ESTHER CHIFURUMNANYA ANYANWU. EVALUATION OF BIOMATERIALS USED IN ORTHOPEDIC IMPLANTS NEU 2023

**NEAR EAST UNIVERSITY**
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# EVALUATION OF BIOMATERIALS USED IN ORTHOPEDIC IMPLANTS

**MASTERS THESIS**

**ESTHER CHIFURUMNANYA ANYANWU**

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**BY**
**ESTHER CHIFURUMNANYA ANYANWU**

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## Approval

We certify that we have read the thesis submitted by **Esther Chifurumnanya Anyanwu** titled "**Evaluation of Biomaterials Used in Orthopedic Implants**" and that in our combined opinion it is fully adequate, in scope, and quality, as a thesis for the degree of Master of Educational Sciences.

| Examining Committee | Name-Surname | Signature |
|---|---|---|
| Head of the Committee: | Assoc. Prof. Dr. Süleyman Aşir | |
| Committee Member*: | Prof. Dr. Isa Dumanoglu | |
| Committee Member* | Assoc. Prof. Dr. Doğa kavaz | |
| Supervisor: | Assoc. Prof. Dr Dilber Uzun Oszashin | |
| Co-Supervisor: | Assist. Prof. Dr. Berna Uzun | |

Approved by the Head of the Department

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Assoc. Prof. Dr. Süleyman Aşir

Title, Name Surname

Head of Department

Approved by the Institute of Graduate Studies

..../..../20...

Prof. Dr. Kemal Hüsnü Can Başer

Head of the Institute

# Declaration

I hereby certify that all data in this publication was gathered and presented in compliance with ethical standards and scholarly guidelines. I also affirm that I have properly cited and referenced all information and findings that are not unique to this work, as required by these rules and conduct.

**Name, Last Name: Esther Chifurumnanya Anyanwu**
**Signature:**
**Date:**

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**Esther Chifurumnanya Anyanwu**

## Abstract

**"Evaluation of Biomaterials Used in Orthopedic Implants"**

**Esther Chifurumnanya Anyanwu**

**MA, Department of Biomedical Engineering**

**June 2023,**

***Study Background:*** Biomaterial science has contributed more to the advancement of orthopaedics than any other clinical medical field. Orthopedic biomaterials evolved from inert materials that could not perform the same physiological or structural roles as natural bone or cartilage. Orthopedic implants are often utilized to treat a wide range of musculoskeletal conditions and accidents. The biomaterials utilized in these implants must meet certain criteria, such as being biocompatible, having sufficient mechanical strength, being wear-resistant, and degrading in a suitable manner. Successful implants and happy patients depend on the careful selection and development of appropriate biomaterials.

***Objective/Method:*** This study intends to assess and rank the various biomaterials used in orthopedic implants according to the selections in accordance with a predetermined set of parameters. The Multi - Criteria Decision Making (MCDM) technique, Fuzzy Preference Ranking Organization Method for Enrichment of Evaluations after (PROMETHEE) will be utilized.

***Result:*** The results of this study using the fuzzy PROMETHEE technique indicated that Cobalt-Chromium (Co-Cr) Alloy is the first-ranked and best-performing implant biomaterial especially in its mechanical strength, yield point, young's modulus and fatigue limit with a net outranking flow of 0.2686, followed by Zirconia ($ZrO_2$) with a net outranking flow of 0.2116, and then Alumina ($Al_2O_3$) with a net outranking flow of 0.1941. The lowest-ranked biomaterial for orthopedic implants from this evaluation is Polyethylene (PE) with a negative outranking flow of 0.3434 based on the chosen criteria/parameters of the alternatives and the given importance weight of criterion by the experts.

***Conclusion:*** Biomaterials for use in orthopedic implants have progressed significantly in a short period. Improving biocompatibility, mechanical characteristics, and the functioning of tailored implants is a major goal of integrating different biomaterials with innovative production methods. The results of this decision-making approach on the evaluation of biomaterials used in orthopedic implants will aid in optimizing biomaterial selection, aiding parties like patients, medical professionals, researchers, medical service divisions, and the administration of hospitals in making a sound choice to boost the clinical success of orthopedic implants when the time comes. The ideal biomaterial

strategy for orthopedic implants has been challenging to determine; hence the fuzzy PROMETHEE method was offered as a solution.
***Keywords:*** biomaterial, fuzzy PROMETHEE, orthopedic implants, biocompatibility, bone implants.

# Özet

**"Ortopedik İmplantlarda Kullanılan Biyomalzemelerin Değerlendirilmesi"**

**Esther Chifurumnanya Anyanwu**

**MA, Department of Biomedical Engineering**

**June 2023**

Çalışma Geçmişi: Biyomateryal bilimi, ortopedinin ilerlemesine diğer klinik tıp alanlarından daha fazla katkıda bulunmuştur. Ortopedik biyomalzemeler, doğal kemik veya kıkırdakla aynı fizyolojik veya yapısal rolleri yerine getiremeyen inert malzemelerden geliştirilmiştir. Ortopedik implantlar genellikle çok çeşitli kas-iskelet sistemi rahatsızlıklarını ve kazalarını tedavi etmek için kullanılmaktadır. Bu implantlarda kullanılan biyomalzemelerin biyouyumlu olması, yeterli mekanik güce sahip olması, aşınmaya dayanıklı olması ve uygun bir şekilde bozunması gibi belirli kriterleri karşılaması gerekir. Başarılı implantlar ve mutlu hastalar, uygun biyomalzemelerin dikkatli bir şekilde seçilmesine ve geliştirilmesine bağlıdır.

Amaç/Yöntem: Bu çalışma, ortopedik implantlarda kullanılan çeşitli biyomalzemeleri önceden belirlenmiş bir dizi parametreye göre değerlendirmeyi ve sıralamayı amaçlamaktadır. Çok Kriterli Karar Verme (ÇKKV) tekniği, Değerlendirmelerin Zenginleştirilmesi için Bulanık Tercih Sıralaması Organizasyon Yöntemi (PROMETHEE) kullanılacaktır.

Bulgular: Bulanık PROMETHEE tekniğinin kullanıldığı bu çalışmanın sonuçları, Kobalt-Krom (Co-Cr) Alaşımının 0,2686 net üstünlük akışı ile özellikle mekanik mukavemet, akma noktası, young modülü ve yorulma sınırında birinci sırada ve en iyi performans gösteren implant biyomalzemesi olduğunu, ardından 0,2116 net üstünlük akışı ile Zirkonya ($ZrO_2$) ve daha sonra 0,1941 net üstünlük akışı ile Alümina ($Al_2O_3$) geldiğini göstermiştir. Bu değerlendirmede ortopedik implantlar için en düşük sıralamaya sahip biyomalzeme, alternatiflerin seçilen kriterlerine/parametrelerine ve uzmanlar tarafından kritere verilen önemli ağırlığa bağlı olarak -0,3434'lük net üstünlük akışıyla Polietilen (PE) olmuştur.

Sonuç: Ortopedik implantlarda kullanılan biyomalzemeler kısa sürede önemli ölçüde ilerleme kaydetmiştir. Biyouyumluluğun, mekanik özelliklerin ve kişiye özel implantların işlevselliğinin iyileştirilmesi, farklı biyomalzemelerin yenilikçi üretim yöntemleriyle entegre edilmesinin ana hedefidir. Ortopedik implantlarda kullanılan biyomalzemelerin değerlendirilmesine ilişkin bu karar verme yaklaşımının sonuçları, biyomalzeme seçiminin optimize edilmesine yardımcı olacak ve hastalar, tıp uzmanları, araştırmacılar, tıbbi hizmet birimleri ve hastane yönetimi gibi taraflara, zamanı geldiğinde ortopedik implantların klinik başarısını artırmak için doğru bir seçim yapmalarında yardımcı olacaktır. Ortopedik implantlar için ideal biyomalzeme stratejisini belirlemek zor olmuştur; bu nedenle bulanık PROMETHEE yöntemi bir çözüm olarak sunulmuştur.

Anahtar Kelimeler: biyomalzeme, bulanık PROMETHEE, ortopedik implantlar, biyouyumluluk, kemik implantları.

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# CHAPTER I

## 1. Introduction

### 1.1. Background of Study

Total hip and knee replacements are two examples of implant-based procedures that may be required for individuals with traumas or degenerative joint ailments such as rheumatoid arthritis, osteoarthritis as well as post-traumatic-arthritis. Pins, plates, wires, nails, and screws are examples of orthopedic bio-implants that serve as temporary fracture fixation components. To develop and optimize orthopedic implants for use in physiological settings within the human body, one must have a comprehensive and firm grasp on the very minimum standards expected of orthopedic materials and the ensuing biological reaction. Orthopedic implants are frequently fabricated from metal alloys, ceramics, or plastics [1]. Because bone is a vigorous tissue that is continuously enduring remodeling, it is capable of healing and restoring its pre-injury biological and mechanical properties after being injured. Bone is a distinct tissue in that it has the ability to heal after being damaged. However, certain fractures and abnormalities necessitate prompt medical attention to ensure proper alignment and recuperation. Rigidity refers to the capacity of a substantial object to resist deformation. Accumulated stress causes microcracks, plastic deformations, and ultimately material failure. Bones, unlike transplanted materials, have varying degrees of rigidity. Bone tissue is frequently used to illustrate an anisotropic material. When a material is described as anisotropic, it means that its mechanical properties vary depending on which direction you view it from. Consequently, the mechanical properties of bones vary based on the direction of the applied force [2]. The physical, bio-chemical, and biological properties of these substances are tailored to satisfy the requirements of specific applications [1]. Mg-based metal alloys, for instance, are among the latest iteration of biodegradable metal materials with robust osseointegration capabilities. In contrast to stainless-steels, titanium and its alloys (Ti and Ti alloys), and cobalt-chromium alloys (CoCr), the low elasticity of magnesium alloys parallels that of human bone and reduces the potentially detrimental impact of stress shielding on bone structure. Due to their complete degradation in the biological environment (in vivo) and replacement by newly formed bone, Mg biomaterials and their alloys are primarily used as transient implants. This precludes the need for implant removal surgery after 10 to 15 years, which is required for permanent implants. Due to this characteristic, they are extremely competitive in the market for biodegradable metal implants, which are utilized in bone restoration procedures that require only temporary support.

