"UTILITY OF CONTRAST ENHANCED MR ANGIOGRAPHY FOR DELAYED INTRACRANIAL IN-STENT STENOSIS IN NON-ATHEROSCLEROTIC CEREBRAL VASCULAR DISEASES"

THESIS

SUBMITTED IN PARTIAL FULFILLMENT FOR DEGREE OF **DM (NEUROIMAGING AND INTERVENTIONAL NEURORADIOLOGY)**

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DECLARATION

I hereby declare that this thesis entitled "**UTILITY OF CONTRAST ENHANCED MR ANGIOGRAPHY FOR DELAYED INTRACRANIAL IN-STENT STENOSIS IN NON-ATHEROSCLEROTIC CEREBRAL VASCULAR DISEASES"** has been prepared by me under the supervision and guidance of Dr. Jayadevan E R, Assistant Professor, Department of Imaging Sciences and Interventional Radiology, Sree Chitra Tirunal Institute for Medical Sciences and Technology, Trivandrum.

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CERTIFICATE

This is to certify that the work incorporated in this thesis entitled "**Utility of Contrast Enhanced MR Angiography for Delayed Intracranial In-Stent Stenosis In Non-atherosclerotic Cerebral Vascular Diseases"** for the degree for **DM (NUEORIMAGING AND INTERVENTIONAL NEURORADIOLOGY)** has been carried out by **Dr. Harsha K J** under my supervision and guidance. The work done in connection with this thesis has been carried out by the candidate himself and is genuine.

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CONTENTS

INTRODUCTION

Vascular stent is a metallic mesh 'tube' inserted into a vessel with intent to remodel the vessel lumen. Initial uses of intracranial stents were mainly limited to treat vascular stenosis with an aim to open up the stenosed vessel. However soon its use in non-stenotic vascular disease was explored, one such important etiology is for aneurysm coiling.

The introduction of Guglielmi detachable coils for intracranial aneurysm in 1991 revolutionarised the endovascular treatment of aneurysm and it has become widely accepted treatment modality. However coil prolapse remained significant risk in wide necked aneurysms. Higashida et al [**1**] in 1997 reported the application of intravascular stent as an adjunctive device to support the endovascular occlusion of a cerebral aneurysm. Since then dedicated intracranial stents were introduced and are widely in practice since last decade. Stent associated flow remodeling also causes further occlusion of incompletely coiled aneurysms (Lawson MF) [**2**]**.**

Only balloon-expandable coronary stents were used as adjuncts for the treatment of cerebral aneurysms before the availability of Neuroform stent. The Cerebrence (Medtronic, Minneapolis, MN) is a balloon- mounted coronary stent derivative, approved for the treatment of intracranial aneurysms in the Europe, but which was finally withdrawn from the market. Balloon expandable stents were not infrequently employed effectively. Their lack of flexibility made navigation through the

tortuous cerebral vasculature difficult and sometimes dangerous or technically impossible.

The deployment of a balloon mounted stent inevitably results in endothelial disruption and denudation over the treated vascular segment. In the absence of the regulation provided by a functional endothelium, there is a proliferation and activation of regional smooth muscle cells, resulting in neointimal tissue formation, which can lead to restenosis within the stent [**3**]. The degree of neointimal hyperplasia is linked directly to the severity of endothelial injury induced by the angioplasty balloon and intravascular stent. In-stent stenosis is a common and well-described delayed complication of angioplasty and stenting for atheromatous disease. In the Stenting of Symptomatic Atherosclerotic Lesions in the Vertebral or Intracranial Arteries trial, > 50% delayed in-stent stenosis was observed in 32% of intracranial lesions, 43% of extra-cranial lesions, 45.2% of the younger group (<55 years), 24.2% in the older group, 66.6% supraclinoid stents, 24.4% in infra-clinoid stents and symptomatic in-stenosis 40% [**4**,**5**]. In-stent stenosis was focal in 61.0% of the patients; in more than half of the cases the stenosis was more extensive than the original lesion treated in terms of lesion length or stenosis severity [**6**].

The endothelial disruption injury resulting from self-expanding stent deployment in non-atherosclerotic cerebral vasculature is negligible in comparison with either angioplasty alone or the deployment of a conventional balloon-mounted stent.

Hence the delayed in-stent stenosis is expected to be much lower than atherosclerotic stenting.

Though neo-intimal hyperplasia is hypothesized to be the cause of delayed in-stent stenosis, recent observations favour more towards thrombus development and its spontaneous resolution being key factor in in-stent stenosis in non-cerebrovascular diseases. However even thrombus development as an etiology for in-stent stenosis is also questioned in view of smooth/regular and circumferential appearance of the stenosis & time course for development and the delayed onset and incomplete resolution at long-term follow-up argue against a vasospastic process. The absence of a pre-existing stenosis within the treated vascular segment and reversibility make elastic recoil or progression of native atheromatous disease unlikely. The different type of stents with different physical properties, use of different antiplatelet agents, patient factors further complicate this issue. Hence etiology of in-stent stenosis, incidence in different stents is still poorly understood and required further evaluation.

Nevertheless, these findings stress the need for identification of delayed in-stent stenosis and its long term follow up. Detection of high-risk in-stent restenosis would identify a subgroup of patients who may benefit from close observation/early treatment.

Digital Subtraction Angiography is the gold standard imaging modality for follow up of stents. However its invasive nature and a high complication rate (1.8-2.1%) would limit its use

for repeated and long term evaluation. Various non-invasive imaging modalities were described for in-stent stenosis evaluation. However exact accuracy of each modality is not widely studied.

The incidence of in-stent stenosis in non-atherosclerotic diseases has been described in small case series, though large randomized data is unavailable. Based on previous evidence of SSYLVIA trial in which stenosis > 50% grouped as high risk group, the delayed in-stent stenosis in our study also defined > 50% delayed in-stent stenosis as "significant stenosis" requiring atleast clinical attention/close follow up/intervention. Hence we aimed to identify significant delayed in-stent stenosis by non-invasive imaging modality as compared to DSA.

The current study aims to address two important issues:

1) Incidence of in-stent stenosis.
2) The accuracy of contrast enhanced MRA source images for identification >50% delayed in-stent stenosis as compared to CE reformatted image, TOF reformatted image, TOF source images.

We hypothesized that contrast enhanced MRA source images are as accurate as DSA for identification of "significant in-stent stenosis".

AIMS AND OBJECTIVES

1) TO DETERMINE THE DELAYED IN-STENT STENOSIS IN NON-ATHEROSCLEROTIC INTRACRANIAL DISEASES.

2) TO DETERMINE UTILITY OF CE-MRA SOURCE IMAGE IN DELAYED INTRACRANIAL IN-STENT STENOSIS DETECTION.

REVIEW OF LITERATURE

Review of literature has been described under following headings:

I. Intracranial stents and their physical properties.

II. Imaging modalities available for intracranial stent evaluation.

III. Delayed in-stent stenosis in non-atherosclerotic cerebrovascular diseases

I. INTRACRANIAL STENTS AND THEIR PHYSICAL PROPERTIES.

Five self-expanding intracranial stents are currently available, they are Neuroform Solitaire, Leo +, Enterprise and Wingspan. Two flow diversion devices are currently available namely Pipeline Embolization Device and Silk stent.

NEUROFORM STENTS:

Neuroform 1 stent - Neuroform 1 stent (Boston Scientific Corporation, Natick, MA), a self-expanding Nitinol stent introduced in 2002. This was the first stent designed specifically for use in the cerebral vasculature to support aneurysm treatment (Fiorella D) [**7**]**.** The device was approved as a humanitarian

device for use with embolic coils for the treatment of wide-neck, intracranial, saccular aneurysms. It is made of nickel-titanium alloy. The stent had open-cell design, which has low radial force, resulting in inadequate support for the coil mass within the aneurysm. Several technical problems with stent delivery were reported, including misplacement of the stent into the aneurysm lumen or stent dislodgement during catheterization.

Neuroform 2 stent – was introduced in 2003, minimum size available was 3.5 mm and minimum length available was 15 mm. Though some disadvantages were overcome with this stent, many remained, hence soon further modifications were done and Neuroform 2 Treo was launched.

Neuroform 2 Treo - was launched in 2004, is also an open-cell design. However it had few disadvantages like invisibility of the stent meshes despite high-quality fluoroscopy, causing displacement of the struts into the aneurysm. But it contains a modified geometry with 3 connectors between adjacent segments, providing a 39% decrease in the area of the open cells, with the advantage of increased aneurysm neck coverage. Nevertheless, open cell design limitations were overcome by introducing hybrid cell design in Neuroform 3 stent.

Neuroform 3 stent – was introduced in 2005, has a hybrid cell design. Stabilizer catheter features advanced hypotube shaft construction designed for improved access and controlled deployment. The stent is claimed to have highly conformable with a segmented design for vessel apposition in tapered vessels.

