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Comparative Study of Biomechanics and Biocompatibility of Knee Implant Materials

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Abstract: ***Knee implants have been used to replace damaged cartilage and bone in the tibiofemoral and patellofemoral joints since the 1950s. At least 150 implants are available today, thanks to advances made by physicians and engineers in simulating the geometry and behavior of a healthy knee joint. Several researchers have assessed the biomechanics of knee implant components to evaluate the performance of some knee implant models. Many authors have studied biomechanical factors such as contact stresses, kinematics, and fatigue to validate the quality of knee implants under various loading conditions. Metal alloys have been the materials of choice since the start of orthopedic surgery. Orthopedic materials must fulfill the mechanical, biological and physical necessities of their proposed utilization. Knee joint is the most complex joint in human body gets the discriminating loads in different moving conditions. Accordingly, the material utilized for knee implant assumes exceptionally essential part for long survival of knee prosthesis. The materials that are utilized as biomaterials incorporate polymers, metals, ceramics, and composites. The main objective of the paper is to compare various implant materials based on cost, density, modulus of elasticity, tensile strength, elongation percentage, corrosion resistance, wear resistance and osseointegration.***

Keywords: modulus of elasticity, wear resistance, Osseointegration, Titanium and Titanium alloy, SS 316L

1. Introduction

The knee joint is extremely important in human locomotion. Its structure and time behavior during various types of motion demonstrate that the knee has fully adapted to its required function. The knee is the largest jointand the most heavily loaded joint in the human body The knee is made up of the two largest bones in the human skeleton – the femur and the tibia. The patella is an important component of the knee, especially when the joint is extended. The articular surface of the tibia bone is formed by the lateral and medial meniscus. Degenerative arthritis of the knee joint is a disease that affects the tibial and femoral line cartilage. It causes severe pain and may necessitate knee replacement surgery with artificial components. Artificial joints must meet certain design criteria, including being ergonomic and biocompatible. During activation, stresses develop at the joint interface. This, in turn, determines the joint's performance. The intensity of the developed stresses is determined by several factors. It is critical to optimize the design of the prosthetic knee joint to ensure the stress intensity.

Life on earth has begun with the self -organization of molecules. Due to change in lifestyle, the human knee joints are facing a lot of problems which includes the damage of the cartilage. The damaged cartilage can be cured by using total knee replacement surgery where an implant is fixed to the knee joint. The foreign body gives a lot of relief to the patient but due to their daily activities the wear is slowly developed between the implants. With the development of technology day by day advanced and functional materials are being developed by the researchers [1].The materials used for implants have direct interaction or contact with human body. So, it must be non -toxic, biocompatible, and meet the required specification for which it will be used. Biomaterials are used to replace or repair some diseased, damaged, or nonfunctional piece of tissue or bone like replacement of joints. Knee replacement surgery comprises of resurfacing the damaged knee with artificial components called implants. The commonly used biomaterials for knee implantation are cobalt- chromium SS316 L, Ni-Ti alloy, titanium, and its alloys [2-5].Many important properties must be considered while designing biomaterials as mentioned below

- Inflammatory response of the material
- They can be placed in the body without creating a rejection response
- They must be able to retain their shape and strength for a long time.
- Produce non- toxic degradation product that can be readily resorbed or excreted
- Must be strong enough to take weight bearing loads, flexible enough to bear stress without breaking
- Must be able to move smoothly against each other.

2. Material and Method

In this review paper we have taken different implant materials. The decision is based on cost, density, modulus of elasticity, tensile strength, elongation percentage, corrosion resistance, wear resistance and osseointegration. Healthy organic cartilage surfaces have almost zero friction but the man -made bearing surfaces have high friction. The weight and density of biological material for a knee implant need to be equivalent to that of bone.[6,7,8]. The modulus of elasticity of biomaterial is responsible for stress -shielding. The biomaterials must possess the low elastic modulus near to bone (15 – 30 GPa) to overcome the stress-shielding. The leading cause of revision surgery in the case of knee replacement is corrosion. The metallic implants generally emit unwanted metallic ions, which are not biocompatible to human body. This leads to reduction of implant life. These unwanted metal ions may lead to severe ailment, such as cancer, and may reduce human life [9]. Corrosion resistance must be considered while selecting the material for transplant. Wear is the mechanically induced surface damage that result in progressive removal of material due to

relative motion between that surface and a contacting substance or substances. Low wear resistance is leading cause for implant loosening. Osseointegration is direct structural and functional connection between ordered living bone and the surface of load carrying implant. It is critical for implant stability and prerequisite for the long -term success of implant. Biocompatibility is the ability of a substance being compatible with living tissue in a specific application.

