



THE INFLUENCE OF ANTIBIOTICS ON THE FATIGUE LIFE OF ACRYLIC BONE CEMENT: ASSURING CLINICAL STRUCTURAL INTEGRITY

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INTRODUCTION

Aseptic loosening attributed to cement fracture and the subsequent disruption of fixation interfaces remains a major long-term failure mode of cemented arthroplasty. Knowledge of the fracture strength of bone cement, especially in fatigue, is an important indicator of cement integrity and the potential for fixation failure.

In current practice, orthopaedic surgeons may choose to utilize antibiotics in bone cement for prophylaxis or treatment of a known infection. However, the antibiotics, bone cements and mixing methodologies employed lead to variability in the quality of the end product.^{1,2,6,9}

To date, several orthopaedic manufacturers have received Food and Drug Administration (FDA) 510[k] clearance for their pre-packaged antibiotic-loaded bone cement for use in the second stage of a two-stage revision situation where the initial infection has been cleared. This availability provides a more uniform cement mix with known mechanical and elution characteristics at the 0.5 to 1.0g level of antibiotic per 40g of polymer powder.

This study evaluates the influence of antibiotic inclusion on the porosity, strength and fatigue life of six contemporary bone cements.

MATERIALS

Six surgical quality and commercially available bone cements were evaluated: Endurance™ and Endurance Gentamicin (DePuy Orthopaedics, Inc., Warsaw, IN, USA); Surgical Simplex® P and Simplex™ P with Tobramycin (Stryker® Orthopaedics, Mahwah, NJ, USA); and VersaBond™ and VersaBond™ AB with Gentamicin (Smith + Nephew, Inc., Memphis, TN, USA).

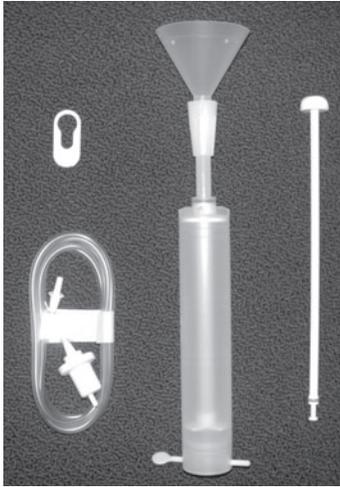
Additionally, ten 1.2g doses of Tobramycin for injection USP were acquired (Pharma-Tek, Huntington, NY, USA), which is the base quantity supplied to the operating theater.



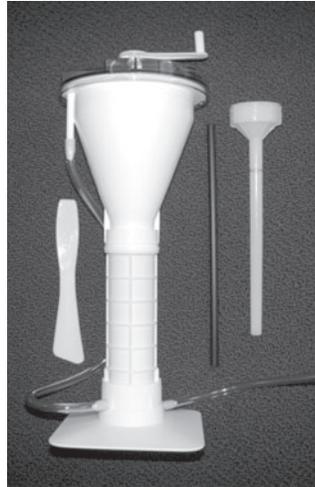
Failed cemented total hip replacement showing marked radiolucency indicating disruption of the bone-cement interface.⁴

MATERIALS (Cont.)

Three vacuum mixing systems were acquired directly from their respective manufacturers, the Cemvac® (DePuy Orthopaedics, Warsaw, IN, USA), the ACM® (Stryker® Orthopaedics, Mahwah, NJ, USA), and the Vortex (Smith + Nephew, Inc., Memphis, TN, USA).



Cemvac®



ACM®



Vortex

METHODS

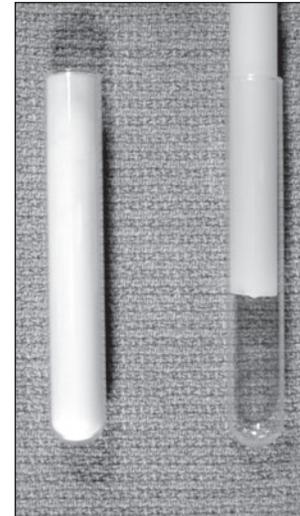
Vacuum mixing was in precise compliance with the specific manufacturer's instructions. Further, to simulate a standard operating room procedure, 1.2g of crystalline Tobramycin was hand blended with 40g of Surgical Simplex® P powder and then vacuum mixed. For all cements studied, a double dose of bone cement was retro-filled into 10 mm DIA x 75 mm long flint glass tubes.

