Proceedings of The National Conference
On Undergraduate Research (NCUR) 2008
Salisbury University, Salisbury, MD
April 10 – 12, 2008

Cardiovascular Stents & the Celtic Knot

Lisa Martinez
Department of Biology
Washington and Lee University
Lexington, VA 24450. USA

Faculty Advisor: James C. Squire, Ph.D., P.E., Virginia Military Institute

The single leading cause of death in America today is a silent killer, the beginnings of which can be present in an individual since birth. This silent killer, commonly known as coronary artery disease, is caused by atherosclerosis, a condition in which the coronary arteries of the heart harden and thicken due to plaque build-up within the innermost lining of the artery. It is a slow, progressive, and potentially lethal illness, generally affecting large and medium-sized arteries. Complications of atherosclerosis arise when the lumens of plaque-encrusted arteries become so occluded that adequate blood flow is impeded. When the condition reaches this level of advancement, the oxygen supply to vital organs is diminished and a heart attack, stroke, and/or tissue necrosis often quickly follow. For years, coronary angioplasty was the sole treatment used to combat atherosclerosis and its devastating effects, yet even this procedure was not always effective; the plaque could and often did “spring-back” and resume its former position.

Then, in the early 1990s, the world of interventional cardiology received a new and innovative tool with which to combat the troublesome plaque: the cardiovascular stent. These mesh implements, designed to act as a scaffolding support system in arteries affected by severely advanced atherosclerosis, seemed to offer a longer-lasting form of correction and were thus greatly welcomed. Stents have indeed made a large and beneficial contribution in the treatment of atherosclerosis. However, even with all of the progress that has been made using modern stents, designs in current use still have their shortcomings. One obvious inadequacy that affects many stents is called “foreshortening”, which refers to the contraction of the stent along its long axis while it is being circumferentially expanded. This poses a perturbing problem, for cardiologists must determine a stent’s length prior to implantation based on the length of the affected area in the artery in which the apparatus is to be inserted. Although some improvements have been made in newer stent models, high degrees of recoil remain a persistent problem.

It is this problem that is the focus of my current research. I was first exposed to the intricacies involved in intravascular stent design and functionality last year while enrolled in course that integrated approaches to cardiology from both a biological and engineering perspective. It had occurred to me that traditional Celtic designs had the potential to possess more than just aesthetic qualities, an idea which I pursued further while participating in a semester-study-abroad program in Scotland this past term. The natural flow of the lines that comprise them allows for not only easy connectivity, but for strength and a certain degree of independence within each individual unit. This approach to stent design is fundamentally different from any used in stents that are currently in existence, as the concept of numerous interwoven individual rings makes a clean and definitive break from the traditional mold. Indeed, it is this individuality, inherent to each ring, that is the key ingredient to their potential in lowering, perhaps even abolishing, the occurrence of high degrees of recoil.

Stents on the market at present are essentially strips of metal that have laser-cut patterns on them, and, as such, function as a conglomeration of rings welded together (see Figure 1.a). Their static and fairly rigid structure have rendered them unable to fully accommodate the level of flexibility that they should ideally possess, ultimately leading to consequences such as undesirably high degrees of recoil. It is my hope that stents comprised of the designs that I am researching would not suffer from these limitations, as their structure would not be based on a rigid scaffold of welded rings but rather on a network of individual yet interwoven units (see Figure 1.b). This design allows each individual ring to possess a degree of freedom of motion all its own within the whole of the stent structure. Portions of the individually connected rings are able to slide past each other, providing different regions of the stent with the ability to respond to the stresses relevant to a given area.

Although this research is still in its preliminary stages, I have spent the past semester working in conjunction with an engineering student who was familiar with the technological manipulations necessary to produce three dimensional graphic models of the numerous metal models which I had previously constructed (see Figure 1.c). To create these digital models, she first needed to analyze the geometric behavior of the design in order to obtain an idea of how the different layers of the design interacted with one another. Once this lengthy process was complete, an engineering analysis of the design was necessary in order to determine the potential strengths and weaknesses of the design. To do this, she then had to separate the geometry of the design into smaller domains in order to solve equations for each small portion of the geometry; the equations of these pieces were then combined to produce an overall solution for the design as a whole. This procedure, referred to as meshing, is one of the most difficult parts of a Finite Element Analysis.

After the mesh was complete, it was possible to define the properties of the design and apply a displacement to the area of the design which would typically experience pressure or load during the stenting procedure. This thus made it possible to observe the design's behavior under such conditions. It was our hope that the design would not undergo axial contraction as in current stents, as reduction in axial contraction would minimize the resulting damage done to the artery wall which often leads to restenosis. However, the digital modeling indicated that there is indeed some axial contraction present, as in designs currently in use.

Yet, the research possibilities with this design are far from exhausted. The next phase of the project is to analyze how alterations in the dimensions of the design would affect its properties. For instance, one such logical approach would be to vary thickness at various points within the design in an effort to limit any axial contraction. Another approach might be to conduct trials in which different materials are used for the actual model itself, and to monitor the changes in property that result. Furthermore, three-dimensional physical models, which can be generated using the rapid prototyper present in the lab in which we have been working, may better allow us to monitor the stress that the design is subjected to upon expansion.

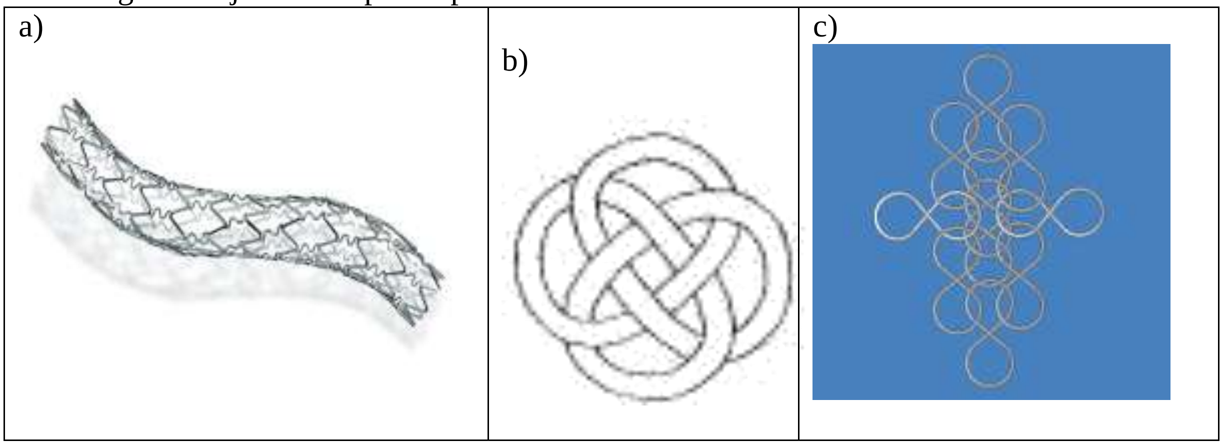

Figure 1. Comparison of current stents and Celtic stents. **(a)** A typical stent currently in use, composed of numerous rings welded together; such stents are single-layered and tend to be rigid and inflexible in nature, leading to complications such as high degrees of recoil. **(b)** One of the Celtic designs which I am currently researching; a stent made of multiple rings such as this would have a dual-layer design that could have mechanical advantages not present in the common single-layer designs (a). **(c)** A digital draft of the manner in which each individual Celtic shape could be interwoven to create the overall stent structure.