College of Engineering, Visakhapatnam, A.P, INDIA

Prof. K. Venkata Subbaiah

Senior Professor, Mechanical Engineering Department, Andhra University, Visakhapatnam, A.P, INDIA

Dr. Challa. Suresh

Associate professor, Avanthi College of Engineering and technology , Visakhapatnam, A.P, INDIA

Abstract

The purpose of this research is to determine the most appropriate material that can be used in tooth implantation by employing multi-criteria decision-making techniques. The following techniques used in this research paper: Entropy weighting with Combinative Distance-Based Assessment (CODAS), The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Additive Ratio Assessment (ARAS), Titanium grades 1–4 and Ti-6Al-4V, Ti-6al-7Nb, and Ti–29Nb–13Ta–4.6Zr are used as selection criteria. The proposed material selection technique is relatively inexpensive and may be advantageous when numerical selection of material properties or aspects of user interaction are required. The purpose of this paper is to determine which material is the most compatible from a health and transactional standpoint. Ti-6Al-4V is the optimal material for dental implant design, according to proposed techniques, followed by Ti–6al–7nb.

Keywords -- Multi-criteria decision making, weighting estimation by entropy, ARAS, TOPSIS, CODAS, material selection, dental implant

I. INTRODUCTION

The human body is made up of numerous organic and inorganic components. Bones are a critical component of the human body as they provide the body with strength, flexibility, and form via the collagen and hydroxyapatite found in bone [1,2]. Calcium, magnesium, and potassium, as well as electrolytes, are the primary components of bones. Accidents, aging, and illness are the leading causes of bone failure. The use of biomedical implants is necessary to compensate for the limitations imposed by bone fracture [3,4]. Although the human body does not completely absorb foreign substances except those that are edible, it is noted that Titanium is a Benchmark discovery that can be used in a variety of compositions as titanium alloy for medical implants.

The materials used in the development and adoption of a product are critical. Numerous products with a variety of different properties are now available. The design engineer should think multiple times prior selecting the best material for a particular application [5]. Material selection error can wreak havoc on the manufacturing and implementation processes. When selecting materials for a particular product, the engineer must take a number of factors into account. Material selection has become more complicated and difficult in recent years because of material properties such as physical, electric, magnetic, efficiency, mechanical, and chemical [6]. Additionally, the material's performance, availability, cost, and manufacturing shape. Market impact should also be considered. As a result, a more detailed mathematical approach to material collection are expected, with a variety of alternative strategies and influencing parameters [7].

Rigid materials and superalloys play a significant part in the world's most advanced technical areas, including aerospace, marine, chemical, and biomedical applications. Rigid materials and superalloys are essentially materials and alloys with superior chemical, physical, thermal, and biological characteristics [8]. There is a need of research to comprehend and find the most notable materials for their particular functions in the engineering and biological fields. Despite decades of research, selecting the best material with the lowest cost, highest sustainability, and longest life remained as an incomplete challenging problem and seeking new contributions. Additionally, the difficulty increases when selecting materials for objects with smaller dimensions such as dental implants, heart stunts.

This prompted us to develop a method for selecting the optimal material for dental implantation. The purpose of this research paper is to determine the most effective material selection techniques. There is a dearth of research on effective strategies for material selection for small dimensions.

In this paper, we show that the Suitable approaches for selection of material using MCDM techniques. MCDM methods such as TOPIS, ARAS, and CODAS using entropy weight methodology are taken into consideration. From the overall literature review, MCDM can be categorized as below:

1. MCDM approaches can be grouped into two categories – Qualitative and Quantitative measurements
2. Qualitative measurements include TOPSIS, SAW, COPRAS, COPRAS-G methods.
3. Quantitative measurements include AHP and Fuzzy procedures.
4. MCDM problem can be solved using the below steps:

a. Creation of Decision-making Matrix

b. Normalization of Decision-making Matrix

c. Weighted Decision-making Matrix of normalization

d. Assessment Scoring

e. Ranking

II. METHODS

The overall process flow of this research is depicted in Figure 1, along with the stages involved. Six stages comprise the proposed framework. The material is selected in phase 1, and the entropy-based calculation criteria are determined in phase 2. Phase 3 implements the TOPSIS method, while phases 4 and 5 implement the CODAS and ARAS methods, respectively. The final phase represents the rankings of the selected materials and presents the conclusion.

