Journal of Endovascular Therapy

Anatomical Modifications After Stent Implantation: A Comparative Analysis Between CGuard (CG), Wallstent (WS), And Roadsaver (RS) Carotid Stents.

Journal:	*Journal of Endovascular Therapy*
Manuscript ID	JEVT-21-0457.R1
Manuscript Type:	Vascular Images
Keywords:	Stent *, Computed tomographic angiography, Carotid stent/stenting, Common carotid artery, External carotid artery
Abstract:	

SCHOLARONE™
Manuscripts

Abstract

Purpose

Carotid revascularization can be associated with modifications of the vascular geometry, which may lead to complications. The changes on the vessel angulation before and after a carotid WallStent (WS) implantation is compared against two new dual-layer devices, CGuard (CG) and RoadSaver (RS).

Materials and methods

The study prospectively recruited 217 consecutive patients (112 GC, 73 WS, and 32 RS, respectively).

Angiography projections were explored and the one having higher arterial angle was selected as basal view. After stent implantation, a stent control angiography was performed selecting the projection having the maximal angle. The same procedure is followed in all the three stent types to guarantee comparable conditions.

The angulation changes on the stented segments were quantified from both angiographies. The statistical analysis quantitatively compared the pre-and post- angles for the 3 stent types. The results are qualitatively illustrated using boxplots. Finally, the relation between pre-and post- angle measurements is analyzed using linear regression.

Results

For CG, no statistical difference in the axial vessel geometry between the basal and postprocedural angles was found. For WS and RS, statistical difference was found between pre-and post- angles. The regression analysis shows that CG induces lower changes from the original curvature with respect to WS and RS.

Conclusion

Based on our results, CG determines minor changes over the basal morphology than WS and RS stents. Hence, CG respects better the native vessel anatomy than the other stents.

“Level of Evidence: Level 4, Case Series.”

Keywords

Stent, angle analysis, pre-post-deployment, angiography

Abbreviations

WS	WallStent stent
CG	CGuard stent
RS	RoadSaver

For Peer Review

Introduction

Stroke is the second leading cause of death and a cause of disability worldwide [1]. Approximately 80% of strokes are ischemic [2] and more than 10% of them associated with internal carotid artery disease [3]. International guidelines state that carotid revascularization is indicated in symptomatic patients with stenosis between 50% and 99% or asymptomatic patients with stenosis between 70% and 99% [4]. Besides surgical endarterectomy, carotid artery stenting (CAS) has emerged as an alternative to carotid endarterectomy (CEA) for the treatment of carotid artery occlusive disease [5].

However, carotid artery stenting (CAS) is often associated with post-procedural modifications from the original vascular geometry [6], which may favor further complications and recurrent disease. Stent implantation changes 3-D vessel geometry in such a way that regions with decreased and increased shear stress occur close to the stent edges. These changes might be related to the asymmetric patterns of in-stent restenosis [7].

Hence, due to the lack of comparisons between different stent brands and types, it is not easy the optimal stent choice. For instance, in a recent review, De Vries [8] compares carotid stent characteristics. Regarding flexibility (defined as the bending or torsion stiffness of the stent) six papers are compared, while regarding conformability (the ability of the stent to conform to the geometrical shape of the artery) four papers are analyzed. The author concludes that a variety of methodologies and outcome measures are used to quantify carotid artery stent characteristics, which hampers comparisons between published studies, and between the literature and data as provided by device manufacturers.

Consequently, there is a need of quantitative and objective stent comparisons to determine which one induce lower anatomical modifications.

In this study, the stents available in the institution were evaluated: a commonly used close-cell first generation carotid WallStent (WS) is compared against two second generation dual-layer stent devices CGuard (CG), and RoadSaver (RS). As illustrated by Tanaka in 2004 [9], the Wallstent implant intertwined with continuous filaments, induced considerable straightening on the carotid bifurcation angle. Moreover, the authors [9] also demonstrated how the segmented models of modular stents conformed better vascular tortuosity, and showed a better fit between the stent and the endoluminal surface of the model. One option of modular stent is CGuard (CG), which is a self-expanding, nitinol carotid stent covered by a polyethylene terephthalate (PET) micromesh [10]. Another option is RoadSaver, which is a carotid stent covered by a double nitinol micromesh [11].

