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Outcomes of Endovascular Treatment of Intracranial Aneurysms at Bifurcation Sites

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Abstract

Background and Purpose: Endovascular coiling is widely used for treatment of both ruptured and unruptured aneurysms. Intracranial bifurcation aneurysms were classically considered unsuitable for endovascular treatment because of the risk of coil protrusion into the parent vessel. The introduction stent assisted coiling has allowed the bifurcation aneurysms to be endovascularly treated. The present study aims to evaluate the efficacy of the endovascular treatment of the intracranial bifurcation aneurysms. **Methods:** This study was conducted on 76 patients with radiologically documented intracranial aneurysms at bifurcation sites either ruptured (12 aneurysms) or unruptured (64 aneurysms). Endovascular coiling of intracranial aneurysms was done for all patients in our study aided in some with single or Y-configuration stenting. The radiological outcome was assessed immediately postoperative, and at follow-up at 6 and 12 month with grading of the angiograms on the basis of modified 3-point Raymond scale. **Results:** In terms of the Raymond grading (RG), the initial angiographic outcome was complete occlusion (RG1) in 45 aneurysms (59.2%), neck remnant (RG2) in 20 aneurysms (26.3%), and body filling (RG3) in 11 aneurysms (14.5%), while the final angiographic outcome at 1 year was RG1 in 55 aneurysms (72.4%), RG2 in 13 aneurysms (17.1%), and RG3 in 8 aneurysms (10.5%). Eleven aneurysms (14.5%) showed recanalization. The aneurysm size and the neck width were the statistically significant factors affecting the initial RG (P = 0.0005, 0.001 respectively), final RG (P = 0.015, 0.012 respectively), and the recanalization rate (P = 0.012, 0.01 respectively). **Conclusions:** Endovascular treatment of intracranial aneurysms at bifurcation sites is safe and effective. Stent assisted coiling (SAC) has enabled us to offer a safe and effective endovascular treatment for bifurcation aneurysms by preventing coils herniation. Smaller aneurysm size and neck size are indicators of complete occlusion and lower recanalization rate.

Keywords

Bifurcation Aneurysm, Stent Assisted Coiling, Recanalization, Simple Coiling

1. Introduction

Intracranial aneurysm tends to occur at regions of sharp vessel curvature, and bifurcations such as the basilar bifurcation, the internal carotid artery (ICA) bifurcation, the middle cerebral artery (MCA) bifurcation, and the anterior communicating artery. The reason for this is unknown, but the heterogeneous distribution suggests the presence of local contributing factors such as high wall shear stress, turbulence, and other hemodynamic forces implicated in its pathogenesis [1].

Most intracranial aneurysms are clinically silent until rupture, which is unpredictable and sometimes associated with subarachnoid hemorrhage, intraparenchymal hemorrhage, and an intraventricular hemorrhage [2].

Decision for treatment of intracranial aneurysm is based on clinical and anatomic factors such as the patient's age, family history of intracranial aneurysm, symptomatic aneurysms, aneurysm size, aneurysm location, and associated conditions like autosomal dominant polycystic kidney disease (ADPKD) [2]. Endovascular coiling is considered the first line treatment of ruptured and unruptured aneurysms especially after the publication of International Subarachnoid Aneurysm Trial (ISAT) results [3].

Intracranial bifurcation aneurysms were previously considered unsuitable for endovascular treatment because of the risk of coil protrusion into the parent vessel and were typically managed by surgical clipping. Recent advancements in endovascular devices and techniques have placed such aneurysms within the range of endovascular therapy. The introduction of stent assisted coiling has allowed the bifurcation aneurysms to be endovascularly treated [4].

Follow-up imaging after endovascular management of intracranial aneurysm by digital subtraction angiography (DSA) or magnetic resonance angiography (MRA) is crucial. The most important reason for this follow-up is the fact that recanalization after coiling has a high frequency; the issue that exposes the patient to the risk of recurrent subarachnoid hemorrhage (SAH) [5]. Previous studies reported the immediate and follow-up angiographic results without attention to recanalization and the factors that may be responsible for failure of treatment at follow-up after initially successful outcomes.

