Intravascular ultrasound (IVUS) has become an indispensable part of all drug-eluting stent (DES) studies; findings must be put into context with the IVUS findings in bare metal stents. Unfortunately, there is not yet a complete picture of either the Cypher (Cordis, Miami, Florida) or the Taxus (Boston Scientific, Maple Grove, Minnesota) stent (the two U.S. Food and Drug Administration-approved devices). Intimal hyperplasia volume in DES is reduced to <15% of stent volume, but stent underexpansion continues to be a consistent finding in DES failures (restenosis and thrombosis). The utility of IVUS to assure adequate stent expansion may be more important whenever there are clinical risk factors for DES failure. (J Am Coll Cardiol 2006;48:421–9) © 2006 by the American College of Cardiology Foundation

INTIMAL HYPERPLASIA

In the bare-metal stent (BMS) era serial (post-intervention and follow-up) intravascular ultrasound (IVUS) was crucial to understanding how stents worked and why they failed. Chronic stent recoil was rare, and late lumen loss was almost entirely the result of intimal hyperplasia (IH) (1). To date, IVUS studies of most DES devices have mainly reported and compared percentage IH (%IH) volume, an IVUS measure of efficacy (Fig. 1). Only the IVUS results from the sirolimus-eluting Cypher stent (Cordis, Miami, Florida), the polymeric paclitaxel-eluting Taxus stent (Boston Scientific, Maple Grove, Minnesota), and a nonpolymeric paclitaxel-eluting stent have been studied and reported in detail. This review focuses on the two U.S. Food and Drug Administration (FDA)-approved devices, Cypher and Taxus.

In the SIRIUS (Sirolimus-Eluting Stent in Coronary Lesions) trial, Cypher stents reduced 9-month %IH volumes from 33.4% to 3.1% (p < 0.001) (4). There was a tendency for greater neointima suppression in the middle of the stent compared with the edges, the opposite of BMS (5). There was: 1) no difference in IH between lesions with moderate/severe calcium (arc >120°) versus no/mild calcium; 2) no difference between lesions with positive versus negative pre-intervention vessel remodeling; 3) no correlation between IH and pre-interventional plaque burden (plaque and media [P&M]/external elastic membrane [EEM]); 4) no effect from stent asymmetry; and 5) no difference between overlap versus nonoverlapped segments (6–8). Many weak predictors of BMS restenosis (i.e., pre-intervention positive remodeling and pre-intervention or residual plaque burden) were not predictive after Cypher implantation, because marked IH suppression masked any effect from weaker predictors.

In the São Paulo registry, IH within Cypher stents was stable or increased slightly beyond the time points reported in the RAVEL (6 months) and SIRIUS (9 months) trials. The %IH volume in 14 patients treated with the fast-release formulation was 2.3% at 1 year, 9.2% at 2 years, and 9.1% at 4 years; %IH volume in 14 patients treated with the slow-release formulation was 2.2% at 1 year, 3.3% at 2 years, and 5.7% at 4 years (9–11).

**Taxus stent.** In the TAXUS-II trial, 6-month %IH volume measured 7.8 ± 9.9% in slow-release Taxus stents (vs. 23.2 ± 18.2% in control subjects) and 7.8 ± 9.7% in moderate-release Taxus stents (vs. 20.5 ± 16.7% in control subjects) (12). The distribution of IH over the length of the stent was neither increased (as in BMS) nor more suppressed in the center (as in Cypher) (13).

The findings of the TAXUS-II trial were supported by the TAXUS-IV trial (14); 9-month %IH measured 12.2 ± 12.4% in slow-release Taxus stents versus 29.4 ± 14.0% in control subjects (p < 0.0001). As in the TAXUS-II trial, IH was flat over the length of the stent.
The TAXUS-V trial randomized more complex lesions than the TAXUS-IV trial; %IH volume measured 13.2 ± 12.0% with Taxus stents versus 31.8 ± 15.1% with control subjects (p < 0.0001) (15). The TAXUS-VI trial studied moderate-release Taxus stents in longer lesions; %IH volume measured 10.7 ± 10.8% versus 33.0 ± 15.1% in control subjects (p < 0.0001) (N. J. Weissman, unpublished data, 2005).