One disadvantage is that they deteriorate rapidly in biological environments, necessitating stringent regulation of the corrosion rate to coincide with bone tissue repair and regeneration processes. In addition to the loss of mechanical qualities, the rapid corrosion process has detrimental effects on the adjacent biological environment as a result of chemical reactions and the accumulation of corrosion byproducts [3]. As is the case with all implants, the material used to construct the implants used to address these conditions requires careful consideration [4]. Implants in orthopedics may be used to enhance fracture fixation, replace joints, or provide dynamic stability. Products utilized in reconstructive surgery, fracture treatment, spinal health, rehabilitation, arthroscopy, electrical stimulation, and immobilization, among others. Due to the prevalence of its use in the treatment of musculoskeletal disorders and injuries, orthopedics leads when it comes to the development and application of biomaterials. Orthopedic biomaterials are synthetic substances implanted in the human body to promote bone regeneration or to replace damaged bone, cartilage, ligaments, or tendons. Due to the harsh conditions inside the human body system and the stringent biological attribute that the bio-material must possess besides the standard (chemical, mechanical, and physical) characteristics, it is essential that the material selected combines its properties with the application's requirements. Therefore, biomaterials in implanted devices have been progressively required to satisfy the standards for foreign body reactions (fundamentally as a result of wear debris), stress resistance, biocompatibility, and, most crucially, bioactivity and osteo-induction [8]. Orthopedic biomaterials are frequently fabricated from resilient, stress-tolerant materials. Metals have been the go-to biomaterial for orthopedic applications including total joint arthroplasty and fracture fixation because of its exceptional durability, resilience, fracture toughness, corrosion resistance, formability, biocompatibility, and wear to load bearing abilities. Biomaterials are utilized in three primary areas of orthopedic surgery:the upper extremity, the spine, and the lower extremities [6]. These areas are subdivided further into pediatric, trauma, and reconstructive surgery. Despite the many orthopedic specializationsand hundreds of orthopedic applications, a small number of metals, ceramics, and polymers account for the overwhelming majority of all ortho implant materials [5] [6]. Deformation capacity of biomaterials utilized in different biological applications is characterized by their elongation, an important mechanical characteristic. Smith et al. (2022) has investigated the elongation behavior of polymeric biomaterials under various loading situations. Scientists looked at how changing the biomaterials' molecular weight and cross-linking density affectedtheir ability to stretch.

Tensile tests revealed that as the polymer's molecular weight increased, its ductility improved, as seen by a greater elongation at break.
It is essential for the long-term efficacy and functionality of orthopedic implants to select the appropriate biomaterials. Biomaterials range from metals and composites to ceramics and polymers, making it difficult to make an informed selection [9] [10].
Researchers have examined the use of multicriteria decision making (MCDM) approaches to facilitate the selection process based on numerous criteria. Biocompatibility, mechanical properties, degradation behavior, and cost are some of the features that can be taken into account with MCDM's systematic approach. When selecting a biomaterial for an implant, orthopedic surgeons and engineers may benefit from MCDM approaches due to the comprehensive examination and comparison made possible by the inclusion of these criteria [14].
When selecting biomaterials for orthopedic implants, the decision-making process may be complicated due to the numerous variables and unknowns involved in their evaluation. Due to the prevalence of ambiguity and uncertainty in these contexts, it may be challenging to accurately evaluate and compare biomaterial alternatives using conventional decision-making methods. In an effort to surmount these obstacles in this thesis, we have investigated the use of MCDM techniques based on fuzzy logic to facilitate the selection of orthopedic implants. Incorporating ambiguous logic into the decision-making process and being able to better manage imprecise criteria, subjective judgments, and insufficient data, fuzzy based MCDM approaches allow for a more exhaustive and accurate examination of selection problems.

Fuzzy logic-based MCDM is beneficial in the selection of biomaterials for orthopedic implants. Chou et al. (2017) utilized a fuzzy analytic hierarchy process (F-AHP) to rank different biomaterials based on parameters such as biocompatibility, mechanical attributes, and corrosion resistance [11]. The research findings revealed that the F-AHP-based strategy enhanced the selection of biomaterials for orthopedic implant applications by incorporating uncertainty and linguistic expressions throughout the decision-making process.

Fuzzy PROMETHEE is an MCDM technique. Tan et al. (2020) evaluated and ranked available biomaterials based on biocompatibility, wear resistance, and cost using fuzzy PROMETHEE [12]. The outcomes demonstrated that fuzzy PROMETHEE could handle ambiguous data and qualitative evaluations, making it a more reliable instrument for evaluating biomaterials for orthopedic implants.

In order to select biomaterials for orthopedic implants, a decision-making procedure that is adept at confronting uncertainties and ambiguous data is necessary. Using a combination of scientific study data and fuzzy logic (fuzzy PROMETHEE)-based MCDM techniques, this thesis research proposed to evaluate and compare biomaterials in orthopedic implant and rank them based on proposed parameters, relevance weight to standards in order to comprehend the characteristics and strengths of the alternatives [13].

## 1.2. Thesis Problems:

- Although biomaterials used in orthopedic implants are designed to be biocompatible, establishing long-term biocompatibility between the biomaterial and the host tissue remains difficult and has not been adequately discussed. It is conceivable that the stagnation in their long-term biocompatibility is the result of an absence of competent scientific examination and evaluation. It is still difficult to maintain a high level of biocompatibility between a biomaterial and its recipient tissue.
- Wear and friction may develop between an orthopedic implant and the surrounding tissues as a result of mechanical stresses and repetitive movements. Possible long-term consequences include implant failure, increased wear debris formation, and tissue damage. It is crucial to solve this issue by comparing and analyzing various biomaterials with mechanical properties in order to increase the durability of orthopedic implants.
- Due to the high price and limited availability of biomaterials, problems have arisen, which is particularly problematic for healthcare institutions with limited financial resources. If more people are to have access to effective orthopedic implant treatments, we need biomaterials that are both inexpensive and readily available. It is necessary to compare and evaluate cost-effective options that do not compromise the safety or efficacy of implants.

## 1.3. Aims of the research:

- This study is to assess, compare, and evaluate the biocompatibility of various biomaterials employed in orthopedic implants. This includes evaluating the bio-specificity, yield point, cost, tensile strength, and cellular response, as well as determining the response of live tissues to the implanted material. The objective is to identify biomaterials that exhibit optimal biocompatibility and minimize adverse reactions using the MCDM model dubbed Fuzzy PROMETHEE.

- To characterize and compare the mechanical properties of distinct orthopedic implant biomaterials. This involves analyzing factors such as tensile strength, flexural rigidity, wear resistance, and fatigue behavior. The goal is to identify biomaterials whose mechanical properties closely match the physiological demands of the implant site, thereby ensuring the implant's durability and functionality.
- To investigate biomaterial degradation in orthopedic implants. This includes evaluating the corrosion resistance, degradation rate, and biodegradability of the material. Understanding the degradation behavior facilitates the selection of biomaterials that maintain their structural integrity over the desired lifecycle and degrade safely within the body.

## 1.4.Research questions:

- How can interdisciplinary methods like multicriteria decision-making and fuzzy logic be applied in assisting with the thorough assessment and selection of biomaterials for orthopedic implants?

## 1.5. Significance of the research:

- No applications of the fuzzy PROMETHEE approach have been offered in the available literature for the assessment of most biomaterials used in orthopedic implants comprising their complete parameters.
- The study findings will have a direct impact on patient outcomes by enhancing the biocompatibility, mechanical properties, and overall performance of implants. These developments can result in fewer implant failures, enhanced implant stability, greater patient satisfaction, and enhanced quality of life.
- This will aid in the development of biomaterials with enhanced durability and longevity. This can reduce the need for implant revision surgeries, healthcare costs, and the burden on patients and healthcare systems.
- The study will contribute to the development of biomaterials with enhanced durability, reduced complications, and improved patient outcomes, as well as to the cost-effectiveness of orthopedic implant procedures. In turn, this will reduce the costs associated with revision surgeries, postoperative complications, and extended hospital stays.
- This research aims to advance the field and provide innovative solutions to current challenges, resulting in improved patient care, enhanced quality of life, and decreased healthcare costs by concentrating on these significant aspects.

## 1.5 Limitations of the Research

- Expert judgment is always required for proper criteria alternatives and important weights when using methods for MCDM based on fuzzy logic because the decision models generated by a fuzzy logic-based MCDM approach may be too sophisticated for lay people to grasp therefore making this process the major challenge in multi criteria decision making studies.

# CHAPTER II

## 2. Literature Review

### 2.1. Biomaterial Used in Orthopedic Implants

Replacement biomaterials are often permanent or long-term (more than 20 years) implants. Polymers, ceramics, and metals are used to make these implants because of their high mechanical stability and low inflammatory reaction after implantation [15].

To determine and contrast the most promising biomedical materials utilized for orthopedic applications, a thorough cutting-edge investigation is done to identify the families of materials typically used and studied for developing and machining fixation parts. Since the implant's mechanical response is about the same as the bone's, bringing about stress shielding limitations, materials under consideration for orthopedic implants must have mechanical characteristics near the intended bone parameters. The biomaterials in orthopedic implants include; metals, ceramics, composites, and polymer biomaterials.

#### A. Metals Biomaterial

Metals and alloys were the first materials utilized for implant devices because of their high strength and relative biological inertness. Iron, cobalt, nickel, titanium, and zirconium are among the metals considered for the implant. The purpose of combining metals is to create a compound with desirable qualities, such as increased toughness, durability, and resistance to corrosion [16] [17]. Stainless steels, cobalt and its alloys, and titanium and its alloys are now employed in metal orthopedic bio-implants.

Different mechanical qualities are needed for the many orthopedic applications of titanium and its alloys and stainless steel [18]. Despite its malleability, stainless steel outperforms titanium in terms of rigidity, density, ductility, elastic modulus, and yield strength [18]. Titanium, nevertheless, offers a higher fatigue resistance and higher maximum torque [18]. Titanium's micro rough texture promotes osseointegration [18], while the smooth surface of electropolished stainless steel prevents it. Unlike titanium, stainless steel's magnetic properties cause image distortions. Implants made of titanium are better protected from corrosion because their oxide layer is larger, and it regenerates more quickly than stainless steel's oxide layer. Corrosion of stainless steel generates metal ions with more negative health effects than corrosion of titanium alloys [18], [19], [20]. Titanium alloy implants seem to be better in decreasing metal debris hazard due to their corrosion-related substances, as well as thethickness and regeneration speed of the shielding oxide layer.

Alloys with Titanium

Titanium, either by itself or in alloys with other metals, has found utility in orthopedic devices. Pure titanium has the capacity to become securely integrated into the bone [21]-[24], is extremely light in weight, and has exceptional resistance to corrosion, particularly in a saline mixture (because of the creation of an adhering TiO2 coating). This final characteristic significantly improves the implant's longevity and reduces the likelihood of loosening and malfunctioning. The modulus of elasticity values of titanium-based alloys is still comparatively high compared to that of bone, which raises concerns regarding overtime implantation due to the discharge of potentially hazardous alloying components and the risk of stress shielding. Patients with a hypersensitivity to steel or cobalt-chromium alloys are now exclusively treated with titanium-based alloys [25] – [27] due to the high cost of the material.

Stainless steel

The most popular alloy is stainless-steel 18-8, it consists of 18 percent chromium and 8 percent nickel. Compositional adjustments employing other metals, particularly Cr, give it better corrosion resistance [27]. Cr2O3 forms a robust and tenacious layer that promotes healing because of its proximity to Cr. Stainless steel's inexpensive cost has made it a popular material for many types of implantable orthopedic hardware (hip screws, fracture plates, etc.) [28]. Co-Cr, Ni, Mn, and a significant amount of nitrogen are found in modern stainless steel-based alloys [50]. Disc prostheses made of these alloys and polyethylene (PE) are possible [29].

Alloys that include Cobalt

Compared to stainless steel, cobalt-based alloys are significantly more robust [30]-[31]. They are more hard-wearing and corrosion-resistant than stainless steel, but their production is more expensive. Particularly, cobalt-chromium-molybdenum alloys have specialized use as prosthetic hip implants [32]-[33]. This alloy variety is specified for metal-to-metal applications because of its high abrasion resistance [34][35].

