

# Advances in drug eluting stents – focus on the Endeavor<sup>®</sup> zotarolimus stent

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**Abstract:** Coronary artery disease remains one of the leading causes of death in the United States. Over the last 30 years, the development of coronary artery angioplasty and stenting has drastically reduced mortality during acute coronary syndromes while also reducing symptoms of chronic coronary artery disease. Unfortunately, the placement of stents in a coronary artery can be complicated by in-stent thrombosis or restenosis. In 2003–2004, a new generation of stents was introduced to the market with the goal of reducing the rate of restenosis. These stents, called drug eluting stents (DES), are coated with a pharmacological agent designed to reduce the neointimal hyperplasia associated with restenosis. Within a year, approximately 80% of all percutaneous coronary interventions performed within the US involved placement of a DES. In 2006, a controversy arose about the possibility of a statistically significant increased risk of acute stent thrombosis associated with DES especially when used for an “off label” indication. This risk was attributed to delayed endothelialization. This controversy has led to a reduction in the use of DES along with longer use of dual platelet inhibition with aspirin and clopidogrel. Recently Medtronic introduced a new DES to the market called the Endeavor<sup>®</sup> stent – a zotarolimus eluting stent.

**Keywords:** Endeavor<sup>®</sup> stent, zotarolimus stent, drug eluting stent

Coronary artery disease (CAD) remains the single leading cause of death in the US. According to the American Heart Association, an estimated 13 million Americans suffer from CAD and over 450 thousand Americans die from the disease every year.<sup>1</sup> Nevertheless, over the past 3 decades there have been remarkable developments in both early identification and treatment that have resulted in steadily improved outcomes. One of these developments has been the performance of percutaneous coronary intervention (PCI), which has seen dramatic revolution since the first percutaneous transluminal coronary angioplasty (PTCA) was performed by Andreas Gruntzig in 1977.

Modern PTCA involves passing a steerable guidewire into a coronary artery beyond an atherosclerotic lesion. Once the wire passes beyond the lesion it serves as a rail system that allows for the delivery of a balloon to the intraluminal site of the lesion. The balloon is then inflated with the intent of expanding the diameter of the lumen – cracking the intimal plaque while stretching the media and adventitia layers, frequently resulting in dissection of the intima and media. While most of these dissections are minor without any short or long term adverse clinical outcomes, a small number lead to abrupt closure of the vessel during the procedure or subsequent (subacute) closure within the first several days after PTCA. Abrupt or subacute closure occurred in 5% to 11% of procedures during the era before coronary stents,<sup>2,3</sup> and resulted in death, Q wave myocardial infarction (MI), or requirement for emergent bypass surgery in a large proportion of these patients. Since the availability of coronary stents for “tacking up” these dissections, these major complications have been reduced to <1%.<sup>4</sup>

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A less disastrous but more frequent complication of PTCA is restenosis. Acute injury during expansion of an angioplasty balloon, with de-endothelialization, dissection and stretching, triggers an inflammatory response. Researchers have shown that restenosis involves 3 phases. The initial component occurs almost immediately following deflation of the angioplasty balloon, when the stretched elastic fibers return to their original position resulting in a decreased post angioplasty luminal diameter. This loss of luminal diameter is called recoil and is the major component of lumen loss after PTCA.<sup>5,6</sup> In the second phase the exposed collagen and activated Von Willebrand Factor lead to platelet adherence and aggregation at the site of endothelial injury. Circulating leukocytes then attach to the platelets via adhesion molecules (platelet adhesion molecule P-selectin) and transmigrate to the injured area. The platelets and leukocytes then locally release cytokines and other growth factors. Finally, these factors directly stimulate the rapid proliferation and migration of smooth muscles cells. This neointimal hyperplasia leads to a further decrease in lumen diameter.

In the early 1980s, physicians struggled with these two complications of PTCA – 5% of the cases suffered from acute vessel closure and over 30% experienced restenosis. In 1986, in an effort to reduce the need for emergent coronary artery bypass surgery, cardiologists placed the first stents to mechanically support coronary arteries that acutely closed following angioplasty. These devices were successful in restoring acute patency, but were associated with an unacceptable >20% rate of stent thrombosis during the first 14 days.<sup>7</sup> Subsequent development utilized aggressive anticoagulation protocols to reduce the risk of stent thrombosis to approximately 3% to 4%. In 1993, two landmark multicenter studies were published. The Belgium Netherlands Stent (BENESTENT) study enrolled a total of 520 patients with de novo single vessel coronary artery disease randomized to receive either a Palmaz–Schatz stent or PTCA. The primary end points were death, stroke, need for emergent coronary artery bypass graft (CABG), MI or a repeat angioplasty procedure within 7 months. The BENESTENT investigators found 52 (20%) stent patients and 76 (30%) PTCA patients experienced a primary end point. The major factors accounting for the difference was the reduced need for emergent CABG and repeat coronary angioplasty procedures in the stent group.<sup>8</sup> The second study, Stent Restenosis Study (STRESS), enrolled a total of 410 patients randomized to receive a stent or PTCA alone. The group of patients who received a stent demonstrated a higher event free survival (80.5% vs 76.2%). Events were

defined as death, MI, coronary artery bypass surgery, abrupt vessel closure or repeat angioplasty.<sup>9</sup> These two landmark studies demonstrated that elective stenting not only reduced the need for emergent coronary artery bypass surgery for abrupt closure, but also reduced the need for repeat revascularization procedures due to restenosis. Despite these benefits, the requirement for aggressive anticoagulation with attendant bleeding risk and prolonged hospitalization and persistent risk of stent thrombosis remained as concerns.

