Introduction: Metallic porous coatings are routinely applied to orthopaedic implants to facilitate bone ingrowth, providing excellent fixation without the use of bone cement [1-3]. The purpose of this study was to evaluate the tensile and shear strength of plasma-sprayed titanium coatings on magnesia-stabilized zirconia (Mg-PSZ) substrates. We hypothesized that the tensile and shear strength of the coating would be equally strong on cast cobalt chromium (CoCr, ASTM F75), titanium alloy (Ti-6-4, ASTM F1472), and zirconia ceramic (Mg-PSZ, ASTM F2393) substrates.

Materials and Methods: Disk-shaped tensile test specimens (25.27mm D x 6.35mm H) were machined from CoCr, Ti-6-4, and Mg-PSZ bar stock for tensile testing (ASTM C633). The surface to be coated was grit-blasted to a roughness of at least 3 µm, and a commercially pure titanium (CP Ti) porous coating was applied by arc plasma spraying. After measuring coating thickness, epoxy was applied to the non-coated face for adhesion to an uncoated test specimen for mechanical testing (Figure 1A). The average stress was calculated from the load at failure, with only tensile failure through the porous coating (100% "top coat middle", or TC-M) considered to be valid.

Cylinder-shaped shear test specimens (19.05mm D x 25.4mm H) were likewise machined from CoCr, Ti-6-4, and Mg-PSZ bar stock for shear testing (ASTM F1044), plasma sprayed on one face, and adhered to an aligned interface specimen with epoxy for mounting to the shear fixture (Figure 1B). Shear stress at failure was calculated, and the mode of failure was also noted (100% TC-M or 100% epoxy failures were considered valid). Means were compared by t-tests, with p < 0.05 for significance.

Results: Tensile test results for different coating thicknesses and substrates revealed that the tensile strength of CP Ti on a Mg-PSZ substrate was 13-25% lower than similar coatings on CoCr and Ti-6-4 substrates (p < 0.001; Table 1, Figure 2). In contrast, the shear strength of the CP Ti coating on Mg-PSZ was greater than that of the epoxy, with a shear strength equal to similar coatings on CoCr substrates and at least 27-59% higher than Ti-6-4 (p < 0.0001; Table 2, Figure 3).

Discussion: This study found that the tensile strength of plasma-sprayed CP Ti coatings on ceramic substrates to approach the strength on CoCr and Ti-6-4 substrates, while exceeding the shear strength of the epoxy in shear tests. Shear failure through the epoxy means the actual shear strength of the porous coating was not measured, but is greater than the shear strength of the epoxy (about 44 MPa). A previous study [4] reported porous-coated grit-blasted CoCr and Ti-6-4 specimens to have tensile adhesion strengths of 47.1 and 50.7 MPa, respectively, which is considerably lower than the current study. While their specimens were also grit-blasted prior to coating, they did not report surface roughness, which has been shown to increase interface strength through mechanical interlocking [5,6]. The CoCr and Ti-6-4 shear data were also comparable, with average shear failure strengths of 48.8 (8 of 10 specimens with 100% epoxy failures) and 41.8 MPa [4], respectively.

The primary advantage of applying a strong porous coating on a ceramic substrate is in the treatment of osteoarthritis in patients with a metal hypersensitivity (usually to cobalt chromium or nickel), without the use of bone cement. Unlike yttria-stabilized zirconia, Mg-PSZ has been shown to not degrade in vivo or in artificial aging studies [7,8]. The clinical performance of alumina ceramic femoral components has been comparable to those made from cobalt chromium alloy [9], and the authors believe Mg-PSZ will likewise prove to be suitable for use in TKA.

In summary, the tensile and shear adhesion of plasma-sprayed titanium coatings to magnesia-stabilized zirconia ceramic substrates was found to meet or exceed current and previously published adhesion data from cast cobalt chromium alloy and titanium alloy substrates. Because of its excellent adhesion strength, porous-coated Mg-PSZ ceramic components are a viable option for cementless TKA in patients with metal hypersensitivities.