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Materials Selection for Hip Prosthesis by the Method of Weighted Properties

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Abstract – *Process of materials selection for an artificial part, which is planted in vivo, has been always a vital procedure. Production and construction requirements for implants would involve a wide variety of considerations from mechanical specifications to medical limitations. From mechanical point of view, it is desired the implant exhibits mechanical properties of the missing bone as close as possible to reduce the risk of failure and provide a high level of comfort to the patient. The most bolded medical trait that prostheses must possess is the quality of biocompatible being; meaning that, they have to be accepted by the body's living organisms. In this paper, five common biocompatible materials as candidates for hip prostheses production namely, 316L St Steel (cold worked, ASTM F138), Co–28Cr–6Mo (cast, ASTM F75), Ti–6Al–4V (hot forged, ASTM F620), Zirconia (ceramic, 3Y-TZP) and Alumina (ceramic, ZTA) are selected and evaluated by the method of weighted properties, in order to narrow down the search to find the candidate which best fit the real bone's mechanical traits. For the analysis, six attributes were considered and weighted against each other namely, elastic modulus, yield strength, tensile strength, fatigue strength, corrosion rate and density. From the results, alumina and stainless steel show highest performance indexes but as it is discussed, due to the importance of biocompatibility required in practical, materials ranked on position 4th and 5th which are respectively of cobalt and titanium alloys–although are less mechanically similar to the real bone, are the most desirable choices in the industry. Indeed, biocompatibility trait outweighs the highest mechanical similarity to real bone. It will be concluded that in the process of materials selection for implants, WPM is not able to solely predict the best candidate unless, the results are compared with experimental data concerning the body response to candidate materials.*

Keywords: Materials Selection, Hip Prosthesis, Weighted Properties Method, Biocompatible Material, Performance Index, Implant

1.0 INTRODUCTION

Historically, the development of modern biomaterials is related to the combined development of modern medicine and new materials. A variety of materials are currently available for use as implants in the human body. The following are a few types of materials that have potential use in biomedical applications. Metals such as stainless steels, Cr-Co alloys and more recently Ti-based materials have been used for this purpose [1, 2]. Polymers like low-density polyethylene serve as tubing in catheters. Ultra-high-molecular-weight (UHMW) polyethylene is one of the major articulating surfaces used in total hip or knee replacements. Biodegradable polymers, used in absorbable sutures, are gaining popularity as biomaterials as well. Ceramics have been widely used in biomedical applications for load bearing implants

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and the dental industry [3]. Metals, such as 316L stainless steel, titanium alloys, and Cr-Co alloys when suitably processed possess high tensile, fatigue and yield strengths, low reactivity and good ductility for use as stems of hip implant devices. Composite materials are another class of materials where the individual advantages of polymers, ceramics, and metals combine in different applications. A typical example is hydroxyapatite coated Ti-C based materials.

The most important characteristics that determine the feasibility of the use of metals as implants are biocompatibility, strength including yield strength, tensile strength, fatigue strength, and corrosion resistance. A biocompatible material may disrupt normal body functions as little as possible. A biocompatible material causes no thrombogenic, toxic, or allergic inflammatory response when the material is placed in vivo. The material must not stimulate changes in plasma proteins and enzymes or cause an immunological reaction, nor can instigate carcinogenic, mutagenic, or teratogenic (gross tissue change) effects.

2.0 BIOMATERIALS

There are many definitions for biomaterials. The most appropriate for current research is, biomaterials are any materials which are used to make artificial devices to replace a part or a function of the body in safe, reliable, economic and physiologically accepted manner [4]. A biomaterial is synthetic material used to replace part of living system or to function in intimate contact with living tissue [5]. Biomaterials have been formally defined as “a systematically and pharmacologically inert substances designed for implantation within or incorporation with living systems [6].

Successful design and development of biomaterials also requires characterization of physical and chemical properties. As for instance, important physical and chemical properties include porosity, protein adhesion, elastic modulus, yield stress, tensile strength, elongation, fracture toughness, durability and in vivo stability [6]. Corrosion resistance in hip prosthesis should be strong, durable and non-degradable in vivo.