Soon after approval of the Palmaz-Schatz stent it was discovered that with high-pressure stent deployment and anti-platelet therapy alone stent thrombosis risk could be substantially reduced.<sup>10–12</sup> Two randomized clinical trials, confirmed this finding, demonstrating stent thrombosis in the first 30 days after stenting in only about 1% of patients treated with this strategy.<sup>13,14</sup> This represented a major advance, since stent thrombosis has been associated with mortality of 20% in the first 6 months after the event and large myocardial infarction in essentially all cases.<sup>15</sup> The improved safety profile coupled with improvements in second-generation stent designs paved the way for stenting to become the preferred revascularization strategy in the vast majority of patients by the mid 1990s.

Unfortunately, improvement in the design of second-generation stents had little impact on risk for restenosis. Even with treatment of non-complex lesions, repeat revascularization procedures were required in approximately 12% of patients.<sup>16–18</sup> These rates were even higher in certain subsets, such as longer lesions, smaller vessels, and patients with diabetes. Other complex lesion characteristics including ostial location,<sup>19</sup> bifurcations,<sup>20</sup> chronic occlusions,<sup>21</sup> and prior restenosis<sup>22</sup> have been associated with increased risk for restenosis. The mechanism of restenosis differs between PTCA alone and stenting. Early recoil, the primary mechanism for lumen loss after PTCA, is prevented by the scaffolding effect of a metallic stent. Neointimal hyperplasia, however, is much greater after stenting due to increased vessel injury, and accounts for the persistent high rate of restenosis.

Multiple treatment options were developed to deal with restenosis. These therapies included repeat balloon angioplasty, treatment with a cutting balloon and brachytherapy. Brachytherapy involves intracoronary delivery of either beta or gamma wave radiation waves designed. Brachytherapy, unfortunately, was plagued by severe restenosis along the margins of the applied radiation field (edge effect) and provided the first recognition of a new phenomenon – late stent thrombosis.<sup>23</sup>

As researchers learned more of the complex molecular process of restenosis, the concept of local delivery of agents designed to inhibit cellular proliferation developed. Specifically, the stent was viewed not only as a mechanical tool but also as a drug-delivery system. This new generation of stents, known as drug eluting stents (DES), is composed of three distinct components. The first part is the stent platform, which is the scaffold used to maintain coronary artery lumen patency. The second component is the pharmacologic agent designed to reduce the amount of neointimal hyperplasia (restenosis). The final component is a polymer or drug delivery vehicle designed to attach the drug to the stent and control drug delivery and dosing.

In 2003 and 2004, the US Food and Drug Administration (FDA) approved the first two DES for use in the US. The first stent approved was the Cypher® stent marketed by Cordis (Miami Lakes, FL, USA), a medical division of Johnson and Johnson. This stent elutes sirolimus (rapamycin), a macrolide antibiotic possessing both antiproliferative and immunosuppressive properties. The rapamycin mechanism of action involves binding to the intracellular protein called FK binding protein 12 (FKBP12). Once bound, the FKBP 12-rapamycin complex then inhibits a protein kinase called mammalian target of rapamycin (mTOR). mTOR plays a crucial role in phosphorylating a number of proteins involved with protein synthesis and translation. Blocking mTOR's ability to phosphorylate these proteins prevents the cell from advancing to the next phase in the cell cycle – ultimately prohibiting cell proliferation.<sup>24</sup>

The Randomized Study with the Sirolimus-Eluting Velocity Balloon-Expandable Stent (RAVEL) randomized 238 patients to receive either a single sirolimus (SES) or bare metal stent (BMS) to treat a non-complex lesion. At the required 6 month follow up angiogram, the SES group demonstrated a significant reduction in the amount of in-stent loss with a reduction in the rate of restenosis from 41.7% in the BMS group to 0% in the SES group ( $p = 0.002$ ).<sup>24-27</sup> The 1-year clinical follow up demonstrated a marked reduction in the overall major adverse cardiac event (MACE) rate for the SES group (5.8% vs 28.8%  $p < 0.001$ ). This difference was due to a marked reduction in the need for repeat percutaneous revascularization of the target lesion (TLR, 0% vs 22.9%,  $p = 0.001$ ) with rates of death and MI similar between the two groups.<sup>24-27</sup> Clinical follow up at three years after stent deployment continued to demonstrate significant benefits associated with the sirolimus stent for MACE (15.8% vs 33.1%,  $p = 0.002$ ) and TLR (6.3% vs 25%).<sup>26</sup>

