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 ± 10.5 years) at five centers. 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 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 stents (97.4 %). No deaths and no Q-wave myocardial infarctions or emergency coronary artery bypass grafts occurred during the hospital stay. Clinical success, defined as successful deployment without procedural or clinical event, was achieved in 230 patients (95.4 %). One-year clinical follow-up showed a very low need for target lesion revascularization (17/237 patients: 7.1 %) and a 15.8 % 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 larger 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 appears to be very important in determining endothelial injury and, as a consequence, neointimal proliferation, which is the main mechanism for restenosis within the stent [3,4]. It is possible that other factors, such as the structure and the material of the stent, are important in 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 registry was kept to assess initial and follow-up outcomes of a silicon carbide coated stent.

Materials and Methods

Stent Design

The Tenax coronary stent 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 a-SiC:H (amorphous silicon carbide) surface coating increases ideal interaction with blood and tissue. The stent is available in lengths ranging from 10 to 30 mm and diameters ranging from 2.5 to 4.5 mm.

Stent Implantation Procedure

In the majority of cases (79.1 %), predilation was performed before stent implantation, using the balloon-catheter of the physician's choice. In general, initial

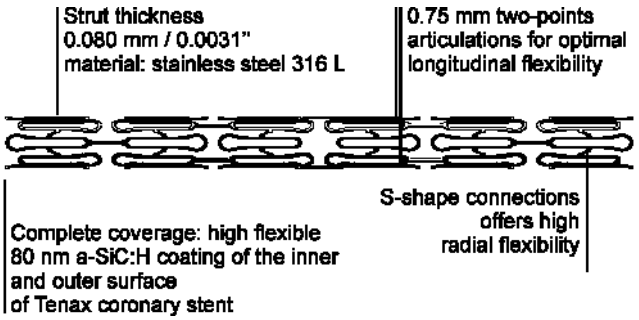

Figure. 1. Tenax coronary stent design.

vessel dilation 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. This resulted in a final stent diameter equal to or slightly larger than the reference vessel diameter adjacent to the stented segment. Stent deployment was performed without intravascular ultrasound guidance.

Medical Regimen

All patients received aspirin (250 mg orally/day) in the 24 hours prior to the angioplasty. During the procedure, 10,000 units of heparin were given intravenously. Following the procedure, all patients received 500 mg 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 procedural or clinical event.

Major adverse coronary events included:

- death;
- myocardial infarction, defined as the development of new pathological Q-waves or elevation of 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 re-ascension of CK's in acute myocardial infarction group;
- repeated coronary angioplasty;
- coronary bypass surgery; and
- bleeding that required blood transfusion or surgical repair at the entry site.

Statistical Analysis

All statistics were calculated using the Stat View package V4.5 and Systat V7 package. Data are expressed as mean ± SD or percent. Categorical variables were analyzed by the chi-square test. Paired numerical data in serial angiograms were compared by the paired t-test, and other continuous variables by the unpaired t-test or Fisher exact test when appropriate. Variables with a $p < 0.05$ on monovariate 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 Tenax coronary stents were implanted in 241 patients (62.7 ± 10.5 years). Table 1 summarizes patient baseline clinical and angiographic characteristics. In many cases, the clinical indication for intervention was unstable angina

	n	Percent
Male	197	82
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	3.9
Multi vessel disease	117	48.6
Indications for stenting		
Primary implantation	141	53
Incomplete result	73	27.4
Bail out/dissection	46	17.3
Restenosis	6	2.3
Target lesion location		
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		
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
Mean age ± SD (years)	**62 ± 10**	

Table 1. Baseline clinical and angiographic characteristics (n = 241 (%)).

(33.2 %) and recent myocardial infarction (29.5 %). The target vessel for stenting was the left anterior descending in 42.5 % of cases and the right coronary artery in 36.8 %. The majority of lesions (152: 57.2 %) had complex characteristics (class B2 or C).

Procedural characteristics and in-hospital clinical and angiographic outcome are summarized in Table 2. Two hundred forty-one patients were implanted with 266 stents (1.29 stents/patient; 1.11 Tenax stent/patient). Due to excessive tortuosities of coronary arteries, five primary stent deployment failures occurred and two stents were lost in the peripheral circulation. Four other stents were implanted in these remaining patients and the fifth had a successful balloon angioplasty. Implantation was successful in 259 out of 266 stents (97.4 %). After the procedure, angiography showed residual stenosis < 20 % in 60.3 % of patients and < 30 % in 87.7 %. No deaths, and no emergency coronary artery bypass grafts (CABG) occurred during the hospital stay. One patient suffered acute thrombosis and Q-wave myocardial infarction and was treated medically. 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 out of 241 patients (95.4 %) implanted with the Tenax system.

Clinical Follow-up Outcome

Mean clinical follow-up time was 11.6 ± 2 months in 97.8 % of the patients. Seven patients (3.1 %) died from problems of extra-cardiac (1 patient) or cardiac (6 patients) origin; one of which was certainly stent related, but no autopsy was performed (Table 3). Two patients required elective bypass surgery for restenosis at 1 and 3 month follow-up and five others had surgery between 6 and 12 months for progression of coronary artery disease. Twenty-two patients underwent repeat PTCA for restenosis or non-target lesions. The rates of target lesion revascularization (TLR) and major adverse cardiac events (MACE) were 7.1 % (17 out of 237 patients) and 15.8 % (36 out of 237 pts), respectively. In monovariate analysis, ostial lesion ($p < 0.0001$), diabetes ($p = 0.09$), preprocedural 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 the 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 MACE rate.

Discussion

Procedural Outcome

In this independent registry, our initial results demonstrate that the Tenax coronary stent can be safely and successfully implanted. On 266 attempted stent implantations, there were 5 Tenax stent failures. Four other stents were implanted following unsuccessful

	N	Percent
Stent length		
15 mm	208	78.2
20 mm	40	15
25 mm	17	6.4
30 mm	1	0.4
Stent diameter		
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) ± SD mm		
Pre-procedure	3.06 ± 0.6	
Post-procedure	3.13 ± 0.6	
Minimal lumen diameter (MLD) ± SD mm		
Pre-procedure	0.80 ± 0.42	
Post-procedure	2.60 ± 0.43	
Percentage diameter stenosis (% DS)		
Pre-procedure	72.09 ± 12.1	
Post-procedure	15.8 ± 8.5	
Procedural success	259	97.4
Clinical success	**230 / 241**	**95.4**
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 (%)).

Eligible patients	n = 237	
Clinical follow-up	232	97.8 %
Mean follow-up	11.6 ± 2 months	
Unstable angina	17	7.1 %
Death	7	3.1 %
Target lesion revascularization	17	7.1 %
Major adverse cardiac events	36	15.8 %

Table 3. One year clinical follow-up (FTU).

Tenax stent delivery attempts, and one lesion was treated with balloon angioplasty. For the two lost stents, medical treatment was initially required.

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 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. However, not only did this patient survive, but also an emergency CABG was not required during the 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 with 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 coronary artery bypass grafts (2 patients between 1 and 3 months and 3 patients between 6 and 12 months) and

twenty-two patients had re-percutaneous transluminal coronary angioplasty 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 (7.1 %) in comparison with other data in the literature. In the very effective Benestent II trial, 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 [17].

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 dilation pressure was moderate (11.5 ± 2.0 atm), and may have helped to decrease the restenosis rate.

Conclusion

The Tenax coronary stent proves 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), and excellent flexibility, trackability and scaffolding after deployment. The deposit of 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 in the effective clinical outcome.

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