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Evolution of the patient-first approach: a dual-trained, single-neurosurgeon experience with 2002 consecutive intracranial aneurysm treatments

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OBJECTIVE The paradigm for intracranial aneurysm (IA) treatment is shifting toward a hybrid approach involving open and endovascular techniques. The authors chronicled the evolution of IA treatment by retrospectively examining a large series of IA cases treated by a single dual-trained neurosurgeon, focusing on evolving technology relative to the choice of treatment options, perioperative morbidity, and mortality.

METHODS The aneurysm database at the authors' institution was searched to identify consecutive patients treated with endovascular or open microsurgical approaches by one neurosurgeon during an 18-year time span. Patients were included regardless of IA rupture status, location or morphology, or treatment modality. Data collected were baseline clinical characteristics, aneurysm size, treatment modality, operative complications, in-hospital mortality, and retreatment rate.

RESULTS A total of 1858 patients with 2002 IA treatments were included in the study. Three-hundred fifty IAs (17.5%) were ruptured. Open microsurgery was performed in 504 aneurysms (25.2%) and endovascular surgery in 1498 (74.8%). Endovascular IA treatments trended toward a growing use of flow diversion during the last 11 years. In-hospital mortality was 1.7% overall, including 7.0% in ruptured and 0.5% in unruptured cases. The overall complication rate was 3.3%, including 3.4% for microsurgical cases and 3.3% for endovascular cases. The rate of retreatment was 3.6% after clipping and 10.7% for endovascular treatment.

CONCLUSIONS This study demonstrates complementary use of open and endovascular approaches for IA treatment. By customizing treatment to the patient, comparable rates of procedural complications, mortality, and retreatment were achieved for both endovascular and microsurgical approaches.

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KEYWORDS intracranial aneurysm; endovascular neurosurgery; coiling; clipping; vascular disorders

The management of intracranial aneurysms (IAs) continues to evolve at a remarkable pace. Throughout the past 2 decades, endovascular technology has seen paradigm-changing technological progress in IA treatment. During this time period, flow diverters, intrasaccular flow-disruptive devices, and most recently, surface-modified implants have been introduced.[1–4] With the growing armamentarium of endovascular techniques, the indications for endovascular treatment of IAs have expanded from narrow-necked sidewall aneurysms to bifurcation, wide-necked, and fusiform aneurysms.[5–7] The minimally invasive nature of the procedures, lower morbidity,[8] and shorter length of stay[9] have been the main driving forces behind the growth of the endovascular field.[10] Nevertheless, endovascular treatments are not without complication and certainly should not routinely be considered first-line care in the treatment of IAs.[11] Endovascular treatment still lacks equipoise for certain aneurysms with respect to effectiveness and long-term outcomes, and furthermore may be a suboptimal choice in certain complex cerebrovascular anatomy. Although the role of microsurgery may have decreased over the years,[12–14] it remains an essential tool in

ABBREVIATIONS ACoA = anterior communicating artery; IA = intracranial aneurysm; ICA = internal carotid artery; ISAT = International Subarachnoid Aneurysm Trial; MCA = middle cerebral artery; WEB = Woven EndoBridge.

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the hands of neurosurgeons and is a mainstay of treatment for several types of IAs.[15]

The availability of a perpetually expanding tool kit affords neurosurgeons a plethora of treatment modalities, allowing for a focused priority of maximizing optimal outcomes and minimizing untoward complications. Tailored and personalized treatment must be considered, based on a patient-first philosophy. A hybrid, dual-trained neurosurgeon occupies a unique position, capable of making an unbiased decision with respect to the best treatment option. Certainly, a team with combined skill sets may offer the patient the same potential treatments, but often personal treatment biases influence a surgeon's decisions. Although several articles have reported a hybrid neurosurgery experience, most of the reports present a selective, location-based analysis instead of a holistic, nonselective, and consecutive case experience that would reflect a true pattern of modern cerebrovascular neurosurgery practice.[4]

By carefully examining our retrospective series of consecutive patients treated by a single dual-trained neurosurgeon, we demonstrate the evolution of IA treatment in the era of hybrid complementary neurosurgery with a special focus on the evolving technology as it relates to the choice of treatment options, perioperative morbidity, and mortality. This study provides a unique perspective on modern cerebrovascular surgery from the 18-year career of a dual-trained neurosurgeon that began before the availability of flow diverters and intrasaccular stents or flow-disrupting devices.

