Theoretical Piezoelectric Composite Model for Use in a Spinal Fusion Cage

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Statement of Purpose: Back pain is one of the most common neurological diseases, with only headaches occurring more frequently. The primary surgical treatment for low back pain is lumbar interbody fusion. The goal of this surgery is to restore disc height and proper vertebral orientation, remove pathological tissue, and stabilize the joint so that bone can fuse the adjacent vertebrae together. While this surgery is performed roughly half a million times per year, over half the patient population is considered difficult to fuse. For these patients, failure rates are typically reported as being between 10% and 46%. Adjunct therapies, such as electrical stimulation, significantly increase fusion rates; however, current delivery methods are complicated with patient compliance concerns, or the need to implant a large battery into the patient.

Aiming to improve upon these methods, the authors have begun to develop a piezoelectric spinal fusion cage. The cage will improve the rate of fusion by generating electricity as it is compressed between the vertebrae during normal activities. The implant relies on the development of a piezoelectric composite material in order to overcome the limitations of common piezoceramics.

Methods: To determine whether power adequate to stimulate bone growth can be generated, a theoretical model for piezoelectric composite power generation was developed by integrating a dynamic lumped parameters model and equations calculating the material properties of structured piezoelectric composites (1). Constraints specific to the material's use as a fusion cage were applied to the model, such as implant geometry and applied force. $BaTiO_3$ and PEEK were selected as the ideal materials for the composite's fibers and matrix, respectively, due to their advantageous material properties and biocompatibility.

Results: Utilizing the theoretical model, several relationships between power and composite material parameters were established (Fig. 1). For a cyclic force of set magnitude, power was found to increase proportional to composite thickness and inversely proportional to cross-sectional area.

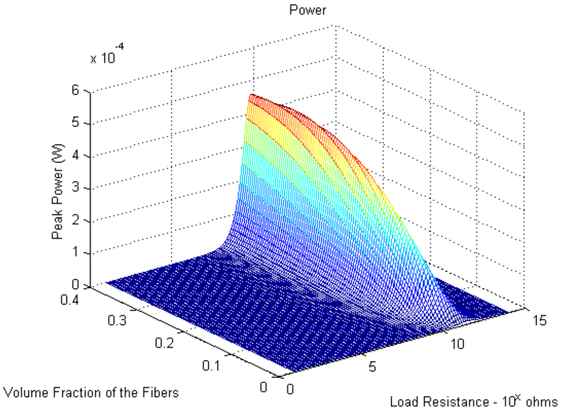

Fig 1. Theoretical results for peak power versus volume fraction of the fibers and load resistance.

This means maximum power occurs at a composite thickness of 20 mm and a cross-sectional area of 120 mm^2, based on the material's constraints as a fusion cage. Power was also found to increase with fiber aspect ratio, but shows little change (<1%) at aspect ratios greater than 100. Maximum power was generated with a load resistance of 8.5 GΩ and a fiber volume fraction between 30-35%, depending on the composite's dimensions and fiber aspect ratio.

Conclusions: According to the theoretical analysis, an implant made of $BaTiO_3$ fibers and a PEEK matrix can generate 0.33 mW, 2.4 times the power generated by current electrical stimulation adjuncts. Therefore, a piezoelectric spinal fusion cage is a viable option to stimulate bone growth.

Reference: (1) Van den Ende et al. (2012) Journal of Applied Physics 111: 124107.

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