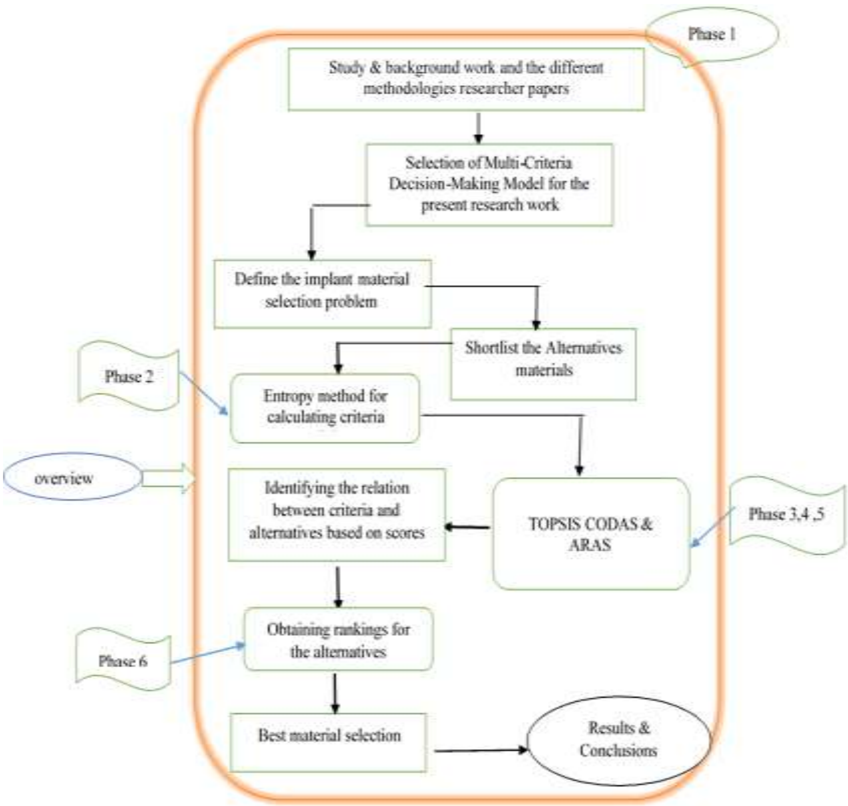

Figure 1: Process Overall Flow

2.1 Entropy weight

Claude E. Shannon invented the idea of "entropy" in the year 1948 to measure the weights of attributes. According to the author [8], entropy is indeed a calculation of its unsafeness related to a probability distribution of the knowledge quality of a particular message and examined the weights incertitude by differential distribution of chance. The following stages represents the calculated attribute weights:

Step 1: Decision-Making Matrix (z_{ij})

$$Z = [z_{ij}]_{n\times m} = \begin{bmatrix} z_{11} & z_{12} & \dots\dots & z_{1m} \\ z_{21} & z_{22} & \dots\dots & z_{2m} \\ \dots & \dots & \dots & \\ z_{n1} & z_{n2} & \dots\dots & z_{nm} \end{bmatrix} \quad (1)$$

Step 2: Determination of Normalized-Decision Matrix (Q_{ij})

$$Q_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \quad (2)$$

Step 3: Entropy Estimation (E_j)

$$E_j = -k \sum_{i=1}^{m} Q_{ij} \ln Q_{ij} \quad (3)$$

Where, $k = \frac{1}{\ln(m)}$; m = number of attributes.

Step 4: Determination of Degree of Diversification (D_j)

$$D_j = 1 - E_j \quad (4)$$

Step 5: Determination of Weights of Criteria (W_j)

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \quad (5)$$

2.2 CODAS Technique:

CODAS technique for problem-solving of material selection is discussed in [9]. The technique utilizes two measures for the determination of the acceptability of alternatives of the materials. The first measure is the negative-ideal outcome of Euclidean distance between the key and principal metric. The second measure is the Taxicab distance between the standard space apathies. CODAS steps are defined as below:

Step 1: Decision-making Matrix of normalisation (k_{ij})

$$k_{ij} = \begin{Bmatrix} \frac{z_{ij}}{\max_i z_{ij}}, \text{ if } j = K_b \\ \frac{\min_i z_{ij}}{z_{ij}}, \text{ if } j = K_{nb} \end{Bmatrix} \quad (6)$$

Where K_b & K_{nb} are beneficial and non- beneficial values.