Hence, the aim of this study is to analyze the different conformability and post-procedural vessel anatomical changes in these three different carotid stent groups.

Material and Methods

For Peer Review

From March 2017 till October 2020, a population of 217 consecutive high-risk surgery patients referred to CAS, were analyzed in a retrospectively study. All patients underwent CT before inclusion into the study by institution protocol. The informed patient consent was obtained from all patients. The patients were treated based upon standard CEA protocols and guidelines. The principal acceptance criteria were: a) asymptomatic patients with tomographic evidence of carotid stenosis between 70% to 99% according to the NASCET index. The principal exclusion criteria were: a) patients without preprocedural CT imaging; b) patients undergoing carotid stenting for different pathologies than atherosclerotic de-novo lesions c) patients with carotid pathology not localized on the bifurcation.

Patient demographic characteristics and clinical signs were collected.

Previous to the intervention, a CT study of the target carotid bifurcation was performed for assessing the projection offering the higher angular view.

All the procedures were performed in a surgery room (Philips Allura Xper FD20), under local anesthesia, and conducted by two senior interventional radiologists, each of them with at least 8 years of experience in endovascular carotid stenting. Three types of carotid stents were available at the hospital by tender, according the operator preferences. One physician threated patients with WallStent or RoadSaver, while the other one selected CGuard for all his cases. After the procedure, a third expert radiologist (different from the ones who performed the procedures) evaluated the basal and post-stenting bidimensional angiographies and quantified the stented segment angulation changes.

For all the patients, the position on the surgical table was supine with head immobilization. Ultrasound-guided transfemoral vascular access was performed in all the patients. After selective catheterization of the target carotid artery, a preliminary angiography was performed at the predefined projection. After crossing the stenosis with a guidewire and successfully releasing a protective filter beyond the stenosis, a dedicated endovascular stent was implanted. Regardless to stent brands, all stents were post dilated according to institution guidelines. After stent dilatation and the filter retrieval, a bidimensional angiographic stent control to assess the angular vessel change was performed at the same predefined projection.

The carotid axis geometry was obtained by calculating the angle between the central axis of the common carotid artery (CCA) and the central axis of the proximal segment of the internal carotid artery (ICA) in the predefined projection (see Figure 1). The calculation was performed in all patients before and after stent release (see Figure 2).

Patients were divided into three groups based on the type of stent implanted:

in 112 patients (51.6%) a CGuard (CG) was implanted (stent 1); in 73 patients (33.6%) a WallStent (WS) was implanted (stent 2); in 32 patients (14.7%) a Roadsaver (RS) was implanted (stent 3).

Statistical methodology

For Peer Review

Study population information, including the plaque type description for the index carotid lesion (calcified, fibro-lipidic, and lipidic), are provided per patient. Basal measurements were obtained in the projection established by the preliminary analysis of the preprocedural CT, which offered the higher angular view. Post-procedural measurements were obtained from the same projection. The differences between basal and post- stent deployment angles were evaluated according to three carotid stents types compared in the study. The statistical expert performing the computations was blinded to each stent brand's product vendor to ensure unbiased analysis.

The statistical analysis performed in this paper is computed as follows: continuous data are summarized in terms of mean, standard deviation (SD), median. One decimal is reported for all the measurements. Categorical data are summarized in terms of the number of cases (n), frequency counts, and percentages. Percentages are presented with one decimal place. One-way ANOVA analysis was performed within and between-group comparisons for continuous data. Chi-square tests were performed for categorical data analysis. A p-value (p-value) inferior to 0.05 has been considered statistically significant in all the statistical tests. The results are qualitatively illustrated by means of boxplots, in which the blue box illustrates the first and third quartile of the data distribution, while the black dotted line illustrates the range between the lowest and highest data point excluding any outliers. The red horizontal line represents the median value of the dataset.

