INTERVENTIONAL CARDIOLOGY AND SURGERY

Shortening the stent length reduces restenosis with bare metal stents: matched pair comparison of short stenting and conventional stenting

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Objective: To investigate the effect of reducing stent length on the rate of target lesion restenosis.
Design: In a prospective investigation, acute and long term results of a short stenting procedure were analysed by quantitative angiography and compared with results of a conventional stenting procedure selected according to a matched pairs analysis.
Patients: Short stents were implanted in 400 consecutive patients with 464 lesions and conventional stents in 430 patients. Demographic and lesion characteristics were comparable between groups.
Interventions: In short stenting, the shortest stent length to cover only segments with > 30% reduction in vessel diameter was used. In conventional stenting, full coverage of a stenotic vessel segment was intended.
Main outcome measures: The mean stent lengths of the short stent group (9.8 (4) mm) and the conventional stent group (16.3 (7) mm) differed significantly ($p < 0.0001$); all other procedural and angiographic parameters were the same. Procedural success was similar for both groups. Control angiography after six months was conducted in 92% of patients.
Results: Short stenting resulted in both less restenosis (68 of 431 (15.8%)) than conventional stenting (93 of 381 (24.4%), $p = 0.007$) and less late lumen loss (0.6 (0.6) mm *v* 0.75 (0.5) mm, $p = 0.0001$). Residual stenosis (< 45%) in adjacent vessel segments after short stenting did not affect the restenosis rate. Only the implantation of a ⩽ 9 mm stent predicted the absence of restenosis in a multivariate analysis.
Conclusion: Shortening the length of bare metal stents reduces the restenosis rate as compared with conventional stenting.

Drug eluting stents (DES) have reduced restenosis rates compared with bare metal stents.[1] However, the superiority of DES has been proved for only a few lesion characteristics. Another restriction for the liberal use of DES is their costs. A recently published cost effectiveness analysis for the use of DES showed that treatment with DES would save costs for patients with a bare metal stent target vessel revascularisation (TVR) rate > 20%.[2] Although the length of the DES does not seem to influence the restenosis rate, the length of bare metal stents was found to predict restenosis independently.[3 4] Furthermore, much longer stents were used than necessary to cover the target lesion in most lesions as reported in an analysis of several interventional trials of bare metal stents.[5] In a previous study, we could show that, with a single short stent (9 mm), 52% of all treated coronary lesions could be treated successfully, yielding a low restenosis rate.[6] In the present study we compared the strategy of implanting the shortest stent length, covering only the clinically relevant parts of a lesion, with conventional stenting—that is, a stent sized to cover the target lesion completely.

METHODS

Objectives

The study was designed to investigate, prospectively, both the short term and long term results of inserting the shortest possible stent into lesions requiring a stent. Immediately adjacent plaques causing less than 30% diameter stenosis were left unstented. Possible effects of this procedure on the restenosis rate were assessed angiographically.

Patients

Four hundred consecutive patients attending our clinic between 2002 and 2003 with symptoms of angina pectoris or proven ischaemia and > 60% diameter stenosis requiring a stent were treated according to the protocol below. Also, a comparable number of matched control patients treated routinely between 1999 and 2001 by conventional stenting that completely covered the target lesions were selected from a registry. Lesions in the two groups of patients were pair matched on the basis of demographic (age, sex, and diabetes) and angiographic data (reference diameter, lesion length, and American Heart Association criteria for lesion morphology). Patients with acute myocardial infarction and target lesions > 30 mm long were excluded.

Intervention

Short stenting

Primary stenting was considered only for target lesions < 10 mm long located in a proximal segment of the left anterior descending coronary artery or the right coronary artery with a reference diameter > 3 mm. In all of the remaining interventions percutaneous transluminal coronary angioplasty (PTCA) was the primary intervention. A stent was inserted if angiography performed five minutes after the initial intervention showed a residual stenosis > 30% according to visual assessment or a dissection that required a stent. In all cases we used the shortest possible stent

Abbreviations: DES, drug eluting stents; MACE, major adverse cardiac events; PTCA, percutaneous transluminal coronary angioplasty; TVR, target vessel revascularisation

compatible with immediate success according to visual assessment or online quantitative coronary angiography—that is, covering the most severe residual stenosis with a final diameter stenosis $< 30\%$ within the stent and $< 50\%$ diameter stenosis of the target vessel without need of an additional stent. The intended inflation pressure was > 12 atm for all stent implantations. The nominal stent size was chosen to achieve a final stent to artery ratio of 1.1 at the inflation pressure used.