The interstices of the stent measure slightly <1 mm (2–2.5 F), allowing the placement of a microcatheter through the stent into the aneurysm sac.

Neuroform EZ stent – was introduced in 2010, claimed to have segmental expansion designed to promote stent anchoring and stent stability. Compared to the Neuroform 3 delivery system, which required en bloc advancement of catheter and loaded stent, the Neuroform EZ allows the operator to select their desired micro-catheter without stent transfer. The operator may obtain access with their choice of microwire and microcatheter and avoid the difficulty of en bloc advancement through tortuous anatomy. The bumpers allow the stent to be moved backward and forward prior to unsheathing to achieve optimal positioning and microcatheter stability prior to deployment. Placement of overlapping stents requires fewer steps because the microcatheter and wire are left in place for loading subsequent stents, providing a key advantage over the Neuroform 3 design.

The all Neuroform stents are not retrievable.

ENTERPRISE STENT:

Enterprise Stent (Codman Neurovascular, Ratham, Massachusetts) was launched in 2007. This is a self expandable nitinol stent with a closed cell design. The stent has four markers on each end, and is coated with a polymer. It is especially known for its navigability in tortuous anatomy. This stent can be retrieved into the delivery catheter unless more than two thirds

(2/3rd) of the entire stent length has been deployed due to its closed cell design.

SOLITAIRE STENT:

Solitaire Stent (Dendron, Acquired By Ev3, Inc**.)** is first closed-cell design, self-expanding stent for intracranial vessels received its initial CE mark in 2003. Two forms of Solitaire stent are available, Solitaire AB and Solitaire FR.

Solitaire AB Remodelling Device is the only self-expanding stent designed for bridging the neck of aneurysms that can be completely retrieved, even when fully deployed for unmatched procedural control. It has three distal and single proximal markers ensure that the exact position of Solitaire AB under fluoroscopy.

Solitaire FR revascularization device (EV3, Irvine, California, USA) is a stent based thrombectomy system, used as a clot retriever in acute stroke.

LEO, LEO + AND LEO+ BABY STENTS:

All previously described stents are laser-cut from Nitinol hypotubes. The Leo and Leo + **(**Balt Extrusion, Montmorency, France), in contrast, are braided structures made from a single Nitinol wire. This stent can be retrieved into the delivery catheter unless more than 90 % of the entire stent length has been deployed. LEO PLUS stent showed symmetric deployment at all tested degrees of curvature, without flattening or kinking which were the limiting factors in Leo stent [**8**]. The high radial force

of the stent is said to have reduced the possibility of stent displacement after deployment. Because of its braided architecture, the stent show no protrusion in the aneurysm sac or kinking within the vessel. LEO+BABY 2, 0 has a diameter of 2mm, intended for 1.5 to 2.5 mm vessel diameter, LEO+BABY 2, 5 has a diameter of 2.5 mm, intended for 2.00 to 3.1 mm. All stents has two longitudinal radio-opaque markers and hence full stent body visibility under fluoroscope.

WINGSPAN STENT:

Wingspan Stent System with Gateway PTA Balloon catheter (Boston Scientific Corporation, Natick, MA) was approved as a humanitarian device by the FDA in 2005 to treat symptomatic atherosclerotic stenoses who have failed medical management. Gateway PTA Balloon Catheter features a semi-compliant balloon designed for controlled, low-pressure inflation (6 atm). The stent is designed to support the vessel lumen by minimizing vessel recoil after angioplasty and exerting active, controlled, outward radial force using thicker and shorter struts.

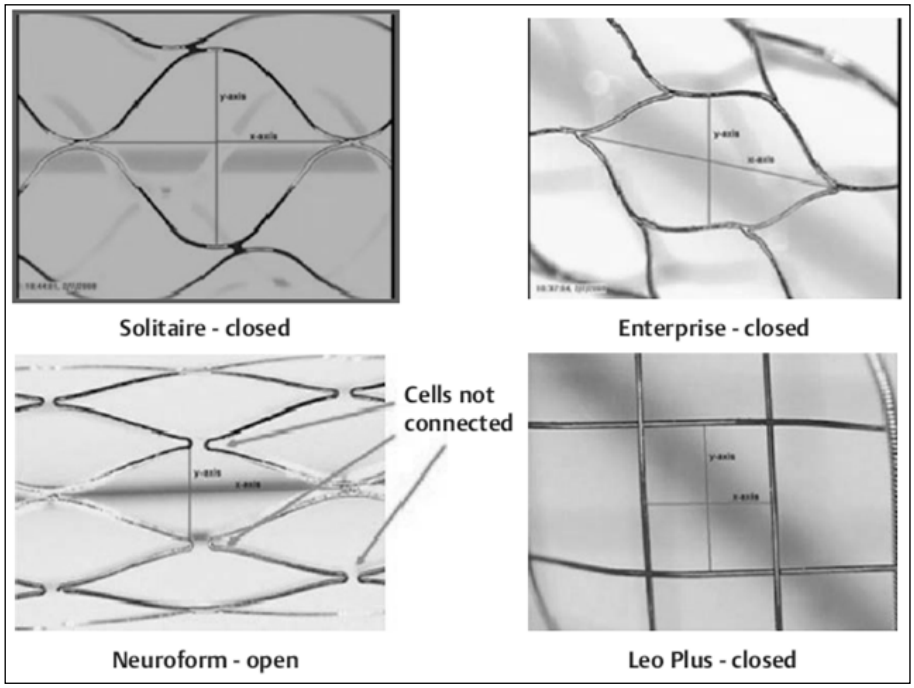

Figure 1. Cell patterns of Solitaire, Neuroform3, Enterprise, and Leo + are shown. The Wingspan stent has a similar cell pattern as the Neuroform3.

	Solitaire (ev3)	Enterprise (Codman)	Neuroform (Stryker)	Wingspan (Stryker)	Leo Plus (Balt)
indication	intracranial vascular disease	intracranial aneurysms	intracranial aneurysms	intracranial atherosclerotic stenosis	intracranial aneurysms
retrievable/ repositionable	yes	partially	no	no	partially
sizes: diameter (mm)	3,4,5,6	4.5	2.5, 3, 3.5, 4, 4.5	2.5, 3, 3.5, 4, 4.5	2.5, 3.5, 4.5, 5.5
lengths (mm)	15,20, 30,40	14, 22, 28, 37	10, 15, 20, 30	10, 15, 20	12, 15, 18, 20, 25, 30, 35, 40, 50, 75
vessel range (mm)	2.25–5.5	2.5–4	2–4.5	2–4.5	2–5.5
cell type	closed	closed	open	open	closed
radial force (1–4, where 4 is the highest)	2	2	3	4	1
markers	3 distal and 1 proximal	4 markers on each end	4 markers on each end	4 markers on each end	2 platinum threads on stent body

Table 1. Summary of the characteristics of various commercially available stents.

FLOW DIVERTERS:

Some limitations of stent assisted coiling of aneurysms like fusiform aneurysms or very large neck aneurysms are treated by alternative approach: parent vessel reconstruction. This concept

away from coil embolization and toward parent vessel reconstruction and flow diversion, as well as vessel-preserving strategy for vascular wall lesions. Flow diverters are dedicated to this type of approach. Two devices are currently included in the flow diverter group: pipeline embolization device and silk stent. Detailed description of these stents is beyond the scope of this study.

II. IMAGING OF INTRACRANIAL STENTS

One invasive modality (DSA) and three non-invasive modalities (MRA, CTA and TCD) are available for stent stenosis evaluation.

DIGITAL SUBTRACTION ANGIOGRAPHY

Digital subtraction angiography (DSA) is the gold standard for both aneurysm detection and stent patency evaluation. DSA is an invasive technique with a reported complication rate of 1.8-2.1% [**9**]. During the past decade, safer contrast agents have become available, and important technical advances have been made, including digital imaging systems, smaller catheters, and hydrophilic guide wires. Three-dimensional rotational angiography (3DRA) involves a novel software application that reconstructs standard rotational angiographic data into a computer rendering that can be manipulated by the operator at any angle or viewpoint [**10**].

COMPUTERIZED TOMOGRAPHY ANGIOGRAPHY(CTA):

Computerized tomographic angiography (CTA) is based on volumetric scanning of the brain after intravenous administration of contrast medium. The quality of CTA images has been improved by the multislice technology and the development of post processing hardware and software. The value of CTA for post coiling stent patency evaluation is limited due to the artifacts caused by clip or coil mesh.

Gated CTA is a promising technique to reduce the amount of artifacts induced by stent-assisted intracranial coils. Image quality and assessment of treatment outcome in patients with stent-assisted coiling is superior compared with TOF-MRA [**11**].

MAGNETIC RESONANCE ANGIOGRAPHY (MRA):

Magnetic resonance angiography (MRA) is a non-invasive method for stent evalution. The advantages of MRA include non-invasiveness, lack of radiation, and good visualization of the residual aneurysm and the adjacent brain parenchyma. Its usefulness is, however, limited in the case of small aneurysms and aneurysms located close to the skull base. The available intracranial stents are MR compatible; hence MRA is a safe and feasible method for stent patency evaluation [**12**].

