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Biocompatible Material Selection and Sensitivity Analysis for Femoral Component using Entropy based MCDM Methods: A Comparative Approach

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Abstract: *In recent years, the world creating more and more global marketplaces, advanced technologies and efficient workers in medical sector. This global environment is forcing health organizations to accept almost everything into consideration at the same time. Increase flexibility is needed to remain competitive and respond to rapidly changing health sector. An effective material selection process is very important to the success of any operation. Biomaterials are used to perform the functions with living tissues in the body. Biomaterials are in contact with fluids continuously or for a certain period. The body's reactions are varying differently to these materials. Due to this, the proper biomaterial selection is essential. The efficiency, longevity and cost-effective design comes through proper material selection. To avoid the fatigue failure, a body system needs a suitable design considering mechanical properties. Due to the entropy process and sensitivity analysis, the results are more accurate as well as the design process is smooth. The methodology of Simple Additive Weighting (SAW), Multi Objective Optimization Ratio Analysis (MOORA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are implemented first time and comparative analysis is to determine the best material for better product development.*

Key Words: *Biocompatibility; Material Selection; MCDM; MOORA; SAW; TOPSIS; Orthopaedic; Health sector.*

1. INTRODUCTION:

The femur bone [Fig:1] is also known as thigh bone. It is the longest and strongest bone in human body. It helps to stand and move in our body. This bone also supports important muscles, tendons, ligaments and circulatory system. It also helps to keep our balance. Femur bone only break from serious trauma like car accident, fall. Femur is also affected by osteoporosis.

If femur shaft fracture occurs, mainly surgical treatment needed. Sometimes very young children are treated with a cast. Mainly femur fractures are fixed within 24 to 48 hrs. two type of surgical procedure seen- external fixation and intra medullary nailing.

- External fixation: metal pins and screws are placed into the bone above and below the fracture site. Pins and screws are attached to bar outside the skin. This device holds the bones in the proper position. It is the temporary procedure for femur fracture.
- Intra medullary nailing: most surgeons used this method for treating femoral shaft fracture. In this procedure a specially designed metal road is inserted into the femur canal. Screws are placed above and below the fracture to hold the leg in correct alignment. these nails are usually made of titanium.

Fig:1: Femur Bone

This research ventures one of the major concerns in the field of strategy to select suitable material for femoral component of knee prosthesis based on a entropy method, namely SAW, MOORA, TOPSIS, in order to improve the longevity and quality of human life.

In this article, a novel MCDM methods have been used for orthopaedists/practitioners, and prosthesis and implant manufacturers. This project addresses modelling an automated selection methodology for orthopaedic research.

2. LITERATURE REVIEW :

In this section, the material selection methodologies are reviewed for replacing the existing material to select a right candidate material of Femoral component system of health sector, the selection of material methodologies presented in this article contains important selection attributes and its applications

- ✓ Bahraminasab M, Sahari B, Edwards K, Farahmand F, Jahan A, Hong T S and Arumugam M (2014): work on the influence of shape and material used for the femoral component pegs in knee prostheses for reducing the problem of aseptic loosening.
- ✓ Kabir G and Lizu A (2016) proposed that material selection for femoral component of total knee replacement integrating fuzzy AHP with PROMETHEE.
- ✓ Bahraminasab M and Jahan A (2011) researched on Material selection for femoral component of total knee replacement using comprehensive VIKOR.
- ✓ MEHMET ALPER SOFUOG˘ LU (2020) proposed on A new biomaterial selection approach using reference ideal method

3. METHODOLOGY :

3.1 Multi Criteria Decision Making (MCDM)

Considering multiple conflicting criteria, selecting the best path from a set of feasible alternatives known as Multiple criteria decision making (MCDM). This process always goes through at least two alternatives and two conflicting criteria. MCDM are divided two broad categories: Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). Several useful tools for solving of MCDM problems are

- ➢ Simple Additive Weighting method (SAW)
- ➢ Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
- ➢ Multi Objective Optimization Ratio Analysis (MOORA)
- ➢ Analytical Hierarchy Method (AHP)
- ➢ Analytical Network Method ANP etc.

