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Fast Transition from Open Surgery to Endovascular Treatment of Unruptured Anterior Communicating Artery Aneurysms—A Retrospective Analysis of 128 Patients

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■ OBJECTIVE: **Anterior communicating artery aneurysms (ACoAAs) are challenging to treat both surgically and endovascularly. In this study, we evaluate the treatment-related morbidity and clinical outcome of microsurgical clipping and endovascular treatment for a consecutive series of unruptured ACoAAs while the treatment paradigm was in transition from surgical to endovascular first.**

■ METHODS: **We retrospectively reviewed clinical and radiologic data of adult patients who underwent microsurgical clipping or endovascular treatment of an unruptured ACoAA at a high-volume academic neurovascular center (Helsinki University Hospital) during 2012–2019. During this period, a transition from microsurgical clipping to endovascular treatment took place. Regarding outcome, we focused on treatment-related complications, discharge-to-home rates, functional performance (modified Rankin Scale score), and obliteration rates.**

■ RESULTS: **Of 128 treated ACoAAs, 81 (64%) were treated surgically and 47 (36%) endovascularly. There was no difference in major complications, intracranial hemorrhagic complications or ischemic complications, discharge-to-home rates, or functional performance between the surgically and endovascularly treated patients. With time, a decrease in major complications was observed in the surgical cases (from 29% to 17%), whereas the major complication rate increased in the endovascularly patients (from 0% to 25%). Cerebral ischemia was the most frequent complication in both groups. The risk for permanent neurologic deficit remained low in both groups (9% for endovascular and 5% for surgery).**

■ CONCLUSIONS: **We did not find any major differences regarding complications and outcomes after the treatment paradigm shift from clipping to endovascular of unruptured ACoAAs. Prospective studies evaluating durability of treatments are needed to compare overall effectiveness.**

INTRODUCTION

Anterior communicating artery aneurysms (ACoAAs) encompass around 30%–35% of all intracranial aneurysms (IAs).[1-3] Because ACoAAs (including small ACoAAs) have a high tendency to rupture,[1,3,4] preventive treatment of unruptured ACoAAs is often justified. The preventive nature of this treatment demands a high and durable occlusion rate, and treatment-related morbidity and mortality must be minimal. Until 25–30 years ago, microsurgical clipping of ACoAAs was the preferred treatment strategy worldwide, including in Helsinki, Finland.[1,5] However, the development and introduction of endovascular coiling led to a paradigm shift: endovascular

Key words
- Aneurysm
- Anterior communicating artery
- Clipping
- Coiling
- Complications
- Outcome
- Unruptured

Abbreviations and Acronyms
ACoAA: Anterior communicating artery aneurysm
aSAH: Aneurysmal subarachnoid hemorrhage
CTA: Computed tomography angiography
DSA: Digital subtraction angiography
IA: Intracranial aneurysm
ICU: Intensive care unit
MRA: Magnetic resonance angiography
mRS: Modified Rankin Scale
WEB: Woven EndoBridge

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coiling became the first choice treatment.[5-10] A subsequent evolution of endovascular techniques resulted in the introduction of intraluminal devices as well as stents and flow diverters.[11,12] The continuously improving clinical outcome of IA treatment was mainly attributed to these developments.[7,10,11]

Worldwide, the transition from open surgery to endovascular therapy took place in the last 2 decades.[5,10] During that time, many other outcome-affecting factors (e.g., centralized tertiary neurovascular centers, protocolized medicine, radiologic imaging quality, and intensive care unit [ICU] treatment) have improved as well.[10,13,14] In our department, the treatment paradigm was modified in 2015 from clipping first to endovascular first. Compared with transitions elsewhere, our transition took place relatively fast, which enables a more specific estimation of the paradigm shift effect. Moreover, Helsinki University Hospital is the single referral neurosurgical center for a large catchment area with long-standing experience in the treatment of neurovascular disorders. We can analyze large consecutive series of unruptured IAs.

Among IAs, ACoAAs are often considered relatively difficult to treat and come with a higher complication rate, which is because of their deep interhemispheric location, complex anatomy with 2 afferent and 2 efferent arteries, and numerous important perforators (e.g., recurrent artery of Heubner).[1,15,16] Changes in treatment-related morbidity and outcome are therefore easier to detect when evaluating ACoAAs, even in small cohorts.

The aim of this study is to evaluate complications and outcomes of microsurgical clipping and endovascular treatment for a consecutive series of unruptured ACoAAs while a treatment paradigm transition was established. To consider the treatment paradigm transition as safe and successful, endovascular treatment should at least be noninferior to microsurgical clipping. Therefore, we hypothesize that the transition from open surgery to endovascular therapy to treat unruptured ACoAAs does not increase the complication and discharge-to-home rate, nor does it affect functional outcome.

METHODS

Ethical Considerations

This retrospective study was conducted following approval of the Helsinki University Hospital institutional review board. The requirement to obtain informed consent was waived.

