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REVIEW

Treatment strategies and outcomes for intracranial fusiform aneurysms: A systematic review and meta-analysis

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Abstract

Background Fusiform aneurysms are a distinct subgroup of intracranial aneurysms with unique characteristics and pose a treatment challenge compared to common saccular aneurysms. Traditionally, surgery was the main treatment; however, endovascular techniques are gaining favor.

Methods We searched major databases for studies on treatment, clinical outcomes, and radiological outcomes of intracranial fusiform aneurysms published before May 31st, 2023 in order to compare surgical Vs endovascular treatment strategies. Pooled data analysis was performed using a random-effects model.

Results This systematic review and meta-analysis analyzed 1704 patients with 1737 fusiform aneurysms from 63 studies. Endovascular treatment, particularly stent-assisted coiling and stenting, emerged as the preferred approach with lower mortality and complication rates compared to surgery. Aneurysm location played a role in outcomes, with anterior circulation aneurysms generally faring better.

Deconstructive strategies, designed to occlude the parent artery, carried a doubled risk of complications compared to reconstructive approaches, which aim to preserve blood flow (OR: 2.188; 95% CI: 1.474–3.248; $p<0.001$).

Conclusion Endovascular techniques are becoming the mainstay of treatment for fusiform aneurysms, offering improved safety and efficacy compared to surgery. Anterior circulation location and reconstructive strategies are associated with better outcomes. However, no significant differences in OR for early complete occlusion were found between surgery and endovascular techniques at discharge and follow-up with very low heterogeneity among studies.

Keywords Endovascular Procedures · Fusiform Aneurysm · Intracranial · Microsurgery · Stent · Subarachnoid Hemorrhage

Introduction

Fusiform and dolichoectatic aneurysms represent a distinct subgroup of intracranial aneurysms with distinctive morphological characteristics and clinical presentations and pose a therapeutic challenge compared to the more common saccular malformations [1].

These aneurysms encompass a spectrum, ranging from subtle, fusiform dilatations of a single vessel to massive, dolichoectatic lesions often harboring a wall thrombosis [1]. Traditionally, the vertebrobasilar system has been recognized as the predominant topography [2, 3], although recent studies suggest a higher prevalence within the anterior circulation [1].

The absence of a well-defined neck amenable to surgical clipping for parent artery preservation presents a significant obstacle for the surgical management of fusiform and dolichoectatic aneurysms. Dolichoectatic aneurysms manifest with a diverse range of clinical symptoms attributable to three primary mechanisms: compression of adjacent neural structures, rupture leading to hemorrhage, and ischemia arising from thromboembolic events [1].

The management of fusiform aneurysms is inherently complex, demanding meticulous preoperative planning and skillful execution for both endovascular and open surgical approaches. Although the specific treatment strategy need to be individually tailored for each according to factors like aneurysm topography, morphology, size and

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hemodynamic characteristics, certain general principles may be useful to guide the management of most patients [1].

To elucidate the rationale behind various treatment approaches, their radiologic outcomes, and associated clinical results, we conducted a comprehensive systematic review and meta-analysis of the relevant literature. Although similar previous papers were retrievable in literature, their search strategy appears weak due to the numerous nomenclatures that have been attributed to this subclass of aneurysms over time.

Material and methods

This meta-analysis was performed according to the PRISMA 2020 guidelines [4] and not registered in any database.

Search strategy

Two authors (GT and CLS) performed a comprehensive literature search of the PubMed/MEDLINE, Cochrane Library databases and main on-line trials registries (clinicaltrials.gov; clinicaltrialsregister.eu) to identify relevant studies on treatment, clinical and radiological outcomes of intracranial fusiform aneurysms.

The search algorithm used was based on a combination of terms, as follows: *(fusiform OR non-saccular OR nonsaccular OR dolichoectasi* OR dissect*) AND (aneurysm) AND (intracranial OR willis OR carotid artery OR middle cerebral artery OR anterior cerebral artery OR vertebral artery OR basilar artery OR brain OR cerebral) AND (treatment OR surgery OR endovascular OR clipping OR trapping OR by-pass OR coiling OR stent OR flow-diver*).*

We excluded "complex aneurysms" from the search-terms as this definition includes heterogeneous cases that go beyond the morphological definition of fusiform aneurysm (according to Huber's definition [5]), such as, for example, giant saccular, thrombosed saccular, serpentine and saccular aneurysm branching collaterals.

We considered as complications all symptomatic both ischemic or hemorrhagic events occurred after surgical or endovascular treatment.

The search was updated to December 31st, 2023, with no beginning time limit. To expand the search, a forward search within the references of the retrieved articles was performed to screen for additional studies.

Studies selection

Studies investigating the treatment of intracranial fusiform aneurysms, namely an arterial dilation greater than 1.5 times the normal diameter without any neck [5], were included. The following exclusion criteria were used: (a) studies on post-traumatic dissection or on aneurysms defined more generally as complex; (b) case reports or series with fewer than 5 patients; (c) reviews, editorials, and letters; (d) studies lacking specific treatment details or focusing solely on radiology; (e) studies pooled with literature reviews preventing extraction of detailed of institutional series; (f) animal studies; (g) studies not published in English.

A conservative management was defined as clinic-radiological observation plus or not antithrombotic or antiplatelet therapy.

In cases of potential patient overlap between publications, the most comprehensive article was included in the meta-analysis to avoid duplication.

Two reviewers (CLS and AB) independently screened titles and abstracts retrieved by the search algorithm. Studies meeting inclusion/exclusion criteria were selected for full-text review. After excluding ineligible articles, a forward citation search of the references identified additional relevant studies for inclusion. Disagreements were resolved through consensus meetings.

Data extraction

For each eligible paper, we retrieved: basic study characteristics (author, year, study design), patient characteristics (total number of patients, number of aneurysms, demographics), characteristics of the aneurysm (location, size), presenting symptoms, treatment data (surgical or endovascular and specific treatment), treatment complications, radiological (aneurysm occlusion) and clinical outcome at discharge and follow-up according to either modified Rankin Scale (mRS) or Glasgow Outcome Scale (GOS). A good functional outcome was defined as mRS $\leq$ 2 or GOS $\geq$ 4.

Statistical analysis

Data from both dual-arm studies comparing surgical and endovascular methods and single-arm studies investigating each method separately were included in the analysis. Data derived from the single studies were statistically pooled according to a bivariate random-effects model (DerSimonian–Laird method). Pooled data are presented with 95% confidence intervals (95%CI). The pooled mean of quantitative data as patients' age, aneurysms' length and diameter were calculated by combining data exclusively from studies that reported mean values and standard deviations. One-arm or two-arms meta-analysis of proportions were used as appropriate. Incidence estimation was performed using either untransformed proportions or logit-transformed proportions, as appropriate. Odds Ratio (OR) were calculated to assess the association between a potential risk factor and VST. Heterogeneity was calculated by the I-squared index (I^2), representing percentage variation across studies that is due to heterogeneity rather than chance. In the presence of high heterogeneity, a meta-regression analysis was conducted to explore potential sources of variation. Statistical analyses were performed using OpenMetaAnalyst software (http://www.cebm.brown.edu/openmeta/). P values < 0.05 were considered statistically significant.

Results

Literature search

Our initial search identified 8435 papers potentially relevant to our topic based on our search algorithm. Following title and abstract screening, 54 articles were selected for full-text review. Further evaluation resulted in the exclusion of 11 articles and the identification of 20 additional studies through forward citation searching of the included papers' references. Ultimately, 63 studies reporting data on 1704 patients harboring 1737 intracranial fusiform aneurysms were included in the final analysis (Fig. 1, Table 1).