The Sirolimus-Coated BX Velocity Balloon Expandable Stent in the Treatment of Patients with De Novo Coronary Artery Lesions (SIRIUS) trial was a large multicenter trial. A total of 1101 patients were randomized (double blind) to receive either a SES or a BMS. The study was designed to evaluate the efficacy of the SES in a patient population at higher risk for developing restenosis – 25% of the patients had diabetes; longer lesions were stented (mean 14.4 mm) and vessels with smaller diameter (mean 2.8 mm) were allowed into the study. The exclusion criteria for SIRIUS included MI within 48 hours, depressed left ventricular function (LVEF  $< 25\%$ ), presence of thrombus or severe calcification and lesions at the ostium, bifurcation or an unprotected left main. The primary endpoint of target vessel failure (TVF, composite of cardiac death, MI or repeat revascularization procedure of the target vessel) at 9 months was significantly lower in the SES arm (8.6% vs 21%,  $p < 0.001$ ). The MACE rate, driven by the lower rate of repeat revascularization, was also significantly lower in the SES group (7.1% vs 18.9%). There was no statistically significant difference in death or MI.<sup>27</sup>

The second DES approved by FDA was the TAXUS stent marketed by Boston Scientific (Natick, MA, USA). The stent's active medication is paclitaxel (Taxol®), a plant alkaloid. Paclitaxel is a common chemotherapy medication for the treatment of both breast and ovarian cancers. The drug inhibits depolymerization of the microtubules, which inhibits microtubule function and blocks cellular replication. A series of clinical trials have demonstrated significant benefits associated with the paclitaxel eluting stents (PES) for reductions in restenosis. The TAXUS IV trial randomized 1314 patients to receive either a PES or a BMS. The population was similar to that enrolled in SIRIUS (% with diabetes, lesion length, vessel diameter). The primary endpoint of nine month target vessel revascularization was lower for PES (4.7% vs 12.0%,  $p < 0.001$ ) as were TLR (3.0% vs 11.3%) and late lumen loss (0.39 mm vs 0.92 mm).<sup>28</sup> There was no difference in death or MI between groups.

It is also important to note that after 1 year of follow-up the observed rate of stent thrombosis was  $< 1\%$  for both the SES and PES stents, nearly identical to the BMS counterparts in the respective trials as well as in subsequent meta-analyses. This had been a concern based on reports of stent thrombosis beyond 30 days after intracoronary brachytherapy, but appeared to have been avoided by dual anti-platelet therapy extended to 3 months in SIRIUS trial and 6 months in TAXUS IV. Based on these encouraging results, DES became the preferred strategy, with use in over 80% of all PCIs by late 1995. In March 2006, however, the

first of 3 reports to suggest an increased risk for late death, MI or stent thrombosis was presented.

The Basel Stent Kosten Effektivitäts Trial – Late Thrombotic Events (BASKET-LATE) found that among patients who were free of events after 6 months there was a higher rate of cardiac death, nonfatal MI and stent thrombosis between months 7 and 18 for patients who received a DES compared with those receiving a BMS.<sup>29</sup> In 2006 Camenzind et al reported higher rates of death or Q wave MI for SES versus BMS during long-term follow-up of the Cypher clinical trials,<sup>30</sup> and Nordmann et al reported slightly higher risk for non-cardiac mortality for SES in a meta-analysis including 17 DES trials.<sup>31</sup> While each of these studies has limitations, they served to raise a strong signal of caution about possible increased stent thrombosis risk for SES and PES in the period beyond the duration of dual anti-platelet therapy used in the randomized clinical trials.

Subsequent to these reports, independent analyses of pooled SES and PES clinical trial data confirmed a small but clinically significant increased risk of very late (beyond 1 year) stent thrombosis.<sup>32,33</sup> The estimated increase is approximately 0.2%/year among clinical trial populations, although it may be higher in more complex lesions.<sup>34</sup> The mechanism of ongoing stent thrombosis risk is related to delayed healing and persistent inflammation involving a majority of stent struts, with effects of late polymer degradation and early cellular inhibition both contributing.<sup>35–38</sup> These concerns prompted a FDA advisory committee to recommend at least 12 months of dual anti-platelet therapy and urge caution with use of DES in patients and lesions not studied in randomized clinical trials.<sup>39</sup>

Future development of the next generation of DES requires addressing several questions that have been raised by study of the SES and PES. Among these is whether the degree of inhibition of neointimal hyperplasia (late lumen loss) is directly proportionate to reduced TLR or whether the curvilinear relationship between late lumen loss and TLR is such that inhibition only beyond a moderate threshold is necessary.<sup>40</sup> It is also important to discern whether more severe inhibition imposes an increased risk for stent thrombosis or whether the delayed healing is more the consequence of inadequate polymer integrity and poor stent design. Finally, the possibility of an abbreviated course of dual antiplatelet therapy for a stent that demonstrates timely and complete healing is critical to future use.

