DOI: 10.5797/jnet.oa.2024-0095

Original Article

Multifactorial Assessment of Complication Risks in Embolization for Ruptured Cerebral Aneurysm

Arata Nagai,[1] Shinya Sonobe,[1,2,3,4] Kuniyasu Niizuma,[1,2,3,4] Tetsuo Ishikawa,[5,6,7,8] Eiryo Kawakami,[5,6] Yasushi Matsumoto,[9] Hirotoshi Imamura,[10] Tetsu Satow,[11] Koji Iihara,[10] Chiaki Sakai,[12] Nobuyuki Sakai,[13] Shigeru Miyachi,[14] Hidenori Endo,[1] and Teiji Tominaga[1]

Objective: Complications in neuroendovascular therapy for cerebral aneurysm (AN) affect the clinical course of patients. Patient conditions, operating procedures, and operator expertise were highlighted as risk factors for complications. These risk factors often combine and constitute particularly strong risks, resulting in a worsened clinical course. In this study, we performed a multifactorial assessment of complication risks in neuroendovascular therapy.

Methods: We analyzed patient data from the Japanese Registry of NeuroEndovascular Therapy 3, which is a nationwide retrospective cohort study of neuroendovascular procedures conducted between 2010 and 2014. Patients who underwent coil embolization for a ruptured anterior communicating artery (Acom) AN, an internal carotid artery-posterior communicating artery (IC-PC) AN, or basilar artery bifurcation (BA-bif) AN were included in this analysis. Information on 16 explanatory variables and 1 objective variable for each patient was obtained from the dataset as nominal variables. The explanatory variables consisted of patient factors, procedural factors, and an operator factor. The objective variable was whether the following complications occurred: intraprocedural bleeding, postprocedural bleeding, and procedure-related infarction. The specific situations involving multiple risk factors associated with high complication rates were identified using a programmed method. The impact of the absence of a supervising physician was also assessed.

Results: A total of 2971 patients were analyzed. The complication rates for patients with Acom ANs, IC-PC ANs, and BA-bif ANs were 12.9%, 10.2%, and 13.7%, respectively. A total of 15 specific situations were identified as follows: 3 related to an Acom AN, with complication rates ranging from 19.3% to 20.3%; 4 related to an IC-PC AN, with complication rates ranging from 15.6% to 17.9%; and 8 related to a BA-bif AN, with complication rates ranging from 20.6% to 33.3%.

[1]*Department of Neurosurgery, Tohoku University Graduate School of Medicine, Sendai, Miyagi, Japan*
[2]*Department of Neurosurgical Engineering and Translational Neuroscience, Tohoku University Graduate School of Medicine, Sendai, Miyagi, Japan*
[3]*Department of Neurosurgical Engineering and Translational Neuroscience, Graduate School of Biomedical Engineering, Tohoku University, Sendai, Miyagi, Japan*
[4]*AI Lab, Tohoku University Hospital, Sendai, Miyagi, Japan*
[5]*Medical Data Mathematical Reasoning Team, Advanced Data Science Project, RIKEN Information R&D and Strategy Headquarters, RIKEN, Yokohama, Kanagawa, Japan*
[6]*Department of Artificial Intelligence Medicine, Graduate School of Medicine, Chiba University, Chiba, Chiba, Japan*
[7]*Department of Extended Intelligence for Medicine, The Ishii-Ishibashi Laboratory, Keio University School of Medicine, Shinjuku-ku, Tokyo, Japan*
[8]*Collective Intelligence Research Laboratory, Graduate School of Arts and Sciences, The University of Tokyo, Meguro-ku, Tokyo, Japan*
[9]*Division of Development and Discovery of Interventional Therapy, Tohoku University Hospital, Sendai, Miyagi, Japan*
[10]*Department of Neurosurgery, National Cerebral and Cardiovascular Center, Suita, Osaka, Japan*
[11]*Department of Neurosurgery, Kindai University, Osaka-Sayama, Osaka, Japan*
[12]*Department of Neurosurgery, Kyoto University Graduate School of Medicine, Kyoto, Kyoto, Japan*
[13]*Department of Neurosurgery, Seijinkai Shimizu Hospital, Kyoto, Kyoto, Japan*
[14]*Department of Neurological Surgery, Aichi Medical University, Nagakute, Aichi, Japan*