Methods

Ethical Considerations

Written informed consent for treatment was provided by each patient or a legally authorized representative. The study was approved by the University at Buffalo IRB.

Data Extraction

We performed a retrospective search of our institution's aneurysm database (January 2004 to September 2021) to identify those aneurysms treated by the senior author (E.I.L.), who has received training in microsurgical and endovascular approaches. We extracted demographic information (age and sex), aneurysm locations and rupture status, date of treatment and modality, occurrence of intraoperative rupture, in-hospital mortality, clinical and imaging follow-up length, and retreatment. Microsurgical clipping, wrapping, and bypass were considered open treatments. Primary coil embolization, stent- or balloon-assisted coiling including use of the PulseRider (Cerenovus/Johnson & Johnson) and Comaneci (Rapid Medical) devices, flow diversion, flow disruption (Woven EndoBridge [WEB] device, MicroVention-Terumo), or parent vessel sacrifice using coiling or embolization coils were grouped as endovascular treatments. The yearly trends in open and endovascular treatment modalities were plotted. Specifically, annual trends of flow diversion and non–flow diversion modalities were represented. Additionally, the trends in complication rates, mortality, and retreatment were calculated. A subgroup analysis was performed for ruptured and unruptured aneurysms.

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline was implemented in this paper. Written informed consent for treatment was provided by each patient or a legally authorized representative.

Treatment Selection

Fundamentally, the primary driving philosophy for treatment decision-making centered on the simplest and safest possible treatment option that could adequately secure the aneurysm. In general, clipping was recommended over endovascular options for relatively younger patients, middle cerebral artery (MCA) bifurcation aneurysms, internal carotid artery (ICA) bifurcation aneurysms, and posterior communicating artery aneurysms, especially in the presence of a fetal circulation.[16] For cases with poor Hunt and Hess grade, old age, or medical comorbidities, endovascular options were prioritized, even for aneurysm location and morphology otherwise suitable for open surgery. The importance of these factors has been highlighted in IA treatment guidelines.[17] Use of the endovascular approach is particularly supported in the literature for patients with poor neurological status, advanced age, and comorbidities.[17] Complex cases were discussed during our weekly multidisciplinary vascular case conferences.

Statistical Analysis

A descriptive analysis was performed using SPSS (version 24, IBM Corp.). Percentages and proportions were used to present categorical variables. Means and standard deviations (SDs) were used to represent continuous data with a normal distribution. The data were independently reviewed and analyzed by a statistician.

Results

Patient Demographics and Aneurysm Characteristics

A total of 1858 patients with 2002 aneurysms were identified for inclusion in the study. The mean (± SD) age of the patients was 58.2 ± 13.2 years, and 1406 (75.7%) were women. Three hundred fifty aneurysms (17.5%) were ruptured. The most frequent aneurysm locations were the ICA (45%), MCA (18.9%), and anterior communicating artery (ACoA; 16.5%). All locations are detailed in Table 1.

Aneurysm Treatments

Open microsurgery was performed in 504 aneurysms (25.2%) and endovascular surgery in 1498 (74.8%). The distribution of treatment modality according to location is listed in Table 1. Notably, 226 (59.6%) of all open microsurgery cases were performed for MCA aneurysms, and this was the only location significantly associated with the decision to be treated with open surgery (59.6% vs 40.4%, $p < 0.001$). During the first half of the present study, clipping constituted 25.5% of all IA treatments, whereas during the second half, this percentage remained consistent at 24.2%. The proportion of each approach for each year of the study is depicted in Fig. 1. The majority of open procedures consisted of microsurgical clipping (98.8%). Primary coil embolization was the predominant modality (n =