Conventional stenting

The intention was to cover completely the obturating plaque without residual stenosis. This could be done by either primary stenting or performing PTCA first. There was no need to wait for the angiographic result after initial PTCA if it was decided to proceed with stent implantation.

Concomitant medication

All patients received acetylsalicylic acid (ASA, aspirin) 100 mg for at least 14 days before the intervention. Patients scheduled for elective surgery also received clopidogrel 75 mg daily from four days before the intervention. Heparin (5000 IU) was given to all patients as an intravenous bolus before the procedure and then by infusion during the procedure at doses that would achieve a 2.5-fold prolongation of activated prothrombin time. After the intervention all patients were prescribed ASA 100 mg/day, indefinitely, and clopidogrel 75 mg daily for four weeks.

Quantitative coronary angiography

A CAAS II research system (Pie Medical Imaging, Maastricht, the Netherlands) was used for automated contour detection and quantification. The system and validation data have been published as have been the measurement procedures.[7 8] Angiography was performed before and after all interventions and at angiographic follow up with identical projections and analyses. Frames were selected as recommended by Herrington and Walford.[9] Analysis followed the guidelines proposed by Reiber *et al*.[10] Lesion length, mean diameter within the lesion (mean stenosis diameter), and minimum lumen diameter were calculated for the target vessel segment. Also, diameter stenosis and minimum lumen diameter were measured 5 mm from each stent edge. In-stent restenosis was defined as percentage diameter stenosis $> 50\%$ at control angiography.

Statistical analysis

Continuous variables are expressed as the mean (SD). Mann-Whitney tests were used to assess differences in continuous variables between the intervention groups. χ^2 tests assessed the dependence between categorical variables. Effects of potential risk factors for restenosis were analysed by a linear regression model for continuous variables. A stepwise logistic regression model tested all qualitative and quantitative lesion characteristics independently, and then analysed all independent variables associated significantly with restenosis by a backward approach. Probability values of $p < 0.05$ were considered significant.

Table 1 Patient baseline characteristics

	Short stent group (n = 400)	Conventional stent group (n = 430)	p Value
Age (years)	64 (9)	64 (10)	0.90
Men	304 (76%)	322 (75%)	0.82
CCS angina class III–IV	156 (39%)	163 (38%)	0.88
Hypertension	316 (79%)	344 (80%)	0.68
Hypercholesterolaemia	300 (75%)	327 (76%)	0.88
Diabetes mellitus	104 (26%)	103 (24%)	0.62
Multivessel coronary disease	212 (53%)	237 (55%)	0.48

Data are mean (SD) or number (%).
CCS, Canadian Cardiovascular Society.

Table 2 Lesion baseline characteristics

	Short stent group (n = 464)	Conventional stent group (n = 430)	p Value
De novo lesion	385 (83%)	353 (82%)	0.90
Total occlusion	9 (1.9%)	10 (2.2%)	0.78
Left anterior descending artery	158 (34%)	155 (36%)	0.66
Left circumflex artery	93 (20%)	95 (22%)	0.75
Right coronary artery	144 (31%)	124 (29%)	0.70
Coronary artery branches	60 (13%)	43 (10%)	0.45
Venous coronary bypass	9 (2%)	13 (3%)	0.68
Lesion morphology			
Eccentric	316 (68%)	280 (65%)	0.66
Diffuse	60 (13%)	69 (16%)	0.28
AHA type A/B1 lesions	186 (40%)	163 (38%)	0.64
AHA type B2/C lesions	278 (60%)	267 (62%)	0.76

Data are number (%).
AHA, American Heart Association.

RESULTS

Of 536 consecutive patients undergoing a percutaneous coronary intervention 400 patients with 464 stenotic coronary lesions met the criteria for short stenting and received a short stent. For the matched pairs analysis 430 control patients, with 430 lesions treated by conventional stenting, were selected from a registry. No match could be found for 34 lesions (7.3%) in the short stent group. Baseline clinical and angiographic data were comparable between groups (tables 1 and 2).

Immediate results

The shortest available stent ($\leqslant 9$ mm) was implanted in 371 of 464 lesions (80.0%); however, an additional stent had to be implanted subsequently in 22 of these 371 lesions (5.9%) because of persisting residual stenoses $> 45\%$ or dissection. A longer stent was inserted in 93 of 464 lesions (20.0%) of the short stent group. Stents used for short stenting were 397 MultiLink stents (Guidant), 79 NIR stents (Medinol Ltd), and 10 other stents. Angiographic analysis of the short stent group showed residual diameter stenosis (from 25–45%) in 87 of 464 (18.8%) lesions caused by residual plaque outside the stent. Dissections were observed in 154 lesions, of which 45 (29.2%) were not fully covered by the stent.