## Endeavor<sup>®</sup> Zotarolimus-Eluting Stent

The first of the next generation of DES to gain FDA approval is the Endeavor<sup>®</sup> Zotarolimus-Eluting Stent (ZES, Medtronic, Santa Rosa, CA, USA). Similar to PES and SES, the Endeavor

consists of a bare-metal stent backbone, a drug-delivery vehicle and active drug. The stent backbone is the Medtronic Driver<sup>®</sup>, a cobalt-based alloy modular design with low profile and thin struts (0.0036 inch diameter [0.09 mm]), resulting in a stent with high flexibility and excellent radial strength.

The Endeavor stent is coated with a synthetic phosphorylcholine thin layer that contains and controls delivery of the active drug. Phosphorylcholine (PC) is the dominant phospholipid found on the outer membrane of red blood cells. It is a zwitterionic lipid – a compound that is electrically neutral overall but carries both positive and negative charges on different atoms. In theory this polymer should be more biocompatible than other polymers and not attract negatively charged proteins. The increased biocompatibility should be both less thrombogenic and less inflammatory than other polymers.<sup>41–43</sup> The first generation of DES had polymers that remained on the stent long after the drug dose had been delivered. In theory the remnant polymer can trigger an inflammatory reaction that may be directly responsible for delayed healing/endothelization and late stent thrombosis.<sup>44</sup> Several studies have demonstrated PC's antithrombotic properties by resisting platelet activation and fibrinogen absorption.<sup>45,46</sup> In addition to being antithrombotic, PC appears to not invoke an inflammatory reaction. Studies comparing the hyperplastic reaction following implementation found no significant difference in the PC coated stents compared to bare metal stents. The PC monolayer does not substantially increase the thickness of the stent struts or rigidity of the stent, thereby not reducing the stent deliverability; and allows for controlled release of the zotarolimus, although delivery is fairly rapid with 95% of drug eluted within 15 days.<sup>47</sup>

Zotarolimus (ABT-578, Abbott Laboratories, Abbott Park, IL, USA) is an analog of sirolimus made by substituting a tetrazole ring for a hydroxyl group at position 42. This substitution makes the compound more lipophilic, which favors crossing of cell membranes and delivery to targeted cells. The lipophilic property also helps prevent rapid release of the drug into the circulation.<sup>48</sup>

## Clinical trial data

The ENDEAVOR I trial was a nonrandomized, first-in-human study.<sup>49,50</sup> The trial enrolled one hundred patients with symptomatic ischemic coronary artery disease from January 2003 through April 2003. Lesions eligible for the trial had to be focal (<5 mm), de novo, non-restenotic lesions in native coronary arteries with reference diameter of 3 to 3.5 mm and diameter stenosis greater than 50%. Exclusion criteria for ENDEAVOR I included a LVEF less than 30%; significant (>50%) stenosis

proximal or distal to the target lesion; an MI occurring within 72 hours prior to stent placement; or any PCI within 30 days of the clinical stent placement.

The major results of this study were demonstration of 100% acute procedural success, 30-day MACE rate of 1.0% and 12 month in-stent late lumen loss  $0.61 \pm 0.44$  mm. After 4 years, the MACE rate was 7.2% (7/97) with only 2 patients requiring TLR. There was only 1 case of reported stent thrombosis, occurring on day 10 post stent deployment resulting in a non-Q wave MI.

Based on these encouraging feasibility results the ENDEAVOR II trial was designed as a pivotal randomized trial, in which 1197 patients with single vessel coronary artery disease were randomized to receive either the Endeavor stent (598 patients) or Driver bare-metal stent.<sup>51</sup> Inclusion criteria included a reference vessel diameter between 2.25 and 3.0 mm with a lesion length  $>14$  mm and  $\leq 27$  mm with other inclusion and major exclusion criteria similar to ENDEAVOR I. High risk lesions including bifurcations, left main, ostial or heavily calcified lesions were excluded from the study.

Among 1183 patients (98.8%) completing clinical follow up at 9 months, the primary endpoint of target vessel failure (TVF, cardiac death, MI or TVR) was reduced by 47% in the Endeavor group. This was primarily due to a 61% reduction in TLR with no differences in death or MI. Stent thrombosis did not occur in either group after 30 days. In an angiographic follow-up subset of 531 patients, in-stent late lumen loss was significantly reduced for the Endeavor group ( $0.61 \pm 0.46$  mm vs  $1.03 \pm 0.58$ ,  $p < 0.001$ ).

After 4 years of clinical follow-up, TLR remained significantly lower (7.2% vs 15.8%,  $p < 0.001$ ) with no difference in death or MI (5.3% vs 7.0%) for Endeavor compared with Driver. There were two stent thromboses after 30 days, including one event beyond one year in each group.<sup>52</sup>

The ENDEAVOR III trial was a prospective, single-blinded, randomized multicenter study, in which 436 patients were randomized in a 3:1 ratio to receive either an Endeavor ZES or Cypher SES with a primary objective to demonstrate non-inferiority in in-segment (segment = stent + 5 mm proximal and distal margin) late lumen loss.<sup>53</sup> The inclusion and major exclusion criteria for the study were similar to the criteria in both ENDEAVOR I and II. Clinical events were assessed throughout the hospitalization along with clinical visits at one month and 9 months following the initial intervention. The patients were scheduled for routine follow-up angiography and intravascular ultrasound at 8 months or sooner if they developed angina or target vessel ischemia and this was completed in 87% of ZES and 83% of SES.