We identified studies dating back to 1981; among them, 35 focused exclusively on posterior circulation fusiform

Fig. 1 Prisma Diagram

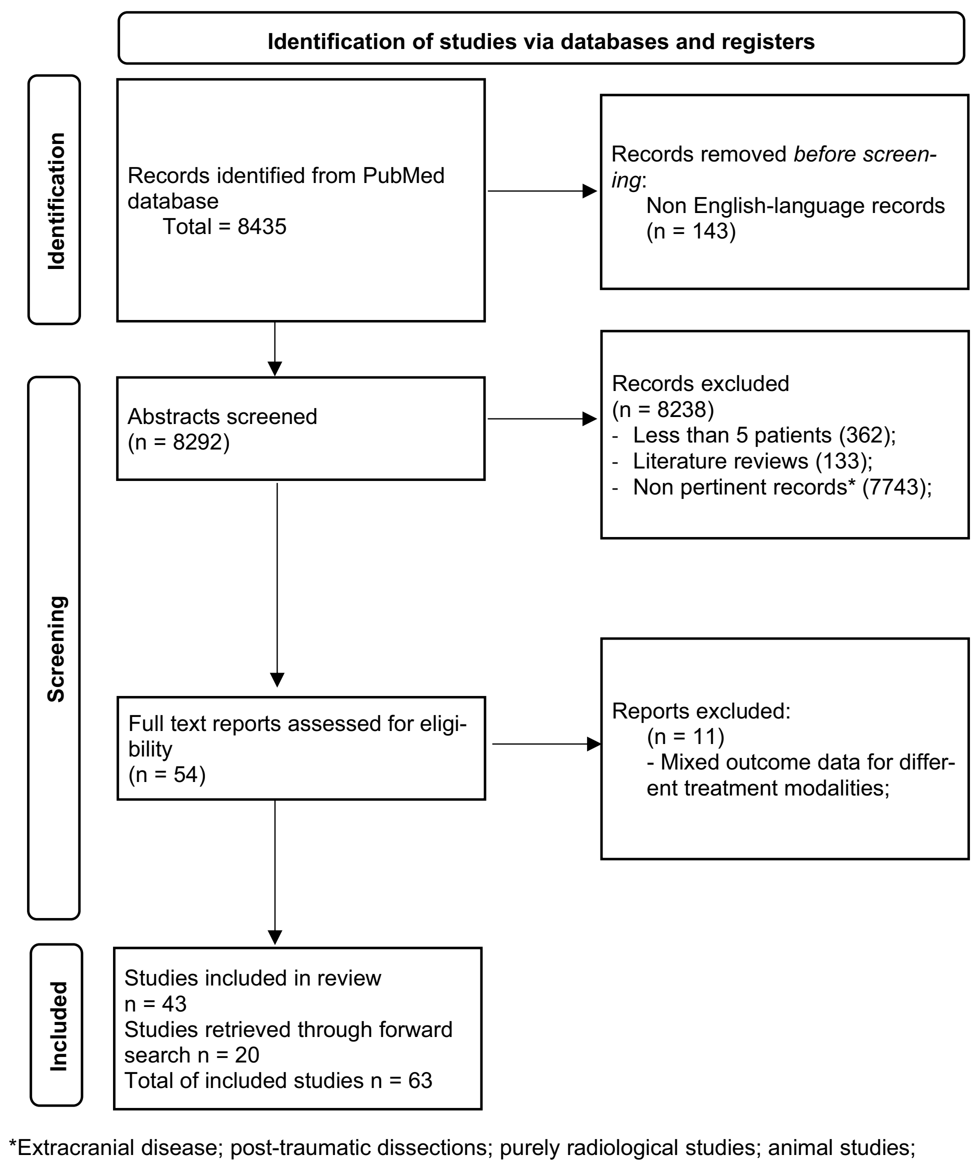

Table 1 Summary of the included papers

Author	Year	Patients N	Aneu-rysms N	AC N (%)	PC N (%)	Treatment					Radiological Out-come		Clinical Outcome				
						Conserv-ative N (%)	Surgery		Endovascular		Complete Occlusion (FUP)		Mortality			Functional Outcome in Alive Patients	
							AC N (%)	PC N (%)	AC N (%)	PC N (%)	Surgery N (%)	Endovas-cular N (%)	Con-servative N (%)	Surgery N (%)	Endo-vascular N (%)	Poor N (%)	Good N (%)
Little et al. [57]	1981	11	12	11 (91.7)	1 (8.4)	5 (41.7)	7 (58.3)	0	0	0	2 (16.7)	-	2 (18)	0	-	1 (9)	8 (73)
Chang et al. [8]	1986	6	6	0	6 (100)	0	0	6 (100)	0	0	na	-	-	0	-	0	5 (80)
Echiverri et al. [13]	1989	13	13	0	13	13	0	0	0	0	-	-	5 (38.5)	-	-	na	na
Yamaura et al. [39]	1990	24	26	0	26 (100)	7 (26.9)	0	19 (73.1)	0	0	na	-	2 (7.7)	0	-	4 (16.7)	18 (75)
Anson et al. [1]	1996	40	40	21 (52.5)	19 (47.5)	2 (5)	21 (52.5)	17 (42.5)	0	0	na	-	-	3 (7.5)	-	6 (15)	31 (77.5)
Gobin et al. [54]	1996	9	9	4 (44.5)	5 (55.5)	0	0	0	4 (44.5)	5 (55.5)	-	5 (55.5)	-	-	0	0	9 (100)
Drake et al. [51]	1997	113	113	23 (20.3)	90 (79.7)	0	23 (20.3)	88 (77.9)	1 (0.9)	1 (0.9)	na	na	-	15 (13.3)	1 (0.9)	6 (5.3)	91 (80.5)
Arat et al. [6]	2002	8	8	0	8 (100)	0	0	0	0	8 (100)	-	7 (87.5)	-	-	0	0	8 (100)
Findlay et al. [52]	2002	11	11	2 (18.2)	9 (90.9)	0	1 (9.1)	8 (72.7)	0	2 (18.2)	9 (90.9)	1 (9.1)	-	1 (9.1)	0	0	10 (90.9)
Leibowitx et al. [21]	2003	13	13	0	13 (100)	0	0	0	0	13 (100)	-	5 (38.5)	-	-	4 (30.8)	na	na
Deshmukh et al. [49]	2006	14	14	9 (64.3)	5 (35.7)	0	9 (64.3)	5 (35.7)	0	0	0	-	-	2	-	0 (14.3)	12 (85.7)
Coert et al. [11]	2007	49	49	0	49 (100)	0	0	22 (44.9)	0	27 (55.1)	na	na	-	na	na	8 (16.3)	29 (59.2)
Lubicz et al. [59]	2008	13	13	7 (53.8)	6 (46.2)	0	0	0	7 (53.8)	6 (46.2)	-	7 (53.8)	-	-	0	0	13 (100)

Table 1 (continued)

Author	Year	Patients N	Aneurysms N	AC N (%)	PC N (%)	Treatment					Radiological Outcome		Clinical Outcome				
						Conservative N (%)	Surgery		Endovascular		Complete Occlusion (FUP)		Mortality			Functional Outcome in Alive Patients	
							AC N (%)	PC N (%)	AC N (%)	PC N (%)	Surgery N (%)	Endovascular N (%)	Conservative N (%)	Surgery N (%)	Endovascular N (%)	Poor N (%)	Good N (%)
Park SH et al. [61]	2008	22	22	17 (77.3)	5 (22.7)	3 (13.6)	17 (77.3)	2 (9.1)	0	0	na	-	-	1 (4.5)	-	1 (4.5)	20 (90.9)
Wakhloo et al. [65]	2008	28	28	18 (64.3)	10 (35.7)	0	0	0	18 (64.3)	10 (35.7)	-	23 (82.1)	-	-	1 (3.6)	0	27 (96.4)
Seo et al. [44]	2009	6	6	6 (100)	0	0	6 (100)	0	0	0	na	-	-	1 (16.7)	-	2 (33.3)	3 (50)
Lv et al. [23]	2010	23	23	0	23 (100)	0	0	0	0	23 (100)	-	16 (69.6)	-	-	1 (4.4)	0	22 (95.6)
Sampath et al. [43]	2010	5	5	5 (100)	0	0	5 (100(	0	0	0	4 (80)	-	-	0	-	0	5 (100)
Suh et al. [64]	2010	20	20	5 (25)	15 (75)	0	0	0	5 (25)	15 (75)	-	15 (75)	-	-	2 (10)	0	18 (90)
Wang Q et al. [37]	2010	17	17	0	17 (100)	0	0	0	0	17 (100)	-	5 (29.4)	-	-	1 (5.9)	0	16 (94.1)
Liu et al. [22]	2011	12	12	0	12 (100)	0	0	0	0	12 (100)	-	5 (41.7)	-	-	0	0	12 (100)
Raphaeli et al. [29]	2011	31	31	0	31 (100)	0	0	0	0	31 (100)	-	18 (58.1)	-	-	6 (19.3)	3 (9.7)	22 (71)
Jeon et al. [56]	2012	12	12	7 (58.3)	5 (41.7)	0	0	0	7 (58.3)	5 (41.7)	-	7 (58.3)	-	-	0	0	12 (100)
Siddiqui et al. [33]	2012	7	7	0	7 (100)	0	0	0	0	7 (100)	-	na	-	-	4 (57.1)	1 (14.3)	2 (28.6)
Chen et al. [9]	2013	10	10	0	10 (100)	0	0	0	0	10 (100)	-	4 (40)	-	-	1 (10)	0	9 (90)
Devulapalli et al. [50]	2013	18	18	4 (22.2)	14 (77.8)	0	0	0	4 (22.2)	14 (77.8)	-	4 (22.2)	-	-	2 (22.2)	2 (22.2)	14 (77.8)