Calculations were performed using Matlab (The MathWorks, Inc., Natick, Massachusetts, United States) data analysis software, version 2020.

Population cohorts

Descriptive statistics in Table 1 summarizes demographics and baseline disease characteristics. Demographic data includes gender, age; while baseline characteristics include: stent type, left/right internal carotid artery location, aorta type, bovine arch, and plaque type.

It is particularly interesting to analyze the last row of Table 1 corresponding to the basal “stent angle,” where the p-value is superior to 0.05. This variable is further studied in the boxplot reported in Figure 3. The figure compares the distribution of the “angle pre-” variable in the three stent types. It can be noted that the boxplots are overlapped, confirming the results observed in the quantitative analysis of Table 1.

Angle of the stent before and after intervention

For Peer Review

- **Absolute analysis**

Table 2 quantitatively compares the pre- and post- angles for the three stent categories. For each variable, the mean and standard deviation are reported. Then the difference between pre- and post- grades is computed. Then the p-value obtained using the ANOVA test is reported. Finally, the last column illustrates when the p-value is <0.05, hence illustrating when the difference is significant.

Observing the results depicted in Table 2, we can conclude that the deployment of stent 2 and 3 induce a significant change in the vessel geometry between the pre- and post- acquisition, while in stent 1 no significant change can be observed.

The difference between pre- and post- angles in stents 2 and 3 (mean: 19.9° and 18.2°, respectively) is almost three times larger than the stent 1 (6.0°). It is quite interesting to note that the standard deviation of stent 1 (5.8°) is two and three times smaller respectively, then the one of stents 2 and 3 (12.2° and 16.5°), showing that the values of the distribution are spread over a narrow range and hence the measurement is statistically reliable.

The quantitative analysis illustrated in Table 2 can be confirmed observing Figure 4 in which the angle of the stent is compared before and after intervention for the three stents types. It can be observed that for stent 1 the pre- and post- boxes are overlapped, while for stents 2 and 3 the boxes are not overlapping in amplitude.

The fifth row (Diff) of Table 2 is qualitatively illustrated in Figure 5 in which the differences between pre-post stent angles are shown. It can be observed that stent 1 displays smaller differences in angle with respect to stent 2 and 3 and the distribution of the box (1st and 3rd quartile of the distribution) is smaller than the other two groups.

For Peer Review

- **Linear regression of pre-post measurements**

The relation between pre-and post- angle measurements, for stent of types 1,2 and 3 respectively, is analyzed using a linear regression curve, as shown in Figure 6. The slope of the linear regression is reported in row 1 of Table 3. The closest the slope is to 45 degrees, the lower change in angle is induced by the stent implantation. Indeed, the expected angular decrease (row 2 of Table 3) due to stenting implantation corresponds to the difference between 45 degrees and the slope angulation in each of the groups.

In particular, the angular change (5.8°) observed in stent 1 type, is lower. Instead, stent types 2 and 3 show a higher angular change (22.3° and 21.6° respectively), indicating that the deployment of stent 2 and 3 induces a higher change from the original curvature.

For each of the three stents, most of the measurements lays within the 95% of confidence interval of the regression line. Consequently, we could conclude that the angle change induced by the stent implantation is consistent and proportional in all the cases.

For Peer Review

Discussion

Carotid artery stenting is being increasingly accepted as an alternative to CEA in some high-risk patients with carotid artery stenosis [12].

Carotid stents used in common clinical practice are divided into two macro-areas: a) self-expanding stents with simple metal mesh (WS) b) self-expanding stents with an additional protective micro-mesh (CG and RS). Instead, open-cell stents have demonstrated better conformability than close cell stents and, they are penalized with the increase of plaque prolapse. To eliminate plaque prolapse, the second generation stents combine a mesh to close-cell stent design (RS) or to open-cell stent (CG).