3.2 Entropy Method

Entropy was originally a thermodynamic concept, first introduced into information theory by Shannon. It has been widely used in the engineering, socioeconomic and other fields. According to the basic principles of information theory, information is a measure of system’s ordered degree, and the entropy is a measure of system’s disorder degree [Table 2].

3.3 Sensitivity Analysis

In actual situation decision-making is rather dynamic not static process. Changing with environment it varies in the continuously. In reality the value of decision-making attitude depends upon decision maker’s personal choice but now a days the artificial intelligence remove the personal biases. Keeping it in mind, the proposed model for the selection of femur material has been enhanced by sensitivity analysis [Fig:4,6] to provide a readymade solution of the current problem under variable decision-making attitude[Table:6,12].The governing equation of the material measure (AM) is given by

$$AM_i = \alpha(OFM_i - SFM_i) + SFM_i$$

where, i = 1, 2…m.

OFM_i = Objective factor measure for the alternative i

SFM_i = Subjective factor measure for the alternative i

α = Objective factor decision weight/Coefficient of attitude

3.4 The Flowchart of the Proposed Methods

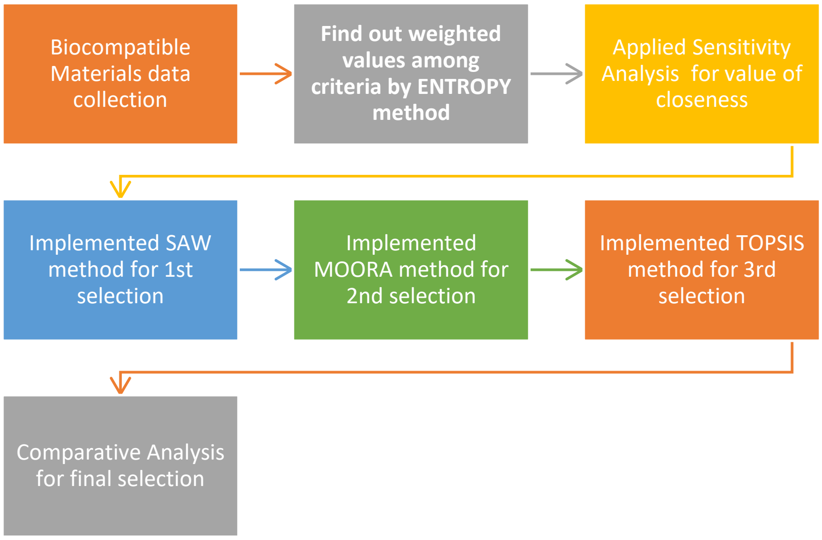


Fig: 2 Flowchart of Methodology

4. MATERIAL:

The selection of femoral component for total knee replacement in health sector considering technical, economic and supply aspects. The paper involves identification of different material [Table:1] that are used in the manufacturing of bio-material and to give a best result. Ten materials with five important properties are considered. The decision maker has to compare all the materials regarding each aspect and has to judge the best one, and this is difficult decision-making problem. So, these MCDM methods is applied to select optimal material in this section.

	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	896	20	0.745	0.865	0.665
M2 Co–Cr alloys (castable Co–Cr–Mo)	655	20	0.745	0.865	0.665
M3 NiTi SMA	1240	12	0.955	0.955	0.5
M4 Porous NiTi SMA	1000	12	0.745	0.955	0.955
M5 Ti alloys (pure Ti)	550	54	0.955	0.59	0.745
M6	985	12	0.955	0.665	0.745

Ti6Al4V					
M7 SS L316 (cold worked)	862	12	0.665	0.745	0.59
M8 SS L316 (annealed)	517	40	0.665	0.59	0.59
M9 Ti–6Al–7Nb (IMI-367 wrought)	900	10	0.955	0.665	0.745
M10 Ti–6Al–7Nb (Protasul-100 hot forged)	1050	12.5	0.955	0.665	0.745

Table 1: Femur component material selection matrix [8]

5. RESEARCH GAP:

Selection and proper decision making brings success in any operation. When a problem arise for total knee replacement then proper decision approach is needed for human body system. Maximum biomaterial industry is spent their money to developed an efficient decision-making system. This paper is projected to improve this system in normal and emergency environment. According to literature review, biomaterial selection of femoral component in medical industry some piecemeal work has been done. Comparative analysis by various MCDM methods on Material selection process and Sensitivity analysis are implemented first to know the best material as well as the value of closeness.