Table 1 (continued)

Author	Year	Patients N	Aneurysms N	AC N (%)	PC N (%)	Treatment					Radiological Outcome		Clinical Outcome				
						Conservative N (%)	Surgery		Endovascular		Complete Occlusion (FUP)		Mortality			Functional Outcome in Alive Patients	
							AC N (%)	PC N (%)	AC N (%)	PC N (%)	Surgery N (%)	Endovascular N (%)	Conservative N (%)	Surgery N (%)	Endovascular N (%)	Poor N (%)	Good N (%)
Kalani et al. [17]	2013	11	12	0	12 (100)	0	0	12 (100)	0	0	na	-	-	3 (27.3)	-	4 (36.4)	4 (36.4)
Meckel et al. [24]	2013	6	6	0	6 (100)	0	0	0	0	6 (100)	-	2 (33.3)	-	-	4 (66.7)	0	2 (33.3)
Pumar et al. [62]	2013	20	20	5 (25)	15 (75)	0	0	0	5 (25)	15 (75)	-	15 (75)	-	-	0	0	20 (100)
Rho et al. [31]	2013	11	11	0	11 (100)	0	0	0	0	11 (100)	-	9 (81.8)	-	-	0	0	11 (100)
Van Oel et al. [34]	2013	13	13	0	13 (100)	0	0	0	0	13 (100)	-	9 (69.2)	-	-	3 (23.1)	1 (7.7)	9 (69.2)
Dabus et al. [12]	2014	9	9	0	9 (100)	0	0	0	0	9 (100)	-	7 (77–8)	-	-	0	0	9 (100)
Ertl et al. [14]	2014	6	6	0	6 (100)	0	0	0	0	6 (100)	-	1	-	-	4 (67)	2 (33)	0
Fischer et al. [53]	2014	65	69	31 (44.9)	38 (55.1)	0	0	0	31 (44.9)	38 (55.1)	-	33 (47.8)	-	-	4 (6.1)	15 (23.1)	46 (70.8)
Kivipelto et al. [42]	2014	16	16	16 (100)	0	0	16 (100)	0	0	0	16 (100)	-	-	1 (6.3)	-	4 (25)	11 (68.7)
Monteith et al. [60]	2014	24	24	17 (70.8)	7 (29.2)	0	0	0	17 (70.8)	7 (29.2)	-	7 (29.2)	-	-	1 (4.2)	3 (12.5)	20 (83.3)
Munich et al. [25]	2014	12	12	0	12 (100)	0	0	0	0	12 (100)	-	11 (91.7)	-	-	1 (88.4)	4 (33.3)	7 (58.3)
Wang Y et al. [38]	2014	6	7	0	7 (100)	0	0	0	0	7 (100)	-	na	-	-	0	2 (33.4)	4 (66.6)

Table 1 (continued)

Author	Year	Patients N	Aneurysms N	AC N (%)	PC N (%)	Treatment					Radiological Outcome		Clinical Outcome				
						Conservative N (%)	Surgery		Endovascular		Complete Occlusion (FUP)		Mortality			Functional Outcome in Alive Patients	
							AC N (%)	PC N (%)	AC N (%)	PC N (%)	Surgery N (%)	Endovascular N (%)	Conservative N (%)	Surgery N (%)	Endovascular N (%)	Poor N (%)	Good N (%)
Park W et al. [28]	2015	21	21	0	21 (100)	0	0	4 (19)	0	17 (80.9)	4 (19)	13 (61.9)	-	0	1 (4.8)	4 (19)	16 (76.2)
Saliou et al. [32]	2015	18	18	0	18 (100)	0	0	11 (61.1)	0	7 (28.9)	7 (38.9)	4 (22.2)	-	3 (16.7)	1 (55.5)	1 (55.5)	13 (72.2)
Lawton et al. [20]	2016	16	16	0	16 (100)	0	0	16 (100)	0	0	3 (18.7)	-	-	12 (75)	-	3 (18.7)	1 (6.3)
Natarajan et al. [27]	2016	12	12	0	12 (100)	0	0	0	0	12 (100)	-	12 (100)	-	-	0	1 (8.3)	11 (91.7)
Bhogal et al. [7]	2017	56	58	0	58 (100)	0	0	0	0	58 (100)	-	27 46.6)	-	-	9 (16.1)	6 (10.7)	41 (73.2)
Safavi-Abbasi et al. [63]	2017	45	48	37 (77.1)	11 (22.9)	0	46 (95.8)	2 (4.2)	0	0	na	-	-	1 (2.2)	-	na	na
Wang J et al. [36]	2017	8	8	0	8 (100)	0	0	0	0	8 (100)	-	0	-	-	1 (12.5)	0	7 (87.5)
Zhang Y et al. [40]	2017	309	323	27	296	0	0	0	27	296	-	250	-	-	9 (2.9)	15 (4.9)	285 (92.2)
Lozupone et al. [58]	2018	9	9	5 (55.6)	4 (44.4)	0	0	0	5 (55.6)	4 (44.4)	-	8 (88.9)	-	-	1 (11.1)	1 (11.1)	7 (77.8)
Xu F et al. [46]	2018	20	20	20 (100)	0	0	20 (100)	0	0	0	19 (95)	-	-	0	-	2 (10)	18 (90)
Zhang H et al. [67]	2018	12	12	0	12 (100)	0	0	7 (58.3)	0	5 (41.7)	na	na	-	2 (16.7)	0	3 (25)	7 (58.3)

Table 1 (continued)

Author	Year	Patients N	Aneurysms N	AC N (%)	PC N (%)	Treatment					Radiological Outcome		Clinical Outcome				
						Conservative N (%)	Surgery		Endovascular		Complete Occlusion (FUP)		Mortality			Functional Outcome in Alive Patients	
							AC N (%)	PC N (%)	AC N (%)	PC N (%)	Surgery N (%)	Endovascular N (%)	Conservative N (%)	Surgery N (%)	Endovascular N (%)	Poor N (%)	Good N (%)
Griessenauer et al. [15]	2018	53	53	0	53 (100)	0	0	0	0	53 (100)	-	39 (73.6)	-	-	5 (9.6)	7 (13.5)	40 (76.9)
He et al. [16]	2019	19	19	0	19	0	0	0	0	19 (100)	-	15 (78.9)	-	-	1 (5.3)	3 (15.8)	15 (78.9)
Hu et al. [41]	2019	5	5	5 (100)	0	0	5 (100)	0	0	0	5 (100)	-	-	0	-	0	5 (100)
Laukka et al. [19]	2019	5	5	0	5 (100)	0	0	0	0	5 (100)	-	5 (100)	-	-	0	1 (20)	4 (80)
Wagner et al. [35]	2020	45	45	0	45 (100)	33 (73.3)	0	3 (6.7)	0	9 (20)	na	na	19 (61.3)	1 (3.2)	6 (19.3)	1 (3.2)	4 (12.9)
Borota et al. [48]	2021	26	26	13 (50)	13 (50)	0	0	0	13 (50)	13 (50)	-	14 (53.8)	-	-	0	2 (7.7)	24 (92.3)
Church et al. [10]	2021	84	84	0	84 (100)	0	0	31	0	53 (63.1)	na	na	-	na	na	19 (32.2)	40 (67.8)
Griffin et al. [55]	2021	29	30	16 (53.3)	14 (46.7)	0	0	0	16 (53.3)	14 (46.7)	-	15 (50)	-	-	1 (16.7)	3 (50)	2 (33.3)
Nakatomi et al. [26]	2021	32	32	0	32 (100)	11 (34.4)	0	21 (65.6)	0	0	15 (46.9)	-	10 (32.2)	11 (35.5)	-	4 (12.9)	6 (19.4)
Rezai Jahromi et al.30	2022	10	10	0	10 (100)	0	0	10 (100)	0	0	3 (30)	-	-	4 (10%)	-	1 (16.7)	5 (83.3)
Teranishi et al. [45]	2022	8	8	8 (100)	0	0	0	0	8 (100)	0	-	8 (100)	-	-	0	0	8 (100)
Xu C et al. [66]	2022	67	71	26 (36.6)	45 (63.4)	0	0	0	26 (36.6)	45 (63.4)	-	50 (70.4)	-	-	1 (1.5)	1 (1.5)	65 (97)