In-segment late lumen loss was significantly lower for the SES group ( $0.13 \pm 0.32$  mm vs  $0.34 \pm 0.44$  mm,  $p < 0.001$ ;  $p = 0.65$  for non-inferiority), causing the trial to fail its primary objective. The ZES stent did demonstrate a significantly higher initial device success rate (98.8% vs 94.7%,  $p = 0.02$ ) due to improved device delivery success. At 9 months there were no episodes of stent thrombosis reported in either group and MACE rates were similar for ZES and SES (7.6% vs 7.1%). Clinically driven target vessel revascularization was required in 6.3% of the ZES group and 3.5% of the SES group. The study was not statistically powered to assess differences in clinical endpoints.

To assess clinical outcomes relative to an approved DES the ENDEAVOR IV trial was designed, in which 1548 patients were randomized in a single-blind design to receive the Endeavor ZES ( $n = 773$ ) or the Taxus® PES ( $n = 775$ ). The results were presented during the 2007 Transcatheter Cardiovascular Therapeutic (TCT) conference. The major inclusion criteria for the study included clinical evidence of ischemia; single de novo lesion in a native coronary artery; TIMI 2 or greater flow in the target vessel; lesion length  $\leq 27$  mm; diameter stenosis 50% to 99%; target vessel diameter 2.5 to 3.5 mm. The major exclusion criteria included an acute MI within 72 hours of procedure; previous PCI to the target vessel in previous 9 months; history of stroke of depressed left ventricle ejection fraction ( $<30\%$ ); a history of gastrointestinal bleeding within 6 months; target vessel with thrombus or severe calcification; lesions involving the left main, ostium or at a bifurcation. The primary endpoint was non-inferiority for target vessel failure at 9 months. Routine angiographic follow-up at 8 months was planned in a pre-specified subset of 144 ZES and 135 PES patients.<sup>54</sup>

At 9 months, target vessel failure occurred in 6.6% of ZES and 7.2% of PES patients, meeting the non-inferiority margin of difference ( $p$  value  $< 0.001$  for non-inferiority). There were more stent thromboses in the ZES group (0.8% vs 0.1%), with 3 of the 6 ZES events occurring before 30 days. Of note, despite clinical similarity, in-stent late lumen loss was higher for ZES ( $0.67 \pm 0.42$  mm vs  $0.36 \pm 0.23$  mm,  $p = 0.023$ ) with a trend for more frequent binary angiographic restenosis (13.3% vs 6.7%,  $p = 0.075$ ).

There has been interest whether the risk for late stent thrombosis may be lower with the second-generation Endeavor stent than the first generation SES and PES. With three year data available for 648 ZES and 542 BMS patients, rates of stent thrombosis were numerically lower for the ZES (0.8% vs 1.5%) with only 1 stent thrombosis after 1 year in the ZES group.<sup>55</sup> Longer follow-up of more patients with

**Table 1** Characteristics and performance of selected drug eluting stents

Stent type	Platform (strut thickness)	Polymer type (thickness)	Late loss <sup>a</sup>	Target lesion revascularization <sup>a</sup>
Cypher (sirolimus)	Stainless steel (140 µm)	PEVA/PBMA (12.6 µm)	-0.01 ± 0.33 mm	10.3% at 5 years
Taxus (paclitaxel)	Stainless steel (132 µm)	Translute (SIBBS) (16 µm)	0.36 ± 0.23 mm	4.7% at 9 months
Endeavor (Zotarolimus)	Cobalt chromium (91 µm)	Phosphoryl Choline (5.3 µm)	0.67 ± 0.42 mm	6.3% at 12 months
Endeavor-Resolute (zotarolimus)	Cobalt chromium (91 µm)	Biolynx	0.22 ± 0.27 mm	<1% at 12 months
Xience (everolimus)	Cobalt chromium (81 µm)	Fluoropolymer (7.6 µm)	0.16 ± 0.41 mm	3.4% at 12 months

<sup>a</sup>Stent performance characteristics from included references as noted; Cypher<sup>26</sup>; Taxus<sup>54</sup>; Endeavor<sup>54</sup>; Endeavor-Resolute<sup>57</sup>; Xience<sup>58</sup>.