Aim of the study: The aim of present study is to evaluate the efficacy of the endovascular treatment of the intracranial bifurcation aneurysms, and to analyze the factors that may affect the angiographic outcomes.

2. Patients and Methods

This study was conducted in the neurosurgery department at RUSH medical center, Chicago. IL, from December 2016 to May 2018. The inclusion criteria were:

1) Patients with radiologically documented ruptured or unruptured intracranial bifurcation aneurysms.

2) Patients physically fit for the endovascular treatment procedures.

It was conducted on76casesof bifurcation sites intracranial aneurysms either ruptured (12 aneurysms) or unruptured (64 aneurysms) after obtaining written informed consent from all patients. All patients are subjected to detailed history taking, physical examination, laboratory investigations. All the aneurysms were radiologically documented by conventional digital subtraction angiography (DSA).

Endovascular coiling of intracranial aneurysms was done for all patients in our study aided in some cases with single or Y-configuration stenting. Immediate postoperative angiographic runs were obtained in working projections to determine the angiographic end result. Patients were subjected to angiographic follow-up (DSA or MRA) at 6 and 12 month following the treatment. The degree of aneurysm occlusion was graded immediately after treatment and at follow up using modified Raymond grading, where grade 1, complete occlusion; grade 2, residual neck; and grade 3, aneurysm body filling [6]. At follow-up, an aneurysm was considered recanalized if any further filling of the aneurysm neck or sac was observed compared with the initial treatment findings [7].

2.1. Analysis of Certain Factors in Relation to the Angiographic Outcomes

Certain factors were analyzed in relation to angiographic outcomes like the pretreatment angiographic data and the treatment related factors. Pretreatment geometric data included aneurysm site, aneurysm size, neck width, dome-neck ratio, and aspect ratio. Treatment related factors included treatment modality, stent type, initial RG, and the packing density (≤24% or >24%). Packing density was available for only 51 aneurysms using AngioSuite software system (Cascade Medical, Knoxville, TN, USA).

2.2. Statistical Analysis

Sample size was calculated. Data were statistically analyzed using SPSS 21 (IBM Corp. Armonk, New York). Statistical analysis was done for comparing variables between the groups using Mann-Whitney nonparametric test for numerical variables and Fisher's exact test for categorical variables. P value ≤ 0.05 was considered to be statistically significant. Multivariable logistic regression was performed on candidate predictor variables to identify variables independently associated with occlusion after adjustment for potential confounders.

3. Results

The current study was conducted on 76 radiologically documented aneurysms both ruptured and unruptured at different bifurcation sites.

1) Demographic data:

In the current study, 29 patients were males (38.2%) and 47 were females (61.8%) with male-to-female ratio of 1:1.6. The patients' age ranged from 31 to 88 years, with a mean of 61 years (±12.4). Regarding male patients the mean age was 58.4 years (±11.8), whereas the mean age of the female patients was 62.7 years (±12.3). Out of the 76 patients included in the study 34 patients (44.7%) have no special habits, 30 patients (39.5%) were both cigarette smokers and alcoholics, 12patients (15.8%) were cigarette smokers only. The frequency of risk factors among the studied groups showed that hypertension was the commonest risk factor. Fifty four patients (71.1%) were hypertensive, 26 patients (34.2%) had dyslipidemia, and 5 (7.4%) patients had family history of aneurysms.

2) Clinical data:

Out of our study group, only 12 patients (16%) presented with SAH due to aneurysmal rupture. Most of the patients (31 patients, about 41%) presented by headache, only 4 patients (5%) presented by loss of consciousness, while the remaining (29 patients, about 38.2%) were incidentally discovered.

