



Comparison of surgical and endovascular treatments for fusiform intracranial aneurysms: systematic review and individual patient data meta-analysis

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Abstract

Fusiform intracranial aneurysms (FIA) are associated with significant morbidity and mortality. We carried out a systematic review and meta-analysis of individual participant data with propensity score adjustment to compare the functional and angiographic outcomes between surgical and endovascular approaches to FIA. We conducted a systematic review for articles on the treatment of FIA with individual patient-level detailing. Data from patients treated for FIA in our institution from 2010 to 2018 were also collected. The primary studied outcome was morbidity, and secondary outcomes were angiographic results and retreatment. Propensity score-adjusted mixed-effects logistic regression models evaluated treatment options, stratified by anatomical location. Compiling original and published data, there were 312 cases, of which 79 (25.3%) had open surgery, and 233 (74.5%) were treated with endovascular procedures. There were no differences between treatment groups, for neither cavernous ICA (OR 1.04, 95% CI 0.05–23.6) nor supraclinoid aneurysms (OR 7.82, 95% CI 0.65–94.4). Both size (OR 1.11, 95% CI 1.03–1.19) and initial mRS (OR 2.0, 95% CI 1.2–3.3) were risk factors for morbidity, independent of location. Neither age nor rupture status influenced the odds of posterior morbidity. Unfavorable angiographic outcomes were more common in the endovascular group for supraclinoid and vertebrobasilar aneurysms (χ^2 , $P < 0.01$). There were no differences between morbidity of surgical and endovascular treatments for FIA, regardless of aneurysm location. Size and initial mRS were correlated with functional outcomes, whereas age and rupture status were not. Microsurgery seems to yield better long-term angiographic results compared to endovascular procedures.

Keywords Fusiform aneurysm · Microsurgery · Endovascular · Meta-analysis

Introduction

Fusiform intracranial aneurysms (FIA) are circumferential arterial dilatations 1.5 times the normal diameter of an arterial segment with any degree of tortuosity, without a definable neck. [9, 36] Significant morbidity and mortality are

attributable to those spindle-shaped aneurysms, which have exhibited annual growth rates of 12% and a 3% annual rupture risk. [12, 13, 36, 37] In a landmark study on the topic, Mizutani and colleagues reported a mortality rate of 35.3%. [30]

The origin and development of FIA remain subject to debate. There are probably many different mechanisms of formation, as histopathological analyses have proven. [6, 15, 21, 30, 35] However, as stressed by Horie and colleagues, [15] the term fusiform refers mainly to a specific morphology, since pathological examination is not possible preoperatively. Multiple treatment strategies for FIA exist, which are often classified as deconstructive or reconstructive, both presenting microsurgical and endovascular choices.

The literature on this topic is composed mostly of case reports and small series [40], and few studies to date directly

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compare different treatment options. We performed a systematic review and meta-analysis of individual participant data, including original data from our institution, to compare the functional and angiographic outcomes between surgical and endovascular approaches to FIA.

Methods

Literature search

We conducted a systematic review based on the PRISMA-IPD guidelines [22, 31], searching the Medline database for articles published on the treatment of FIA. Last date of search was March 3, 2020. The PICOS components of the research question we sought to answer were (P) patients with FIA, (I) neurosurgery, (C) endovascular treatments, (O) long-term functional and angiographic outcomes, and (S) any study design presenting individual patient data. The search strategy combined the terms “fusiform,” “intracranial,” “cerebral,” “vertebrobasilar,” and “aneurysm,” in both “AND” and “OR” combinations, in the “all fields” modality. The term “vertebrobasilar” was included due to the higher prevalence of fusiform morphology in this specific location. No time or language restrictions were applied, and additional articles were identified by hand searching the articles’ references.

Study selection

Abstracts were screened and selected for full article consideration according to the following inclusion criteria: studies of intracranial aneurysms in humans detailed at patient-level describing clinical outcomes in terms of performance scales (e.g., Modified Rankin Scale, Glasgow Outcome Scale). To optimize the number of patients included, we sought not only for studies exclusively about FIAs but also papers on intracranial aneurysms in general that included at least five patients with FIAs.

Studies were excluded if not fulfilling all the inclusion criteria, written in languages other than English, patients who had both endovascular and surgical treatments, single case reports or technical notes, or if the number of subjects with fusiform aneurysms < 5. All pediatric patients (< 18 years old) were excluded from the analysis, regardless of studies being focused exclusively on this population or not. Two independent authors retrieved the data, and disagreements were solved with a senior author’s opinion.