The ultimate goal of biomaterials is to improve human health by replacing the function of natural living tissue and organs in the body, it is necessary to understand their properties. The success of any biomaterials depends on three factors: biocompatibility, health of recipient, and skill of surgeon who performs the replacement surgery. Required characteristics of biomaterials are: [6]

1. Biocompatibility,
2. Pharmacological acceptability (non toxic, non immunogenic, non carcinogenic),
3. Chemically inert and stable (no time dependent degradation),
4. Adequate mechanical strength (atomic bonding and elasticity, static load),
5. Sound engineering design,
6. Adequate fatigue life,
7. Proper weight and density.

Biocompatibility is one of the most important attributes which needs to be fulfilled by biomaterials used in medical devices. Biocompatibility can be defined as the ability of the material to perform with an appropriate host response in a specific application [7]. “Appropriate host response” implies identification and characterization of tissue reactions and responses that could prove harmful to the host and/or lead to ultimate failure of the biomaterial, medical device or prosthesis through biological mechanism.

On the other side, appropriate host response does imply the success of biomaterial to tissue reactions and response critical to use of biomaterial for particular implant. In selection of biomaterials for making a medical device certain considerations are kept in practice. These include chemical, toxicological, physical, electrical, morphological, and mechanical properties.

3.0 REQUIREMENTS OF BIOMATERIALS

In order to serve for longer period without rejection, an implant should possesses the following attributes:

Mechanical Properties. Properties which are of prime interest for hip implants are hardness, tensile strength, yield stress, modulus of elasticity and elongation. The response of the material to repeated cyclic loads is determined by fatigue strength of the material. The material replaced for bone is expected to have modulus equal to that of bone. The bone modulus varies in the magnitude from 4 to 30 GPa depending on the type of the bone and direction of measurement [8]. The current metallic and ceramic implant materials have higher stiffness than bone, resulting in bone overloading and resorption around the implant and consequently to implant loosening. Hence, biomaterial with excellent combination of high strength and low modulus closer to bone has to be used for implantation to mitigate loosening potential of implant and has potentially higher rate of success.

Biocompatibility. The materials used for implants should be non-toxic and should not cause any inflammatory or allergic reactions in human body. The success of biomaterials is mainly dependent on the reaction of human body to the implant, this reaction defines the level of biocompatibility of material inside the human body environment [9]. Two main factors that influence bio compatibility of material are the host response induced by the material and materials degradation in the body environment. Types of the commonly used biomaterials are listed in Table 1. When implants are exposed to human tissues and fluids, several reactions take place between host and the implant material and these reactions dictate the success factor of implant. Electrochemical reactions take place where metal ions interact with body fluids, proteins and it may be cause allergic reactions like toxicity, carcinogenicity if metal degrades inside the body environment it includes wear debris, free metallic ions, inorganic metal salts or oxides. All metals in contact with biological systems corrode, and the released ions can cause toxic reactions to immune system of body [10].

High Corrosion and Wear Resistance. The low wear and corrosion resistance of the implants in the body fluid results in the release of non-compatible metal ions by the implants into the body. The released ions are found to cause toxic and allergic reactions [11]. The low wear resistance of biomaterial results in implant loosening and wear debris is found to cause several reactions in tissues where they are deposited [12]. Thus development of implant with high corrosion and wear resistance is of utmost importance for high success rate of implant.

4.0 PERFORMANCE OF BIOMATERIALS

The performance of a biomaterial used for implant after insertion can be considered in terms of reliability. For example, there are four major factors contributing to the failure of hip joint replacements. These are fracture, wear, infection, and loosening of implants. If the

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probability of failure of a given implant is assumed to be *f*, then reliability, *r*, can be expressed as below[6].

$$r = 1 - f \tag{1}$$

Total reliability r can be expressed in terms of reliability of each contributing factor for failures:

$$r = r_1,\ r_2,\ r_3, \dots ,\ r_n \tag{2}$$

where $r_1 = 1 - f_1$, $r_2 = 1 - f_2$ and so on.

Eq. 2 implies that even though if an implant has perfect reliability of one (i.e. $r = 1$), if an infection occurs every time it is implanted then the total reliability of an operation is zero.

Table 1: List of typically used biomaterials [6].