3) Pretreatment anatomical and geometric data:

The bifurcation aneurysm sites were distributed as follows: 30 (39.5%) in the basilar tip, 20 (26.33%) in the ICA terminus, 15 (19.7%) in the AcomA, and 11 (14.5%) in the MCA bifurcation. The median aneurysm size was 5 mm (range 1.4 - 17.4 mm), the mean neck width was 4.13 ± 1.64 (range 1.5 - 9 mm), dome neck ratio was 1.4 ± 0.6 (range 0 - 4), and aspect ratio was 1.45 ± 0.58 (range 0.5 - 3.7).

4) Treatment related factors:

Fifty three patients (69.7%) were treated by single SAC, 15 patients (19.7%) were treated by simple coiling, and 8 patients (10.5%) were treated by Y-stenting. Stents used were 39 Neuroform EZ (Stryker, Fremont, CA, USA), 9 Enterprise (Codman Neurovascular, Raynham, MA, USA), and 13 LVIS Jr. (Microvention, Tustin, CA, USA).

5) Treatment outcomes:

In terms of the RG, the initial angiographic outcome was complete occlusion (RG1) in 45 aneurysms (59.2%), neck remnant (RG2) in 20 aneurysms (26.3%), and body filling (RG3) in 11 aneurysms (14.5%). The 6 months' angiographic outcome was RG1 in 58 aneurysms (76.3%), RG2 in 13 aneurysms (17.1), and RG3 in 5 aneurysms (6.6), while the final angiographic outcome at 12 months' follow-up was RG1 in 55 aneurysms (72.4%), RG2 in 13 aneurysms (17.1%), and RG3 in 8 aneurysms (10.5%) (Table 1, Table 2). Eleven aneurysms (14.5%) showed recanalization (Table 3). There were no periprocedural complications or mortalities. There were no thromboembolic or hemorrhagic complications during follow-up period. In stent stenosis was found in one case at 6 months' follow-up.

Analysis of the factors affecting the angiographic outcome showed that the aneurysm size and the neck width were the statistically significant factors affecting

Table 1. Statistical analysis for individual factors in relation to the initial RG.

Demographic and clinical data				
	Initial RG			
	1 N%	2 N%	3 N%	
	45 (59.2)	20 (26.3)	11 (14.5)	76 (100)
Age (years) **Mean ± SD**	61.8 ± 11.6	61.5 ± 13.7	57.4 ± 12.1	P = 0.56
Gender				
Male	18 (62.1)	8 (27.6)	3 (10.3)	P = 0.72
Female	27 (57.4)	12 (25.5)	8 (17.0)	
Hypertension	33 (61.1	13 (24.1)	8 (14.8)	P = 0.78
Dyslipidemia	16 (61.5)	7 (26.9)	3 (11.5)	P = 0.85
Smoking	25 (59.5)	10 (23.8)	7 (16.7)	P = 0.81
Alcohol drinking	15 (50.0)	9 (30.0)	6 (20.0)	P = 0.37
Clinical presentation				
• Unruptured	38 (59.5)	17 (26.5)	9 (14.0)	P = 0.62
• Ruptured	7 (58.3)	3 (25.0)	2 (16.7)	
Pretreatment geometric data				
Site				
• Basilar	19 (63.3)	8 (26.7)	3 (10.0)	P = 0.64
• Carotid	11 (55.0)	7 (35.0)	2 (10.0)	
• ACOM	10 (66.7)	2 (13.3)	3 (20.0)	
• MCA	5 (45.5)	3 (27.3)	3 (27.3)	
Aneurysm size **Mean ± SD**	4.5 ± 2.66	9.6 ± 3.76	5.61 ± 3.36	F = 8.55 P = 0.0005*
Neck width **Mean ± SD**	3.13 ± 0.88	5.22 ± 1.9	3.90 ± 1.4	F = 8.13 P = 0.001*
Aspect ratio **Mean ± SD**	1.47 ± 0.54	1.35 ± 0.49	1.56 ± 0.88	F = 0.55 P = 0.58
Dome neck ratio **Mean ± SD**	1.34 ± 0.51	1.4 ± 0.62	1.75 ± 0.89	F = 2.05 P = 0.14
Treatment related factors				
Treatment modality				
• Simple coiling	10 (66.7)	3 (20.0)	2 (13.3)	MC P = 0.61
• Single SAC	32 (60.4)	13 (24.5)	8 (15.1)	
• Y-stenting	3 (37.5)	4 (50.0)	1 (12.5)	
Stent used				
• Neuroform	22 (61.3)	12 (29)	5 (9.7)	MC P = 0.67
• Enterprise	6 (66.7)	1 (11.1)	2 (22.2)	
• Elvis	7 (53.8)	3 (23.1)	3 (23.1)	

