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TOPSIS Method for Selection of the Best Stent Material for Damaged Blood Vessels

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Abstract

An angioplasty medical procedure is the most effective method currently used to treat a blocked coronary artery. It is carried out by trying to insert a mesh-shaped tubular medical device called a stent inside the blocked coronary artery to expand it and allow blood to pass through the damaged blood vessel. The properties of the stent play a significant role in determining its behavior after being implanted in a human body. The Technique for Ordering Performance by Similarity to the Ideal Solution (TOPSIS) was used to choose the best material for a stent. A set of materials that are suitable for the ideal stent's properties has been chosen. These materials have then been contrasted based on a set of criteria including biocompatibility, visibility to x-ray, yield strength, ultimate tensile strength, modulus of elasticity, and ductility. The developed model results show that cobalt-chromium alloy ranks first among the alloys and refractory metals studied based on the considered criteria.

Keywords
TOPSIS, Decision making, Materials selection, Stent and Damaged blood vessel.

1. Introduction
The cardiovascular system is made up of a lot of blood vessels and a heart. The heart's job is to pump blood and oxygen through a system of blood vessels to the various parts of the body (Humphery and McCullosh 2003). Recently, there has been a sharp rise in cardiovascular disease, which has raised the global death rate (Udriște et al 2021). Any deterioration or damage to the coronary arteries or the vessels that branch off of them constitutes cardiovascular disease (CVD) (Gaziano et al 2006). The internal wall of the coronary artery is where fat or lipid substances build up over time, and this accumulation is what causes the vessel blockage (Pan et al 2021). These deposits (fat and lipid substances) combine to form numerous plaques; as the plaque accumulated, the coronary artery's thickness increased, leading to a vascular blockage and restricting blood flow (Pan et al 2021). Numerous factors contributed to the buildup of these plaques in the arteries, including smoking, high cholesterol levels, a sudden rise in blood pressure, an increase in blood sugar levels, recurrent heavy alcohol consumption, a sedentary lifestyle (less physical activity), and a deficiency in fruit consumption (Kerkar 2017). The most effective method currently used in medical procedures to treat a blocked coronary artery is known as angioplasty (Pan et al 2021). This is carried out by trying to insert a mesh-shaped tubular medical device called a stent inside the blocked coronary to expand it and allow blood to pass through the damaged blood vessel (Yoshino and Inoue 2010, Schneider and Dichek 1997). In balloon angioplasty, a small balloon is pressed onto the catheter and inserted through various human arteries after making an incision in the groin, neck, or wrist. This process is repeated until the catheter is delivered to the precise location of the blockage as guided by a special X-ray machine. Once the catheter has reached the proper obstruction, air pressure will inflate the compressed balloon. The plaques in the blocked coronary artery will be compressed as a result, causing blood to flow back through the artery. The balloon will then deflate and be extracted from the artery using the catheter (Kulathilake 2017). When a stent is implanted through the artery, the cells on the internal coronary artery grow toward the stent,

resulting in the stent becoming permanently embedded in the human body (MFMER 2023). Scientists highlighted some of the most popular biomaterials used in ideal stents, including refractory metallic elements and alloys (Udriște et al 2021, Poncin and Proft 2003). In this study, decision-making Technique for Ordering Preference by Similarity to the Ideal Solution (TOPSIS) was used to choose the best material for a stent among a set of materials that are suitable for the ideal stent's properties. This will support physicians and researchers in making well-informed judgments, which aid in improving the clinical outcomes and patient care.

1.1 Objectives

This study aims to develop a comprehensive methodology to choose the best material for stent of damaged blood vessels using TOPSIS decision-making method. Because of the fact that properties of the stent play a significant role in determining its behavior after being implanted in a human body, the proposed model considers all the important criteria that should exist in stent, including biocompatibility, visibility to x-ray, yield strength, ultimate tensile strength, modulus of elasticity, and ductility.