Received: October 2, 2024; Accepted: December 5, 2024
Corresponding author: Shinya Sonobe. Department of Neurosurgical Engineering and Translational Neuroscience, Graduate School of Biomedical Engineering, Tohoku University, 2-1 Seiryo-machi, Aoba-ku, Sendai, Miyagi 980-8575, Japan
Email: shinya.sonobe.d7@tohoku.ac.jp

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

©2025 The Japanese Society for Neuroendovascular Therapy

In 4 of these situations, the absence of a supervising physician significantly impacted complication rates. For instance, the complication rate for patients with IC-PC AN treated under local anesthesia was 16.0% overall, but it was 23.8% without supervising physicians.

Conclusion: Multifactorial assessment based on patient, procedural, and operator factors provides more reliable risk estimations and will help improve the clinical course.

Keywords cerebral aneurysm, complication, supervising physician

Introduction

Complications in neuroendovascular therapy for cerebral aneurysm (AN) affect the clinical course of patients.[1–3] Patient conditions, operating procedures, and operator expertise have been highlighted as risk factors for complications.[4–13] Although risk factors are often statistically calculated as independent risk factors, they can combine and sometimes present strong risks, resulting in a worsened clinical course.[14–16] Therefore, it is necessary to perform a multifactorial assessment to evaluate the risk in patients with multiple risk factors.[17]

The Japanese Registry of NeuroEndovascular Treatment 3 (JR-NET3) is a nationwide retrospective cohort study that includes 40177 neuroendovascular procedures conducted between 2010 and 2014.[18] This dataset is widely utilized in many studies due to its large volume, high coverage, and few missing data points.[19–23] In this study, we performed a multifactorial assessment of complication risks in neuroendovascular therapy using the JR-NET3 dataset.

Materials and Methods

All patients who underwent coil embolization for a ruptured anterior communicating artery (Acom) AN, an internal carotid artery-posterior communicating artery (IC-PC) AN, or a basilar artery bifurcation (BA-bif) AN enrolled in the JR-NET3 study were included in this analysis. Patients with AN at other sites were not included because the number of patients was insufficient to apply the methods used in this study. Patients under 15 years of age, treated more than 4 days after onset, treated for multiple ANs simultaneously, or with any missing data were excluded from the study.

Information on 16 explanatory variables and 1 objective variable for each patient was obtained from the dataset as nominal variables. The explanatory variables consisted of patient factors, procedural factors, and an operator factor. The patient factors were young (50 years old or younger), elderly (76 years old or older), severe (World Federation of Neurosurgical Societies Grade 4–5), small AN (less than 3 mm), large AN (greater than 10 mm), and non-saccular AN. The procedural factors were local anesthesia, double catheter technique, balloon-assisted technique, stent-assisted technique, no antiplatelets, no heparin, bioactive coils, hydrocoils, and single-plane angiography. The operator factor was whether at least 1 supervising physician participated in the procedure. Supervising physicians refer to Board Certified Consulting Specialists of the Japanese Society for Neuroendovascular Therapy.[24] The objective variable was whether the following complications occurred: intraprocedural bleeding, postprocedural bleeding, and procedure-related infarction. Intraprocedural bleeding was defined as an aneurysmal rupture, a vessel rupture, or a vessel perforation during the procedure. Postprocedural bleeding was defined as symptomatic bleeding from the AN or a vessel within 30 days after the procedure. Procedure-related infarction was defined as a symptomatic cerebral infarction confirmed by imaging within 30 days after the procedure. “No antiplatelets” refers to the confirmation that antiplatelet agents were not used before the procedure. Information on the aneurysmal neck was not included as an explanatory variable, as it was not obtained as continuous values.

Multifactorial assessment was performed using the following 3-step programmed method (**Fig. 1**).