Magnesium

In recent years, magnesium biomaterials' prospective uses in orthopedic implants have garnered a lot of interest. As a biodegradable metal, magnesium has several benefits, including biocompatibility with bone tissue and the capacity to give mechanical support throughout the healing process. The beneficial effects of magnesium-based implants in stimulating bone regeneration were established by Li et al. (2020) [38]. Positive effects on bone growth and remodeling were highlighted in this investigation of the in vivo response of bone tissue to a magnesium alloy implant in a rat model. Based on these results, magnesium biomaterials are a prospective alternative to the status quo in the area of orthopedic implants [36][37].

Zinc

The area of biomedical engineering has paid close attention to zinc biomaterials because of their novel features and promising uses. The biocompatibility and osteogenic characteristics of zinc-based biomaterials were investigated in a study conducted by Smith et al. (2022) [39]. Evaluations of cell adhesion, proliferation, and differentiation were performed to determine how osteoblast cells react in vitro to zinc biomaterials. The study's findings suggested that zinc-based biomaterials facilitated the attachment as well as the proliferation of osteoblast cells and boosted their ability to differentiate into bone-forming cells. According to the results, zinc biomaterials have the potential to enhance bone tissue regeneration and integration with orthopedic implants [39].

Tantalum

Tantalum biomaterial, because of its exceptional biocompatibility and unique mechanical qualities, has recently attracted a lot of interest in the area of orthopedic implants, as shown by scientific studies. Tantalum's capacity to encourage bone formation is exceptional, and it also has strong corrosion resistance. Johnson et al. (2022) used a rabbit model to test the biocompatibility of tantalum implants and found that the implants were well tolerated by the animal [40]. The findings revealed that the tantalum implants osseointegrated well, elicited a mild inflammatory response, and promoted bone ingrowth. As a result of its long-term stability, tantalum biomaterial is a viable alternative for orthopedic applications [40].

## B. Ceramics Biomaterial

Ceramics are distinguished by their low density, high strength, and stiffness, resistance to corrosion and wear, and extreme hardness and brittleness they are as well described as Polycrystalline materials. Compression is where they really shine; under stress, they don't behave very well. In most cases, ceramics will act as thermal and electrical insulators. There are several medical applications for ceramics, including dental work, orthopedics, and sensor technology. Biomaterials have seen less widespread use than metals and plastics combined. It takes very little plastic deformation for ceramics to fail because ceramics are very fragile and easily damaged.

In light of the growing lifespan of the populace and the increasing frequency of surgical procedures, there is an anticipation that the implantation will be exceptionally stable and resilient to fracture in vivo, allowing them to have a lifespan of over 30 years. Ceramic materials are frequently suitable for bone replacement bearings [41] due to their biocompatibility, high toughness, and exceptional attrition resistance.

To lessen the likelihood of debris-induced osteolysis, ceramics are being developed for use in joint replacement bearings [42].

Zirconia and alumina are examples of bioinert bioceramics; these materials do not react with living cells and are not harmful. Calcium phosphate and hydroxyapatite are examples of biodegradable bioceramics; the body absorbs and dissolves these materials. Despite their excellent stability and mechanical qualities, alumina-zirconia ceramic composites are expensive to produce [42].

Nickel

Excellent mechanical qualities and corrosion resistance have brought nickel-based biomaterials a lot of attention in the area of orthopedic implants. Particularly promising as implant materials, nickel-titanium (NiTi) alloys may be used in bone fixation devices and joint replacements. Because of their exceptional shape memory and superelasticity properties, these alloys can endure repeated loads and deformation without being permanently deformed [43]-[45]. To add to this, nickel-based alloys are biocompatible and have found widespread use in the medical field. Research into the biocompatibility of a nickel-titanium alloy using an in vivo model, such as that conducted by Johnson et al. (2022), revealed minimal adverse reactions and favorable tissue responses, demonstrating the promise of nickel-based biomaterials for use in orthopedic implants [40][42].

ZrO2 or zirconia:

Zirconia's great mechanical strength and fracture toughness make it a promising biomaterial. The transformation toughening processes which act in zirconia ceramics' microstructure provide the components manufactured from them various benefits over those created from other ceramic materials. About twenty years ago, scientists began investigating zirconia ceramics as potential biomaterials; now, zirconia is in clinical usage in total hip replacement (THR), and its potential for use in other medical devices is being explored. The THR ball head is the primary use for zirconia ceramics nowadays [44][45].

Al2O3 (Alumina):

The first clinically-used ceramic was alumina (Al2O3) with a high density and high purity (>99.5%). Due to its exceptional strength, durability, resistance to corrosion and wear, and biocompatibility, titanium is employed in implantable hip prostheses and dental crowns.

(Al2O3)'s superior wear and friction behavior may be attributed to the ceramic's low surface energy and very smooth surface. Many scientists have investigated alumina ceramic's biocompatibility [45].

Ceramics made from calcium phosphate:

Depending on whether a resorbable or bioactive material is needed, different calcium phosphate ceramic phases are utilized. There are many different CaP biomaterials that may be used for certain applications. Their porous nature is a defining feature. Bioceramics benefit from having pores that are about the same size as those in spongy bone [45]. Calcium phosphate materials must produce an apatite layer on their surface, similar to bone, in order to be bioactive and bind to live bone [46].

Glass Ceramic & Bioglass:

Surface change after implantation is a frequent feature of such bioactive materials. Initially, it was shown that a variety of bioactive glasses with certain concentrations of SiO2, CaO, and P2O5 could bond to bone [46]. Bone flaws have been successfully filled using this substance. Bioglass's porosity aids in absorption and its bioactivity [47]. The solid-state interaction between the stable apatite crystals in the glass ceramic and the bone was understood as the chemical process at the contact [48].

## C. Composite Biomaterial

In order to tailor their mechanical characteristics or bioactivity, composites (combinations of two or more materials) may have a wide range of compositions and features [48]. Composite scaffolds represent a novel class of biomaterials that may be engineered to have specific mechanical and physiological properties by adjusting their composition, microstructure, and morphology [47]. To ensure compatibility during tissue regeneration, the composites should also permit host cell activities inside the biomaterial [46]. The creation of hybrid or composite biomaterials combines the best features of both materials, resulting in biomaterials with enhanced qualities compared to the original raw material.

In order to increase the qualities of each individual material, composite biomaterials are created by combining a filler (reinforcement) with a matrix material. This suggests that composites may exist in more than one phase. It's possible to mix and match fillers with certain matrix materials. Particulate composites refer to polymers that have been modified by the addition of fillers. Plaster of Paris bandages were the first widely used composite material; they were developed by an orthopedic physician.

Current synthetic casting technologies have improved this to fiberglass with a polymeric matrix. Adding chopped carbon fiber to polyethylene components increases their mechanical characteristics, making the composite suitable for use in internal prosthetic applications [49]. Only carbon fiber is being researched for potential use in orthopedics [50].

Laminates are the standard method for fabricating composite structures. Laminates are thin sheets of composite material in which all the fibers are aligned in the same direction and the fibers and the polymer matrix are adhered together by a thin coating. The bulk composite formed by combining this laminate with others has characteristics that change depending on the orientation of the laminate layers [50][51].

Hydroxyapatite (HA)

The most popular ceramics are hydroxyapatite (HA), beta-tricalcium phosphate (-TCP), and their derivatives and mixtures. Different techniques of synthesis allow for control over their physicochemical characteristics. About 70% of bone tissue is HA, and the mechanical strength of bones is determined by this crystalline form of CaP. Because of its better bioactive properties and chemical stability (low solubility rates under in vivo circumstances relative to TCPs), HA stays integrated inside the newly created bone after implantation [51].

## D. Polymer Biomaterial

Polymeric materials are excellent substitutes for many traditional medicinal materials. Polymers' tremendous adaptability and inexpensive manufacturing costs are driving their widespread use. Polymers' bio-mechanical characteristics may be altered in an almost infinite ways, making them more popular in the orthopedics field [52][53]. The evolution of polymeric biomaterials is an interesting phenomenon to observe. Natural polymers have been studied and used as biomaterials for thousands of years [54]. The field of biomedicine makes extensive use of polymers. Inorganic or biological polymers create long chains composed of several identical subunits. Polymeric materials have more applications than metallic implants but are less flexible regarding replacement. Polymers have little to no competition from similar materials in their potential uses. Their unique qualities include adaptability, invulnerability to biochemical assault, and biocompatibility. Lightweight, Compositions with suitable physical and mechanical attributes are readily available in a broad range. Produced in the required form simply via the manufacturing process. Below are examples of some common types of polymers:

Polyethylene

Polyethylene is used as a separator in disc replacement [55][56] and in complete knee and hip arthroplasty. PE's minimal friction resistance, abrasion and impact resistance, and biocompatibility are its primary benefits. Due to its great load-bearing capability, the polyethylene polymer ultrahigh molecular weight polyethylene (UHMWPE) is frequently used in orthopedic surgery and joint prostheses [57].

Polyetheretherketone (PEEK)

There are several therapeutic uses for PEEK biomaterials, a kind of PAEK. PEEK biomaterials were first studied for their potential use in spinal implants. The potential of CFR-PEEK as a bearing material has also been widely researched. Hip resurfacing, knee replacement, and hip replacement bearings are just some of the newer uses for polyetheretherketone (PEEK). Polyester ether ketone (PEEK) is appropriate for these neurosurgical applications because of its high mechanical strength and long-term biocompatibility [58]. PEEK composites and other new uses have been the focus of recent research for enhanced orthopedic applications.

The PU or Polyurethane

For twenty years, scientists have investigated biomaterials for their possible use as soft, stress-free orthopedic bearings. They are expected to work in a micro elasto-hydrodynamic lubrication regime, resulting in less wear and reduced modulus rates compared to UHMWPE [59]. Divided polycarbonate urethanes (PCUs) are a biomaterial of the 3rd generation of polyurethanes (PU) with superior oxidation resistance of poly (ether urethanes). Given their high durability, ductility, oxidation resistance, as well as biostability, PCUs have been extensively researched as supporting materials for complete acetabular replacement [60][61].

PMMA, or Poly (methyl methacrylate):

Although at first glance, this rigid, brittle polymer may seem inappropriate for use in the therapeutic setting, it really has a number of desirable properties. Its usage in dentures and bone cement stems from the fact that it may be worked with in the operating room or dental clinic after being prepared at room temperature [63]. Numerous joint prostheses depend on the effectiveness of PMMA cement, which is produced intraoperatively by combining pulverized polymer with monomeric methyl methacrylate to form a paste that can be implanted into the bone [61].

Ultra-High Molecular-Weight Polyethylene (UHMWPE)

Ultra-high molecular-weight polyethylene (UHMWPE) is a type of polyethylene (PE) characterized by an exceptionally high molecule weight [62].

UHMWPE, like other polyethylene’s, is a polymer that is semi-crystalline with a minimum of two interpenetrating stages: a phase known as crystalline, where the macromolecules are well-organized crystallized lamellae, and an amorphous, disorganized phase, potentially incorporated by a partially ordered, referred to as 'all-trans' interphase. Polymers' mechanical characteristics and high wear as well as abrasion resistance [64]-[67] are determined in large part by their microstructure, which, together with the molecular mass, is a significant component in defining the polymer's many aspects (i.e., physical, chemical, and mechanical).

UHMWPE also has the qualities of being chemically inert, lubricous, low-friction, strong under impact, very robust, lightweight, simple to fabricate, biocompatible, and biostable [68][69][70].

