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Comparative Analysis of Various Biomaterials Used in Artificial Knee Implant

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Abstract—*The increasing cases of implant surgeries have resulted in the increasing demand for biocompatible biomaterials for medical implants. The aim of this paper is to make a comparative analysis between different types of biomaterials widely used in case of implant surgeries to study various mechanical properties like wear resistance and fatigue strength, deformation under varying loading conditions. Since from the starting of orthopedic surgeries implants made up of metal alloys are always being the first choice of surgeons. With increasing development in the field of medical surgeries, several biomaterials have proven their existence with better properties in comparison to conventional metal alloys.*

In this paper, we try to compare various mechanical properties of different biomaterials special emphasis to their mechanical, biomechanical demands of medical implants. The widely used biomaterials used as medical implants like metal alloys, titanium alloy, and various ultra-high molecular polyethylene.

Keywords: - *Medical Implants, UHMWPE, Total Knee Replacement, Biomaterial, 3D CAD Model, Artificial Knee Joint*

1. INTRODUCTION

Increasing cases of arthroplasty has resulted in more emphasis towards development of new medical implant materials which can compete with the properties of naturally used bone .When case of total knee replacement arises the need of more stiff and accurate biomaterials came into demand. The knee being the most load bearing joint of human body it is important to study the anatomy of this joint to understand the design as well as material requirement. Due to the high mechanical demand of the nature of load it possess during daily activities it is necessary to design material of implant as per the requirement it should possess all the qualities that of natural bone so that it can perform same function with greater ease. It is subjected to ligament ruptures, cartilage injuries, and tissue dislocation resulting in replacement surgeries.

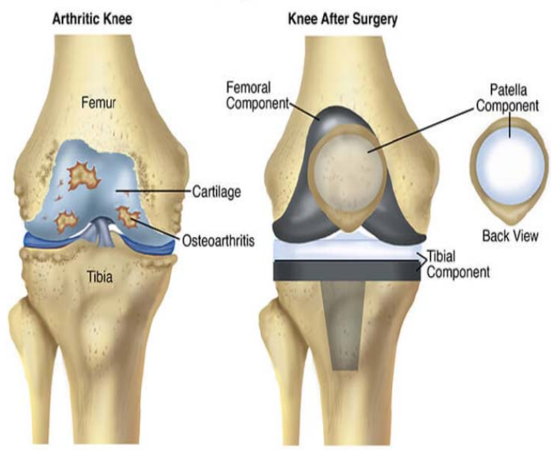

Figure 1:- Total Knee Replacement

Knee joint replacement is very crucial with respect to host reaction of implant material with the body as response intervene to the regeneration process of the bone. The field of biomaterials is on increasing demand as due to high ranging demand of medical implants with aging population as well as weight of body due to imbalance daily routine. Artificial implants are solution to these problems of arthroplasty and are designed in such a way to restore the normal function of knee motion.

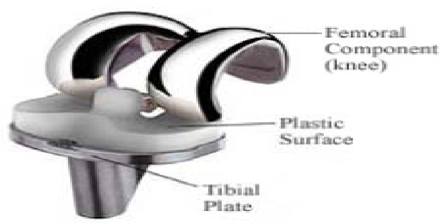

Figure 2: Components of Artificial Knee Joint Implant

These revision surgeries may result in post-operative surgeries due to failure of implant material so it is very important to select implant materials with utmost care.

In this paper we have done a comparative analysis of materials used for medical implants their mechanical capabilities and we have modelled 3D model of components of artificial Knee Implants and performed FEA analysis to compare their performance under varying load conditions. We have tried to find out the best suited material The aim of this paper is to present an approach of developing a 3D model of knee prosthesis and find out the best suited material for implants.

Thus need of development of suitable material with high wear resistance, superior corrosive resistance is the need of hour, low Young´s modulus high ductility, excellent biocompatibility and nontoxicity is highly essential.

Figure 3:- Side view of Artificial Knee Implant

2. TOTAL KNEE REPLACEMENT MATERIALS:-

Since era of orthopedic surgeries started the search of efficient medical implant biomaterials started.Genrally metallic biomaterials were used for medical implants specifically for hip and knee replacement or where load bearing application is needed with sufficient fatigue strength to endure daily activities with proper ease.