Table 1 (continued)

Author	Year	Patients N	Aneurysms N	AC N (%)	PC N (%)	Treatment					Radiological Outcome		Clinical Outcome				
						Conservative N (%)	Surgery		Endovascular		Complete Occlusion (FUP)		Mortality			Functional Outcome in Alive Patients	
							AC N (%)	PC N (%)	AC N (%)	PC N (%)	Surgery N (%)	Endovascular N (%)	Conservative N (%)	Surgery N (%)	Endovascular N (%)	Poor N (%)	Good N (%)
Ban et al. [47]	2023	25	25	6 (24)	19 (76)	0	0	0	6 (24)	19 (76)	-	21 (84)	-	-	0	0	25 (100)
Kim et al. [18]	2023	36	36	0	36 (100)	0	0	0	2 (5.6)	34 (94.4)	-	22 (61.1)	-	-	1 (2.7)	3 (8.6)	32 (91.4)
TOTAL		1704	1737	371 (21.4)	1366 (78.6)	74 (4.3)	176 (10.1)	284 (16.4)	202 (11.6)	1001 (57.6)	87/138 (63)	719/1091 (65.9)	38 (2.2)	61 (3.6)	77 (4.5)	150 (8.8)	1240 (72.8)

Abbreviations: follow-up (FUP), anterior circulation (AP), posterior circulation (PC)

Functional outcome was assessed in surviving patients using the modified Rankin Scale (mRS) and Glasgow Outcome Scale (GOS). Outcomes were considered good if mRS was 0–2 or GOS was 4–5, and poor if mRS was 3–5 or GOS was 2–3

Follow-up total occlusion rates were calculated based on the number of patients with available follow-up data for each treatment

aneurysms [6–40], and other 6 reported data only on anterior circulation [41–46]. The majority of the retrieved papers were monocentric studies and only 2 presented prospective series [21, 36], while the remaining 61 reporting retrospective data [1, 6–20, 22–35, 37–67].

A pooled quantitative analysis (meta-analysis) was performed for those data which were numerically reported in the manuscript or that could be inferred by an accurate reading of the full text.

Epidemiology and presenting symptoms

Selected papers report data on 1704 patients harboring 1737 aneurysms. Of the 24 manuscripts that reported mean age and standard deviation, the pooled mean age was 51.2 years (CI95%: 49.5–55.8 years). Unlike saccular aneurysms, males showed a significantly higher estimated risk difference (RD) to develop a fusiform aneurysm compared with females (RD: 0.148; 95%CI: 0.053–0.243; $p = 0.002$).

Overall, fusiform aneurysms were significantly more frequent in the posterior circulation (1366 out of 1737 cases), with a pooled prevalence (PP) of 74.3% (95%CI: 69%−79.5%, $p < 0.001$). The most common locations were the basilar and vertebral arteries (31.1% and 30.7% of cases, respectively), followed by the internal carotid (11.7%), middle cerebral (10%), posterior cerebral (9.9%), posterior-inferior cerebellar (3.1%), anterior cerebral (2.3%), superior cerebellar (0.8%) and anterior communicating (0.5%) arteries.

The mean length and maximum diameter of the fusiform aneurysms were incompletely reported, with data available in 10 and 35 papers, respectively. The pooled mean length was 23.7 mm (95% CI: 15.1–32.3 mm), and the pooled mean maximum diameter was 15.7 mm (95% CI: 8.5–22.9 mm).

While vessel dissection is considered the main culprit behind fusiform aneurysms, only a small number of the retrieved studies (13 out of 63) investigated the actual aneurysm etiology [21, 22, 24, 28, 31, 32, 34, 40, 49, 54, 59, 61, 65]. Among these studies, dissection was presumed to be the cause in 420 out of 503 aneurysms (83.5%). Likewise, data on intra-aneurismal spontaneous thrombosis at neuroimaging were incompletely reported. Indeed, 524/933 aneurysms (56.2%) were partially thrombosed at diagnosis.

The most common presenting symptoms were headache (436 patients; PP: 30%; 95%CI: 23.2%–36.7%), motor deficits (110 patients; PP: 6.8%; 95%CI: 4.9%–8.7%) and cranial nerves deficits (62 patients; PP: 4.1%; 95%CI: 2.6%–5.6%).

The main causes of these symptoms were bleeding, mass effect or stroke. Bleeding at presentation occurred in 394 cases (PP: 26%; 95%CI: 20.6%–31.4%), with no higher Odds Ratio (OR) in anterior compared with posterior circulation aneurysms (OR: 1.344; 95%CI 0.838–2.155; $p = 0.2$). The unruptured aneurysms caused mass effect in 216 cases (PP: 13.8%; 95%CI: 10.7%–16.8%), while an aneurysm-related stroke occurred in 208 patients (PP: 9.4%; 95%CI: 7.1%–11.7%).

Treatment

Conservative treatment

The majority of patients received invasive treatment for their aneurysms. Indeed, conservative management, including observation or antithrombotic therapy, was implemented in only 74 of the 1737 aneurysms studied (PP: 5.5%; 95%CI: 3.8%−7.2%) [1, 13, 26, 35, 39, 57, 61]. Echiverri et al. [13] were the only authors to report a solely pharmacological approach using antithrombotic medications.

Surgical treatment

Surgery was performed in 460 aneurysms (PP: 30.9%; 95%CI: 22.3%−39.4%). Notably, the OR for surgical treatment was significantly higher for anterior circulation fusiform aneurysms compared with posterior circulation ones (OR: 3.588; 95%CI: 2.081–6.186; $p = < 0.001$), with very low heterogeneity among studies ($I^2 = 0$).

Parent artery occlusion (PAO) was the most common surgical technique (190/460 cases, 41.2%). Among the different techniques of PAO, surgical trapping was used in 24 out of 190 cases (5.2% of total surgical cases), followed by by-pass surgery (142 cases, 30.7%) associated with PAO (surgical or endovascular) or aneurysm trapping or resection. Clipping reconstruction was used in 66 cases (14.3%), aneurysm wrapping in 56 (12.5%), other techniques including thrombectomy in 6 cases (1.3%).

Endovascular treatment

Endovascular treatment was performed in 1203 aneurysms (PP: 64.4%; 95%CI: 54.6%–74.3%), with a trend towards an increasing utilization of endovascular techniques in more recent studies. The Odds Ratio of posterior circulation aneurysms receiving endovascular intervention was significantly higher compared with anterior circulation ones (OR: 2.521; 95%CI: 1.457–4.359; $p < 0.001$). Among endovascular techniques, stenting was the most common (549/1203 cases, with 373 of these being a flow-diverter device and the remaining 176 a conventional intracranial stent, followed by stent-assisted coiling (439 cases), parent artery occlusion (PAO) using coils, glue, or balloon (199 cases) and simple coiling (16 cases).

Comparing surgical and endovascular treatment, the overall OR of an intracranial fusiform aneurysm to be treated with an endovascular technique is significantly higher than to be treated with surgery (OR: 2.521; 95%CI: 1.457–4.359; $p < 0.001$). This is particularly evident in posterior circulation aneurysms (OR:19.554; 95%CI: 7.329–52.172; $p < 0.001$) but not in anterior circulation ones (OR: 0.427; 95%CI: 0.144–1.266; $p = 0.1$).