Contrast-enhanced MRA (CEMRA) with ultra fast imaging sequences and image subtraction has been established as superior

to 3D TOF in accurately depicting lateral aneurysms detection and follow up [**13, 14, 15**].

Depictions of parent artery lumen and the aneurysm neck in Enterprise stent is found superior in CEMRA as compared to TOF MRA, and as clear as DSA [**16**]**.**

In 64% cases, CE MRA revealed a short focal "pseudo-stenosis" where the stent's marker bands were described. This was noted whenever the stent's marker bands were located in an artery with luminal diameter ≤2 mm and was called "marker band effect". Apparent stenosis of the stented parent artery on CE-MRA has been noted, which is often false or exaggerated. "Marker band effect" should be recognized as an artifact that appears when stent's marker bands are in a small artery [**17**].

Prabhakaran S et al, in their small series of 14 intracranially stented patients, quantitative magnetic resonance angiography demonstrated 14% in-stent stenosis. 3 patients had Neuroform stents placed for wide-neck cerebral aneurysms and 1 patient had a Wingspan stent placement for atherosclerotic stenosis. 2 patients (14.3%) had >50%in-stent stenosis on angiography. Time-of-flight MRA was non-diagnostic in each case because of artifact from the stent or coils [**18**]. Few other authors have exploited the quantitative magnetic resonance angiography for stent stenosis, the degree of flow decrement correlates with symptomatic in-stent stenosis, though further evaluation is needed before its widespread use [**19**].

TRANSCRANIAL DOPPLER (TCD):

Transcranial Doppler ultrasound allows measurements of blood flow velocity to be made from the basal intracerebral vessels.

TCD is sensitive and specific in determining the site of the arterial occlusion. [**20, 21**]. SONIA trial was conducted to prospectively evaluation of TCD and MRA to identify stenosis, as compared to DSA. The trial enrolled 407 patients at 46 sites in the United States. For prospectively tested noninvasive test cutpoints, positive predictive values (PPVs) and negative predictive values (NPVs) were TCD, PPV 36%; NPV, 86%; MRA, PPV 59%; NPV, 91%. For cutpoints modified to maximize PPV, they were TCD, PPV 50%, NPV85%; MRA PPV66%, NPV 87%. The trial concluded transcranial doppler ultrasound and magnetic resonance angiography both can noninvasively identify 50 to 99% intracranial large vessel stenoses with substantial negative predictive value. However they suggested abnormal findings on transcranial Doppler ultrasound or magnetic resonance angiography require a confirmatory test such as angiography to reliably identify stenosis [**22**].

TCD & CONTRAST ENHANCED TRANSCRANIAL DOPPLER (CETCD) IN STENT EVALUATION:

Contrast enhanced TCD has been found to be superior compared to TCD for intracranial stenosis evaluation [**23**].

A case report of proximal severe basilar stenosis for which he was stented, postprocedural follow-up imaging was done suing CTA, MRA and CETCD. Digital subtraction angiography revealed the stent patency, with a characteristic image of the stent. Transcranial colour-coded duplex sonography under basal conditions was not able to visualize the colour signal within the stent, even though pulsed wave Doppler imaging showed normalized flow velocities and pulsatility indices. With the use of the sulphur hexafluoride contrast agent SonoVue (Bracco SpA, Milan, Italy) intravenously, TCCD showed normal visualization of colour flow within the stent, and pulsed wave Doppler imaging confirmed the normal flow velocities and pulsatility indices, with the typical microbubble spectrum [**24**].

Apart from these report, no other reports about intracranial stent evaluation using CETCD are available in current literature.

III. DELAYED IN-STENT STENOSIS

DELAYED IN-STENT STENOSIS IN NEUROFORM STENT:

First report of delayed in-stent stenosis occurring of Neuroform stent-supported coil embolization of an unruptured cerebral aneurysm was reported by Fiorella D [**25**]. In their case in-stent stenosis occurred 3 months after the placement of a Neuroform stent.

The same authors [**26**] described a case series with 5.8% patients of delayed Neuroform in-stent stenosis. They defined “delayed in-stent stenosis” as more than 2 months duration. Though total in-stent stenosis cases were significant, symptomatic stenosis among them occurred in only two cases (1.3%). Of 9 cases of delayed in-stent stenosis, two had spontaneous partial resolution and two complete resolutions on further follow up. This phenomenon has important clinical implications for patient management, supporting a conservative approach in patients presenting with asymptomatic stenosis (i.e., the continuation or reinstitution of dual antiplatelet therapy, close observation for neurological symptoms, and follow-up imaging). Such asymptomatic patients were followed with short echo time magnetic resonance angiography/magnetic resonance imaging or conventional angiography.

Low rate of delayed in-stent stenosis of 1.25% noted in 160 angiographically followed aneurysms treated with Neuroform stent-assisted coiling [**27]**. In another study of sixty-eight patients harbouring 76 unruptured aneurysms located primarily in the anterior circulation, treated by Neuroform stent-assisted coiling, 4 patients developed in stent stenosis of which one symptomatic and 3 asymptomatic delayed in-stent thrombosis [ ]. In another short case series of 32 aneurysms treated by Neuroform stent assisted coiling, 22 (68.7%) patients were followed with angiography (average follow-up, 12 mo; range 4–24 mo), none of which showed delayed in-stent stenosis. [**29**].

In another retrospective study, one of 42 patients had asymptomatic delayed in-stent stenosis [20]. In a midterm follow up study by Yoon KW and Kim YJ [**30**], among follow-up cerebral angiography done in 102 patients, 8 patients (7.8%) were shown an in-stent stenosis. Number of Neuroform stents were 7 cases (7.5%) and Enterprise stent in 1 case (11.1%). Six patients demonstrated in-stent stenosis at 6 months after stent application and remaining two patients were shown at 12 months, 18 months, respectively.

DELAYED IN-STENT STENOSIS IN ENTERPRISE STENT:

A restenosis was comparable to other bare metal stents (>50%) in atherosclerotic stenosis. it was observed in 43 (24.7%) cases after 4.2 months (mean) in 209 atherosclerotic stenosis patients undergoing endovascular treatment using the Enterprise stent [**31]**.

In a mid-term results (mean follow-up of 144 days) after Enterprise assisted embolization of 219 aneurysms in 213 patients, 8 (7%) demonstrated angiographic stenosis, thrombosis, or dissection [**32]**. However exact incidence of stenosis alone was not mentioned.

In a compiled data on consecutive patients treated with Enterprise stent assisted coiling of aneurysms from 9 high-volume neuro-interventional centres, 229 patients with 229 aneurysms, were included in the study. Mean clinical and angiographic

follow-up was 619.6 ± 26.4 days and 655.7 ± 25.2 days. Some degree of angiographic in-stent stenosis was seen in 7 patients (3.4%) during the follow-up period. Only 2% of patients demonstrated 50% or greater stenosis. The degrees of stenosis included less than 50% (n = 3), approximately 50% (n = 3), and greater than 50% (n = 1). On reinstitution of Plavix (clopidogrel), the stenosis greater than 50% resolved entirely, and 1 patient with 50% stenosis improved to only 17%. Development of stenosis was not associated with parent vessel diameter (P = .44) or vessel tortuosity [**33**].

In a survey of thirty-nine articles with 1517 patients, approximately 3.5% in-stent stenosis and 0.6% stent occlusion observed at angiographic follow-up [**34**].

DELAYED IN-STENT STENOSIS IN SOLITAIRE AB:

Though solitaire AB stent has shown been used in stent assisted aneurysm coiling, the delayed in-stent stenosis data are not available **[35, 36]**.

DELAYED IN-STENT STENOSIS IN FLOW DIVERTERS: the incidence of in-stent stenosis in flow diverts is not significantly different from ‘conventional’ self expanding stents, detailed description of which is beyond scope of the study.

MATERIALS AND METHODS

PATIENT SELECTION:

This study was conducted in the department of Imaging Sciences and Interventional Radiology, Sree Chitra Tirunal Institute for Medical Sciences and Technology, a tertiary care centre in Thiruvananthapuram, Kerala, INDIA. The study was a retrospective - prospective evaluation of patients who underwent endovascular stent placement in intracranial circulation (defined as cavernous ICA and beyond, V4 vertebral artery and beyond) and were undergoing scheduled follow-up MRA during January 2005 to October 2012 as part of routine clinical practice. Informed consent of all patients had been obtained both for Magnetic resonance Angiography (MRA) and Digital Subtraction Angiography (DSA) separately prior to procedure as a routine institutional policy. All patients were aware of the study objectives and of the potential clinical benefit the findings might reveal.