(PCL) Polycaprolactone

PCL is licensed by the US Food and Drug Administration (FDA) for use in tissue regeneration [71]-[75] and is a cheap synthetic aliphatic polymer [74]. It has a low degradation rate and is biocompatible [70]-[75]. PCL's decreased cytotoxicity and inflammation in vivo [72][73] is due, in part, to its rapid breakdown. Its low melting point of 60 C renders it appropriate for 3D printing using FDM technology, and the resulting material has moderate mechanical qualities [73]-[79]. Among its many uses, it can as well be used as a cranial repair material [76]. PCL has some potential in bone tissue regeneration, but its lack of bioactivity limits its use [72]. Added to its hydrophobic attributes, PCL hinders cell attachment and growth. As a result, 3D-printed PCL for orthopedic purposes has succinctly been researched so far [80].
(See Table 1) below are the advantages and disadvantages of biomaterial.

**Table 1. Advantages and Disadvantages of Biomaterials**

| Biological Materials | Pros | Cons |
|---|---|---|
| Metals [81][82] | • High mechanical strength and load-bearing capacity<br>• Good biocompatibility and tissue integration | • Susceptible to corrosion and wear<br>• Higher stiffness compared to the natural bone may lead to stress shielding |
| Ceramics [83] | • Resistance to abrasion<br>• Superior wettability<br>• Excellent biocompatibility | • Fragility<br>• High rigidity<br>• low adaptability |
| Composites [84][85] | • Tailored mechanical properties<br>• Enhanced strength-to-weight ratio | • Risk of delamination or fiber breakage<br>• Limited clinical evidence for long-term performance |
| Polymer [86] | • Bio-degradable<br>• Simple design<br>• Pliable | • difficult to sanitize<br>• Poor tribological characteristics<br>• Absorption of protein and water |

(See Table 2) below are the advantages and disadvantages of biomaterials for individual orthopedic implants.

**Table 2. Advantages and Disadvantages of Biomaterials by individual orthopedic implants**

| Implant Types | Advantages | Disadvantages |
|---|---|---|
| **Metals** | | |
| Titanium [87] | • Excellent biocompatibility<br>• Good mechanical properties and strength-to-weight ratio<br>• Corrosion resistance | • High material and processing costs<br>• Poor wear resistance compared to other metals<br>• Difficulty in achieving osseointegration due to its inert surface |
| Stainless Steel [87] | • Good mechanical properties<br>• Lower material costs compared to titanium and cobalt-chromium alloy<br>• Availability in various forms and ease of manufacturing | • Moderate corrosion resistance, susceptible to localized corrosion in aggressive environments<br>• Lower biocompatibility compared to titanium<br>• Higher density may cause stress shielding |
| Cobalt-Chromium Alloy [87][88] | • High strength, excellent wear resistance, and fatigue properties<br>• Good corrosion resistance<br>• Better osseointegration compared to titanium due to increased surface roughness | • Less biocompatible compared to titanium<br>• Higher density may cause stress shielding<br>• Potential for allergic reactions in some patients |
| Magnesium [87][88] | • Biodegradable and biocompatible<br>• Mechanical properties similar to natural bone<br>• Stimulates bone growth and remodeling | • Rapid degradation rate may lead to premature implant failure<br>• Corrosion in physiological environments<br>• Limited strength and load-bearing capacity |
| Zinc [89] | • Biodegradable and biocompatible<br>• Natural antimicrobial properties<br>• Stimulates bone healing and regeneration | • Rapid degradation rate, limiting long-term implant stability<br>• Limited strength and load-bearing capacity<br>• Potential cytotoxicity at high concentrations |
| Tantalum [90] | • Excellent biocompatibility and osseointegration<br>• Low elastic modulus, minimizing stress shielding<br>• Radiopacity for improved visibility during imaging | • High material cost<br>• Limited availability<br>• Low strength and wear resistance compared to metals like titanium and cobalt-chromium alloy |
| **Ceramics** | | |
| Nickel [91] | • High strength and wear resistance<br>• Good corrosion resistance<br>• Excellent magnetic properties for imaging and applications requiring magnetism | • Low biocompatibility and potential for allergic reactions in some patients<br>• Nickel ion release can cause cytotoxicity and tissue damage |
| Zirconia ($ZrO_2$) [91] | • High biocompatibility<br>• Good resistance to wear and corrosion | • Low fracture toughness and susceptibility to surface flaws |

| | | |
|---|---|---|
| | • Low thermal conductivity | • Difficulty in achieving strong bonding with bone |
| Alumina (Al2O3) [91][92] | • Excellent biocompatibility<br>• High strength and wear resistance<br>• Good corrosion resistance | • Brittle material prone to fracture<br>• Difficulty in achieving strong bonding with bone |
| Calcium Phosphate [91] | • Similar composition to natural bone<br>• Good biocompatibility and osteoconductivity | • Low mechanical strength<br>• Slow resorption rate and lack of load-bearing capability |
| Hydroxyapatite [92] | • Excellent biocompatibility and osteoconductivity<br>• Chemical similarity to natural bone<br>• Stimulates bone growth and integration | • Low mechanical strength<br>• Slow resorption rate |
| Glass Ceramics [92] | • Tailorable properties (e.g., strength, transparency, bioactivity)<br>• Good biocompatibility and osteoconductivity<br>• Versatile processing options | • Limited mechanical strength compared to metals<br>• Brittle material susceptible to fracture |
| **Composites** | | |
| Hydroxyapatite (HA)/Polyethylene (PE) [93] | • HA provides excellent biocompatibility and osteoconductivity<br>• Good wear resistance of PE<br>• HA improves the bonding and integration of the implant with the surrounding bone | • PE has lower mechanical strength compared to metals<br>• PE is susceptible to degradation and wear over time<br>• Limited load-bearing capacity of PE |
| Hydroxyapatite (HA)/Polyether ether ketone (PEEK) [94] | • HA enhances biocompatibility and osteoconductivity<br>• PEEK exhibits excellent mechanical properties, such as high strength and stiffness<br>• HA improves the osseointegration and bone integration of the implant | • PEEK has lower mechanical strength compared to metals<br>• PEEK may induce inflammatory responses in some patients<br>• Limited load-bearing capacity of PEEK |
| Graphene Oxide (GO)/Polyether ether ketone (PEEK) [95] | • GO enhances the biocompatibility and osteoconductivity of PEEK<br>• Improved mechanical properties of PEEK, such as strength and stiffness, due to the addition of GO<br>• GO promotes the integration of the implant with the surrounding bone | • PEEK has lower mechanical strength compared to metals<br>• PEEK may induce inflammatory responses in some patients<br>• Limited load-bearing capacity of PEEK |
| Carbon Fiber Reinforced Polymer (CFRP) [96] | • High strength and stiffness of CFRP<br>• Lightweight material<br>• Tailorable mechanical properties through fiber orientation and matrix composition | • Limited biocompatibility compared to othermaterials<br>• Potential for fiber delamination or breakage<br>• Difficulty in achieving strong bonding with bone |
| **Polymer** | | |
| Polyethylene (PE) [97] | • Excellent wear resistance<br>• Good biocompatibility<br>• Cost-effective | • Relatively low mechanical strength compared to metals |

| | | |
|---|---|---|
| | | • Limited load-bearing capacity |
| Polyether Ether Ketone (PEEK)<br>[97] | • High strength and stiffness<br>• Excellent biocompatibility<br>• Good resistance to wear and corrosion | • Potential for inflammatory responses in some patients<br>• Limited load-bearing capacity |
| Polylactic Acid (PLA)<br>[97] | • Biodegradable and bioresorbable<br>• Good biocompatibility<br>• Can be easily processed into various shapes | • Relatively low mechanical strength<br>• Fast degradation rate, which may not be suitable for long-term implants |
| Polyurethane (PU)<br>[98] | • Good biocompatibility<br>• Excellent flexibility and elasticity<br>• Versatile material with a wide range of applications | • Moderate mechanical strength<br>• Potential for degradation and wear |
| Polycaprolactone (PCL)<br>[98] | • Biodegradable and bioresorbable<br>• Good biocompatibility<br>• Can be easily processed into various shapes | • Relatively low mechanical strength<br>• Slow degradation rate, which may not be suitable for some applications |

# CHAPTER III

## 3. Methodology

### 3.1. Study Design:

The study design includes information about the literature sources, biomaterials approach criteria, and the fuzzy based MCDM model used in this study analysis.

#### 3.1.1. Sources of Literature

Biomaterials, tissue engineering, and medicinal material science in orthopedic implants were used to search across 6 different database which includes Google Scholar, IEEE, Science Direct, Mendeley, PubMed, and Scopus. The literature review spanned the years 2011 and 2023's May.

### 3.2. Fuzzy Logic and its Applications

Fuzzy logic is an effective method for dealing with uncertain data.
Fuzzy logic is a set of mathematical rules for forming inferences and taking action in the face of uncertainty. Allowing for a spectrum of truthfulness rather than either true or untrue gives a more comprehensive framework for dealing with ambiguous data. Fuzzy sets are used in fuzzy logic in order to express vague conditions numerically, and the membership degrees are used to determine how strongly an element belongs to a particular set [106].

**Key Concepts of Fuzzy Logic:**

A. An element's level of membership in a fuzzy set is described by its membership function. It converts the element's value to a membership degree at intervals zero and one, where (0) stipulates no membership, and (1) designates partial membership [107].
B. Qualitative concepts, rather than exact numerical values, are represented by linguistic variables in fuzzy logic. These variables provide reasoning similar to that of humans by using fuzzy sets labeled with language phrases [107].
C. Relationships between input and output variables may be mapped out with the use of fuzzy rules. IF-THEN statements are used to capture fuzzy reasoning. Common syntax for expressing such rules is "IF [antecedent], THEN [consequence]."
D. Fuzzy inference is a method for producing a clear output value by using both fuzzy rules and membership functions. Steps in this process include fuzzifying (transforming data into fuzzy sets), evaluating rules, and de-fuzzifying (returning a vague result to a single number) [107].

**Applications of Fuzzy Logic:**

A. Fuzzy logic has successful application in control systems, especially in situations when obtaining exact data, is difficult. Therefore, due to its ability to deal with uncertainties and non-linear connections, intuitive control is made possible [108].

B. Fuzzy logic is an essential tool for situations when partial knowledge is available [137].

C. Because of its ability to include ambiguity in feature extraction and classification, fuzzy logic is particularly useful for pattern recognition applications. Fuzzy pattern modeling and dealing with overlapping or confusing data are made easier with its help [138].

D. Fuzzy logic facilitates the creation of expert systems that simulate human judgment. Expert systems are able to deal with imprecise and unpredictable inputs because knowledge is represented using fuzzy rules and linguistic variables [139].

### 3.2.1. Multicriteria Decision Making Models (MCDM)

One of the most reliable approaches to make decisions is multi-criteria decision making (MCDM), also known as multi-criteria decision analysis (MCDA) [100]. Many disciplines, from economics to engineering design, may benefit from the vast variation provided by MCDM. When several criteria must be met in order to arrive at an optimal solution that satisfies all decision-makers, MCDM is put to use in practice to manage the structure, decision-making, and planning stages [100]. Different scientists have created and refined various MCDDM approaches throughout the course of the previous several decades. The algorithms' complexity, the weighting techniques for criteria, the manner that preferences assessment criteria are represented, the potential of ambiguous data, and the style of data aggregation are the primary differentiating factors among various approaches [101]. The fuzzy PROMETHEE is a method of multi-criteria decision making (MCDM) that aids decision-makers in conducting in-depth analyses, even when only qualitative or imprecise data is available [99][103], [102]. Fuzzy logic helps decision-makers make sense of ambiguous information [104].

