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# Global Outcomes for Microsurgical Clipping of Unruptured Intracranial Aneurysms: A Benchmark Analysis of 2245 Cases

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**BACKGROUND AND OBJECTIVES:** Benchmarks represent the best possible outcome and help to improve outcomes for surgical procedures. However, global thresholds mirroring an optimal and reachable outcome for microsurgical clipping of unruptured intracranial aneurysms (UIA) are not available. This study aimed to define standardized outcome benchmarks in patients who underwent clipping of UIA.

**METHODS:** A total of 2245 microsurgically treated UIA from 15 centers were analyzed. Patients were categorized into low- ("benchmark") and high-risk ("nonbenchmark") patients based on known factors affecting outcome. The benchmark was defined as the 75th percentile of all centers' median scores for a given outcome. Benchmark outcomes included intraoperative (eg, duration of surgery, blood transfusion), postoperative (eg, reoperation, neurological status), and aneurysm-related factors (eg, aneurysm occlusion). Benchmark cutoffs for aneurysms of the anterior communicating/anterior cerebral artery, middle cerebral artery, and posterior communicating artery were determined separately.

**RESULTS:** Of the 2245 cases, 852 (37.9%) patients formed the benchmark cohort. Most operations were performed for middle cerebral artery aneurysms (53.6%), followed by anterior communicating and anterior cerebral artery aneurysms (25.2%). Based on the results of the benchmark cohort, the following benchmark cutoffs were established: favorable neurological outcome (modified Rankin scale ≤2) ≥95.9%, postoperative complication rate ≤20.7%, length of postoperative stay ≤7.7 days, asymptomatic stroke ≤3.6%, surgical site infection ≤2.7%, cerebral vasospasm ≤2.5%, new motor deficit ≤5.9%, aneurysm closure rate ≥97.1%, and at 1-year follow-up: aneurysm closure rate ≥98.0%. At 24 months, benchmark patients had a better score on the modified Rankin scale than nonbenchmark patients.

**CONCLUSION:** This study presents internationally applicable benchmarks for clinically relevant outcomes after microsurgical clipping of UIA. These benchmark cutoffs can serve as reference values for other centers, patient registries, and for comparing the benefit of other interventions or novel surgical techniques.

**KEY WORDS:** Aneurysm, UIA, Outcome, Clipping, Microsurgery, Microsurgical

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**ABBREVIATIONS: ACOM,** anterior communicating; **PCOM,** posterior communicating

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In recent years, performance monitoring and quality assessment have become increasingly important in the medical field. Particularly in surgical disciplines, there is an increased interest in evaluating outcomes after surgery to improve long-term patient safety. Nevertheless, to date, quality measurements are mainly available from national databases or from cohorts of individual centers, which lack a standardized method of analysis and hampers comparisons between different centers and countries.[1-3] To address this issue, the concept of benchmarking was introduced to the field of surgery by Staiger et al[4] in 2018. Since then, standardized benchmark outcomes for several surgical techniques have been established.[5-8] Benchmarking represents the best achievable outcome of a given procedure and is the desirable goal to achieve.[4] The ambition to achieve this best possible outcome should lead to a reduction in postoperative morbidity and mortality of patients after surgery and enables a worldwide comparison of defined benchmark cutoffs for certain procedures.[4,9] The methodology and recommendations were further refined in a Delphi process.[9] This standardized method was successfully described for many surgical techniques, such as liver transplantation[8] and pancreaticoduodenectomy,[5] with technique-specific outcomes described in addition to general morbidity and mortality. These efforts provide reason to expect that surgical benchmarking will emerge as an effective tool to collect patient-reported outcomes in a standardized format and to improve outcomes in the long term.[10] However, the concept of benchmarking has not yet been applied to neurosurgical interventions.

One challenging neurosurgical procedure is microsurgical clipping of unruptured intracranial aneurysms (UIA). Because of the increasing use of MRI and computed tomography (CT) diagnostics, UIAs are being diagnosed with increasing frequency and affect 3%–5% of the adult population.[11-13] Because UIA rupture is known to occur in up to 6.0% of patients during a follow-up period of 24 months, preventive microsurgical or endovascular treatment of aneurysms is a potential option, although the optimal choice of treatment poses challenges to clinicians.[14-16] Available data report a risk of unfavorable outcome in 6.7% and a mortality of 1.7% after microsurgical clipping.[17] However, the literature on microsurgical treatment of UIA is heterogeneous and does not follow standardized methods, making comparison with other modalities such as endovascular treatment difficult.

With this in mind, we aimed to define the best possible outcome by assessing benchmark cutoffs for microsurgical clipping of UIA in 15 centers on 4 continents. We selected 23 patient-centered perioperative outcome variables and defined benchmark cutoffs for each variable. These results can serve as a reference for other centers by establishing milestones to strive for and facilitating comparison with other treatment modalities or novel surgical techniques and even help in the discussion of centralization of complex procedures to ensure quality associated with case volume.