**Abbreviations:** PEVA, polyethylene-co-vinyl acetate; PBMA, poly-n-butyl methacrylate; SIBBS, styrene-b-isobutylene-b styrene.

increased lesion complexity will be needed to determine if these encouraging rates of very late stent thrombosis are verified. It has been speculated that less late loss prevention may be an advantage in reducing stent thrombosis risk, but this remains controversial and has not been confirmed.<sup>56</sup>

In 2007, Medtronic introduced another version of the zotarolimus stent called the Endeavor<sup>®</sup> Resolute. The major difference between the Endeavor Resolute stent and the Endeavor stent is the polymer. The Endeavor Resolute stent uses a polymer called BioLinx<sup>™</sup> – the first polymer designed specifically for DES. This polymer is actually a composite of three separate polymers: a hydrophilic C19; water soluble polyvinyl pyrrolidinone (PVP); and a hydrophobic C10 polymer. The three polymers each react differently with zotarolimus. The C10 polymer holds on to the zotarolimus drug tightly to allow for extended diffusion of the drug. The C19 polymer allows for rapid release of the drug. The PVP polymer allows for both rapid initial release and prolonged drug release. Combined, these three polymers allow for a more gradual controlled release of zotarolimus over a longer period of time.<sup>57</sup>

There are limited clinical data available for Endeavor Resolute. The RESOLUTE trial enrolled a total of 130 patients from 12 clinical centers in Australia and New Zealand.<sup>58</sup> The study's primary endpoint was late lumen loss (in-stent) at 9 months by angiography/intravascular ultrasound (IVUS) and clinical secondary endpoints. Thirty-day clinical results for 130 patients showed a Major Adverse Cardiac Event (MACE) rate of 3.8%. There were no examples of Target Lesion Revascularization (TLR) or in-stent thrombosis. In 30 patients with 4-month angiographic follow-up, in-stent late loss was 0.12 mm while in-segment late loss was 0.05 mm. Both in-stent and in-segment binary restenosis were zero,

and IVUS results showed neointimal volume obstruction of 2.2% at 4 months.

Recently, the Xience<sup>®</sup> V stent (Abbott Vascular Devices, Santa Clara, CA, USA) has also been approved for use by FDA based on demonstration of non-inferior clinical results compared with Taxus in the SPIRIT III trial.<sup>59</sup> This second-generation DES also has unique polymer characteristics with both very low late loss and encouraging early safety profile (Table 1).

## Disclosures

Neither author has conflicts of interest to declare.

## References

1. Minino AM, Heron MP, Murphy SL, Kochanek KD. Deaths: final data for 2004. *Natl Vital Stat Rep.* 2007;55:1-119.
2. Tan K, Sulke N, Taub N, Sowton E. Clinical and lesion morphologic determinants of coronary angioplasty success and complications: current experience. *J Am Coll Cardiol.* 1995;25:855-865.
3. Lincoff AM, Popma JJ, Ellis SG, Hacker JA, Topol EJ. Abrupt vessel closure complicating coronary angioplasty: clinical, angiographic and therapeutic profile. *J Am Coll Cardiol.* 1992;19:926-35.
4. Seshadri N, Whitlow PL, Acharya N, Houghtaling P, Blackstone EH, Ellis SG. Emergency coronary artery bypass surgery in the contemporary percutaneous coronary intervention era. *Circulation.* 2002;106:2346-5230.
5. Mehran R, Mintz GS, Popma JJ, et al. Mechanisms and results of balloon angioplasty for the treatment of in-stent restenosis. *Am J Cardiol.* 1996;78:618-622.
6. Mintz GS, Popma JJ, Hong MK, et al. Intravascular ultrasound to discern device-specific effects and mechanisms of restenosis. *Am J Cardiol.* 1996;78:18-22.
7. Serruys PW, Strauss BH, Beatt KJ, et al. Angiographic follow-up after placement of a self-expanding coronary-artery stent. *N Engl J Med.* 1991;324:13-17.
8. Serruys PW, de Jaegere P, Kiemeneij F, et al. A comparison of balloon-expandable-stent implantation with balloon angioplasty in patients with coronary artery disease. Benestent Study Group. *N Engl J Med.* 1994;331:489-495.