For stent 1 (CG), no statistical difference in the axial vessel geometry was found between the basal and postprocedural angles. Instead, for stent 2 (WS) and stent 3 (RS) the changes in the axial vessel geometry was statistically significant.

The conclusions illustrated in this paper are in agreement with previous in-vitro / ex-vivo research [13,14,15].

One of the main problems concerning the treatment of carotid artery stenosis could be the variation of the native anatomy of the carotid axis. In fact, an alteration of the vascular anatomy could have repercussions in an alteration of the blood flow [7].

The future goal will certainly be to demonstrate how the flow changes within the carotid axis after the placement of the different types of stent.

The study's main limitation is that the angle estimation was obtained from two-dimensional CT angiographic projections which may induce measurement inaccuracies due to the projection angle choice. A possible improvement would be to assess the angle directly form three-dimensional vessel reconstructions.

Conclusion

It can be concluded that stent 1 (CG) has a better conformability with respect to the native vessel anatomy compared to stent 2 (WS) and stent 3 (RS). Hence, stent 1 (CG) determines a minor alteration with respect to the physiological morphology of the patient.

Declarations

Conflict of interest. The authors declare no conflicts of interest

Consent for Publication For this type of study, consent for publication is not required.

Ethical Approval For this type of study, consent is not required. This study was approved by the Institutional Review Board (IRB).

Bibliography:

[1] Katan, Mira, and Andreas Luft. "Global burden of stroke." Seminars in neurology. Vol. 38. No. 2. Georg Thieme Verlag, (2018) pages 208-211.

[2] Béjot, Yannick, et al. "Epidemiology of stroke in Europe and trends for the 21st century." La Presse Médicale Vol 45. No. 12 (2016) pages e391-e398.

[3] Rangel-Castilla, Leonardo, et al. "Endovascular prevention and treatment of stroke related to extracranial carotid artery disease." The Journal of cardiovascular surgery Vol. 58 No. 1 (2016): pages 35-48.

[4] Kwolek, Christopher J., et al. "Results of the ROADSTER multicenter trial of transcarotid stenting with dynamic flow reversal." Journal of vascular surgery Vol 62. No. 5 (2015) pages 1227-1234.

For Peer Review

[5] Helton, Thomas J., et al. "The optimal treatment of carotid atherosclerosis: a 2008 update and literature review." Postgraduate medicine 120.3 (2008): 103-112.

[6] Kamenskiy, Alexey V., et al. "Effects of carotid artery stenting on arterial geometry." Journal of the American College of Surgeons Vol. 217 No. 2 (2013) pages 251-262.

[7] Wentzel, Jolanda J., et al. "Coronary stent implantation changes 3-D vessel geometry and 3-D shear stress distribution." Journal of biomechanics 33.10 (2000): 1287-1295.

[8] De Vries, Evelien E., et al. "(In) comparability of carotid artery stent characteristics: a systematic review on assessment and comparison with manufacturer data." Cardiovascular and interventional radiology Vol. 43 No. 10 (2020) pages 1430.

[9] Tanaka, Norimitsu, et al. "Conformity of carotid stents with vascular anatomy: evaluation in carotid models." American journal of neuroradiology Vol. 25 No. 4 (2004) pages 604-607.

[10] Mazzaccaro, Daniela, et al. "Initial experience with the inspire MD C-Guard stent in the treatment of carotid artery disease." The Journal of cardiovascular surgery Vol. 57 No. 3 (2016) pages 474-478.

[11] Montorsi, Piero, et al. "Carotid wallstent versus roadsaver stent and distal versus proximal protection on cerebral microembolization during carotid artery stenting." Cardiovascular Interventions Vol. 13 No. 4 (2020) pages 403-414.

[12] Yadav, Jay S., et al. "Protected carotid-artery stenting versus endarterectomy in high-risk patients." New England Journal of Medicine Vol. 351 No. 15 (2004) pages 1493-1501.