TABLE 1. Aneurysm locations and treatment modalities

Location	Total, n (%)	Open Surgery, n (%)	Endovascular, n (%)	p Value
ICA	900 (45)	116 (12.9)	784 (87.1)	<0.001
MCA	379 (18.9)	226 (59.6)	153 (40.4)	<0.001
ACA	86 (4.3)	20 (23.3)	66 (76.7)	0.7
ACoA	330 (16.5)	125 (37.9)	205 (62.1)	<0.001
VA	24 (1.2)	0 (0)	24 (100)	0.001
PICA	62 (3.1)	6 (9.7)	56 (90.3)	0.003
VBJ	13 (0.6)	0 (0)	13 (100)	0.05
BA	158 (7.9)	5 (3.2)	153 (96.8)	0.005
AICA	9 (0.5)	2 (22.2)	7 (77.8)	>0.99
SCA	18 (0.9)	2 (11.1)	16 (88.9)	0.3
PCA	23 (1.1)	2 (8.7)	21 (91.3)	0.09
Total	2002 (100)	504 (25.2)	1498 (74.8)	NA

ACA = anterior cerebral artery; AICA = anterior inferior cerebellar artery; BA = basilar artery; NA = not applicable; PCA = posterior cerebral artery; PICA = posterior inferior cerebellar artery; SCA = superior cerebellar artery; VA = vertebral artery; VBJ = vertebrobasilar junction.

713, 47.6%) among the endovascular procedures. Among the aneurysms treated with endovascular surgery, a trend toward a growing use of flow diversion in the last 11 years is illustrated in Fig. 2. A detailed overall breakdown of treatment modalities is given in Table 2. Overall, intraoperative rupture occurred in 13 aneurysms (0.6%). The rate of in-hospital mortality was 1.7% overall, 1.3% among microsurgery cases and 1.8% among endovascular cases ($p = 0.4$). With regard to rupture status, in-hospital mortality was 7% in ruptured cases and 0.5% in unruptured cases ($p < 0.001$). In ruptured cases, the in-hospital mortality rate was 7.1% among microsurgery cases versus 6.9% among endovascular cases ($p = 0.9$). The overall complication rate was 3.3%, including 3.4% for microsurgical cases and 3.3% for endovascular cases ($p = 0.9$). A breakdown of complication rates according to each 6-year period for both microsurgery and endovascular is shown in Fig. 3. The rate of complications in the endovascular group increased from 2.6% (2004–2009) to 3.0% (2010–2015), which corresponds to the early years after the introduction of flow diversion. From 2016 to 2021, the complication rate decreased to 1.7%. For the microsurgical group, the complication rate decreased from 3.4% (2004–2009) to 2.0% (2010–2015) and remained at 2.0% (2016–2021). The rates of retreatment were 3.6% after clipping and 10.7% after endovascular treatment ($p < 0.001$). Of note, the retreatment rate of previously flow-diverted aneurysms with another flow-diverting device was 5% (17 aneurysms).

Discussion

Key Results and Context

This study highlights the complementary use of microsurgery and endovascular techniques for the treatment