Step 1: For each AN site, the complication rate was calculated using the number of patients as the denominator and the number of patients with complications as the numerator (CR_{site}). For each AN site, combined risk factors were comprehensively created employing the 15 explanatory variables except the operator factor (**Supplementary Table**). The complication rate was calculated for patients meeting each combined risk factor ($CR_{combined}$). A combined risk factor was identified as a multifactorial risk factor (MFR) if the associated $CR_{combined}$ exceeded 1.5 times the CR_{site}.

CR_{site}

Combination	Risk Factors						Number of Patients		Complication Rate	$CR_{combined}$ / CR_{site}	Multifactorial risk factor (MFR)
	Elderly	Severe	Small	…	No Antiplatelet	No Heparin	Meeting Condition	With Complication			
Overall	0	0	0	…	0	0	1290	167	12.9%	-	-
1	1	0	0	...	0	0	389	52	13.4%	1.04	No Match
2	0	1	0	...	0	0	297	39	13.1%	1.02	No Match
3	0	0	1	...	0	0	118	24	20.3%	***1.57***	**Match**
:	...	...	...	...	...	...					...
14	0	0	0	...	1	0	1163	159	13.7%	1.06	No Match
15	0	0	0	...	0	1	76	13	17.1%	1.33	No Match
16	1	1	0	...	0	0	123	13	10.6%	0.82	No Match
:	...	...	...	...	...	...					...
30	0	1	1	...	0	0	65	14	21.5%	***1.67***	No Match
:	...	...	...	...	...	...					...
110	0	0	0	...	1	1	65	13	20.0%	***1.55***	**Match**
:	...	...	...	...	...	...					...
124	1	1	0	...	1	0	22	10	45.4%	***3.52***	No Match
:	...	...	...	...	...	...					...

$CR_{combined}$

Thresholds for MFR

① $$\frac{CR_{combined}}{CR_{site}} \geqq 1.5$$

② $$CR_{combined\ (factor\ A+B)} \geqq CR_{combined\ (factor\ A)} \times 1.1$$
&
$$CR_{combined\ (factor\ A+B)} \geqq CR_{combined\ (factor\ B)} \times 1.1$$

③ $$\frac{\text{Number of Patient meeting } CR_{combined}}{\text{Number of Patient meeting } CR_{site}} \geqq 0.05$$

Demonstration of MFR Identification

Combination 1:

$CR_{combined\ (Elderly)} / CR_{site} = 1.04 < 1.5$ ⟹ MFR: No Match

Combination 3:

$CR_{combined\ (Small)} / CR_{site} = 1.57 \geqq 1.5$ ⟹ MFR: **Match**

Combination 30:

$CR_{combined\ (Severe + Small)} = 21.5\%$, $CR_{combined\ (Small)} = 20.3\%$

$CR_{combined\ (Severe + Small)} < CR_{combined\ (Small)} \times 1.1 = 22.3\%$ ⟹ MFR: No Match

Combination 110:

$CR_{combined\ (No\ Antiplatelet + No\ Heparin)} = 20.0\%$, $CR_{combined\ (No\ Antiplatelet)} = 13.7\%$, $CR_{combined\ (No\ Heparin)} = 17.1\%$

$CR_{combined\ (No\ Antiplatelet + No\ Heparin)} \geqq CR_{combined\ (No\ Antiplatelet)} \times 1.1 = 15.1\%$

$CR_{combined\ (No\ Antiplatelet + No\ Heparin)} \geqq CR_{combined\ (No\ Heparin)} \times 1.1 = 18.1\%$ ⟹ MFR: **Match**

Combination 124:

Number of Patient meeting $CR_{combined\ (Elderly + Severe + No\ Antiplatelet)} = 22$

Number of Patient meeting $CR_{site} = 1290$

Number of Patient meeting $CR_{combined\ (Elderly + Severe + No\ Antiplatelet)}$ / Number of Patient meeting CR_{site}