After the tubes were filled, all specimens were handled identically. 1) Tubes were immediately suspended without immersion in 37°C water for 24 hours and allowed to cure. 2) The glass tubes were broken and the cement sectioned with a diamond wire saw into 20 mm ± 0.5 lengths. 3) The cut faces were wet polished to a surface finish of ~7 µm with 600 grit silicon carbide abrasive paper. 4) Specimens were labeled and their length and diameter measured within ± 0.01 mm. 5) Specimens were stored in 37°C, aerated saline for 7 days before testing.

Specimens were drawn randomly for each test from available populations.

Porosity

Surface porosity was calculated by optical analysis for a minimum of 10 dry test specimens sectioned into half cylinders with a diamond wire saw and wet polished. The sectioned surfaces were then stained with India ink and dry polished. The surface was digitally photographed and a functional accuracy was achieved to identify voids down to 0.001 mm². The area percent of voids was calculated using image analysis software.



Creation of bone cement specimens through retro-filling.

Diametral Tension Strength

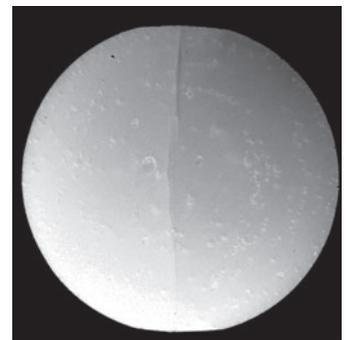
Ultimate Diametral Tension Strength (DTS) was measured on a minimum of ten test specimens per ASTM D3967. Specimens were compressed in a 25 kN, closed-loop, servo-hydraulic testing machine (MTS Mini-Bionics, model 358.1, MTS Corporation, Eden Prairie, MN, USA) at a rate of 5 mm/s until fracture. This rate corresponds to a strain rate of 50% per second.



Environmental Test Chamber

Diametral Tension Fatigue Life

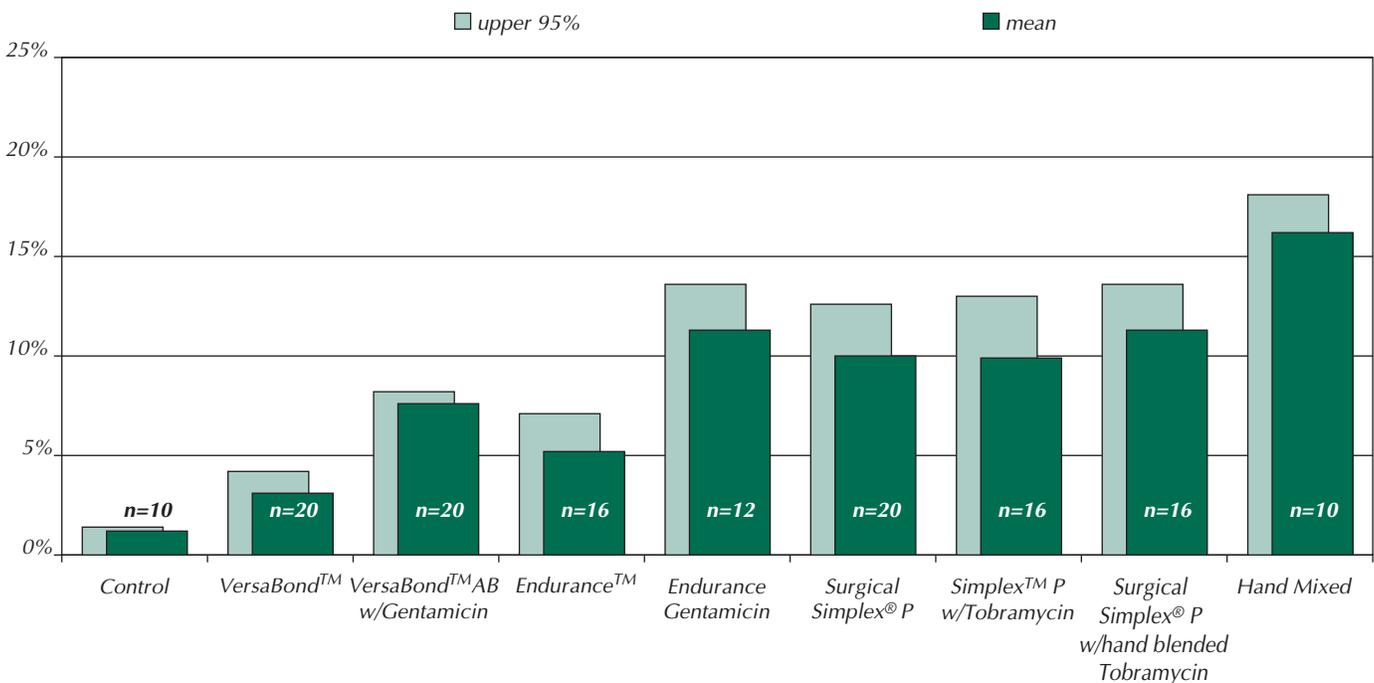
Diametral Tension Fatigue Life was measured on a minimum of ten test specimens per ASTM D3967 by modifying the loading profile. A sinusoidal fatigue load of -3.80 ± 0.02 kN was applied in compression to the test specimens at 3 Hz and R=10. This corresponds to peak DTS of 11.6 ± 0.3 MPa.