Table 2. Statistical analysis for individual factors in relation to the final RG.

Demographic and clinical data				
	Final RG			
	1 **N (%)**	**2** **N (%)**	**3** **N (%)**	

Continued

	55 (72.4)	13 (17.1)	8 (10.5)	76 (100)
Age (years) **Mean ± SD**	62 ± 11.9	54.7 ± 13.4	64.7 ± 9	P = 0.09
Gender				
• Male	21 (72.4)	1 (24.1)	1 (3.4)	P = 0.16
• Female	34 (72.3)	6 (12.8)	7 (14.9)	
Hypertension	38 (70.4)	10 (18.5)	6 (11.1)	P = 0.85
Dyslipidemia	18 (69.2)	5 (19.2)	3 (11.5)	P = 0.93
Smoking	31 (73.8)	9 (21.4)	2 (4.8)	P = 0.13
Alcohol drinking	18 (60.0)	8 (26.7)	4 (13.3)	P = 0.13
Clinical presentation				
• Unruptured	45 (70.4)	11 (17.1)	8 (12.5)	P = 0.65
• Ruptured	10 (83.3)	2 (16.7)	0 (0.0)	
Pretreatment geometric data				
Site				
• Basilar	19 (63.3)	6 (20.0)	5 (16.7)	P = 0.78
• Carotid	15 (75.0)	3 (15.0)	2 (10.0)	
• ACOM	12 (80.0)	2 (13.3)	1 (6.7)	
• MCA	9 (81.8)	2 (18.2)	0 (0.0)	
Aneurysm size **Mean ± SD**	5.6 ± 3.1	7.5 ± 4.1	9.5 ± 5.2	F = 4.45 P = 0.015*
Neck width **Mean ± SD**	3.81 ± 1.4	4.75 ± 2.1	5.39 ± 1.99	F = 4.73 P = 0.012*
Aspect ratio **Mean ± SD**	1.45 ± 0.55	1.34 ± 0.75	1.65 ± 0.52	F = 0.69 P = 0.50
Dome neck ratio **Mean ± SD**	1.38 ± 0.59	1.3 ± 0.60	1.81 ± 0.62	F = 2.02 P = 0.14
Treatment related factors				
Treatment modality				
• Simple coiling	12 (80.0)	3 (20.0)	0 (0.0)	P = 0.53
• Single SAC	40 (75.5)	8 (15.1)	5 (9.4)	
• Y-stenting	3 (37.5)	2 (25.0)	3 (37.5)	
Stent used				
• Neuroform	29 (83.9)	6 (9.7)	4 (6.5)	P = 0.13
• Enterprise	6 (66.7)	3 (33.3)	0 (0.0)	
• Elvis	8 (61.5)	2 (15.4)	3 (23.1)	

the initial RG (P = 0.0005, 0.001 respectively), final RG (P = 0.015, 0.012 respectively), and the recanalization rate (P = 0.012, 0.01 respectively) (Tables 1-3).

4. Discussion

The present study consisted of series of 76 aneurysms at 4 different bifurcation sites (basilar tip, ICA terminus, MCA bifurcation, and AcomA) treated by different endovascular modalities. Clinical and angiographic data were collected. Aneurysm occlusion after treatment was categorized according to modified Raymond classification. At follow-up, an aneurysm was considered recanalized

Table 3. Statistical analysis for individual factors in relation to the recanalization rate.