9. Fischman DL, Leon MB, Baim DS, et al. A randomized comparison of coronary-stent placement and balloon angioplasty in the treatment of coronary artery disease. Stent Restenosis Study Investigators. *N Engl J Med.* 1994;331:496–501.
10. Moussa I, Di Mario C, Di Francesco L, Reimers B, Blengino S, Colombo A. Subacute stent thrombosis and the anticoagulation controversy: changes in drug therapy, operator technique, and the impact of intravascular ultrasound. *Am J Cardiol.* 1996;78:13–17.
11. Moussa I, Oetgen M, Roubin G, et al. Effectiveness of clopidogrel and aspirin versus ticlopidine and aspirin in preventing stent thrombosis after coronary stent implantation. *Circulation.* 1999;2364–2366.
12. De Servi S, Repetto S, Klugmann S, et al. Stent thrombosis: incidence and related factors in the R.I.S.E. Registry (Registro Impianto Stent Endocoronarico). *Catheter Cardiovasc Interv.* 1999;46:13–18.
13. Leon M, Baim D, Popma J, et al. A clinical trial comparing three antithrombotic-drug regimens after coronary-artery stenting. *N Engl J Med.* 339:1665–1671.
14. Schömig A, Neumann F-J, Kastrati A, et al. A randomized comparison of antiplatelet and anticoagulant therapy after the placement of coronary-artery stents. *N Engl J Med.* 1996;334:1084–1089.
15. Cutlip DE, Baim DS, Ho KK, et al. Stent thrombosis in the modern era: a pooled analysis of multicenter coronary stent clinical trials. *Circulation.* 2001;103:1967–1971.
16. Cutlip DE, Chauhan MS, Baim DS, et al. Clinical restenosis after coronary stenting: perspectives from multicenter clinical trials. *J Am Coll Cardiol.* 2002;40:2082–2089.
17. Cutlip DE, Chhabra AG, Baim DS, et al. Beyond restenosis: five-year clinical outcomes from second-generation coronary stent trials. *Circulation.* 2004;110:1226–1230.
18. Mauri L, O'Malley AJ, Cutlip DE, et al. Effects of stent length and lesion length on coronary restenosis. *Am J Cardiol.* 2004;93:1340–6, A5.
19. Topol EJ, Ellis SG, Fishman J, et al. Multicenter study of percutaneous transluminal angioplasty for right coronary artery ostial stenosis. *J Am Coll Cardiol.* 1987;9:1214–1218.
20. Mathias DW, Mooney JF, Lange HW, Goldenberg IF, Gobel FL, Mooney MR. Frequency of success and complications of coronary angioplasty of a stenosis at the ostium of a branch vessel. *Am J Cardiol.* 1991;67:491–495.
21. Berger PB, Holmes DR Jr, Ohman EM, et al. Restenosis, reocclusion and adverse cardiovascular events after successful balloon angioplasty of occluded versus nonoccluded coronary arteries. Results from the Multicenter American Research Trial With Cilazapril After Angioplasty to Prevent Transluminal Coronary Obstruction and Restenosis (MARCATOR). *J Am Coll Cardiol.* 1996;27:1–7.
22. Kitazume H, Ichiro K, Iwama T, Ageishi Y. Repeat coronary angioplasty as the treatment of choice for restenosis. *Am Heart J.* 1996;132:711–715.
23. Waksman R, Bhargava B, Mintz G, et al. Late total occlusion after intracoronary brachytherapy for patients with in-stent restenosis. *J Am Coll Cardiol.* 2000;36:65–68.
24. Morice MC, Serruys PW, Sousa JE, et al. A randomized comparison of a sirolimus-eluting stent with a standard stent for coronary revascularization. *N Engl J Med.* 2002;346:1773–1780.
25. Serruys PW, Degertekin M, Tanabe K, et al. Intravascular ultrasound findings in the multicenter, randomized, double-blind RAVEL (RANDOMIZED study with the sirolimus-eluting VELOCITY balloon-expandable stent in the treatment of patients with de novo native coronary artery Lesions) trial. *Circulation.* 2002;106:798–803.
26. Fajadet J, Morice MC, Bode C, et al. Maintenance of long-term clinical benefit with sirolimus-eluting coronary stents: three-year results of the RAVEL trial. *Circulation.* 2005;111:1040–1044.
27. Moses JW, Leon MB, Popma JJ, et al. Sirolimus-eluting stents versus standard stents in patients with stenosis in a native coronary artery. *N Engl J Med.* 2003;349:1315–1323.
28. Stone GW, Ellis SG, Cox DA, et al. One-year clinical results with the slow-release, polymer-based, paclitaxel-eluting TAXUS stent: the TAXUS-IV trial. *Circulation.* 2004;109:1942–7.
29. Pfisterer M, Brunner-La Rocca HP, Buser PT, et al. Late clinical events after clopidogrel discontinuation may limit the benefit of drug-eluting stents: an observational study of drug-eluting versus bare-metal stents. *J Am Coll Cardiol.* 2006;48:2584–2591.
30. Camenzind E, Steg PG, Wijns W. Stent thrombosis late after implantation of first-generation drug-eluting stents: a cause for concern. *Circulation.* 2007;115:1440–55; discussion 1455.
31. Nordmann AJ, Briel M, Bucher HC. Mortality in randomized controlled trials comparing drug-eluting vs. bare metal stents in coronary artery disease: a meta-analysis. *Eur Heart J.* 2006;27:2784–2814.
32. Mauri L, Hsieh WH, Massaro JM, Ho KK, D'Agostino R, Cutlip DE. Stent thrombosis in randomized clinical trials of drug-eluting stents. *N Engl J Med.* 2007;356:1020–1029.
33. Farb A, Boam AB. Stent thrombosis redux – the FDA perspective. *N Engl J Med.* 2007;356:984–987.
34. Daemen J, Wenaweser P, Tsuchida K, et al. Early and late coronary stent thrombosis of sirolimus-eluting and paclitaxel-eluting stents in routine clinical practice: data from a large two-institutional cohort study. *Lancet.* 2007;369:667–678.
35. Finn AV, Joner M, Nakazawa G, et al. Pathological correlates of late drug-eluting stent thrombosis: strut coverage as a marker of endothelialization. *Circulation.* 2007;115:2435–2441.
36. Luscher TF, Steffel J, Eberli FR, et al. Drug-eluting stent and coronary thrombosis: biological mechanisms and clinical implications. *Circulation.* 2007;115:1051–1058.
37. Virmani R, Guagliumi G, Farb A, et al. Localized hypersensitivity and late coronary thrombosis secondary to a sirolimus-eluting stent: should we be cautious? *Circulation.* 2004;109:701–705.
38. Farb A, Burke AP, Kolodgie FD, Virmani R. Pathological mechanisms of fatal late coronary stent thrombosis in humans. *Circulation.* 2003;108:1701–1706.
39. Maisel WH. Unanswered questions – drug-eluting stents and the risk of late thrombosis. *N Engl J Med.* 2007;356:981–984.
40. Mauri L, Orav EJ, Kuntz RE. Late loss in lumen diameter and binary restenosis for drug-eluting stent comparison. *Circulation.* 2005;111:3435–3442.
41. Schwartz RS, van der Giessen WJ, Holmes DR Jr. Biomimicry, vascular restenosis and coronary stents. *Semin Interv Cardiol.* 1998;3:151–156.
42. Hayward JA, Durrani AA, Shelton CJ, Lee DC, Chapman D. Biomembranes as models for polymer surfaces. III. Characterization of a phosphorylcholine surface covalently bound to glass. *Biomaterials.* 1986;7:126–131.
43. Lewis AL, Tolhurst LA, Stratford PW. Analysis of a phosphorylcholine-based polymer coating on a coronary stent pre- and post-implantation. *Biomaterials.* 2002;23:1697–1706.
44. Virmani R, Guagliumi G, Farb A, et al. Localized Hypersensitivity and late coronary thrombosis secondary to a sirolimus-eluting stent should we be cautious? *Circulation.* 2004;109:701–705.
45. Whelan DM, van der Giessen WJ, Krabbendam SC, et al. Biocompatibility of phosphorylcholine coated stents in normal porcine coronary arteries. *Heart.* 2000;83:338–345.
46. Malik N, Gunn J, Shepherd L, Crossman DC, Cumberland DC, Holt CM. Phosphorylcholine-coated stents in porcine coronary arteries: in vivo assessment of biocompatibility. *J Invasive Cardiol.* 2001;13:193–201.
47. Kandzari DE, Leon MB. Overview of pharmacology and clinical trials program with the zotarolimus-eluting endeavor stent. *J Interv Cardiol.* 2006;19:405–413.
48. Burke SE, Kuntz RE, Schwartz LB. Zotarolimus (ABT-578) eluting stents. *Adv Drug Deliv Rev.* 2006;58:437–446.
49. Meredith IT, Ormiston J, Whitbourn R, et al. Four-year clinical follow-up after implantation of the endeavor zotarolimus-eluting stent: ENDEAVOR I, the first-in-human study. *Am J Cardiol.* 2007;100:56M–61M.
50. Meredith IT, Ormiston J, Whitbourn R, et al. First-in-human study of the Endeavor ABT-578-eluting phosphorylcholine-encapsulated stent system in de novo native coronary artery lesions: Endeavor I trial. *EuroIntervention.* 2005;1:157–164.