Classic Diametral Tension Fracture

RESULTS

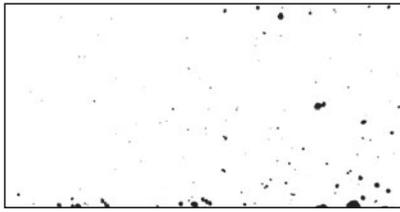
Porosity



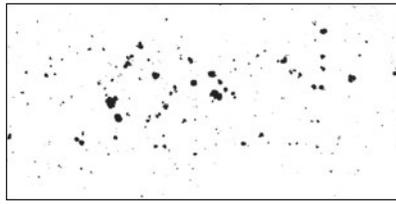
Percent Porosity for each bone cement evaluated. Bars depict the mean porosity and the upper 95% confidence interval.

Porosity (Cont.)

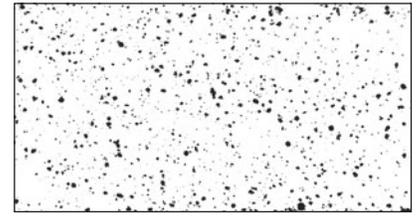
These images represent a median porosity specimen for each bone cement evaluated.



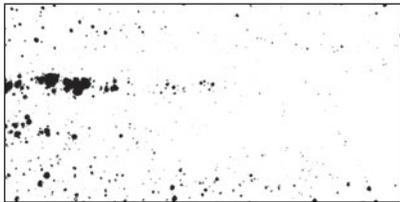
Hand Mixed Surgical Simplex® P with Centrifugation (Control)



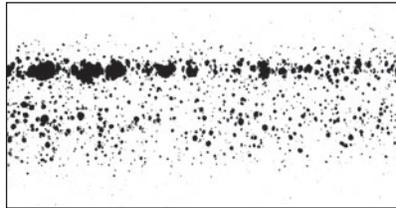
Vacuum Mixed VersaBond™



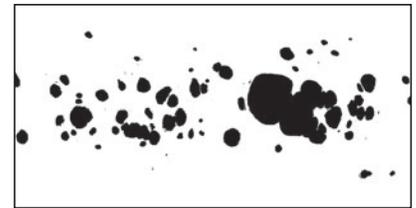
Vacuum Mixed VersaBond™ AB with Gentamicin



