Synergistically Enhanced Functions of Superelastic Nitinol and Biodegradable Metals to Develop A Growing Percutaneous Heart Valve Frame for The Pediatric Patients

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Statement of Purpose: As a crude estimate one in 125 babies born in the United States has a congenital heart defect, which must be surgically repaired. Recently, percutaneous heart valve replacement has been introduced with the development of novel biomaterials suggesting an innovative treatment strategy. While percutaneous heart valve replacement is an emerging technology with a few commercially available devices, the devices does not grow with a child. To address this issue, the use of two types of novel metallic biomaterials (i.e., superelastic nitinol and biodegradable mg or iron) is proposed for developing a low-profile growing percutaneous pediatric heart valve frame. Biodegradation of either magnesium or iron will enable the pediatric device to grow with a child, while superelastic nitinol can play an important role for self-expanding mechanism.

Methods: The prototype device consists of three types of primary materials: 0.055-0.120" diameter of superelastic nitinol wire, thin wall tube with inner diameter of 0.06 inch (Confluent Medical, Fremont, CA), 125µm biodegradable magnesium wire (WE43B, Fort Wayne, OH), 125µm pure iron wire (GoodFellowUSA, PA). Computational modeling for the structural behavior study was conducted using Ansys. Cell viability was quantified by MTS assay after 3days contacting with rat smooth muscle cells (rSMC).

Results: Two types of a growing heart valve frame were fabricated via computational modeling. Figure 1A shows the Nitinol-Iron valve frame fabricated for *in vitro* device performance tests. Figures 1B and C show the details of the device fabrication methods used in the prototype. Figure 1D shows the Nitinol-Mg valve frame and Figures 1E and F show the details of the connection of three different components, which are nitinol tube, magnesium wire, and "V" or "X" shape nitinol strut. A low-energy laser joining method was applied in the connection regions to transfer mechanical force, e.g., torque, bending, tension and compression, to the other segments of the frame. Figure 1G shows the representative computational modeling results of the 15mm diameter Nitinol-Mg valve frame for 10% diameter reduction. More detailed relationship between the % diameter reduction and the exerted radial force of this device was illustrated in Figure 1H demonstrating that all valve frames designed using both nitinol and magnesium show similar ranges of radial force for the frames that have 10mm to 15mm in the deployed diameter. Figure 1I shows the cell viability comparison results of the thermally treated iron wires at 1.5kW intensity of laser for 1.2 millisecond and a spot diameter of 900µm. Two different forces were applied to evaluate the relationship between the applied force and cell viability of the valve frame, i.e., 0.005N and 0.01N. The thermally treated iron wires under 0.01N (sample #2-2) showed the highest cell viability (i.e., no significant cytotoxic effect) in 3 days compared to non-treated or treated samples with lower applied force.

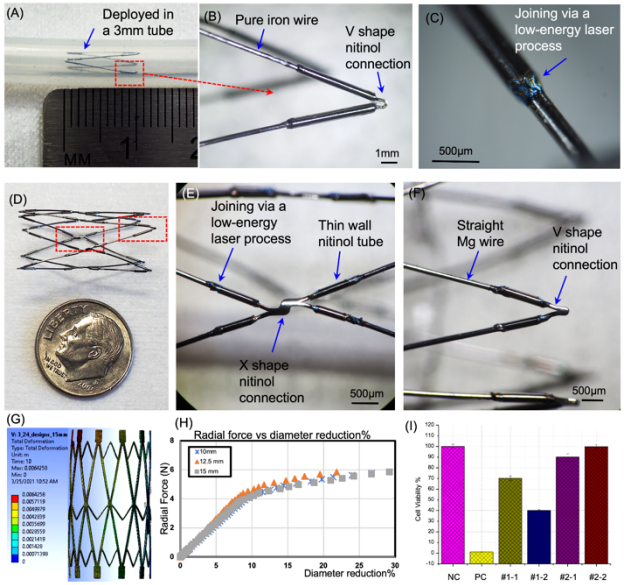

Figure 1. Prototype heart valve frames; (A-C) Nitinol-Iron valve frame, (D-F) Nitinol-Mg valve frame, (G) colored illustration of the computational structural modeling results, (H) relationship between the radial force and diameter reduction, and (I) cell viability comparison of thermally treated iron wires using MTS assay, NC (Negative control): normal cell medium without sample, PC (Positive control): 1M acrylamide in cell medium without sample, #1-1: untreated with 0.005N, #1-2: untreated with 0.01N, #2-1: thermally treated with 0.005N, and #2-2: thermally treated with 0.01N

Conclusions: A new heart valve frame was designed via finite element analysis (FEA) to evaluate the structural design with the radial force and % diameter reduction. Two prototypes with superelastic nitinol and biodegradable Iron or Mg materials have been successfully fabricated using a laser joining process and mechanical clamping process. These devices will enable the device sufficiently elastic for self-expanding percutaneous heart valves, while uniquely designed biodegradable metals will provide degradation strut portions for the growing heart valve frame.

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