### 3.2.2. Fuzzy PROMETHEE and its Applications

Fuzzy PROMETHEE is an approach that provides ranking for the MCDA problems. There are many uses for both science and technology, as well as in sociology, medicine, and other disciplines [104]. In order to compare and evaluate different levels of uncertainty, the fuzzy based MCDM method was developed. [103].

Fuzzy logic is a kind of human thinking that takes into account a range of possible outcomes when dealing with fuzzy data [104].

It provides a plausible line of thought that may be used to address issues of uncertainty. Fuzzy systems provide an answer that is neither yes nor no but somewhere in between. Using this framework, people may factor in emotional considerations while deciding between yes and no or between the two options True and False, unlike machines. Certainly Yes, Possibly Yes, Cannot Say, Yes, NO, Possibly NO, Certainly NO are all examples of the Fuzzy logic that Lofti Zadeh [105] proposed as an extension of the Boolean Logic to create possible facts in between YES and NO.

Fuzzy PROMETHEE takes in fuzzy data to provide a unique ranking [104]. Since fuzzy PROMETHEE takes into account data from micro to big networked control systems, it is a highly recommended comparison system [104]. When compared against Bayesian logic, commonly known as classical logic, it was found that fuzzy logic was the superior approach. Since the fuzzy PROMETHEE method may be applied to a large variety of situations, it is often used in studies to compare and evaluate options according to predetermined criteria. The sustainable biomaterial for Covid-19 was assessed using fuzzy PROMETHEE in research by [100]. The outcome of the study indicated that the fuzzy PROMETHEE method is an effective tool for assessing alternatives while facing ambiguity in the selection of materials as well as its functionality in monitoring Covid-19 patients in the contemporary context. Using the fuzzy PROMETHEE method, [105] examined the effectiveness of AuNPs and other nanomedicines in targeting cancer. The research found that when comparing, assessing, and rating many sets of options, the fuzzy PROMETHEE method produced credible results [105].

Very high (VH), high (H), moderate (M), low (L), and very low (VL) on a comparable linguistic fuzzy scale (see Table 3) indicate the scalar values of fuzzy data. When deciding on an analysis, we took into account the following criteria: biocompatibility, bio-specificity, yield point calculated in Mpa, mechanical strength, degradation rate, cost, corrosion, young modulus, and fatigue limit.

**Table 3. Linguistic Fuzzy Scale**

| Linguistic Scale | Fuzzy numbers |
|---|---|
| Very High (VH) | (0.75,1,1) |
| High (H) | (0.5,0.75,1) |
| Moderate (M) | (0.25,0.5,0.75) |
| Low (L) | (0,0.25,5) |
| Very Low (VL) | (0,0,0.25) |

In this thesis, we used the Yager index for the defuzzification of the fuzzy numbers\sets.

### 3.3. Determining Weights of Importance to Material Properties

Orthopedic implants are intended to repair and stabilize injured musculoskeletal structures. For the development of secure implants with an extended lifespan and without inducing disapproval, biomaterials must possess the following properties: mechanical properties, biocompatibility, wear, resistance to corrosion, and on occasion osseointegration. In the below section, we explain how we arrived at the relative value we've given each criterion using a combination of prior research and expert opinion.

**Biocompatibility:** Assessing a material's biocompatibility is a lengthy process that ensures it will not cause any unwanted side effects and will serve its intended purpose when introduced into a living organism. The Food and Drug Administration (FDA) provides some basic yet essential ideas about biocompatibility. In addition to bio-inertia, biocompatibility also encompasses bio-functionality and bio-stability. This fundamental concept is significantly affected by the material's properties (roughness, smoothness, crystallization, wettability, chemical composition of the surface, breakdown products, costs, stiffness), how it interacts with the biological surroundings of the targeted tissues (protein adsorption, inflammation, blood contact), the length of time the device is in use, and the device's intended function. It is critical to understand that a material's biocompatibility might vary greatly based on the exact anatomical region inside the body where it is applied. As an illustration, a biomaterial deemed highly biocompatible in bone tissue might not be as effective when implanted in the soft tissues or the circulatory system. Therefore, data on biocompatibility is utilized on each varying host location and the determined alternatives. As an example, Titanium alloys are frequently utilized in non-weight-bearing surfaces that include femoral stems and necks because they possess a smaller elastic modulus, leading to reduced stress shielding of bone [142], while Magnesium possesses greater strength compared to natural bone, decreasing stress shielding through load transfer at the implant-bone interface [143]. It is used to treat spine fractures [144]. Chandorkar et al. (2018) examined the biocompatibility of a novel polymer encasing in bone and heart tissue. When applied to bone, the polymer covering revealed great integration and a low response to inflammatory agents, but when implanted in heart tissue, it generated a more substantial inflammatory response. This emphasizes the need of taking into account the individual anatomical setting when evaluating the biocompatibility of biomaterials for various applications in order to ensure superior efficiency and favorable results for patients. [109]-[111][141].

**Bio - specificity:** Orthopedic implants and other biomedical applications rely heavily on specificity in their design and development. Specificity in biomaterials is their capacity to stimulate desired cellular responses while suppressing undesired ones. The specificity of a new composite biomaterial for bone regeneration was studied by Smith et al. (2019). providing an example of this idea. Surface changes and functionalization procedures were used to improve the material's interaction with osteoblasts, which in turn improved cellular adhesion, proliferation, and differentiation. Conclusions Bio-specificity in biomaterials has the potential to enhance the clinical performance of orthopedic implants, as shown by the study's results [112].

**Yield point (Mpa):** To what extent a biomaterial can tolerate mechanical stress without permanently deforming is determined by its yield point, a critical mechanical feature. It is the tension at which a material begins to deform plastically rather than elastically. When designing and evaluating biomaterials for diverse purposes, such as orthopedic implants, knowledge of the yield point is essential. The yield point of titanium alloys is important since they are often used in orthopedic implants, as shown by research by Johnson et al. (2019). This research looked at how alloy composition and microstructure affected titanium's yield point behavior, providing insight into titanium's mechanical reaction and helping to optimize implant designs for maximum performance and durability [113].

**Mechanical strength (Mpa):** Mechanical strength refers to the ability of a material to withstand applied forces or loads without permanent deformation or failure, indicating its resistance to mechanical stress and strain as shown by research by Gupta & Kumar et al. (2021). Implant materials are selected for their mechanical qualities and wear resistance. Important properties include hardness, tensile strength, modulus, and elongation. One of the causes of implant damage is biomechanical incompatibility; thus, the material used must have a modulus that is comparable to that of bone [114].

Newer, stiffer materials may lead to bone loss in the implant's surrounding area. Therefore, in order to prevent the implant from being destroyed, a material with the required combination of high strength and low modulus of elasticity should be utilized for implantation.

**Degradation rate:** Orthopedic implants, particularly prosthetic implants that cannot be changed, could be at risk of structural failure requiring revision surgery if they degrade over time. The predicted lifespan of implants that sites in the human body can only be achieved via the invention of implant materials with superior resistance to corrosion in physiological settings. Temporary orthopedic implants made from materials with regulated degradation rates have enormous promise since they are only meant to serve a purpose during the healing process and may be removed once the patient has fully recovered [115].

**Cost:** According to the literature, it is crucial for efficient healthcare administration to assess the financial consequences of biomaterials used in orthopedic implants. Smith et al. (2020) report that the initial cost of implant materials has a significant effect on the total cost of orthopedic treatments. The total cost-effectiveness of biomaterial options is affected by aspects including long-term maintenance fees, revision operations, and post-operative problems (Jones & Johnson, 2018). In order to maximize both patient outcomes and the use of healthcare resources, it is crucial to conduct an in-depth examination of the financial implications of various biomaterial choices [116][117].

**Corrosion:** Extreme rusting of material due to chemical reactions within the implanted environment. Metallosis and allergy responses are caused when low corrosion of implants releases non-compatible metal ions. As a result, making implants that are resistant to corrosion is important for their long-term use in humans. Metals in living systems are more vulnerable to corrosion. Human bodily fluids include several different types of ions, including cations and anions. Therefore, corrosion resistance is a crucial feature of metallic biomaterials [118].

**Young's modulus (Gpa):** Depending on their function and setting, orthopedic implant materials have different mechanical requirements. Five crucial mechanical parameters are Young's modulus, the strength of yield, the ultimate strength of tensile, fracture resistance, and elongation at break. These 'five' characteristics may be used to anticipate and analyze the behavior of materials with unique mechanical properties, such as fatigue resistance. Bone loss or the resorption of bone and implant disengagement may occur if the implant biomaterials contain a reduced amount of Young's modulus than the surrounding bone. As a result, it is preferable for orthopedic implant bio-materials to possess Young's modulus close to that found in human bones [119].

**Fatigue limit (Mpa):** Joint replacements, especially for the hip, knee, and ankle, must meet stringent biomechanical criteria, and resilience to fatigue is one of the most important of them. When it comes to THRs, the loading stress level might easily exceed the patient's body weight by a significant margin. Hip surgical replacements are supposed to last two decades, which means that their physical integrity must be preserved after being loaded. The combination of tension and corrosion may lead to a condition such as wear fatigue or wear corrosion fatigue in humans. Biomaterials that have strong fatigue stamina are desired for orthopedic implants because fatigue fracture has been the leading cause of unsuccessful bio-medical implants after a short period [120]. (See Table 4) below is the dataset change in content for biomaterials used in orthopedic implants.