Treatment and Patient Selection

We included patients who underwent treatment of an unruptured ACoAA between January 1, 2012 and December 31, 2019. ACoAAs were treated primarily by microsurgical clipping until 2015. For the implementation of the policy change in clinical practice, we considered a transition period of 2 years. Hence, we differentiate 3 periods: 1) the clipping-first period from January 1, 2012 to December 31, 2014, 2) the transition period from January 1, 2015 to December 31, 2016, and 3) the endovascular-first period from January 1, 2017 to December 31, 2019. Allocation to surgical or endovascular treatment was primarily based on the policy during each period. Nevertheless, allocation of treatment modality was discussed for each patient in a multidisciplinary meeting including interventional neuroradiologists and neurosurgeons. Any deviation of the treatment policy was considered and discussed in cases of, for example, complex aneurysm configuration or the presence of multiple aneurysms.

We included 1) adult patients aged 18 years and older, with 2) radiologically confirmed ACoAA, based on cerebral computed tomography angiography (CTA), digital subtraction angiography (DSA) and/or magnetic resonance angiography (MRA), and with 3) complete clinical and radiologic (i.e., ≥1 postoperative CTA, DSA, or MRA, follow-up up to 6 months postoperatively. We excluded patients if they had experienced an aneurysmal subarachnoid hemorrhage (aSAH) previously, if the ACoAA was treated previously, if a bypass was performed as primary aneurysm treatment, or if the treatment was performed by an external neurosurgeon during our annual Helsinki Live course. Endovascular treatment modalities included stand-alone coiling, stent-assisted coiling, flow diverter placement, or Woven EndoBridge (WEB) device placement. In Helsinki, endovascular treatment of IAs was established in 1998.

Clinical Data and Outcome Measures

Clinical data were extracted from the electronic patient files. Clinical follow-up included a regular outpatient visit at around 3 months for patients treated surgically and 6 months for patients treated endovascularly. We noted patient characteristics, the presence of risk factors (e.g., smoking and hypertension), and preoperative use of antithrombotic medication. In addition, according to our protocol, all patients treated by coiling or with the WEB device are prescribed aspirin 100 mg once daily for 1 month. For patients treated by stent-assisted coiling or flow diverter, dual antiplatelet treatment (aspirin 100 mg once daily and clopidogrel 75 mg once daily, or in cases of insufficient clopidogrel response, prasugrel 10 mg once daily) is prescribed for 3 months.

As primary outcome measures, we evaluated major postoperative complications and discharge location. Postoperative complications were classified as major or minor, as reported previously.[17] Major complications included new or worsened (hemi)paresis, silent stroke, acute myocardial infarction, pneumonia, pulmonary embolism, deep venous thrombosis and unplanned repeat craniotomy or endovascular intervention within 30 postoperative days. Minor complications included wound infections, minor infections (e.g., urinary tract infections), subjective visual disturbances, new or worsened cranial nerve palsy, dysphagia, dysphasia, and dysarthria within 30 postoperative days. For secondary outcome we used preoperative and postoperative functional performance using modified Rankin Scale (mRS) score; length of ICU and hospital stay; and obliteration, re-treatment, and rupture rates. An ICU stay of longer than 1 night was defined as prolonged. Preoperative and postoperative mRS scores were determined retrospectively based on patient files of outpatient visits. Clinical mRS scoring was performed by A.H. and R.R., who were independent of the treatments, and are both well experienced with mRS scoring. Although we regard the mRS score as a poor measure to evaluate surgical outcome of elective cranial neurosurgery,[18] we included this measure to enable a comparison with previous studies. We considered mRS score of 0–1 as showing a good functional outcome and mRS score of 2–5 as showing a poor outcome. A relevant decrease in functional performance was defined as worsening from a preoperative good mRS score (0–1) to a postoperative poor mRS score (2–5).

Radiologic Data

Preoperative CTA, DSA, or MRA was used for the assessment of the maximum diameter of the neck, width, and height of the aneurysm, and calculation of the dome/neck ratio (ratio of the maximum aneurysm width and neck diameter).[19] Aneurysm projection was based on the sagittal A1 direction and classified as anterior-inferior, anterior-superior, posterior-inferior, and posterior-superior.[15]

Because high complexity of ACoAAs may form an important confounder for treatment outcomes, we applied the criteria of Andaluz and Zuccarello[20] for complex IAs on ACoAAs: giant size, maximal diameter ≥25 mm[1,21]; configuration, posterior direction of the aneurysm sac[1,15,22]; broad neck, dome/neck ratio ≥2.0[21,23]; aneurysmal branches, large branches from ACoAA[1]; parent artery part of the aneurysm itself, relation with afferent A1s[1]; and wall morphology, presence of calcifications.[1,21] We did not include absence of collateral circulation and embedding in surrounding brain, brainstem, or cranial nerves, because this is applicable to nearly all ACoAAs, nor did we assess intraluminal thrombus because preoperative magnetic resonance imaging was not performed routinely.

Radiologic follow-up included native brain computed tomography the day after the treatment. We assessed aneurysm obliteration on postoperative CTA, DSA, or MRA. We categorized the obliteration of clipped aneurysms as complete or incomplete, and the occlusion of endovascularly treated aneurysms according to the Raymond-Roy classification.[24] Radiologic follow-up of completely clipped ACoAAs was not deemed necessary, whereas incompletely clipped ACoAAs were re-evaluated with CTA after 6 months. Follow-up of endovascular ACoAAs always included DSA or MRA at 6 months.