Table 3 Procedural data and baseline characteristics of quantitative coronary angiography

	Short stent group (n = 464)	Conventional stent group (n = 430)	p Value
Stent length (mm)	9.8 (4)	16.3 (7)	0.0001
Nominal device diameter (mm)	2.9 (0.5)	3.1 (0.5)	0.45
Inflation pressure (atm)	13 (3)	14 (4)	0.72
Device:artery ratio	1.13 (0.1)	1.12 (0.1)	0.88
Reference diameter (mm)	2.9 (0.5)	3.0 (0.5)	0.40
Diameter stenosis, before (%)	74.4 (14)	76.2 (11)	0.62
Minimum lumen diameter, before (mm)	0.76 (0.5)	0.74 (0.3)	0.18
Mean stenosis diameter, before (mm)	1.6 (0.5)	1.7 (0.5)	0.76
Plaque area (mm^2)	10.2 (6)	11 (6)	0.82
Lesion length (mm)	11.5 (8)	12.2 (6)	0.38

Data are mean (SD).

Table 4 Clinical and angiographic outcomes

	Short stent group (n = 464)	Conventional stent group (n = 430)	p Value
Angiographic success	458 (99%)	417 (97%)	0.26
Procedural success	458 (99%)	417 (97%)	0.26
Final minimum lumen diameter (mm)	2.6 (0.5)	2.7 (0.4)	0.18
Final mean stenosis diameter (mm)	2.9 (0.5)	2.9 (0.4)	0.66
Final diameter stenosis (%)	14 (13)	16 (12)	0.08
Acute gain (mm)	1.8 (0.5)	1.9 (0.4)	0.24
Final plaque area (mm^2)	2.7 (3)	2.3 (2.5)	0.07

Data are mean (SD) or number (%).

Stents used for conventional stenting were 276 MultiLink stents, 111 NIR stents, and 43 other stents. Quantitative coronary angiography showed residual diameter stenosis (from 25–45%) outside the stent in 16 of 430 (3.7%) lesions and dissections in 64 stented lesions, which persisted in six (9.4%) cases after conventional stenting. The stent was significantly shorter in the short stent group; all other procedural data and lesion characteristics were comparable between groups (table 3).

Major adverse cardiac events ((MACE) myocardial infarction, TVR, or death) occurred in seven patients of the short stent group, comprising five cases of non-ST elevation myocardial infarction and two of ST elevation myocardial infarction caused by vessel occlusion. Similarly, in the conventional stent group, the five cases of MACE were three non-ST elevation myocardial infarctions and two ST elevation myocardial infarctions. Baseline lesion characteristics, angiographic success (diameter stenosis $< 30\%$ within the stent and diameter stenosis $< 50\%$ in target vessel), and procedural success (angiographic success and absence of MACE) were similar between the two groups (table 4). Glycoprotein IIb/IIIa antagonists were administered to 13 of 400 patients receiving short stents (3.3%) and 19 of 430 patients receiving conventional stents (4.4%).

Clinical follow up

Five patients in the short stent group and seven in the conventional stent group experienced recurrent angina pectoris, Canadian Cardiovascular Society class III or IV, during follow up. MACE occurred in two patients of the short stent group and three of the conventional stent group, all of whom died during the follow up period. The target vessel was revascularised in the presence of clinical symptoms or a positive stress test and a diameter stenosis $> 50\%$. This was done in significantly ($p = 0.0018$) fewer patients of the short stent group (58 of 431 (13.5%)) than in the conventional stent group (95 of 381 (24.9%)). They were treated with coronary artery bypass grafting ($n = 8$ *v* $n = 19$, respectively) and percutaneous coronary interventions ($n = 50$ *v* $n = 76$, respectively).

Table 5 Angiographic outcome after six months

	Short stent group (n = 431)	Conventional stent group (n = 381)	p Value
Diameter stenosis (%)	32 (20)	40 (23)	0.0016
Minimum lumen diameter (mm)	2.0 (0.7)	1.8 (0.65)	0.036
Mean stenosis diameter (mm)	2.4 (0.6)	2.1 (0.6)	0.014
Late loss (mm)	0.6 (0.6)	0.75 (0.5)	0.0001
Loss index	32 (27)	46 (36)	0.0001
Net gain (mm)	1.2 (0.7)	1.1 (0.7)	0.64
Net gain index	41 (22)	36 (26)	0.74
Neo-plaque area (mm^2)	2.3 (3.8)	3.8 (5)	<0.001
Net plaque reduction (mm^2)	5.4 (4.8)	4.7 (3)	0.45
Length of in-stent restenosis (mm)	8.2 (4)	13.5 (2)	0.0001
Number of lesions with restenosis (%)	68 (15.8%)	93 (24.4%)	0.0071

Data are mean (SD) or number (%).