Data extraction

Abstracted data included age (in years), gender, location of the aneurysm, size (defined as the largest diameter), rupture status, treatment modality (surgical or endovascular), and

conflict of interest in the study. For cases in which age was reported, for example, as “early 40s,” “mid 40s,” or “late 40s,” these were considered 40, 45, and 50, respectively.

The primary studied outcome was morbidity, defined as mRS worsening compared to pretreatment status. For unknown baseline assessment, mRS worsening was defined as final mRS > 1. Functional status pre and postoperatively was converted to modified Rankin Scale (mRS) whenever possible.

Secondary outcomes were long-term angiographic results and retreatment. Long-term angiographic outcomes (> 3 months) were coded as Favorable (complete occlusion, aneurysm obliteration, bypass patent, stable wrapping) or Unfavorable (recanalization, residual aneurysm, incomplete occlusion, bypass occluded).

Original data

Data from patients treated for FIA in our institution from 2010 to 2018, both surgically or endovascularly, were also collected according to the same specifications above. Medical records were retrospectively analyzed, including admissions and outpatient visits. The final mRS refers to the latest available consultation, which was > 6 months for all cases except the deceased and one lost to follow-up.

Decision on treatment options for FIA at our institution is multidisciplinary. A board of vascular neurologists, vascular neurosurgeons, and expert endovascular practitioners discusses each case. The proposed alternatives are then explained to the patient, until a final decision is reached.

Data analysis

Since treatment nuances vary widely among anatomical sites, analyses were stratified according to three location groups—cavernous ICA (cICA), supraclinoid (ACA, MCA, and supraclinoid ICA), and vertebrobasilar (vertebral, basilar, and posterior cerebral arteries).

Mixed-effects logistic regressions with propensity score (PS) adjustment were modeled to evaluate predictors of morbidity. The PS regressed treatment category (surgical or endovascular) on age, size, rupture status, and initial mRS. Details of PS calculation are reported in the [Electronic Supplementary Material](#). Studies were treated as clusters on the univariate and multivariable analyses [1], and we used a one-step meta-analytical approach. [7, 14, 17, 44]

Sensitivity analyses were conducted to model the primary outcome without propensity score adjustment. Secondary outcomes were studied with chi-squared tests. Risk of bias was assessed across studies by identifying papers that did not meet our eligibility criteria, excluding series with less than five participants, and excluding studies that did not report the primary outcome.

All tests were 2-sided, and final *P* values under 0.05 were considered statistically significant. Normality assumptions were checked with Shapiro-Wilk's test. Results are presented as count (valid percentage) or mean (standard deviation/interquartile range). Analyses were conducted with R (R Foundation for Statistical Computing, Vienna, Austria, 2018) and the STATA software (StataCorp. 2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP). This study was approved by the local Ethics Committee (ID: 12089), and patient consent was waived because of the retrospective design.

Results

Systematic review

We identified 1219 records in the database, plus three additional relevant studies by hand search. After duplicates were removed, 891 were screened, 159 full articles were assessed for eligibility, and 29 were included in the final synthesis, providing 296 individual patient data. [3, 5, 8, 10, 11, 16, 18–20, 24–29, 32–34, 38, 41–43, 45, 46, 48–52] The selection process is detailed in a flow diagram (Fig. 1).

Original data

Medical records of patients followed at our institution's cerebrovascular surgery clinic were reviewed, identifying 16 patients who underwent interventions for FIA (Table 1). Ten of them were submitted to endovascular procedures: 1 balloon occlusion, 6 embolizations, and 3 flow diverting stents. Six were treated with microsurgery: 2 clippings, 3 clip-wrappings, and 1 saccular bleb clipped.

Two patients died in the same admission: one from complications of SAH from the fusiform lesion (patient 5), one from SAH by another aneurysm later in the course of her hospital stay (patient 6). The only unfavorable angiographic outcome was a 28-year-old male who had a flow diverting stent placed in V4, whose 12-month angiographic follow-up demonstrated incomplete aneurysm obliteration.

Patient characteristics and treatment options

Compiling original and published data, there were 312 cases, of which 79 (25.3%) were treated with microsurgery and 233 (74.5%) were treated with endovascular procedures. Patient characteristics stratified by aneurysm location for 283 of them are summarized in Table 2, because anatomical site was not available for the other 29.