Step 2: Weighted Decision-making Matrix of normalisation (r_{ij}) $r_{ij} = w_j n_{ij}$ (7)

Step 3: Solution with a negative-ideal outcome (ks)

$$ks = [ks_j]_{1\times m} \quad (8)$$

Step 4: Euclidean (E_i) and Taxicab (T_i)values

$$E_i = \sqrt{\sum_{j=1}^{m}\left(r_{ij} - ns_j\right)^2} \quad (9)$$

$$T_i = \sum_{j=1}^{m}\left|r_{ij} - ns_j\right| \quad (10)$$

Step 5: Determination of Relative assessment (h_{ik})

$R_a = [h_{ik}]_{n\times m}$

$$h_{ik} = (E_i - E_k) + (\Psi(E_i - E_k) \times (T_i - T_k)) \quad (11)$$

Ψ Denotes equality of the Euclidean

$$\Psi(z) = \begin{Bmatrix} 1\,, & if\ |z| \geq \tau \\ 0, & if\ |z| < \tau \end{Bmatrix}$$

Step 6: Score of Assessment (H_i)

$$H_i = \sum_{j=1}^{m} h_{ik} \quad (12)$$

2.3 TOPSIS Technique:

Yoon and Hwang established TOPSIS as a criterion based decision-making technique [10]. TOPIS is a multi-objective optimization approach, to achieve the specific optimal condition by considering all response parameters of a material. TOPSIS execution steps are as below:

Step 1: Decision-making Matrix of normalisation (n_{ij})

$$n_{ij} = \frac{z_{ij}}{\sqrt{\sum_{i=1}^{m} z_{ij}^2}} \quad (13)$$

Step 2: Weighted Decision-making Matrix of normalisation (r_{ij})

$$r_{ij} = w_j n_{ij} \quad (14)$$

Where w_j (0< w_j< 1), $\sum_{i=1}^{n} W_i = 1$

Step 3: Solution with a positive & negative-ideal outcome solution (S_p & S_n)

$$S_p = \left\{max(r_{ij}), min(r_{ij})\right\} \quad (15)$$

$$S_n = \left\{min(r_{ij}), max(r_{ij})\right\} \quad (16)$$

Step 4: Euclidean (E_i) values

$$E_{pi} = \sqrt{\sum_{j=1}^{m}\left(r_{ij} - s_{pj}\right)^2} \quad (17)$$

$$E_{ni} = \sqrt{\sum_{j=1}^{m} \left(r_{ij} - s_{pj}\right)^2} \qquad (18) \qquad (18)$$

Step 5: Relative assessment (h_{ik})

$$h_{ik} = \frac{E_{pi}}{(E_{pi}+E_{ni})} \qquad (19)$$

Step 6: Assessment score (H_i)

$$H_i = \sum_{j=1}^{m} h_{ik} \qquad (20)$$

2.4 ARAS Technique:

The ARAS approach is based on ratio sums of alternatives with a two-stage linear normalization procedure [12]. In this approach, the optimal parameters are determined using a utility function [13]. Below are the execution steps of ARAS Technique:

Step 1: Determination of Normalization of Decision matrix (n_{ij})

$$n_{ij} = \frac{z_{ij}}{\sum_{i=0}^{m} z_{ij}} \quad \text{For Beneficial attributes} \qquad (21)$$

$$n_{ij} = \frac{\mathbf{1}/\boldsymbol{z_{ij}}}{\sum_{i=0}^{m} \mathbf{1}/\boldsymbol{z_{ij}}} \quad \text{For Non- Beneficial attributes} \qquad (22)$$

Step 2: Determination of Weighted normalized decision matrix (r_{ij})

$$r_{ij} = w_j n_{ij} \qquad (23)$$

Step 3: Optimality function (S_i)

$$S_i = \sum_{j=0}^{n} r_{ij} \qquad (24)$$

Step 4: Degree of the utility (K_i)

$$K_i = \frac{S_i}{S_o} \qquad (25)$$

Step 5: Assessment score ($\mathrm{H_i}$)

$$\mathrm{H_i} = \sum_{\mathrm{j=1}}^{\mathrm{m}} \mathrm{K_i} \qquad (26)$$

CASE STUDY:

CLINICAL ORTHODONTIC IMPLANT MATERIALS SELECTION

Nowadays, dental implants made of titanium and its components account for a sizable portion of the market [13]. Seven distinct forms of titanium are discussed in this article as implant biomaterials (ASTM). Titanium alloys from Grade 1 to Grade 4 , Ti-6Al-4V (Ti-64), Ti-6Al-7Nb (Ti-6/7) and Ti–29Nb–13Ta–4.6Zr (TNTZ) as listed in Table 1[14,15] along with their mechanical and physical properties are used in this study. Youngs Modulus (Gpa), Ultimate Tensile Strength (MPa), Yield Strength (MPa), Elongation (%), density (g/cc), and Cost ($/kg) are six different parameters that have been taken into consideration for this study. The purpose of this research paper is to compare the above mentioned MCDM approaches (CODAS, TOPSIS & ARAS) for determining the optimal material for dental implantation.

The entropy weights are calculated and evaluated for all selected materials using three multi-criteria decision-making techniques; the results are compared for accuracy using Spearman rank-order correlation coefficients; and finally, the materials are ordered in highest to the lowest according to the rank obtained by the assessment score (H_i). The material with the highest score of assessment would be chosen. Youngs Modulus, Ultimate Tensile Strength, and Yield Strength are considered beneficial criteria when selecting a material, whereas Elongation, density, and cost are considered non-beneficial criteria.

TABLE 1: MECHANICAL CHARACTERISTICS OF SELECTED TITANIUM COMPONENTS

Criteria	EM	UTS	YS	EL	DE	CO
Ti-35A	0.8947	0.2581	0.1932	0.4167	0.9778	0.9231
Ti-50A	0.8947	0.3710	0.3125	0.5000	0.9778	1.0000
Ti-65A	0.8947	0.4839	0.4318	0.5556	0.9778	0.9231
Ti-75A	0.9123	0.5914	0.5489	0.6667	0.9778	0.8571
Ti-64	1.0000	1.0000	0.9875	1.0000	1.0000	0.4138
Ti-6/7	1.0000	0.9677	1.0000	1.0000	1.0000	0.3429
TNTZ	0.7018	0.9796	0.9818	0.7576	1.0000	0.2857

TABLE 2: NORMALIZED DECISION-MAKING MATRIX

Criteria/ Alternatives	Elastic Modulus (GPa) EM	Ultimate Tensile Strength (MPa) UTS	Yield Strength (MPa) YS	Elongation (%) EL	Density (g/cc) DE	Cost ($/kg) CO
Titanium -35A	102	240	170	24	4.5	1.3
Titanium -50A	102	345	275	20	4.5	1.2
Titanium -65A	102	450	380	18	4.5	1.3
Titanium -75A	104	550	483	15	4.5	1.4
Ti-6Al-4V (Ti-64)	114	930	869	10	4.4	2.9
Ti-6Al-7Nb (Ti-6/7)	114	900	880	10	4.4	3.5
Ti–29Nb–13Ta–4.6Zr (TNTZ)	80	911	864	13.2	4.4	4.2

III. RESULTS

3.1 Entropy weight

The normalized decision-making matrix for titanium materials is shown in Table 2. The entropy weight-based properties have been calculated and tabulated using formulas (1-2).

The entropy weight-based calculation would be carried out using formulas (3-5). The entropy, degree of diversification, and attribute weights are calculated and are represented in Table 3.

TABLE 3 ENTROPY WEIGHTS

	EM	UTS	YS	EL	DE	CO
Entropy	0.9972	0.9481	0.9297	0.9758	1.0000	0.9347
Degree of diversification	0.0028	0.0519	0.0703	0.0242	0.0000	0.0653
Weights of Attributes	0.0131	0.2419	0.3275	0.1128	0.0001	0.3045

3.2 CODAS Approach

CODAS techniques calculate weights for each material and property independently using the Entropy values defined in Table 3. Table 4 summarizes the weights calculated using CODAS techniques and equation (7). For the CODAS technique, Euclidean and taxicab distances should be calculated. Distances are calculated using equations (8,9,10). The Euclidean and taxicab distances are calculated and represented in Table 5 using table 4 as an input. The ranking order would be determined using Equations (11,12). The ranking order is determined using data from Table 5, the equations are applied to the data, and the final output is represented in Table 6. According to Table 6, the optimal material for dental implantation is Ti-6Al-4V.

