

## Initial and Follow-Up Results of the Tenax Coronary Stent

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### Summary

*The Tenax coronary stent is laser sculpted from high-precision 316 L stainless steel using advanced production procedures. An a-SiC:H (hydrogen-rich amorphous silicon carbide) coating reduces its thrombogenicity and improves its biocompatibility. From April to July 1998, 266 stents were implanted in 241 patients (aged  $62.7 \pm 10.5$  years) in five centers. In many cases, the clinical indication for intervention was unstable angina (33.2 %) and recent myocardial infarction (29.5 %). Most lesions (53.8 %) had complex characteristics (class B2 or C). The target vessel was the left anterior descending artery (LAD) in 42.5 % and the right coronary artery in 36.8 % of all cases. Four primary stent deployment failures occurred and implantation was successful in 259/266 stents (97.4 %). No death and no Q-wave myocardial infarction or emergency CABG occurred during hospitalization. Clinical success, defined as successful deployment without procedural or clinical event, was achieved in 230/241 patients (95.4 %). The one-year clinical follow-up shows a very low need for target lesion revascularization (17/237 patients: 7.2 %) and a 15.2 % rate of major adverse cardiac events (36/237 patients). The clinical and angiographic outcomes of our study suggest that the hybrid, amorphous hydrogenated silicon carbide coated design is promising and merits further evaluation in more extensive clinical trials.*

### Key Words

Angioplasty, coronary stenting, coronary artery disease, registry

### Introduction

In recent years, the beneficial effects of intracoronary stenting in reducing the acute complications and restenosis rates of conventional percutaneous transluminal coronary angioplasty (PTCA) have been reported [1,2]. The stent design seems very important in determining endothelial injury and, as a consequence, neointimal proliferation, which is the main mechanism of restenosis within the stent [3,4]. It is possible that other factors, such as the structure and the material of the stent, are important for determining subacute thrombosis and restenosis in addition to the known factors [5]. Several different types of stents are being used or are under clinical investigation [6].

This register was kept to assess initial and follow-up outcomes of a silicon carbide coated stent.

### Materials and Methods

#### Stent Design

The Tenax coronary stent (Biotronik, Germany) is

made of 316 L stainless steel. The tubular slotted design of this stent (Figure 1) contains multiple segments connected by 0.75 mm articulations. The articulation sites are crossed over by overlapping segments to avoid tissue prolapse. An amorphous silicon carbide (a-SiC:H) surface coating increases ideal interaction with blood and tissue. The stent is available in lengths ranging from 10 mm to 30 mm and in diameters ranging from 2.5 mm to 4.5 mm.

#### Stent Implantation Procedure

Predilatation was performed before stent implantation in the majority of cases (79.1 %) using a balloon catheter of the physician's choice. In general, initial vessel dilatation was performed with a balloon-to-vessel diameter ratio of 1:1. Once the balloon had been positioned with the premounted stent in the target lesion, the stent was expanded and deployed with a single or double inflation at 10 - 12 atm for 60 sec, aiming for a final stent diameter equal to or slightly larger

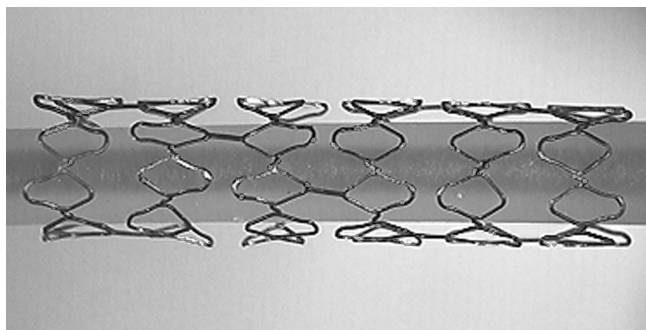


Figure 1. Tenax coronary stent design.

than the reference vessel diameter adjacent to the stented segment. Stent deployment was performed without IVUS guidance.

