1. Abstract

For over a century, orthopedic implants, which are inserted during surgery to support bone damage, have been simultaneously manufactured with stainless steel and titanium. However, due to budget restrictions, many hospitals choose to only order implant sets in one material, therefore necessitating a conclusion in which material is a better choice. This paper serves to investigate the material properties of each metal as well as how the implants react in the environment of the human body. In addition, it summarizes the research published comparing the biomechanical properties and success rates of the two materials when applied to orthopedic implants.

2. Introduction to Orthopedic Implants

Orthopedic surgeons use a variety of implants in order to stabilize bone fractures in bones all throughout the body. These implants are placed carefully in or through bone, and they are never removed unless rare complications, such as malunion, infection, and rod breakage. Intramedullary nails are the most common treatment following fracture of the femoral and tibial shaft because they reliably hold the fractured components in place while it heals [1]. Bone plates are also used to stabilize fractures, however they are more specialized to condylar fractures, or those at the head of a bone. Pins are used when there are fractures in the femoral head, which cannot be easily reached with nails or bone plates. Manufacturing of
orthopedic implants is a growing field, with “world-wide sales of orthopedic implants alone in 2003 [being] $8.7 billion and projected to increase at an annual growth rate of 12.5% and reach $17.9 billion by 2009” [2]. With so many implants in use, it is important to analyze the materials used and how to optimize for the best care.

Each of these implants is commonly made in both stainless steel and titanium. Many metals have been investigated, including aluminum, copper, zinc, iron, carbon steels, silver, nickel, and magnesium, however steel and titanium have proven the most useful due to their lack of reactivity with the environment and resistance to corrosion [2]. Stainless steel is primarily used in cranial plates, orthopedic fracture plates, dental implants, spinal rods, joint replacement prostheses, stents, and catheters. Titanium is primarily used in cranial plates, orbit reconstruction, maxillofacial reconstruction, dental implants, dental wires, orthopedic fracture plates, joint replacement prostheses, stents, and ablation catheters. Both metals have been used for over a century in these implants, yet there is no clear consensus on which is a better choice for the overlapping applications, such as joint replacement prostheses and orthopedic fracture plates. Well-known medical device companies such as Depuy Synthes and Styker continue to make many implants in both materials, so the choice is left to physicians on which they prefer.

This paper serves to describe and compare the use of stainless steel and titanium in orthopedic implants through the investigation of their material properties as well as how each metal reacts in the environment of the human body. It is very important to look at the interaction in the body because it is a very unique environment: “a highly oxygenated saline electrolyte at a pH of around 7.4 and a temperature of 98.6°F... the ionic composition and
protein concentration in body fluids complicate the nascent understanding of biomedical corrosion even further” [2]. In addition, the human body “can contain water, complex organic compounds, dissolved oxygen, sodium, chloride, bicarbonate, potassium, calcium, magnesium, phosphate, amino acids, proteins, plasma, lymph, saliva, etc” [2]. Therefore, the material chosen for orthopedic implants must be resistant to many types of materials that it may interact with inside the human body. This makes the making of implants very difficult, and it has required many iterations.

3. Material Properties of Stainless Steel

Stainless steel has been used in orthopedic implants since the early 1900s [3]. First discovered in 1821 and more specifically defined in 1911, steel is a metal alloy that contains iron and a minimum of 10.5% chromium. Oftentimes, steel includes small percentages of additional metals, such as nickel, molybdenum, titanium, and copper, which serve to adjust the structure and properties to fit the application. For example, the addition of nickel or molybdenum increases the stability of iron’s crystallized structure, therefore making the alloy non-magnetic which is preferable for kitchen appliances, automobile components, and industrial equipment. Another possible addition is carbon, which increases the alloy’s harness, making it suitable for knife blades and other tools that cannot break. However, in all cases, stainless steel is resistant to corrosion in the environment [4]. While there are many types of stainless steel, only two have been used in orthopedic implants: originally type 302 and more recently 316L [3]. Type 302 consists of 70% iron, 18% chromium, 9% nickel, 2% manganese, and small amounts of carbon, phosphorous, sulfur, and silicon. The high nickel content serves to increase the corrosion resistance while lowering the rate of hardening. It also nonmagnetic and
extremely tough [5]. However, steel can become magnetic when a ferrite element is included, which is extremely dangerous because the field of orthopedics relies on Magnetic Resonance Imaging (MRI) frequently. If the steel becomes ferromagnetic, this could be dangerous for the patient by limiting the possible care [3].