## METHODS

### Study Design

The aim of this study was to establish benchmarks for microsurgical clipping of untreated UIA and followed the standardized methodology published by Staiger et al.[4] We performed a multicenter, retrospective cohort study based on institutional databases. The patient population was stratified according to their preoperative risk profile, using defined high-risk criteria (**Supplemental Digital Content 1, Figure 1**, http://links.lww.com/NEU/D944). Once a patient fulfilled a single high-risk criterion, he was assigned to the high-risk (hereafter referred as "nonbenchmark") cohort. Consequently, patients not fulfilling a high-risk criterion were used to define the low-risk (hereafter referred as "benchmark") cohort (**Supplemental Digital Content 1, Figure 1**, http://links.lww.com/NEU/D944).

Next, outcomes were defined for specific variables covering surgery- and aneurysm-related outcomes. For each outcome, a benchmark cutoff (indicating the "best achievable" outcome) was calculated as the 75th percentile of the median values for all centers separately for the benchmark and nonbenchmark cohorts.

The study was registered with ClinicalTrials.gov (NCT 05029947), and ethical approval was granted by the Medical Ethics Committee of the Hamburg Medical Association (2021-300063-WF). A patient consent exemption was granted because of the retrospective nature of the study. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guideline.[18]

### Patient and Hospital Selection

The final collaborative consortium included 15 centers: 7 from Europe (Hamburg, Berlin, Munich, Mainz [all Germany], Vienna, Linz [all Austria], and Milan [Italy]), 5 from North America (Phoenix, San Francisco, San Antonio, Thomas Jefferson Philadelphia, and Penn Medicine Philadelphia [all United States]), 2 from Asia (Novosibirsk [Russian Federation] and Pohang [South Korea]), and 1 from South America (Sao Paulo [Brazil]). All centers were specialized in cerebrovascular treatment defined as possibility for open and endovascular treatment as well as availability of neurosurgical intensive care unit (ICU) ward. From the 15 included centers, consecutive patients who were above 18 years of age and underwent elective microsurgical clipping of untreated UIA between January 2016 and December 2020

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were selected. Additionally, the number of endovascular-treated UIA in each center during the study period was recorded.

### Performance Metrics of Benchmarking

Aiming for a homogeneous group of patients as a mandatory prerequisite for benchmarking, we defined high-risk criteria (**Supplemental Digital Content 1, Figure 1**, http://links.lww.com/NEU/D944), which are known factors that negatively affect outcomes after microsurgical clipping of UIA: age at surgery above 65 years, aneurysm of the posterior circulation, aneurysm diameter above 10 mm, aneurysm calcification, irregular aneurysm configuration, chronic obstructive pulmonary disease, coagulopathy or bleeding disorder, history of congestive heart failure, history of stroke, American Society of Anesthesiology physical status of IV or higher, and body mass index above 40 kg/m$^2$.[17,19-26] After having defined the cohort of benchmark patients, which accordingly had a "low-risk profile," these were used to determine benchmark cutoffs representing the following clinically relevant outcomes: operating duration, blood transfusion, intraoperative aneurysm rupture, wrapping adjunct to clipping, any deviation from the ideal postoperative course, stroke, surgical site infection, meningitis, hydrocephalus, cerebral vasospasm, intracerebral hemorrhage, subdural hematoma, new-onset seizure, pulmonary or cardiac complication, pulmonal embolism, new motor or sensory deficit, new aphasia, length of hospital and ICU stay, in-hospital mortality, and aneurysm occlusion assessed by CT angiography or digital subtraction angiography. In addition, the neurological outcome was assessed using the modified Rankin Scale (mRS) by the treating neurosurgeon. Benchmark cutoffs, calculated as the 75th percentile of each center's median, were used to indicate the best achievable outcomes.

### Statistical Analysis

As first step, we calculated the median values of continuous parameters and the proportional values of categorical variables for each participating center as described previously.[4] Next, the median and IQR of center-specific values were calculated. As determined in the Delphi process,[9] we selected the 75th percentile as the benchmark cutoff. For further statistical analyses, we performed the Shapiro–Wilk normality test for confirming Gaussian distribution. The 2-tailed Student's *t*-test or 1-way analysis of variance with post hoc tests was performed for examining pairwise differences of parametric data.

Kaplan–Meier plot was used to visualize the aneurysm closure rates during follow-up and statistical difference was assessed by log-rank test. A *P*-value less than .05 was considered as statistically significant. All analyses were performed using SPSS Inc. (Version 27). Data illustrations were performed using GraphPad Prism 9.