**Table 4. Dataset**

| Alternatives /Criteria | Biocompatibility | Bio-specificity | Yield point (Mpa) | Mechanical strength (Mpa) | Degradation rate | Cost | Corrosion | Young's Modulus (Gpa) | Fatigue Limit (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| Preference Function | Gaussian | Gaussian | Gaussian | Gaussian | Gaussian | Gaussian | Gaussian | Gaussian | Gaussian |
| Importance Weights | VH | VH | L | H | VL | L | VL | H | VL |
| Aim | Max | Max | Min | Max | Min | Min | Min | Max | Min |
| Titanium [121] | H | L | VH | VH | L | H | VL | L | M |
| Stainless Steel [121] | H | L | L | H | L | L | L | L | L |
| Cobalt-Chromium Alloy [121] [122] [131] | H | L | M | VH | L | H | M | L | H |
| Magnesium [121] [131] | M | H | VL | VL | VH | L | H | VL | VL |
| Zinc [122] [131] | H | M | L | L | M | L | VH | N/A | L |
| Tantalum [122] [123] | H | L | L | H | L | H | VL | L | L |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nickel [124] [125] | M | H | L | H | L | L | M | VL | L |
| Zirconia ($ZrO_2$) [125] | H | L | VH | VH | L | H | L | L | VH |
| Alumina ($Al_2O_3$) [125] [126] | H | L | M | M | L | H | VL | M | H |
| Calcium Phosphate [126] [132] | H | L | VL | VL | L | H | VL | VL | H |
| Hydroxyapatite [126] | H | L | VL | VL | L | H | VL | L | L |
| Glass Ceramics [126] [132] | H | L | M | H | L | H | L | M | M |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hydroxyapatite (HA)/Polyethylene (PE) [127] [133] | H | L | VL | VL | L | M | VL | VL | N/A |
| Hydroxyapatite (HA)/Polyether ether ketone (PEEK) [127] | H | L | VL | VL | L | H | L | H | L |
| Graphene oxide (GO)/Polyether ether ketone (PEEK) [127] [133] | H | L | VL | VL | L | H | L | VL | L |
| Carbon fiber reinforced polymer (CFRP) [128] | H | L | VL | L | L | H | VL | L | L |
| Polyethylene (PE) [129] [134] | H | L | VL | VL | L | L | VL | L | N/A |
| Polyether ether ketone (PEEK) [129] | H | L | VL | VL | L | H | L | VL | L |
| Polylactic Acid (PLA) [129] [134] | H | L | VL | VL | M | M | VL | VL | VL |
| Polyurethane (PU) [130] [134] | H | L | VL | VL | M | H | L | VL | VL |
| Polycaprolactone (PCL) [130] [134] | H | L | VL | VL | L | M | VL | VL | VL |

# CHAPTER IV

## Results and Discussion

The full-ranking results for the different Biomaterials used in orthopedic implants were investigated based on the assigned weight of relevance to the criteria and analyzed characteristics for comparison as (shown in Table 5) below. The results of the fuzzy-PROMETHEE approach show that Cobalt-Chromium (Co-Cr) Alloy ranks top, with a net outranking flow of 0.2686. As a result, Co-Cr Alloy is the first-ranked and best-performing implant biomaterial based on the selected criteria. It has outstanding mechanical strength, allowing it to endure the high loads and stresses experienced in orthopedic implants. This guarantees the implant's long-term stability and resilience, lowering the likelihood of implant failure, and it has greater corrosion resistance, allowing it to tolerate the harsh physiological state found within the human body. This resistance to corrosion assures the implant's lifespan and reduces the discharge of harmful ions onto the neighboring tissues. It also exhibits beneficial biocompatibility, with few negative reactions or responses to inflammation noticed in vivo, and it also happens to be cost-effective, making it an advantageous choice for orthopedic implant uses.

Zirconia ($ZrO_2$) ranks second with a net outranking flow of 0.2116, followed by alumina ($Al_2O_3$) with a net flow of 0.1941 respectively. The ranking result reveals that Polyethylene (PE) is the lowest-ranked biomaterial for orthopedic implants, with a net outranking flow of -0.2791. Table 5 displays the comprehensive ranking results for the alternatives.

**Table 5.** Fuzzy PROMETHEE for Biomaterials Used in Orthopedic Implants

| **Rank** | **Alternatives** | **Net Outranking Flow** | **Positive Outranking Flow** | **Negative Outranking Flow** |
|---|---|---|---|---|
| 1 | Cobalt-Chromium Alloy | 0.2686 | 0.3601 | 0.0915 |
| 2 | Zirconia ($ZrO_2$) | 0.2116 | 0.3259 | 0.1143 |
| 3 | Alumina ($Al_2O_3$) | 0.1941 | 0.3157 | 0.1216 |
| 4 | Tantalum | 0.1773 | 0.3129 | 0.1356 |

| | | | | |
|---|---|---|---|---|
| 5 | Stainless Steel | 0.1736 | 0.3069 | 0.1333 |
| 6 | Hydroxyapatite (HA)/Polyether ether ketone (PEEK) | 0.1354 | 0.2834 | 0.1480 |
| 7 | Carbon fiber reinforced polymer (CFRP) | 0.1236 | 0.2831 | 0.1594 |
| 8 | Titanium | 0.1226 | 0.2825 | 0.1599 |
| 9 | Glass Ceramics | 0.0771 | 0.2571 | 0.1801 |
| 10 | Zinc | 0.0535 | 0.2516 | 0.1980 |
| 11 | Nickel | 0.0528 | 0.2515 | 0.1987 |
| 12 | Magnesium | -0.0046 | 0.2212 | 0.2258 |
| 13 | Hydroxyapatite | -0.0049 | 0.2223 | 0.2271 |
| 14 | Calcium Phosphate | -0.1146 | 0.1635 | 0.2780 |
| 15 | Graphene oxide (GO)/Polyether ether ketone (PEEK) | -0.1437 | 0.1282 | 0.2719 |
| 16 | Polylactic Acid (PLA) | -0.1833 | 0.1083 | 0.2916 |
| 17 | Polyether ether ketone (PEEK) | -0.1887 | 0.1063 | 0.2950 |
| 18 | Hydroxyapatite (HA)/Polyethylene (PE) | -0.2158 | 0.0989 | 0.3147 |
| 19 | Polyurethane (PU) | -0.2184 | 0.0949 | 0.3133 |
| 20 | Polycaprolactone (PCL) | -0.2371 | 0.0844 | 0.3215 |
| 21 | Polyethylene (PE) | -0.2791 | 0.0643 | 0.3434 |

Figure 1-6 depicts the strengths and weaknesses of the biomaterial evaluation for orthopedic implants. As shown in Figure 1, the Cobalt-Chromium Alloy material has a greater positive status for effectiveness when compared to the following criteria: Mechanical strength, Young's Modulus, Bio-specificity, and Cost. while Biocompatibility and Degradation rate sit just in line. It also has a thin unfavorable position for the following criteria: Corrosion. Its Fatigue limit and Yield point are on the negative side. This demonstrates the efficiency of this material in orthopedic implants.

Next to Zirconia ($ZrO_2$), which is a ceramic biomaterial, a crystalline oxide that exhibits a broadly positive stance for efficacy for the following criteria: Mechanical strength, Young's Modulus, Bio-specificity, and Cost. while Biocompatibility, Degradation rate, and Corrosion sit just in line. It has a negative standing for yield point and Fatigue Limit.

Alumina ($Al_2O_3$) which is also a ceramic biomaterial, a high-purity form of aluminum oxide has a positive stance for the following criteria; Young’s Modulus, Mechanical strength, Bio-specificity, and Cost. Biocompatibility and Degradation rate are just in line. Alumina has a negative status for yield point and Fatigue Limit with an unfavorable position for Corrosion.

**Figure 1. Positive and Negative Evaluation Results with the Designated Alternatives**

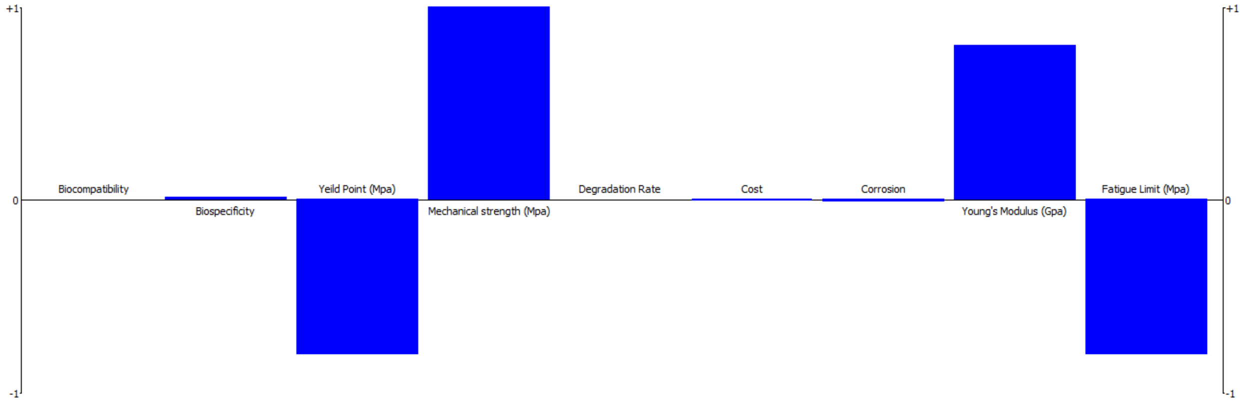


Figure 1. Profile Rank 1 - Cobalt-Chromium Alloy

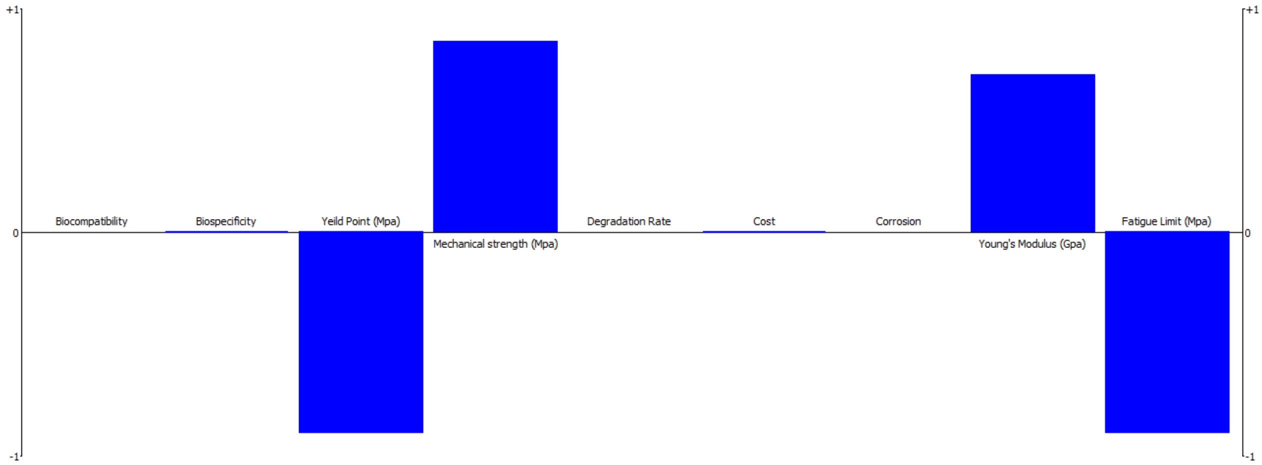


Figure 2. Profile Rank 2 - Zirconia ($ZrO_2$)

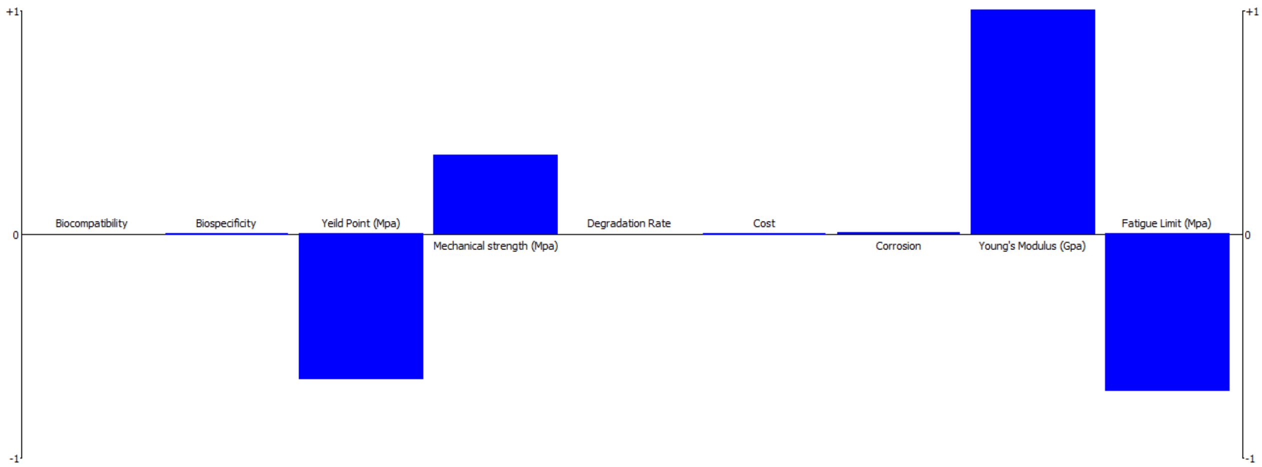


Figure 3. Profile Rank 3 - Alumina ($Al_2O_3$)

Contrary to the positive outcomes, polyurethane (PU) has a more unfavorable position due to its lower effectiveness on the following criteria: Mechanical strength and Young's modulus. Although it is a biocompatible material with its Biocompatibility and Corrosion sitting just in between, its bio-specificity and Degradation rate are considered to be low given that the strength of a biomaterial is concentrated on its mechanics, according to the criteria for comparison given. It has a positive stance showing strength for the following criteria: yield point, as well as Fatigue Limit and is considered low in Cost. This illustration is almost identical to (PCL) as seen in Figure 5 below.