$= 22 / 1290 = 0.017 < 0.05$ ⟹ MFR: No Match

Fig. 1 Identification of multifactorial risk factors. The table demonstrates the procedure for identifying MFRs, using the case of Acom aneurysm as an example. The overall CR_{site} is 12.9%. The complication rate for patients meeting each $CR_{combined}$ is calculated individually. The combination 1 does not match as an MFR because $CR_{combined}$ is under 1.5 times CR_{site}. The combination 3 matches as an MFR because $CR_{combined}$ is over 1.5 times CR_{site}. The combination 30 does not match as an MFR because $CR_{combined}$ is under 1.1 times that of the combination 3. The combination 110 matches as an MFR because $CR_{combined}$ is over 1.1 times those of the combination 14 and 15. The combination 124 does not match as an MFR because the number of patients meeting the condition is under 5% of the total number of patients with Acom aneurysm. Acom, anterior communicating artery; CR_{site}, complication rate; $CR_{combined}$, combined risk factor; MFRs, multifactorial risk factors

Step 2: MFRs that did not meet the following criterion were removed: the number of patients meeting an MFR must be at least 5% of the number of patients with ANs at the same site. This criterion was intended to reduce MFRs with inadequately high complication rates due to sampling bias.

Step 3: MFRs that did not meet the following criterion were removed: the complication rate of the MFR with an additional risk factor must be at least 1.1 times that of the original MFR. This criterion was intended to reduce MFRs that only subdivide patients with the same risk.

After identifying the MFRs, the complication rates in patients meeting each MFR (CR_{whole}) were calculated. In addition, the complication rates in the absence of supervising physicians ($CR_{absence}$) were calculated. The error in the complication rate was defined as 100 divided by the number of patients meeting each MFR. The lack of overlap in the error ranges of CR_{whole} and $CR_{absence}$ was defined as a significant impact on the complication rate due to the absence of a supervising physician.

This study was approved by the Ethics Committee of Tohoku University (2024-1-674).

Results

A total of 3342 patients were included, and 371 patients were excluded; 2971 patients were analyzed, which were composed of 1290 patients with an Acom AN, 1265 patients with an IC-PC AN, and 416 patients with a BA-bif AN (**Fig. 2**). Among these, 354 patients (11.9%) had the following complications: 154 patients (5.2%) had intraprocedural bleeding, 17 patients (0.6%) had postprocedural bleeding, and 183 patients (6.2%) had procedure-related cerebral infarction. The prevalence of risk factors and complications in patients with each aneurysmal site is shown in **Table 1**.

The complication rates for patients with an Acom AN, IC-PC AN, or BA-bif AN were 12.9%, 10.2%, and 13.7%, respectively. A total of 15 MFRs were identified: 3 MFRs related to an Acom AN, 4 MFRs related to an IC-PC AN, and 8 MFRs related to a BA-bif AN. The complications in patients meeting each MFR are shown in **Table 2**.

The absence of supervising physicians significantly impacted complication rates in the following 4 MFRs: an Acom AN treated using a balloon-assisted technique without antiplatelets, a large IC-PC AN, an IC-PC AN treated under local anesthesia, and a BA-bif AN treated using a balloon-assisted technique with single-plane angiography (**Fig. 3**).

Discussion

We performed a multifactorial assessment of complication risks in neuroendovascular therapy for ruptured ANs. A total of 15 MFRs, which are particularly strong risks created by combining risk factors, were identified using a programmed method.

Identifying MFRs revealed the increased risks in specific situations. For example, patients with a large BA-bif AN treated using a double catheter technique had a complication rate of 29.6%, whereas patients with a BA-bif AN had a complication rate of 13.7%, patients with a large BA-bif AN had a complication rate of 16.2% (data not shown), and patients with a BA-bif AN treated using a double catheter technique had a complication rate of 22.0%. Similarly, patients with an IC-PC AN treated with a balloon-assisted technique using bioactive coils had a complication rate of 15.6%, whereas the rate was between 10.2% and 10.9% when a balloon-assisted technique and/or bioactive coils were used (data not shown). Only focusing on individual risk factors does not fully assess such increased risks. Combining risk factors enables multifactorial assessment, as analogous insights have been reported.[25–27] Thus, multifactorial assessment provides more reliable risk estimates.

In a multifactorial assessment of complication risks, an operator factor is also crucial. In 4 MFRs, complication rates were significantly higher when supervising physicians were absent. This indicates that the absence of supervising physicians may contribute to the occurrence of complications. This finding is not surprising, as the role of expertise in avoiding complications has been emphasized across various fields.[28–30] The presence of supervising physicians is thought to be especially important in certain situations, given that their absence did not significantly impact complication rates in the other 11 MFRs. Thus, in addition to patient and procedural factors, taking operator factors into account provides more reliable risk estimations.