Statistical Analyses

We used Stata version 15 (StataCorp LLC, College Station, Texas, USA) for statistical analyses. Given the relatively small cohort, data are evaluated as nonparametric and presented as medians with interquartile ranges. Categorical data are presented as numbers with percentages and compared among groups using a 2-sided χ^2 test. Continuous nonparametric data are compared among groups using the Mann-Whitney U test. To assess trends in continuous nonparametric data among several groups we used a nonparametric test for trend across ordered groups. Because of the relatively low number of cases we did not perform multivariable analyses. A P value <0.05 was used to indicate statistical significance.

RESULTS

Patient Selection and Characteristics

We identified 91 and 72 patients who underwent microsurgical clipping or endovascular treatment, respectively. Ten clipped patients were excluded because of incomplete clinical follow-up, or because they were operated on by an external neurosurgeon during the annual Helsinki Live course. In the endovascular cohort, we excluded 18 patients because the treatment was a re-treatment, and 7 patients because of a previous aSAH. We included 81 patients who were treated surgically and 47 who were treated by endovascular means. Regarding endovascular treatment modalities, stand-alone coiling was performed in 27 aneurysms, stent-assisted coiling in 8 aneurysms, and 12 aneurysms were treated using a WEB device.

The median age of included patients was 60 years, and a comparable number of male and females were included (Table 1). One third of the patients were current smokers, and two thirds had a known history of hypertension. Median age, sex ratio, and the presence of risk factors did not differ between the surgical and endovascular patients. The use of antithrombotic medication was significantly higher among patients treated endovascularly than surgically (38% vs. 16%).

Radiologic Characteristics

Multiple aneurysms were present in 24% of patients (Table 1). Median size of aneurysm neck (3 mm), width (4 mm), height (5 mm), and maximum diameter (5 mm) did not vary between the 2 treatment groups. The median dome/neck ratio was 1.4 and 1.3 for clipped and endovascularly ACoAAs (Table 1). The direction of aneurysm projection was not significantly different. A total of 37% of ACoAAs met the criteria for complex ACoAA, and this was comparable for both groups.

Clinical Outcome Measures

The discharge-to-home rates for patients treated surgically (85%) and endovascularly (85%) were similar (Table 2). Risk factors for discharge to a location other than home included the occurrence of a major complication (P < 0.001) and complex aneurysm configuration (P = 0.010). A complication was recorded in 49 patients (38%), including 29 patients (23%) who experienced a major complication. Among surgically treated patients, a major complication was reported in 26%, compared with 17% of endovascularly treated patients (P = 0.246). Cerebral ischemic events were the most common major complication for both treatment modalities (Table 2). Patient characteristics were not associated with the occurrence of major complications (Table 3). Regarding aneurysm characteristics, a slightly larger median maximal aneurysm diameter, a posterior aneurysm sac projection, aneurysm wall irregularities or calcifications, and a wide neck were slightly more common in patients experiencing a major complication (Table 3). The rate of major complications according to endovascular treatment modality were 11% for stand-alone coiling, 50% for stent-assisted coiling, and 8% after WEB placement.

The mRS was scored on at a median of 187 and 138 days after the endovascular and clipping procedure, respectively. Because of this large difference of timing of postoperative mRS assessment, a comparison of postoperative mRS score between clipping and endovascular is of limited significance. The postoperative mRS score was 2–5 in 14 patients (11%), including 4 patients who had a similar score preoperatively (Table 2). A poor postoperative mRS score was more common in patients who experienced a major complication (P <0.001) or had a complex ACoAA configuration (P = 0.023).

Permanent neurologic deficits were observed in 4 surgically treated patients (5%) and 4 endovascularly patients (9%) (Table 2).

Table 1. Patient Characteristics According to Treatment Modality

Variable	All (N = 128)	Surgery (n = 81)	Endovascular (n = 47)	*P* Value
Patient characteristics				
Age (years), median (IQR)	60 (50—66)	59 (50—66)	61 (49—66)	0.484
Sex				
Female	61 (48)	40 (49)	21 (45)	0.608
Male	67 (52)	41 (51)	26 (55)	
Smoking				
No or former	83 (65)	54 (67)	28 (60)	0.342
Current	45 (35)	27 (33)	19 (40)	
Hypertension	78 (61)	47 (58)	31 (66)	0.375
Antithrombotic medication	31 (24)	13 (16)	18 (38)	0.005
Patient has multiple aneurysms	30 (24)	17 (21)	13 (29)	0.318
Radiologic characteristics				
Aneurysm projection				
Anterior-superior	45 (35)	23 (28)	2 (47)	0.128
Anterior-inferior	72 (56)	51 (63)	21 (45)	
Posterior-superior	2 (2)	1 (1)	1 (2)	
Posterior-inferior	9 (7)	6 (7)	3 (6)	
Aneurysm neck (mm), median (IQR)	3 (2—4)	3 (2—4)	3 (2—4)	0.812
Aneurysm maximal diameter (mm), median (IQR)	5 (4—7)	5 (3—7)	5 (4—8)	0.111
Dome/neck ratio, median (IQR)	1.4 (1.0—1.7)	1.3 (1.0—1.7)	1.5 (1.3—2.0)	0.026
A1 configuration				
Symmetric A1s	81 (64)	54 (68)	27 (57)	0.255
Asymmetric A1s	46 (36)	26 (33)	20 (43)	
A2 configuration				
Normal	120 (95)	77 (96)	43 (92)	0.256
Abnormal	7 (6)	3 (4)	4 (9)	
Aneurysm irregularity	64 (50)	36 (44)	27 (60)	0.099
Aneurysm calcification	16 (13)	11 (14)	5 (11)	0.635
Wide-necked aneurysm*	23 (18)	11 (14)	12 (26)	0.090
Complex aneurysm	47 (37)	28 (35)	19 (40)	0.508