A subset meta-analysis of 566 patients from the TAXUS-IV, V, and VI trials showed: 1) %IH measured 9.8 ± 12.0% in overlapping Taxus segments versus 11.3 ± 10.9% in nonoverlapping segments; and 2) in lesions >26 mm in length, %IH measured 13.4 ± 9.2% (N. J. Weissman, unpublished data, 2005) In that meta-analysis, %IH in 87 diabetics treated with Taxus stents measured 13.7 ± 12.4%, i.e., less than the 34.6 ± 16.7% in 75 diabetics treated with BMS (p = 0.0001) but no different from the 217 nondiabetics treated with Taxus stents (11.6 ± 11.6%) (16).

Two-year TAXUS-II IVUS trial data has been reported in a highly selected group of 32% of Taxus-treated patients who had baseline and 6 month follow-up IVUS. The IH continued to be significantly suppressed compared with BMS. However, IH increased in both the slow-release and moderate-release Taxus stents (0.64 ± 0.81 mm² to 0.94 ± 0.76 mm² [p = 0.01] and 0.66 ± 0.83 mm² to 1.06 ± 0.90 mm² [p = 0.009], respectively) (17).

**EDGE EFFECTS**

Bare-metal stent implantation caused progressively more EEM cross-sectional area (CSA) decrease (negative remodeling) and progressively less P&M CSA or IH increase at greater distances from the stent edges (1).

**Cypher stent.** In the RAVEL trial, IVUS was only performed at follow-up; therefore, edge effects, requiring serial IVUS imaging, were not addressed. Of 31 Cypher failures in the SIRIUS trial, 27 restenoses were focal and 19 were at the stent edges. Larger reference plaque burdens and larger edge stent CSA/reference minimum lumen CSAs were associated with Cypher edge restenosis, suggesting that incomplete lesion coverage—landing the stent edge within a plaque (even a secondary plaque)—contributed to edge restenosis (18). Cypher edge restenosis was associated with negative remodeling (EEM decrease) in the first 1 to 3 mm as well as a focal increase in IH just at the edge of the stent (19).

**Taxus stent.** In the TAXUS-II trial, when analyzed mm by mm, there was an increase in EEM CSA, an increase in P&M CSA, and a decrease in lumen CSA within the first 1 mm proximally and within the first 3 mm distally in both slow- and moderate-release Taxus stents. (Edge effects were less obvious when proximal and distal 5-mm-long segments were analyzed as a volume.) ΔEEM or ΔP&M were similar comparing proximal and distal edges; however, there was a larger decrease in lumen CSA at the proximal versus the distal edges in both moderate- and slow-release groups (20). In both the TAXUS-IV (14) and TAXUS-VI (N. J. Weissman, unpublished data, 2005) trials, there was also a significant increase in distal lumen CSA at follow-up but no significant change in proximal lumen CSA.

**Abbreviations and Acronyms**

- **BMS** = bare-metal stent
- **CSA** = cross-sectional area
- **EEM** = external elastic membrane
- **IH** = intimal hyperplasia
- **ISR** = in-stent restenosis
- **IVUS** = intravascular ultrasound
- **LAD** = left anterior descending
- **LMCA** = left main coronary artery
- **LSM** = late stent malapposition
- **MSA** = minimum stent CSA
- **P&M** = plaque and media

**Figure 1.** This illustration shows the percentage intimal hyperplasia volume from trials of drug-eluting stents. The drug and its carrier vehicle (polymeric or nonpolymeric) and the name of the trial are shown. The time point of the intravascular ultrasound analysis ranged from 4 to 9 months after implantation depending on the trial. (By comparison, after implantation of bare metal stents percentage intimal hyperplasia volume averages 30%). NO = nitric oxide; PC = phosphorylcholine.
VASCULAR RESPONSES

In BMS, vascular responses to stent implantation were not limited to the luminal side of the stent or to the proximal and distal reference segments. Abluminal (peri-stent) EEM and P&M both increased (1).

Vascular responses with DES were not well studied. In an analysis of 30 patients in the São Paulo registry, peri-stent P&M volume did not change in the first 2 years after Cypher stent implantation but decreased between 2 and 4 years as the plaque became more echoreflective (21). In an analysis of the TAXUS-II trial patients, there was a greater 6-month increase in peri-stent EEM CSA in the moderate-release group compared with control subjects (but not in the slow-release group compared with control subjects), suggesting a dose-dependent drug effect (13). At 2 years, the 6-month peri-stent increases in EEM and P&M regressed completely in the slow-release group but only incompletely in the moderate-release group (17).

