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Implant Component: Femoral Replacement

Structure

Material	Class	Atomic Arrangement	Interatomic Bonding Classification
Zirconia (Oxinium) Inside - Zirconium Alloy Outside - Oxidized Zirconium	- Ceramic on the outside - Metal alloy on the inside	- Monoclinic crystal (outside)	- Electrostatic (outside) - Metallic Bonding (Inside)
Calcium Phosphate (Hydroxyapatite)	- Ceramic	- Amorphous/crystalline	- Electrostatic Attraction
Titanium alloy (Ti-6Al-4V alloy)	- Metal alloy (alpha and beta alloys)	- Crystallographic - Microstructure: α phase (hcp) with some retained β phase (bcc)	- Metallic bonds

Properties

Material	Elastic Modulus	Ultimate Strength	Toughness, Fracture (brittle/ ductile)	Wear	Corrosion Resistance	Other (Biocompatibility)
Zirconia (Oxinium) Inside - Zirconium Alloy Outside - Oxidized Zirconium	- 100-250 Gpa	Compressive: - 1200 - 5200 Mpa Tensile: - 115 - 711 Mpa	Outside: - Fracture Toughness: 1 - 8 MPa.m^½ - Brittle fracture Inside: - Ductile fracture due to metal composition	- Excellent wear resistance due to oxidized surface	- The surface of the zinc alloy on its own has excellent corrosion resistance	- Reduced bacterial colonization - Does not induce high cytotoxicity or inflammation on lymphocytes, monocytes, or macrophages - There are no adverse or toxic effects on connective, immunologic, or bone tissues. - There is systemic toxicity and/or adverse reactions in the implanted

						soft tissues.
Calcium Phosphate (Hydroxyapatite)	- 6 GPa	- Average Compressive strength of 175MPa -Diametral Tensile strength up to 18MPa	- Brittle - Fracture propagates through material - Crumbles	- Will wear over time - Will chip away over time	- No specifically but coating can be added	- Antibacterial - Most abundant mineral found in actual bone - Osteoconductive
Titanium alloy (Ti-6Al-4V alloy)	- Low - 110 GPa (greater compared with that of the human bone)	- 900 ~ 950 MPa	- Brittle with a relatively low ductility of elongation(5%)	- Severe adhesive wear	- Excellent corrosion resistance	- High fatigue resistance - Good biocompatibility

Processing

Material	Coatings	Drug Delivery Options	Corrosion Resistance	Strengthening mechanisms
Zirconia (Oxinium) Inside - Zirconium Alloy Outside - Oxidized Zirconium	- The surface is oxidized zirconium which doubles the toughness and corrosion resistance	- There is no need for drugs to be injected	- The surface is oxidized forming a ceramic which makes it twice as corrosion resistant as the inside	- Stress-induced transformation toughening Shape of crystal during strengthening mechanism: - Tetragonal -> monoclinic
Calcium Phosphate (Hydroxyapatite)	- Small pieces of diamond-like carbon to improve strength but still exposing material to allow for antibacterial and bone growth properties	- No need due to antibacterial properties	- Coating would reduce corrosion	- Coating would increase strength - Composite could be created with polymer/metal to increase tensile strength
Titanium alloy (Ti-6Al-4V alloy)	- Diamond-like carbon coatings	- Can include hydrogel layer which allows drug delivery - Water and cross linked polymer network - Encapsulate hydrophilic drugs	- Is able to form an oxide layer to prevent corrosion (TiO_2)	- Titanium is lighter than stainless steel and has a higher resistance to repeated stress loading , however, can become loose if there is not a strong bond with host tissue (need coating of hydroxyapatite to allow for integration)