Table 3 lists the treatment options for FIA within each group. Open interventions tackled cICA aneurysms in 3 cases (2 wrappings and 1 clip wrapping) and by endovascular

procedures in 27 cases (16 stents, 9 stents + coil/balloon, and 2 balloon occlusions). Supraclinoid lesions were approached surgically in 58 patients. The two commonest strategies were bypassing (56.9%, either alone or combined with clipping, trapping, or excision) and clipping/clip reconstruction (15.6%). For the endovascular group, supraclinoid aneurysms were stented in 29 cases, in one case also deploying coils. Vertebrobasilar FIA were operated in 17 cases (6 parent artery occlusions, 5 bypasses, 4 wrappings, and 2 clip-wrappings) and endovascularly treated in 149 instances (70 stents, 46 parent artery occlusions, and 33 stents + coil/balloon).

Clinical outcomes

For each of the location strata, we modeled propensity score-adjusted regressions to study the relationship between treatment category (microsurgery or endovascular) and morbidity, and there were no significant associations (Table 4).

Among cICA aneurysms, post-procedure morbidity inflicted one surgically treated patient (33%) and seven endovascularly treated ones (26%). No differences were observed between groups (OR 1.04, 95% CI 0.05–23.6). Among the patients treated for supraclinoid FIA, 19 (33%) of the microsurgical group and 2 (6.9%) of the endovascular group worsened their clinical status after the intervention. The PS-adjusted analysis failed to demonstrate an association (OR 7.82, 95% CI 0.65–94.4). Patients with vertebrobasilar lesions had an mRS worsening in 4 (23.5%) surgical cases and 43 (28.9%) endovascular ones. There was no significant association between treatment category and morbidity (OR 0.45, 95% CI 0.05–3.9).

Risk factors for morbidity were evaluated in a separate, multivariable model that demonstrated a significant influence of size (each additional mm, OR 1.11, 95% CI 1.03–1.19) and initial mRS (each additional score, OR 2.0, 95% CI 1.2–3.3). Interaction terms were evaluated, all demonstrating that these associations were independent of location groups (all terms, *P* > 0.1). Neither age nor rupture status seemed to alter the odds of posterior morbidity (Table 5 and Fig. 2).

Angiographic outcomes, retreatment, and conflict of interests

Unfavorable long-term angiographic outcomes occurred in 42 cases from the endovascular group and in one case who underwent microsurgery, although this outcome was often unreported (Table 6). Within the group of cICA aneurysms, 7 (30.4%) patients submitted to endovascular procedures had unfavorable angiographic findings, but there were no long-term imaging assessments for any of the surgical cases, and applying the statistical test was considered inappropriate. Within the group of supraclinoid aneurysms, 6 (23.1%)