In recent years, the field has made the switch to type 316L because it is superior in terms of corrosion, which is crucial when inside the human body to limit the risk of infection [3]. Type 316L is composed of 65% iron, 17% chromium, 12% nickel, 2.5% of molybdenum, 2% manganese, and small amounts of carbon, phosphorous, sulfur, and silicon [5]. The addition of molybdenum serves to shield the metal from the acidic environment inside the human body [3]. The “L” type signifies a very low amount of carbon, which reduces the chance of adverse reactions by the tissue [6]. Type 316L stainless steel has both a relatively high tensile strength and young’s modulus (Table 1).

Table 1. Mechanical properties of Type 316L Stainless Steel. [2]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>650 (MN/m)²</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>211 (GN/m)²</td>
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</tbody>
</table>

While stainless steel is extremely well suited for orthopedic devices given the strong corrosive resistance, it cannot be used for extended load bearing activities due to its fatigue failure rates. This means it is not recommended for use in implants that will secure bones in the leg. Therefore, stainless steel is best suited for plates and screws rather than nails [6].

4. Material Properties of Titanium
Titanium began being used in orthopedic implants in 1960 due to its corrosion resistant properties [2]. Titanium was first discovered in 1791 as a component of menachanite, a black sand, and then as an oxide in 1795. However, it was not isolated in purity until 1910 when a General Electric employee heated titanium chloride and sodium metal [7]. Titanium maintains the same similar strength to stainless steel while maintaining a significantly lower weight. Titanium is nonmagnetic, nontoxic, and has very low reactivity [3]. In addition, titanium has a modular of elasticity that is very close to that of bone [1], making it less likely to have long term effects on the bone; because titanium and natural bone move similarly, it will not put additional force on areas where it intersects with the bone. The most commonly used titanium alloy is Ti-6 aluminum Ti-4 vanadium (Ti6Al4V), in which the aluminum and vanadium serve to stabilize the titanium [3]. Titanium has both a relatively high tensile strength and young’s modulus (Table 2).

Table 2. Mechanical properties of Titanium. [2]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Tensile Strength</td>
<td>137.3 (MN/m)^2</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>30 (GN/m)^2</td>
</tr>
</tbody>
</table>

5. **Comparison of Stainless Steel and Titanium for Orthopedic Implants**

The debate over stainless steel and titanium in the use of orthopedic implants is not settled, and many research studies have been completed in order to better understand the advantages and disadvantages of each.
A 2004 study entitled “Biomechanical comparison of stainless steel and titanium nails for fixation of simulated femoral fractures,” investigated and compared the biomechanical effects of stainless steel and titanium intramedullary nails when used to treat transverse and comminuted fractures in a femur. Using a synthetic femur model, the researchers measured the rotational stability, axial compression stiffness, and axial failure load while undergoing a mechanical testing, and the results were analyzed using a two-way ANOVA [8]. The titanium nails had significantly greater rotational stability as well as axial compression stiffness, while no difference was apparent in failure load [8], which suggests that titanium is a better choice for orthopedic implants. These results were confirmed by a 2008 study, “A computational evaluation of the effect of intramedullary nail material properties on the stabilization of simulated femoral shaft fractures,” which followed a similar method to the 2004 study. The results indicated that titanium nails resulted in reduced slippage than the steel alternative and additionally distributed the force along the nail which reduced the magnitude at any one spot [9]. Other research continued to suggest that titanium is superior to steel for orthopedic implants in terms of mechanical properties and effects.