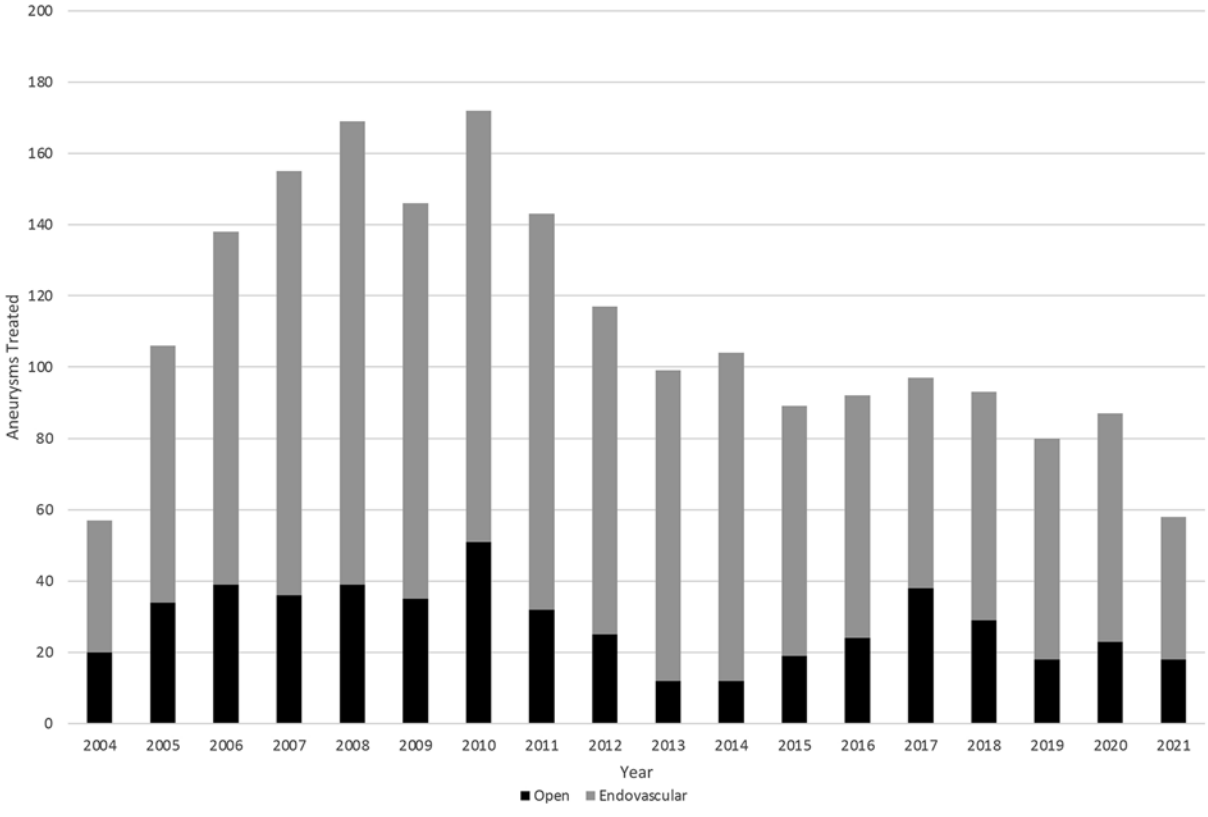

FIG. 1. Yearly trends in the utilization of open (*black*) and endovascular (*gray*) procedures. A consistent proportion of the volumes of these procedures is observed throughout the years.