[13] Wissgott, C., Schmidt, W., Brandt, C., Behrens, P., & Andresen, R. (2015). Preliminary clinical results and mechanical behavior of a new double-layer carotid stent. Journal of Endovascular Therapy, 22(4), 634-639.

[14] Wissgott, C., Schmidt, W., Behrens, P., Brandt, C., Schmitz, K. P., & Andresen, R. (2014, February). Experimental investigation of modern and established carotid stents. In RöFo-Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren (Vol. 186, No. 02, pp. 157-165). © Georg Thieme Verlag KG.

[15] Wissgott, C., Schmidt, W., Behrens, P., Schmitz, K. P., & Andresen, R. (2009). Performance characteristics of self-expanding peripheral nitinol stents. RoFo: Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin, 181(6), 579-586.

For Peer Review

For Peer Review

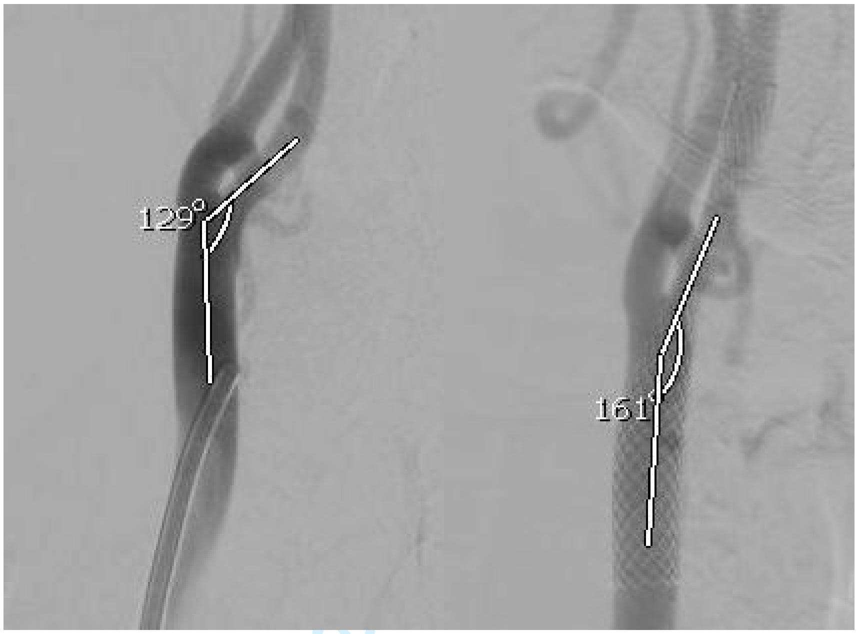

Figure 1 Digital subtraction angiography (DSA) of a patient carotid axis undergoing a carotid stenting procedure before (left) and after (right) stent placement. Both images are acquired using the same view. The angle change between the common carotid axis and the internal carotid axis can be qualitatively observed.

For Peer Review

C-Guard Roadsaver Wallstent

Figure 2 DSA images of carotid bifurcations treated with three different types of stents. The angle measurement performed over the common carotid axis and the internal carotid axis is superimposed to the DSA image.