- Ceramic biomaterials used frequently for their hardness and wear resistance for loading applications in joints and in teeth as well as bone bonding surfaces in hip or knee implants.
- Stainless steel materials are shows more corrosion resistance properties. Major problem is development of debris which result in loosening of implant. Higher young modulus of materials in comparison human bone make them in suitable for using them as implant material.
- Cobalt-chromium alloys widely used as implant materials in different grade of cobalt alloys. They can be classified into two types on the basis of additives :-

1. Co-Cr-Mo:- used in hip and knee replacement , dental implants due to excellent wear resistance
2. Co-Ni-Cr-Mo: - Used for manufacturing of stem of load bearing implants for heavily loaded human joints.

- Titanium and its Alloys:- Used in total hip replacement and total knee replacement due to low density, high strength, high corrosive resistance, biocompatible nature along with inertness. Due to moderate value of elastic modulus approximately 110 GPA in comparison to other material help to create evenly distributed stress over implanted bone.

Table 1: Comparison of Material Properties of various Biomaterials

Material	Tensile strength	Young's modulus	Fatigue limit
316l SS	**650**	**211**	**0.28**
Wrought Co-Cr alloy	**1540**	**541**	**0.49**
Cast Co-Cr alloy	**690**	**241**	**0.30**
Titanium	**710**	**121**	**0.30**
Ti-6Al-4V	**1000**	**121**	**-----**
Human bone	**137.30**	**30**	**-----**

Due to alarming rate of unbalance life cycle a statistical data shows that the rate of total knee replacement will increased to nearly 645 % by the end of 2030 that depicts that need to develop new design and materials for implant is necessary so that we can meet up with such challenge. The currently used medical implant material have shown significant failure in long term use due to lack of compatibility with properties of natural bone.

Failure of implant do not only result in pain but also life vulnerable disease could result in unavoidable circumstances.

2.1 Properties of ideally used Materials:-

- Chemically inert nature
- Non-toxic to the body
- Great strength
- High fatigue resistance
- Low Elastic Modulus
- Corrosive Resistance
- Good wear resistance properties
- Biocompatible nature

2.2 Mechanical properties:-

The mechanical properties which are necessary for suitability of medical implant material are as follows:-such as fracture resistance ,Hardness ,Tensile strength modulus, elastic strain , fatigue life .These properties are deciding factor before selecting a material for implant.

- **Fatigue life:-**

The fatigue strength depicts the behavior on repeated cycle of stress leading to loosening of implant, failure of implant.

- **Strength:-**

Strength of biomaterials used for manufacturing of implants may result in the failure of implant. The relative motion between the contact surface of implant became easy when the interface starts to fail under loading.

Table 2: Material Properties of commonly used biomaterials

Material	Youngs Modulus	Density
Cancellous Bone	0.5-1.5	----
UHMWPE	1.2	----
PMM Bone Cement	2.2	----
Cortical Bonee	7-30	2.0
Titanium Alloy	110	4.4
Stainless Steel	190	8.0
Cobalt Chromium	210	8.5

2.3 Non-mechanical requirements:-

- **High Corrosion Resistance: -**

Corrosion resistance being an important property of metallic biomaterials as the corrosion of metallic implants due to the corrosive nature of body fluid is unavoidable may lead to failure of implants.

- **Wear Resistance:-**

Low value of wear resistance may result in aseptic loosening of implant. Wear debris formed at the surface result in biologically inactive response. metallic ions.

- **Biocompatibility:-**

It is the ability of a material to remain in contact with living tissues of human body without causing any harm to it.

3. FINITE ELEMENT METHOD

Finite element method (FEM) is a method widely used for the prediction of stress failure of dynamic system and as well as biological models. As the demand of medical implants is increasing the prediction of exact failure of such devices is very important to predict the service life of the implant. The different types of finite elements method help to find the effect of loads, their modes of behavior either linear or non-linear, or different types of load application pattern (static, elastic, or dynamic), helps to perform different types of analysis like static structural analysis, modal analysis, fatigue analysis fracture and material optimization, etc help to carry out the real time problem simulations with accurate results.

4. METHODOLOGY:-

We have modeled a 3 D model of Artificial Knee Joint prosthesis in Solidwork and performed FEA analysis for different biomaterials.