TABLE 4: WEIGHTED MATRIX FROM CODAS

Criteria	EM	UTS	YS	EL	DE	CO
Ti-35A	0.0117	0.0624	0.0633	0.0470	0.0001	0.2811
Ti-50A	0.0117	0.0897	0.1023	0.0564	0.0001	0.3045
Ti-65A	0.0117	0.1170	0.1414	0.0627	0.0001	0.2811
Ti-75A	0.0120	0.1431	0.1798	0.0752	0.0001	0.2610
Ti-64	0.0131	0.2419	0.3234	0.1128	0.0001	0.1260
Ti-6/7	0.0131	0.2341	0.3275	0.1128	0.0001	0.1044
TNTZ	0.0092	0.2369	0.3216	0.0855	0.0001	0.0870
Weights	0.0131	0.2419	0.3275	0.1128	0.0001	0.3045
ns	0.009	0.062	0.063	0.047	0.0001	0.0870

TABLE 5: EUCLIDEAN AND TAXICAB FROM CODAS

Criteria	Ei	Ti
Ti-35A	0.1941	0.1966
Ti-50A	0.2229	0.2958
Ti-65A	0.2168	0.3451
Ti-75A	0.2262	0.4021
Ti-64	0.3252	0.5484
Ti-6/7	0.3224	0.5230
TNTZ	0.3141	0.4713

TABLE 6: RANKING FROM CODAS

Criteria	Hi	Rank
Ti-35A	-0.4639	7
Ti-50A	-0.2624	5
Ti-65A	-0.3050	6
Ti-75A	-0.2396	4
Ti-64	0.4563	1
Ti-6/7	0.4366	2
TNTZ	0.3780	3

3.3 TOPSIS Approach

TOPSIS techniques calculate weights for each material and property independently using the Entropy values defined in Table 3. Table 7 summarizes the weights calculated using TOPSIS techniques and equations (13,14). For the TOPSIS technique, positive & negative-ideal outcomes should be calculated. Outcomes are calculated using equations (15,16). The Euclidean distance is calculated on the outcomes using equations (17-20) and are represented in Table 8. The ranking order would be determined using Equations (19,20). The ranking order is determined using data from Table 8, the equations are applied to the data, and the final output is represented in Table 9. According to Table 9, the optimal material for dental implantation is Ti-6Al-4V.

TABLE 7: MATRIX OF NORMALISATION FROM TOPSIS

Criteria	EM	UTS	YS	EL	DE	CO
Ti-35A	0.374	0.134	0.102	0.551	0.382	0.194
Ti-50A	0.374	0.193	0.166	0.459	0.382	0.179
Ti-65A	0.374	0.252	0.229	0.413	0.382	0.194
Ti-75A	0.381	0.308	0.291	0.344	0.382	0.209
Ti-64	0.418	0.521	0.523	0.229	0.373	0.432
Ti-6/7	0.418	0.504	0.530	0.229	0.373	0.521
TNTZ	0.293	0.510	0.520	0.303	0.373	0.626

TABLE 8: EUCLIDEAN FROM TOPSIS

Criteria	Si+	Si-	(Si+) + (Si-)
Ti-35A	0.172	0.132	0.304
Ti-50A	0.146	0.139	0.284
Ti-65A	0.120	0.142	0.262
Ti-75A	0.095	0.149	0.244
Ti-64	0.077	0.180	0.258
Ti-6/7	0.104	0.173	0.277
TNTZ	0.136	0.167	0.303

TABLE 9: RANKING FROM TOPSIS

Criteria	Ci	Rank
Ti-35A	0.433	7
Ti-50A	0.488	6
Ti-65A	0.541	5
Ti-75A	0.611	3
Ti-64	0.700	1
Ti-6/7	0.624	2
TNTZ	0.5500	4

3.4 ARAS Approach

ARAS techniques calculate weights for each material and property independently using the Entropy values defined in Table 10. Table 11 summarizes the weights calculated using ARAS techniques and equations (21,22,23). For the ARAS optimality function

(Si), utility degree (Ui) should be calculated. Si, Ui are calculated using equations (24,25). The calculated Si, Ui for all the materials are represented in Table 11. The ranking order would be determined using Equations (26). The ranking order is determined using data from Table 11, the equations are applied to the data, and the final output is represented in Table 11. As per Table 11, the optimal material for dental implantation is Ti-6Al-4V.