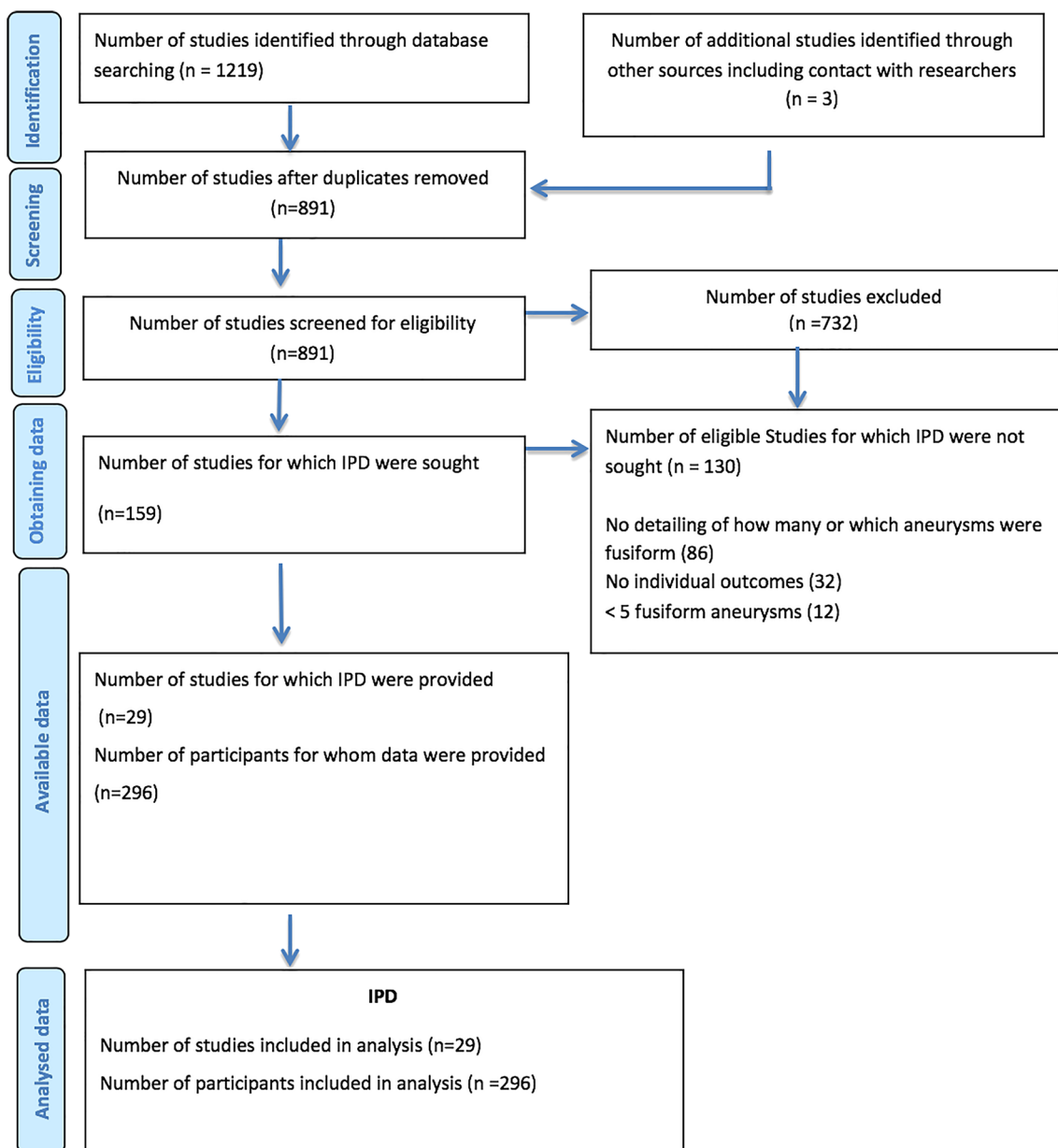


Fig. 1 Flow diagram. Flow diagram based on the PRISMA-IPD guidelines adapted to our study design

endovascular cases had this unfavorable outcome, compared to none of those submitted to microsurgery ($\chi^2 = 33.5$, $P < 0.01$). In the vertebrobasilar territory, endovascular cases yielded worse angiographic results: 29 unfavorable outcomes (26.4%) compared to 1 (16.6%) in the surgical group ($\chi^2 = 140.1$, $P < 0.01$).

Retreatment rates were not significantly different between surgery and endovascular procedures in any of the location strata (all $P > 0.05$, Table 7). Data from 101 patients (32.4%) originated from studies reporting conflicting interests, all of them belonging to the endovascular group (43.3% of those). Conflicting interest was not associated with the primary outcome (OR 1.55, 95% CI 0.86–2.8).

Sensitivity analyses

Sensitivity analyses were performed to evaluate the impact of the PS-adjustment on the results regarding the primary endpoint, morbidity (see Figure 3 of the Electronic Supplementary Material). When removing the PS, surgical treatment is associated with higher rates of morbidity compared to endovascular interventions ($P < 0.04$, see Figure 4, Electronic Supplementary Material). This difference is likely due to the unbalanced mean initial mRS between groups (surgery 1.6, endovascular 0.6), which was corrected via PS-adjustment. Comparisons within the other groups remained unassociated with the primary outcome.