4.1 Material Properties:-

Being heterogeneous and nonlinear in nature, it is very difficult to assign material properties along each direction of the cortical bone model due to which its analysis become complex but modelling artifiicial knee implant gives us ease to assign material properties as per loading conditions.

We have considered following material properties of different biomaterials to perform FEA analysis.

Table 3: Material Properties of Biomaterials used for Knee Prosthesis

Material	Density (Kg/m^3)	Youngs Modulus	Poisson's Ratio	Yield Strength	Utlimate strength
UHMWPE	930	$6.90*10^8$	0.29	$2.10*10^7$	$4.80*10^7$
Ti6AL4V	4430	$1.15*10^{11}$	0.342	$8.80*10^8$	$9.50*10^8$
CoCrMo	8300	$2.30*10^{11}$	0.30	$6.12*10^8$	$9.70*10^8$
361L SS	8000	$1.97*10^{11}$	0.30	$2.80*10^8$	$6.35*10^8$
ZrO_2	6040	$2.1*10^{11}$	0.30	$9*10^8$	$2*10^9$

5. CAD MODELLING OF ARTIFICIAL KNEE JOINT IMPLANT

Design Considerations:-

While modelling the artificial knee joint implant considering material is very important for simulating the desired zone of stresses. As material of the bone is anisotropic not homogeneous so while modelling we consider artifcial implant as homogeneous and isotropic within certain limits so that correct simulation can be done.

6. FEA ANALYSIS OF ARTIFICIAL KNEE IMPLANT

Meshing: After creating model, for further Finite

element analysis (FEA), a tetrahedron surface mesh is generated for artificial knee implant model in ANSYS workbench 17.1. This surface mesh is used to analyse various mesh size with respect to the loading conditions. The volumetric mesh can be generated in ANSYS for the

model of femur bone. The FEA software ANSYS 17.1 was used for generating tetrahedron surface mesh to find out the highly stressed zone.