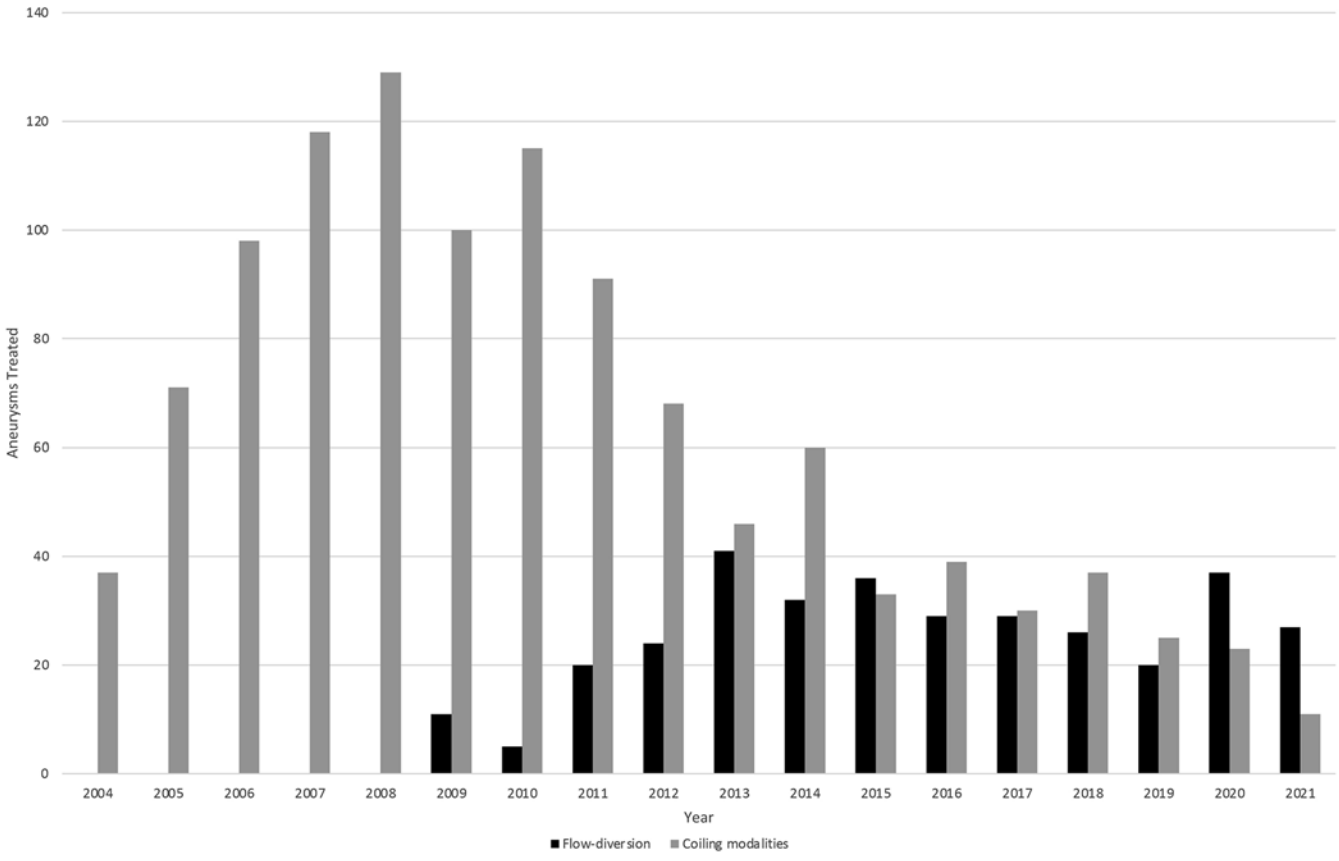

FIG. 2. Yearly trends in the utilization of flow diversion (*black*) and non–flow diversion (*gray*) endovascular procedures. A growing trend is evident in the utilization of flow diversion over coiling since 2009.

of IAs during the 18-year career of a dual-trained neurosurgeon. These modalities should not be considered competitive. Although the relative proportion of endovascular procedures may have increased, open microsurgical procedures constituted a substantial proportion of the cases (n = 504, 25.2%). There has been a national trend toward decreased utilization of microsurgery for IA treatment in recent years.[12,14,18,19] Interestingly, during the first half of the present study, clipping constituted 25.5% of all IA treatments, whereas in the second half, this percentage remained consistent at 24.2%.

TABLE 2. All treatment modalities

Modality	N (%)
Microsurgical clipping	498 (24.9)
Wrapping	5 (0.2)
Bypass	1 (0.05)
Primary coiling	713 (35.6)
Stent-assisted coiling	389 (19.4)
Balloon-assisted coiling	25 (1.2)
PulseRider-assisted coiling	2 (0.1)
Comaneci-assisted coiling	2 (0.1)
Flow diversion	337 (16.8)
WEB device deployment	24 (1.2)
Parent artery sacrifice using coiling	6 (0.3)

In this study, the in-hospital combined mortality rate for ruptured aneurysm cases treated with either endovascular or open surgical approaches was 7.0%. Although a direct comparison with the International Subarachnoid Aneurysm Trial (ISAT) is not possible, for context, 2-month mortality in that trial was 7% for the endovascular coiling group and 7.9% for the microsurgical clipping group,[20] and may be reflective of the baseline severity of the subarachnoid hemorrhage, technical advancements, and device improvements. In the present study, the in-hospital mortality rate for patients with ruptured aneurysms in the microsurgery group was 7.1% versus 6.8% for endovascularly treated patients. Similarly, for unruptured aneurysms, the rate of in-hospital mortality was 0.4%. These rates are also comparable with international data. A meta-analysis of 4899 unruptured aneurysm treatments reported an in-hospital mortality rate of 0.7% for clipping and 0.5% for coiling.[21] However, we believe the selection of cases that is tailored to patient- and aneurysm-specific features may be an important factor. Zanaty et al. presented a single-surgeon experience in treating 252 patients with ruptured aneurysms.[22] Of these patients, 70 underwent clipping and 182 underwent endovascular coil treatment. Mortality in the endovascular treatment group was 13.2%, compared with 10.0% in the coiling group.