6. PROBLEM FORMULATION :

In medical sector, biomaterials are made of stainless Steel and other materials. Among these five criteria [C]- Tensile strength, Corrosion resistance, Wear resistance and Osseointegration are beneficiary and rest of criteria are non-beneficiary. Find out the optimum result among alternatives[M] are difficult task. In the matter of total knee replacement, the proper material selection is challenging task to a decision maker. This paper involved to find out the best result among the alternatives considering criteria.

7. EXPERIMENT AND RESULT:

7.1 The weighted values from entropy method

	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
weighted values	0.2247	0.0844	0.2667	0.1628	0.2614

Table 2:

7.2 In the SAW method

The weighted values got from entropy method

STEP1: Determination of normalized decision matrix

Material	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	0.7226	0.3704	0.7801	0.9058	0.7519
M2 Co–Cr alloys (castable Co–Cr–Mo)	0.5282	0.3704	0.7801	0.9058	0.7519
M3 NiTi SMA	1.0000	0.2222	1.0000	1.0000	1.0000

M4 **Porous NiTi SMA**	0.8065	0.2222	0.7801	1.0000	0.5236
M5 **Ti alloys (pure Ti)**	0.4435	1.0000	1.0000	0.6178	0.6711
M6 **Ti6Al4V**	0.7944	0.2222	1.0000	0.6963	0.6711
M7 **SS L316 (cold worked)**	0.6952	0.2222	0.6963	0.7801	0.8475
M8 **SS L316 (annealed)**	0.4169	0.7407	0.6963	0.6178	0.8475
M9 **Ti–6Al–7Nb (IMI-367 wrought)**	0.7258	0.1852	1.0000	0.6963	0.6711
M10 **Ti–6Al–7Nb (Protasul-100 hot forged)**	0.8468	0.2315	1.0000	0.6963	0.6711

Table 3:

STEP 2: Determination of weighted normalized decision matrix

Material	**C1 Tensile strength (MPa)**	**C2 Elongation**	**C3 Corrosion resistance**	**C4 Wear resistance**	**C5 Osseointegration**
M1 **Co–Cr alloys (wrought Co–Ni–Cr–Mo)**	0.1624	0.0313	0.2080	0.1474	0.1965
M2 **Co–Cr alloys (castable Co–Cr–Mo)**	0.1187	0.0313	0.2080	0.1474	0.1965
M3 **NiTi SMA**	0.2247	0.0188	0.2667	0.1628	0.2614
M4 **Porous NiTi SMA**	0.1812	0.0188	0.2080	0.1628	0.1369
M5 **Ti alloys (pure Ti)**	0.0997	0.0844	0.2667	0.1006	0.1754
M6 **Ti6Al4V**	0.1785	0.0188	0.2667	0.1134	0.1754
M7 **SS L316 (cold worked)**	0.1562	0.0188	0.1857	0.1270	0.2215
M8 **SS L316 (annealed)**	0.0937	0.0625	0.1857	0.1006	0.2215
M9 **Ti–6Al–7Nb (IMI-367 wrought)**	0.1631	0.0156	0.2667	0.1134	0.1754
M10 **Ti–6Al–7Nb (Protasul-100 hot forged)**	0.1903	0.0195	0.2667	0.1134	0.1754

Table 4:

STEP 3: Computation of composite score s......by sum of all weighted normalized rows
The values of (s) are:

Material	M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	M2 Co–Cr alloys (castable Co–Cr–Mo)	M3 NiTi SMA	M4 Porous NiTi SMA	M5 Ti alloys (pure Ti)	M6 Ti6Al4V	M7 SS L316 (cold worked)	M8 SS L316 (annealed)	M9 Ti–6Al–7Nb (IMI-367 wrought)	M10 Ti–6Al–7Nb (Protasul-100 hot forged)
	0.7457	0.7020	0.9343	0.7077	0.7268	0.7527	0.7092	0.6640	0.7342	0.7653

