Surface Imprinting to Enhance Antibiotic Elution of Bone Cement Spacers

David Tran, BS; Hugh Jones, BS; Mark Coggins, BS; Nathan Rogers, MD
Department of Orthopedic Surgery, McGovern Medical School, University of Texas, Houston, Texas

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Introduction

Periprosthetic joint infections (PJI) present a significant clinical challenge in total joint arthroplasty (TJA). The gold-standard treatment approach for infected TJA is a two-stage revision strategy, where polymethyl methacrylate (PMMA) antibiotic spacers play a critical role. These spacers provide localized antibiotic delivery. However, the efficiency of antibiotic release from PMMA is hindered, with approximately 80% of the embedded antibiotics remaining "land-locked" within the construct. Introducing porogens at the point-of-care has been explored to increase antibiotic elution rates but at the cost of compromising mechanical integrity. This study aims to characterize an approach to enhance antibiotic elution by increasing the surface area of antibiotic-loaded constructs in the joint space while maintaining adequate mechanical properties necessary for articular spacers.

Methods

Cylindrical PMMA constructs were created from polyethylene molds having three surface features: solid (smooth surface), dimple (i.e. shallow hemisphere impression), and cavity (i.e. complete through cylindrical cavity). SimplexTM P bone cement mixed with tobramycin and vancomycin were used for compression and antibiotic elution testing, respectively. Six specimens were created for each test. Compressive strength tests were conducted to evaluate the mechanical integrity of the textured surfaces and were compared to standard the solid PMMA specimens. Antibiotic elution was followed for 3 weeks, with samples taken at days 1-5, 8, and then weekly. Kirby-Bauer disk diffusion testing was done at each timepoint by measuring zones of inhibition digitally.

Results

Initial zones of inhibition (ZOI) were comparable across all geometries during the three weeks, with minor, nonsignificant variations. At week 2, cavity and dimple geometries tended to show a 10.8% ($p= 0.08$) and 9.2% ($p= 0.14$) increase in ZOI compared to solid samples, respectively. By week 3, the cavity group's increase dropped to 1.5%, while the dimple group maintained a 7.7% increase. The dimpled specimen tended to have larger zones of inhibition compared to the solid specimen, but not significantly. It was also observed that air pockets had developed within the voids of the through cavity group which may have affected antibiotic release. For mechanical testing, solid geometries demonstrated the highest compressive strength and stiffness. Compared to solid controls, cavity geometries exhibited a 73.0% reduction in ultimate compressive force, 46.6% reduction in stiffness, and 69.2% reduction in yield strength ($p< 0.001$). Dimple geometries showed moderate reductions of 23.2%, 18.0%, and 22.9%, respectively and remained within the compressive strength threshold of the ISO 5822:2002 standard for bone cement ($p<0.001$).

Discussion

In this study, we characterized an alternative method to increase the surface area of antibiotic loaded cement spacers without the pitfalls of employing porogens at the point-of-care. Future work is needed on refining methodology and optimizing imprint depths to maximize antibiotic elution rates while maintaining mechanical properties. Regarding mechanical properties, shallower imprinting imposes adequate resistance to compression whereas deeper imprinting significantly weakened the bone cement construct. Both solid and dimple geometries, however, satisfy the ISO 5833:2002 bone cement standard for a minimum compressive strength of 70 MPa.

Clinical Significance

Approximately 80% of the antibiotic load of two stage revision articulating spacers are inhibited from release. This study characterizes a point-of-care means to potentially increase its reservoir of antibiotics without compromising mechanical properties.