2. Literature Review

The development of stents provides an effective treatment method for damaged blood vessels, as they offer the required mechanical support and make it easier to restore blood flow. The efficiency and durability of these devices are greatly dependent on the stent materials used. Due to their outstanding mechanical and radiopacity properties compared to their polymeric counterparts, metallic stents are more favored clinically. Metals or biodegradable polymers can be used to create bioresorbable stents. However, in order to maintain adequate mechanical properties throughout degradation, a thicker stent is always a requirement for polymer stents (Mani et al. 2007). Additionally, inflammatory reactions are more likely to occur when using biodegradable polymer stents (Su et al. 2005, Van der Giessen et al. 1996).

Metallic stents have been made of alloys based on iron (Fe) and magnesium (Mg) in the last few decades to reduce the mechanical and biological issues with polymers (Moravej and Mantovani 2011). Fe-based stents have excellent mechanical properties and biocompatibility (Peuster et al. 2001). Mg alloys also have some strong mechanical properties and good biocompatibility (Zheng et al. 2014, Zhao and Zhu 2013). However, their rapid deterioration is the major drawback. Zinc (Zn) is a more recent type of biodegradable stent material that is being investigated, but the possible harmful impact on living cells upon the release of Zn in excess is still a major concern (Su et al. 2019, Shearier et al. 2016).

3. Methods

The principle of TOPSIS technique is to select the alternative that has the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. Using this methodology, a poor performance in one criterion can be offset by a good performance in another, which makes it possible to find trade-offs between criteria. Due to the fact that alternative solutions are not excluded based on pre-established thresholds, this modelling approach offers a fairly comprehensive approach. The decision is made using the following steps- (Sanjay et al 2019; Almomani et al 2024):

A-**Building the decision matrix**, (a_{ij})MxN that consists of M alternatives and N criteria.
B-**Calculating the normalized decision matrix**, data normalization is a crucial step in making accurate and understandable comparisons between alternatives (all data are scaled similarly). The normalization of data is conducted using by the following formula:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{1}$$

Where n_{ij} is the normalized value and x_{ij} is the qualification of the alternative.
C- **Calculating the weighted normalized decision matrix**: Each criterion will be given its own weight, the weights may be established in accordance with professional and experts' judgment. Then, the criteria weight is normalized in order for them to all add up to 1. The weighted normalized value is calculated by multiplying each normalized value from the previous step by the corresponding normalized weight according to equation 2:

$$v_{ij} = n_{ij} \text{ x } w_j \tag{2}$$

Where v_{ij} weighted normalized value, w_j is the normalized criterion weight.

D- **Calculation the positive and negative alternative for each criterion**, this will determine the desired level for each criterion, such as the positive solution of yield strength will be minimum, and the negative solution will be maximum. Equations (3) and (4) will be used to determine the ideal positive and ideal negative solution, respectively:

$$A^{+} = \max_{i=1}^{M} V_{ij} \tag{3}$$

$$A^{-} = \min_{i=1}^{M} V_{ij} \tag{4}$$

E-**Computing the separation distance for each alternative from the positive ideal solution and negative** solution using equations (5) and (6) respectively:

$$d_i^{+} = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^{+}\right)^2} \qquad , \text{j} = 1,2,..\text{n} \tag{5}$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^{-}\right)^2} \qquad , \text{j} = 1,2,..\text{n} \tag{6}$$

F- **Calculating the closeness coefficient for each alternative** using equation 7, based on the distances found in the previous step, where the alternative with the largest closeness coefficient has better performance. Thereafter, this will be used to rank the alternatives.

$$cl_i^{+} = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \tag{7}$$

4. Data Collection

The information required to use the suggested methodology can be divided into two groups: the first group consists of the technical properties that must be present in the stent material in order to perform the required function effectively, and the second group consists of a group of materials that have the required properties in varying proportions and can be thought of as suggested alternatives.