Retrospective evaluation of patients' demographic data was done from the institute's Picture Archiving and Communications systems between Jan 2005 to Oct 2012. Medical records were reviewed for patient demographic details like age, sex, clinical presentation, time interval between DSA and MRI study, treatment given including medical and endovascular therapy and follow up. All patients' hospital records, outpatient reports, procedural records, all angiographic, computed tomography and magnetic resonance imaging were carefully subjected to retrospective analysis and were systematically reviewed. Few

patients' MRA was retrospectively evaluated, wile few patients were prospectively followed with DSA/MRA.

INCLUSION CRITERIA:

- Consent to participate in this study.
- Age > 12 yrs.
- Patients with intracranial stents for aneurysm coiling/cartico-cavernous fistula.

EXCLUSION CRITERIA:

- Deranged renal function.
- Contraindications to undergoing MRI (pacemakers, metallic implants, etc.)
- As the follow up MRA is standard of practice of the institute for non-invasive follow up of such patients, based on risk-benefit ratio, pregnancy, lactating mother, neonates, persons incompetent to give informed consent were excluded from investigation.
- Patients with covered stent/stenting for atherosclerotic stenosis were excluded from the study

No specific gender, class, caste, ethnicity, race were entertained in the study.

ANGIOGRAPHIC EQUIPMENT:

During initial study period (2005 to 2009), cerebral angiographies and endovascular treatments were performed on an angiographic unit GE ADVANTIX SINGLE PLANE DSA system. A biplane angiographic unit (Innova 3131, GE Medical

systems, LLC, Milwaukee, WI, USA) was installed in January 2010, thereafter all cerebral angiographies and neuro-interventional procedures have been performed in this suite.

ANESTHESIA AND PERIPROCEDURAL MEDICATION:

Since 2005, all the intracranial stenting were performed under general anesthesia and were actively monitored for vital parameters. Systemic heparinization was used routinely. Initially, 5000 units of heparin were usually administered intravenously. Heparinization was individually decided by the treating interventional radiologist case by case. The level of heparinization was monitored by measuring activated clotting time (ACT) values (target 250-300 seconds) during the procedure, and additional doses of heparin every hourly were given as needed. This was considered essential as risk of thromboembolism is regarded as dominant over the risk of hemorrhage even in acute subarachnoid hemorrhage. At the end of the procedure, heparinization was partially reversed by intravenous protamine sulphate, if needed. In all patients in which stent assisted coiling was planned, preprocedural aspirin 75-325 mg per day and clopidogrel 75 mg per day was given for 5 days before procedure. In case of emergency aspirin 75-325 mg and loading dose of 300 mg clopidogrel was given 6 hrs prior to procedure.

EMBOLIZATION METHODS AND DEVICES:

Transfemoral catheterization (via unilateral or bilateral femoral artery puncture) was used in all cases. The sizes of the transfemorally deployed introducer sheaths ranged from 5 to 7

French (F). After confirming therapeutic anticoagulation, thin walled straight tip guiding catheters (range, from 5F to 7F) were carefully placed in proximal portion target vessel. Guiding catheter offers a combination of very soft flexible distal tip combined with reasonably stiff shaft providing a stable position in parent artery during micro catheter manipulations.

When the stent remodeling technique was used, various stents were deployed as per instructions first, followed by the aneurysm/cavernous sinus was subsequently catheterized through the stent interstices with a micro catheter and packed with coils or micro catheter was jailed within aneurysm followed by deployment of stent. In one patient, non atherosclerotic vertebral artery stenosis, stenting alone was done.

FOLLOW-UP:

First follow up was planned at 3 months, then 2nd follow up at 6th month, followed by every yearly evaluation. Clinical status was noted at each follow up, DSA/MRA at 6 months (± 42 days) and then every yearly TOF + CEMRA to evaluate for interval status of aneurysm and stent. During MRA follow up, if stenosis was more than 50% or patient becoming clinically symptomatic, DSA was performed for accurate status. Follow up angiograms were performed with standard institutional protocols, by transfemoral route and selective acquisition of vessels of interest in standard angiographic projections by iodinated contrast injection (Omnipaque 320; GE Healthcare, Princeton, NJ, USA). 3D rotational angiograms were obtained when needed.

MR IMAGE ACQUISITION:

MR Imaging of the brain was done using a 12-channel matrix coil on a 1.5T clinical scanner (Avanto, SQ Engine; Siemens, Erlangen, Germany). 3D TOF MRA was initially performed followed by CE-MRA during the follow up, though in some cases only one investigation was done. CE-MRA images were acquired after administration of Gadobenate dimeglumine (Multi-Hance; Bracco Imaging SpA, Milan, Italy) at a dose of 0.1 mmol/kg (0.2 mL/kg) bodyweight at a rate of 2mL/sec. All contrast administrations were followed by a 20-mL flush of 0.9% saline injected at the same rate of 2 mL/s. 3D TOF MRA was performed with TR: 36 ms; TE: 6.9 min; slice thickness: 1.4 mm; matrix size: 224×256; FOV: 18 cm; flip angle: 25°. CE-MRA was performed with TR: 3.5 ms; TE: 1.1 min; slice thickness: 1.0 mm; matrix size: 192×256; FOV: 270 mm; flip angle: 30°. Maximum intensity projection images (MIP), surface shaded display images (SSD) and volume rendered images were reconstructed on the vessel of interest for both 3D TOF and CEMRA.

IMAGE ANALYSIS:

Four sets of MR images (TOF MRA volume rendered images, TOF MRA source images, CE MRA volume rendered images, CE-MRA source images) were evaluated independently and in a randomized fashion by 2 highly experienced readers (experience of reader HKJ – 6 yrs, reader PM – 5 ½ yrs) and any

deviation was resolved by consensus. Percentage stenosis was measured by using following formula, percent stenosis = [1-smallest in-stent diameter/diameter at the proximal/distal normal vessel segment] x 100. This calculation is a one-dimensional view. Poor quality images in any one set, the entire patient image sets were excluded from the study. The outcomes were graded in DSA & 4 sets of MRA separately as 0 - no stenosis, 1 <50% stenosis, 2 ≥ 50% stenosis, 3 – occlusion. We defined "significant in-stent stenosis" as≥ 50% stenosis requiring clinical attention and further evaluation/intervention. "Delayed" in-stent stenosis was defined stent stenosis 3 months after stent deployment. The stenosis in 5 sets of images (1 DSA + 4 MRA) was grouped into <50% and ≥ 50% stenosis for statistical analysis.

STATISTICAL ANALYSIS:

A commercially available statistical software package (Statistical Package for the Social Sciences, Version 17; SPSS, Chicago, Illinois) was used for analysis. Sensitivity, specificity, accuracy, and positive and negative predictive values of different imaging sets against DSA were calculated. A level of $P < 0.05$ was regarded as a statistically significant result. Statistical significance of CESI was also calculated between Leo stent and Neuroform 3 stent as they were in significant number in the cohort.

RESULTS

There were 38 patients with intracranial stent deployment for various etiologies. Four patients died during immediate post procedure period/follow up and hence were excluded from the study. Four patients had intracranial stenting for atherosclerotic disease hence they were excluded. Eighteen patients had follow up DSA; all the 18 patients had atleast one follow up MRA, Six patients had two follow up MRA, one each had three and four follow up MRAs.

AGE DISTRIBUTION (N=18):

Mean age was 41.5 years (range 12 years to 80 years).

SEX DISTRIBUTION OF PATIENTS (N=18):

The cohort consists of 9 male and 9 female patients.

Sex	No of patients	Percentage
Male	9	50 %
Female	9	50 %

Table 2: Showing sex distribution in cohort (N=18).

DURATION OF FOLLOW UP (N = 18):

Mean follow up 17.5 months (range 4 months to 62 months).

ETIOLOGY FOR STENTING (N=18):

Sixteen patients underwent stent assisted coiling of aneurysm, one patient underwent stent assisted coiling of cavernous sinus for carotico-cavernous fistula, and one patient

underwent stenting for non-atherosclerotic vertebral artery stenosis.

Etiology	No of patients	Percentage
Stent assisted coiling	16	88.9%
Direct CCF	1	5.5%
Non atherosclerotic stenosis	1	5.5%

Table 3: Showing etiology for stenting (N=18).

LOCATION OF STENTS (N=20):

Twenty stents were deployed in 18 patients. Stents were deployed in both posterior and anterior circulation.

Location of stents	No of patients(N=20)	Percentage
Anterior circulation	12	60%
Posterior circulation	8	40%

Table 4: Showing locations of stents in cerebral circulation

The distribution of stents in various intracranial vessels are as follows:

Location of stents	No of patients(n=20)	Percentage
Cavernous ICA	3	15%
Communicating segment ICA	7	35%
MCA	2	10%
BA	3	15%
BA-PCA	2	10%
VA-Basilar artery	3	15%

Table 5: Showing location of various stents in intracranial circulation.