Materials	Advantages	Disadvantages
Polymers (nylon, silicone rubber, polyester, polytetrafluoroethylene, polyethylene)	Easy to fabricate, low density	Low mechanical strength, time dependent degradation
Metals (Ti and its alloys Co-Cr alloys, Au, Ag, Stainless Steel)	High impact tensile strength, high resistance to wear, tough, ductile.	Low biocompatibility, corrosion in physiological environment
Ceramics (alumina, zirconia, calcium, phosphates including hydroxyapatite, carbon)	Good biocompatibility, corrosion resistance, inert, high compression resistance	Low impact tensile strength, low mechanical reliability, high density

Failure of Implants. Orthopedic implants are artificial devices that are mounted into skeleton system of the human body which help to give support to human joints, bones, or to replace joint or bone. This replacement can fail for reasons as: failure of the bone to heal, bone resorption, inflammation, wear/corrosion of implant, breakage of bone, loosening of implants, bending of implants, and fracture disintegration of implants. Implants can undergo fretting, corrosion, wear and may degrade inside the body. Major standards for orthopedic implant materials have been developed for stainless steel, unalloyed Ti, Ti-6Al-4V (ASTM F1108-97a), cast Co-Cr-Mo alloy, and wrought cobalt based alloy (ASTM F1537-11). Wear of implants causes generation of debris inside the human body environment, debris as well as metallic ions resulting from corrosion which are soluble are carried by blood and eventually can be excreted through urine but the non-soluble debris may cause complex reactions in human body like damage of cell tissue, and in long term, it may cause hypersensitivity, chromosomal disorders like toxic reactions and carcinogenicity. Fractured implants fail because of certain combination of alloys causing revision of surgery which has less rate of success compared to first surgery.

5.0 FERROUS MATERIALS

Metals are by far the oldest biomaterials used in surgical implants. For metallic biomaterials used in orthopedic implants, the functional requirements are optimal mechanical properties including yield strength, ductility, stiffness, fatigue strength and fracture toughness. Metals

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used in orthopedic implants include surgical grade stainless steel, cobalt-chromium alloys, titanium, and titanium alloys.

Stainless Steel. Stainless steel is not highly suitable for permanent implants because of its poor fatigue strength and its ability to undergo plastic deformation which may cause failure of implant in short term. Stainless steel is most commonly used for non-permanent implants such as internal fixation devices for fractures. The type of stainless steel mainly used for implants is 316L stainless steel. It contains C, Ni and Mo to improve the corrosion resistance in body fluid. The maximum carbon content was reduced from 0.08 wt% to 0.03 wt% for better corrosion [6]. The specifications of stainless steels for implants are as given in Table 2.

It was found that lowering carbon content of type 316L stainless steel makes them more corrosion resistant to chloride solutions such as physiological saline in the human body. Therefore, ASTM (American Society of Testing and Materials) recommends type 316L for implants. Corrosion of stainless steel occurs via one or more reason as follows:

1) Incorrect composition or metallurgical conditions. Like for instance, the addition of molybdenum increases the resistance of stainless steels to saline solution, too much of it can result in brittleness.
2) Improper selection and handling of implant. This can arise by the intermixing of components from variety of implants available. The problem with intermixing is, the components may not fit together completely, resulting in corrosion and materials and manufacturing process may not be identical, resulting in corrosion [6].

Table 2: Mechanical properties of Stainless Steel Surgical Implants [6].

Condition	**Ultimate tensile** strength, min, (MPa)	**Yield strength** (0.2% offset), min, (MPa)	**Elongation** Min (%)
Grade 1 (type 316)			
Annealed	75,000 (515)	30,000(205)	40
Cold finished	90,000(620)	45,000(310)	35
Cold worked	125,000(860)	100,000(690)	12
Grade 2 (type 316L)			
Annealed	73,000(505)	28,000(195)	40
Cold finished	88,000(605)	43,000(295)	35
Cold worked	125,000(860)	100,000(690)	12

Cobalt-Chromium Alloys. Before the use of titanium, cobalt based alloys (Co-Cr-Ni, Co-Cr-Mo) had often replaced stainless steel as biomaterials for permanent implants. These alloys are generally more corrosion-resistant because of formation of a durable chromium oxide (Cr_2O_3) surface layer, the so-called passivation layer.