Demographic and clinical data			
	Recanalization		
	No	**Yes**	
	65 (85.5)	11 (14.5)	76 (100)
Age (years) **Mean ± SD**	60.9 ± 12.8	62.1 ± 7.9	P = 0.77
Gender			
• Male	26 (89.7)	3 (10.3)	P = 0.72
• Female	39 (83.0)	8 (17.0)	
Hypertension	45 (83.3)	9 (16.7)	P = 0.39
Dyslipidemia	22 (84.6)	4 (15.4)	P = 0.89
Smoking	37 (88.1)	5 (11.9)	P = 0.48
Alcohol drinking	24 (80.0)	6 (20.0)	P = 0.27
Clinical presentation			
• Unruptured	54 (84.4)	10 (15.6)	P = 0.73
• Ruptured	11 (91.7)	1 (8.3)	
Pretreatment geometric data			
Site			
• Basilar	23 (76.7)	7 (233)	P = 0.22
• Carotid	17 (85.0)	3 (15.0)	
• ACOM	14 (93.3)	1 (6.7)	
• MCA	11 (100)	0 (0.0)	
Aneurysm size **Mean ± SD**	5.9 ± 3.4	8.8 ± 4.9	t = −2.31 P = 0.012*
Neck width **Mean ± SD**	3.9 ± 1.54	5.30 ± 1.81	t = −0.29 P = 0.01*
Aspect ratio **Mean ± SD**	1.40 ± 0.54	1.74 ± 0.78	t = −1.83 P = 0.07
Dome neck ratio **Mean ± SD**	1.36 ± 0.60	1.71 ± 0.58	t = −1.82 P = 0.07
Treatment related factors			
Treatment modality			
• Simple coiling	14 (93.3)	1 (6.7)	P = 0.11
• Single SAC	46 (86.8)	7 (13.2)	
• Y-stenting	5 (62.5)	3 (37.5)	
Initial RG	N (%)	N (%)	
• Complete occlusion	39 (60.0)	6 (54.6)	P = 0.57
• Residual neck	16 (24.6)	4 (36.4)	
• Body filling	10 (15.4)	1 (9.0)	
Packing density	N = 42	N = 9	
• ≤24	26 (61.9)	3 (33.3)	P = 0.39
• >24	16 (38.1)	6 (66.7)	
Stent used			
• Neuroform	33 (90.3)	6 (9.7)	P = 0.55
• Enterprise	8 (88.9)	1 (11.1)	
• Elvis	10 (76.9)	3 (23.1)	

if any further filling of the aneurysm neck or sac was observed compared with the initial treatment findings [7].

About 70% of the patients were treated by single SAC, 19.7% were treated by simple coiling, and 10.5% were treated by Y-stenting. Stent-assisted coiling (SAC) of bifurcation aneurysms has expanded the spectrum of aneurysms amenable to endovascular therapy by providing neck coverage while preserving the involved vessels from coil prolapsed [8]. Y-stenting is usually reserved to the cases were the neck is centered on the bifurcation, as it will be difficult to protect 2 bifurcation branches with a single device. A scoring system was proposed to assist on the selection of Y-stenting to treat bifurcation site aneurysms [9].

In terms of the percentage of complete occlusions, the initial and follow up angiographic results are in range to the majority of results from previously published endovascular series, where complete occlusion has been achieved initially in 26% - 76% of the treated aneurysms and in follow-up in 35% - 86% (**Table 4**).

Table 4. Summary of initial and follow-up angiographic results of endovascular series.