Angiographic follow up

In 361 of 391 patients in the short stent group (92.3%), angiography was repeated at 185 (13) days on 431 of 454 of lesions (94.9%). Similarly, in 381 of 414 patients in the conventional stent group (92.0%), angiography was performed at 182 (15) days on 381 of 414 of lesions (92.0%) (table 5). In-segment restenosis was significantly ($p = 0.0071$) less common in short stented lesions (68 of 431 (15.8%)) than in conventionally stented lesions (93 of 381 (24.4%)), as was late lumen loss (table 5). Both groups had the same number of restenoses in the vessel segment adjacent to the stent (9 of 68 *v* 11 of 93, $p = 0.98$). Proliferative or diffuse in-stent restenoses developed in five lesions of the conventional stent group and in none of the short stent group ($p = 0.14$). In-stent restenosis was longer in the conventional stent group (table 5). The restenosis rate in lesions treated by short stenting did not differ whether the shortest available (53 of 349 (15.2%)) or a longer stent was used (15 of 82 (18.3%), $p = 0.082$).

In the univariate analysis, diffuse lesion type, reference diameter, final minimum lumen diameter, and final mean diameter were all significantly correlated with restenosis in the short stent group. However, in the multivariate analysis, only reference diameter independently predicted restenosis (table 6). When all treated lesions were included in the multivariate model, stent length, reference diameter, and diffuse lesion type predicted restenosis independently. The use of a single stent $\leqslant 9$ mm long independently predicted the absence of restenosis.

DISCUSSION

In-stent restenosis is the major limitation to using bare metal stents. Moreover, a diffuse in-stent restenosis > 10 mm has a high probability of recurrence.[11] Stent length, among other parameters, was found to be predictive for in-stent restenosis in several investigations.[4 12] A recent meta-analysis of several stent trials showed that the stented segment length predicts in-stent restenosis independently of the lesion length.[5] Although more than 50% of all lesions treated by percutaneous coronary intervention in most large interventional studies are < 10 mm long, only 22% of MultiLink stents distributed in Europe are < 12 mm (Guidant Co, sales report Europe 2003). Colombo *et al*[13] reported that multiple short stents inserted into long stenoses at spots with significant residual stenosis after PTCA produced a lower restenosis rate than did a single long stent. Complete stent coverage of an extensive but non-obstructive plaque is unnecessary in preventing restenosis.

Methodological aspects

The criterion that was used to measure lesion length by quantitative angiography (length of plaque causing $> 50\%$ diameter reduction) reflects more precisely the extent of clinically relevant stenoses and allows standardisation of measurements, in contrast to overall lesion length. Also, the algorithm used measures a shorter lesion length than does measuring the overall lesion length.

Most of our interventions consisted of an initial PTCA with balloons, which usually shortened the significantly stenosed vessel segment. Since we did not observe an increased incidence of restenosis in the vessel segments adjacent to the stent, although they are affected by balloon angioplasty, we can assume that stent length, rather than the endothelial

Table 6 Analysis of restenosis after short stent implantation

	Univariate analysis			Multivariate analysis: restenosis
	Restenosis	No restenosis	p Value	p Value
Diffuse lesion	20/68 (29.4%)	48/363 (13.2%)	0.0003	0.08
Reference diameter (mm)	2.8 (0.5)	3.1 (0.4)	0.0023	0.003
Acute gain (mm)	1.7 (0.5)	1.9 (0.5)	0.037	0.12
Final minimum lumen diameter (mm)	2.4 (0.5)	2.6 (0.4)	0.03	0.10
Final mean stenosis diameter (mm)	2.7 (0.5)	2.9 (0.4)	0.035	0.22

Data are mean (SD) or number (%).

damage caused by the intervention, is the determining factor for restenosis. The mean postprocedural diameter stenosis adjacent to the stent was $< 20\%$ (data not shown) and consistent with a high likelihood for a favourable long term result after balloon angioplasty.[14] Furthermore, although residual plaque causing a 25–45% diameter stenosis was left unstented in 19% of all short stented lesions, we observed no increased incidence of restenosis here.

