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MATERIAL SELECTION STRATEGIES FOR INDUCTIVE-RESONANT IMPLANTABLE BIOELECTRONICS

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INTRODUCTION

Implantable bioelectronic sensors enable minimally invasive and continuous monitoring of vital physiological parameters. For instance, inductive-resonance-based sensors integrated into stent grafts allow battery-free, real-time monitoring of hemodynamic conditions, offering a powerful tool for tracking the progression of diseases such as Abdominal Aortic Aneurysm, which affects over 35 million people worldwide [1]. In such implantable sensing systems, wireless communication between an external readout circuit and the in-body sensor is typically achieved through magnetically coupled coils. Therefore, the choice of material for these coils is critical in determining key electromagnetic characteristics. Particularly, the quality factor could be used as an early indicator of coil performance and its applicability for an implantable, wireless sensing system [2]. Copper, known for its excellent performance as coils, is commonly used during early-stage prototyping. However, its poor biocompatibility and susceptibility to oxidation make it unsuitable for long-term implantation devices [3]. Consequently, alternative materials such as brass, stainless steel, and nitinol, each exhibiting unique electromagnetic and biocompatibility properties, must be evaluated for clinical applications.

In this work, we present a comparative assessment of different metallic materials used in biomedical applications and their influence on the performance of sensors utilising inductive coils. The results provide insights into the trade-offs between electrical performance and biocompatibility and outline design strategies for optimizing inductive-resonant implantable sensors.

MATERIALS AND METHODS

To assess the influence of metal selection on sensor performance, four identical coils were fabricated using copper, nitinol, brass, and stainless steel. Each coil was wound around a one mm-thick PLA shell to ensure consistent geometric characteristics across all samples. The inductance (L_S) and resistance (R_S) of each prototype were measured using a calibrated Keysight E4990A impedance analyser over the range of 1 MHz to 15 MHz, which covers the frequencies (f) usually employed for magnetic-resonant implantable sensors. Based on these measurements, the quality factor (Q) of each prototype was calculated as $\boldsymbol{Q = {}^{2\pi f L_S}/_{R_S}}$.

RESULTS AND DISCUSSION

The results in Figure 1 show that the copper coil achieves the highest Q, reflecting its superior ratio of stored magnetic energy to resistive loss, consistent with copper's high electrical conductivity. Brass, a copper-zinc alloy, also displays a relatively high Q. However, both copper and brass are unsuitable for implantation due to oxidation and potential toxicity [3].

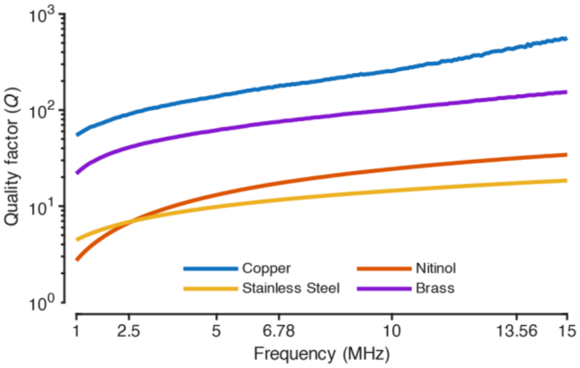

Figure 1 Quality factor (Q) for different implant materials.

The stainless-steel coil exhibits the highest inductance owing to its high magnetic permeability, though this property is frequency-dependent and non-linear, causing inductance to converge with that of other coils at higher frequencies. Steel also shows markedly higher resistance, attributed to its carbon content, which reduces conductivity. Despite its biocompatibility, stainless steel demonstrates poor electromagnetic performance.

Nitinol offers a favourable balance between electromagnetic performance and biocompatibility, along with shape-memory properties. However, it suffers from elevated ohmic losses. These can be mitigated by optimizing the nickel–titanium composition for higher conductivity and coating the coil with a biocompatible, highly conductive metal such as gold or silver. If the coating thickness exceeds the skin depth at the operating frequency, resistive losses can be significantly reduced, improving overall coil efficiency.

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