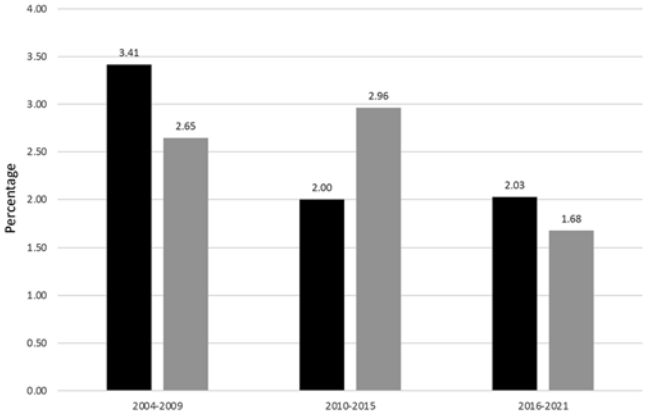

FIG. 3. The rate of procedural complications for microsurgery (*black*) and endovascular (*gray*) approaches in 6-year increments. A reduction in complication rates is seen for both endovascular and microsurgical procedures from the initial 6-year period.

In our series, the rate of retreatment after microsurgical treatment was 3.6%, while that for endovascular treatment was 10.7%. The 6-year results of the Barrow Ruptured Aneurysm Trial (BRAT) revealed a retreatment rate of 4.6% (13 of 280 aneurysms) for clipping and 16.4% (21 of 128 aneurysms) for coiling ($p < 0.0001$).[23] Of note, in our study, the retreatment rate of previously flow-diverted aneurysms with another flow-diverting device was 5.0% (17 aneurysms). For the remaining endovascular procedures treated without flow diversion, the retreatment rate was 12.7%. In a multicenter experience with 2592 aneurysms, the rate of repeat flow diversion was 3.4%.[24] Similarly, in the Pipeline for Uncoilable or Failed Aneurysms (PUFS) trial of 106 IA treatments, only 5 patients (4.7%) required retreatment with repeat flow diversion ($n = 4$) or coiling ($n = 1$).[25,26] These data suggest that as technology evolves, the retreatment rate continues to drop to very low percentages, similar to the rate for surgically clipped aneurysms.

Our study also highlights an evolution in the treatment modalities of endovascular options. From 2004 to 2008, primary coil embolization or coiling adjuncts (balloons and stents) were the only treatment options.[27–29] In 2009, the Pipeline embolization device (Medtronic) was approved for the treatment of wide-necked ICA aneurysms.[30] Since that time, there has been an increase in the number of flow-diversion cases for the dual-trained senior author (Fig. 2). In the last 2 years of the study period, the number of those cases far exceeded the number of other endovascular treatments. The trend toward increasing use of flow diversion is expected to continue as indications for this treatment continue to expand to involve more distal and posterior circulation aneurysms.[30]

Another important finding from this study is a consistent proportion of microsurgical aneurysm treatments. The senior author reserves open surgery for those patients in whom that approach would offer better outcomes and obviates the need for multiple adjunct devices in those who may be at risk for dual antiplatelet therapy. Several other factors are taken into consideration, including age, location, and morphology of the aneurysm. In cases of equipoise, the treatment options were explained to the patient and/or family. In all cases, the final informed decision was made at their discretion.

In another single-surgeon case series of 221 unruptured IAs that were clipped, the perioperative complication rate was 17.3%, with morbidity and mortality rates of 2.1% and 1.5%, respectively.[31] It was suggested that at the same time that more aneurysms were undergoing coil embolization, poor clinical outcomes of open surgery increased.[31] Our study suggests the opposite, that complication rates can be mitigated when endovascular and surgical techniques are used as complementary modalities, rather than as competitive techniques (Fig. 3). The other single-surgeon case series also showed that the endovascular volume for unruptured IAs has overtaken the volume for clipping in recent years.[31] Moreover, an increase in the relative volume of endovascular cases has been reported in the post-ISAT era.[32] It is plausible that as the indications for endovascular treatment are increasing, open surgery is becoming restricted to more challenging cases.