Deconstructive vs. reconstructive strategy

Overall, regardless the choice for surgical or endovascular approaches, the goals of fusiform aneurysms treatment were mainly two: deconstructive or reconstructive strategies. Aneurysm deconstruction aims to occlude the parent artery relying on spontaneous collateral circulation and was used in a total of 389 cases (PP:19.9%; 95%CI: 14.7%−25.1%), while a reconstructive approach through clipping, wrapping, stenting or by-pass aims to preserve a flow in the aneurysmal vessel and was used in 1274 cases (PP: 74.8%; 95%CI: 68.1%−81.5%).

Complications

Complications were reported in 409 patients (27%), with 164 of these showing a new neurological deficit after treatment.

Anterior circulation aneurysms showed a higher risk of complications compared with posterior circulation ones (OR: 1.634; 95%CI:1.104–2.418; $p = 0.01$).

Overall, surgery emerged as at higher risk of new deficits compared with endovascular treatments (OR: 1.757; 95%CI:1.026–3.008; $p = 0.04$), with very low heterogeneity among studies ($I^2 = 0\%$).

Even limiting the field to the two main complications, i.e. strokes and bleeding, surgery appeared riskier than endovascular treatment. In fact, 192 patients (11.2%) had stroke, and 62 (3.6%) experienced post-treatment bleeding. Surgery had an about twofold higher odds ratio compared to endovascular treatment for both complications (OR for stroke: 1.803; 95%CI:1.096–2.966; $p = 0.02$. OR for bleeding: 2.657; 95%CI:1.404–5.032; $p = 0.003$).

Overall, deconstructive techniques carried a significantly higher risk of complications compared with reconstructive techniques (OR: 2.188; 95% CI: 1.474–3.248; $p < 0.001$). This is evidenced by the lower complication rates of stent-assisted coiling (7.5%) and stenting (14.4%), in contrast to both endovascular and surgical PAO (31.9% and 22.6%, respectively). However, among surgical procedures, PAO had a lower complication rate compared with bypass procedures (22.6% vs. 36.6%).

Radiological outcomes at discharge and follow-up

Surgical treatment

Radiological outcomes were inconsistently reported at both early and late time points. Indeed, data on aneurysm occlusion at discharge were available for 76 surgical cases, reported by 7 studies [26, 28, 41, 43, 46, 49, 57]. Among these, complete occlusion was achieved in 50 aneurysms (71% 95%CI: 36.8–91.1%).

At a mean follow-up of 3 years (range: 0.5–7 years), surgical treatment achieved complete occlusion in 87 out of 138 aneurysms (66%; 95% CI: 41.8–84%) based on 12 studies [20, 26, 28, 30, 32, 41–43, 46, 49, 52, 57]. However, this rate was accompanied by a high degree of heterogeneity ($I^2=72.65\%$), suggesting significant variability among studies (Fig. 2).

Due to the limited number of studies with direct comparisons between treatment groups or control groups, an overall meta-regression to investigate the sources of heterogeneity was not feasible. Nevertheless, a subgroup analysis revealed varying rates of complete occlusion at follow-up: surgical PAO (77.3%; 95% CI: 65.3–89.4%; $I^2=0\%$), bypass (70.1%; 95% CI: 34.8–91.2%; $I^2=66\%$), clip reconstruction (84.3%; 95% CI: 70.2–98.3%; $I^2=0\%$), and wrapping (37%; 95% CI: 3.6–90.3%; $I^2=66\%$).

It's noteworthy that surgical PAO and clip reconstruction had consistently high complete occlusion rates with minimal heterogeneity, while wrapping had a lower rate with moderate heterogeneity, with a very limited number of studies reporting outcomes in the latter subgroup. The bypass group demonstrated moderate heterogeneity, and a meta-regression analysis on this subgroup found age to be negatively associated with complete occlusion, with a coefficient of −0.037 (95% CI: −0.067/−0.007; p = 0.017). This indicates that older patients may be less likely to achieve complete occlusion in the bypass group (Fig. 3).

However, these results are subject to limitations due to the irregular reporting of complete occlusion data in the retrieved studies.

Endovascular treatment

Data on early complete occlusion were reported in 20 studies [6, 7, 12, 14, 18, 19, 21–23, 28, 29, 31, 36, 47, 53, 56, 59, 64–66], encompassing 473 aneurysms. Complete occlusion was achieved in 188 of these 473 cases (44.1%; 95%CI: 28.1%–60.6%), with a high degree of heterogeneity ($I^2=91.2\%$).

At a mean follow-up of 1.6 years (range 0.3–4 years) a complete occlusion was achieved in 719 out of 1093

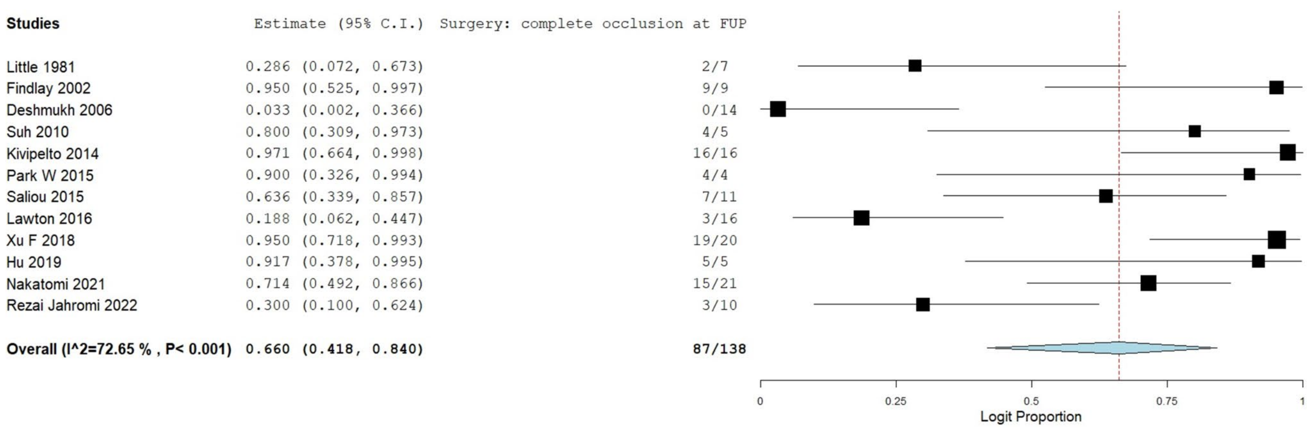

Fig. 2 Complete occlusion at follow-up in surgical cases

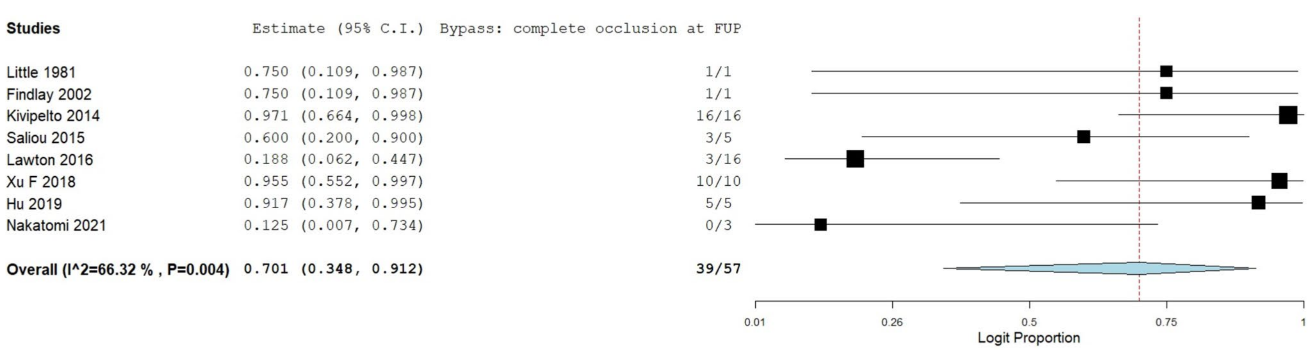

Fig. 3 Complete occlusion at follow-up in bypass surgical cases

aneurysms (62.%; 95%CI: 55.1–68.5%) across 39 studies [6, 7, 9, 12, 14–16, 18, 19, 21–25, 27–29, 31, 32, 34, 36, 37, 40, 45, 47, 48, 50, 52–56, 58–60, 62, 64–66], with high heterogeneity among studies (I^2 = 69.6%; Fig. 4).

