Coronary Stent Failure
Fracture, Compression, Recoil, and Prolapse

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KEYWORDS

• Stent fracture • Longitudinal stent deformation • Stent recoil • Plaque prolapse

KEY POINTS

- Despite significant improvements in coronary stent designs, several important mechanisms of coronary stent failure must be recognized.
- Stent fracture is more common in the right coronary artery, in tortuous lesions, and with stiffer stent scaffold designs.
- Longitudinal stent deformation occurs owing to compression or elongation of a stent and is more likely to occur in stents with 2 or fewer connectors.
- Stent recoil results in suboptimal stent cross-sectional area, and may be more common with bioresorbable scaffolds.

INTRODUCTION

Since the development of balloon-expandable coronary stents, numerous engineering innovations have improved the intraprocedural and long-term outcomes of percutaneous coronary intervention. Despite these innovations, there remain several, albeit uncommon, mechanisms of stent failure that are associated with adverse clinical outcomes. In this paper, we review the major mechanisms of coronary stent failure, including stent fracture, longitudinal deformation, recoil, and plaque prolapse. We also discuss failure mechanisms that are specific to and more common with bioresorbable vascular scaffolds (BVS).

CORONARY STENT FRACTURE

Although less common with current generation of drug-eluting stents, stent fracture was a frequent complication of early generation sirolimus-eluting stents.[1–8] Despite improvements in stent design, stent fracture can still occur with the current of generation drug-eluting stents, with an observed incidence between 0.8% and 8.0%.[9] This large range of incidence is likely multifactorial, owing to the majority of data being derived from single center observational studies, the variability in definition of stent fracture, and the variability of the screening tool used. For example, intravascular ultrasound (IVUS) examination and optical coherence tomography have a much greater sensitivity in detecting stent factures compared with conventional angiography.[10,11] Autopsy studies have suggested that the rate of coronary stent fracture approaches 29%, but only the most severe fractures are associated with evident intracoronary pathologic changes.[12]

Mechanisms of Coronary Stent Fracture

Several factors are associated with an increased incidence of coronary stent fracture. These

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factors include the target vessel, the type of stent, use of overlapping stents, and vessel angulation. Larger stent size may be associated with a lower risk of stent fracture.[13] Importantly, there is no relationship between stent deployment inflation pressures or the routine use of postdilation and the risk of subsequent stent fracture.

The right coronary artery (RCA) is the most common coronary vessel associated with development of stent fracture, with up to 50% of reported stent fractures occurring in the RCA. The anatomic location, angulation, and significant motion of the RCA during the cardiac cycle all play a role in the generation of torsion forces, which may predispose patients to stent fracture. In addition to the RCA, stents placed in saphenous vein grafts are also associated with a higher rate of fracture than those in the left coronary circulation.[14] The mechanisms specific to stent fracture in saphenous vein grafts are unclear, but may also be related to graft movement with the cardiac cycle, especially for stents that are placed at the ostium of a vein graft. Interestingly, the majority of bare metal stent fractures have been reported in saphenous vein grafts, with few published data on bare metal stent fracture in native coronary arteries.[15–17]

Coronary vessel tortuosity and angulation also play an important role in stent fracture. Observational studies have implicated both vessel tortuosity and extreme angulation in the development of a fracture.[7,14,18] These studies suggest that the majority of stent fractures occur when stent angulation exceeds 45°, with 1 study describing greater than 90% of stent fractures occurring in vessels where stent angulation exceeds 75°.[13]

The risk of stent fracture was clearly greater in early generation self-expanding stents as compared with contemporary platforms. However, there are limited clinical and laboratory data regarding the relative incidence, which suggests that even newer generation drug-eluting stents are prone to fracture.[3,19] In 1 series investigating fracture of platinum-chromium everolimus-eluting stents, the reported rate of stent fracture was 1.7%.[3]

In addition to clinical studies, laboratory bench tests evaluating the impact of repetitive bending motion on stent fracture have been performed and corroborate some conclusions garnered from clinical studies. Namely, in vitro studies have shown that vessel motion and angulation play an important role in stent fracture. Additionally, increased stent rigidity (determined primarily by the number of strut connectors) is related to an increased likelihood of stent fracture.[19]

Classification of Coronary Stent Fractures

Because a stent fracture can be detected by various imaging modalities, a single unified classification system for stent fracture does not exist. The most frequently used classification stratifies fracture type by the number and extent of fractured struts (Table 1).[12] In this angiography-based definition, stent fractures are graded as types I through V. Type I fractures are associated with the presence of a single fractured strut; type II fractures involved 2 or more struts, but without stent deformation; type III fractures involve associated stent deformation; type IV fractures comprise transection of the stent without a gap; and type V fractures involve transection with an associated gap in the stent.

In comparison with an angiography-based definition, classification of stent fracture by IVUS is predicated on the presence or absence of aneurysm formation. This is a binary system, with a type I stent fracture not associated with aneurysm and a type II stent fracture associated with aneurysm.[10] In this schema, it is thought that type I fractures are acute and related to bending forces in coronary vessels. In contrast, type II fractures may be related to the biological effects of eluted drugs, with positive vessel remodeling leading to late stent malapposition, aneurysm formation, and stent fracture.[20] Additionally, systems exist for classification of fracture type by computed tomography, although these systems are less often of clinical usefulness in the catheterization laboratory.

Clinical Implications of Coronary Stent Fracture

The presence of stent fracture has clearly been implicated in both in-stent restenosis (ISR) and stent thrombosis with resultant acute coronary syndrome (ACS). The likelihood of superimposed ISR on stent fracture ranges from 15% to nearly 90% in the available literature, with rates of target lesion revascularization of nearly

Table 1
Angiographic classification of coronary stent fractures

Type I	Single Strut Fracture
Type II	≥2 Strut Fracture
Type III	≥2 Strut Fracture with deformation
Type IV	Fracture with transection but no gap
Type V	Fracture with a gap