## RESULTS

### Study Population

Data were available for a total of 2245 cases from the 15 centers that participated in this study (Figure 1). Of the 2245 cases, 1675 (74.6%) were women and 570 (25.4%) were men, with a mean (SD) age of 57.3 (11.1) years (Table 1). Most clippings were performed for middle cerebral artery (MCA) aneurysms (53.6%), followed by anterior cerebral artery (ACA) and anterior communicating (ACOM) aneurysms (25.2%) (Table 1). Of the 2245 cases, 540 (24.1%) patients had more than 1 aneurysm clipped in a single operation, and 77 (3.4%) patients also underwent bypass (Table 1).

### Benchmark Cohort

From the main cohort of 2245 cases, 852 (37.9%) patients were identified as benchmark patients after applying the high-risk criteria (**Supplemental Digital Content 1, Figure 1**, http://links.lww.com/NEU/D944) and constitute the benchmark cohort (Table 2). The proportion of benchmark patients in the final cohort varied from 16.0% to 49.3% depending on the center (Figure 1).

In this benchmark cohort, the mean (SD) age was 53.2 (9.1) years, and 78.3% of patients were female. As expected, patients in the benchmark cohort were significantly less multimorbid than nonbenchmark patients ($P < .01$). Most aneurysms were detected incidentally (87.4%, Table 1) and were located at the MCA (53.0%). The mean (SD) aneurysm diameter was 5.4 (2.4) mm (Table 1). Of the 852 patients, 372 (43.7%) patients had multiple cerebral aneurysms, of whom 223 (26.2%) had their aneurysms clipped in 1 surgical session. Benchmark outcome cutoffs are shown in Table 2. The median (range) operative time was 196.2 (87.4-319.0) minutes, and intraoperative aneurysm rupture occurred in 1.6% of cases. The overall complication rate was 13.6% (Table 2). Closure of the clipped aneurysm was achieved in 98.4% at the time of discharge.

### Benchmark Outcome Cutoffs

We defined 23 benchmark variables to describe the best achievable outcomes (Table 2). Intraoperative benchmark variables were operative time ≤210.8 min, blood transfusion ≤0.4%, aneurysm rupture ≤3.8%, and wrapping ≤6.4%. The benchmark cutoff for length of hospital stay was ≤7.7 days and for length of ICU stay ≤1.0 day. Aneurysm closure is targeted in ≥97.1% at discharge and in ≥98.0% 12 months after surgery. When the outcomes of the nonbenchmark cohort were analyzed, 18 of 23 (78.3%) benchmark values did not reach the cutoff confirming correct stratification of the main cohort (Table 2, **Supplemental Digital Content 2**, **Table 1**, http://links.lww.com/NEU/D945).

### Neurological Status After Microsurgical Clipping

Patients were assessed during follow-up using the mRS (Figure 2). A favorable neurological outcome was defined as mRS ≤2, which was 99.52% in the benchmark cohort before surgery (Figure 2). Of these benchmark patients, 4.1% had an unfavorable neurological status (mRS >2) at the time of discharge, with an in-hospital mortality of 0.62%. During follow-up, neurological recovery was seen in many patients, whereas the rate of mRS >2 decreased to 1.99% at 12 months and 2.03% at 24 months after surgery (Figure 2). In conclusion, 97.98% of benchmark patients had satisfactory neurological outcome at 24 months after surgery. Higher rates of unfavorable neurological outcome were observed in the nonbenchmark patients (Figure 2).

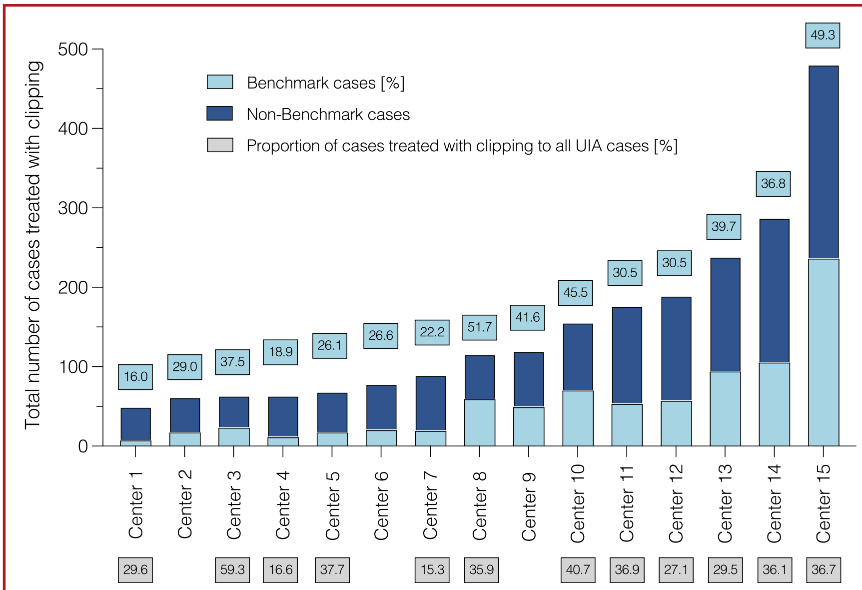


**FIGURE 1.** *Variations in the proportion of benchmark cases performed across the 15 centers. UIA, unruptured intracranial aneurysms.*