4.1 Selection Criteria

The majority of research studies have demonstrated that the properties and design (stent structure) of the stent play a significant role in determining its behavior after being implanted in a human body. The research articles confirmed that the ideal stent should be strong, biocompatible (no negative impact of implanted stent interaction with the human body), ductile, and uniformly deformed to avoid the extreme plastic deformation that can result in stent fracture (Liu et al 2013). It should also be flexible so that it can reach the curved arteries. The ideal stent should, in general, have good mechanical qualities to minimize the stent recoil phenomenon, which is defined as the degree of stent diameter reduction following balloon deflation. Figure 1 presents the essential properties for selecting the balloon-expandable stent material for damaged blood vessels, and Table 1 lists them with their descriptions.

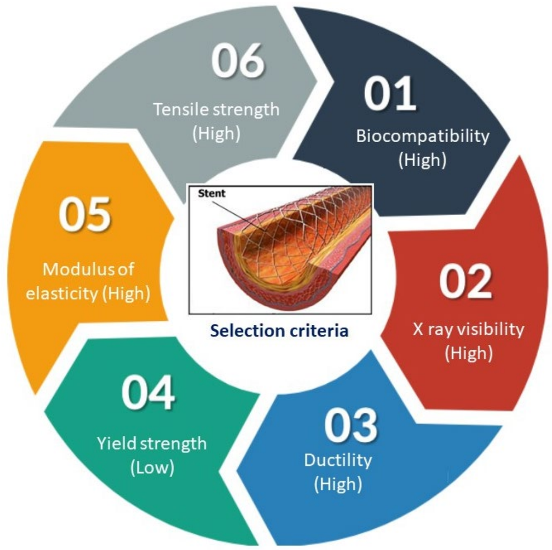

Figure 1. Selection criteria for stent materials for damaged blood vessels.

Table 1**.** List of stent material's selection criteria and their descriptions.

Criteria	Description
Physical properties: Biocompatibility and corrosion resistance (CR)	The stent material must be able to integrate with the human body without undergoing any toxic chemical reactions, as the material may react with bodily fluids over time and become corrosive, which could result in body poisoning (Liu et al 2013).
Physical properties: X-ray visibility	In order to deliver the stent to the precise location of the artery blockage, the stent material must be visible under X-ray during the medical operation (Liu et al 2013). The density of used material (ρ) will be used as a measure for X-ray visibility and penetrability, as the denser material will be more penetrable by X ray.
Mechanical properties: Ductility, (El.%)	To withstand the deformation caused by and during stent expansion, a highly ductile material is needed (Poncin and Proft 2003). As soon as the balloon starts to expand, the stent will plastically deform and widen the blocked artery as much as it can.
Mechanical properties: Yield strength, σ_y (MPa)	In order to prevent applying high loads to the vessel and to facilitate the delivery of stents into blood vessels, a low yield strength is necessary for stent expansion and to make it deformable at acceptable (low) balloon pressures (Poncin and Proft 2003).
Mechanical properties: Modulus of elasticity, E (GPa)	To stop the stent from expanding once more inside the blood vessel, a high modulus of elasticity is necessary (Pan et al 2021). In order to prevent re-expansion after the balloon deflates, the stent must be very resistant to changes in its shape and size.
Mechanical properties : Tensile strength, UTS (MPa)	The radial strength is the amount of external pressure that a stent can withstand before causing any damage to the artery. It is measured in terms of tensile strength. To achieve radial strength with the least amount of cylindrical stent volume, high tensile strength is needed after expansion (Poncin and Proft 2003).

4.2 Alternative Stent Materials

Ceramics cannot be used as a stent material due to their resistance to plastic deformation (making it impossible for the stent to expand due to fracture), despite their strength. Also, polymers, which are organic compounds, can't be used as a stent material because they are made of light elements (carbon and hydrogen), have lower densities than metals, and have low atomic packing efficiency, which restricts their visibility under X-rays as these rays can't pass through them effectively (without scattering), which prevents their use in stents (Poncin and Proft 2003). In addition, polymers also have a lower elastic modulus and tensile strength than metals.

On the other hand, the implanted stent must have high biocompatibility and be manufactured from a substance that can be incorporated into the human body (the host environment) without causing any toxic reactions (Kiran and Ramakrishna 2021). Some refractory metals and alloys possess a set of properties that allow them to be potential candidates as stent materials in varying proportions (high biocompatibility, high Young's modulus, very ductile, and strong) (Al-Mangour et al 2013).