Polycaprolactone (PCL) has a negative rate for less efficacy on the following criteria; Mechanical strength and Young's Modulus. Its Biocompatibility, Degradation rate, and Cost is between the strength and weaknesses. Bio-specificity and Corrosion, cannot be said to be as significant as the above criteria mentioned.

Polyethylene (PE) has a larger negative status for less efficacy on the following criteria: Mechanical strength, Young's Modulus, and Fatigue Limit. Results also show that Biocompatibility and Degradation rate sits between positive and negative, and Bio-specificity, Cost, as well as Corrosion have little significance according to the mentioned criteria. It has a positive stance showing strength for the criteria: yield point.

The parameters above the 0 level show the positive sides of the alternatives while those below the 0 level show the negative sides.

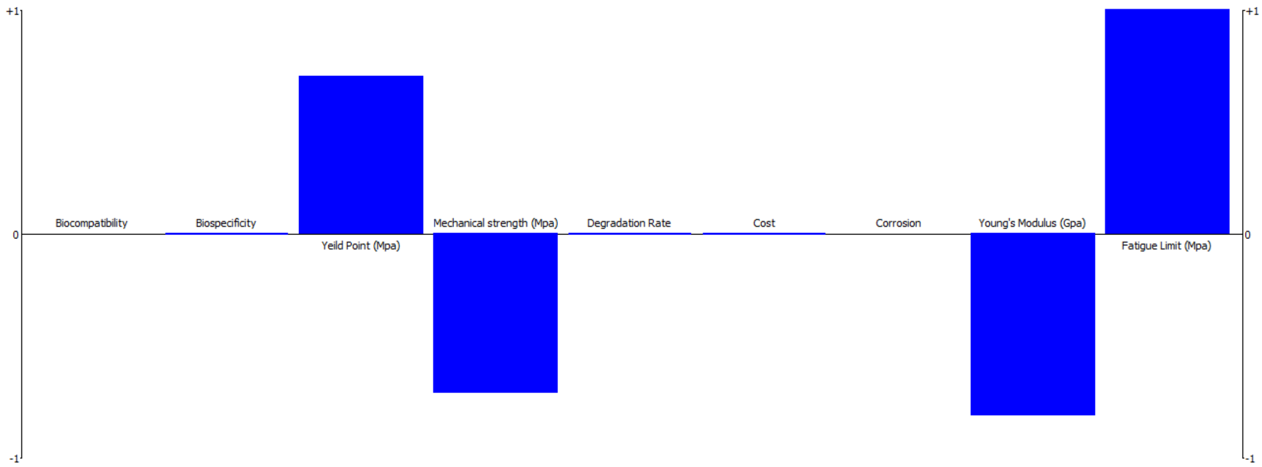


Figure 4. Profile Rank 19 - Polyurethane (PU)

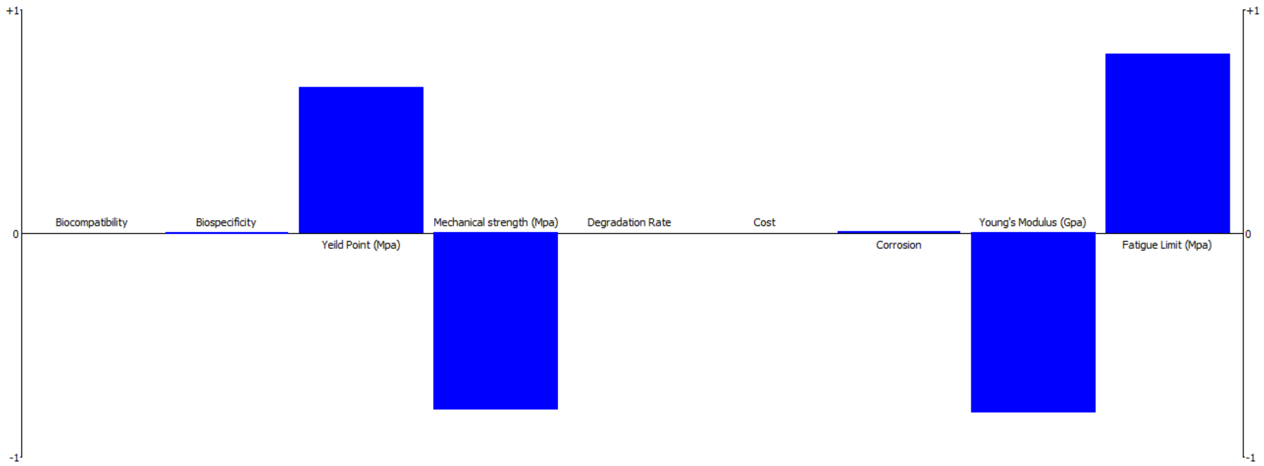


Figure 5. Profile Rank 20 - Polycaprolactone (PCL)

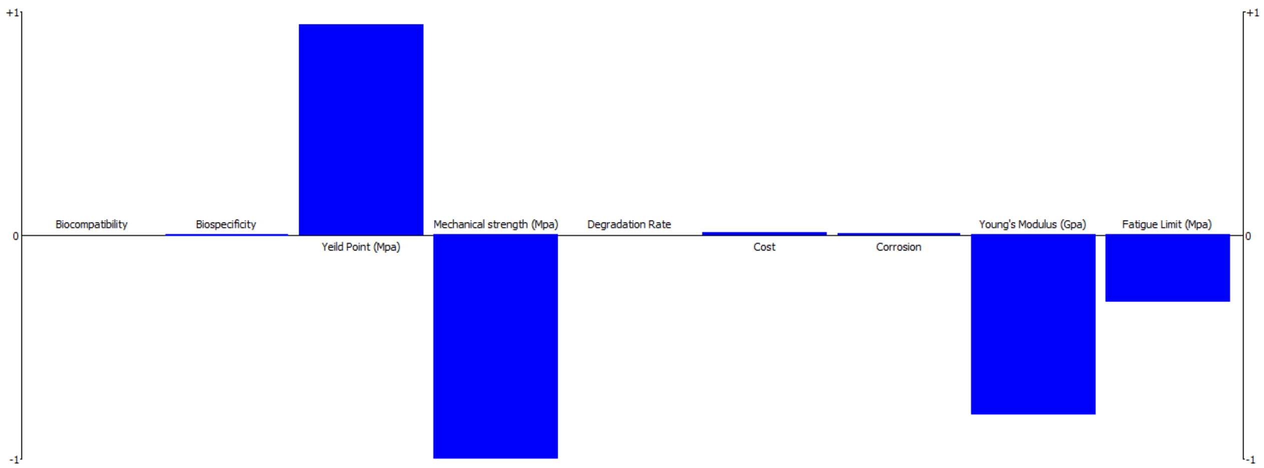


Figure 6. Profile Rank 21 - Polyethylene (PE)

The Cobalt-Chromium Alloy ranks top with an outranking net flow of 0.2686 according to the results obtained using the fuzzy-PROMETHEE approach. It was determined from this assessment and comparison with the (Co-Cr) Alloy that it was a material used in orthopedic implants that were favored and more efficient. A study conducted by [135] discussed and showed that the alloy has good mechanical qualities, including high strength, biocompatibility, and corrosion resistance. The study focuses on the cobalt-chromium alloy's potential for various orthopedic implant applications.

The findings of our simulation using the fuzzy PROMETHEE application are comparable to the results from the literature search.

Zirconia ($ZrO_2$) ranks second on the preference ranking flow with an outranking net flow of 0.2116 followed by Alumina ($Al_2O_3$) with an outranking net flow of 0.1941.

The ranking result shows that Polyethylene (PE) with an outranking net flow of -0.2791, is the least effective biomaterial used in orthopedic implants according to the analyzed characteristics and weighted criteria's relevance as indicated in Table 4. Furthermore, according to a study by [136], Polyethylene (PE), which is commonly utilized in joint replacements, is less suited for orthopedic implants for a number of reasons that were outlined in their scientific research. PE has limits in terms of wear resistance since it can become worn over time and produce debris, which could result in implant loosening and osteolysis.

It is crucial to keep in mind that these conclusions are based on the assessed criteria, mechanisms of action, and weights given to their relative relevance. Depending on the options available for review and the criteria with their assigned weights of importance for comparison, the preferences of the decision-maker for orthopedic implants may differ based on their priorities. Additionally, more than one distinct approach can be blended for effectiveness. A thorough comparison of the biomaterials utilized in orthopedic implants is provided by the study's findings. Based on the particular circumstances and priorities of the decision-makers, the findings may easily be updated. The analysis depends heavily on the expert's guidance when selecting the criteria and setting the weights for the criterion.

# CHAPTER V

## Conclusion

Choosing the right biomaterials for orthopedic implants is a multi-step procedure that needs experts to weigh a number of factors. Multi-criteria decision-making (MCDM) approaches, such as fuzzy PROMETHEE, are useful for dealing with the complexity and uncertainties of biomaterial selection. According to this study, the fuzzy PROMETHEE approach can be used to rank, compare, and assess the biomaterials used in orthopedic implants as well as to find and choose the most suitable replacement materials. The alternatives, criteria, and important weights that affect the ranking, assessment, and comparison were chosen after literature searches and consultation with experts in the field.

By utilizing significant connected factors, as many criteria as are judged required depending on the preferences of the decision-maker, and an efficient ranking, evaluation, and comparison method, selected materials for orthopedic implants can be rationally and methodically compared. According to the findings of this study, which employed the fuzzy PROMETHEE technique, cobalt-chromium alloy, which had an outranking net flow of 0.2686, was the most efficient biomaterial for orthopedic implants, followed by zirconia and alumina, which had outranking net flows of 0.2116 and 0.1941, respectively. With a net flow of -0.2791, polyethylene (PE) ranks as the least orthopedic implant material in this study.

In particular, the fuzzy PROMETHEE technique offers a rigorous and quantifiable way to evaluate and rank potential biomaterials. An all-encompassing assessment of biomaterials' overall performance is possible because it takes into account the weight of each criterion and the level of user satisfaction or preference for each option.

