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A study on Analysing the Selection of Materials for Knee Implant Femoral Component using TOPSIS method

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Abstract: *Specialists are creating more sophisticated and useful materials daily as technology advances. For orthopaedic implants such as "knee replacements, hip replacements, and orthopaedic accessories", biomaterials are employed to produce prosthetic organs. In patients with severe osteoarthritis (OA) of the knee, "total knee replacement (TKR)" is one of the most successful surgical procedures for pain management and functioning rehabilitation. Humans continue to experience issues with the kneecap, such as aseptic dislocation brought on by excessive wear across articular surfaces, stress-shielding of the bone by prostheses, and soft tissue formation at the junction of implanted bone. due to improper "TKR material selection". Since selecting the best materials for the femoral component of TKR requires careful consideration, the "technique for order of preference by similarity to ideal solution (TOPSIS)" is used in this research paper. This technique uses an order of preference based on how closely the preferred option is to the ideal solution. The "equal weights method (EWM)" assigns various criteria distinct weights of importance. The rank of alternatives using the TOPSIS method for "Co-Cr-Mo is fourth, Co-Ni-Cr-Mo is third, NiTi SMA is first, Porous NiTi SMA is second, pure Ti is sixth and Ti-5Al-2.5Fe is fifth". The result indicated that FC material using TKR Nickel Titanium Shape Memory Alloy (NiTi SMA) is at rank 1 with properties such as Tensile Strength 960 MPa, Density 6.45 g/cc, extremely high Corrosion resistance, and exceptionally high Wear resistance.*

Keywords: *Total Knee Replacement, Biomaterials, Tensile Strength, Corrosion Resistance, Wear Resistance And MCDM.*

1. INTRODUCTION

The most prevalent joint condition and the main cause of disability worldwide is knee osteoarthritis (OA). This illness typically worsens gradually over years. However, the condition advances quickly in many subjects (knees). Recent investigations showed that the incidence of "accelerated knee OA" ranged from 0.4% to 22.1% in a population without radiological knee OA [1, 2]. Especially in comparison to knees with a more progressive beginning or without accelerating knee OA, those with accelerating OA had a greater likelihood of having a "total knee replacement (TKR)" [3].Contrary to this sharp increase in TKR surgeries, LOS rates following TKR surgery are decreasing. Evidence currently shows that factors including the utilisation of clinical pathways, developments in blood control, multimodal analgesia, and prompt ambulation can all influence this decline in hospital "length of stay (LOS)" following TKR [4].It is crucial to look at early post-operative inpatient workout therapies because of the reduction in length of stay and attention on ambulation as soon as feasible after surgery. The focus of this analysis is supervised exercise treatment delivered by a physiotherapist in an acute in-patient environment, which can be divided into passive treatments such as "cold therapy, compression, or continuous passive motion" [5].Preparing patients for release following surgery is one goal of early postoperative physical therapy after TKR. Shorter hospital stays have led to an increase in the focus of inpatient physical therapy on early and secure mobility, with hastened rehabilitation pathways emerging as the gold treatment standard [6].Only "gait rehabilitation and exercise medication" are widely used when it comes to the sort of active inpatient therapy that is prescribed, as well as its duration and frequency, between establishments and individual therapists. This variant may produce fewer desirable results at a higher cost [7].Physicians are aware of the potential risks for problems following TKR, and techniques to estimate a patient's risk are widely accessible. There is proof that doctors are restricting patients with some of these risk factors access to TKR since the imposition of "bundled payments (post-policy)". There is also proof that hospitals may have "adjusted the profile of patients [undergoing TKR] towards relatively healthier individuals" during the early, non-mandatory phase of the bundled-payment scheme [8,9].The best biomaterial must be used for TKR implantation to be successful. " Cobalt-chromium (Co-Cr), SS 316L, NiTi alloy, and titanium (Ti) and its alloy"s are the most often utilised biomaterials. These materials are all diverse in their qualities [10]. Co-Cr-Mo, Co-Ni-Cr-Mo, NiTi SMA, Porous NiTi SMA, pure Ti, and Ti-5Al-2.5Fe are used as alternate materials for

TKR. "Tensile Strength (MPa), Corrosion resistance, Wear resistance, Cost and Density" are used to select the best biomaterial for TKR.