Review

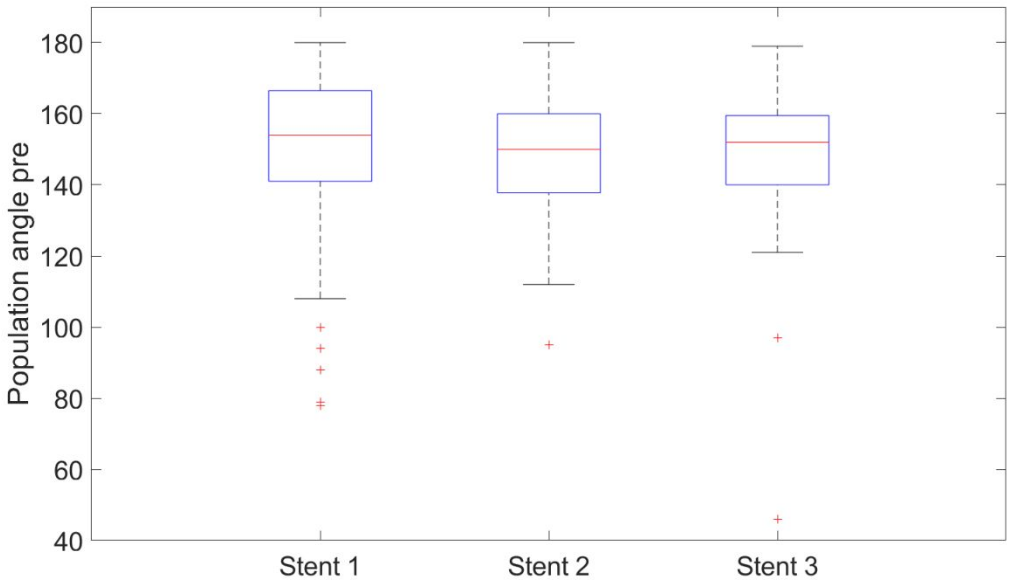

Figure 3 Comparison of pre-deployment stent angle in groups 1, 2, and 3, respectively

eer Review

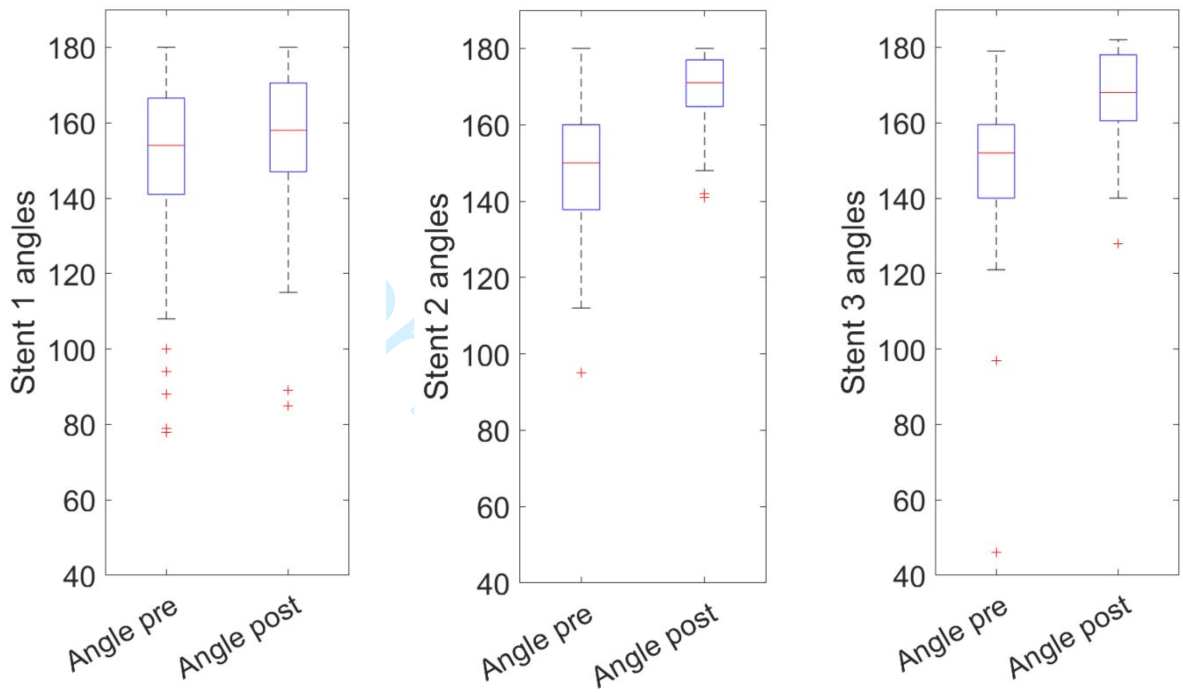

Figure 4 Angle of the stent before and after intervention, for stent types 1,2 and 3, respectively.