Values are number (%) except where indicated otherwise.
IQR, interquartile range.
*Dome/neck ratio ≥2.0.

The rate of permanent neurologic deficits according to endovascular treatment modality was 1 (4%) for stand-alone coiling, 2 (25%) for stent-assisted coiling, and 1 (8%) for WEB treatment. A prolonged ICU stay was more common among the endovascularly treated patients compared with the surgically treated patients (21% vs. 7%), whereas total hospital stay was longer in patients treated surgically (Table 2). A major complication resulted in more frequent prolonged ICU ($P < 0.001$) and hospital stays ($P < 0.001$). The higher rate of prolonged ICU stay in endovascular patients was mostly related to the development of new neurologic deficits, which was a result of ischemic events in most cases. Of those with a prolonged ICU stay, 38% were discharged home and 62% were sent for rehabilitation. The need for rehabilitation after a prolonged ICU stay was comparable between the surgical (4 of 6) and endovascular (6 of 10) patients.

Radiologic follow-up was available for all patients, except for the 6-month imaging of 1 endovascularly treated patient. The

Table 2. Primary and Secondary Clinical Outcome Measures

Variable	All (N = 128)	Surgery (n = 81)	Endovascular (n = 47)	*P* Value
Primary clinical outcomes				
Discharge home	109 (85)	69 (85)	40 (85)	0.990
Complications				
Complication severity				
None	78 (61)	46 (57)	32 (68)	0.413
Minor	21 (16)	14 (17)	7 (15)	
Major	29 (23)	21 (26)	8 (17)	
All complications*				
Infection	9 (7)	6 (7)	3 (6)	0.845
Intracranial hemorrhagic	9 (7)	7 (9)	2 (4)	
Cerebral ischemia	20 (16)	13 (16)	7 (15)	
Neurologic	15 (12)	12 (15)	3 (6)	
Other	9 (7)	7 (9)	2 (4)	
New neurologic deficit	25 (20)	14 (17)	11 (23)	0.400
None	103 (81)	67 (83)	36 (77)	0.098
Permanent	8 (6)	4 (5)	4 (9)	
Transient	12 (9)	5 (6)	7 (15)	
Documented anosmia	5 (4)	5 (6)	0 (0)	
Secondary clinical outcomes				
Days to postoperative mRS assessment, median (IQR)	160 (109—187)	138 (94—169)	187 (167—205)	<0.001
Postoperative mRS score				
0—1	114 (89)	69 (85)	45 (96)	0.065
2—5	14 (11)	12 (15)	2 (4)	
mRS score worsening from 0—1	10 (8)	9 (11)	1 (2)	0.091
Prolonged intensive care unit stay	16 (13)	6 (7)	10 (21)	0.022
Hospital length of stay (days), median (IQR)	6 (4—8)	7 (5—8)	4 (4—6)	<0.001

Values are number (%) except where indicated otherwise.
IQR, interquartile range; mRS, modified Rankin Scale.
*1 patient can have several complications.

initial postprocedural occlusion rate of surgically and endovascularly treated aneurysms was 96% and 89%, respectively (Table 4). At 6 months, the obliteration rate of the endovascularly aneurysms decreased to 78%. At 6 months follow-up, re-treatment was performed in 1 surgically treated and 2 endovascularly treated patients. One patient who was treated endovascularly experienced an aSAH within 6 months after treatment. At the maximally available follow-up period, there were no additional re-treatments in the surgical group (median follow-up time, 7.3 years), whereas there were 2 re-treatments in the endovascular group (median follow-up, 4.8 years). In both these re-treated endovascular patients, a WEB device was the primary treatment. During the complete follow-up period, there was no additional clinically assessed aSAH in either group.

Treatment Paradigm Transition

Before 2015, ACoAAs were predominantly clipped, whereas after 2017, endovascular treatment of ACoAAs prevailed in our treatment paradigm (Figure 1). During the transition phase (2015—2016), the rate of both treatment modalities was comparable. During the treatment paradigm change, the median age of surgically treated patients slowly decreased from 61 to 57 years (P = 0.077), whereas the median age of the endovascularly

Table 3. Differences in Patient and Aneurysm Characteristics Between Those with a Major Complication versus No Major Complication