TYPE OF STENTS USED (N=20):

All the four types of intracranial stents were used, nine Neuroform 3 stents were used in 8 patients, and in one patient both Solitaire AB and Enterprise stents were used. Six Leo stents were used in six patients and three Solitaire AB stents were used in three patients.

TYPE OF STENT	Numbers	Delayed in-stent stenosis in DSA	Delayed stent occlusion in DSA
Neuroform 3	9 (45%)	0	0
Leo	6 (30%)	0	1
\Solitaire AB	4 (20%)	1	0
Enterprise	1 (5%)	0	0
TOTAL	**20 (100%)**	1	1

Table 6: showing number of stents & in-stent stenosis on DSA.

COMPARISON OF CE AND TOF MRA FOR DELAYED IN-STENT STENOSIS:

One Leo stent was found occluded during follow up, one Neuroform stent revealed 50% stenosis. Both patients were asymptomatic. Rest of 18 stents were patent without stenosis. Stent status during follow up were divided into normal + <50% and ≥ 50% stenosis + occlusion. The results of various MRA image sets as compared against follow up DSA.

	Baseline DSA	**Follow up DSA**	**CE MRA SI**	**CE reformatted image**	**TOF MRA SI**	**TOF reformatted image**
Insignificant stenosis (Normal + < 50% stenosis)	19 (95%)	18 (90%)	18 (90%)	14 (70%)	10 (50%)	6 (30%)
Significant stenosis (≥ 50% stenosis + occlusion)	1 (5%)	2 (10%)	2 (20%)	6 (30%)	10 (50%)	14 (70%)

Table 7: showing comparison of different MRA against DSA. SI = source image

SENSITIVITY, SPECIFICITY, PPV, NPV OF DIFFERENT MRA SETS COMPARED TO AGAINST DSA:

	P value	**Sensitivity**	**Specificity**	**Positive predictive value**	**Negative predictive value**
CE MRA SI	1.000	100%(20/20)	100% (2/2)	100% (18/18)	100% (2/2)
CE reformatted image	0.125	77.8% (14/18)	100% (2/2)	100% (14/14)	33% (2/6)
TOF MRA SI	0.008	55.6% (10/18)	100% (2/2)	100% (10/10)	20% (2/10)
TOF reformatted image	0.000	33%(6/18)	100% (2/2)	100% (6/6)	14.3% (2/14)

Table 8: Showing comparison of sensitivity, specificity, PPV, NPV compared against DSA for detection of significant (≥50%) delayed in-stent stenosis. SI = source imae

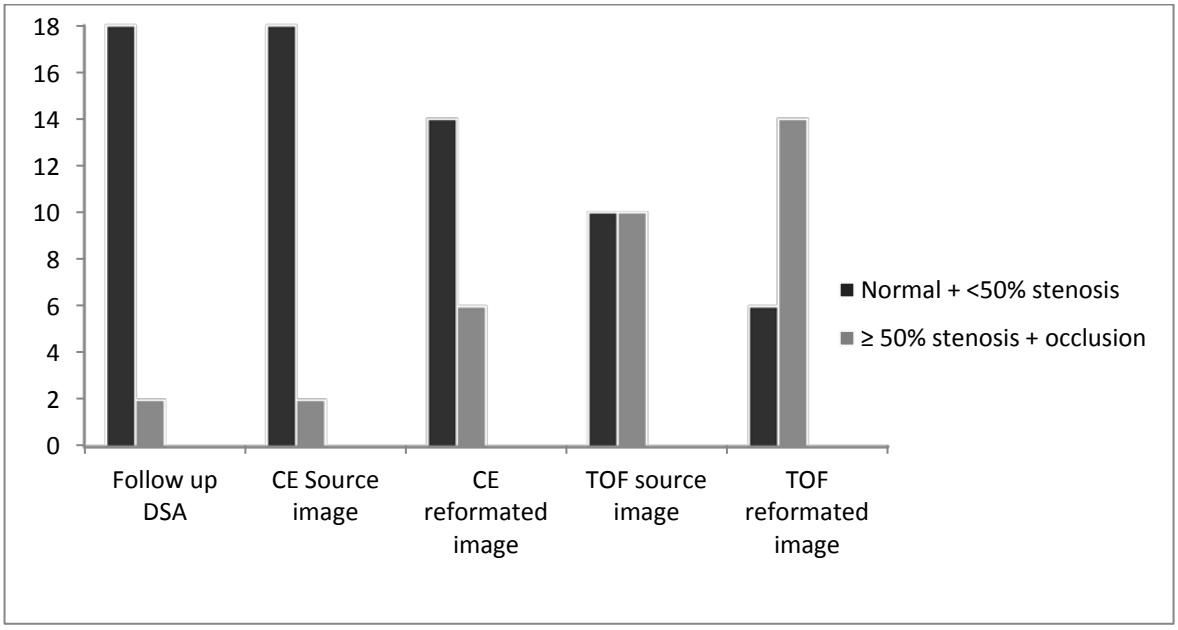

Figure 1: Comparison of TOF MRA reformatted image, TOF MRA source image, CE-MRA reformatted image, CE-MRA source image against DSA for delayed in-stent stenosis.

REPRESENTATIVE IMAGES

IMAGE LEGENDS

IMAGE 1: A 56 year old male, had presented with sudden onset severe headache, vomiting and loss of consciousness, underwent CT followed by DSA.

A. Diagnostic cerebral DSA revealed 9.4 x 4.7mm saccular aneurysm arising from communicating segment ICA.
B. He underwent Solitaire AB stent deployment followed by aneurysm coiling. Post coiling DSA revealed patent lumen. **C.** Sixteen month follow up TOF reformatted image & **D.** TOF source images revealed occlusion (grade 3).
E. CEMRA reformatted images also revealed occlusion. **F.** CEMRA source image revealed 50% stenosis.
G. This finding was confirmed on DSA**.**

IMAGE 2: A 12 year old child had presented with acute onset headache, diplopia and vomiting.

A. Diagnostic cerebral DSA revealed fusiform complex aneurysm of basilar artery, possibly dissecting type.
B. He underwent Neuroform 3 stent deployment in basilar artery followed by coiling of aneurysm.
C. First follow up DSA after 1 year revealed coil compaction with aneurysm expansion, with no stent stenosis (grade 0).

IMAGE 3: A. One year six months follow up of the same patient, TOF MRA reformatted image revealed severe stenosis of 90% at the proximal marker of stent (grade 3).
B. TOF source image revealed approx 50% stenosis at the corresponding site (grade 2).
C. CEMRA reformatted image also revealed severe stenosis (grade 2).
D. CEMRA source image showed less than 30% stenosis (grade 1). **E & F.** AP and lateral view of cerebral DSA vertebral injection showed no stenosis (grade 0).

IMAGE 4: A 54 year old man, non-diabetic, non-hypertensive, non smoker, with no hypercholesterolemia, had presented with occipital headache, giddiness, vomiting of one month duration.

A. DSA revealed tight stenosis distal V4 segment of left vertebral artery. In the absence of atherosclerotic disease in other vessels of body, non-atherosclerotic stenosis was diagnosed.
B & C. Neuroform 3 stent was deployed across stenosis with check DSA Lateral and AP projection on left vertebral injection showing 90% restoration of lumen (grade 2).

D. Twenty seven month follow up TOF MRA reconstructed image revealed 20% stenosis at the proximal end of stent (grade 1). **E.** TOF source image also reveals 10% stenosis of lumen at the corresponding site (grade 1).
F. CEMRA reformatted image also shows 20% stenosis (grade 1).
G. CEMRA source image shows no stenosis (grade 0).

DISCUSSION

A wide range of age (range 12 years to 80 years) also shows heterogeneous age distribution fairly representative of all age group. Equal sex ratio in present cohort rules out any possibility of sex related bias for in-stent stenosis, though large cohort would be required to further confirm this finding. All four type of self expanding 'conventional' intracranial stents were used in the current series, Neuroform 3 was the most used stent, while Enterprise stent was least.

Overall delayed in-stent stenosis during follow up DSA was 10%, which is slightly high as compared to 1.25% to 7.8% of previously published literature.

Though the utility of TOF MRA and CEMRA in in-stent stenosis has been described, accuracy of each modality was not described separately [**37**]. Our study showed that contrast enhanced MRA source image are 100% sensitivity, specificity, positive predictive value and negative predictive value in detecting significant delayed in-stent stenosis (≥50% stenosis). Though specificity and positive predictive value of all 4 MRA image sets was 100%, the sensitivity and negative predictive value was significantly different in four image sets. The sensitivity of TOF reformatted image, TOF source image, CEMRA reformatted image, CEMRA source image are 33% (6/18), 55.6% (10/18), 77.8% (14/18) and 100% (20/20) respectively, while negative predictive value are 14.3% (2/14), 20% (2/10), 33% (2/6) and 100% (2/2) respectively. Patient

compliance of anticoagulant therapy was 100% in all 18 cases, indicating the lesser role of platelet activation by stent as a direct cause for delayed in-stent stenosis.