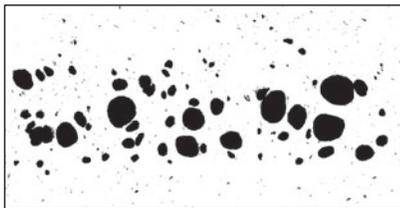
Vacuum Mixed Endurance™



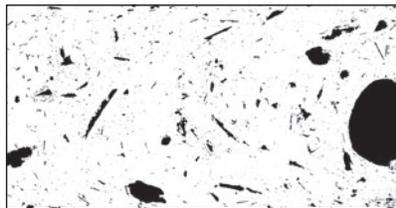
Vacuum Mixed Endurance Gentamicin



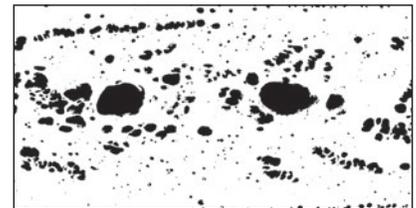
Vacuum Mixed Surgical Simplex® P



Vacuum Mixed Simplex™ P with Tobramycin



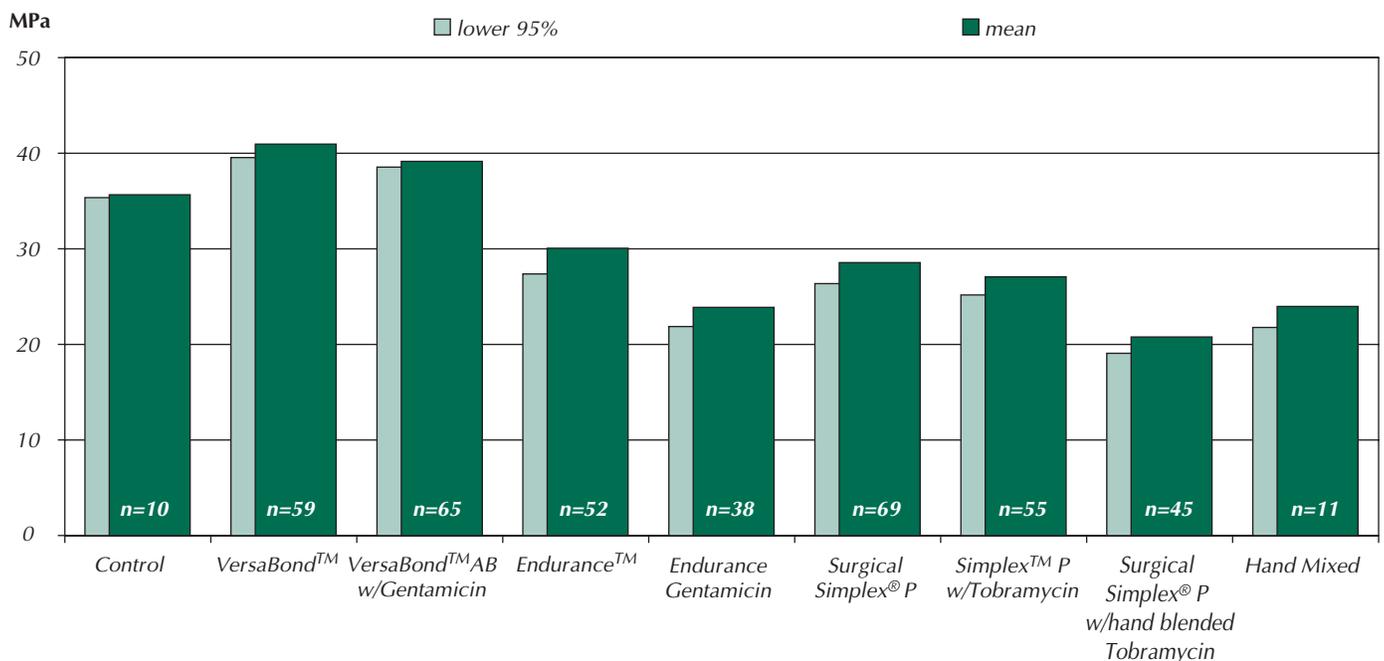
Vacuum Mixed Surgical Simplex® P with hand blended Tobramycin