2. MATERIALS AND METHODS

"TOPSIS" is an appraisal technique that is frequently applied to MCDM issues. It has a variety of practical uses, including comparing business performance, analyzing comparative financial effectiveness within a certain industry, and investing money in modern manufacturing processes, among others. But there are certain restrictions as well [11]. The "TOPSIS method" does, however, have some drawbacks. One of the difficulties that TOPSIS poses is the possibility of the phenomenon known as rank reversal. This occurrence results in a change in the "order of preference for the alternatives" when an option is introduced to or withdrawn from the decision problem [12]. "Total rank reversal", where the order of priorities is fully inverted and the choice that was previously judged to be the greatest now has become the poorest, can occasionally occur when an option is introduced to or excluded from the procedure. Such a phenomenon might not be desirable in many situations [13,14].In "MCDM", a range of alternatives must be looked at and assessed depending on several factors. The goal of MCDM is to help the decision-maker choose from a variety of options. As a result, practical problems are typically described by a variety of conflicting criteria, and no solution will probably be able to fulfil all of the criteria at once. The solution is thus a compromise choice depending on the decision preferences. maker's Thus, TOPSIS is based on the principle that the best outcome should be the one that is most dissimilar from "the Negative Ideal Solution (NIS) and most similar to the Positive Ideal Solution (PIS)". The final ranking is calculated using the closeness measure [15,16].

Step 1: The decision matrix X, which displays "how various options perform concerning certain criteria", is created.

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2: Weights for the criteria are expressed as

$$w_j = [w_1 \cdots w_n], \quad where, \sum_{j=1}^{n}(w_1 \cdots w_n) = 1 \quad (2)$$

Step 3: The matrix x_{ij}'s normalized values are computed as

$$n_{ij} = \frac{x_{ij}}{\sqrt[2]{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

"Weighted normalized matrix N_{ij}" is calculated by the following formula

$$N_{ij} = w_j \times n_{ij} \quad (4)$$

Step 4: We'll start by determining the "ideal best and ideal worst values": Here, we must determine whether the influence is "+" or "-." If a column has a "+" impact, the "ideal best value for that column" is its highest value; if it has a "-" impact, "the ideal worst value is its lowest value".

Step 5: Now we need to find "the difference between each response from the ideal best",

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^+)^2} \quad for\ i \in [1, m]\ and\ j \in [1, n] \quad (5)$$

Step 6: Now we need to find "the difference between each response from the ideal worst",

$$S_i^- = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^-)^2}\ for\ i \in [1, m]\ and\ j \in [1, n] \quad (6)$$

Step 7: Now we need to find "theCloseness coefficient of i_{th} alternative"

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad where, 0 \le CC_i \le 1, i \in [1, m] \quad (7)$$

"The Closeness Coefficient's value" illustrates how superior the alternatives are in comparison. A larger CC_i denotes a "substantially better alternative", whereas a smaller CC_idenotes a "significantly worse alternative".

Co-Cr-Mo, Co-Ni-Cr-Mo, NiTi SMA, Porous NiTi SMA, pure Ti, and Ti-5Al-2.5Fe are used as alternate materials for TKR. "Tensile Strength (MPa), Corrosion resistance, Wear resistance, Cost and Density" are used to select the best biomaterial for TKR.Tensile Strength: Material strength is crucial in a prosthetic knee joint to prevent joint breakage. A difficulty with the bone-implant articulation under stress causes the growth of soft fibrous tissue, which further causes more considerable relative motion. To remove discomfort and other inconveniences, the TKR components may eventually need to be replaced by an artificial organ during revision surgery [17]. Density: For a knee implant, the biological material's weight and density must be equal to those of bone. Therefore, specific strength can usually be used as the primary metric [18]. Corrosion resistance: Due to corrosive bodily fluid, corrosion is a constant worry for metallic biomaterials. Corrosion is the main factor in TKR revision surgery, and it significantly shortens the lifespan of the implants. The metallic ions that the implants often emit are not biocompatible with the human body [19]. Wear resistance: "Higher friction coefficients or reduced wear resistance" are the main contributors to implant movement. Additionally, the biological activity of wear debris produces a plain inflammatory response. All of this could harm the healthy bone supporting the implant itself. Additionally, friction leads to rusting, which is another of the significant problems mentioned previously [20]. Cost: Since the cost of the product relies on its supply, processing, and shipment, this is a crucial consideration when choosing the right material for knee replacement. Due to client affordability considerations, cost combined with material qualities must be taken into account [21].