A detailed analysis of the radiological outcome according to the specific endovascular technique was available for 603 of these 719 cases. Stent-assisted coiling achieved a complete occlusion in 72.2% of cases (95%CI: 61.6–80.7%), with heterogeneity among studies significantly related to the year of publication at meta-regression analysis ($p < 0.001$; Fig. 5).

Regarding stenting, we analyzed the outcomes of sole stenting and flow-diverters separately. Sole stenting achieved a complete occlusion rate of 62.6% (95% CI: 49.8–73.9%). While there was moderate heterogeneity among studies (I^2 = 36%), no significant associations were found between complete occlusion and year of publication, mean follow-up, or aneurysm diameter. Flow-diverter treatment achieved complete occlusion in 60.6% of cases (95% CI: 46.9–72.8%) at follow-up. However, there was substantial heterogeneity among studies (I^2 = 65.45%; Fig. 6a). A meta-regression analysis revealed that complete occlusion was inversely associated with aneurysm diameter (Coefficient: −0.166; 95% CI: −0.326 to −0.005; p = 0.04). In other words, larger aneurysms were less likely to achieve complete occlusion with flow-diverter treatment (Fig. 6b). Year of publication and duration of follow-up were not significantly associated with complete occlusion. No significant difference in OR for complete occlusion was seen between flow-diverters and sole stenting (OR: 1.188; 95%CI:0.545–2.589; p = 0.7).

Data on radiological outcomes of endovascular PAO were limited, with a reported occlusion rate of 56.7% (95% CI: 33.8–77.1%).

Comparison between surgical and endovascular treatment

At discharge, no significant difference in OR for early complete occlusion was found between surgery and endovascular techniques (OR: 1.809; 95%CI: 0.948–3.452; p = 0.07).

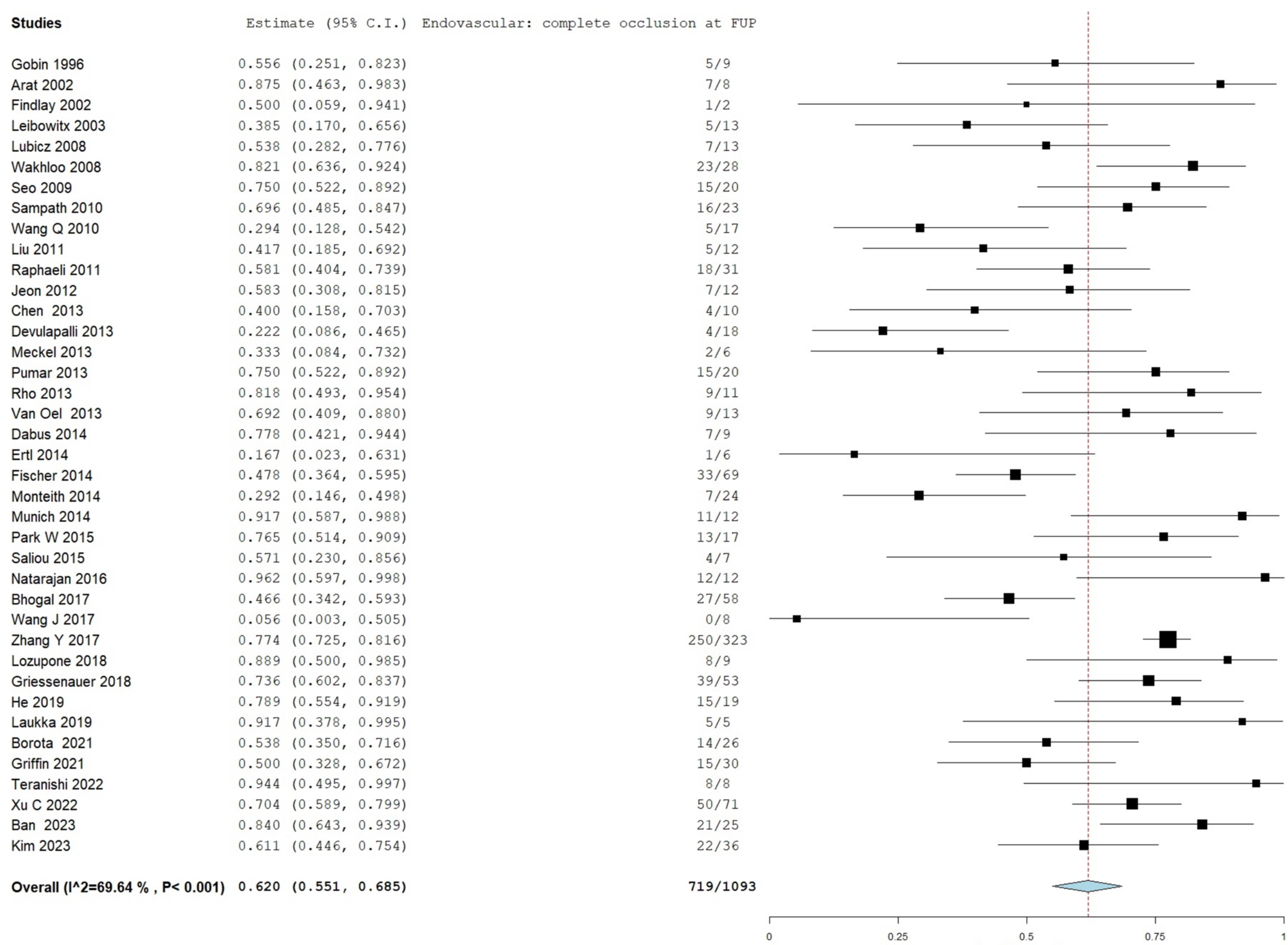

Fig. 4 Complete occlusion at follow-up in endovascular cases

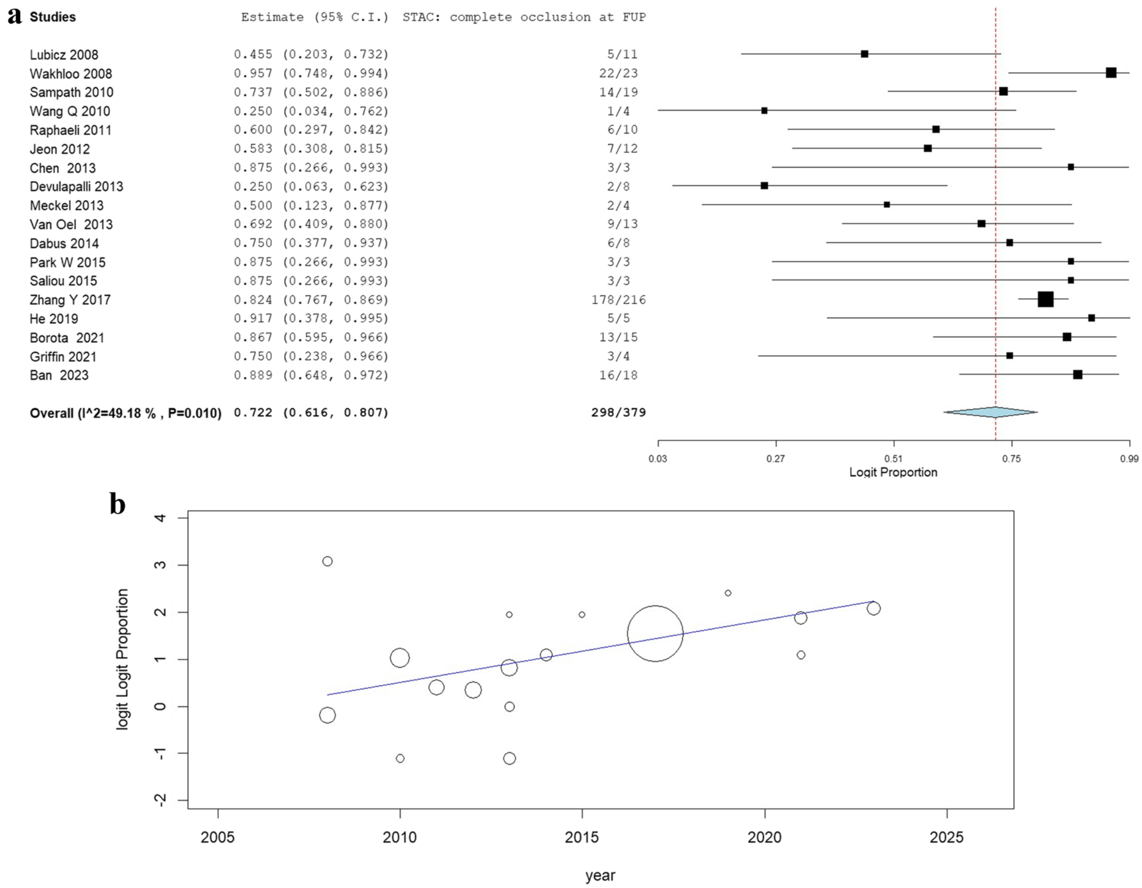

Fig. 5 **a** Complete occlusion at follow-up in stent-assisted coiling (STAC) cases. **b** Meta-regression: association between complete occlusion and publication year in STAC cases

At last follow-up, there was no significant difference in OR for complete occlusion between surgical and endovascular treatment (OR: 0.679; 95%CI: 0.405–1.13; p = 0.14), with very low heterogeneity among studies ($I^2 = 0\%$).