The results of our study are comparable to those for previous studies comparing the outcomes of open and endovascular treatment of ruptured and unruptured aneurysms.[21,22] This contradicts the perception that dual-trained neurosurgeons have inferior outcomes with open microsurgery. We noticed a reduction in the rate of procedural complications over time for both the endovascular and microsurgical groups (Fig. 3). Importantly, the rate of complications in the endovascular group increased from 2.6% (2004–2009) to 3.0% (2010–2015), which corresponds to early years after the introduction of flow diversion. From 2016 to 2021, the complication rate decreased to 1.7%, which may reflect advancements in the endovascular techniques and devices, in addition to increased surgical experience. Complication rates for open microsurgery also decreased over time. This improvement may be a result of the senior author's experience with open surgery gained through time in the operating room and also because more complex aneurysms have become treatable by endovascular means, such as flow diversion, rather than surgical bypass or complex clip reconstruction. Endovascular advancements have resulted in an evolution in the treatment selection criteria over time. The choice of treatment for fusiform or sidewall ICA and posterior circulation aneurysms is predominantly endovascular, whereas microsurgery became reserved for cases in which it was proven to be safer and more effective (such as MCA bifurcation aneurysms in young patients). It is important to note that aneurysm treatment volumes are likely higher for dual-trained neurosurgeons than for neurosurgeons trained in either open microsurgery or endovascular surgery.

Microsurgery was the mainstay of IA treatment for decades, but the publication of ISAT fueled an increase in the number of patients treated with primary coil embolization versus open surgical repair.[32,33] From 2004 to 2014, a significant increase in the annual number of endovascularly treated IAs with a decrease in the annual number of clip placements has been reported. This trend was consistent for both ruptured and unruptured aneurysms.[32] This has led to comparisons between open and endovascular techniques, yet we believe that the two approaches are complementary and should be regarded as such, as docu-

mented in this study and the experiences of other dual-trained neurosurgeons.

Limitations

Our study has limitations. This is a retrospective, single-surgeon case series. We intended to chronicle the practice of a dual-trained neurosurgeon across the years with respect to treatment modality decisions and complication rates, with a patient-first approach in mind. Therefore, retreatment rates were deemed more meaningful than occlusion rates for such a goal, with no angiographic outcomes being extracted for analysis. However, the single-operator feature of our current study indicates that the results must be approached with caution.

Interpretation of Results and Generalizability

This study represents the clinical decision-making and experience of a dual-trained neurosurgeon, whose career follows most of the evolution that occurred in the endovascular field. Therefore, the experience presented is, to an extent, representative of this field's evolution, such as the use of flow diverters when they were introduced, which reduced the number of patients treated with coiling techniques, especially in locations such as the ICA. Our results represent the experience of a single dual-trained neurosurgeon, with the advantage of technical and observational consistency but reduced generalizability, especially to operators who are not dual-trained or centers that are not capable of providing both endovascular and microsurgical treatments.

Conclusions

This study chronicles the complementary use of open and endovascular approaches for the treatment of IAs. Endovascular techniques have evolved significantly over recent years, yet microsurgery remains an essential tool in the armamentarium of a cerebrovascular neurosurgeon. An understanding of the nuances of the evolving tool kit at the disposal of cerebrovascular neurosurgeons, in conjunction with a patient-first approach, will continue to drive optimal outcomes following treatment of IAs.

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Disclosures

Dr. Levy reports receiving consulting fees from Claret Medical, GLG Consulting, Guidepoint Global, Imperial Care, Medtronic, Rebound, StimMed, Misonix, Mosaic, Clarion, and IRRAS; receiving payment or honoraria for lectures, presentations, speakers' bureaus, manuscript writing, or educational events from Medtronic; receiving payment for expert testimony for rendering medical/legal opinions as an expert; receiving support for attending meetings and/or travel; being reimbursed for travel and food for some meetings with the CNS and ABNS; and receiving stock or stock options from NeXtGen Biologics, Rapid Medical, Claret Medical, Cognition Medical, Imperative Care, Rebound Therapeutics, StimMed, and Three Rivers Medical. Dr. Cappuzzo reports being a consultant for Cerenovus, MIVI, Penumbra, and Integra.

Author Contributions

Conception and design: Levy, Waqas. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Waqas. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Statistical analysis: Tutino. Study supervision: Levy.

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