Variable	No Major Complication (n = 99)	Major Complication (n = 29)	*P* Value
Patient characteristics			
Age (years), median (IQR)	59 (49–65)	63 (52–66)	0.112
Sex			
Female	44 (44%)	17 (59%)	0.179
Male	55 (56)	12 (41)	
Smoking			
No or former	60 (61)	23 (79)	0.064
Current	39 (39)	6 (21)	
Hypertension	58 (59)	20 (69)	0.314
Antithrombotic medication	23 (23)	8 (28)	0.630
Patient has multiple aneurysms	25 (26%)	5 (17)	0.344
Treatment modality			
Surgical	60 (61)	21 (72)	0.246
Endovascular	39 (39)	8 (28)	
Aneurysm characteristics			
Aneurysm projection			
Anterior-superior	36 (36)	9 (31)	0.091
Anterior-inferior	57 (58)	15 (52)	
Posterior-superior	2 (2)	0 (0)	
Posterior-inferior	4 (4)	5 (16)	
Aneurysm neck (mm), median (IQR)	3 (2–4)	3 (3–4)	0.052
Aneurysm maximal diameter (mm), median (IQR)	5 (3–7)	6 (4–9)	0.007
Dome/neck ratio, median (IQR)	1.3 (1.0–1.7)	1.5 (1.2–2.0)	0.150
A1 configuration			
Symmetric A1s	61 (62)	20 (69)	0.508
Asymmetric A1s	37 (38)	9 (31)	
A2 configuration			
Normal	91 (93)	29 (100)	0.139
Abnormal	7 (7)	0 (0)	
Aneurysm irregularity	46 (46)	18 (62)	0.139
Aneurysm calcification	12 (13)	4 (14)	0.886
Wide-necked aneurysm*	15 (15)	8 (28)	0.125
Complex aneurysm	33 (33)	14 (48)	0.142

Values are number (%) except where indicated otherwise.
IQR, interquartile range.
*Dome/neck ratio ≥2.0.

patients gradually increased from 42 to 64 years ($P = 0.054$; Table 5). Regarding aneurysm characteristics, the relative number of complex aneurysms and patients harboring >1 aneurysm did not significantly change over time for both treatment cohorts (Table 5).

Regarding primary outcome measures, we found that the discharge-to-home rate during the surgical era (90%) was comparable to that of the endovascular era (89%; Table 6). The overall major complication rate did not change over time. When comparing both treatment eras, we noticed a reduction in major

Table 4. Radiologic Outcome of Aneurysm Treatment Modalities

Radiologic Outcomes	All (N = 128), n (%)	Surgery (n = 81), n (%)	Endovascular (n = 47), n (%)	*P* Value
Immediate postprocedural obliteration*	117 (94)	75 (96)	42 (89)	0.131
Aneurysm obliteration at 6 months†	N/A	N/A	36 (78)	N/A
Aneurysm reintervention at 6 months	3 (2)	1 (1)	2 (4)	0.276
Aneurysm rupture	1 (1)	0 (0)	1 (2)	0.367

N/A, not available.
*Missing for 3 surgical patients. Defined as a Raymond-Roy class I for endovascularly treated.
†Missing for 1 patient. Follow-up imaging modalities were magnetic resonance angiography for 18 patients and digital subtraction angiography for 28 patients.

complications in surgically treated patients from 29% to 17%, whereas the rate of major complications in the endovascular patients increased from 0% to 25% (Table 5). Functional outcome improved in the endovascular era compared with the surgical era (P = 0.074), with less worsening in mRS scores (Table 6). A prolonged ICU stay was more common in the endovascular era, although this did not result in a longer median length of hospital stay (Table 6). The 6-month obliteration rate of endovascular treatment improved from 61% in the transition era to 87% in the endovascular era (Table 5).

DISCUSSION

In this study, we found no significant changes in complication rates and functional outcomes after a fast treatment transition. Because our transition took place in only 2 years, we were able to estimate the results of a transition with a limited confounding effect of other outcome-related factors. Major complications after surgery decreased with time, whereas the major complication rate of endovascular treatment increased simultaneously. This finding could be related to a change in allocation of more complex ACoAAs to endovascular treatment, although such a policy change was not evident in our analyses. Furthermore, we found that mRS score worsening was less common in the endovascular era, whereas a prolonged ICU stay was more frequent.

The Transition from Surgical to Endovascular Treatment

After our fast transition, endovascular treatment progressed as the primary treatment for most unruptured ACoAAs. Nevertheless, microsurgical clipping was still preferred in certain cases. Based on differences between the endovascular and surgical cohort during the endovascular era, we found that reasons to deviate from the new policy included younger age of patients and treating multiple aneurysms in a single procedure (Table 5). Regarding the latter, the concomitant presence of a middle cerebral artery aneurysm, which is primarily clipped in our center, was the most common reason (5 of 12 patients) to prefer clipping over endovascular treatment.

