Study on the Antimicrobial Properties of a High Copper Content Zr-based Bulk Metallic Glass

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Statement of Purpose: Bulk metallic glasses (BMGs) are a group of novel alloys with amorphous microstructure. In contrast to the long-term atomic order of crystalline alloys, the random packing of constituent atoms in BMGs yields a unique combination of properties. The excellent mechanical properties, high chemical stability, and facile thermal formation have attracted a great interest in the biomedical applications of these alloys, especially as hard-tissue prosthesis. In our previous *in-vitro* studies, the initial biocompatibility of BMGs has been revealed using different cell cultures [1]. However, as a promising candidate of implant materials, one of the key issues that need to be further addressed is the possible bacterial infection post implantation. Bacterial infection associated with implantation is a difficulty that has often been encountered during clinical practices. Many approaches have been attempted, including alloy design and surface engineering. BMGs are considered to exhibit potential antibacterial property, owing to the presence of “biocidal” elements (i.e., Cu, Ag, and etc) in various glass-forming compositions. In the current research, the antimicrobial ability of Cu-bearing Zr-based BMGs is investigated.

Methods: Zr-based alloy ingots with a nominal composition of $(Zr_{0.55}Al_{0.10}Ni_{0.05}Cu_{0.30})_{99}Y_1$ (atomic percentage, at.%) were fabricated by arc melting the mixture of pure elements in a high purity argon atmosphere. BMG specimens were obtained by copper mold casting. Cu (purity 99.95%) plates and Ti-6Al-4V alloys (grade 5) were used as positive and negative controls, respectively. The antibacterial ability of the materials was investigated using gram positive staphylococcus aureus (S. aureus, ATCC 6538). Bacterial cells were statically incubated in brain heart infusion (BHI) broth overnight at 37 ^{o}C to allow growth. The optical density was adjusted to 0.01 prior to inoculation. Each specimen was incubated in 3 ml of the bacteria suspension at 37 oC for 24 h in tryptic soy broth (TSB) supplemented with 1% glucose. Biofilm on each specimen was detached with a multi-step vortexing procedure. Number of viable adherent cells was determined serial dilution and the spread plate method. The amounts of Cu released from BMG and pure copper samples were monitored using inductively-coupled plasma (ICP-OES). Ion release profile was established as a function of immersion time.

Results: It was found that biofilms can form on Zr-based BMG, Ti-6Al-4V alloy, and Cu substrates after 1 d culture. Total number of colony forming units (CFUs) found on Zr-based BMG samples are close to that found on Ti-6Al-4V alloys, indicating that the antibacterial ability of Zr-based BMG is comparable to the negative control. A significantly lower number of CFUs were found on pure Cu substrates. After 1 d incubation, notable color change can be observed in cultures containing Cu plates, which suggests the release of Cu ions to the broth. The amount of Cu-ions released from Zr-based BMG samples was determined to be considerably lower than that released from Cu, which is corresponding to their antimicrobial effects.

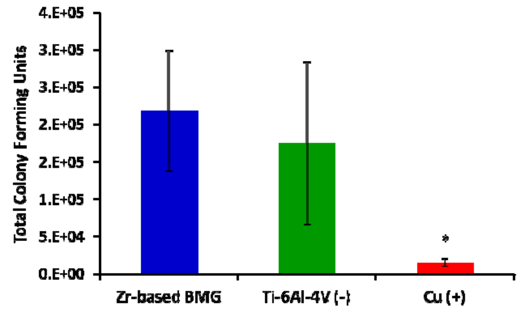

Figure 1. Number of viable adherent bacterial cells on different substrates (Mean ± STDEV, *$p < 0.05$)

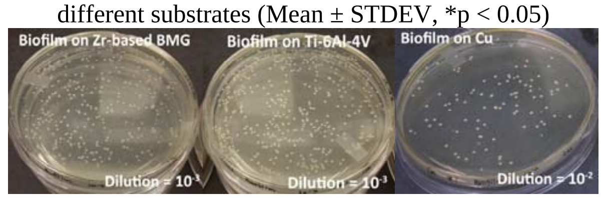

Figure 2. representative photos of colony forming units on difference experimental material surfaces.

Conclusions: Despite the high concentration of Cu (30 at.%) in the amorphous alloy, biofilm formation of s. aureus BMGs was still observed. The lack of compelling antibacterial effect of this Zr-based BMG could be explained by Cu-related biocidal functions. The antibacterial mechanism of Cu lies in its ion forms and the free radicals, which are produced by the redox reaction between Cu^{2+} and Cu^{+} [2]. Under current experiment settings, Cu ions released from the Zr-based BMG did not accumulate to a sufficient amount which is critical to kill the bacterial cells. Since the experiment conditions used in the present study are more severe than those encountered normally *in-vivo*, future experiment will be performed to examine the performance of Zr-based BMGs under a less aggressive condition. Moreover, the extended solubility limit of BMGs facilitates further compositional design of new alloy towards antimicrobial properties.

References:

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