Bioactive Magnetoelastic Materials as Coatings for Implantable Biomaterials

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Enhanced fibroblast activity at the soft tissue-implant interface can dramatically decrease the stability, function, and lifespan of biomedical implants such as bone anchored prostheses. Although bone anchoring systems dramatically improve prosthetic limb mechanical stability, uncontrolled fibrosis at the soft tissue-mounting post interface is a significant problem. The aberrant cell growth leads to irregular skin folds that prevent proper sealing to the bone anchoring post and also serves as a site for opportunistic infection and failure of the prosthetic system. We are developing a bioactive vibrational coating to control fibrous tissue overgrowth. The coating is based on a magnetoelastic (ME) material that can be set to vibrate at a predetermined amplitude and frequency using a controlled magnetic field. We hypothesize that small local vibrations can be used to selectively control cell adhesion and gene expression to promote and maintain functional stability at the implant-tissue interface. For bone anchored prostheses, the ME coating would be applied around the mounting post at the soft tissue interface. The specific aims of this work were to (1) modify the coating for use in contact with a biologic environment and (2) determine if local vibrational strain can efficiently control cell attachment to the coating without significantly influencing viability. First, two common biocompatible polymers, polyurethane and chitosan, were deposited as thin films on the ME coating to allow for its use in tissue culture. An indirect cytotoxicity test was used to determine fibroblast (L929) viability in media conditioned for 24 and 48 hours with uncoated, chitosan coated, and polyurethane coated ME materials. Results demonstrated that both polymer coatings returned cell survival to levels statistically indistinguishable from controls (cells cultured on tissue cultured polystyrene, TCP) with cell viability over 96% under all coating conditions. Second, the affect of local vibrations on cell adhesion was tested in vitro. A cell viability assay (Calcein-AM) followed by fluorescent imaging was used to quantify attachment and viability of fibroblasts cultured directly on the bioactive ME material. Results clearly indicated that controlled local vibrations can induce complete cell detachment from the ME material compared with non-vibrated controls at up to 72 hours post-seeding. Further, cells detached via applied vibrations showed no significant decrease in viability compared to adherent controls. These results suggest the potential for this novel coating to effectively control fibrous tissue overgrowth using the mild application of tunable local vibrations, a significant and cost-effective approach that could improve the stability, function, and lifespan of biomedical implants and reduce the need for surgical revision.

Design Optimization of Single-Port Minimally Invasive Intervention Devices

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Despite the success of multiple-port minimally invasive intervention (MII) systems, current research is fast moving away from standard, kinematically rigid MII instruments toward more flexible, highly articulated devices, such as robotic catheters, probes, and forceps. These new devices afford surgeons the same dexterity and range of motion as multiple-port systems while using only a single incision. Single-port MII devices hold the promise of facilitating procedures in small, geometrically complex spaces, such as those seen cardiothoracic surgery, with even lower risks of infection and patient discomfort than possible with multiple-port systems. However, the mechanical sophistication of these robotic devices requires careful consideration of morphological design to ensure that the complexity and cost of design is not economically prohibitive enough to outweigh the clinical benefits of improved robot flexibility. This study focuses on the intelligent design of a kinematically redundant, single-port MII robot architecture by way of morphological optimization. This MII device morphology is optimized to access the cardiothoracic cavity through a single 12 mm subxiphoid port and reach several regions of interest, consistent with procedures such as epicardial ablation and therapeutic substance injection, with minimal physiologic disturbance. The optimization process employs a recently developed morphological fitness metric to measure a candidate morphology's ability to navigate the cardiothoracic environment and perform surgical maneuvers with high end-effector flexibility while maintaining safe distances from anatomical structures. This fitness metric uses a Jacobian-based formulation to quantify a robot's capacity to avoid collisions with motion impediments and to minimize the mechanical torque required for the intended task. In addition to performance-based criterion, this optimization process also considers design factors such as part manufacturability and expense which heavily influence economic feasibility. Morphological optimization is performed by searching the mechanical design parameter space, which consists of part dimensions and linkage types, using genetic algorithms. The execution of specific surgical maneuvers is simulated for each candidate morphology until the fitness metric is maximized. Final simulations of the optimized device morphology working in the cardiothoracic cavity are performed to demonstate the functional advantages of the optimized single-port robot over current multiple-port systems.