Complication risks in neuroendovascular therapy can be decreased by decision-making based on MFRs. For example, patients with an IC-PC AN had a high complication rate under local anesthesia and in the absence of supervising physicians. Recognizing this should lead to performing procedures under general anesthesia or with supervising physicians in such cases. This means

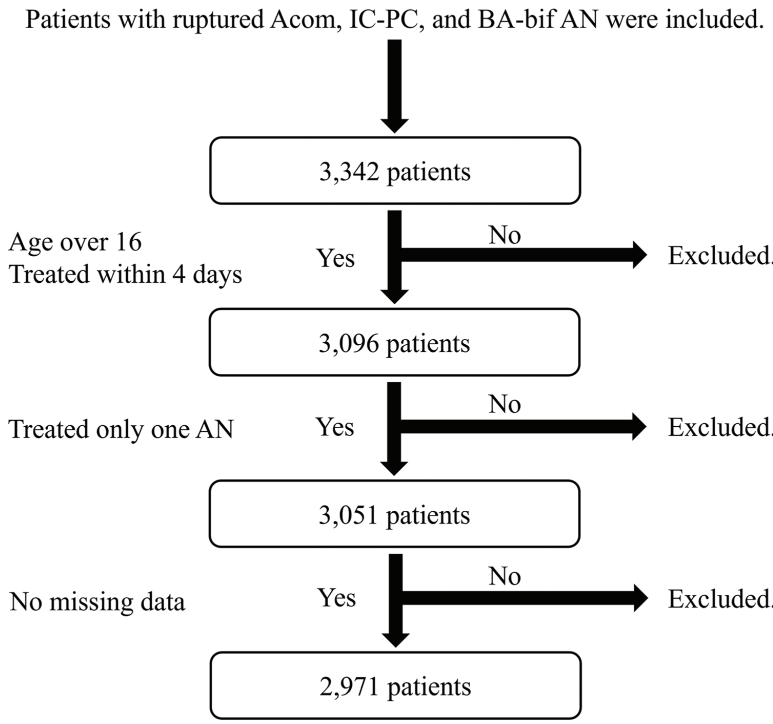

Fig. 2 Flowchart of patient selection. A total of 2971 patients were analyzed in this study. Acom, anterior communicating artery; AN, aneurysm; BA-bif AN, basilar artery bifurcation AN; IC-PC, internal carotid artery-posterior communicating artery

Table 1 Patient background

	Acom (n = 1290)		IC-PC (n = 1265)		BA-bif (n = 416)	
Factor						
Young (≤50)	389	(30.2%)	229	(18.1%)	103	(24.8%)
Elderly (≥76)	297	(23.0%)	499	(39.4%)	100	(24.0%)
Severe (WFNS grade ≥4)	451	(35.0%)	385	(30.4%)	159	(38.2%)
Small (<3 mm)	118	(9.1%)	44	(3.5%)	40	(9.6%)
Large (≥10 mm)	69	(5.3%)	190	(15.0%)	74	(17.8%)
Nonsaccular type	3	(0.2%)	0	(0.0%)	1	(0.2%)
Local anesthesia	102	(7.9%)	100	(7.9%)	42	(10.1%)
Single plane angiography	271	(21.0%)	293	(23.2%)	125	(30.0%)
Double catheter	71	(5.5%)	127	(10.0%)	59	(14.2%)
Balloon assist	176	(13.6%)	683	(54.0%)	191	(45.9%)
Stent assist	5	(0.4%)	38	(3.0%)	18	(4.3%)
No antiplatelet	1163	(90.2%)	1112	(87.9%)	352	(84.6%)
No heparin	76	(5.9%)	59	(4.7%)	24	(5.8%)
Bioactive coil	115	(8.9%)	140	(11.1%)	43	(10.3%)
Hydrocoil	26	(2.0%)	39	(3.1%)	18	(4.3%)
Without supervising physicians	508	(39.4%)	505	(39.9%)	189	(45.4%)
Complications						
Intraprocedural bleeding	81	(6.3%)	50	(4.0%)	23	(5.5%)
Postprocedural bleeding	7	(0.5%)	8	(0.6%)	2	(0.5%)
Cerebral infarction	79	(6.1%)	71	(5.6%)	33	(7.9%)