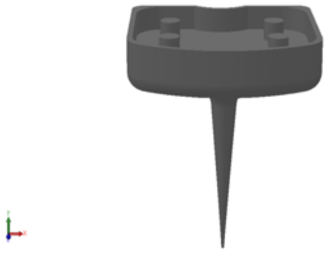

Figure 4 :- FEA Model Of Tibial Stem

Figure 5 :- Posterior View of Plastic Insert

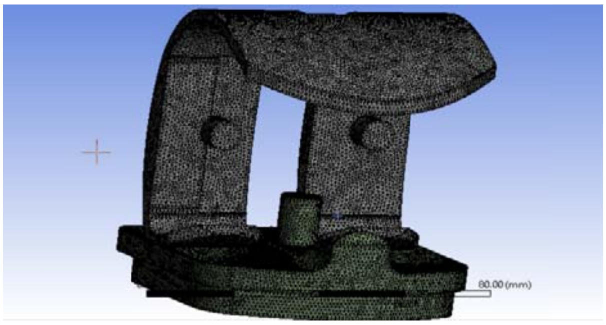

Figure 6 :- Meshing Diagram of designed Artificial Knee Prosthesis

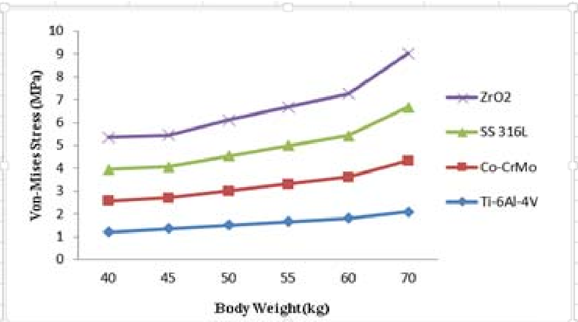

Figure 7:- Comparision of Von- Misses Stress for different Implant Biomaterials

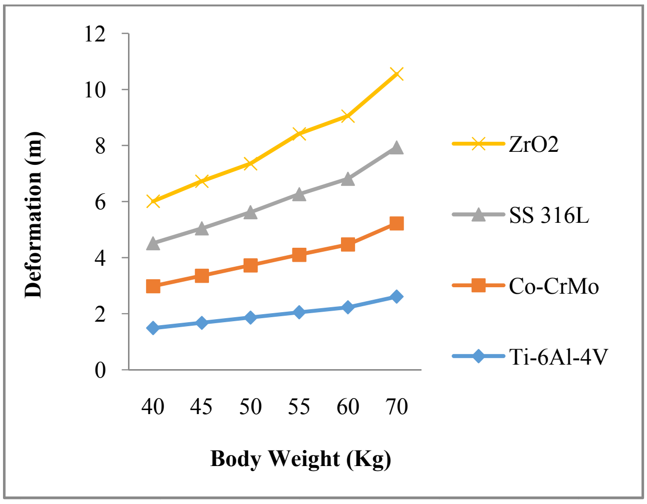

Figure 8:- Comparision of Deformation for different Implant Biomaterials

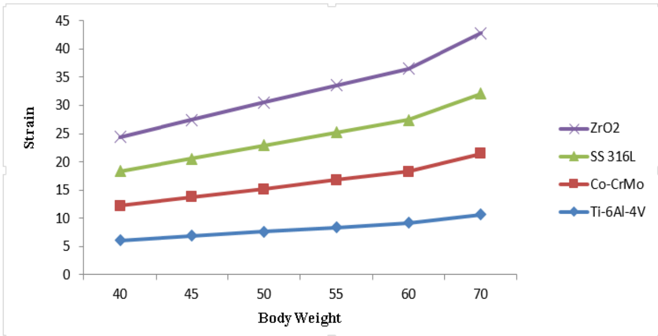

Figure 9:- Comparision of Strain for different Implant Biomaterials

Table 4 : Comparision of different biomaterials with Artificial Knee Implant

Material	Von-Misses Stress (Pa)	Total Deformation (mm)
Ti-6AL-4V	32.86	0.108
Co-Cr-Mo	37.65	0.123
SS 316L	33.85	0.112
ZrO_2	39.63	0.132

Table 5: Comparision of design criterion different biomaterials with Artificial Knee Implant

Material	Yield Strength (MPa)	Permissible Strength(MPa)	Maximum Analysed Stress (MPa)
Ti-6AL-4V	900	300	40.73
Co-Cr-Mo	525	175	45.32
SS 316L	240	80-120	44.36
ZrO_2	900	300	46.78
UHMWPE	52	20	8.365

Result And Discussion:-

The finite element analysis of modeled artificial knee prosthesis is done in Ansys 17.1 and we do static stress analysis of the implant by analysing von-misses stress, total deformation, elastic strain for different biomaterials under different loading conditions.

- We conclude that Ti-6AL-4V shows peak stress of 32.86 MPa lower than other material.
- SS 316 L shows second optimum values of von-misses stress with maximum value 33.85 MPa.
- Co-Cr-Mo shows third optimum value of von misses stress with maximum value of 37.65 MPa.
- ZrO_2 shows highest value of stress making it unsuitable for our designed prosthesis
- The graph between body weight and von misses stress predicted that Ti-6AL-4V is best suited material for designing of artificial knee prosthesis.
- The graph between body weight and total deformation predicted that Ti-6AL-4Vshows less variation and deformation in case of Co-Cr-Mo is same to that of ZrO_2

Von- Misses stress varies from 2.5 MPa to 4.5 MPa for body weight ranging from 40 kg to 80 kg and shows maximum variation in case of ZrO_2.

At different loading conditions total deformation is maximum for ZrO_2 and Co-Cr-Mo and less that in case of

Ti-6AL-4V and SS 316L

The contact pressure between the joint of femoral component and plastic insert is maximum in case of ZrO_2 and UHMWPE.

7. CONCLUSION

In this paper we have compared various biomaterial used for artificial knee prosthesis .We have designed 3D FEA model of artificial knee prosthesis and performed FEA analysis for various biomaterials.

- We observed in our research work that our designed prosthesis is safe for different biomaterials under different loading conditions.In this paper we observed that even under extreme loading conditions the designed prosthesis is safe and gives satisfactory results for all biomaterials.
- We find that biomaterial ZrO_2 is not suitable for artificial knee prosthesis.
- Even after assembly of artificial knee prosthesis it behaves as per the normal knee joint motion.
- Considerable improvement in the properties of oxidized Zirconium (ZrO_2) can help to create a better biomaterial for artificial knee prosthesis.
- From FEA analysis we conclude that Ti-6AL-4V reveals the best result making it best suitable material for artificial knee implants.

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