#### Medical Regimen

All patients received aspirin (250 mg p.o. daily) in the 24 hours prior to the angioplasty. During the procedure, 10,000 units of heparin were administered intravenously. Following the procedure, all patients received 500 mg of ticlopidine/day for 1 month (or 1 to 2 months). Patients who had not taken ticlopidine before the procedure were put back on heparin infusion for 72 hr. Aspirin (100 to 250 mg orally/day) was continued indefinitely.

#### Quantitative Coronary Angiography

Quantitative computer-assisted angiographic measurements of the dilated lesion were performed on angiograms obtained after intracoronary injection of molsidomine (1 mg). The angiograms were taken in the same projections just before and immediately after stent implantation. All the coronary angiograms were recorded on 35 mm cinefilms or CD-ROM (DICOM format) and analyzed in the central Core Lab using the QCA-CMS Medis System (Medical Imaging System). Briefly, the regions of interest were chosen in the vessel and measurements performed on end diastolic frames. The diameter of the coronary catheter was used to convert the imaging data from pixels to millimeters. The mean diameter of the reference vessel, the minimal luminal diameter (MLD), and the percentage of diameter stenosis (% DS) were measured. Other lesion features were noted: eccentricity, calcification, ostial location, thrombus, plaque ulceration, tortuosity and post-procedural dissection, according to the modified American College of Cardiology/American Heart Association (ACC/AHA) classification [7].

#### Definitions

Procedural success was defined as successful stent deployment with final percentage diameter stenosis < 35 % by quantitative analysis.

Clinical success was defined as procedural success without a procedural or clinical event.

Major adverse coronary events included:

- death,
- myocardial infarction, defined as the development of new pathological Q-waves or elevation of creatine kinase (CK) to over twice the upper limit of normal level (normal rate < 150 UI/l) with an elevated CK-MB fraction,
- new chest pain with repeat increase in CK's in acute myocardial infarction group,
- repeat coronary angioplasty,
- coronary bypass surgery, and
- bleeding that required blood transfusion or surgical repair at entry site.

#### Statistical Analysis

All statistics were calculated using the Stat View package V4.5 and Systat V7 package. Data are expressed as mean  $\pm$  SD or as a percentage. Categorical variables were analyzed by the chi-square test. Paired numerical data in serial angiograms were compared using the paired t-test, and, when appropriate, other continuous variables using the unpaired t-test or Fisher exact test. Variables with a  $p < 0.05$  on monivariate analysis were entered into a Cox regression analysis to assess the relation between the clinical follow-up and selected clinical or angiographic variables at baseline. Event-free survival distribution was estimated using the Kaplan-Meier method.

#### Results

From April to July 1998, 266 stents were implanted in 241 patients ( $62.7 \pm 10.5$  years). Table 1 summarizes patient baseline clinical and angiographic characteristics. The clinical indication for intervention was unstable angina (33.2 %) and recent myocardial infarction (29.5 %) in most cases. The target vessel for stenting was the left anterior descending in 42.5 % and the right coronary artery in 36.8 %. The majority of lesions (152: 57.1 %) had complex characteristics (class B2-C or chronic occlusion).

Procedural characteristics and in-hospital clinical and angiographic outcome are summarized in Table 2. 241

**Baseline clinical and angiographic characteristics  
(n = 241 patients)**

	Number of patients	Percent
Mean age $\pm$ SD (years)	62.7 $\pm$ 10.5	
Male	197	81.7
Stable angina	63	26.1
Unstable angina	80	33.2
Recent myocardial infarction	71	29.5
Acute myocardial infarction	19	7.9
Silent ischemia	8	3.3
Multi-vessel disease	117	48.5

**Indications for stenting  
(n = 266 stenoses)**

	Number of stenoses	Percent
Primary implantation	141	(53.0)
Incomplete result	73	(27.4)
Bail out/dissection	46	(17.3)
Restenosis	6	(2.3)
<i>Target lesion location</i>		
Left anterior descending	113	(42.5)
Circumflex artery	49	(18.4)
Right coronary artery	98	(36.8)
Saphenous vein graft	4	(1.5)
Left main	2	(0.8)