51. Fajadet J, Wijns W, Laarman GJ, et al. Randomized, double-blind, multicenter study of the Endeavor zotarolimus-eluting phosphorylcholine-encapsulated stent for treatment of native coronary artery lesions: clinical and angiographic results of the ENDEAVOR II trial. *Circulation*. 2006;114:798–806.
52. Fadajet J. EuroPCR May 2008.
53. Kandzari D, Leon M, Popma J, et al. Comparison of zotarolimus-eluting and sirolimus-eluting stents in patients with native coronary artery disease. *J Am Coll Cardiol*. 2006;48:2440–2447.
54. Leon M, Endeavor IV: A randomized comparison of a zotarolimus-eluting stent and a paclitaxel-eluting stent in patients with coronary artery disease; TCT Conference; Oct 2007.
55. Meredith I. EuroPCR May 2008.
56. Rivero, F, Moreno R, Barreales L, et al. Lower levels of in-stent late loss are not associated with the risk of stent thrombosis in patients receiving drug-eluting stents. *EuroIntervention*. 2008;4:124–132.
57. Udiipi, K, Melder, R, et al. The Next Generation Endeavor Resolute Stent: Role of the Biolinx Polymer System. *EuroIntervention*. 2007;3:137–139.
58. Meredith I, Worthley S, Whitbourn R, et al. The next-generation Endeavor Resolute stent: 4-month clinical and angiographic results from the Endeavor Resolute first-in-man trial. *EuroIntervention*. 2007;3:50–53.
59. Stone GW, Midei M, Newman W, et al. Comparison of an everolimus-eluting stent and a paclitaxel-eluting stent in patients with a coronary artery disease: A randomized trial. *JAMA*. 2008;299:1903–1913.