LATE STENT MALAPPOSITION (LSM)

Late stent malapposition (also called late acquired incomplete stent apposition) occurred in approximately 4% to 5% of BMS, was caused by an increase in EEM that was greater than the increase in peri-stent P&M, but was not associated with adverse events (1).

Cypher stent. Because the RAVEL trial did not include post-intervention IVUS, the high rate of Cypher stent malapposition at follow-up (21% vs. 4% in control subjects) could not be separated into acquired versus persistent malapposition (2). In the SIRIUS trial, which had IVUS both at implantation and follow-up, LSM was seen in 8.7% of Cypher stents versus none in control subjects (p < 0.05) (Fig. 2) and was associated with an increase in peri-stent EEM CSA. There were no deleterious clinical events in any of these 19 patients at 12 months after stent implantation (22). A longer-term follow-up IVUS study from the RAVEL trial indicated that malapposition discovered at 6 months...
after implantation neither progressed nor regressed over the subsequent 12 months (23).

**Taxus stent.** In the TAXUS-II trial, LSM at 6 months was seen in 8.0% of slow-release and 9.5% of moderate-release Taxus stents (p = 0.3 vs. 5.4% in controls). The LSM was caused by an increase in EEM with no increase in peri-stent P&M, and LSM detected at 6 months was not associated with adverse events at 12 months (including no stent thromboses) (24). In a subset of patients studied at 2 years, the incidence of LSM was 0% in the slow-release group (down from 9.3%) and 2.4% in the moderate-release group (down from 9.8%) (17).

In the TAXUS-IV trial, LSM was seen in 1.1% of slow-release Taxus stents versus 2.2% of control subjects (14). In the TAXUS-V trial, LSM was seen in 8.7% of slow-release Taxus stents versus 4.1% of control subjects (p = 0.3) (15). And in the TAXUS-VI trial, LSM was seen in 16.7% of moderate-release Taxus stents versus 4.3% of control subjects (p = 0.018). Finally, in a meta-analysis of the TAXUS-IV, -V, and -VI trials, 9-month LSM was more common in Taxus than in control stents (8.4% vs. 3.5%; p < 0.02); this was predominantly driven by non-FDA-approved moderate-release Taxus stent use in the TAXUS-VI trial. The LSM was associated with less IH than fully apposed stents. One year later, there were no major adverse cardiac events (including stent thromboses) in any patient with LSM (25).

**Asan Medical Center experience.** Hong et al. (26) evaluated LSM in 557 patients. Late stent malaposition occurred in 13.2% of 538 Cypher versus 8.4% of 167 Taxus stents (p = 0.12). The frequency of LSM increased after directional coronary atherectomy before stenting (25%), after primary stenting in acute myocardial infarction (MI) (32%, suggesting that thrombus dissolution may be important in infarct lesions that develop LSM), and in chronic total occlusions (27.5%). Independent predictors of LSM were total stent length, primary stenting in acute MI, and occlusions. In the subgroup of elective stenting after conventional balloon predilation, the only independent predictor of LSM was total stent length. There were no adverse events from implantation to when LSM was detected at 6 months or during the subsequent 12 months.

Thus, current experiences do not suggest any definite clinical sequelae from LSM. However, exaggeration of the mechanisms responsible for LSM can cause aneurysm formation.

**DES THROMBOSIS**

In BMS, minimum stent area (MSA) and stent expansion (MSA divided by the mean reference lumen CSA) were smaller, calcification was rare, and dissections were common when stent thromboses were compared to nontrombosed stents (1).

**Cypher stent.** Fifteen patients who developed Cypher stent thrombosis were compared with 45 matched control subjects. The MSA measured 4.3 ± 1.6 mm² in Cypher thrombosis (vs. 6.2 ± 1.9 mm² in control subjects; p < 0.001); stent expansion was smaller (65 ± 18% vs. 85 ± 14%; p < 0.001); and a residual edge stenosis (reference minimum lumen CSA <4 mm² with a plaque burden >70%) was more common in the thrombosis group (67% vs. 9%; p < 0.001). However, there was no difference in the rate of acute or late stent malaposition between the two groups (27).

**Taxus stent.** There have been no IVUS studies of Taxus stent thrombosis.

**Late thrombosis.** In a study of 11 patients (8 with Cypher stents) with late (>12 months) stent thrombosis, stent expansion (58 ± 25%) was less than in patients without late stent thrombosis (81 ± 17%; p < 0.001); and incomplete stent apposition was more common (55% vs. 12%; p < 0.0001) (28).