**Modified AHA/ACC classification  
(n = 266 stenoses)**

	Number of stenoses	Percent
Type A-B1	95	(35.7)
Type B2-C	143	(53.8)
Acute occlusion	19	(7.1)
Chronic occlusion	9	(3.4)
Calcification	89	(33.5)
Lesion in bend (> 45°)	46	(17.3)
Ostial	17	(6.4)
Bifurcation	12	(4.5)

Table 1. Patient baseline clinical and angiographic characteristics.

patients were implanted with 266 stents (1.29 stents/pt; 1.11 Tenax stent/pt). Due to excessive tortuosities of coronary arteries, five primary stent deployment failures occurred and two stents were lost in peripheral circulation. Four other stents were implanted in these remaining patients. The fifth had a successful balloon angioplasty. So, implantation was successful in 259/266 stents (97.4 %). After the procedure, angiography showed residual stenosis < 20 % in 60.3 % of patients and < 30 % in 87.7 % of patients. No death, and no emergency CABG occurred during hospitalization. One patient suffered acute thrombosis and Q-wave myocardial infarction and was treated medically.

**Procedural characteristics and in-hospital clinical and angiographic outcomes  
(n = 266)**

	Number of patients	Percent
<b>Stent length</b>		
15 mm	208	78.2
20 mm	40	15.0
25 mm	17	6.4
30 mm	1	0.4
<b>Stent diameter</b>		
2.5 mm	1	0.4
3 mm	123	46.2
3.5 mm	106	39.8
4 mm	33	12.4
4.5 mm	3	1.1

**Procedure**

Tenax/pt	1.11	
Stent/pt	1.29	
Other PTCA	36	13.5
Other Stenting	46	17.3
Overall additional procedures	82	30.8

**QCA analysis (223/266)****Reference vessel diameter (RVD)  $\pm$  SD mm**

Pre-procedure	3.06 $\pm$ 0.6
Post-procedure	3.13 $\pm$ 0.6

**Minimal lumen diameter (MLD)  $\pm$  SD mm**

pre-procedure	0.80 $\pm$ 0.42
Post-procedure	2.60 $\pm$ 0.43

**Percentage diameter stenosis (% DS)**

Pre-procedure	72.09 $\pm$ 12.1
Post-procedure	15.8 $\pm$ 8.5

<b>Procedural success</b>	259	97.4
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<b>Clinical success</b>	230/241	95.4
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**Procedural complications after successful Tenax**

lateral occlusion	6
Dissection	6
Acute or sub-acute occlusion	1
QMI	1
Death, emergency CABG	0

Table 2. Procedural characteristics and in-hospital clinical and angiographic outcomes [n = 266 stenoses (%)].

Twelve patients had procedural complications after successful implantation but without clinical complications (lateral branch occlusion in 6 patients and dissection in 6 patients). Finally, clinical success was achieved in 230/241 patients (95.4 %) implanted with the Tenax system.

### Clinical Follow-up Outcome

One-year clinical follow-up outcomes are summarized in Table 3. Mean clinical follow-up time was  $11.6 \pm 2$  months in 97.8 % of all patients. Seven patients (3.0 %) died from problems of extra-cardiac (1 patient) or cardiac (6 patients) origin, one of which was certainly stent-related, but no autopsy was required. Two patients required elective bypass surgery for restenosis at 1- and 3-month follow-up, and five others underwent surgery between 6 and 12 months due to a progression of the coronary artery disease. Twenty-two patients underwent repeat PTCA for restenotic or non-target lesions. So, the rates of target lesion revascularization (TLR) and major adverse cardiac events (MACE) were 7.2 % (17/237 patients) and 15.2 % (36/237 patients), respectively. In monovariate analysis, ostial lesion ( $p < 0.0001$ ), diabetes ( $p = 0.09$ ), pre-procedural reference diameter of artery  $< 3$  mm ( $p = 0.0037$ ), calcifications ( $p < 0.05$ ) and worse post-procedural MLD ( $p = 0.0055$ ) were associated with an increase in coronary events.