3. ANALYSIS AND DISCUSSION

TABLE 1. TKR Material Properties

Bio Material	Tensile Strength (MPa)	Corrosion resistance	Wear resistance	Cost	Density(g/cc)
Co-Cr-Mo	655	7	8	74	8.3
Co-Ni-Cr-Mo	896	7	8	103	9.13
NiTi SMA	960	8	9	450	6.45
Porous NiTi SMA	1000	7	9	370	4.3
pure Ti	517	6	5	15	8
Ti-5Al-2.5Fe	862	6	7	31	8

Table 1 shows the performance data of selected TKR Material Properties. In this paper Co-Cr-Mo, Co-Ni-Cr-Mo, NiTi SMA, Porous NiTi SMA, pure Ti, and Ti-5Al-2.5Fe are used as alternate materials for TKR. “Tensile Strength (MPa), Corrosion resistance, Wear resistance, Cost and Density” are used to select the best biomaterial for TKR.

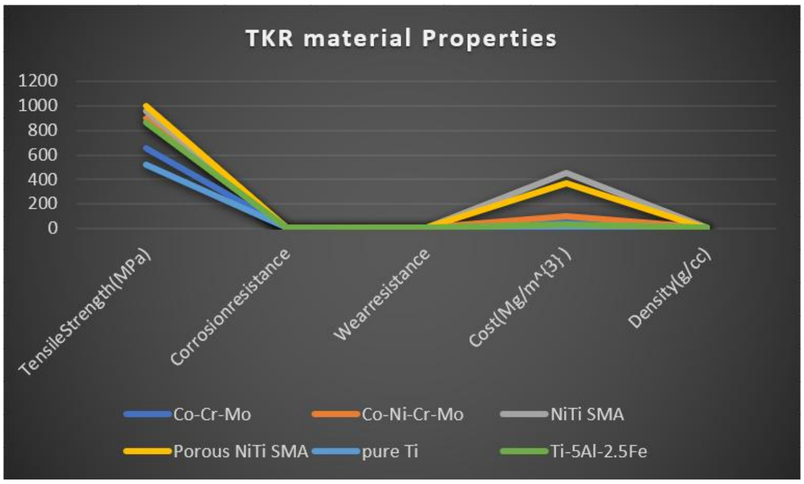

FIGURE 1. TKR Material Properties

Figure 1 shows a graphical view of selected TKR Material Properties. In this paper Co-Cr-Mo, Co-Ni-Cr-Mo, NiTi SMA, Porous NiTi SMA, pure Ti, and Ti-5Al-2.5Fe are used as alternate materials for TKR. “Tensile Strength (MPa), Corrosion resistance, Wear resistance, Cost and Density” are used to select the best biomaterial for TKR.

TABLE 2. Normalized Data

0.3210	0.4161	0.4193	0.1239	0.4499
0.4391	0.4161	0.4193	0.1725	0.4949
0.4705	0.4756	0.4717	0.7535	0.3496
0.4901	0.4161	0.4717	0.6195	0.2331
0.2534	0.3567	0.2621	0.0251	0.4336
0.4224	0.3567	0.3669	0.0519	0.4336

The normalized matrix of the Ratings of the performance of selected TKR materials is displayed in Table 2 above. This matrix was produced using equation three.

TABLE 3. Weight

0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20

The preferred weight for the evaluation parameters is shown in Table 3. In this case, weights are equally distributed among "Tensile Strength (MPa), Corrosion resistance, Wear resistance, Cost and Density". The sum of weights distributed equals one.

TABLE 4. Weighted normalized decision matrix

0.06420	0.08322	0.08386	0.02478	0.08998
0.08782	0.08322	0.08386	0.03449	0.09898
0.09409	0.09511	0.09435	0.15070	0.06993
0.09801	0.08322	0.09435	0.12391	0.04662
0.05067	0.07133	0.05241	0.00502	0.08673
0.08449	0.07133	0.07338	0.01038	0.08673

Table 4 shows the weighted normalized matrix of the decision matrix and it is calculated by table 2 and table 3 using equation 4.