Despite the good corrosion resistance ion release inside the body is major concern. Chromium and nickel are known carcinogens, and cobalt is suspected carcinogen [6]. Chromium, nickel and cobalt are not only found in the tissues surrounding the implants, but also found in blood and urine sample which is cause of concern [13].

The modulus of elasticity ranges from 220 to 234 GPa, which are higher that other materials such as stainless steels. Modulus of elasticity is defined as substance tendency to deform elastically when force is applied to it, which is one of important characteristic for biomaterial

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used in implant design. The mode of load transfer from the implant to the bone is affected by the modulus of elasticity of the implants. Two types of alloys recommended by ASTM for surgical implant applications are: cast CoCrMo alloy and wrought CoNiCrMo alloy (F562). One of the most promising wrought Co-based alloys is the CoNiCrMo alloy, which contains approximately 35 wt% Co and Ni each. The alloy was developed to have high degree of corrosion resistance in seawater (chlorine), under stress [6]. Cold working is the process of shaping up the metal below re-crystallization, at room temperature. It increases strength and hardness. The wear properties of the wrought CoNiCrMo alloy are similar to the cast CoCrMo alloy (0.14 mm/year) however the former is not recommended for bearing surfaces of joint prostheses because of its poor frictional properties with itself or other materials. The superior fatigue and ultimate tensile strength of the wrought CoNiCrMo alloy make it suitable for applications that require long service life without fracture or stress fatigue.

Table 3: Mechanical properties of Co-Based Alloys [6].

			Wrought CoNiCrMo (F562)		Wrought CoNiCrMoWFe (F563)			
						Cold-worked / cold-worked and aged		Cold-worked and aged
	Cast CoCrMo (F76)	**Wrought CoCrWNi (F90)**	**Solution annealed**	**Cold-worked and aged**	**Fully annealed**	**Medium Hard**	**Hard**	**Extra Hard**
Tensile Strength (MPa)	655	860	795-1000	1790	600	1000	1310	1586
Yield Strength (0.2% offset) (MPa)	450	310	240-665	1585	276	827	1172	1310
Elongation (%)	8	10	50	8	50	18	12	-
Reduction of Area (%)	8	-	65	35	65	50	45	-
Fatigue Strength (MPa)	310, 793	-	-	-	340	400	500	400

Titanium Alloys. In recent years, titanium (Ti) and its alloys have proven as very good biomaterials for medical application, especially for orthopedic applications. Titanium and its alloys are used because of their excellent biocompatibility connected with good balance of corrosion resistance and mechanical strength.

Titanium exists in two allotropic forms where at low temperatures it has a hexagonal closed packed crystal structure (hcp), which is commonly known as α phase, whereas above 883 °C it has a body centered cubic structure (bcc) termed as β phase. The α to β transformation temperature of alloyed titanium either increases or decreases based on the nature of the alloying elements. The elements which tend to stabilize the α phase and hence increases the α-β TT, (Al, O, N) are α stabilizers while elements which stabilize β phase and hence decreases α-β TT, (V, Mo, Nb, Fe, Cr) are β stabilizers. Alloys having only a stabilizers (Al, O, N and C) and consisting entirely of α phase are known as α alloys. Alloys containing 1-2% of β stabilizers and about 5-10% of β phase are termed as near-α alloys.

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Table 4 lists the typical properties for Ti-6Al-4V alloys with oxygen content and equiaxed or lamellar microstructure. The mechanical properties of commercially pure titanium vary with the presence of other elements, specifically with the changing concentration of interstitial oxygen. By increasing oxygen level it will increase the ultimate tensile strength to decrease both ductility and fatigue strength. Fatigue property becomes important because they are exposed to relatively high repetitive load cycles.

