Design and Comparison of Large Vessel Stents

Balloon Expandable and Self-Expanding Peripheral Arterial Stents

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KEYWORDS

• Endovascular stenting • Stent design • Balloon expandable stent • Self-expanding stent

KEY POINTS

- Vascular injury with balloon angioplasty and endovascular stent implantation induces neointimal hyperplasia and results in clinical restenosis.
- Endovascular stent design and engineering impact clinical performance and influences the vascular response to injury.
- Restenosis remains a vexing problem in endovascular intervention requiring adaptation of principles of stent design from balloon expandable to self expanding stents due to the need for peripheral stents to have greater elasticity.
- Optimization of stent design has led to novel approaches to modulating the vascular response to injury and improving the hemodynamic and rheological impact of stenting with clinical improvements in stent performance.
- Continued evolution of stent design and engineering will hopefully yield improved clinical outcomes in more demanding peripheral vascular applications.

BACKGROUND

The origin of the word "stent" hails from Charles Thomas Stent, a London dentist who created Stent's compound to fill the empty space inside the root of a tooth.[1] The word was subsequently adapted into the surgical and urologic world to describe a substance that holds a graft in place or, in reference to intraluminal use, to maintain patency.[1]

Although the concept of arterial stenting was first described by Drs Charles Dotter and Melvin Judkins in 1964, it was not until 1983 that the word "stent" was used in the literature to describe the use of an endoluminal coil stent.[1,2] Thereafter, Dr Julio Palmaz developed the balloon-expandable (BX) Palmaz stent in 1985, and Drs Ulrich Sigwart and Jacques Puel developed the self-expanding (SX) Wallstent in 1987. Since then, stents have been widely adopted for revascularization of a wide variety of vascular beds.

Due to its widespread use in critical vascular territories, the mechanical and biologic performance of a stent is crucial. Some important parameters of stent performance include deliverability, ease of deployment, and long-term patency. In all forms of endovascular stenting, angioplasty occurs concomitantly with stent implantation and produces vessel injury by way of plaque disruption, endothelial denudation, disruption of the intima media, and thrombus formation. This injury activates the stereotypical cascade of the vascular response to injury ultimately resulting in subsequent neointimal proliferation and adverse remodeling. Stents were

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introduced as a way to prevent abrupt vessel closure and to reduce late lumen loss as discussed elsewhere in this issue (See Elmore JB, Mehanna E, Parikh SA, et al: Restenosis of the Coronary Arteries: Past, Present, Future Directions). However, stent implantation results in not only an immediate but also a chronic vascular injury, resulting in vigorous and prolonged neointimal proliferation.[3] Long-term patency rates are driven by several factors, including procedural components, such as acute tissue injury and stent expansion, and pharmacologic determinants, such as stent-bound antiproliferative drugs and systemic antiplatelet inhibition. However, underpinning all of these aspects is the fundamental design of the bare metal scaffold itself.

Endovascular stenting has evolved over the last 50 years since its inception into the framework of management of vascular atherosclerotic disease. Stent design has evolved as lesion complexity has increased. Nevertheless, certain first principles regarding stent design have been recapitulated time and again with every new iteration of endovascular stents. This article reviews the principles of endovascular stent design (Fig. 1),[4] and compares and contrasts key aspects of BX and SX stents.

STENT DESIGN: PHYSICAL PROPERTIES

At the crux of stent design is the balance of clinical characteristics and performance. As one attribute improves, it is typically at the expense of another attribute. First, a clear understanding of four basic physical properties is important to conceptualize the engineering of stents: (1) yield stress, (2) tensile strength, (3) Young's modulus of elasticity, and (4) strain. The static properties of stent material include yield stress and tensile strength, whereas the dynamic properties include Young's modulus and strain.[5] Since the ratio of force to unit area defines stress, thus yield stress refers to the ability of a metal to undergo a specific stress until it deforms irreversibly (plastic deformation). At the other extreme is tensile strength, which is the highest level of stress a material can withstand before it fails or fractures. Strain is the amount of deformation a material can undergo for a unit of given stress. If stress and strain are plotted, the slope of the line is referred to Young's modulus of elasticity (Fig. 2). The stiffer the material, the larger the modulus because there is less deformation per unit of stress. A complex interplay between the stent composition including metal and polymeric components and these physical properties allows for optimization of stent deliverability, performance, and lifespan (Table 1).

STENT DESIGN: THREE-DIMENSIONAL PROPERTIES

The three-dimensional (3D) construction of an endoluminal stent results in three additional design parameters that can be modified to alter stent performance: (1) radial resistive force, (2) chronic outward force (COF), and (3) hoop

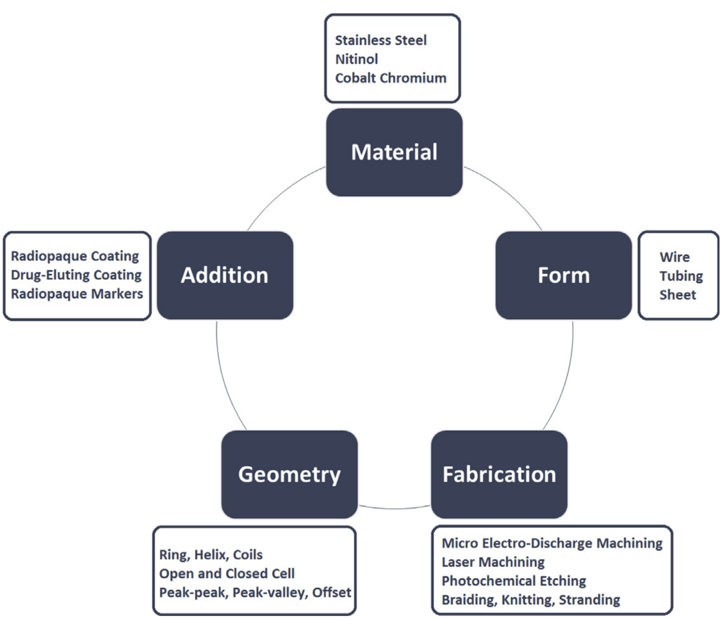

Fig. 1. The five pillars of stent engineering. (*Adapted from* Sangiorgi G, Melzi G, Agostoni P, et al. Engineering aspects of stents design and their translation into clinical practice. Ann Ist Super Sanita 2007;43:90.)

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