CEMRA source image was found superior to quantitative MRA in detecting > 50% stenosis. CE MRA reformatted images were also had better specificity and positive predictive value, though sensitivity and negative predictive value is low. As QMRA, the CEMRA technique is easy to perform as well for interpretation, less subjected to artifacts from variable velocities.

Author	**Imaging modality**	**SENSITIVITY**	**SPECIFICITY**	**POSITIVE PREDICTIVE VALUE**	**NEGATIVE PREDICTIVE VALUE**
Prabhak-aran S et al.	QMRA	100%	92%	67%	100%
Current study	CEMRA source image	100%(20/20)	100% (2/2)	100% (18/18)	100% (2/2)
	CEMRA reformatted image	77.8% (14/18)	100% (2/2)	100% (14/14)	33% (2/6)

Table 8: Comparison of accuracy between QMRA and CEMRA.

CE MRA reformatted image, though less sensitive as compared to CEMRA source image, both these image sets showed no statistically significant difference. Also the reformatted images were also statistically insignificant as compared to DSA in detection of >50% stenosis.

CEMRA identified significant stenosis≥(50% stenosis + occlusion) correctly in all cases. However as compared to DSA, CEMRA showed 7 (35%) cases of less than 50% stenosis. Nevertheless it was significantly less than previously reported 64%.

Of the two stents showing significant stenosis, one of nine Neuroform 3 stent and one of six Leo stent. There was no statistically significant difference in the involvement between Neuroform 3 and Leo stents. Hence superiority of one stent over other could not be drawn based on our results.

All the stenosis found were focal, as against the in-stent stenosis in atherosclerotic disease in which not only diffuse narrowing along stent was noted but also stenosis extended beyond the stent site [4].

One of patient revealed asymptomatic 50% stenosis of Neuroform 3 stent which was developed during the period of follow up angiography; he was treated with Tirofiban infusion. Following Tirofiban infusion, the stenosis reduced significantly. The other patient with Leo stent occlusion was managed conservatively due to his asymptomatic clinical status and presence of other co-morbidities.

Our study is first to show high sensitivity and specificity of CEMRA source image for detection of significant delayed in-stent stenosis. Also our study compared instent stenosis between Leo and Neuroform 3, which was not compared in previous studies.

The study results suggest avoiding TOF MRA for stent evaluation due to its low sensitivity and negative predictive value. The results also support conservative management in patients with < 50% in-stent stenosis of asymptomatic patient detected by both CEMRA and DSA. We suggest further evaluation of >50% in-stent stenosis detected by CEMRA by DSA. However controversy remains in patients with > 50% in-stent stenosis detected on DSA. Some authors suggest aggressive management while other suggests close follow up. In view of resolution of even high grade delayed in-stent stenosis as shown recently, an initial close follow up before aggressive management would be appropriate, though needs further prospective study.

Limitations of the study were 1) small number of cases in the cohort, the findings needs to support by larger cohort study 2) the study was retrospective – prospective study. We suggest need for prospective blinded study. 3) Though the CEMRA identified significant stenosis (≥ 50% stenosis + occlusion) correctly in all cases. However as compared to DSA, CEMRA showed 7 cases of less than 50% stenosis. 4) The number of Solitaire AB and Enterprise stents were very less, hence direct comparison between these two stents against other stents were not possible. 5) Larger FOV (including neck + brain) used for CEMRA image acquisition likely result in spread of acquired data over larger pixel. This limitation could be overcome by using small FOV for intracranial circulation only. This modified technique may further decrease false positive cases of delayed in-stent stenosis, though this aspect was not studied in the current study.

CONCLUSION

1) Overall delayed in-stent stenosis during follow up DSA was 10%, which is slightly high as compared to 1.25% to 7.8% of previously published literature.

2) CEMRA source image is as specific and sensitive as DSA to identify significant (>50%) delayed in-stent stenosis, though CEMRA reformatted image also has good sensitivity as compared to DSA.

3) There was no statistically significant difference between Neuroform 3 and Leo stents for development of delayed in-stent stenosis.

4) Long term follow up is essential for stent patency evaluation despite continued anti-coagulant medication.

5) The study results suggest avoiding TOF MRA for stent evaluation due to its extremely low sensitivity and negative predictive value.

6) No preferential involvement of particular sex for delayed in-stent stenosis, though larger study needed in this regard.

7) Less than 50% stenosis detected in asymptomatic patients by CEMRA/DSA can safely be conservatively managed, while > 50% stenosis on CEMRA requires further evaluation/confirmation.

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ANNEXURES

PATIENT PROFORMA

Patient history:

- Age, Gender

- Clinical presentation, duration of illness

- Pre-procedural clinical findings of patient

- CT, MR, CTA, MRA, DSA findings preprocedure.

Stent features:

- Number and type of stents used.

- Location and size (Diameter and Length)

- Etiology for which stenting was done

- Parent artery status

Endovascular treatment:

- Date of first treatment

- Dates of retreatments

- Procedural complications - related to coil, related to stents, related to anesthesia.

- Angiographic results.

- Clinical outcome (GOS).

- Failure to navigate stent/deployment/abandoning of procedure.

Follow up findings:

- Date

- Drug compliance

- Angiographic result and imaging method

- Clinical recovery/worsening

- Indication for additional treatment

- CT, MR, CTA, MRA, DSA findings post procedure.

DSA and MRA evaluation:

Stenosis was calculated $\frac{\text{1- In-stent diameter}}{\text{Diameter at the proximal/distal normal vessel segment}} \times 100$

- 0 = No stenosis
- 1 = <50% stenosis
- 2 = >50% stenosis
- 3 = Occlusion

Table for DSA evaluation results:

TYPE OF STENT	Numbers	Baseline DSA	Follow up DSA No stenosis	Delayed in-stent stenosis in **<50% stenosis**	Delayed in-stent stenosis in **>50% stenosis**	Delayed stent occlusion
Neuroform 3						
Leo						
Solitaire AB						
Enterprise						
TOTAL						

Table for TOF MRA reformatted image evaluation results:

TYPE OF STENT	Numbers	Baselline DSA	Follow up TOF MRA Reformated image No tenosis	Follow up MRA reformatted image **<50% stenosis**	Follow up MRA reformatted image **>50% stenosis**	Follow up MRA reformatted image stent occlusion
Neuroform 3						
Leo						
Solitaire AB						

Enterprise						
TOTAL						

Table for TOF MRA source image evaluation results:

TYPE OF STENT	Numbers	Baselline DSA	Follow up TOF MRA source image **No tenosis**	Follow up TOF MRA source image **<50% stenosis**	Follow up TOF MRA source image **>50% stenosis**	Follow up TOF MRA source image **stent occlusion**
Neuroform 3						
Leo						
Solitaire AB						
Enterprise						
TOTAL						

Table for CE MRA reformatted image evaluation results:

TYPE OF STENT	Numbers	Baselline DSA	Follow up CE MRA Reformated image No tenosis	Follow up CE MRA reformatted image **<50% stenosis**	Follow up CE MRA reformatted image **>50% stenosis**	Follow up CE MRA reformatted image stent occlusion
Neuroform 3						
Leo						
Solitaire AB						
Enterprise						
TOTAL						

Table for TOF MRA source image evaluation results:

TYPE OF STENT	Numbers	Baselline DSA	Follow up CE MRA source image No tenosis	Follow up CE MRA source image **<50% stenosis**	Follow up CE MRA source image **>50% stenosis**	Follow up CE MRA source image stent occlusion
Neuroform 3						
Leo						
Solitaire AB						
Enterprise						
TOTAL						