Table 5:

STEP 4:
Arranging the final value (s) in descending order: --------->>> M3 > M10 > M6 > M1 > M9 > M5> M7> M4> M2> M8....in SAW method

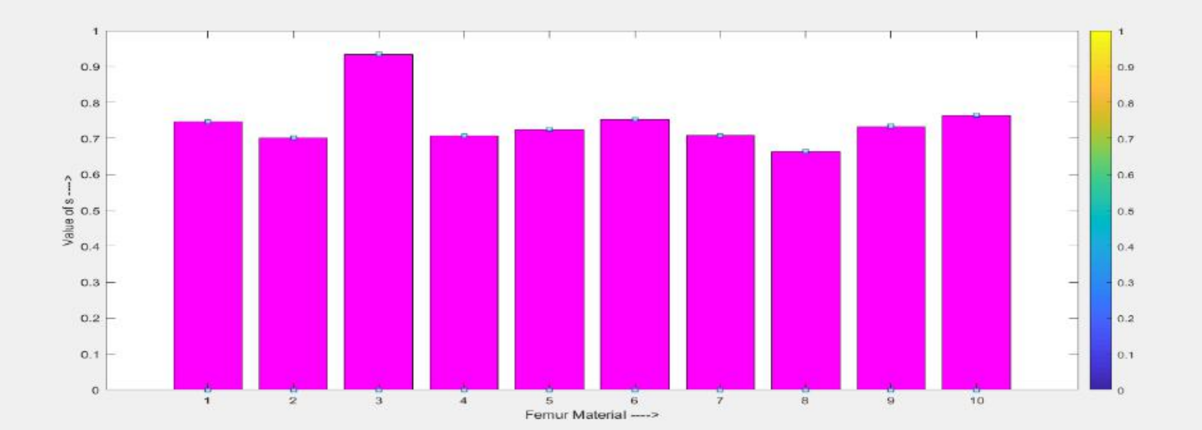
>> 

Fig:3

7.2.1 Sensitivity Analysis:

The value of closeness co-efficient in SAW method

Material	when alpha=0	when alpha=1
M1	0.1965	0.5491
M2	0.1965	0.5054
M3	0.2614	0.6729
M4	0.1369	0.5708
M5	0.1754	0.5513
M6	0.1754	0.5773
M7	0.2215	0.4876
M8	0.2215	0.4425
M9	0.1754	0.5587
M10	0.1754	0.5898

Table 6:

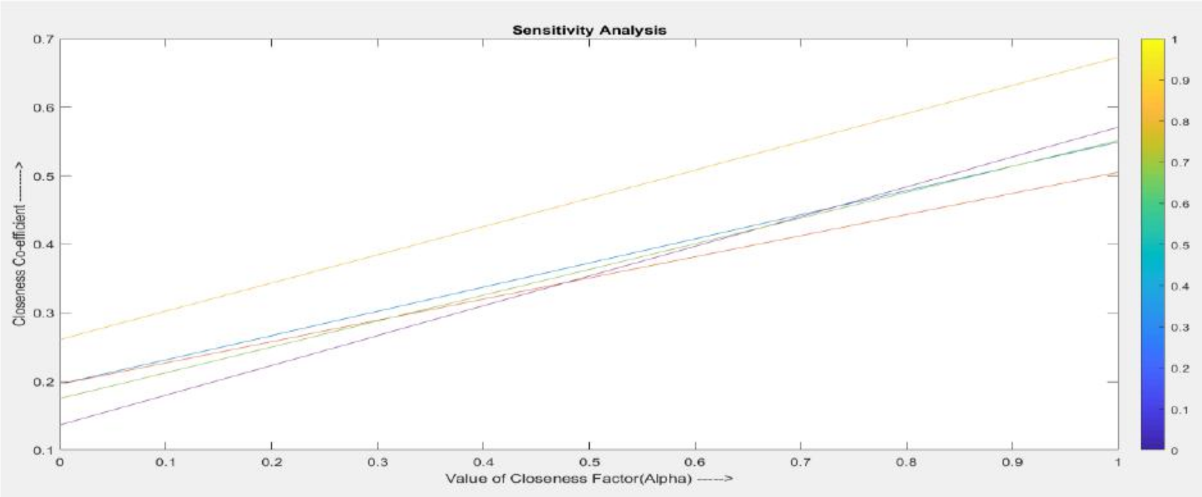


Fig:4

7.3 In the MOORA method

The weighted values got from entropy method

STEP 1 Determination of normalized decision matrix

Material	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	0.3175	0.2551	0.2794	0.3562	0.2985
M2 Co–Cr alloys (castable Co–Cr–Mo)	0.2321	0.2551	0.2794	0.3562	0.2985
M3 NiTi SMA	0.4394	0.1530	0.3582	0.3932	0.2244
M4 Porous NiTi SMA	0.3543	0.1530	0.2794	0.3932	0.4287
M5 Ti alloys (pure Ti)	0.1949	0.6887	0.3582	0.2429	0.3344
M6 Ti6Al4V	0.3490	0.1530	0.3582	0.2738	0.3344
M7 SS L316 (cold worked)	0.3054	0.1530	0.2494	0.3068	0.2648
M8 SS L316 (annealed)	0.1832	0.5101	0.2494	0.2429	0.2648
M9 Ti–6Al–7Nb (IMI-367 wrought)	0.3189	0.1275	0.3582	0.2738	0.3344
M10 Ti–6Al–7Nb (Protasul-100 hot forged)	0.3720	0.1594	0.3582	0.2738	0.3344

Table 7:

STEP 2: Determination of weighted normalized decision matrix

Material	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	0.0713	0.0215	0.0745	0.0580	0.0780
M2 Co–Cr alloys (castable Co–Cr–Mo)	0.0522	0.0215	0.0745	0.0580	0.0780
M3 NiTi SMA	0.0987	0.0129	0.0955	0.0640	0.0587
M4 Porous NiTi SMA	0.0796	0.0129	0.0745	0.0640	0.1121
M5 Ti alloys (pure Ti)	0.0438	0.0581	0.0955	0.0395	0.0874
M6 Ti6Al4V	0.0784	0.0129	0.0955	0.0446	0.0874
M7 SS L316 (cold worked)	0.0686	0.0129	0.0665	0.0499	0.0692
M8 SS L316 (annealed)	0.0412	0.0431	0.0665	0.0395	0.0692
M9 Ti–6Al–7Nb (IMI-367 wrought)	0.0717	0.0108	0.0955	0.0446	0.0874
M10 Ti–6Al–7Nb (Protasul-100 hot forged)	0.0836	0.0135	0.0955	0.0446	0.0874

Table 8

STEP 3: Determination of weighted multi objective optimization
the value of a ......sum of all weighted normalized values for all beneficial column

Material	M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	M2 Co–Cr alloys (castable Co–Cr–Mo)	M3 NiTi SMA	M4 Porous NiTi SMA	M5 Ti alloys (pure Ti)	M6 Ti6Al4V	M7 SS L316 (cold worked)	M8 SS L316 (annealed)	M9 Ti–6Al–7Nb (IMI-367 wrought)	M10 Ti–6Al–7Nb (Protasul-100 hot forged)
	0.2254	0.2062	0.2712	0.2311	0.2370	0.2314	0.1980	0.1903	0.2225	0.2371

Table 9:

the value of b ......sum of all weighted normalized values for all non-beneficial column

Material	M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	M2 Co–Cr alloys (castable Co–Cr–Mo)	M3 NiTi SMA	M4 Porous NiTi SMA	M5 Ti alloys (pure Ti)	M6 Ti6Al4V	M7 SS L316 (cold worked)	M8 SS L316 (annealed)	M9 Ti–6Al–7Nb (IMI-367 wrought)	M10 Ti–6Al–7Nb (Protasul-100 hot forged)
	0.0780	0.0780	0.0587	0.1121	0.0874	0.0874	0.0692	0.0692	0.0874	0.0874

Table 10:

STEP 4: the value of a-b

Material	M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	M2 Co–Cr alloys (castable Co–Cr–Mo)	M3 NiTi SMA	M4 Porous NiTi SMA	M5 Ti alloys (pure Ti)	M6 Ti6Al4V	M7 SS L316 (cold worked)	M8 SS L316 (annealed)	M9 Ti–6Al–7Nb (IMI-367 wrought)	M10 Ti–6Al–7Nb (Protasul-100 hot forged)
	0.1473	0.1281	0.2125	0.1190	0.1496	0.1440	0.1288	0.1211	0.1351	0.1497

Table 11:

STEP 5:
Arranging the final value in descending order: --------->>> M3 > M10 > M5 > M1 > M6 > M9> M7 > M2 > M8 > M4

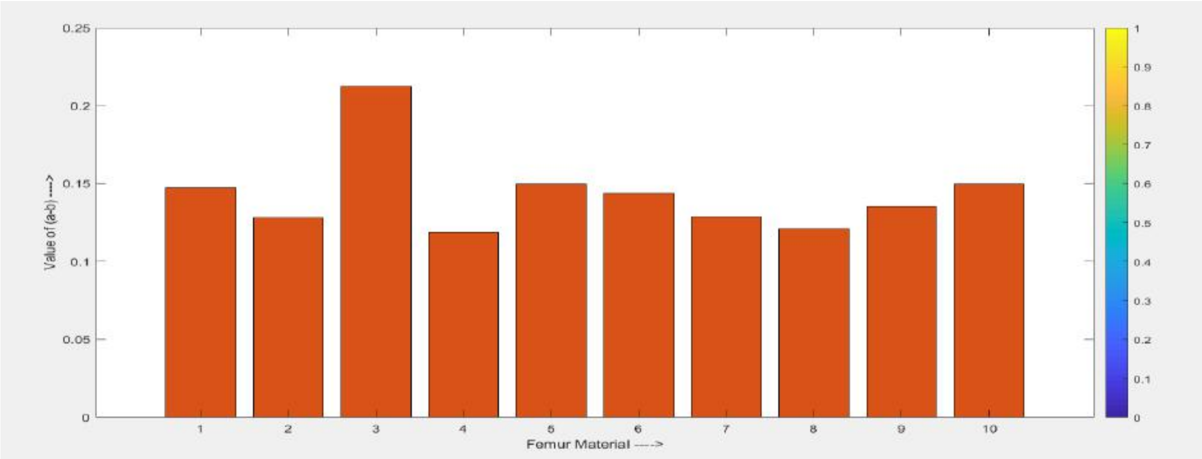


Fig:5

7.3.1 Sensitivity Analysis:

The value of closeness co-efficient in MOORA method

Material	when alpha=0	when alpha=1
M1	-0.0780	0.2254
M2	-0.0780	0.2062
M3	-0.0587	0.2712
M4	-0.1121	0.2311
M5	-0.0874	0.2370
M6	-0.0874	0.2314
M7	-0.0692	0.1980
M8	-0.0692	0.1903
M9	-0.0874	0.2225
M10	-0.0874	0.2371

Table 12:

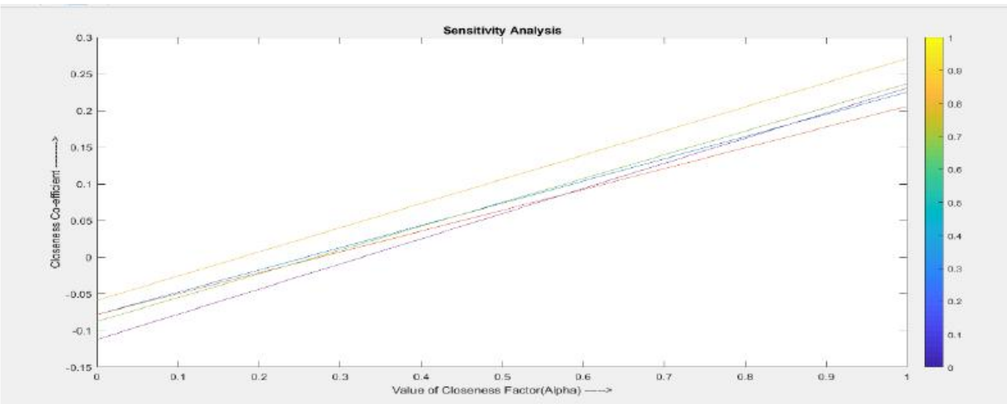


Fig:6

7.4 In the TOPSIS method

The weighted values got from entropy method

STEP1: Determination of normalized decision matrix

Material	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)	0.7226	0.3704	0.7801	0.9058	0.7519
M2 Co–Cr alloys (castable Co–Cr–Mo)	0.5282	0.3704	0.7801	0.9058	0.7519
M3 NiTi SMA	1.0000	0.2222	1.0000	1.0000	1.0000
M4 Porous NiTi SMA	0.8065	0.2222	0.7801	1.0000	0.5236
M5 Ti alloys (pure Ti)	0.4435	1.0000	1.0000	0.6178	0.6711
M6 Ti6Al4V	0.7944	0.2222	1.0000	0.6963	0.6711
M7 SS L316 (cold worked)	0.6952	0.2222	0.6963	0.7801	0.8475
M8 SS L316 (annealed)	0.4169	0.7407	0.6963	0.6178	0.8475
M9 Ti–6Al–7Nb (IMI-367 wrought)	0.7258	0.1852	1.0000	0.6963	0.6711
M10 Ti–6Al–7Nb (Protasul-100 hot forged)	0.8468	0.2315	1.0000	0.6963	0.6711

Table 13:

STEP 2:

Determination of positive ideal solution: taking the maximum values of each column from the normalized decision matrix

Criteria	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
	1	1	1	1	1

Table 14:

Determination of negative ideal solution: taking the minimum values of each column from the normalized decision matrix

Criteria	C1 Tensile strength (MPa)	C2 Elongation	C3 Corrosion resistance	C4 Wear resistance	C5 Osseointegration
	0.4169	0.1852	0.6963	0.6178	0.5236

Table 15:

STEP 3:
Calculation of the separation measure from the positive ideal solution(di_Plus)

Material	**M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)**	**M2 Co–Cr alloys (castable Co–Cr–Mo)**	**M3 NiTi SMA**	**M4 Porous NiTi SMA**	**M5 Ti alloys (pure Ti)**	**M6 Ti6Al4V**	**M7 SS L316 (cold worked)**	**M8 SS L316 (annealed)**	**M9 Ti–6Al–7Nb (IMI-367 wrought)**	**M10 Ti–6Al–7Nb (Protasul-100 hot forged)**
	0.2850	0.3375	0.2260	0.3629	0.3488	0.3223	0.3324	0.3695	0.3409	0.3137

Table 16:

Calculation of the seperation measure from the negetive ideal solution(di_Minus)

Material	**M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)**	**M2 Co–Cr alloys (castable Co–Cr–Mo)**	**M3 NiTi SMA**	**M4 Porous NiTi SMA**	**M5 Ti alloys (pure Ti)**	**M6 Ti6Al4V**	**M7 SS L316 (cold worked)**	**M8 SS L316 (annealed)**	**M9 Ti–6Al–7Nb (IMI-367 wrought)**	**M10 Ti–6Al–7Nb (Protasul-100 hot forged)**
	0.2300	0.1862	0.4292	0.2447	0.2941	0.2518	0.2219	0.2313	0.2296	0.2702

Table 17:

STEP 3: Calculation of R_i

Material	**M1 Co–Cr alloys (wrought Co–Ni–Cr–Mo)**	**M2 Co–Cr alloys (castable Co–Cr–Mo)**	**M3 NiTi SMA**	**M4 Porous NiTi SMA**	**M5 Ti alloys (pure Ti)**	**M6 Ti6Al4V**	**M7 SS L316 (cold worked)**	**M8 SS L316 (annealed)**	**M9 Ti–6Al–7Nb (IMI-367 wrought)**	**M10 Ti–6Al–7Nb (Protasul-100 hot forged)**
	0.4466	0.3556	0.6551	0.4027	0.4575	0.4386	0.4003	0.3850	0.4025	0.4627

Table 18:

STEP 4:
Arranging the final value in descending order: --------->>> M3 > M10 > M5 > M1 > M6 >M4 > M9> M7 > M8 > M2