Implant Component: Dual Mobility Cup

Structure

Material	Class	Atomic Arrangement	Interatomic Bonding Classification	Molecular weight
Highly cross linked UHMWPE (Ultra High Molecular Weight Polyethylene) with vitamin E	- Polymer, UHMWPE, semi crystalline	- Linear (non-branching) with two phases (crystalline and amorphous) - Crystalline: chains, folded into oriented lamellae - Amorphous:orthorhombic	- Covalent bonds	- 1000 000g/mole to 3.1mil g/mol
Alumina (Aluminum oxide, Al2O3)	- Ceramic	- Initially have thin platelets in a rhombus shape. After calcination at very high temps (900-1100 degrees celsius), the structure is a complex combination of varying crystal domains.	- Has partly covalent and ionic bonds	- 101.961 g/mol
Stainless Steel	- Metal	- Crystallographic	- Metallic	- Composition of different kinds of metal materials - Generally 75-90% iron which has a molar mass of 55.945g/mol

Properties

Material	Elastic Modulus	Ultimate Strength	Toughness, Fracture (brittle/ ductile)	Wear	Friction	Corrosion Resistance	Biocompatibility
UHMWPE with vitamin E	- Varies depending on compound of materia. Fillers such as graphene oxide change this value.	- The ultimate strength is increased with vitamin E diffused is 46MPa	- High plasticity - Hard - Durable	- With vitamin E diffused, the fatigue resistance was 0.70-0/77MPa.m^½ - High fatigue resistance of UHMPWE but due to oxidation, reduces to 0.19MPa.m^½ - Incorporating vitamin E will increase the fatigue resistance	- Low coefficient of friction	- Vitamin E helps reduce oxidation which would corrode the implant	- Biological antioxidant (alpha-tocopherol) - Abundant in the body and interacts with free radicals to reduce oxidation
Alumina	- Depends on the porosity of alumina used, can range from 330GPa -410 GPa	- 580 MPa	- Strength of alumina is higher in compression than in tension/bending.	- Lower wear rates than both metal on polymer and metal on metal prosthesis. Should function in the body for nearly 10 years.	- Low coefficient of friction	- Resistant to corrosion	- One of the most common materials used in total hip arthroplasties, biologically inert. Safe to use in the body
Stainless Steel	- 193-200 GPa	- 505MPa	- Ductile - 112-278 MPa.m^(½)	- Fatigues after a while	- Low coefficient of friction	- Resistant to corrosion	- Can be used in body

Processing

Material	Coatings	Drug Delivery Options	Corrosion Resistance	Incorporation	Additional properties
UHMWPE with vitamin E **Vitamin E concentrations above 3% reduces the degree of crystallinity which decreases the hardness and density**	N/A	N/A	- Radiation crosslinking and thermal treatments would improve oxidative stability and prevent osteolysis	- 1.Blend in VE and UHMWPE powder before consolidating - 2.diffuse the VE into the UHMWPE after radiation cross linking	-Antibacterial (decreases the ability of bacteria found in periprosthetic joint infections) -*Staphylococcus epidermidis, Staphylococcus aureus* and *Escherichia coli)* - Change the surface to prevent microbial adhesion process
Alumina	- Zirconia toughened alumina strengthens the alumina and makes it more biocompatible	- N/A	- ZTA, like alumina, is corrosion resistant.	- N/A	- ZTA possesses a high biocompatibility and lowest abrasion + wear debris in comparison to other bearings. This makes it easier for patients to have an active lifestyle
Stainless Steel	- Has a natural zinc coating	- Not needed as it doesn't directly come in contact with bone	- Zinc prevents rusting and corrosion	N/A	N/A

Detail Design:

Femoral Stem:

Based on the tables on the previous pages, your team will consider **calcium phosphate (hydroxyapatite)** and **zirconia** as potential materials for this component.

Explain why you selected these based on their structure, processing, or performance?

Calcium Phosphate (Hydroxyapatite) - We chose this material because it is very similar to bone. It is an abundant mineral inside of natural bone, so it is very osteoconductive and biocompatible. It has a similar elastic modulus to bone, which prevents stress shielding and allows the bone to continue to be used and be maintained around the implant by osteoblasts. It is antibacterial, which prevents the growth of infections near the implant. This material fits the needs of our patient because the material will aid in the growth and maintenance of new bone, which is important due to the natural bone imperfections of our patient. The combination of the new bone and implant will fix these imperfections and allow him to go back to his active lifestyle and prevent pain. This material could also be made into a composite to be made stronger in order to allow more force to be applied to it. The hydroxyapatite, which is a specific type of calcium phosphate, is the most stable form of calcium phosphate in the temperature, pH, and composition of body fluids.