**DES RESTENOSIS**

When a patient presented with BMS restenosis, IVUS often showed either stent underexpansion or another mechanical complication. The single major IVUS predictor of clinical, angiographic, or IVUS BMS restenosis was the absolute final MSA (1).

**Cypher stent failure.** In a substudy of the SIRIUS trial where adequate patency was defined as a follow-up IVUS minimum lumen CSA >4 mm², the post-intervention MSA that best separated “adequate” from “inadequate” patency was 5.0 mm². The positive predictive value for this cut-off point was 90%, suggesting that Cypher failure in the SIRIUS trials was mostly due to stent underexpansion at the time of implantation (29).

In a study of 550 patients with 670 native coronary artery lesions treated with Cypher stents, IVUS cut-offs that best predicted angiographic restenosis were an MSA of 5.5 mm² and a stent length of 40 mm. When patients were divided into subgroups, angiographic restenosis rates were 0.4% (MSA >5.5 mm² and stent length <40 mm), 2.4% (MSA <5.5 mm² and stent length <40 mm), 5.1% (MSA >5.5 mm² and stent length >40 mm), and 17.7% (MSA <5.5 mm² and stent length >40 mm) (30).

In one IVUS study of 33 Cypher failures, an MSA <5.0 mm² was observed in 67% (31). In another study of 26 DES failures (21 Cypher stents), MSA measured 4.6 ± 1.5 mm²; 61% had an MSA <5.0 mm², and 38% had an MSA <4.0 mm² (32).

Stent underexpansion is the most common mechanism of Cypher failure. Once IH is suppressed, the impact of stent underexpansion becomes magnified. However, in an analysis of 48 Cypher restenoses, 71% of stents had an MSA <5.0 mm² somewhere within the stent, but this occurred at the minimum lumen site in only 46.9%. Therefore, other mechanisms must be considered (33).

Cypher stent failure has also been attributed to either strut fractures or gaps between adjacent stent struts (34).
Because transducer angulation can affect the number and distribution of the struts seen on a single frame, the diagnosis of strut fracture requires IVUS documentation of stent struts present immediately after the procedure that are no longer seen at follow-up, not merely a paucity of struts at follow-up (Fig. 3). It is not clear whether strut fractures occur with BMS or whether they have been missed, and it is not clear whether Cypher strut fracture is a common or uncommon cause of restenosis. Circumferential stent strut expansion homogeneity can be unpredictable. In 24 Cypher restenoses the minimum lumen site had a larger maximum interstrut angle and fewer stent struts even when normalized for the number of stent cells compared to nonrestenotic sites and stents. By implication, circumferential stent strut distribution affected the dose of sirolimus delivered to the arterial wall and therefore the amount of IH (Fig. 4) (35). There were fewer stent struts in restenotic lesions with adequate stent expansion than in lesions with an MSA <5.0 mm² at the minimum lumen site. (33).

**Taxus stent.** There are no data regarding predictors of Taxus stent failure (i.e., the importance of stent underexpansion), stent strut fracture, or effect of nonuniform strut distribution.

**DES TREATMENT OF BARE-METAL IN-STENT RESTENOSIS**

**Cypher stent.** The randomized INDEED (Treatment of IN-stent Restenosis with Drug-Eluting Stent versus Intracoronary bEta-raDiation) trial reported less recurrent IH after Cypher stent implantation (0.84 ± 0.78 mm²) versus intracoronary brachytherapy (1.39 ± 1.46 mm²) (p = 0.048) (S-J. Parks, unpublished data, 2005). Feres et al. (36) reported less recurrent IH after Cypher...
implantation (9.8 ± 6.3 mm³) in 25 patients treated with Cypher stents versus 25 patients treated with beta-irradiation (18 ± 14 mm³) (p < 0.0001). Conversely, in the randomized SISR (Sirolimus-Eluting Stent Versus Brachytherapy in Patients With Bare Metal In-Stent Restenosis) trial, mean recurrent IH was similar after Cypher implantation (0.5 ± 0.8 mm³/mm) and after brachytherapy (0.2 ± 1.0 mm³/mm) (p = 0.3), although proportionately fewer brachytherapy-treated patients were available for analysis, which might have biased the findings (37).