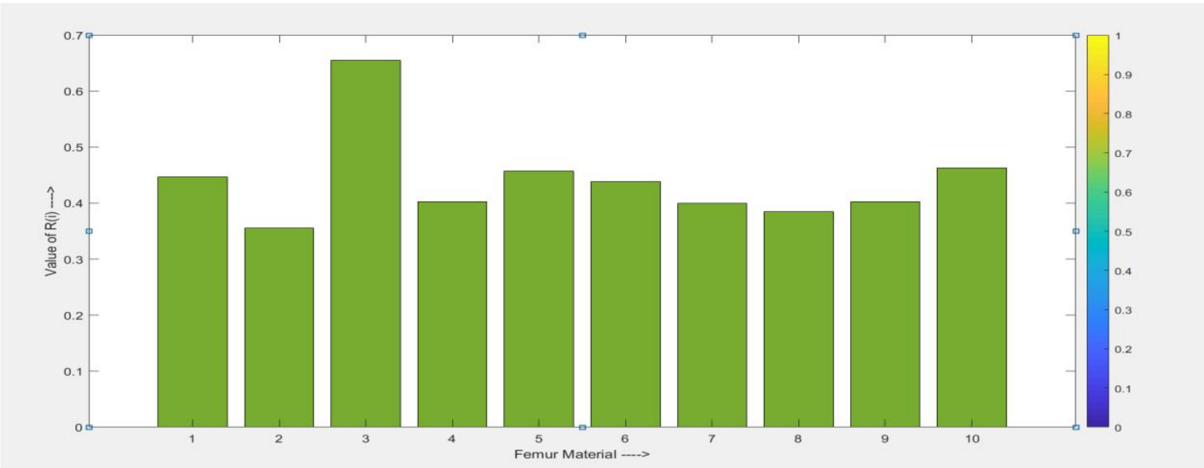


Fig:7

7.5 Comparative Analysis of MCDM Methods:

MATERIAL	SAW (RANK)	MOORA (RANK)	TOPSIS (RANK)
(M1)	4	4	4
(M2)	9	8	10
(M3)	1	1	1
(M4)	8	10	6
(M5)	6	3	3
(M6)	3	5	5
(M7)	7	7	8
(M8)	10	9	9
(M9)	5	6	7
(M10)	2	2	2

Table 19

8. DISCUSSION :

From the result, we see that for the three different processes of MCDM, the result is same. The ranking of first two choices is same for those different processes. In SAW, MOORA and TOPSIS methods, ranks of alternatives are given in descending order of their respective composite score. So, the ranking of alternatives of materials are as follows: NiTi SMA(M3) > Ti–6Al–7Nb (M10) It means that Material 3 and Material 10 are the best as it maximizes the benefit criteria respectively.

We have also made the sensitivity analysis with graphical representation in which we see that in SAW and MOORA methods. From the sensitivity analysis graph, we also get the rank of the lathes for any alpha value by drawing a vertical line from that alpha value to the straight line of the lathe in the graph. That's why for doing the sensitivity analysis our result does not depends any different decision makers with their different weighted values.

9. CONCLUSIONS :

It is quite clear that the use of SAW, MOORA and TOPSIS methods are observed to be quite capable and computationally easy to evaluate and select the proper femoral component from a given set of alternatives. These methods use the measures of the considered criteria with their relative importance in order to arrive at the final ranking of the alternative material. Thus, these popular MCDM methods can be successfully employed for solving knee replacement biomaterial selection decision-making problems having any number of criteria and alternatives in the manufacturing domain.

As a future scope, a fuzzy TOPSIS, fuzzy SAW, fuzzy MOORA based methodology may be developed to aid the decision makers to take decisions in health sector. The proposed future research work is planned into different stages: Objective setup, analysis of parameter and design of experiments, experimentation and validation of results, alternative solution search. In second phase the project research can be taken to the next level by designing in CATIA and finding the stress analysis by ANSYS and implementation of Finite Element Analysis (FEA) and henceforth comparing the life cycles. Application of software like Delcam would convert this theoretical approach to the final product, which in turn, would be of great help in medical sector.

DECLARATION BY AUTHORS

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