Albeit our paradigm shift was relatively fast, the shift did not significantly affect the overall complication rates or number of new neurologic deficits. We noted a decrease in complications

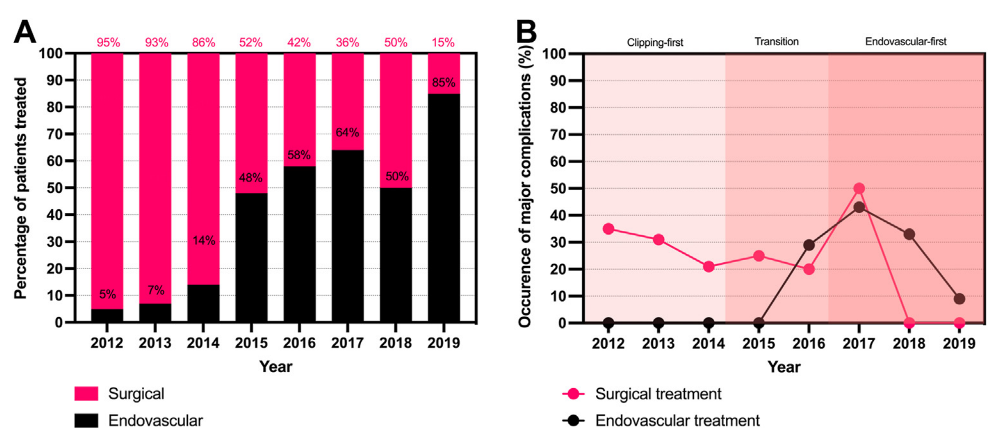

Figure 1. (**A**) The relative changes in numbers of treatment modality over the years. A clear shift in the treatment paradigm can be noted from 2015, when endovascular treatment became the preferred treatment modality. (**B**) The rates of major complications after surgical clipping and endovascular treatment of unruptured anterior communication artery aneurysms from 2012 to 2019.

Table 5. Patient Characteristics According to Treatment Modality and Era of Treatment

Variable	Surgical Era (2012–2014)	Transition Era (2015–2016)	Endovascular Era (2017–2019)	*P* Value
Surgical patients (n)	52	17	12	
Age (years), median (IQR)	61 (52–68)	54 (44–63)	57 (48–65)	0.077
Female	27 (52)	7 (41)	7 (58)	
Smoking				
No or former	37 (71)	13 (76)	5 (42)	0.100
Current	15 (29)	24 (4)	7 (58)	
Hypertension	30 (58)	9 (53)	8 (67)	0.759
Antithrombotic medication	8 (15)	2 (12)	3 (25)	0.618
Patient has multiple aneurysms	9 (17)	3 (18)	5 (42)	0.163
Aneurysm neck (mm), median (IQR)	3 (2–4)	3 (2–3)	3 (2–3)	0.251
Aneurysm maximal diameter (mm), median (IQR)	5 (3–7)	4 (4–6)	5 (3–6)	0.580
Dome/neck ratio, median (IQR)	1.3 (1.0–1.5)	1.3 (1.0–1.7)	1.5 (1.3–1.7)	0.131
Complex aneurysm	18 (35)	7 (41)	3 (25)	0.666
Major complication	15 (29)	4 (24)	2 (17)	0.664
New permanent neurologic deficit	2 (4)	2 (12)	0 (0)	0.295
Endovascular patients (n)	5	18	24	
Age (years), median (IQR)	42 (31–63)	61 (49–67)	64 (54–67)	0.054
Female	4 (80)	11 (61)	11 (46)	0.309
Smoking				
No or former	3 (60)	9 (50)	16 (67)	0.552
Current	2 (40)	9 (50)	88 (33)	
Hypertension	2 (40)	11 (61)	18 (75)	0.278
Antithrombotic medication	2 (40)	10 (56)	6 (25)	0.131
Patient has multiple aneurysms	1 (20)	6 (35)	6 (26)	0.734
Aneurysm neck (mm), median (IQR)	2 (2–2)	3 (2–4)	4 (2–4)	0.014
Aneurysm maximal diameter (mm), median (IQR)	4 (3–4)	6 (4–9)	5 (4–8)	0.111
Dome/neck ratio, median (IQR)	1.5 (1.5–1.88)	1.6 (1.3–2.0)	1.5 (1.0–1.7)	0.093
Complex aneurysm	1 (20)	7 (39)	11 (45)	0.556
Major complication	0 (0)	2 (11)	6 (25)	0.279
New permanent neurologic deficit	0 (0)	1 (6)	3 (13)	0.561
Aneurysm obliteration at 6 months*	5 (100)	11 (61)	20 (87)	0.063
All patients (n)	57	35	36	
Age (years), median (IQR)	42 (31–63)	61 (49–67)	64 (54–64)	0.989
Female	313 (54)	188 (51)	18 (50)	0.911
Smoking				
No or former	40 (70)	22 (63)	21 (58)	0.487
Current	17 (30)	13 (37)	15 (42)	0.487
Hypertension	32 (56)	20 (57)	26 (72)	0.261

Values are number (%) except where indicated otherwise.
IQR, interquartile range; mRS, modified Rankin Scale.
*One patient can have several complications.
*Missing for 1 patient. Follow-up imaging modalities were magnetic resonance angiography for 18 patients and digital subtraction angiography for 28 patients.