Nevertheless, the recurrence rate is higher after Cypher treatment of BMS restenosis than after de novo implantation (38). In 1 study, 9 of 11 patients who failed Cypher stent treatment of BMS restenosis had an MSA <5.0 mm² versus 5 of 19 nonrecurrences (p = 0.003); 7 recurrent lesions had an MSA <4.0 mm² versus 4 nonrecurrences (p = 0.02); and a gap between Cypher stents was identified in 3 recurrences versus 1 nonrecurrence (39). Recurrent IH often appeared echolucent, especially in patients with previous brachytherapy failures (40).

**Taxus stent.** In the TAXUS-V ISR, %IH volume measured 12.2 ± 10.3% in 42 patients treated with Taxus stents. (G. W. Stone, unpublished data, 2006). However, predictors of recurrence have not been reported.

**CLINICAL USES OF IVUS IN THE DES ERA**

There are no studies specifically addressing the clinical utility of IVUS in the DES era. In particular, there are no randomized angiographic versus IVUS trials.

**Assessment and treatment of intermediate stenoses.** In the BMS era, a minimal luminal CSA <4.0 mm² in a major (>3 mm) epicardial vessel (excluding the left main coronary

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**Figure 4.** Pre-intervention, post-intervention, and follow-up angiograms, respectively, are shown at top; slices a, b, and c in the post-intervention and follow-up angiograms correspond to the intravascular ultrasound examples at bottom. In slice b, corresponding to the center of the in-stent restenosis, there is heterogeneous stent strut distribution. Note that the three struts marked with the asterisk are farther apart than the others and that this is associated with more neointimal hyperplasia. (From Takebayashi et al. [35].)
artery [LMCA]) correlated with ischemia, and a minimal luminal CSA >4.0 mm² was associated with a low rate of events with medical therapy (41,42). Moses et al. (43) reported 167 patients with intermediate lesions (angiographic diameter stenosis <50%) from the SIRIUS, TAXUS-IV, and FUTURE I/II (First Use to Underscore Restenosis Reduction With Everolimus) trials. At 1 year, patients treated with DES had similar rates of cardiac death or MI (3.4% vs. 5.4% in BMS; p = 0.49) and fewer target vessel revascularizations (3.4% vs. 20.3%; p = 0.0004), major adverse cardiac events (5.6% vs. 25.4%; p = 0.0003), and binary angiographic restenoses (1.8% vs. 34.0%; p < 0.0001); no patient in either group developed stent thrombosis. Stenting of borderline lesions was safe, with a rate of events similar to deferred intervention, questioning the need for IVUS or physiologic assessment of intermediate non-LMCA lesions. Conversely, routine DES implantation was not better than judicious decision-making and was presumably more expensive. Intravascular ultrasound can also unmask occult stenoses that may warrant treating with a second or a longer first DES (44).

Acute DES expansion, stent apposition, and full lesion coverage. As noted in the preceding, the single number that best predicts an adequate IVUS minimum lumen CSA at follow-up or freedom from angiographic restenosis is a Cypher MSA of 5.0 to 5.5 mm². Is this always adequate? First, there are no similar data with Taxus stents. Second, there is still a step-wise relationship between a larger MSA and a lower restenosis rate. Third, SIRIUS trial patients are low risk. Fourth, even this modest cut-off is often not achieved. Interventionists routinely rely on manufacturer-supplied compliance charts to target final stent dimensions based on stent size and inflation pressure. However, a critical IVUS analysis shows that: 1) Cypher and Taxus achieve only 75 ± 10% of predicted minimal stent diameter and 66 ± 17% of predicted MSA; and 2) approximately 25% of Cypher and Taxus implanted into >3.0-mm vessels do not achieve an MSA of >5.0 mm² (45). Thus, manufacturer-supplied charts underestimate final stent size.

Full stent-vessel wall apposition appeared to be less important than adequate stent expansion. In the study by Hong et al. (26), post-procedure (acute) incomplete stent apposition was observed in 51 DES-treated lesions (7.2%). There were no major adverse cardiac events (including target lesion revascularization), and maximum intra-stent IH CSA at follow-up measured 1.2 ± 0.5 mm², similar to stents with complete apposition. In another IVUS study of incompletely apposed Cypher stents, IH at the site of complete malapposition resolution was many times greater than at the site of persistent stent malapposition, and no patient developed angiographic restenosis (46). In the TAXUS-II trial, 8 of 13 acute stent malappossitions in the slow-release group resolved, all acute stent malappossitions in the moderate-release group resolved, and at 12 months acute stent malapposition was not associated with an increase in adverse clinical events (24). Thus, initial concerns that acute incomplete stent apposition would affect drug delivery to the vessel wall and lead to DES failure appeared to be unfounded, and aggressive adjunct inflations to eliminate acute stent malapposition seemed unwarranted.