Clinical and angiographic results

We previously showed in 331 consecutive patients that using only the shortest available stent (8 or 9 mm) in 221 of 424 lesions (52.1%) was sufficient for angiographic success.[6] The restenosis rate was remarkably low in lesions that received a $\leqslant 9$ mm stent and in lesions that received a longer but the shortest possible stent. Results of the investigation presented here were in accordance with our feasibility study of short stenting published previously.[6] We showed in both investigations that most coronary lesions can be treated successfully with the shortest stent available when preceded by PTCA as the primary treatment. A second stent was needed in very few cases (5.9%); however, in all other stent implantations the use of an additional stent was not necessary ($p = 0.0001$). We are not aware of other clinical trials of short stenting or of short stents used in a similar proportion of total stent implantations. Only a few trials with bare metal stents have reported comparable rates of restenosis or TVR; however, these lesions were preselected or angiographic control was infrequent, which may also account for the low number of revascularisation procedures.[15–18]

Clinical implications

DES reduce the rate of restenosis to about 2% in non-complex lesions and to about 8% in long complex lesions.[1] Treatment costs for DES are significantly higher than those for bare metal stents at present, but this difference diminishes within one year when costs for repeat revascularisation procedures are included.[19] Geenberg *et al*[2] recently calculated that treatment with the available DES would be cost saving for patients with a TVR rate $> 20\%$ and cost effective for patients with a TVR rate $> 12\%$ after bare metal stents. With the TVR rate of 14.2% after short stenting, routine use of DES would not have saved costs compared with the use of conventional stents to treat lesions. Furthermore, our results indicate that short stenting is cost effective as compared with DES when lesions in vessels > 2.7 mm are treated with bare metal stents (TVR 11.0%, data not shown), which accounted for 91.3% of all lesions stented.

Limitations

Short stenting was evaluated prospectively, whereas the control group was analysed retrospectively. Although both patients and lesions were well matched between the two groups, the absence of randomisation may have introduced a selection bias that affected the results.

Patients with lesions that had a > 3 cm long $> 50\%$ diameter stenosis were excluded because the long term results are considerably less favourable with bare metal stents than with surgical revascularisation or DES in these cases.[20] Lastly, stent design also influences the rate of restenosis.[21] Patients of the control group and of the short stent group were treated mainly with MultiLink stents. Since then the design of the MultiLink stents, implanted in most of our patients, has been improved, which has been shown to improve long term angiographic parameters, and this may have affected the results.[22] However, none of the stent types used in this study exhibited an increased restenosis rate in larger investigations (for example, as gold stents). Furthermore, analysis of the stent type used did not show an impact on restenosis within or between the two groups.

Conclusions

Our goal was to use the shortest possible stent for a successful outcome in a series of consecutive patients with non-selected coronary artery stenoses. We showed that the shortest available stent ($\leqslant 9$ mm) was sufficient in the majority of cases. Compared with a control group with conventional stent lengths covering all plaque segments, all our patients achieved similar immediate results, both clinical and angiographic, with significantly shorter stent lengths. Therefore, restenosis and the consequent need for target lesion revascularisation can be reduced by implanting short stents, without increasing the risk of restenosis in immediately adjacent vessel segments. The low restenosis rate with short stenting suggests an economically attractive alternative to the routine use of DES in suitable patients.

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IMAGES IN CARDIOLOGY

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Percutaneous removal of embolised vegetation from left main coronary artery

A 55 year old man presented with acute central chest pain two weeks after undergoing redo aortic valve replacement for *Streptococcus mitis* prosthetic endocarditis. His past history included cadaveric renal transplantation for adult polycystic kidney disease. He was receiving intravenous antibiotics at presentation and was afebrile with a normal white count. His ECG is shown in the upper panel.

Primary percutaneous coronary intervention (PCI) was planned. Diagnostic angiography via the right radial demonstrated a filling defect in the left main stem not present at preoperative angiography (panel A).

Emergency bypass surgery was considered to be of prohibitively high risk. In view of the likely haemodynamic instability a percutaneous left ventricular assist device (PVAD) (TandemHeart) was inserted (panel B, arrow). The 21 French venous cannula which was passed across the atrial septum (after predilatation of a patent foramen ovale) and the 17 French femoral artery cannula allowed a flow of approximately 3 l/min. Following this the vegetation was aspirated using an Angiojet device. The filling defect was successfully removed but the left main ostium appeared compromised (panel C). A 3.5 × 20 mm Taxus stent was deployed in the left main ostium, which was then post-dilated with a 4 × 20 Quantum non-compliant balloon. An excellent angiographic result (panel D) was obtained with no evidence of major distal embolism. The PVAD was removed after 48 hours. Over the next week, the patient's ejection fraction improved from 25% to 45% and he was discharged home on day 10 after intervention.

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