Table 1 Patients treated for fusiform intracranial aneurysms at our institution

No.	Age	Gender	Ruptured	Diameter (mm)	Location	Procedure	Initial mRS	mRS discharge	Follow-up (months)	mRS FU	Angiographic outcome
1	60	F	No	36	cICA	Balloon occlusion	0	1	32	1	Favorable
2	53	F	Yes	8	V4	Embolization	2	1	19	1	Favorable
3	23	F	Yes	5	PCA	Embolization	0	NA	12	1	Favorable
4	30	M	No	6	PCA	Embolization	1	0	7	0	Favorable
5	61	M	Yes	6	V4	Embolization	5	6	0	6	NA
6	83	F	No	18	cICA	Embolization	5	6	0	6	NA
7	38	F	Yes	4.3	V4	Embolization	4	4	11	4	Favorable
8	58	M	Yes	2.4	Basilar	Flow diverting stent	0	1	6	1	NA
9	28	M	No	2.5	V4	Flow diverting stent	0	0	12	0	Unfavorable*
10	69	F	No	13	sICA	Flow diverting stent	2	1	6	1	NA
11	60	F	Yes	10	ACM	Clipping	3	1	6	1	Favorable
12	64	M	Yes	5	ACA	Clipping	1	3	6	3	Favorable
13	53	M	Yes	6	AComm	Clip wrapping	1	1	9	1	Favorable
14	70	F	No	5	sICA	Clip wrapping	1	3	6	3	Favorable
15	52	F	No	3.5	AComm	Clip wrapping	5	3	NA	NA	NA
16	61	F	Yes	9	sICA	Saccular bleb clipped	2	1	8	1	Favorable

cICA, cavernous ICA; sICA, supraclinoid ICA; NA, not available

*Follow-up angiography (12 months) showed residual aneurysm

Table 2 Patient baseline characteristics

		All	Surgical	Endovascular	P^\dagger
Cavernous ICA	<i>n</i>	30 (100)	3 (10)	27 (90)	
	Age	58.8 (22)	50 (8.5)	59.8 (21)	0.18
	Female	18 (85.7)	3 (100)	15 (83.3)	0.45
	Size (mm)	13.3 (9.9)	4 (0)	13.6 (9.9)	-
	Ruptured	9 (30)	1 (33.3)	8 (29.6)	0.89
	Initial mRS	1.1 (1.5)	NA*	1.1 (1.5)	-
Supraclinoid	<i>n</i>	87 (100)	58 (66.6)	29 (33.3)	
	Age	50.5 (21.5)	48.2 (20.7)	55.3 (19)	0.03
	Female	47 (54.6)	30 (51.7)	17 (60.7)	0.43
	Size	15.2 (13)	16 (12)	13.5 (8.5)	0.33
	Ruptured	20 (23)	20 (34.5)	0 (0)	< 0.01
	Initial mRS	1.4 (2)	1.6 (1.5)	0.6 (1)	0.02
Vertebrobasilar	<i>n</i>	166 (100)	17 (10.2)	149 (89.8)	
	Age	51.7 (18)	47.1 (17)	52.2 (17)	0.14
	Female	52 (40.3)	6 (35.3)	46 (41.1)	0.65
	Size	13.5 (11.7)	23 (13.7)	12.6 (9.8)	0.02
	Ruptured	67 (40.4)	5 (29.4)	62 (41.6)	0.33
	Initial mRS	2.3 (2)	2.6 (1)	2.3 (2.2)	0.51

Data are presented as either mean (interquartile range) or count (valid percentage)

Supraclinoid refers to ICA, ACA, and MCA

$^\dagger P$ values refer to *t* tests, Mann-Whitney *U* tests, or chi-squared tests, as appropriate

*Initial mRS was not available for any of these patients

Table 3 Surgical and endovascular treatment options

	Treatment	Cavernous ICA	Supraclinoid	Vertebrobasilar
Surgical	Bypass + clipping/trapping/excision		33 (56.9)	5 (29.4)
	Wrapping	2 (66.6)	4 (6.9)	4 (23.5)
	Parent artery occlusion		1 (1.7)	6 (35.3)
	Clipping/clip reconstruction		9 (15.6)	
	Clip wrapping	1 (33.3)	5 (8.6)	2 (11.8)
	Trapping ± excision		5 (8.6)	
	Excision + reanastomosis		1 (1.7)	
	Total	3 (100)	58 (100)	17 (100)
Endovascular	Stent alone	16 (59.3)	28 (96.6)	70 (47)
	Stent + coil/balloon	9 (33.3)	1 (3.4)	33 (22.1)
	Balloon/coil parent artery occlusion	2 (7.4)		46 (30.9)
	Total	27 (100)	29 (100)	149 (100)

Data are presented as count (valid percentage)

Discussion

Post-procedure morbidity was not significantly different between surgical and endovascular treatments for fusiform intracranial aneurysms. Larger aneurysms and higher initial mRS were correlated with morbidity, but age and rupture status were not. Angiographic results tend to be more favorable in surgically treated patients, except for cICA aneurysms, in which no analyses were possible. Retreatment rates did not differ between treatment categories, and conflicting interests did not seem to influence the primary outcome.