### Aneurysm Occlusion

To further describe surgical success after microsurgical clipping, the rate of aneurysm occlusion is undeniably an important parameter, especially when comparing different treatment modalities. To investigate this aspect, we documented the closure rates at discharge and during follow-up in 1091 (48.6%) patients. In 364 benchmark patients, the benchmark cutoffs for aneurysm closure of ≥97.1% at the time of discharge and ≥98.0% 12 months after surgery were calculated (Table 2). Aneurysm closure rates were highest after clipping of MCA aneurysms and lowest for posterior communicating (PCOM) aneurysms (**Supplemental Digital Content 3**, **Table 2**, http://links.lww.com/NEU/D946). After exclusion of aneurysms of the posterior circulation and PCOM, comparable aneurysm closure rates were seen between benchmark and nonbenchmark patients during follow-up (*P* = .17, Figure 3).

### Location-Specific Benchmark Values

Because it is well known that the outcome after clipping may differ depending on the location of the aneurysm and therefore influences the decision for or against microsurgical treatment, we further subdivided the benchmark cohort depending on the location of the aneurysm. **Supplemental Digital Content 3**, **Table 2**, (http://links.lww.com/NEU/D946) shows the 3 most treated aneurysm locations in our patient cohort: ACOM/ACA, MCA, and PCOM. As done previously, we calculated separate benchmark cutoffs for each location using the benchmark cohort. This showed that aneurysms of the ACOM/ACA and PCOM had shorter operative times, less temporary vessel occlusion, and less intraoperative aneurysm rupture (**Supplemental Digital Content 3**, **Table 2**, (http://links.lww.com/NEU/D946). Nevertheless, the rates of overall complication, stroke, and intracerebral hemorrhage were lowest after clipping of MCA aneurysms (**Supplemental Digital Content 3**, **Table 2**, http://links.lww.com/NEU/D946).

### Correlation of the Benchmark Proportions With the Centers' Volume

To further understand the differences in the proportions of benchmark cases between centers, we correlated them with the number as well as the proportion of cases that were treated with clipping (**Supplemental Digital Content 4**, **Figure 2**, http://links.lww.com/NEU/D947). This showed an increased proportion of benchmark cases in centers with higher case volume (*P* = .03, **Supplemental Digital Content 4**, **Figure 2A**, http://links.lww.com/NEU/D947) and proportion of cases treated with clipping when compared proportionally with endovascular cases (*P* = .09, **Supplemental Digital Content 4**, **Figure 2B**, http://links.lww.com/NEU/D947). Nevertheless, there was no correlation between the percentage of cases treated with clipping and the number of endovascular patients (*P* = .36, **Supplemental Digital Content 4**, **Figure 2C**, http://links.lww.com/NEU/D947), suggesting that the preference for a particular method depends on the center's practice rather than the overall caseload.

## DISCUSSION

Although surgery is an essential part of UIA treatment and outcomes are of great importance to patients, there is no standardized