Clinical outcomes

Most studies reported data on clinical outcomes only at a single time point, more often being at last follow-up rather than at discharge.

Overall, 191 patients (pooled 10.5%; 95%CI: 8%−13.5%) died during follow-up, with only 2 Authors not reporting the distribution of 15 deceased patients between treatment groups [10, 11]. Mortality was significantly high in patients treated conservatively (38/74 patients, pooled 43.4%, 95%CI: 20.2%−66.7%) compared with surgery (61/460, pooled 16.6%, 95%CI: 8.1%−19.2%) and endovascular treatment (77/1203, pooled 5.5%, CI95%: 3.7%−7.3%). Nonetheless, surgery showed a significantly higher OR for mortality compared with endovascular therapy (OR: 2.353; 95%CI: 1.351–4.1; p = 0.003).

Accurate data on performance status after treatment was reported in 1397 of the 1510 surviving patients, with 1240 of these patients in a good status (mRS0-2 or GOS 4–5) at last available follow-up (45.5%; 95%CI: 67.9%−81.2%). However, we found a high heterogeneity between studies ($I^2 = 95$).

Patients with anterior circulation aneurysms achieved better outcomes at discharge (mean mRS: 1 for endovascular and 1.2 for surgical) compared to posterior circulation cases (mean mRS 1.2 and 1.8 for endovascular and surgical treatment, respectively). This favorable trend persisted at last follow-up, with anterior circulation aneurysms showing mRS of 0.7 and 1.4 for endovascular and surgical approaches, respectively, compared to 1.7 and 2.2 for posterior circulation cases.

Despite limited data on individual treatments, endovascular PAO showed the best outcomes (discharge mRS: 0.8, follow-up: 1.9) compared to other endovascular techniques (stenting: discharge 1.5, follow-up 1.4; stent-assisted coiling: discharge 1.7, follow-up 1.3) and surgical approaches (clipping: discharge 1.0, follow-up 1.4; bypass: discharge

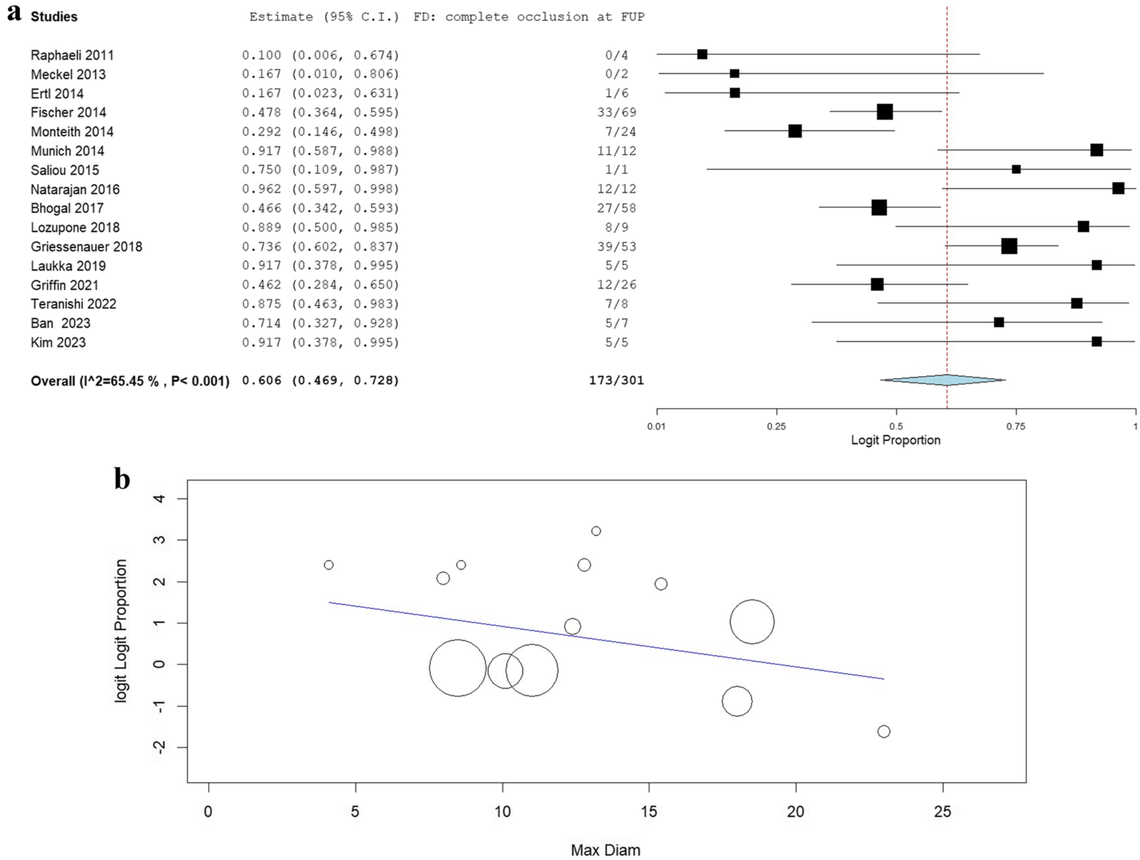

Fig. 6 **a** Complete occlusion at follow-up in flow-diversion stent (FD) cases. **b** Meta-regression: association between complete occlusion and maximum diameter in FD cases

2.6, follow-up 2.0). Within surgery, clipping had favorable results, while bypass had the highest mRS scores.

Discussion

Dolichoectasia or fusiform aneurysm of a cerebral artery is described as a dilation and elongation of the vessel's lumen.

The two terms are different in the original significance as one refers to a clearly pathological condition (fusiform aneurysm) and the other (dolicoectasia) to a para-physiological condition. However, these terms are often confused and indistinguishable in the literature. Our effort in this comprehensive review was trying to identify those clinical-radiological pictures which, although defined as dolichoectatic, were then judged worthy of treatment because they were instead more similar to proper fusiform aneurysms.

The overall prevalence of this type of aneurysm is about 0.05% of the general population and comprises up to 7% of intracranial aneurysms. Fusiform aneurysms are found more frequently in the posterior circulation and more common in men at older age, whereas saccular aneurysms are more common among women and occur at a younger age [68].

Thus, intracranial fusiform aneurysms are quite rare, although the number of cases has increased in recent years [61]. However, as for the more common saccular aneurysms, this can be due to the increasing availability of neuroimaging than to a real modification in their incidence, since, especially in industrialized countries, the habit of cigarette smoking is decreasing and screening for cardiovascular risk factors is increasingly promoted in the population.

This is the largest systematic review on intracranial fusiform aneurysms analyzing over 1700 cases. Relatively few data on this type of aneurysms are retrievable in literature and the clinical experience on their treatment is limited. In fact, dolichoectatic and fusiform aneurysms only represent a small portion of intracranial aneurysms as revealed by autoptic (< 0.1%) [1, 69, 70] and angiographic series (0.06%–0.7%) [71, 72]. Post-traumatic arterial dissections were not included to reduce heterogeneity and focus on the primary study population of idiopathic fusiform aneurysms.

These aneurysms are predominantly found in the posterior circulation, whereas the MCA is most commonly involved in anterior circulation, probably due to its greater length compared with the other vessels. Moreover, fusiform aneurysm involving the anterior circulation and in particular carotid artery and MCA has a greater chance of becoming symptomatic than vertebrobasilar lesions and other aneurysms of anterior circulation. Thus justifying their higher representation in clinical series compared with the other anterior circulation topographies. In contrast, vertebrobasilar lesions often remain asymptomatic for long time and are discovered only in autoptic series [72].