Conservative management and interventions

Many authors have proposed conservative management for asymptomatic lesions. [23, 39, 40] This is indeed a reasonable option because, as we have found in our study, treatment for FIAs still harbors significant risks and often leads to functional impairment. Other studies with designs focused on comparing watchful waiting and invasive management are needed to determine when and which interventions are beneficial.

However, when clinical presentation prompts intervention, the strategy will depend on patient status and characteristics of

the lesion. [4, 40, 41] Arguments in favor of endovascular treatments include the invasiveness of their surgical counterparts, while open surgeries are usually seen as definitive solutions with frequently satisfying angiographic results.

Treatment options differ among anatomical locations

The procedural risk and technical considerations for approaching lesions vary widely among anatomical locations. For instance, a large M1 aneurysm cannot be compared to a small V4 one. In order to provide an adequate comparison, we chose to analyze three territories separately: cICA, supraclinoid, and vertebrobasilar.

Cavernous ICA aneurysms present very specific particularities due to their anatomical location, rarely presenting with SAH. Reports of cICA FIAs treated microsurgically were very scarce, and intervention options included stenting and parent artery occlusion.

On the other hand, supraclinoid are more easily accessed using standard pterional and orbitozygomatic craniotomies, and this group concentrated most of the microsurgically treated lesions. Reconstructive techniques in these cases, such as

Table 4 Comparison of morbidity between surgical and endovascular treatments

	Surgical	Endovascular	OR	95% CI	P value
Cavernous ICA	1 (33.3)	7 (26)	1.04	0.05–23.6	0.98
Supraclinoid	19 (33.3)	2 (6.9)	7.82	0.65–94.4	0.11
Vertebrobasilar	4 (23.5)	43 (28.9)	0.45	0.05–3.9	0.47

Mixed-effects, propensity score–adjusted logistic regression models compared morbidity after surgery and endovascular procedures. The propensity score included age, size, rupture status, and initial functional performance score, according to the modified Rankin Scale

OR, odds ratio; CI, confidence interval; ICA, internal carotid artery

Table 5 Risk factors for morbidity

	OR	95% CI	P value
Age	1.03	0.99–1.06	0.1
Size	1.09	1.04–1.15	<0.01
Ruptured	1.29	0.43–3.91	0.65
Initial mRS	1.51	1.1–2.07	0.01

Mixed-effects logistic regression studying possible risk factors for morbidity. Separate analyses demonstrated that size and initial mRS were risk factors independent of the location

OR, odds ratio; mRS, modified Rankin Scale

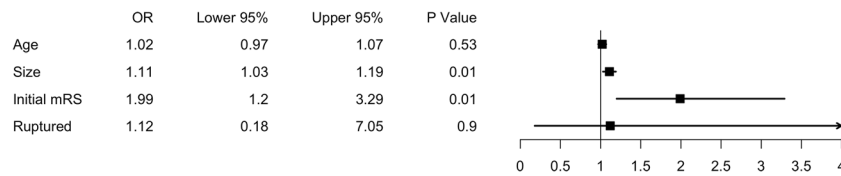


Fig. 2 Risk factors for postoperative morbidity. Forest plot showing the results of the mixed-effects logistic regression, evaluating risk factors for morbidity after treatment of fusiform aneurysms, both surgically and

endovascularly. The odds ratios (OR) are shown, together with the 95% confidence intervals and *P* values for the coefficients

wrapping or clip reconstruction, are focused on reestablishing the normal vessel lumen. [47] Endovascular techniques in this territory have to avoid occlusion of crucial perforators and preserve distal irrigation. [27]

Vertebrobasilar FIAs presented multiple treatment strategies in the included studies. While some vertebral aneurysms can be treated with parent artery occlusion without neurological compromise, exclusion of other arteries in this territory (such as the PICA) would lead to devastating outcomes due to cerebellar and brainstem infarcts. In these latter cases, stents and anastomoses are needed to preserve distal blood flow. [24, 47]