**TABLE 1. Characteristics of All Patients Included in This Study**

| Characteristic | N = 2245 | Low-risk cohort (N = 852) | High-risk cohort (N = 1393) | *P* value[a] |
|---|---|---|---|---|
| Age, [y], mean (SD) | 57.2 (11.1) | 53.2 (9.1) | 59.8 (11.5) | **<0.01** |
| Sex, n (%) | | | | |
| Female | 1675 (74.6) | 667 (78.3) | 1008 (72.4) | **<0.01** |
| Male | 570 (25.4) | 185 (21.7) | 385 (27.6) | |
| ASA, n (%) | | | | |
| I | 211 (9.4) | 120 (14.1) | 91 (6.5) | **<0.01** |
| II | 1169 (52.1) | 526 (61.7) | 643 (46.2) | **<0.01** |
| III | 814 (36.3) | 206 (24.2) | 608 (43.6) | **<0.01** |
| IV | 51 (2.3) | 0 (0.0) | 51 (3.7) | **<0.01** |
| BMI, [kg/m$^2$], mean (SD) | 27.1 (5.4) | 26.4 (4.2) | 27.6 (5.4) | **<0.01** |
| Hypertension, n (%) | 1433 (63.8) | 474 (55.6) | 959 (66.9) | **<0.01** |
| Congestive heart failure, n (%) | 118 (5.3) | 0 (0.0) | 118 (8.5) | **<0.01** |
| COPD, n (%) | 120 (5.3) | 0 (0.0) | 120 (8.6) | **<0.01** |
| Diabetes mellitus, n (%) | 210 (9.4) | 52 (6.1) | 158 (11.3) | **<0.01** |
| Previous stroke, n (%) | 293 (13.1) | 0 (0.0) | 293 (21.0) | **<0.01** |
| Coagulopathy, n (%) | 47 (2.1) | 0 (0.0) | 47 (3.4) | **<0.01** |
| Reason for imaging, n (%) | | | | |
| Incidental | 1840 (82.0) | 745 (87.4) | 1095 (78.6) | **<0.01** |
| Cranial nerve deficit | 190 (8.5) | 54 (6.3) | 136 (9.8) | **<0.01** |
| Thromboembolic event | 81 (3.6) | 0 (0.0) | 81 (5.8) | **<0.01** |
| Epilepsy | 36 (1.6) | 9 (1.1) | 27 (1.9) | 0.11 |
| Migraine | 30 (1.3) | 2 (0.2) | 28 (2.0) | **<0.01** |
| Aneurysm location, n (%) | | | | |
| Anterior communicating artery | 429 (19.1) | 183 (21.5) | 246 (17.7) | **0.03** |
| ACA A1 | 36 (1.6) | 15 (1.8) | 21 (1.5) | 0.64 |
| ACA A2 | 50 (2.2) | 24 (2.8) | 26 (1.9) | 0.14 |
| ACA A3 | 45 (2.0) | 18 (2.1) | 27 (1.9) | 0.76 |
| ACA A4 | 5 (0.2) | 1 (0.1) | 4 (0.3) | 0.66 |
| MCA M1 | 759 (33.8) | 282 (33.1) | 477 (34.2) | 0.58 |
| MCA M2 | 421 (18.8) | 161 (18.9) | 260 (18.7) | 0.91 |
| MCA M3 | 20 (0.9) | 8 (0.9) | 12 (0.9) | **<0.01** |
| MCA M4 | 3 (0.1) | 1 (0.1) | 2 (0.1) | 0.87 |
| ICA pars cerebralis | 94 (4.2) | 47 (5.5) | 47 (3.4) | **0.02** |
| ICA pars cavernous | 49 (2.2) | 22 (2.6) | 27 (1.9) | 0.37 |
| Ophthalmic artery | 116 (5.2) | 61 (7.2) | 55 (3.9) | **<0.01** |

**TABLE 1. Continued.**

| Characteristic | N = 2245 | Low-risk cohort (N = 852) | High-risk cohort (N = 1393) | *P* value[a] |
|---|---|---|---|---|
| Anterior choroidal artery | 39 (1.7) | 19 (2.2) | 20 (1.4) | 0.18 |
| Posterior communicating artery | 126 (5.6) | 10 (1.2) | 116 (8.3) | **<0.01** |
| Posterior cerebral artery | 17 (0.8) | 0 (0.0) | 17 (1.2) | **<0.01** |
| Basilar artery | 16 (0.7) | 0 (0.0) | 16 (1.1) | **<0.01** |
| Vertebral artery | 20 (0.9) | 0 (0.0) | 20 (1.4) | **<0.01** |
| Aneurysm calcification, n (%) | 212 (9.4) | 0 (0.0) | 212 (15.2) | **<0.01** |
| Aneurysm morphology, n (%) | | | | |
| Regular | 1646 (73.3) | 852 (100.0) | 794 (56.9) | **<0.01** |
| Irregular or lobular | 599 (26.7) | 0 (0.0) | 599 (41.6) | |
| Aneurysm multiplicity, n (%) | 938 (41.8) | 372 (43.7) | 566 (40.6) | 0.16 |
| Neck diameter, [mm], mean (SD) | 3.7 (2.1) | 3.2 (1.3) | 3.9 (2.2) | **<0.01** |
| Maximum diameter, [mm], mean (SD) | 6.7 (4.9) | 5.4 (2.4) | 7.5 (5.6) | **<0.01** |
| Size of parent vessel, [mm], mean (SD) | 2.3 (0.6) | 2.2 (0.5) | 2.4 (0.6) | **0.03** |
| Simultaneous clipping of >1 aneurysm, n (%) | 540 (24.1) | 223 (26.2) | 317 (22.8) | 0.07 |
| Simultaneous bypass, n (%) | 77 (3.4) | 5 (0.6) | 72 (5.2) | **<0.01** |

ACA, anterior cerebral artery; ASA, American Society of Anesthesiology score; BMI, body mass index; COPD, chronic obstructive pulmonary disease; ICA, internal carotid artery; MCA, middle cerebral artery.
[a]Bold indicates significant *p*-value <.05.

reporting of surgical outcomes. This multicenter study describes the best possible outcomes after microsurgical clipping of UIA using an international cohort by establishing benchmark cutoffs for several outcome variables. In addition, we report the expected neurological outcome and location-specific aneurysm closure rate up to 2 years after treatment.