TABLE 5. Positive Matrix

0.0980	0.0951	0.0943	0.1507	0.0990
0.0980	0.0951	0.0943	0.1507	0.0990
0.0980	0.0951	0.0943	0.1507	0.0990
0.0980	0.0951	0.0943	0.1507	0.0990
0.0980	0.0951	0.0943	0.1507	0.0990
0.0980	0.0951	0.0943	0.1507	0.0990

Table 5 shows the positive matrix calculated by using table 4. The ideal best for a column is the maximum value of that column in table 4.

TABLE 6. Negative matrix

0.0507	0.0713	0.0524	0.0050	0.0466
0.0507	0.0713	0.0524	0.0050	0.0466
0.0507	0.0713	0.0524	0.0050	0.0466
0.0507	0.0713	0.0524	0.0050	0.0466
0.0507	0.0713	0.0524	0.0050	0.0466
0.0507	0.0713	0.0524	0.0050	0.0466

Table 6 shows the negative matrix calculated by using table 4. The Ideal best for a column is the minimum value in that column in table 4.

TABLE 7. SI Plus and Si negative

Bio Material	**SI Plus**	**Si Negative**
Co-Cr-Mo	0.13165	0.05987
Co-Ni-Cr-Mo	0.11772	0.07823
NiTi SMA	0.02932	0.16116
Porous NiTi SMA	0.06001	0.13518
pure Ti	0.16105	0.04011
Ti-5Al-2.5Fe	0.14501	0.05675

Table 7 shows the "Si plus and Si negative values". The difference between each response from the "ideal best (S_i^+)" is found utilizing equation 5 and the difference between each response from the "ideal worst (S_i^-)" is found utilizing equation 6.

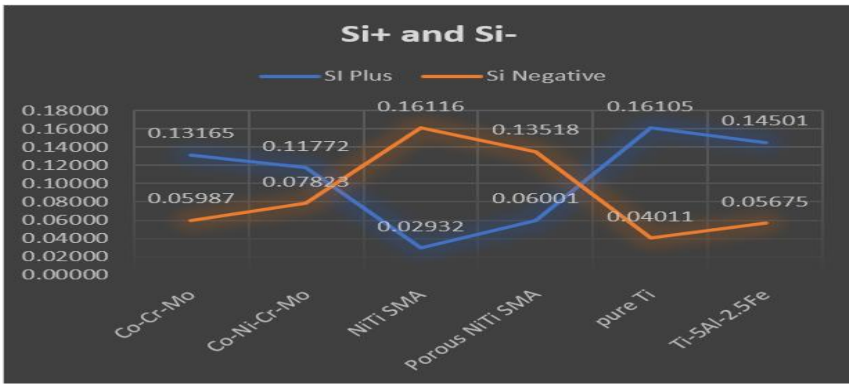

FIGURE 2. SI Plus and Si negative

Figure 2 illustrates the graphical representation of the Si plus and Si negative values. The difference between each response from the “ideal best (S_i^+)” is found utilizing equation 5 and the difference between each response from the “ideal worst (S_i^-)” is found utilizing equation 6.

TABLE 8. Closeness coefficient

Bio Material	Ci
Co-Cr-Mo	0.31260
Co-Ni-Cr-Mo	0.39924
NiTi SMA	0.84609
Porous NiTi SMA	0.69257
pure Ti	0.19941
Ti-5Al-2.5Fe	0.28128

The proximity coefficient values of the alternatives are displayed in Table 8. Equation 7 is employed in the calculation. Here Closeness coefficient value for Co-Cr-Mo is 0.31260, Co-Ni-Cr-Mo is 0.39924, NiTi SMA is 0.84609, Porous NiTi SMA is 0.69257, pure Ti is 0.19941 and Ti-5Al-2.5Fe is 0.28128.