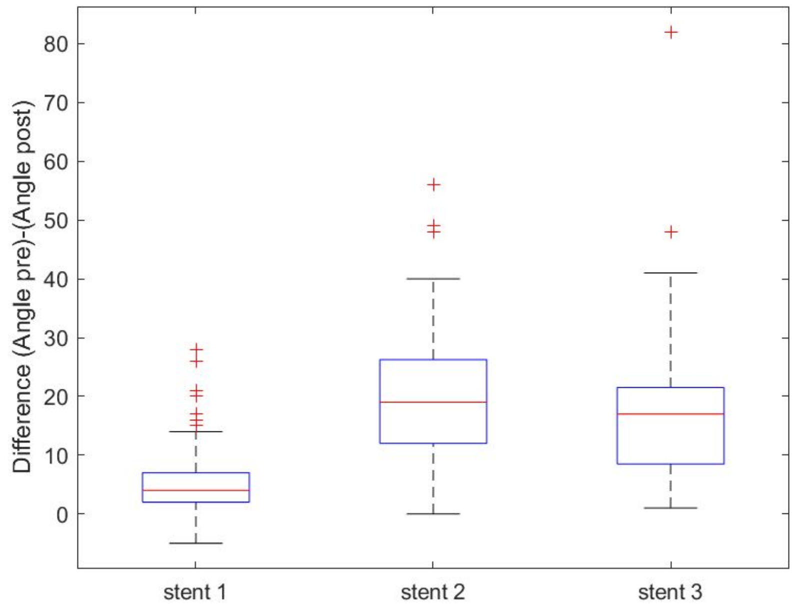

Figure 5 differences between pre-post stent angle, for stent types 1, 2 and 3, respectively.