Intracranial aneurysms are diagnosed with increased frequency in recent years because of improved imaging.[11] Because of mostly absent symptoms, as in our study, but a risk for growth and associated increasing rupture risk, the optimal management of a UIA presents clinicians with challenging decisions.[19,27,28] For this decision-making, it is highly relevant to know what outcome can be expected after treatment. Therefore, with this study, we present internationally applicable benchmark cutoffs, which may be considered in the process of decision-making, may serve to reflect on the performance of any given center in the context of certifications, and allow for comparison between alternative treatment modalities and new endovascular technologies.

To test the internal validity of the benchmarks, we compared the high-risk, nonbenchmark patients with the defined benchmark cutoffs and observed that the median of the nonbenchmark cohort was inferior to the cutoff in most outcomes. Therefore, the high-risk criteria and outcomes with cutoffs can be assessed as sensitive to represent the best possible outcome. The literature to date on the complication rates after microsurgical treatment of unruptured aneurysms is very heterogeneous, so that morbidity varies between 4.1% and 10.9% and the mortality between 0.5% and 2.6%.[17,29-32] This variation is mainly due to a heterogeneous patient population and different proportions of the aneurysm locations. Most of the data presented here fit well into previous studies, for example, the low mortality rate or a benchmark cutoff of ≤3.8% for intraoperative aneurysm rupture.[17,32] Complementary to the current literature, we present the neurological outcome assessed by the mRS up to 24 months after clipping. An unfavorable neurological outcome (mRS ≥3) of 4.1% at discharge and 2.03% at 24 months after clipping demonstrates an acceptable outcome and correlates with the previous findings of Wiebers and colleagues.[19]

Another benchmark variable of particular interest is length of hospital stay after clipping, which in our study has a benchmark cutoff of ≤7.7 days. Given the ambition to reduce healthcare costs worldwide in recent years and, consequently, to shorten the length of stay as one major cost factor,[33] this cutoff seems comparatively long. Recent studies have described a significant decrease in length of stay after management of an UIA from approximately 8–5 days within the past 20 years in the United States.[34,35] However, this strong trend is not evident from administrative databases of European countries with, in addition, generally longer hospital stays after interventional procedures when compared to US

**TABLE 2. Outcome Benchmarks After Microsurgical Clipping of UIA From 15 International Centers**

| Characteristic | Low-risk cohort Median (range) across centers | Benchmark cutoff 75th percentile of medians | High-risk cohort Median (range) across centers |
|---|---|---|---|
| Aneurysm-related outcome | | | |
| Operating duration | 196.2 (87.4-319.0) min | ≤210.8 min | 234.3 (95.0-236.0) min |
| Intraoperative blood transfusion | 0.0 (0.0%-6.4%) | ≤0.4% | 1.6 (0.0%-17.3%) |
| Intraoperative aneurysm rupture | 1.6 (0.2%-11.7%) | ≤3.8% | 4.1 (0.0%-12.5%) |
| Wrapping | 0.0 (0.0%-16.8%) | ≤6.4% | 4.6 (1.8%-38.2%) |
| Occlusion of aneurysm | 98.4 (84.5%-100.0%) | ≥97.1% | 94.6 (79.2%-100.0%) |
| Postoperative outcome | | | |
| Any complication | 13.6 (1.2%-39.2%) | ≤20.7% | 21.9 (3.0%-48.2%) |
| In%-hospital mortality | 0.0 (0.0%-2.1%) | ≤0.0% | 0.6 (0.0%-6.2%) |
| Favorable neurological outcome mRS ≤2 | 98.5 (90.8%-100.0%) | ≥95.9% | 92.7 (84.1%-98.5%) |
| New motor deficit | 0.0 (0.0%-7.7%) | ≤5.9% | 9.1 (1.6%-27.1%) |
| New sensory deficit | 0.0 (0.0%-6.3%) | ≤0.3% | 2.1 (0.0%-7.1%) |
| New aphasia | 0.0 (0.0%-5.4%) | ≤3.2% | 2.6 (0.0%-6.8%) |
| Stroke | | | |
| Asymptomatic | 1.8 (0.0%-12.9%) | ≤3.6% | 4.9 (1.3%-19.9%) |
| Symptomatic | 0.0 (0.0%-3.4%) | ≤0.3% | 1.5 (0.0%-8.7%) |
| Cerebral vasospasm | 0.0 (0.0%-11.9%) | ≤2.5% | 3.6 (0.0%-15.7%) |
| Intracerebral hemorrhage | 0.0 (0.0%-6.9%) | ≤1.4% | 2.7 (0.0%-9.0%) |
| Subdural hematoma | 0.0 (0.0%-3.2%) | ≤0.5% | 1.5 (0.0%-9.8%) |
| Surgical site infection | 0.0 (0.0%-6.9%) | ≤2.7% | 1.2 (0.0%-6.8%) |
| Reoperation rate | 0.0 (0.0%-9.1%) | ≤1.7% | 3.9 (0.0%-19.4%) |
| New%-onset seizure | 0.0 (0.0%-9.4%) | ≤0.9% | 3.1 (0.0%-6.4%) |
| Pulmonary complication | 0.0 (0.0%-4.8%) | ≤0.9% | 1.1 (0.0%-13.1%) |
| Pulmonal embolism | 0.0 (0.0%-6.9%) | ≤0.2% | 0.0 (0.0%-4.3%) |
| Length of ICU stay | 1.0 (0.0-2.0) d | ≤1.0 d | 1.0 (0.0-4.0) d |
| Length of hospital stay | 6.0 (1.0-11.0) d | ≤7.7 d | 6.0 (1.0-14.4) d |
| 12 months outcome | | | |
| Occlusion of aneurysm | 99.0 (80.0%-100.0%) | ≥98.0% | 94.5 (43.1%-100.0%) |