Here, the suggested alternatives are divided into two classes: alloys and refractory metals. Stainless steel 316LVM, commercially pure titanium alloy, and cobalt chromium alloy L605 make up the first class, while niobium, tungsten, and tantalum make up the second class. These materials are described below, where each material has been assigned a special designation that will be used in all the subsequent tables, and Table 2 lists some of these materials properties.

Class I (alloys): Three alloys were selected as alternatives for this application, which are:

1. **Material A**: Stainless steel 316LVM (low carbon vacuum melt): This stainless steel is 316L that has been re-melted to remove impurities and increase purity. This increases corrosion resistance. Compared to stainless steel 316L, stainless steel 316 LVM has higher Ni percentages and lower C, Mo, and Cr percentages (Geanta et al 2014). It has the following composition: (Fe-18Cr-14Ni-2.5Mo) (Poncin and Proft 2003).
2. **Material B:** Commercially pure titanium (cp-Tia) alloy has a high resistance to corrosion and a low yield strength when compared to other alloys (Poncin and Proft 2003).
3. **Material C:** The cobalt-chromium alloy L605 has a composition percentage of (Co-20Cr-15W-10Ni) [10]. It has high ductility, hardness, and corrosion resistance.

Class II (refractory metals): These metals have high density, a high Young's modulus compared to alloys, and high corrosion resistance, but low ductility (Snead et al 2019). This class includes: **material D** (niobium); **material E** (tungsten); and **material F** (tantalum).

Table 2. List of some candidate stent materials for damaged blood vessels

Material / Property	A	B	C	D	E	F
ρ(g/cm^3)	7.95	4.50	9.10	8.57	19.3	16.60
E (GPa)	193	107	243	103	411	185
UTS (MPa)	670	300	820-1200	195	3126	207
σ_y (MPa)	340	200	380-780	105	3000	138
El.%	48	30	35-55	25	3	25

The corrosion resistance of the compared alternatives was expressed using a scale from 1 to 10 as follows: poor: up to 1, moderate: (2-4), below high: 5, high: (6-7), very high: (8-9), and extreme high: 10.

5. Results and Discussion

The TOPSIS method was applied to select a potential stent material for damaged blood vessels. All the steps described earlier for this decision-making method were followed precisely and completed. Table 3 displays the values of the candidate material properties and the weight assigned to each property, while Tables 4-8 display the numbers derived from the direct application of TOPSIS method equations 1-7. Hence, the decision matrix, normalized decision matrix, weighted normalized decision matrix, ideal positive and ideal negative solution for each criterion, separation distance for each alternative from the ideal solution, closeness coefficient, and ranking are shown in Tables 3-8, respectively. Figure 2 shows the closeness factor for each one of the alternatives, alternative C which is cobalt-chromium alloy has the highest closeness factor indicating it is the best alternative for this application.

Table 3. Decision matrix

Wt.	0.10	0.17	0.12	0.15	0.26	0.20
	ρ	**E**	**UTS**	**σ_y**	**El.%**	**CR**
A	7.95	193	670	340	48	7
B	4.5	107	300	200	30	10
C	9.1	243	1000	400	45	8
D	8.57	103	195	105	25	6
E	19.3	411	3126	3000	3	5
F	16.6	185	207	138	25	9

Table 4. Normalized decision matrix

	ρ	E	UTS	σ_y	El.%	CR
A	0.27	0.34	0.20	0.11	0.60	0.37
B	0.15	0.19	0.09	0.07	0.37	0.53
C	0.31	0.43	0.30	0.13	0.56	0.42
D	0.29	0.18	0.06	0.03	0.31	0.32
E	0.65	0.72	0.93	0.98	0.04	0.27
F	0.56	0.33	0.06	0.05	0.31	0.48