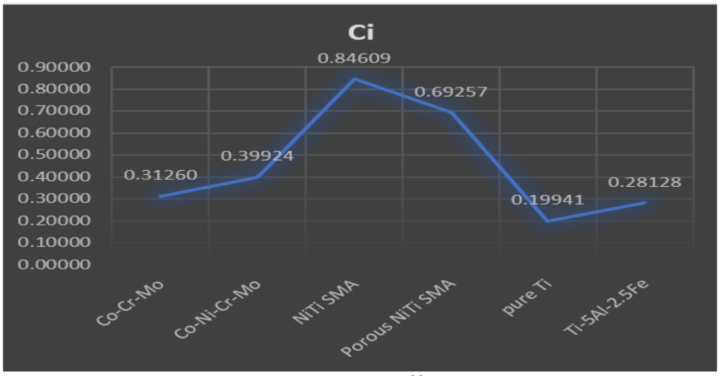

FIGURE 3. Closeness Coefficient (CCi)

Figure 3 illustrates the graphical representation of CCi. It is calculated by using equation 7. Here Closeness coefficient value for Co-Cr-Mo is 0.31260, Co-Ni-Cr-Mo is 0.39924, NiTi SMA is 0.84609, Porous NiTi SMA is 0.69257, pure Ti is 0.19941 and Ti-5Al-2.5Fe is 0.28128.

TABLE 9. Rank

Bio Material	Rank
Co-Cr-Mo	4
Co-Ni-Cr-Mo	3
NiTi SMA	1
Porous NiTi SMA	2
pure Ti	6
Ti-5Al-2.5Fe	5

Table 9 shows the analysis of the selection of biomaterials for TKR. Here rank of Co-Cr-Mo is fourth, Co-Ni-Cr-Mo is third, NiTi SMA is first, Porous NiTi SMA is second, pure Ti is sixth and Ti-5Al-2.5Fe is fifth.

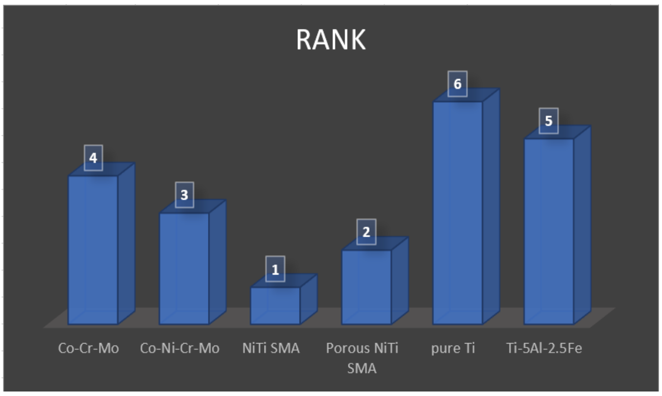

FIGURE 4. Rank

Figure 4 illustrates the ranking of Ui from Table 9. Here rank of alternatives using the TOPSIS method for Co-Cr-Mo is fourth, Co-Ni-Cr-Mo is third, NiTi SMA is first, Porous NiTi SMA is second, pure Ti is sixth and Ti-5Al-2.5Fe is fifth.

The result indicated that FC material using TKR Nickel Titanium Shape Memory Alloy (**NiTi SMA)** is at rank 1 with properties such as Tensile Strength 960 MPa, Density 6.45 g/cc, extremely high Corrosion resistance, and exceptionally high Wear resistance.

4. CONCLUSION

Given the vital biochemical and mechanical demands, biomaterial advancement and decision have become two difficult problems in recent years. " Total knee replacement (TKR)" is one of the most contentious topics in the biomedical field because of the concurrent rise in replacement and revision operations. The most serious concern with surgical repair is aseptic loosening, which is brought on by wear and tear between joint surfaces, prosthetics protecting the bone from stress, and the formation of soft tissue at the implant-bone contact.Applying the best material to the tibial insertion or femoral element can lower the likelihood of implant dislocation and abrasive wear. Additionally, young's modulus of the femoral element on the upper section and the tibial tray on the bottom section of the component that interfaces with the bone is primarily responsible for the "stress shielding effect". The choice of the optimal material for the femoral component of a knee prosthesis for a particular design shape appears to be crucial in preventing the aseptic instability of the artificial joint.Since selecting the best materials for the femoral component of TKR requires careful consideration, the "technique for order of preference by similarity to ideal solution (TOPSIS)" is used in this research paper. This technique uses an order of preference based on how closely the preferred option is to the ideal solution.The result indicated that FC material using TKR Nickel Titanium Shape Memory Alloy (NiTi SMA**)** is at rank 1 with properties such as Tensile Strength 960 MPa, Density 6.45 g/cc, extremely high Corrosion resistance, and exceptionally high Wear resistance.

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