Hand Mixed Surgical Simplex® P

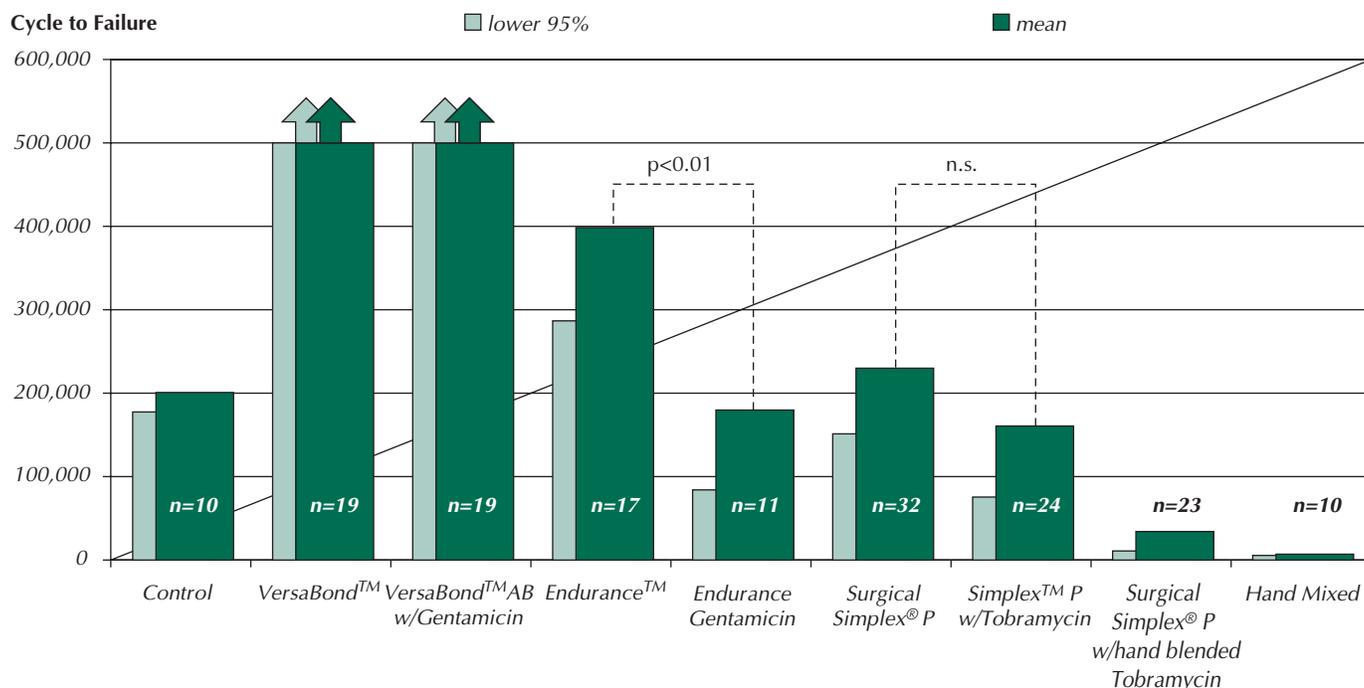
Diametral Tension Strength

All specimens fractured in classic DTS manner with the crack forming in a plane containing the long axis of the cylindrical specimens and the loading axis.



Ultimate Diametral Tension Strength for each bone cement evaluated. Bars depict the mean strength and the lower 95% confidence interval.

Diametral Tension Fatigue Life



Fatigue Life in diametral tension for each bone cement evaluated. Bars depict the mean life and the lower 95% confidence interval.

DISCUSSION

For historical and comparative purposes, hand mixing and hand mixing with centrifugation (Control) of Surgical Simplex® P are included in the data presentation.^{7,8}

Vacuum-mixed VersaBond™ and VersaBond™ AB with Gentamicin results in specimens with the greatest fatigue life, while hand-mixed Surgical Simplex® P produces the weakest cement. While both Endurance Gentamicin and Simplex™ P with Tobramycin demonstrate a decrease in fatigue life from their respective non-antibiotic cements, only the Endurance Gentamicin was found to be statistically significant ($p<0.01$). Not only are all of the vacuum-mixed bone cements stronger than the hand-mixed Surgical Simplex® P, but the pre-packaged antibiotic-loaded bone cements outperform the Surgical Simplex® P with hand-blended Tobramycin.

With the recent FDA 510[k] clearance of several pre-packaged antibiotic-loaded bone cements, it is important to appreciate the influence of antibiotic inclusion on the mechanical characteristics of the bone cement, especially in fatigue. This study strongly suggests that antibiotic hand blending, as well as, open hand mixing at the time of surgery are practices that should be avoided. Additionally, a continual finding of these evaluations is that neither porosity nor static strength is a consistent predictor of bone cement fatigue life.^{7,8}

EPILOGUE

- This laboratory study demonstrates that in two of the three commercially available surgical bone cements evaluated, the inclusion of antibiotics in bone cement decreases the fatigue life of the cement, but only one is statistically significant.
- Further, it affirms that vacuum mixing of pre-packaged antibiotic-loaded bone cement is structurally superior to hand blending the antibiotic at the time of surgery with subsequent vacuum mixing.
- It is recommended in the strongest terms that the practice of hand mixing should be abandoned in joint arthroplasty procedures.
- FDA has 510[k] cleared the pre-packaged antibiotic loaded bone cements evaluated in this study for use in the second stage of a two-stage revision where an infection has been cleared. Although the Swedish⁵ and Norwegian³ Registries strongly support the efficacy of prophylactic use at the pre-packaged antibiotic inclusion levels, orthopaedic surgeons should be aware that this remains an off-label use in the United States.

REFERENCES

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