However, titanium’s superiority was not found universally in research studies in the last twenty years. A 2008 study entitled “Complications of titanium and stainless steel elastic nail fixation of pediatric femoral fractures” retroactively analyzed the complication rates following the treatment of pediatric patients with femoral fractures with either a titanium or stainless steel nail of the same design. Statistical analysis revealed that the rate of malunion, in which the bone does not properly heal, was almost four times higher with the use of titanium nails than the rate when steel was used. The rate of major complications, such as malunion, a second
surgery, infection, delayed union, and rod breakage was similarly skewed in favor of steel. In addition, the study noted that a stainless steel nail was much lower cost than a titanium nail, at $78 for stainless steel as compared to $259-328 for titanium [10]. These results suggest that stainless steel is a more reliable choice for minimizing adverse effects post-treatment for patients with a femoral fracture.

6. Conclusions

While the majority of research on the biomechanical differences of stainless steel and titanium suggest that titanium is a better choice for orthopedic implants, the clinical evidence supporting stainless steel as a safer choice of material cannot be ignored. Because research has been found to support both stainless steel and titanium as the ideal material for orthopedic implants, physicians must choose for themselves which research to value, leading to which implants to choose. In fact, there are some articles that have compiled the research and organized it by priority for orthopedic surgeons to consult when selecting the correct implant for a specific surgery. However, since implants are so expensive, hospitals often only keep one set of implants in stock, so they must choose which material to order in advance, forcing physicians to decide based on one generalized priority rather than specific ones for individual patients [11].

One very common characteristic for physicians to consider is corrosion because, as mentioned above, it can be very dangerous to the patients. Side effects are common because “when a metal implant is placed in the human body, it becomes surrounded by a layer of fibrous tissue of a thickness that is proportional to the amount and toxicity of the dissolution products and to the amount of motion between the implant and the adjacent tissues” [12].
When the implant is composed of stainless steel, metal ions diffuse over time, therefore increasing the motion which in turn increases the layer’s thickness [12]. A large layer of fibrous tissue is unhealthy and therefore avoided by physicians.

Another common measure that physicians consider is the adverse side effects because their ultimate goal is to treat a patient without any complications. If this is decided as the most important factor, then physicians would select stainless steel based on the research detailed above [10].

The final common factor for physicians to consider is cost; with the cost of titanium implants three to four times higher than that of stainless steel implants [10], hospitals with limited funding may decide to purchase the stainless steel implants. All of these factors are important to consider when making the decision, yet it is still the responsibility of the physician or hospital institution to choose rather than a clear decision from the medical community.

7. **Looking Forward**

In recent years, material scientists, biologists, and chemists have together explored the addition of a biocompatible coating to implants, such as calcium phosphates and biomolecules, to negate some of the negative interactions metal can have with the human body. As discussed, these negative interactions can result in infection, present in 5% of all cases, that leads to the implant being removed and unable to heal the bone [13]. Most successful of the calcium phosphate-like coatings is carbonated hydroxyapatite, which is a large component of bone. With this coating, the bone sees the implant as another bone rather than an alien object, which greatly limits the chance of infection. In addition, the coating is able to form bonds with the surface of the bone which increases the strength of the interface and allows bone healing occur
more quickly. Moving forward, developers are considering the addition of growth factors to further help the process of bone formation [13].

Many types of biomolecule coatings have been developed, such as collagen, small peptides, DNA molecules, and chondroitin sulfate. In order to hold these biomolecules on the implant, researchers have employed two methods: hydrogels and layer-by-layer coatings. These methods are still under development and less used than carbonated hydroxyapatite thus far [13]. The field of implant coatings is still very new, and significant more research can be anticipated in the coming years.

Whether a physician chooses stainless steel, titanium, or any other material, orthopedic implants are not long-lasting because they cannot withstand the repetitive movements and loading or the hostile environment of the human body. Therefore, researchers are continuously looking for new materials that may be applied to implant technology.
Works Cited