Zirconia (Oxinium) - We chose to consider this material as a component of the femoral stem because of many features. The oxinium material is composed of zirconium alloy (95% zirconium) which is oxidized on the surface thus producing a ceramic coating that is twice as tough and corrosion resistant than the inside. Since the inside is composed of zirconium alloy, it's fracture would be ductile and thus presents evidence of plastic degradation before fracturing which is prefered in a hip replacement rather than a sudden brittle fracture with no visible evidence prior to fracture. In addition, this oxidized zirconium is very biocompatible as it does not induce cytotoxicity (toxicity towards cells), inflammation or adverse effects on connective, immunologic, or bone tissues while reducing bacterial colonization as it does not allow adhesion of bacteria to the surface.

Dual-Mobility Cup:

Based on the tables on the previous pages, your team will consider **UHMWPE doped with vitamin E** and **alumina** as potential materials for these components.

Explain why you selected these based on their structure, processing, or performance?

UHMWPE doped with vitamin E - We chose this since it is a very tough and durable material that will withstand the physical activities that Hounsou takes part in, specifically basketball and daily activities. Its low coefficient of friction is very important since in the dual mobility liner, the component must have very little friction so that it can move against the acetabular cup and the head of the femoral stem. The introduction of vitamin E lowers the risk of oxidation, which is the largest reason these implants fail. Essentially, if implants are oxidized they not only degrade faster, they increase the rate of bone degradation. In addition, with the high fatigue resistance and antibacterial properties, this material is able to improve the stability of the implant by preventing the occurrence of osteolysis, which may require revision surgery due to the loss of bone. The antibacterial properties prevents periprosthetic joint infections but changing the adherence of microbes to the surface, such as *Staphylococcus epidermidis, Staphylococcus aureus* and *Escherichia coli,* which are most commonly found in joint infections.

Alumina - This is a ceramic material can withstand large amounts of compressive stress and has low wear rates when compared to metals and polymers. This would improve the lifespan of the implant, allowing Hounsou to go years without a replacement. It has been used in implants for years, and has proven to be very biocompatible and resistant to corrosion. This factor increases the safety of the material as it would not be rejected by the body. Its low coefficient of friction is useful for the dual mobility cup because it must be able to move against the acetabular cup and femoral shaft.

Whole Design:

Comment on why the materials selected for all components makes the most sense **for your patient**:

We decided to use a composite of calcium phosphate and zirconia so that our patient would be able to benefit from the characteristics of both materials. The calcium phosphate is very similar to bone, increasing the osseointegration of the material. In addition, calcium phosphate has an elastic modulus slightly lower than bone, preventing the occurrence of stress shielding. To compensate for this, the addition of zirconia would strengthen the material, lowering the risk of fracture. By integrating both materials, creating a composite, we are able to incorporate the high strength of zirconia and its resistance to wear and corrosion, with the osteoconductive material of calcium phosphate. The zirconia is able to improve the properties of calcium phosphate, being able to imitate the fibers of bone, being able to hold the material together (preventing crumbling/chipping over time). In addition to that, calcium phosphate is very light weight - similar to bone. As a result, Hounsou would be able to go back to his active lifestyle without worry of dislocation.

For the dual mobility cup, incorporating UHMPWE doped with vitamin E, by incorporating vitamin E, we are able to reduce oxidation with in term prevents the corrosion of this material. In addition, the antibacterial properties of this material ensures post surgical complications are prevented, such as the loosening of the implant due to bone degradation, and the uptake of bone from the body (osteolysis). The prevention of microbial adhesion maintains the antibacterial properties ,maintains long term implant osseointegration and promotes osteogenic induction. We want to elongate the implant life for our patient to prevent post surgical revisions, allowing our patient to lead an active lifestyle without.