Table 4: Mechanical properties of Ti-6Al-4V alloy with different oxygen content. [12]

Oxygen content microstructure	Yield strength[1] (MPa)	Ultimate tensile strength[2] (MPa)	Elongation[3] (%)	Reduction of area (%)	Fatigue strength (MPa)	Tensile strength (MPa)
0.15 – 0.2% equiaxed	951	1020	15	35	226	135
0.15 - 0.2% lamellar	884	949	13	23	223	123
0.13 max equiaxed	830	903	17	44	247	136
0.18 – 0.2% equiaxed	1068	1096	15	40	282	155

[1]The stress necessary to produce given plastic strain in a material.
[2]Ultimate tensile strength (UTS): The highest endurable stress at which the test specimen begins to neck in tensile tests.
[3]Elongation (EL): is a measure of the deformability or the ability of a material to accommodate stress concentrations. It also measures ductility of material.

6.0 WEIGHTED-PROPERTIES METHOD

In the weighted-properties method each material requirement, or property, is assigned a certain weight, depending on its importance to the performance of the part in service. A weighted-property value is obtained by multiplying the numerical value of the property by the weighting factor (α). The individual weighted-property values of each material are then summed to give a comparative materials performance index (γ). Materials with the higher performance index (γ) are considered more suitable for the application.

Digital Logic Method. In the cases where numerous material properties are specified and the relative importance of each property is not clear, determinations of the weighting factor α can be largely intuitive, which reduces the reliability of selection. The digital logic approach can be used as a systematic tool to determine α. In this procedure evaluations are arranged such that only two properties are considered at a time. Every possible combination of properties or goals is compared and no shades of choice are required, only a yes or no decision for each evaluation. To determine the relative importance of each property or goal, a table is constructed, the properties or goals are listed in the left-hand column, and comparisons are made in the columns to the right.

In comparing two properties or goals, the more important goal is given the number 1 and the less important is given as 0. The total number of possible decisions is $N = n\ (n-1)/2$, where n is the number of properties or goals under consideration. A relative emphasis coefficient or weighting factor α for each goal is obtained by dividing the number of positive

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decisions for each goal (*m*) into the total number of possible decisions (*N*). In this case $\Sigma\alpha = 1$. To increase the accuracy of decisions based on the digital logic approach, the yes–no evaluations can be modified by allocating gradation marks ranging from 0 (no difference in importance) to 100 (large difference in importance). In this case, the total gradation marks for each selection criterion are reached by adding up the individual gradation marks. The weighting factors are then found by dividing these total gradation marks by their grand total (Table 5). A simple interactive computer program can be written to help in determining the weighting factors. A computer program will also make it easier to perform several runs of the process in order to test the sensitivity of the final ranking to changes in some of the decisions — sensitivity analysis.

Table 5: Objective of each required property to be achieved.

Symbol	Property	Objective
P1	Elastic modulus (GPa)	MAX
P2	0.2% Yield Strength (MPa)	MAX
P3	Tensile Strength (MPa)	MAX
P4	Fatigue Strength (MPa)	MAX
P5	Corrosion Rate (mpy)	MIN
P6	Density (g/cm^3)	MIN

Table 6: Comparative importance of the required properties against each other.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Positive Decision	α
P1	0.3	0.6	0.2	0.5	0.7											2.3	0.15
P2	0.7					0.6	0.5	0.3	0.7							2.8	0.19
P3		0.4				0.4				0.4	0.3	0.5				2.0	0.13
P4			0.8				0.5			0.6			0.6	0.8		3.3	0.22
P5				0.5				0.7			0.7		0.4		0.8	3.1	0.21
P6					0.3				0.3			0.5		0.2	0.2	1.5	0.1
SUM																15.0	1.0

Performance Index. In its simple form, the weighted-properties method has the drawback of having to combine unlike units, which could yield irrational results. This is particularly true when different mechanical, physical, and chemical properties with widely different numerical values are combined. The property with higher numerical value will have more influence than is warranted by its weighting factor. This drawback is overcome by introducing scaling factors. Each property is so scaled that its highest numerical value does not exceed 100. When evaluating a list of candidate materials, one property is considered at a time. The best value in the list is rated as 100 and the others are scaled proportionally. By introducing a scaling factor it will facilitate the conversion of normal material property values to scaled

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dimensionless values. For a given property, the scaled value β for a given candidate material is equal to (refer to Table 7)

$$\beta = \text{scaled property} = \frac{\text{numerical value of property}}{\text{maximum value in the list}} \times 100 \tag{3}$$