For Peer Review

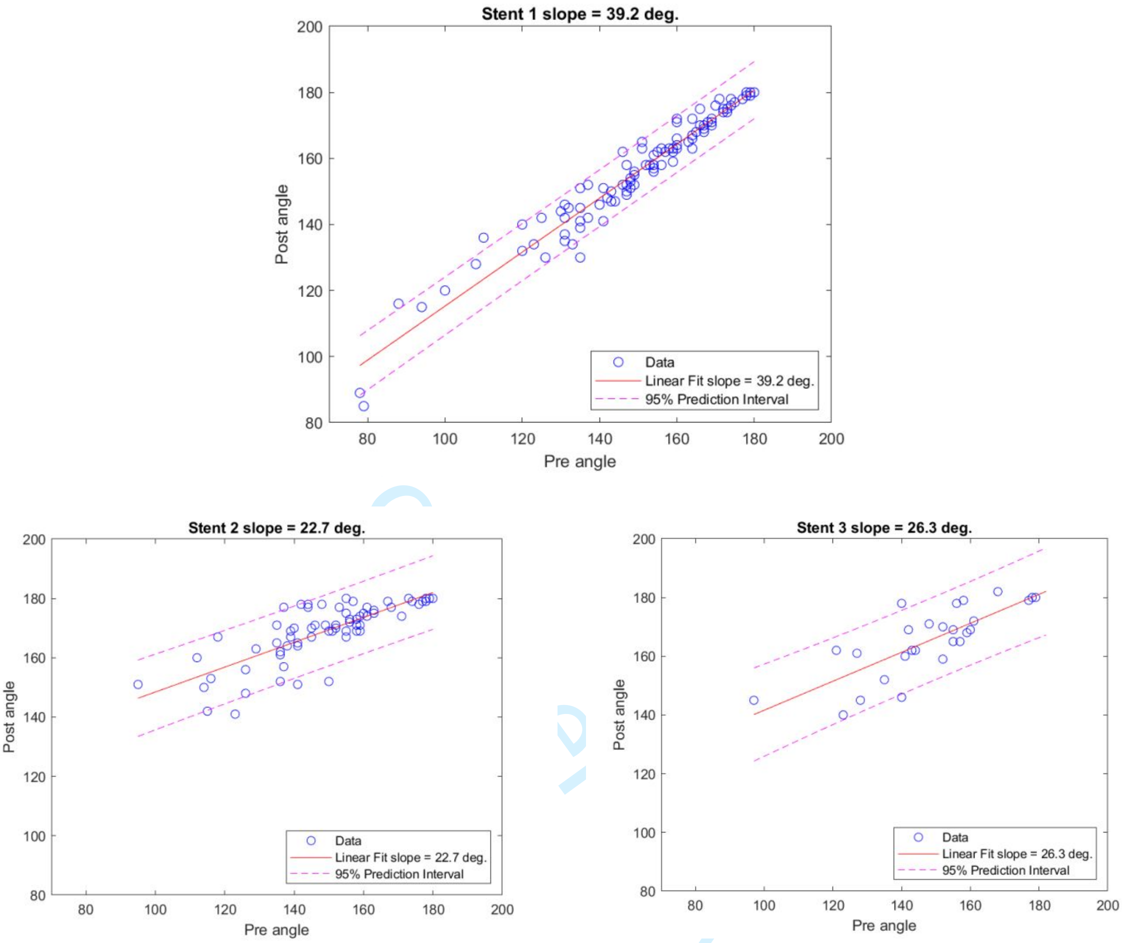

Figure 6 linear regression of pre-post measurements, for stent types 1,2, and 3, respectively.

Blue circles indicate each stent measurements. The red straight line corresponds to the linear regression, and the dashed blue line represent the 95% of confidence interval.

Table 1 Demographic characteristics per stent type

label	All data	%	Type 1	%	Type 2	%	Type 3	%	p-value
N	217	100%	112	51.6%	73	33.6%	32	14.7%	
Age (SD)	75.5 (11.8)		75.1 (13.2)		75.7 (11.0)		76.5 (8.5)		0.838
Male	146	67.3%	76	67.9%	54	74%	16	50%	0.061
stent 1	112	51.6%	112						
stent 2	73	33.6%			73				
stent 3	32	14.7%					32		
RICA	110	50.7%	54	48.2%	41	56.2%	15	46.9%	0.512
LICA	107	49.3%	58	51.8%	32	43.8%	17	53.1%	0.512
Aorta type 1	73	33.6%	39	34.8%	25	34.2%	9	28.1%	0.767
Aorta type 2	84	38.7%	46	41.1%	28	38.4%	10	31.3%	0.595
Aorta type 3	60	27.6%	27	24.1%	20	27.4%	13	40.6%	0.200
Bovine	41	18.9%	17	15.2%	17	23.3%	7	21.9%	0.347
Calcific	85	39.2%	43	38.4%	30	41.1%	12	37.5%	0.914
Fibro lipidic	71	32.7%	44	39.3%	17	23.3%	10	31.3%	0.071
Lipidic	61	28.1%	25	22.3%	26	35.6%	10	31.3%	0.133
Angle Pre (STD) [°]	149.7 (21.1)		150.8 (21.3)		149.2 (18.2)		147 (26.4)		0.635

For Peer Review

Table 2 Pre- Post- angle statistics whole population

label	N	Pre- angle [°]		Post- angle [°]		Diff [°]		p-value	Significance
		Mean	STD	Mean	STD	Mean	STD		
stent 1	112	151	21.3	157	17.9	6.0	5.8	0.0739	N.S.
stent 2	73	149	18.2	169	9.7	19.9	12.2	$1.023.10^{-13}$	<0.05
stent 3	32	147	26.4	165	13.4	18.2	16.5	0.000905	<0.05

For Peer Review

Table 3 Slope of the regression curve for each stent type and angular decrease due to the stent implantation

	Type 1	Type 2	Type 3
Slope [Deg.]	39.2°	22.7°	23.4°
Angular decrease [Deg.]	5.8°	22.3°	21.6°

For Peer Review