Symptoms are in general referable to compression of the surrounding neural structures, especially in case of vertebrobasilar aneurysms, which may lead to lower cranial nerves deficit [1]. Enlarging basilar dolichoectatic aneurysms can also produce symptoms by direct brainstem and cerebellum compression leading to ataxia, quadriparesis, and hydrocephalus resulting from mass effect on fourth ventricle or aqueduct; an altered level of consciousness may be present in the most severe cases.

In this meta-analysis, headache appeared the most frequent presenting symptom, followed by movement disorders. Interestingly, bleeding upon diagnosis occurred at a similar rate regardless of aneurysm location.

As regard their pathogenesis, spontaneous dissection is suspected to be a possible cause of these aneurysms, but only a limited number of studies investigated this factor. On the other hand, no angiographic signs of dissection were retrievable in most of non-thrombosed fusiform aneurysms such as intimal flaps, double lumens or post-aneurysm stenosis.

The unfavorable natural history of symptomatic fusiform aneurysms significantly limits the role of conservative approaches. The majority of patients in this meta-analysis presented with symptoms, and there is strong agreement on the need for intervention.

Invasive treatment is based on two main goals: deconstructive or reconstructive approaches. Each one can be pursued either with surgery or with endovascular techniques. Deconstructive techniques aim to occlude the parent vessel, relying on collateral/spontaneous anastomotic blood supply or deliberately scarifying terminal branches. Reconstructive approaches presuppose the preservation of blood flow by reconstructing the vascular wall with multiple clipping or restoring the normal flow through an extracranial-intracranial (EC-IC) or intracranial-intracranial (IC-IC) bypass, thus reconstituting the vascular lumen and preserving parent arteries and collaterals.

The choice between surgery and endovascular approaches is mainly influenced by aneurysms topography with a clear-cut preference for endovascular techniques for posterior circulation lesions similarly to the same trend observed in the treatment of the most common saccular aneurysms. In this scenario, flow diverters have emerged as the treatment of choice as they allow a vessel wall reconstruction and spare the origin of collaterals and perforators.

Conversely, surgery remains a viable option for anterior circulation aneurysms, particularly those amenable to clipping or bypass procedures, especially when associated with thrombosis.

In this meta-analysis, we found that about ¼ out of patients experienced complications (27%), with higher prevalence anterior circulation topography and open surgery approaches, which showed about twofold higher odds ratio compared to endovascular treatment for strokes and bleeding. All in all, deconstructive techniques carried a significantly higher risk of complications compared with reconstructive techniques. However, surgical PAO showed a lower complication rate compared with bypass procedures (22.6% vs. 36.6%).

Nonetheless, patients with anterior circulation aneurysms achieved in general better outcomes at discharge compared to posterior circulation cases and this favorable trend persisted at last follow-up.

Among all treatments, endovascular PAO showed the best outcomes compared to other endovascular and surgical techniques. Total mortality rate, however, was not negligible with 194 patients (10.5%) died during follow-up, mainly among those treated conservatively (43.4%) compared with surgery (16.6%) and endovascular treatment (5.5%). Surgery, in particular, showed a twofold OR for mortality compared with endovascular therapy.

Not surprisingly, our data suggests a higher rate of complete occlusion at short term follow-up measured at discharge with surgery (68.1%) compared with endovascular approach (44.1%), At longer follow-up (mean 2.6 years), the rate of occlusion increases both for patients treated with open surgery (65.2%) and endovascular approaches (61.1%), but without significant difference in OR.

Since their introduction, flow-diverters have emerged as a leading treatment option for fusiform aneurysms and non-saccular aneurysms, particularly those located in the posterior circulation [73, 74]. Despite their widespread adoption in most recent series, our review suggests that flow-diverters do not consistently outperform sole stenting in terms of occlusion rates. In 2021, Telles et al. published a similar meta-analysis, but according to their search strategy and adding their institutional series, these authors identified only 312 cases, of which 79 (25.3%) had open surgery, and 233 (74.5%) were treated with endovascular procedures [75]. According to our more detailed initial search strategy including terms such as *"non-saccular OR nonsaccular OR dolichoectasi* OR dissect*"* and *"treatment OR surgery OR endovascular OR clipping OR trapping OR by-pass OR coiling OR stent OR flow-diver*"* and thank to a subsequent forward search that screened some additional papers reporting larger series of “complex aneurysms” including real fusiform aneurysms, we identified 8435 papers Vs only 1219 by Dr. Telles, and we were finally able to include 63 articles Vs 29 after only 3 years from the previous meta-analysis.

Unlike the results of the present study, they did not identify differences between treatment groups, but size and initial mRS appeared as risk factors for morbidity, independent of location. Neither age nor rupture status influenced the odds of posterior morbidity.

Moreover, they reported no differences between morbidity of surgical and endovascular treatments regardless of aneurysm location but observed that unfavorable angiographic outcomes were more common in the endovascular group for supraclinoid and vertebrobasilar aneurysms, with microsurgical approach showing better long-term angiographic results compared to endovascular techniques.

Many of these differences with the present study are certainly attributable to the large difference in the sample size collected [75].

Limitations

This study has several limitations.

First, the heterogeneity of treatments and their evolution over time introduce potential confounding factors. Indeed, patients included in previously reported series were treated since the 1960s [57, 57]. During this period, surgery was the dominant treatment, and both intraoperative tools and postoperative management differed significantly from contemporary practices. Notably, the emergence and subsequent refinement of endovascular techniques, particularly flow-diversion stenting, were not captured in these earlier series. This shift in treatment paradigm adds another layer of complexity when comparing outcomes across different eras. Furthermore, the sensitivity for assessing clinical outcomes, reporting complications, and interpreting neuroradiological findings may have changed over the decades.

Second, reporting of functional and radiological outcomes was incomplete and extended follow-up would be beneficial for a more comprehensive assessment.

Third, we grouped all stenting techniques into a single category ("stent") without differentiating between various technologies, limiting to a gross distinction between sole stenting and flow-diverters. This broad categorization may obscure potential differences in efficacy and complication profiles between distinct stent designs.

Fourth, outcome was not possible to be stratified according to the clinical status at admission as it was not always distinguished in the original studies.

Fifth, not all the retrieved papers reported detailed data on clinical presentation and symptoms, thus these findings might be underestimated.

Finally, while this systematic review offers a comprehensive overview of intracranial fusiform aneurysm treatment outcomes, it is limited by its inability to delve into specific topographies within the anterior and posterior circulation. Notably, vertebral and basilar artery aneurysms may exhibit distinct clinical characteristics and treatment outcomes due to their unique anatomical features and associated risks, such as perforator vessel involvement. A detailed subanalysis of these aneurysms, however, is beyond the scope of this study.

Conclusions

This comprehensive meta-analysis investigated the treatment of intracranial fusiform aneurysms analyzing over 40 years of literature on the topic.

Treatment primarily involves invasive procedures, with endovascular techniques becoming increasingly preferred over surgery. While both methods have comparable rates of complete occlusion, endovascular treatment is associated with lower mortality and complication rates.

Outcome is influenced by aneurysm location, with anterior circulation topography generally having better prognoses. Deconstructive treatment strategies carry higher risks compared to reconstructive approaches. Overall, endovascular treatment, particularly stent-assisted coiling and stenting, appears in general to be a safer and more effective option for treating fusiform aneurysms compared to surgical interventions.

However, no significant differences in OR for early complete occlusion were found between surgery and endovascular techniques at discharge and follow-up with very low heterogeneity among studies.

Author Contribution GT: conceived the study, data analysis, drafted the manuscript, approved the final version AB: collected data, revised the manuscript, approved the final version GC: collected data, helped to revise the manuscript, approved the final version CLS: conceived the study, data analysis revision, drafted the manuscript, critical revision, approved the final version.

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Data Availability No datasets were generated or analysed during the current study.

Declarations All authors have read and approved the submitted manuscript.

Consent for publication The manuscript has not been submitted nor published elsewhere in whole or in part.

Conflict of interest The authors declare no competing interests.

Ethical statement IRB approval was not required in our institutions for systematic review papers.

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