Continues

Table 5. Continued

Variable	Surgical Era (2012–2014)	Transition Era (2015–2016)	Endovascular Era (2017–2019)	*P* Value
Antithrombotic medication	10 (18)	12 (34)	9 (25)	0.189
Patient has multiple aneurysms	10 (18)	9 (26)	11 ((13)	0.288
Aneurysm neck (mm), median (IQR)	2 (2–2)	3 (2–4)	4 (2–4)	0.524
Aneurysm maximal diameter (mm), median (IQR)	4 (3–4)	6 (4–9)	5 (4–8)	0.219
Dome/neck ratio, median (IQR)	1.5 (1.5–1.8)	1.6 (1.3–2.0)	1.5 (1.0–1.7)	0.194
Complex aneurysm	19 (33)	14 (40)	14 (39)	0.772
New permanent neurologic deficit	2 (4)	3 (9)	3 (9)	0.517
Major complication	15 (26)	6 (17)	8 (22)	0.593

Values are number (%) except where indicated otherwise.
IQR, interquartile range; mRS, modified Rankin Scale.
*One patient can have several complications.
*Missing for 1 patient. Follow-up imaging modalities were magnetic resonance angiography for 18 patients and digital subtraction angiography for 28 patients.

among the surgical cases over time, whereas the complication rate increased for the endovascular treatments. This finding could be related to a more careful selection of patients undergoing surgery in the later years, and more complex aneurysms being treated by clipping initially, but being treated endovascularly after the transition. Statistically, we did not find an association between complex aneurysms and major complications, which may be because of the low number of patients. During the surgical era, the number of surgically treated complex aneurysms was 18 (35%), compared with 3 (25%) in the endovascular era. On the contrary, the number of complex aneurysms treated endovascularly increased from 1 (20%) in the surgical to 11 (45%) in the endovascular era, respectively. This finding suggests a relation between aneurysm complexity and the occurrence of (major) complications. Moreover, various aneurysm characteristics that have been reported to complicate the treatment of ACoAAs[1,21,23] were associated with the occurrence of complications: larger maximal diameter, posterior aneurysm projection, wall irregularities or calcifications, and a wider neck. These findings imply that in high-volume neurovascular centers, aneurysm complexity may affect the complication rate more strongly than does the choice of treatment modality.

In our series, a major complication occurred in 23% of the patients. Compared with previous studies, our overall complication rate is relatively high, particularly for the endovascular cohort. This finding may be related to the relatively limited experience with endovascular treatment of ACoAAs and the relatively fast transition, including the transition of complex ACoAAs. However, our endovascular team was established in 1998 and has gained wide experience with endovascular treatment of IAs since then. Besides this factor, the increased rate of complications in the endovascular group could also be related to an increased rate of complex ACoAAs being treated endovascularly. Moreover, these more complex ACoAAs were increasingly treated by advanced endovascular techniques (e.g., stent-assisted coiling, flow diverter, and WEB device placement) in the transition (50%) and endovascular era (50%) compared with the surgical era (0%). Of the 20 patients treated by advanced endovascular techniques, 9 had a complication, of whom 5 were major complications. Previous reviews have shown that advanced endovascular techniques for the treatment of unruptured ACoAAs come with higher complication rates than do stand-alone coiling.[25,26] Moreover, our complication figure also includes systemic complications, such as pneumonia

Table 6. Differences in Primary and Secondary Outcomes Between the Surgical and Endovascular Era

Variable	Surgical Era (n = 57)	Endovascular Era (n = 36)	*P* Value
Discharge home	49 (90)	32 (89)	0.682
New permanent neurologic deficit	2 (4)	3 (8)	0.315
Modified Rankin Scale score			
0–1	49 (86)	35 (97)	0.074
2–5	8 (14)	1 (3)	
Modified Rankin Scale score worsening from 0–1 to 2–5	6 (11)	1 (3)	0.168
Prolonged intensive care unit stay	2 (4)	8 (22)	0.005
Length of hospital stay (days), median (interquartile range)	6 (5–8)	5 (4–8)	0.020

Values are number (%) except where indicated otherwise.

and pulmonary embolism, which are not directly caused by intervention, whereas previous studies included procedure-related thromboembolic and neurologic complications only,[27,28] making it more difficult to compare the complication rates. In our series, permanent neurologic deficits were detected in only 4 of 47 patients (8.5%) treated endovascularly, which is comparable to previous studies.[27,28] In line with the observations of Nussbaum et al.,[28] we found no significant difference in the complication rate between the surgically and endovascularly treated patients.

In our study, the direct obliteration rate was 96% and 89% for clipping and endovascular treatment, respectively. This is a relatively small difference, and rates are comparable to previous reports.[28-30] We assessed the obliteration rate in surgical cases using CTA, whereas a DSA was performed in most endovascular cases. Because DSA has a higher accuracy for detecting aneurysm remnants than does CTA,[31] a fair comparison of the obliteration rate of the surgical and endovascular cohort cannot be performed. To assess obliteration durability, long-term results of both modalities need to be compared. Our department's protocol does not include radiologic follow-up of clipped IAs, because the recurrence rate after complete occlusion is low.[29]