For properties like cost, corrosion or wear loss, and weight gain in oxidation, a lower value is more desirable. In such cases, the lowest value is rated as 100 and β is calculated as

$$\beta = \text{scaled property} = \frac{\text{minimum value in the list}}{\text{numerical value of property}} \times 100 \tag{4}$$

For material properties that can be represented by numerical values, application of the above procedure is simple. However, with properties like corrosion, wear resistance, machinability, and weldability, numerical values are rarely given and materials are usually rated as very good, good, fair, poor, etc. In such cases, the rating can be converted to numerical values using an arbitrary scale. For example, corrosion resistance ratings excellent, very good, good, fair, and poor can be given numerical values of 5, 4, 3, 2, and 1, respectively. After scaling the different properties, the material performance index γ can be calculated as (refer to table 8)

$$\gamma = \sum_{i=1} \beta_i \ \alpha_i \tag{5}$$

where i is summed over all the n relevant properties.

Table 7: Scaled property value of the materials' attributes.

	β_{P1}	β_{P2}	β_{P3}	β_{P4}	β_{P5}	β_{P6}
M1	60.6	68.9	96.2	55.9	100	48.6
M2	63.6	48.3	86.2	43.8	22.2	46.8
M3	36.4	82.7	100	84.7	5	88
M4	75.8	100	80.4	95	2.5	64.3
M5	100	90	83	100	3.3	100

Table 8: Evaluated performance indexes for the material candidates of this research.

Symbol	Candidate Material	Performance Index γ	Ranking
M1	316L St Steel (cold worked, ASTM F138)	72.85	2
M2	Co–28Cr–6Mo (cast, ASTM F75)	48.90	5
M3	Ti–6Al–4V (hot forged, ASTM F620)	53.60	4
M4	Zirconia (ceramic, 3Y-TZP)	68.70	3
M5	Alumina (ceramic, ZTA)	75.60	1

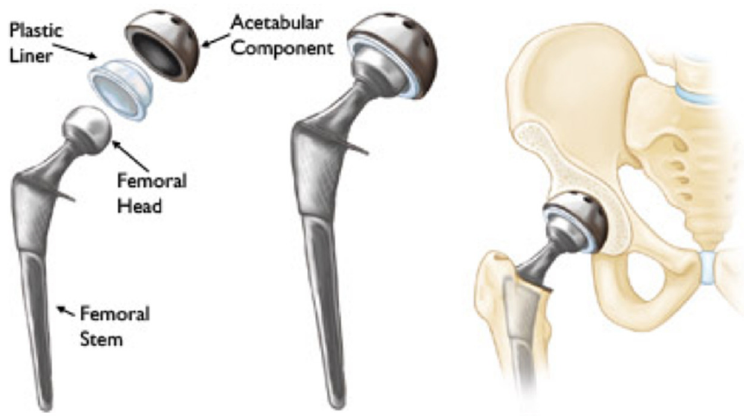

Figure 1: Illustrative a total hip replacement prosthesis.

7.0 RESULTS AND DISCUSSION

Early prosthetic hip designs called for both the femoral stem and ball to be of the same material e.g. a stainless steel. Subsequent improvements have been introduced, including the utilization of materials other than stainless steel and, in addition, constructing the stem and ball from different materials. Indeed, stainless steel is rarely used in current implant designs. Fig. 1 shows an example of a hip replacement design. Currently, the femoral stem is constructed from a metal alloy of which there are two primary types: cobalt–chromium–molybdenum and titanium. Some models still use 316L stainless steel, which has a very low sulfur content in its composition. The principal disadvantages of this alloy are its susceptibility to crevice corrosion and pitting and its relatively low fatigue strength. As a result the usage of this material has decreased.

Table 8 illustrates the performance index evaluated for each of the material candidates studied within this research. As shown, Alumina appears to be the most suitable candidate with regards to its performance index, which is the greatest, followed by 316L St Steel and Zirconia respectively as the second and third. Various Co–Cr–Mo alloys are used for artificial hip prostheses. One that has been found to be especially suitable, designated F75, is a cast alloy that has a composition of 66 wt% Co, 28 wt% Cr, and 6 wt% Mo. The corrosion and

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fatigue characteristics of this alloy are excellent. Of those metal alloys that are implanted for prosthetic hip joints, probably the most biocompatible is the titanium alloy Ti–6Al–4V; its composition is 90 wt% Ti, 6 wt% Al, and 4 wt% V. The optimal properties for this material are produced by hot forging; any subsequent deformation and/or heat treatment should be avoided to prevent the formation of microstructures that are deleterious to its bioperformance.