MASTER CHART

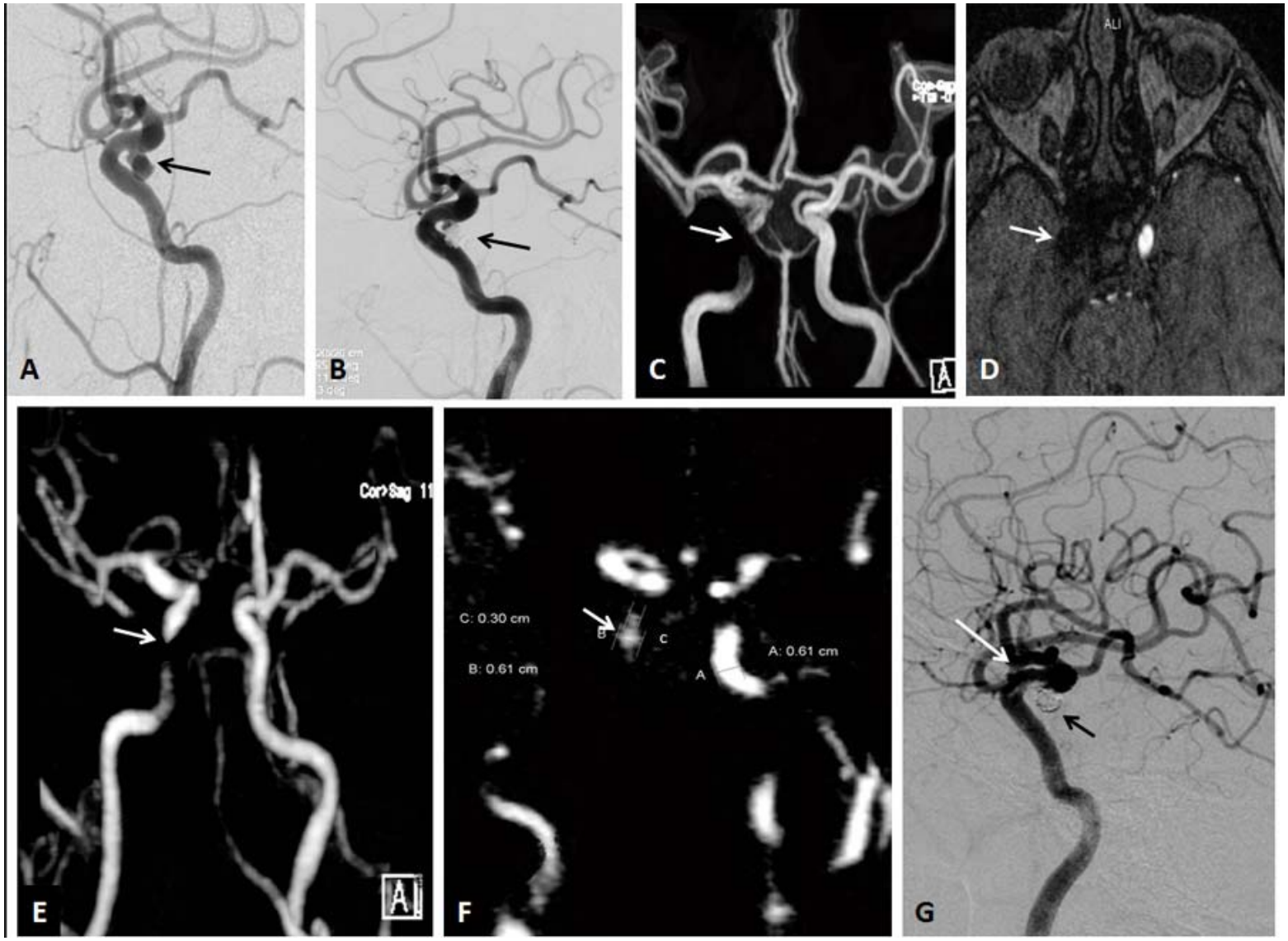

IMAGE 1

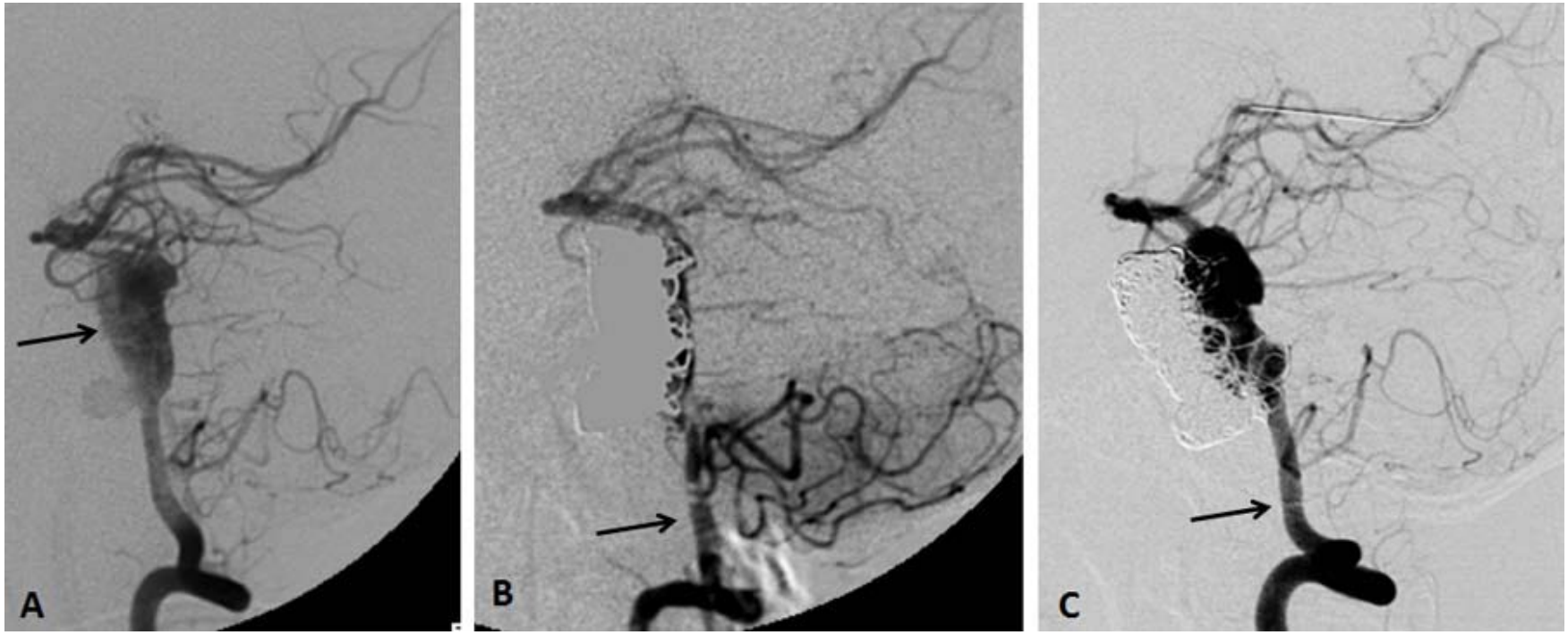

IMAGE 2

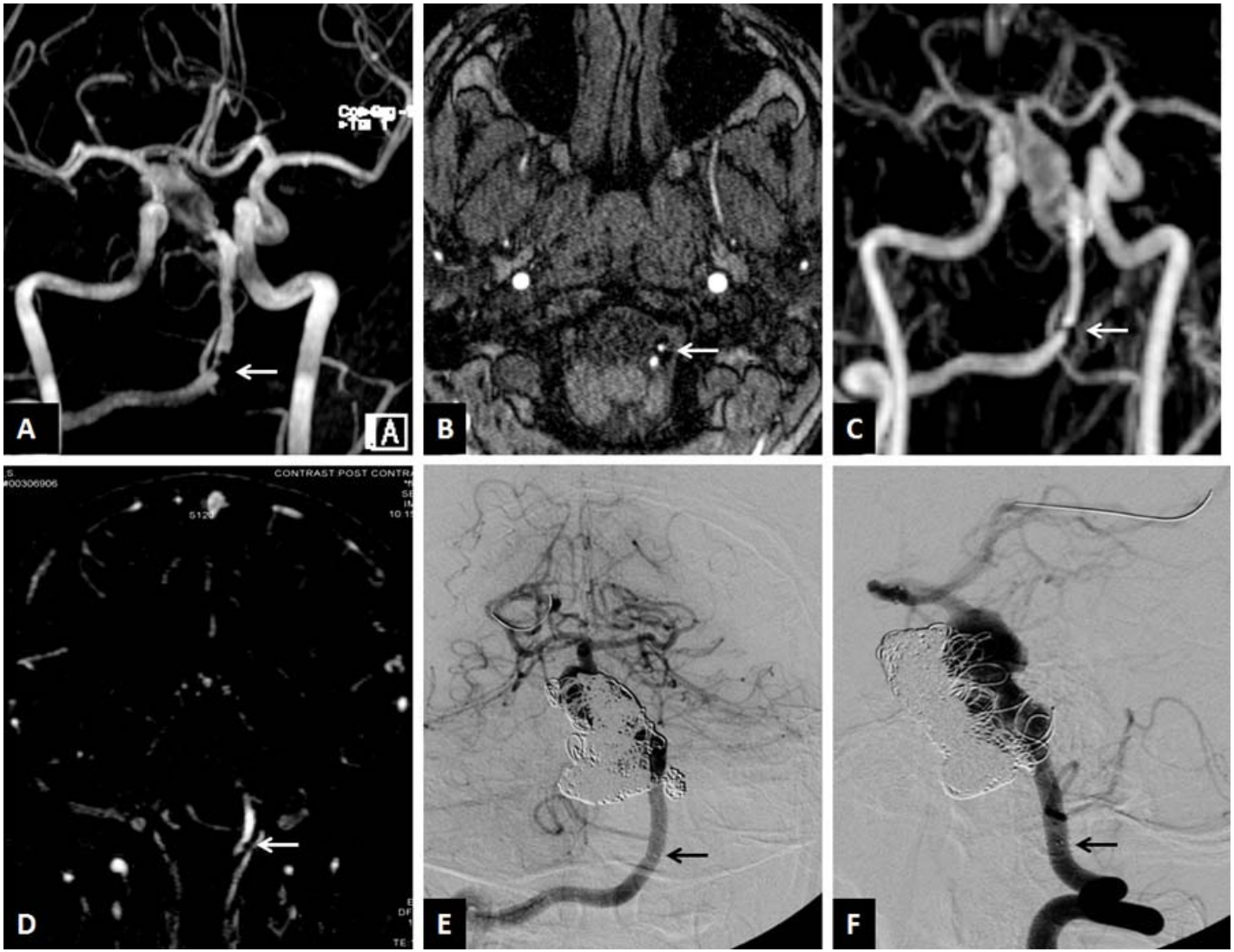

IMAGE 3

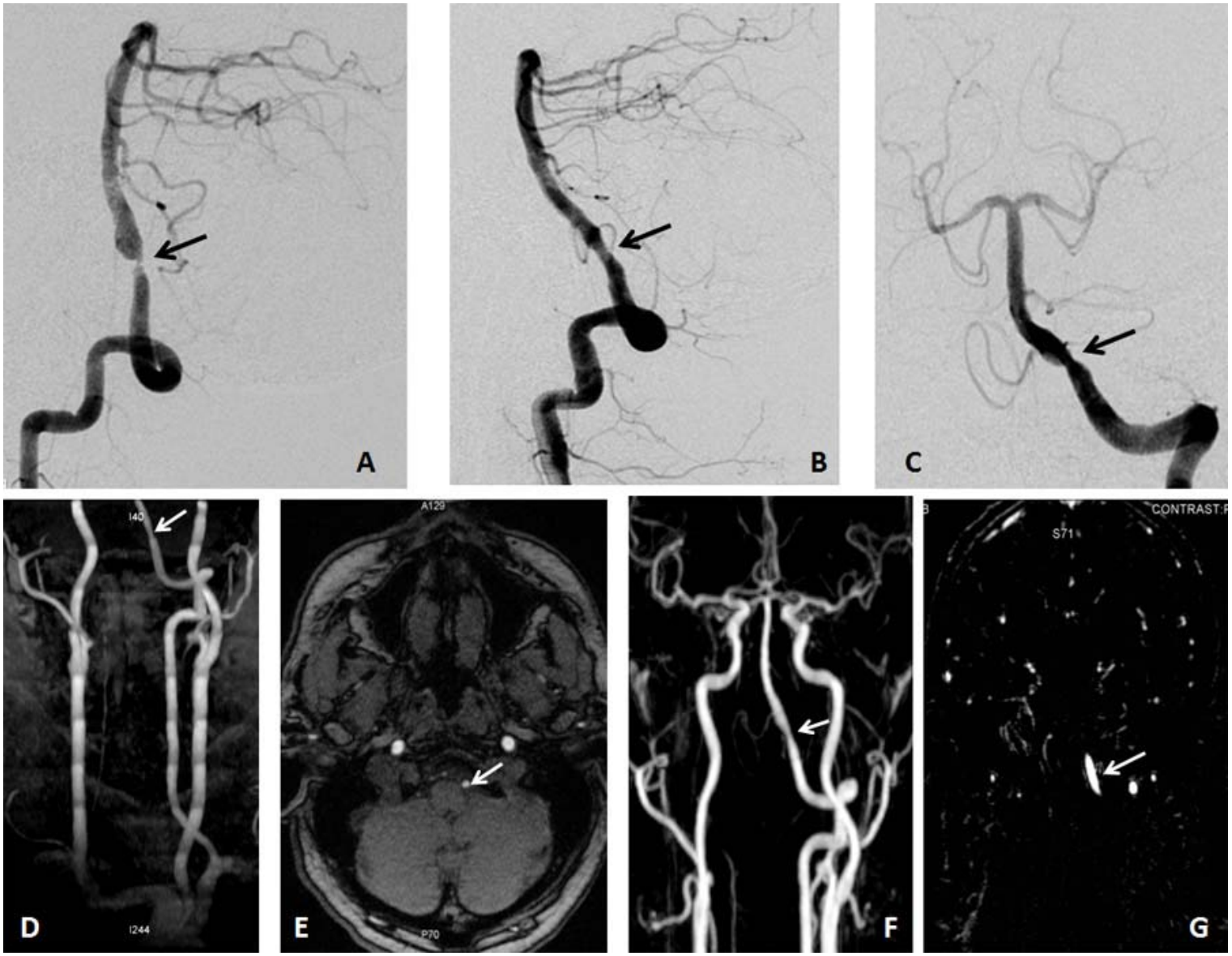

IMAGE 4

SL NO.	AGE	SEX	DIAGNOSIS	DATE OF STENT DEPLOYMENT	NAME OF STENT	SIZE OF STENT
1	37 Y	F	Basilar artery dissecting aneurysm	29-MAR-2005	LEO STENT	3.5mm X 18mm
2	31 Y	M	Bilateral carotico-cavernous fistula	19-MAY-2005	LEO STENT	4.5mm X 30mm
3	48 Y	M	Right MCA bifurcation aneurysm	12-NOV-2005	LEO STENT	3.5 mm X 15mm
4	39 Y	M	Right MCA aneurysm	19-JAN-2007	LEO STENT	3.5 mm X 15mm
5	37 Y	M	Basilar top aneurysm	12-MAR-2007	LEO STENT	3.5 mm X 15mm
6	24 Y	M	Right cavernous ICA aneurysm	30-MAR-2007	LEO STENT	3.5 mm X 2.5 mm
7	12 Y	M	Basilar artery aneurysm	10-NOV-2007	2 X NEUROFORM 3	4 mm X 20mm 4 mm X 20mm
8	45 Y	F	Right supraclinoid ICA aneurysm	25-FEB-2010	NEUROFORM 3	4.5 mm x 20 mm
9	54 Y	M	Left V4 vertebral artery stenosis	05-MAR-2010	NEUROFORM 3	4mm x 30 mm
10	37 Y	F	Left V4 vertebral artery aneurysm	09-JUN-2010	NEUROFORM 3	5 mm X 30 mm
11	39 Y	F	Right supraclinoid ICA aneurysm	11-JUN-2011	NEUROFORM 3	3 mm X 30 mm
12	43 Y	F	Basilar top aneurysm	30-SEP-2010	NEUROFORM 3	3 mm X 20 mm
13	53 Y	M	Left V4 vertebral artery aneurysm	11-APR-2011	NEUROFORM 3	4.5 mm X 30 mm
14	58 Y	F	Basilar top aneurysm	13-MAY-2011	NEUROFORM 3	3 mm X 20 mm
15	56 Y	M	Left supraclinoid ICA aneurysm	21-MAY-2011	ENTERPRSE SOLITAIRE AB	4.5 mm X 28 mm 4 mm X 20 mm