Multivariate analysis demonstrated that ostial lesion ( $p = 0.0011$ ; RR 4; 95 % IC: 1.75 - 9.09), preprocedural reference diameter of artery  $< 3$  mm ( $p = 0.0077$ ; RR 2.82; IC: 1.32 - 6.05) and diabetes ( $p < 0.08$ ; RR 1.96; IC: 0.93 - 4.17) were significantly associated with a higher rate of major adverse cardiac events (MACE).

## Discussion

### Procedural Outcome

In this independent register, our initial results demonstrate that the Tenax coronary stent can be safely and successfully implanted. On 266 attempted stents, there were 5 Tenax stent implantation failures. Four other stents were deployed following unsuccessful Tenax stent delivery attempts and one lesion was treated with balloon angioplasty. For the two lost stents, medical treatment was initially performed.

The 97.4 % procedural success rate achieved with this stent compares well with the 94 - 98 % reported for the Palmaz-Schatz stent [8,9]. Despite the frequently unfavorable angiographic characteristics of the lesions, the 95.4 % clinical success rate was comparable to the 83.2 % - 98 % reported with the Palmaz-Schatz stent [10,11]. Although sufficient biocompatibility is currently available, coronary stents have less-than-ideal hemocompatibility. As a consequence of inherent

Eligible patients	n = 237	
Clinical follow-up	232	(97.9 %)
Mean follow-up	11.6 $\pm$ 2 months	
Unstable angina	17	(7.2 %)
Death	7	(3.0 %)
Target lesion revascularisation	17	(7.2 %)
Major adverse cardiac events	36	(15.2 %)

Table 3. One-year clinical follow-up (FU) outcomes.

thrombogenicity, coronary stenting is associated with a significant number of acute and subacute thromboses. Improvement of the hemocompatibility of the materials themselves is a new concept [12-14] that addresses stent thrombosis directly.

Subacute stent thrombosis only occurred in one patient with conventional anticoagulation therapy including ticlopidine-aspirin; no death and no emergency CABG occurred during in-hospital follow-up.

### Clinical Follow-up Outcome

Preliminary clinical results for the Tenax stent, with its highly biocompatible and hemocompatible a-SiC:H coating, indicate reduced complication rates as compared to uncoated metallic stents [15]. This may be particularly important for high-risk lesions, such as thrombotic lesions, or small vessels. In comparison with the first generation design (Tensum), the second generation of silicon carbide coated stents (Tenax), which are differently articulated stainless steel slotted tubular stents coated with the same compound, may indeed play a role in reducing both subacute stent thrombosis and restenosis [16].

Twenty-seven patients had another revascularization during the follow-up. Five patients underwent CABG (2 patients between 1 and 3 months and 3 patients between 6 and 12 months) and twenty-two patients had re-PTCA for restenosis or new lesions with a majority of cardiac events after the sixth month. Considering the patient and lesion characteristics of our study population, this registry shows an extremely favorable TLR rate (7.2 %) in comparison with other data in the literature. In the very effective Benestent II trial [17], at one year the rates of repeat PTCA and any of the above major adverse cardiac events were 9.4 % and 15.7 %, respectively, in the heparin-coated-stent group.

Moreover, some of the differences observed might be

attributed to modern procedures. Excessively high-pressures may injure deep layers of the vessel wall at the dilated or adjacent sites, and may be detrimental by promoting arterial remodeling or tissue proliferation [18]. In our registry, post-stenting dilatation pressure was moderate:  $11.5 \pm 2.0$  atm, and may have helped to decrease the restenosis rate.

### Conclusion

The Tenax coronary stent proved to be safe and efficacious in the treatment of coronary lesions, even in the presence of unfavorable characteristics. It has a very low profile (0.040 inch), and excellent flexibility, trackability, and scaffolding after deployment. The deposit of silicon carbide (a-SiC:H) on metallic stent surfaces forms a hybrid designed device, which promises reduced immediate and long-term complication rates. This registry suggests it is a promising design that merits further comparative studies to determine the importance of a-SiC:H surface coating for an effective clinical outcome.

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