Recent improvements for this prosthetic device to include using a ceramic material for the ball component rather than any of the aforementioned metal alloys. The ceramics of choice are a high-purity and polycrystalline aluminum oxide or zirconium oxide, which are harder and more wear resistant than metals, and generate lower frictional stresses at the joint. However, the elastic moduli of these ceramics are large and the fracture toughness of alumina is relatively low. Hence, the femoral stem, is still fabricated from one of the above alloys, and is then attached to the ceramic ball; this femoral stem–ball component thus becomes a two-piece unit.

The materials selected for use in an orthopedic implant come after years of research into the chemical and physical properties of a host of different candidate materials. Ideally, the material(s) of choice will not only be biocompatible but will also have mechanical properties that match the biomaterial being replaced—bone. However, no man-made material is both biocompatible and possesses the property combination of bone and the natural hip joint—low modulus of elasticity, relatively high strength and fracture toughness, low coefficient of friction, and excellent wear resistance.

Consequently, material property compromises and trade-offs must be made. For example, recall that the modulus of elasticity of bone and femoral stem materials should be closely matched such that accelerated deterioration of the bone tissue adjacent to the implant is avoided. Unfortunately, man-made materials that are both biocompatible and relatively strong also have high modulus of elasticity. Thus, for this application, it was decided to trade off a low modulus for biocompatibility and strength.

Some acetabular cups are made from one of the biocompatible alloys or aluminum oxide. More commonly, however, ultra-high molecular weight polyethylene is used. This material is virtually inert in the body environment and has excellent wear-resistance characteristics; furthermore, it has a very low coefficient of friction when in contact with the materials used for the ball component of the socket. A two-component cup assembly is shown for the total hip implant in the chapter-opening photograph for this chapter. It consists of an ultrahigh molecular weight polyethylene insert that fits within the cup; this cup is fabricated from one of the metal alloys, which, after implantation, becomes bonded to the pelvis.

8.0 CONCLUSION

According to the nature of the problem studied here, the choices of materials suitable to build a hip plant were reduced to a few options whose properties meet biocompatibility as the major aim. Thus, five candidates as the most common biomaterials were adopted namely 316L St Steel (cold worked, ASTM F138), Co–28Cr–6Mo (cast, ASTM F75), Ti–6Al–4V (hot forged, ASTM F620), Zirconia (ceramic, 3Y-TZP) and Alumina (ceramic, ZTA) to be evaluated by the method of weighted properties (WPM) in order to narrow down the search to distinguish the best suitable one. In this search, WPM was evaluated based on the mechanical properties of the agents as highest mechanical similarity to that of the real bone is of great interest, and quality of being biocompatible did not affect the process of evaluation.

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Contrary to other engineering problems which cost is considered as one of the main goals, in medical procedures, due to the importance of health issues, focus on cost is considered as a secondary objective and the challenge is a matter of biocompatibility.

Based on the analysis carried out, Alumina ceramic proved to be the best material for the artificial hip with highest value of performance index. Ranked second appeared to be 316L St Steel (cold worked) whereas this type of implant is not utilized any more due to its susceptibility to crevice corrosion and pitting and its relatively low fatigue strength. In contradistinction to the results obtained here currently, femoral stem is constructed from materials on position 4 and 5 of our rankings, which are of cobalt and/or titanium alloys. The reason is that, although they are not the best ones with regards to their mechanical properties compared with other opponents but since they have experimentally proven to be more biocompatible compared with the other candidates so, they are still the most employed agents.

It is concluded that a material that exhibits the best performance index is not necessarily the most suitable material for an implant product and there will be always a demand to check the results with experimental data since, as far as mechanical analysis concerns, specifications such as biocompatibility are not capable to be formulated mathematically. Other factors and requirements need to be taken into consideration in such a selection, as instance, cost, formability, service condition, etc.

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