Acom, anterior communicating artery aneurysm; BA-bif, basilar artery bifurcation aneurysm; IC-PC, internal carotid artery-posterior communicating artery aneurysm; WFNS, World Federation of Neurosurgical Societies

Table 2 Multicatorial risk factors of complication

Aneurysmal site	Multifactorial risk factors	Number of patients		Complication rate			
		Meeting MFR	With complication	Intraprocedural bleeding	Postprocedural bleeding	Procedure-related cerebral infarction	Total
Acom	Small	118	24	16.1%	0.0%	4.2%	20.3%
	No antiplatelet, no heparin	65	13	15.4%	1.5%	3.0%	20.0%
	No antiplatelet, balloon assist	161	31	8.7%	0.6%	9.9%	19.3%
IC-PC	Large	190	34	4.2%	0.5%	13.2%	17.9%
	Local anesthesia	100	16	6.0%	1.0%	9.0%	16.0%
	Balloon assist, bioactive coil	77	12	6.5%	2.6%	6.5%	15.6%
	Balloon assist, young, no antiplatelet	108	19	5.6%	1.9%	10.2%	17.6%
BA-bif	Double catheter	59	13	5.1%	1.7%	15.3%	22.0%
	Bioactive coil	43	12	7.0%	0.0%	20.9%	27.9%
	Local anesthesia	42	11	14.3%	2.4%	9.5%	26.2%
	Young, single plane angiography	30	10	10.0%	0.0%	23.4%	33.3%
	Young, severe	32	8	9.4%	0.0%	15.7%	25.0%
	Elderly, single plane angiography	25	6	12.0%	0.0%	12.0%	24.0%
	Balloon assist, single plane angiography	63	13	7.9%	1.6%	11.1%	20.6%
	Large, double catheter	27	8	3.7%	3.7%	22.2%	29.6%

Acom, anterior communicating artery; BA-bif, basilar artery bifurcation aneurysm; IC-PC, internal carotid artery-posterior communicating artery; MFR, multifactorial risk factor

that MFRs support decision-making for a better clinical course. Similarly, patients with a small Acom AN experienced a high complication rate, particularly due to the occurrence of intraprocedural bleeding. Recognizing this should lead to greater attention directed toward recovery shots for intraprocedural bleeding in such cases. This means that MFRs support decision-making for minimizing damage. Thus, multifactorial assessment will help improve the clinical course.

This study has several limitations. First, the identified MFRs comprised only some potential MFRs. For example, IC-PC AN patients treated using a balloon-assisted technique with hydrocoils had a high complication rate; however, due to the small number of patients meeting the criteria, it was not identified as an MFR in the analysis using the JR-NET3 dataset. Also, MFRs for ANs other than Acom AN, IC-PC AN, and BA-bif AN were not analyzed. Moreover, information regarding aneurysm morphology, including the aneurysmal neck, is not reflected in the MFR. Further accumulation of data will help identify additional MFRs. Second, procedural factors may be biased due to the occurrence of complications. For example, Acom AN patients treated using a balloon-assisted technique without antiplatelets had a high complication rate; this result suggests that the use of balloon catheters induces complications, or the result could be biased due to the use of balloon catheters to address complications. Prospective data collection will help resolve this bias. Third, the reasons for the complications in these identified situations are not discussed. For example, patients with an IC-PC AN treated under local anesthesia had a high complication rate; however, the reason why local anesthesia is associated with complications in treating IC-PC ANs cannot be determined from the current dataset alone. Studies with chemical and/or physical perspectives are crucial to resolve such questions. Fourth, this study analyzes procedures performed between 2010 and 2014, without considering subsequent developments. Information on new devices and improvements in device performance will provide more interesting insights. Fifth, there are no datasets of similar scale from other countries, and we did not verify the possibility that the results are specific to our country. It is hoped that our country's research findings will encourage similar studies to be promoted worldwide.