- **Stainless steel implant**

Stainless steel is used in surgical practices since 1900s.There are multiple forms of stainless steel. Type SS 316L is commonly used in surgical practices as it is the most corrosion resistant of all types of stainless steel when in direct contact with biological fluids. The corrosion resistance of the metal is high. Lack of inclusion in SS 316L makes it ideal as a surgical implant. Molybdenumaddedto stainless steel forms a protective layer that shelters the metal from exposure to acidic environment. It has a density of 8.0 gm/cc and tensile strength of 655 MPa [10]. Due to limited ability to withstand corrosion in the human body in long term, stainless steel is not often used in knee replacement implants [12]. It is more suited to being used as temporary implants such as fracture plates and screw. Stainless steel implants have been associated with high rates of infection.

- **Cobalt Chromium Alloys implant**

Cobalt Chromium alloys represents very important group of materials used for medical application. It is the most frequently used metal for knee implants. It represents very important group of materials used for medical application. It is tough, corrosion resistant and biocompatible metal. Increased chemical purity and reduced grain size have led to increased strength and a dramatic reduction in the number of fractures seen clinically. Numerous studies have evaluated the effect of surface modification that influence wear resistance, and test protocols have been established to characterize tri biological properties. Osteolysis and other unfavorable reactions are associated with the generation of implant wear debris. Joint movement may lead to the release of metal ions in the body, which may cause allergic reactions. Cobalt -Chromium alloys (Co-Cr-Mo) has a USD 74 (mg/m3) price, with properties such as density 8.3 gm/cc, modulus of elasticity240 GPa , tensile strength 655 MPa, elongation 20%, very high corrosion resistance , and high osseointegration [10]

- **Titanium and Titanium alloys**

Pure titanium is generally used in implants where high strength is not necessary. Commercially pure titanium possesses elastic modulus 165 GPa more than bone and high content impurity makes the alloy unsuitable for knee implants. Knee implants made of titanium are more like natural joints due to metal's lower density and elastic nature. The most used titanium alloy in knee implants is Ti-6Al-4V.Titanium and titanium alloys have exceptionally high corrosion resistance, making them inert biomaterial. The metal will not change after being implanted in the body. Ti-6Al-4V has a USD 105(mg/m3) price, with properties such as density4.5 gm/cc, modulus of elasticity100 GPa, tensile strength 550 MPa, elongation 54%, exceptionally high corrosion resistance, above average wear resistance and high osseointegration [10]. As titanium implants act more like the natural joint so the risk of some complications like bone resorption and atrophy are reduced [1]. Lighter weight and lower modulus are potential advantages of titanium implants over cobalt- chromium in case of knee implants.[13]

- **Oxinium -zirconium knee implant**

Oxinium oxidized zirconium is a new material used in knee implants. It contains zirconium and niobium alloy. It is twice as hard as cobalt chromium and provide half the friction thus perform with higher quality and lasts for a longer time. Zirconium alloy implants eliminate the risk to nickel -allergic patients because this new material contain no nickel.

3. Result and Discussion

The paper discussed the biomechanical compatibility of many metallic materials, and it brings out the overall superiority of Titanium based alloys, even though it is costlier. The most widely used titanium alloy Ti-6Al-4V in knee implants have several drawbacks such as low hardness, poor wear resistance, and Al/V ions releases in the host body that creates allergic reactions [14].The wear resistance of titanium alloy is more than alloys. In artificial knee joints the bearing is lubricated by body's own synovial fluid which is constantly replenished by living cells. While using stainless steel the ferrite should not be incorporated as it gives magnetic property to the metal. It may interfere with magnetic resonance imaging (MRI) equipment. The power to move the knee joints come from muscles. If a person is allergic to metal cannot have knee implants made of cobalt chromium alloy. Zirconium alloy implants eliminate the risk to nickel -allergic patients because this new material containno nickel.

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