Using fuzzy PROMETHEE, decision-makers can better understand the costs and benefits of various biomaterials. Using this data, clinicians and patients can choose biomaterials that improve the chances of a successful implant.

Research and development efforts in MCDM, fuzzy logic, and biomaterial science are underway and will be necessary to address these constraints. Improvements can be made in areas such as data collection and analysis, decision model openness and interpretability, and methodology refinement and standardization.

In conclusion, MCDM techniques, such as fuzzy PROMETHEE, provide helpful resources for determining which biomaterials to use in orthopedic implants. These techniques allow for the objective and thorough assessment of various biomaterial options according to various criteria and user preferences. While not without flaws, MCDM approaches combined with biomaterial research show significant potential for boosting patient outcomes and quality of life by improving biomaterial selection and usage in orthopedic implants.

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# APPENDICES

## Appendix A

## Ethical Approval Document

There is no ethical approval document that can be presented.

## Appendix B

## Curriculum Vitae

**ESTHER CHIFURUMNANYA ANYANWU**

+2347083032161 estherfrancisa@gmail.com

**RESEARCH INTERESTS**

CRISPR-Cas9 Engineering
Genome Editing and Developmental BiologyImaging
and Medical Devices
Molecular, Cellular, and Tissue Engineering
Regenerative Medicine, Instrumentation, and Diagnostics
Entrepreneurship

**EDUCATION**

**MSc.** Biomedical Engineering. Near East University, Nicosia/TRNC — February, 2022 - Present
**BSc.** Biomedical Engineering. Near East University, Nicosia/TRNC — February, 2019 – August, 2021
**Diploma.** Pre – Medical. Girne American University, Kyrenia/TRNC — October, 2013 – May 2016
**Certificate.** Preparatory Health Courses. College of Light Industry, Grodno/Belarus — September, 2012 – June 2013

**RESEARCH EXPERIENCE**

**Master Research Projects, Near East University**
**Project Title:** Application of CRISPR Cas9 in Cancer Therapy — March, 2022 – June, 2022
**Supervisor:** Prof. Dr. Ayse Gunay Kibarer

**Project Title:** The Holter Monitor — February, 2022 – June, 2022
**Supervisor:** Assoc. Prof. Dr. Dilber Uzun Ozsahin
**Asst. Supervisor:** Assist. Prof. Dr. Berna Uzun

**Project Title:** Importance of Cell adhesion and migration in Tissue Engineering — February, 2022 – May, 2022
**Supervisor**: Prof. Dr. Terin Adali

- Researched methodologies, modalities, as well as applications and gathered data from the University Library
- Using Microsoft Excel spreadsheet and MCDM approach, acquired data were inspected and evaluated.
- Utilized Fuzzy logic algorithm for absolute values of acquired data

**Undergraduate Research Projects, Near East University**

**Thesis 1**: Goal programming and its application in healthcare February, 2021 – June, 2021
**Thesis 2**: Nausea and vomiting in pregnancy June, 2021 – August 2021 **Project**
**Title**: The importance of herbal medicine in advance medical care February, 2020 – June, 2020
**Supervisor**: Assoc. Prof. Dr. Dilber Uzun Ozsahin

- Reviewed data obtained from GOOGLE SCHOLARS and PUBMED
- Conducted research on the methods of control and their effects, collected data from the University hospital
- Inspected and analyzed data using a Microsoft excel spreadsheet
- Acquired results via MCDI techniques.

**INTERNSHIP EXPERIENCE**

**Near East University Robotic Laboratory, Nicosia, TRNC** June, 2021 - August, 20213D

Printing laboratory training in the production of ventilators and face mask shield cover.

SOLIDWORKS utilization in

- Flow simulation of a lamina pipe
- Prosthetic hand and Hex nut Design

**AWARDS AND HONORS**

**Near East University Scholarship Award** **February 2022 - Present**
60% Funding Scholarship for Master Program

Dean's Certificate of High Honour for Academic Performance and Conduct 2020 – 2021
Dean's Certificate of High Honour for Academic Performance and Conduct 2019 – 2020

**PUBLICATIONS**

1. Chinyerem, E. D., Okwubanego, D. C., Chukwuemeka, O. A., **Chifurumnanya, E. A**., Chike, C.U. Prevalence of Malaria and Vector Abundance in Amichi Community. Journal of Global Ecology and Environment. (2022)

2. Hafiz, L., Okafor, J. C., **Chifurumnanya, E. A.,** Chukwuemeka, O. A., Anyanwu, A. C., Okwubanego, D. C., Chike, C. U. The impact of talent management on the performance of employees at Barau Dikko TeachingHospital (BDTH), Kaduna. South Asian Journal of Social Studies and Economics. (2022)

**PROFESSIONAL DEVELOPMENT TRAINING**

**Workshop**
Breast Cancer Awareness (Operational Research Center in Healthcare) – Workshop, Near East University, Nicosia,TRNC, November 14, 2022

Capacity building workshop, VOIS Cyprus, Northern Cyprus, TRNC, February 28, 2020. The Workshop focused on thegoal of empowering international students in Northern Cyprus.

**Moderated Lecture**
Defibrillators in Biomedical Instrumentation. Faculty of Science, Near East University, Nicosia, TRNC. August 13,2021.

**Seminars/Webinars**
Stanford University School of Medicine, 2022 CISL Symposium: Fostering the Next Generation of Health Equity Advocates. December 14, 2022

Stanford University School of Medicine, Prostate Cancer CME Series – Treatment Across the Prostate Cancer Continuum – Specialist Track (Recorded Webinar). December 11, 2022

Stanford University School of Medicine, (Recorded Webinar) Physician Distress – Risk Factors and Prevention in Physician Suicide. December 11, 2022

Stanford University School of Medicine, Pediatric Grand Rounds (Recorded Webinar) Neglected Children – A Role forChild Health Professionals. December 11, 2022

Stanford University School of Medicine, Pediatric Grand Rounds (Recorded Webinar) The Case for Bringing Precision Molecular Medicine into the Neonatal ICU. December 11, 2022

Stanford University School of Medicine, Pediatric Grand Rounds (Recorded Webinar) The Long and Winding Road – Steps Towards 3D Printing a Heart. December 11, 2022

Stanford University School of Medicine, Pediatric Grand Rounds (Recorded Webinar) Integrating Community HealthWorkers into Team-Based, Early Childhood Preventive Care. December 11, 2022

Massachusetts Institute of Technology, Inside Supply Chain Analytics & Fundamentals (Webinar). September 7, 2022.

Girne American University, How Green is Your Campus – Predominantly on Environment and Its Effects on Health (Seminar). May 8, 2014

**PROFESSIONAL AFFILIATIONS AND LEADERSHIP SERVICES**

Member, Nigeria Student Association Near East University 2019 – 2020

Leader (Welfare Department), Alight House International, Kyrenia, TRNC 2015 – 2017

**CERTIFICATIONS**

Most Used SOLIDWORKS Tools By Students (UDEMY) 2022

Python For Beginners – All Basics of Python (UDEMY) 2022

Introduction To Cybersecurity (UDEMY) 2022

Nutrition Disorders and Oral Health (UDEMY) 2022

Heart Attack and Diabetes Prediction Project in Apache Spark (UDEMY) 2022

Entrepreneurship and Innovation (UDEMY) 2022

Infection Prevention and Control (IPC) for Novel Coronavirus COVID-19 (WHO) 2020

Discovering Science – Medicinal Chemistry (FUTURELEARN) 2018

IP Tutor – Modules in Trademarks, Patents, Designs (Intellectual Property Office) 2016

**WORK EXPERIENCE**

**Previc Specialist Hospital, Rivers State, Nigeria.** November, 2022- Present

Biomedical Engineer Assistant

- Assist with medical device and equipment installation, adjustment, maintenance, and repair.
- Prepare and present engineering solutions to existing and new clients. Assist with the operation of IT-based service application software for diagnostics and troubleshooting.
- Inspect and evaluate finished installations to verify compliance with design and equipment requirements, aswell as operating and safety regulations.
- Generate documentation for installation and maintenance operations before and after installation.
- Successfully maintained laboratory including instrumentation maintenance, checking equipment for proper function as well as various other support duties which grew the hospital's operation to 5%.
- Collaborated with team members to boost customer satisfaction by 52% by properly assessing visitor feedback and converting it into useable evaluations to encourage changes in procedures and organizationalstructure.
- Completed projects and special assignments by establishing objectives; determining priorities, managingtime, gaining the cooperation of other staff, monitoring progress, and making adjustments to plans.

**VOLUNTEER EXPERIENCE**

**Cancer Awareness Fund Raising Campaign Kyrenia, TRNC** 2019

**SOS Children's Association, Fund Raising Campaign Kyrenia, TRNC** 2019

**Previc Specialist Hospital Port Harcourt Nigeria** 2017 – 2018

- Medical Assistant, Clinic Volunteer.

**Department of Pre-Medical, Girne American University, Kyrenia, TRNC** 2015

Initiated and actualized model concept of a medical tent for a spring festival event

**De Lamb Nursery and Primary School, Port Harcourt, Nigeria** 2012

- Mentored and tutored struggling students, Promoted Social Gatherings in the school, and provided encouraging team to students with low self-esteem.

**All Best Health Center, Port Harcourt, Nigeria** 2010 – 2011

- Provided assistance in the child care department – Monitoring, serving, and teaching. Permanent medicalstaff assistance.

**SKILLS**

- SOLIDWORKS 3D CAD: Associate level on a standard Model
- Programming: Intermediate R, Beginner Python
- Operating Systems: Windows 10 / 8 / 7, MAC OS
- Computer Skills: Microsoft Word, Excel, Powerpoint and SPSS
- Analytical Research Skills: Data collection, analysis, and interpretation; Report and Manuscript writing; Literature searching

**LANGUAGES**

**English**: Official Language, Advanced levels in Speaking, Listening, Reading and Writing.
**Russian**: Intermediate Levels in Speaking, Listening, Reading and Writing
**Turkish**: Basic Levels in Speaking, Listening, Reading and writing

## Appendix C

INBOX | NOW VIEWING: NEW PAPERS ▾

Submit File

Online Grading Report | Edit assignment settings | Email non-submitters

| AUTHOR | TITLE | SIMILARITY | GRADE | RESPONSE | FILE | PAPER ID | DATE |
|---|---|---|---|---|---|---|---|
| Esther Chifurumnanya... | Abstract | 0% | -- | -- | | 2151128234 | 25-Aug-2023 |
| Esther Chifurumnanya... | Chapter 1 Introduction | 0% | -- | -- | | 2151129294 | 25-Aug-2023 |
| Esther Chifurumnanya... | Chapter 4 Results and Discussion | 0% | -- | -- | | 2151135273 | 25-Aug-2023 |
| Esther Chifurumnanya... | Chapter 5 Conclusion | 0% | -- | -- | | 2151137407 | 25-Aug-2023 |
| Esther Chifurumnanya... | Chapter 2 Literature | 1% | -- | -- | | 2151136345 | 25-Aug-2023 |
| Esther Chifurumnanya... | Chapter 3 Material and Method | 7% | -- | -- | | 2151146650 | 25-Aug-2023 |
| Esther Chifurumnanya... | Chapter 1-5 Full Thesis | 9% | -- | -- | | 2151148861 | 25-Aug-2023 |