Microsurgical and endovascular outcomes

We collected results from patients with fusiform lesions treated at our institution in the last 8 years and performed a systematic review to study a large number of cases from various centers. Our meta-analysis included individual patient data from over 300 patients, including our original sample and 29 published series. Selection bias is a critical concern in case reports and series, and studies with less than five patients were excluded in an attempt to minimize this problem. Furthermore, the lack of randomization also entails several biases, and we attempted to address this concern through propensity score adjustment. [14]

Surgery and endovascular did not result in significantly different morbidity for any of the anatomical sites. For the supraclinoid aneurysms, the unadjusted model demonstrated significance, but the adjusted regression did not. We believe

the large difference between baseline functional assessment was a confounder in the unadjusted analysis. However, the large confidence intervals for cICA and supraclinoid anterior circulation aneurysms should be interpreted carefully, signaling that a larger sample could be necessary for more robust conclusions.

Size and initial mRS seem to be more important risk factors for morbidity than age and rupture status. Although patient independence and functionality is always the priority, angiographic outcomes are another essential part of the treatment evaluation. In our analysis, microsurgery seems to have yielded better angiographic results after the treatment of supraclinoid and vertebrobasilar aneurysms, but these were exploratory analyses that should be validated in other studies.

This sort of information is valuable when facing difficult clinical decisions where both surgical and endovascular treatments are feasible. For patients with small aneurysms and good initial functional assessment, surgical intervention could provide definitive angiographic resolution with minimal functional impairment, regardless of rupture status. Especially in younger patients undergoing elective procedures, a definitive solution is extremely desirable, and microsurgery still yields adequate long-term solutions.

Our results also suggest that FIA are still associated with poor functional outcomes, much worse compared to saccular aneurysms. In a meta-analysis including 2404 clipped MCA aneurysms [2], unfavorable neurological outcomes were reported for 2.1% of the patients, while in our study, the rates range from 23.5 to 33.3%, depending on the location. The same meta-analysis also reported less than 5% of unfavorable neurological outcomes for coiling, whereas morbidity rates for endovascular procedures in the present study range from 6.9

Table 6 Long-term angiographic outcomes

	Surgical	Endovascular	χ^2	<i>P</i> value
Cavernous ICA	0 (0)*	7 (30.4%)		
Supraclinoid	0 (0)**	6 (23.1%)	33.5	< 0.01
Vertebrobasilar	1 (16.6%)	29 (26.4%)	140.1	< 0.01

Chi-squared tests compared long-term angiographic outcomes between surgical and endovascular procedures. Since no such outcomes were reported for patients with cavernous ICA aneurysms, the test was not performed for this population

ICA, internal carotid artery

*None reported; **26 cases reported

Table 7 Retreatment

	Surgical	Endovascular	χ^2	<i>P</i> value
Cavernous ICA	0 (0)*	1 (5.3)	0.16	0.68
Supraclinoid	2 (5)	0 (0)**	1.44	0.23
Vertebrobasilar	1 (5.9)	11 (8.4)	0.12	0.72

Chi-squared tests compared retreatment rates between surgical and endovascular patients

ICA, internal carotid artery

*3 cases; **28 cases

to 28.9%. [2] There is an urgent necessity to devise more efficient operative techniques, clinical management practices, or neurointerventional devices to improve the quality of life of patients with FIA.

Study limitations

This study presents several limitations. The design brings a significant amount of selection and publication biases that were minimized with study eligibility criteria and statistical methods, but most certainly not abolished. Particularly for angiographic outcomes, reporting was very heterogeneous, which is why we chose to conduct only chi-squared analyses, not more sophisticated regression models. These results should be interpreted as exploratory and need clarifying in further studies.

Moreover, both endovascular and surgical techniques evolve rapidly with time, and even though the earliest included study is from 2002, some of the outcomes could be different using current techniques. Conclusions must be evaluated carefully, and randomized clinical trials are ideally necessary to compare the different techniques.

Conclusion

There were no differences between morbidity of surgical and endovascular treatments, regardless of aneurysm location. Size and initial mRS were correlated with functional outcomes, whereas age and rupture status were not. Microsurgery seems to yield better long-term angiographic results compared to endovascular procedures.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10143-020-01440-x>.

Compliance with ethical standards

Conflict of interest the authors declare that they have no conflict of interest.

Ethics approval This study was approved by the local Ethics Committee (ID: 12089), and patient consent was waived because of the retrospective design.

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