Compression Strength and Porosity of Single-Antibiotic Cement Vacuum-Mixed with Additional Vancomycin

Introduction

Frequently in joint replacement surgery, antibiotics are combined with acrylic cement to provide high local drug concentrations for prevention and treatment of infection. In 2003, the FDA approved the sale of single-antibiotic cement for use in septic arthroplasty cases. Such cements can now be purchased from various manufacturers. A major disadvantage of adding antibiotics to bone cement is the detrimental effect antibiotics have on cement strength. Seeking even greater advantages over infection, surgeons have recently begun adding an additional antibiotic, vancomycin, to these already single-antibiotic cements.

The objective of this study was to determine the maximum amount of vancomycin that could be added (vacuum-mixed) to two commonly-used commercially available single-antibiotic cements while still maintaining an ultimate compression strength (UCS) above the Intermountain Orthopaedics for Standards (ISO) minimum of 70 MPa. We also investigated surface characteristics of the cement to elucidate the mechanism for this detrimental effect. We hypothesized that antibiotics decrease the strength of bone cement by increasing porosity.

Methods

We tested Palacos R + 0.5 g gentamicin per 40 g of cement (PRG), and Simplex P + 1 g tobramycin per 40 g of cement (SPT). Each batch of cement was tested alone and with the addition of 2, 4, 6, and 8 g of vancomycin hydrochloride powder.

Mixing and compression testing were performed in a similar fashion to ASTM F451 specifications. The antibiotic-cement mixture was sealed in a cement mixer and stirred under a 30 kPa vacuum for 30s for PRG and 1 minute for SPT as per their respective manufacturer’s recommendations. The cement was either injected or spatulated into 6.0 mm holes milled into a 12.7 mm wide stainless steel die. Bottom and top plates were fastened with clamps to the die. The samples were stored at 23 ± 2°C and 50 ± 10% humidity for one hour and then tamped out of their molds.

Axial computed tomography (CT) images were obtained with a slice-width of 0.625 mm to evaluate each specimen for pores. The largest diameter of each pore was measured or the depth of the pore was determined if it merged with the edge of a sample. Pores were categorized as having diameters or depths of less than 1 mm, between 1 and 2 mm, or greater than 2 mm. Samples containing pores greater than 1 mm were eliminated from compression testing. The samples were stored for 24 hours at 23 ± 2°C and 50 ± 10% humidity.

The sample smoothed using a rotating sander with 320 grit sandpaper and measured to ensure they measured 6 x 12 mm. Compression testing was carried out on an 858 Bionic II materials testing machine. The crosshead speed was set to 22 mm/min and the maximum load at 5000 N. Failure was defined as the first to occur between the load at 2.0% offset and the load at the upper yield point.

Up to six samples per batch were then fractured using a 3-point bend force after notching the opposite side with a hand saw. One surface per sample was coated in gold and subsequently analyzed for micropores (diameter < 1 mm) using scanning electron microscopy (SEM). Five images were taken per surface at 70 times magnification. Pore areas were measured using Scion Image. Microporosity was determined by dividing the sum area of all the micropores per slide by the area of the slide and multiplying by 100. Pores with areas greater than or equal to a 0.2% offset and the load at the upper yield point.

Means and standard deviations of UCS, total number of pores, and microporosity were calculated for each antibiotic-cement batch and compared using multivariate analysis of variance (MANOVA). Compression strength values were compared between both cement types and to the ISO standard of 70 MPa.

Discussion

Our primary finding was that vacuum-mixing allows a total of 8 g of vancomycin to be added to one batch of PRG and 6 g per batch of SPT while maintaining an UCS above the minimum ISO standard of 70 MPa. This is at least an additional 4 g compared to a previous report in the literature using hand-mixing technique. Our compression strength data are consistent with the literature which shows antibiotics have a detrimental effect on the mechanical properties of bone cement. Vacuum-mixing most likely diminishes the negative effect antibiotics have on cement strength.

We did not find a correlation between vancomycin concentration and cement porosity; however, we did show a trend towards increasing cement surface roughness with higher amounts of antibiotic. Antibiotics most likely decrease cement strength by interfering with the polymerization process. This may be represented by rougher surfaces found in samples mixed with higher concentrations of vancomycin.