Regarding radiologic follow-up of our endovascular cohort, we were only able to provide complete 6-month follow-up data, which is too short to estimate durability. Nevertheless, the obliteration rate of endovascularly treated patients decreased to 78% at 6 months. Of these recanalized aneurysms, a relevant recanalization leading to re-treatment of the aneurysm was needed in only 4 endovascular cases and 1 surgical case during the complete follow-up, whereas 1 endovascularly treated patient experienced an aSAH. The high rate of recanalization is mainly related to recanalization of wide-neck aneurysms treated with a WEB device. Of the 12 aneurysms treated with a WEB device, 4 showed some degree of refilling. In comparison, only 1 of 7 stent-assisted coiled aneurysms (14%) and 5 of 26 (19%) stand-alone coiled aneurysms showed some degree of recanalization (1 coiled patient had no radiologic follow-up). Fifty percent of the recanalized aneurysms were treated with a WEB device. A recent review evaluating various advanced endovascular techniques[25] described recanalization rates ranging from 50% to 83% at 12 months follow-up. The higher radiologic recanalization rate of WEB devices has been reported repetitively.[32-34] This finding has been related to a compression effect[34] and does not seem to predict re-treatment or rerupture.[32-34] This factor has also led to the development of a specific occlusion classification for WEB devices, which we did not apply in this study.[35] Regarding recurrence, O'Neill et al.[26] calculated a pooled angiographic median rate of aneurysm recurrence of 0% after clipping (median follow-up, 16.2 months), 7.2% after stand-alone coiling (median follow-up, 29 months), and 12.3% after stent-assisted coiling (median follow-up, 18.5 months).

Other Findings

Regarding functional outcome, worsening in mRS score was less frequently observed in the endovascular era compared with the surgical era. However, functional outcome was assessed significantly earlier in surgically treated patients (median, 138 days) compared with patients who underwent endovascular treatment (median, 187 days). This difference was a result of different time points in our clinical follow-up protocol for both treatment modalities. This situation could have affected the outcome differences because the recovery time was shorter for the surgically treated patients. Overall, we observed a good functional outcome of 89%, which is worse compared with the median good functional outcome of around 97% among previous studies, as reviewed by O'Neill et al.[26] and Nussbaum et al.[28] On the one hand, this finding might be related to our definition of good functional outcome (i.e., mRS score of 0−1), whereas most other studies consider an mRS score of 2 as showing a good outcome. If mRS score 0−2 is considered a good outcome, 95% reached a good functional outcome in our cohort. On the other hand, the median follow-up time of functional outcome in these studies ranged from 6 to 49 months.[26,28] Unsurprisingly, a major complication resulted in increased rates of prolonged ICU and hospital stay, worse functional outcome, and lower discharge-to-home rates. We found that the median hospital stay was shorted for endovascular patients compared with clipped patients (median, 7 vs. 4 days). However, a prolonged ICU stay was more common among patients treated endovascularly than surgically (21% vs. 7%). This finding was mainly the result of newly developed neurologic deficits caused by ischemic events, for which a prolonged ICU observation was deemed necessary. However, the need for rehabilitation after a prolonged ICU stay was similar between the groups, suggesting that endovascularly treated patients are followed up at the ICU with a lower threshold.

Strengths and Limitations

Our study may have some strengths. First, the department's treatment paradigm was changed in a relatively short time, thereby enabling us to evaluate the results of both treatment modalities regardless of presumed factors favoring either modality. Second, our cohort encompasses a consecutive series of patients with unruptured ACoAAs treated in the single referral center of a large catchment area. Our study also has limitations. The retrospective nature of our study entails a potential selection bias. Moreover, patients included in this study were derived from a single high-volume academic neurovascular center, limiting external validity. Although treatment allocation was primarily based on a specific policy during each treatment era, deviations of the policy occurred and were substantiated. However, this limitation may have introduced a selection bias. In addition, we assessed patients' functional outcome using the mRS score. We consider the mRS score a poor measure to evaluate surgical outcome of elective cranial neurosurgery.[18] This theory is probably even more true for the treatment of ACoAAs, in which cognitive and neuropsychological deficits are described relatively frequently,[36] and such deficits are often missed with mRS sores.[37] Nonetheless, the mRS score was included to enable a comparison with previous studies. Future studies of the treatment of unruptured ACoAAs should consider reporting outcome from a broader and societal perspective, including cognitive functioning, quality of life, and return-to-work rates. The absolute number of patients and complications were low. Therefore, findings regarding trends in complications, and other even smaller subgroups, should be interpreted with caution because they are driven by low numbers, increasing the likelihood of type 2 error in the analyses. The durability of the treatment modalities was not evaluated adequately in this study because we did not follow up clipped ACoAAs radiologically and were able to provide complete 6-month follow-up data of only endovascular patients. However, we did include the number of relevant recanalizations (i.e., the number of patients who needed a retreatment or presented with aSAH after treatment). Nonetheless, adequate estimation of recanalization rates of endovascularly treated ACoAAs requires a longer follow-up duration, including predefined radiologic modalities and follow-up schemes, which were not applied in our study population. Prospective studies including such predefined long-term radiologic follow-up schemes are needed to provide accurate data on the durability of both treatments.

CONCLUSIONS

We did not find significant changes in complications, functional outcome, or discharge-to-home rates after the treatment paradigm transition from microsurgical clipping to endovascular therapy for treating unruptured ACoAAs. Because the overall complication rate remained the same throughout the study period, the transition seemed to be performed safely and successfully.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Roel Haeren: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – review & editing. **Ahmad Hafez:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – review & editing. **Miikka Korja:** Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Rahul Raj:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. **Mika Niemelä:** Methodology, Resources, Supervision, Writing – review & editing.

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