TABLE 10. WEIGHTED MATRIX FROM ARAS

Criteria	EM	UTS	YS	EL	DE	CO
Ti-35A	0.002	0.011	0.012	0.008	0.000	0.049
Ti-50A	0.002	0.016	0.019	0.010	0.000	0.053
Ti-65A	0.002	0.021	0.026	0.011	0.000	0.049
Ti-75A	0.002	0.025	0.033	0.013	0.000	0.045
Ti-64	0.002	0.043	0.059	0.019	0.000	0.022
Ti-6/7	0.002	0.041	0.060	0.019	0.000	0.018
TNTZ	0.001	0.042	0.059	0.014	0.000	0.015
Weights	0.0131	0.2419	0.3275	0.1128	0.0001	0.3045
optimal value	0.0018	0.0428	0.0600	0.0191	0.0000	0.0530

TABLE 11. RANKING FROM ARAS

Criteria	Si	Ki	Rank
Ti-35A	0.0812	0.4591	7
Ti-50A	0.0988	0.5590	6
Ti-65A	0.1078	0.6099	5
Ti-75A	0.1181	0.6681	4
Ti-64	0.1450	0.8200	1
Ti-6/7	0.1406	0.7952	2
TNTZ	0.1318	0.7455	3
optimal value	0.1768		

III. RESULT AND DISCUSSION

Table 12 shows the rankings of all the alternative materials derived using the three preference ranking methods. Spearman's rank correlation coefficients between the rankings obtained using different methods. It is found that the Spearman's rank correlation coefficients between the rankings are reasonable, and the coefficient between ARAS and CODAS is higher than those of other pairs. Different coefficients have been obtained in the literature depending on the rankings obtained with the methods. The coefficient ARAS and CODAS methods was obtained as 1 in our study. Chatterjee and Chakraborty [22] obtained this value as 1.00 with a perfect correlation. The correlation coefficient value (0.96 in our study) for TOPSIS methods was obtained as 0.83. It can be concluded that the correlations acquired between these methods are generally in acceptable range. Accuracy of calculations is measured according to proposed algorithm; the higher ranking accuracy can be reached when aggregating the both particular methods in comparison with accuracy of Entropy weight.

TABLE 12 RANKINGS

Method	Material Ranks					
	Ti-35A	Ti-50A	Ti-65A	Ti-75A	Ti-64	Ti-6/7	TNTZ
CODAS	7	5	6	4	1	2	3
TOPSIS	7	6	5	3	1	2	4
ARAS	7	6	5	4	1	2	3

In this article the effectiveness of the number of criteria in the ranking performance of CODAS, TOPSIS, and ARAS methods is represented by seven Titanium material selection for dental applications areas. Consequently, the choosing of the best and worst materials depends solely upon the most relevant parameter for the highest priority weight. Dental implant designers will now be able to focus on defining the most relevant criteria dictating the whole selection process rather than designing detailed material selection decision matrices. A significant position can also be given to the methods using which parameters weights are calculated. This statistical approach significantly reduces the difficulty of the decision-making process, as the right material can now be selected on the basis of a single criteria. In all three methods the ranking of the material is found to outperform MCDM approaches.

1. A comprehensive study has been performed on the chosen seven distinct materials, using entropy approaches in conjunction with hybrid multi-criteria procedures and ranking was obtained. Ti-6Al-4V was assessed to be the optimal material for dental implants, Ti-6Al-7Nb was found to be the second most effective material.
2. Finally, the CODAS, TOPSIS, and ARAS approaches were compared using Spearman rank order correlation coefficients, and the results indicate a strong and positive correlation between these three approaches. As a result, MCDM approaches are an effective tool for resolving complex material selection challenges for dental restorations as well as other medical surgical components.

FUTURE SCOPE

It may be the scope for future scholars to explore the validation of the relevant result of this report for other decision-making issues.

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