ICU, intensive care unit; mRS, modified Rankin Scale.

hospitals.[36,37] Because our study reflects data from centers on 4 continents, the cutoff represents a global practice pattern but is not specific to any healthcare system. Nevertheless, it is highly conceivable that the cutoffs presented here can be transferred to national registries (such as National Surgical Quality Improvement Program)[38] in future studies and serve as reference values. A direct calculation of benchmark cutoffs from different national registries is not recommended in view of inhomogeneous variables in international comparison and often limited postoperative follow-up (eg, 30-day outcome).[10]

An ongoing discussion is the choice between microsurgical or endovascular aneurysm closure.[11,14] The paucity of randomized controlled trials hampers the comparison of treatment risks and general recommendations in favor of one treatment

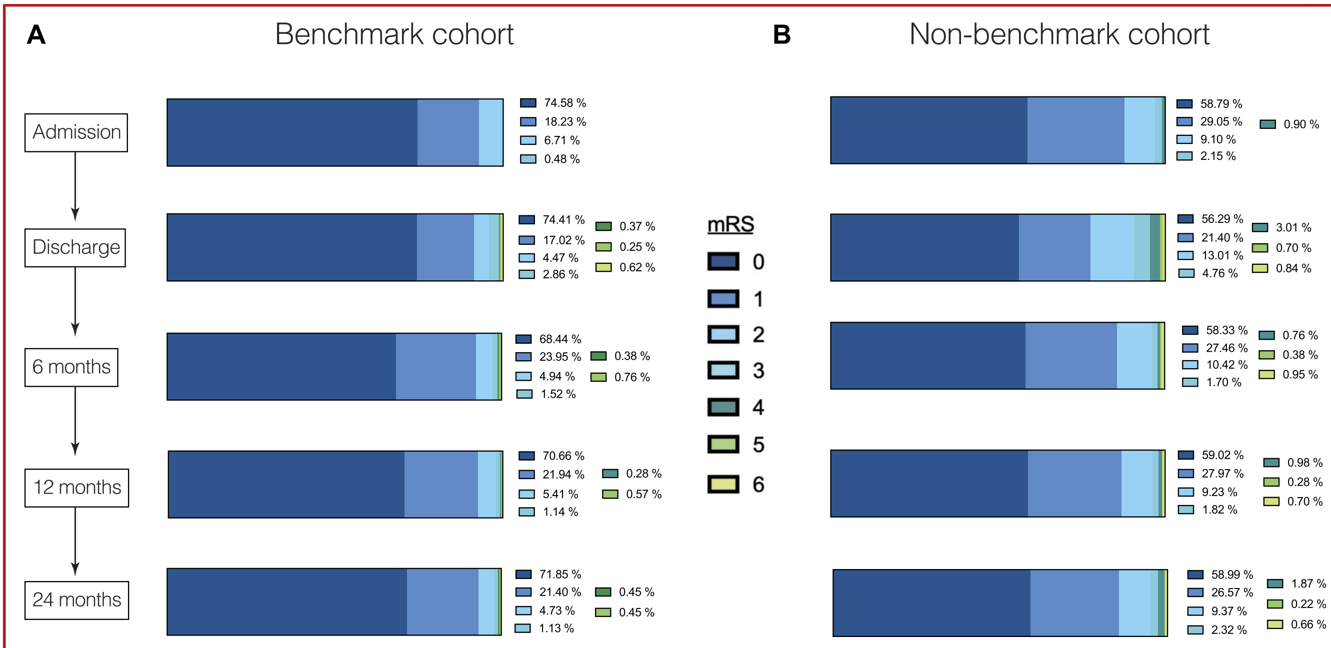


**FIGURE 2.** *Stacked bar charts of mRS results at admission, discharge, 6 months, 12 months, and 24 months in the* **A**, *benchmark cohort and* **B**, *nonbenchmark cohort after surgical clipping. mRS, modified Rankin scale.*

modality or another.[1,27,32] Recent pooled analyses were able to reveal location-specific risk factors, such as an increased risk of complications in posterior circulation aneurysms for microsurgical therapy or for broad-neck aneurysm for endovascular therapy.[21] To further reflect location-specific outcomes after microsurgical clipping, benchmark cutoffs for different aneurysm locations are reported separately in our study. These can be used to compare the location-specific outcome with that of other modalities in more detail and can aid in decision-making.