Table 5. Weighted normalized decision matrix

	ρ	E	UTS	σ_y	El.%	CR	rank
A	0.03	0.06	0.02	0.02	0.15	0.07	2
B	0.02	0.03	0.01	0.01	0.10	0.11	4
C	0.03	0.07	0.04	0.02	0.15	0.08	1
D	0.03	0.03	0.01	0.01	0.08	0.06	5
E	0.06	0.12	0.11	0.15	0.01	0.05	6
F	0.06	0.06	0.01	0.01	0.08	0.10	3

Table 6. The ideal positive and ideal negative solution for each criterion

	ρ	E	UTS	σ_y	El.%	CR
A+	0.06	0.12	0.11	0.01	0.15	0.11
A-	0.02	0.03	0.01	0.15	0.01	0.05

Table 7. The separation distance for each alternative from the positive ideal solution and negative solution

	d+	d-
A	0.12	0.20
B	0.16	0.17
C	0.10	0.20
D	0.17	0.16
E	0.21	0.15
F	0.15	0.17

Table 8. Closeness factor and rank for the compared alternatives

Alternatives	Closeness factor	Ranking
A	0.62	2
B	0.52	4
C	**0.66**	**1**
D	0.49	5
E	0.41	6
F	0.54	3

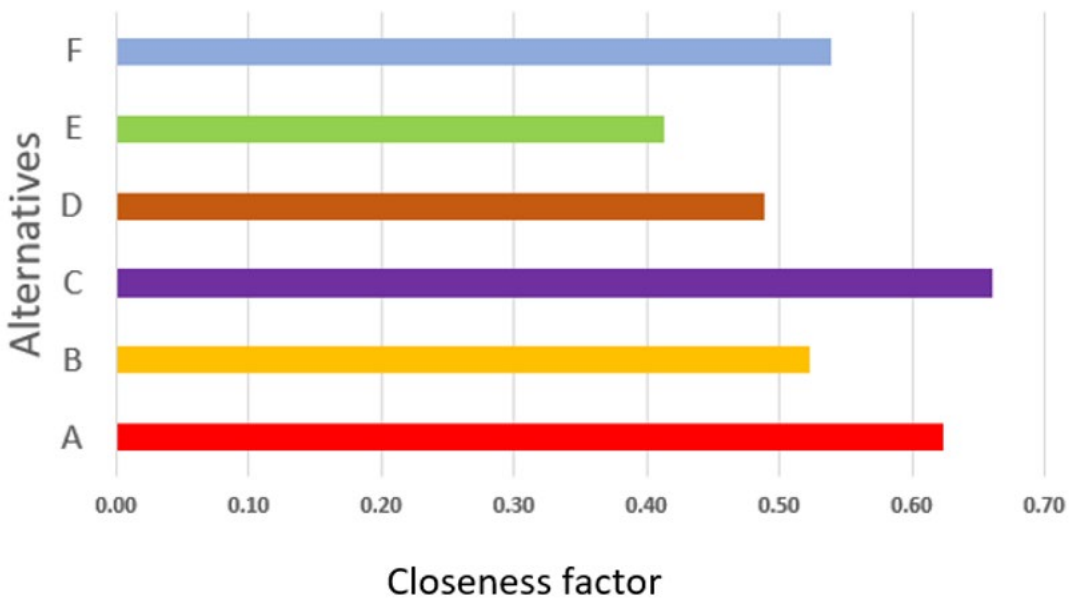

Figure 2. The closeness factor for each one of the alternatives.

Figure 2 shows the closeness factor for each one of the alternatives.

6. Conclusions

A stent is the most effective device that is used to expand the blocked coronary artery; its properties play a significant role in determining its behavior after being implanted in a human body. In this study, research on the material properties required for such a product has been conducted, and then the TOPSIS decision-making method was used to select the best material for this application. In light of the attained results, the following points can be attained:

- The stent material should be biocompatible, have high visibility to x-ray, high yield strength, high ultimate tensile strength, a high modulus of elasticity, and high ductility.
- Ceramic materials can't be used for this product because of their poor ductility.
- Polymer materials can't be used for this product because of their poor visibility from x-rays.
- TOPSIS decision-making results show that cobalt-chromium alloy ranks first among the alloys and refractory metals studied based on the considered criteria.

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