16	39 Y	F	Left supraclinoid ICA aneurysm	21-SEP-2011	SOLITAIRE AB	5 mm x 20mm
17	51y	F	Left supraclinoid ICA aneurysm	09-MAR-2012	SOLITAIRE AB	6 mm x 30 mm
18	80y	F	Left supraclinoid ICA aneurysm	31-AUG-2010	SOLITAIRE AB	4 mm X 20 mm

SL NO.	Duration of follow up.	Clinical status at follow up
1	31 months	Asymptomatic
2	8 months	Asymptomatic
3	11 months	Asymptomatic
4	18 months	Asymptomatic
5	62 months	Asymptomatic
6	17 months	Asymptomatic
7	29 months	Asymptomatic
8	16 months	Asymptomatic
9	18 months	Asymptomatic
10	22 months	Asymptomatic
11	13 months	Asymptomatic
12	10 months	Asymptomatic
13	15 months	Asymptomatic
14	10 months	Asymptomatic
15	16 months	Asymptomatic
16	4 months	Asymptomatic
17	5 months	Asymptomatic
18	10 months	Asymptomatic

Stent Serial No.	Immediate post stent DSA status	Follow up DSA	Follow up CESI	Follow up CE MIP	Follow up TOF SI	Follow up TOF MIP
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	1	1	1	1	1	1
4	1	1	1	1	1	1
5	1	1	1	1	1	1
6	1	1	1	1	1	1
7	1	1	1	1	1	2
8	1	1	1	1	1	2
9	1	1	1	1	1	2
10	1	1	1	1	1	2
11	1	1	1	1	2	2
12	1	1	1	1	2	2
13	1	1	1	1	2	2
14	1	1	1	1	2	2
15	1	1	1	2	2	2
16	1	1	1	2	2	2
17	1	1	1	2	2	2
18	1	1	1	2	2	2
19	1	2	2	2	2	2
20	1	2	2	2	2	2

1 = [Normal + < 50% stenosis], 2 = [≥ 50% stenosis + occlusion], DSA- Digital Subtraction Angiography, TOF – time-of-flight, CEMRA – contrast enhanced magnetic resonance angiography.