Study	Number of aneurysms	Initial			Follow up months	Follow-up		
		RG1 %	RG2 %	RG3 %		RG1 %	RG2 %	RG3 %
Brilstra *et al.* 1999 [10]	201	61	26	13	NA	NA	NA	NA
Raymond & Roy 1997 [17]	75	40	37	23	6	46	42	12
Kuether *et al.* 1998 [18]	74	40	52	8	26	41	46	13
Byrne *et al.* 1999 [12]	317	NA	NA	NA	22	64	34	2
Vanninen *et al.* 1999 [19]	52	50	35	15	3	67	28	5
Koivisto *et al.* 2000 [20]	52	50	35	15	12	77	19	4
Ng *et al.* 2002 [21]	136	46	16	38	NA	NA	NA	NA
Friedman *et al.* 2003 [22]	83	33	63	5	19	35	61	3
Murayama *et al.* 2003 [11]	818	55	35	10	NA	NA	NA	NA
Sluzewski *et al.* 2003 [23]	160	71	22	8	6	59	25	16
Henkes *et al.* 2004 [24]	1811	66	21	13	NA	NA	NA	NA
Cronqvist *et al.* 2005 [25]	46	37	50	13	NA	NA	NA	NA
Molyneux *et al.* 2005 [26]	881	NA	NA	NA	NA	66	26	8
Norbäck *et al.* 2005 [27]	239	53	21	26	NA	NA	NA	NA
Geyik *et al.* 2010 [28]	80	71	28	1	10.5	86	8	6

Continued

Maldonado *et al.* 2010 [29]	76	31	26	42	16.4	65	13	13
Yue, 2011 [30]	80	76	10	14	NA	NA	NA	NA
Nanda *et al.* 2013 [31]	66	72	NA	NA	NA	NA	NA	NA
Liu *et al.* 2017 [32]	113	26	61	13	NA	NA	NA	NA
Adeeb *et al.* 2017 [9]	74	53	23	24	15	70	20	9
Our study	76	59.2	26.3	14.5	14	72.4	17.1	10.5

These results obtained (complete occlusion initially in 59.2% of the aneurysms) are comparable to the range of the published series [9] [10] [11] and the results obtained (complete occlusion at 14 months follow up in 72.4% of the aneurysms) are comparable to the range of the published series (70% at 15 months FU) [9]. In terms of neck remnant (RG2), the results of the present study (26.3% initially and 17.1% in follow-up) are in the range of the other published series (10% - 63% initially and 8% - 61% in follow-up). In terms of incomplete occlusions (RG3), the results of the present study (14.5% initially and 10.5% in follow-up) are in the range of the other published series (1% - 38% initially and 2% - 16% in follow-up) (**Table 4**).

In the present study, recanalization was present in only 14.5% of the aneurysms at the latest follow up which is less than most of the literature reports. The reported rates of aneurysm recanalization vary over a wide range from 17% to 90% [7] [12] [13] [14] [15].

Variety of factors influence the rate of occlusion and recanalization including aneurysm-specific factors such as size, neck width, dome-to-neck ratio, location and whether the aneurysm is ruptured or unruptured, and treatment-related factors such as the treatment modality, packing density, and the initial RG [9] [15]. Analysis of these factors showed that the aneurysm size and the neck width were the statistically significant factors affecting the initial RG ($P = 0.0005$, 0.001 respectively), final RG ($P = 0.015$, 0.012 respectively), and recanalization rate ($P = 0.012$, 0.01 respectively). There was no statistically significant difference regarding the other factors. This is in congruence with the literatures reporting the aneurysm size and neck width as the main factors influencing the occlusion and recurrence. Smaller aneurysm and neck size were predictors of complete occlusion and non-recanalization [9] [15] [16].

The major limitation of our study was the follow up interval. Our follow up interval was 12 months; longer intervals may be more conclusive.

5. Conclusion

Endovascular treatment of intracranial aneurysms at bifurcation sites is safe and effective. Stent assisted coiling (SAC) has enabled us to offer a safe and effective endovascular treatment for bifurcation aneurysms by preventing coils herniation. Smaller aneurysm size and neck size are indicators of complete occlusion and lower recanalization rate.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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