The restenosis penalty of longer DES is less than after BMS supporting “full DES lesion coverage” (47). Intravascular ultrasound can be used to identify the proximal and distal reference sites (cross-sections with the largest lumen and least plaque), to measure the distance between these two sites using motorized transducer pullback, and to avoid placing the stent edge into a plaque, a predictor of edge restenosis (18). Selecting the correct DES length the first time should be cost-effective compared with having to implant a second, overlapping stent, and it may be associated with fewer acute complications (48).

Specific patient and lesion subsets. Patients at higher risk for Cypher stent thrombosis (49) or restenosis (38) have been described. Whenever these risk factors are present or when consequences of failure would be significant (i.e., unprotected LMCA lesions) (Table 1), stent dimensions should be optimized for vessel size rather than settling for an MSA of 5.0 to 5.5 mm². For example, in one published study of 102 patients with LMCA disease treated with Cypher stents where IVUS guidance was used in 86%, MSA measured 9.6 ± 2.6 mm², and 1-year target lesion revascularization was necessary in only 2 patients (50). Similarly, in 68 patients with ostial left anterior descending (LAD) stenoses treated with Cypher stents, the MSA measured 7.4 ± 1.4 mm², distal LMCA involvement (angiographic diameter stenosis ≥30% and IVUS plaque burden >40%) was covered with longer stents, only 5.1% developed angiographic restenosis, and none required target lesion revascularization (51). (Conversely, an MSA of 5.0 mm² may not be achievable in small vessels, because it corresponds to a 0% residual stenosis in a 2.5-mm vessel and a negative residual stenosis in a <2.5-mm vessel; but it still can be vessel size optimized, and stent expansion [MSA/reference lumen area] in smaller vessels may be the best predictor of an adequate lumen at follow-up [52].)

A recent analysis of LAD/diagonal bifurcation lesions treated with the crush technique found the MSA at the side

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<th>Table 1. Indications for IVUS Imaging During DES Implantation</th>
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<td><strong>High-risk patient subsets</strong></td>
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<tr>
<td>1) Renal failure (45)</td>
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<tr>
<td>2) Limitations to dual antplatelet therapy use (45)</td>
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<tr>
<td>3) Diabetes mellitus (34,45)</td>
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<tr>
<td>4) Poor left ventricular function (45)</td>
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<tr>
<td><strong>High-risk lesion subsets</strong></td>
</tr>
<tr>
<td>1) Left main disease</td>
</tr>
<tr>
<td>2) Bifurcations (34,45)</td>
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<tr>
<td>3) Ostial lesions (34)</td>
</tr>
<tr>
<td>4) Small vessels (34)</td>
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<tr>
<td>5) Long lesions (34)</td>
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<td>6) Treatment of ISR (34)</td>
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DES = drug-eluting stent; ISR = in-stent restenosis; IVUS = intravascular ultrasound.
branch ostium in 68%, where it measured <4 mm² in 44% and <5 mm² in 82% (53). When treating bifurcation lesions with DES, it may be necessary to pay more attention to the side branch ostium, the most common restenosis location, than was done in the BMS era. Pre-intervention IVUS can determine whether the side branch is involved, whether it is diseased but not stenotic, or whether it is stenotic. Post-intervention imaging can determine whether the side branch has been compromised (after provisional stenting) or whether there is adequate stent expansion (after stenting both branches). However, IVUS cannot adequately assess the side branch from the main vessel; it is necessary to image the side branch directly.

DES failure. Currently, IVUS is the best way to identify and exclude causes of DES failure. All DES failures warrant IVUS study.

The optimal treatment for DES failure is not clear. At the least, underexpanded stents (the most common mechanism) should be properly expanded before placing another DES to avoid perpetuating the problem. (It is unclear whether merely expanding an underexpanded DES will be effective, because the drug has already been eluted and additional expansion may cause vessel trauma.)

Concerns regarding LSM have been minimized. Late stent malapposition appears to be stable or regress and does not appear to warrant catheter-based treatment.

Reprint requests and correspondence: Dr. Gary S. Mintz, Cardiovascular Research Foundation, 611 Pennsylvania Avenue, SE #386, Washington, DC 20003. E-mail: gsm18439@aol.com.

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