# An Overview of Internal Fixation Implant Metallurgy and Galvanic Corrosion Effects

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Orthopedic and hand surgery implants for internal fixation of fractures have evolved substantially over the past 50 years. Newer metal compositions have been used, and new standards have been applied to older alloys, resulting in modern implants with unique physical properties and better clinical performances. Conventional wisdom has long dictated that implanting different metals should be avoided, but few guidelines exist regarding the safety of using in proximity implant systems of dissimilar metals. To better characterize the landscape of internal fixation implant metallurgy, we have compiled the recommendations and conclusions of the currently available and pertinent literature. *(J Hand Surg Am. 2015;40(8):1703−1710. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)*

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OVER THE PAST 50 YEARS, ORTHOPEDIC and hand surgery implants for internal fixation of fractures have evolved dramatically. Advances include the development of materials designed for optimal biocompatibility, effective fracture reduction, and minimal anatomical profile. Orthopedic implants in the wrist proved particularly challenging owing to the complex anatomy and stress that this area endures. Fortunately, improvements of internal fixation implant design have identified a set of materials with excellent biocompatibility and corrosion resistance—each material presents its own unique properties and limitations.[1–3] Moreover, implant failure due to galvanic corrosion from implant assemblies involving dissimilar components has become a concern for hand surgeons. This review outlines the properties of metals most frequently used in hand surgery for internal fixation and the alloys used in other orthopedic applications. We also outline the science driving corrosion through galvanic coupling and investigate the evidence guiding current practices to minimize corrosion and implant failure.

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## METALS COMMONLY USED FOR IMPLANTS IN HAND SURGERY

The most common metals used for internal fixation implants for hand fractures are titanium and stainless steel. These 2 metals are quite different in terms of mechanical properties and fabrication, but modern standards for implant-grade metals yield excellent biocompatibility and stability for both.

### Stainless steel

Stainless steel has been applied in orthopedic surgery since 1926. Industry standardization has led to the newer compositions of surgical-grade stainless steel. The American Society for Testing and Materials (ASTM) and the International Organization for Standards guidelines for surgical-grade stainless steel include parameters listed in Table 1.

As outlined by Disegi and Eschbach,[1] minimum percent compositions for molybdenum and chromium

**TABLE 1. Composition Limits for Implant Quality Stainless Steel**

| Element | ISO 5832-1 Composition D [Wt. %] |
|---|---|
| Carbon | ≤ 0.030 |
| Manganese | ≤ 2.0 |
| Phosphorus | ≤ 0.025 |
| Sulfur | ≤ 0.010 |
| Silicon | ≤ 1.0 |
| Chromium | 17.0−19.0 |
| Nickel | 13.0−15.0 |
| Molybdenum | 2.25−3.5 |
| Nitrogen | ≤ 0.10 |
| Copper | ≤ 0.50 |

ISO, International Organization for Standards.

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are necessary to prevent local corrosion and pitting defects. Beyond these parameters, International Organization for Standards guidelines dictate maximum allowed levels for other trace elements to prevent damage to the surface finish or imperfections that hamper the austenitic iron organization (stainless steel's atomic crystal structure—austenitic crystals exist as face-centered cubic crystals). For example, limiting silicon content minimizes disruptive silicate inclusions, and excessive carbon affects the heating process during steel fabrication, resulting in chromium-sequestering carbon deposits that may lead to intergranular corrosion. Although ASTM includes permissible levels of nickel in its steel formulas, studies have also explored the benefits of minimizing nickel in steel compositions to minimize allergic reactions to nickel while also improving corrosion resistance (Table 2). However, despite some anecdotal incidence of hypersensitivity reactions to stainless steel hardware, this phenomenon has not been extensively researched.[4,5]

### Titanium

Owing to concern regarding its mechanical properties, titanium was not initially readily chosen for orthopedic applications despite a theoretical advantage of creating a thinner implant compared with equivalent-strength stainless steel. As a result, titanium alloys were developed to compensate for titanium's perceived weaknesses. Metals added to titanium include aluminum, vanadium, and niobium.

The 2 most common alloys currently in use are: Ti-6Al-4V (titanium alloyed with aluminum and vanadium) and Ti-6Al-7Nb (titanium alloyed with aluminum and niobium). The latter was introduced in 1986 and developed to address the potentially cytotoxic properties of Ti-6Al-4V. Granular vanadium is highly cytotoxic.[6,7] However, a study examining the cytotoxic properties of passivated Ti-6Al-4V discs against murine fibroblasts did not show appreciable cytotoxicity or genotoxicity.[8] Given the current safety profile, many orthopedic implant manufacturers continue to produce implants composed of Ti-6Al-4V.[2,9]

## PROPERTY DIFFERENCES BETWEEN STAINLESS STEEL AND TITANIUM

Property differences between stainless steel and titanium are briefly summarized in Table 3.

### Density

The stainless steel alloys prepared according to ASTM standards have a density of approximately 7.9 g/cm$^3$, greater than titanium in comparable applications. Surgical-grade stainless steel, typically 316L, also has an 80% higher elastic modulus (193 gigapascals [GPa]) than titanium. The elastic modulus refers to a material's susceptibility to nonpermanent deformation when subjected to force. Both titanium alloy compositions have similar densities (4.42 for Ti-6Al-4V and 4.52 for Ti-6Al-7Nb) and tensile strengths. The elastic modulus for Ti-6Al-4V is 114 GPa, and the elastic modulus for Ti-6Al-7Nb is 105 GPa.[10] These properties make stainless steel implants much stiffer than their titanium counterparts and less likely to deform under applied stress. These differences in elastic modulus do not carry considerable clinical implications but are related to the alloys' different tactile sensations during implant placement.

### Tensile properties

The tensile properties of metals include hardness, ductility, and malleability. Hardness is defined by susceptibility to permanent deformation under force. Ductility is deformability under tensile stress (eg, drawing a metal into a wire). Malleability is the ability for a metal to be pounded into a flat plate.

The physical properties of stainless steel may be adjusted based on fabrication method, allowing for appropriate conditioning to match specific applications (Table 4).[1,2,9] For example, cerclage wires require greater ductility with less inherent strength, whereas Kirschner wires require stiffness and strength. As a

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