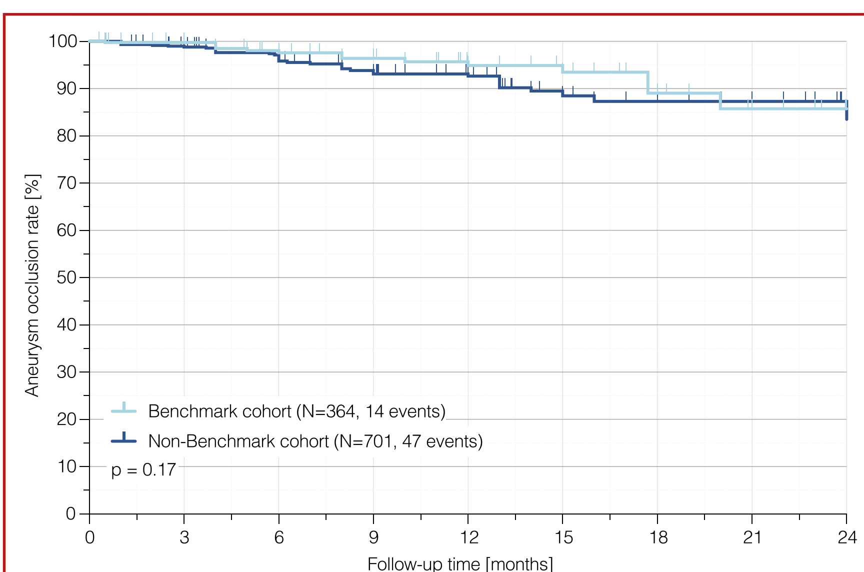


**FIGURE 3.** *Representation of occlusion rates from time of discharge until 24 months after surgical clipping. Aneurysms of the posterior circulation and the posterior communicating artery were excluded in this analysis.*

In addition, our study provides data on aneurysm closure rates for various time points up to 2 years after surgical clipping. This is a valuable contribution to the current literature, because data on occlusion rates are mostly lacking in publications investigating surgically treated aneurysms.[39,40] A meta-analysis by Kotowski et al[17] found that 82.2% of clipped aneurysms had missing data for closure rate. Of the available data, an overall closure rate of 91.8% was reported although the modality of assessment was mostly unclear.[17] Another meta-analysis by Smith et al[41] examined unruptured MCA aneurysms, which reported failure of aneurysm closure in 3.0% of surgically treated cases, assessed by postoperative digital subtraction angiography. Our study sets the benchmark cutoff for aneurysm closure at ≥97.1% at discharge and ≥98.0% at 24 months in benchmark patients, as assessed by CT angiography, but also provides separate closure rates for ACOM, MCA, and PCOM aneurysms. These data demonstrate excellent closure rates for surgically treated ACOM, ACA, and MCA aneurysms both postoperatively and 12 months after clipping. When putting these data into context of current literature, these occlusion rates are superior to endovascular-treated aneurysm and aid in the decision-making on the right treatment depending on the aneurysm location.[42-45]

### Limitations

The present work is subject to limitations. First, this study includes patients from a retrospective data analysis rather than a prospective randomized clinical trial. These data may have been collected and recorded differently at different sites. Second, we focused on surgical outcome after index surgery with a follow-up period of 24 months and could not report on long-term outcome and the failure of aneurysm occlusion after this period. In addition, the high number of patients lost to follow-up must be mentioned at this point. Third, we did not consider the number of cases performed per neurosurgeon but only per center, which needs to be investigated in further studies.

## CONCLUSION

In conclusion, this global multicenter study is the first to apply the concept of benchmarking in microsurgical clipping of UIA and to present internationally valid benchmark cutoffs for key outcomes. These cutoffs reflect the surgical and neurological outcome after clipping for different subgroups and can serve as reference values for other interventions as well as for comparing potential benefits of future techniques.

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**Supplemental Digital Content 1, Figure 1.** Study flow diagram.
**Supplemental Digital Content 2, Table 1.** Interquartile range (25th to 75th percentile) of outcome benchmarks in the low-risk cohort. *ICU: intensive care unit.*
**Supplemental Digital Content 3, Table 2.** Outcome benchmarks stratified according to aneurysm location. *ICU: intensive care unit.*
**Supplemental Digital Content 4, Figure 2.** Correlation between proportion of benchmark cases and **A** total number of cases treated with clipping in 15 centers, and **B** percentage of cases treated with clipping to all UIA cases in 13 centers. **C** Correlation between percentage of cases treated with clipping and total number of endovascular treated patients.

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