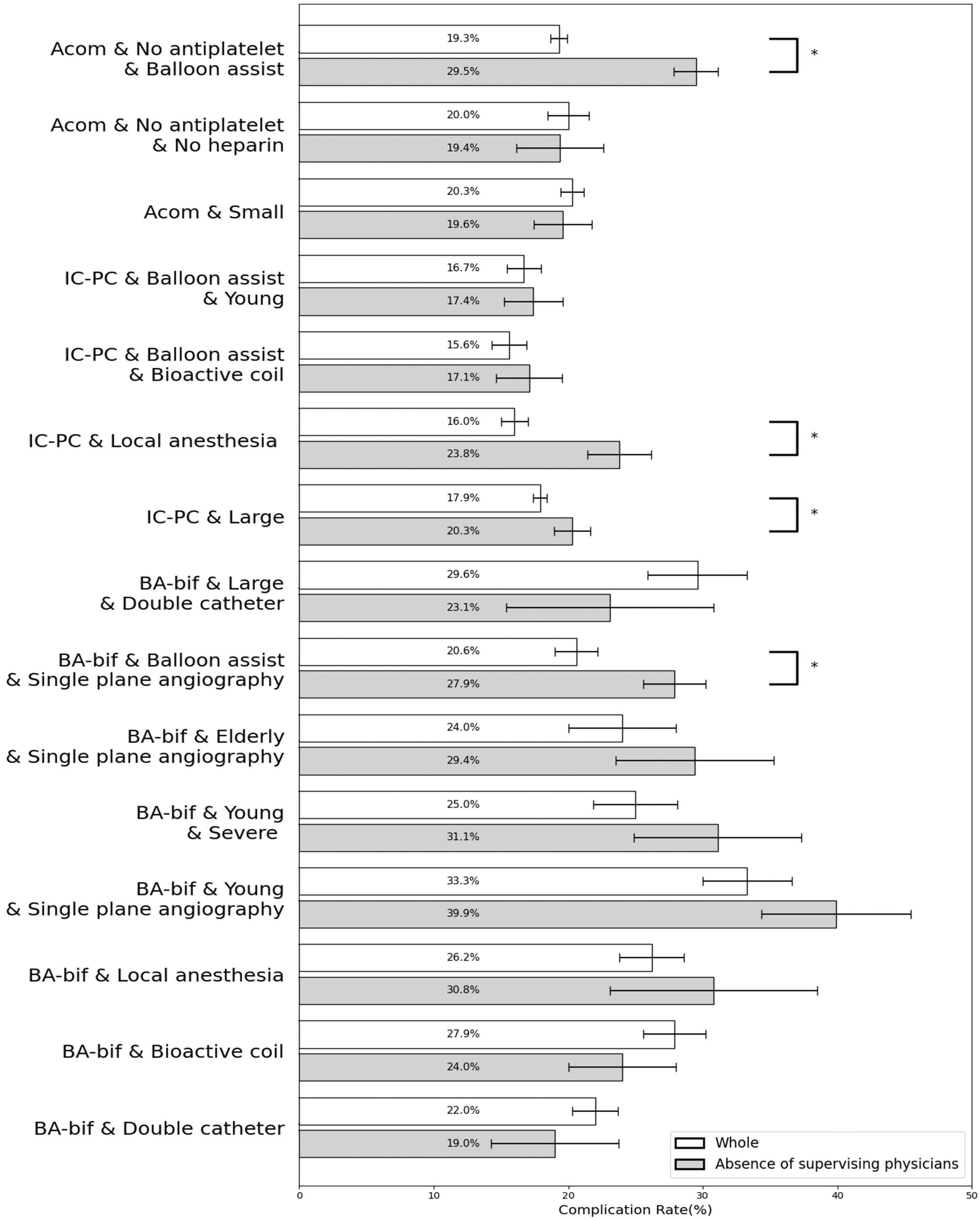

Fig. 3 The impact of the absence of supervising physicians. The white bar graph illustrates the complication rates for patients with various multifactorial risk factors. In contrast, the gray bar graph displays the complication rates in the absence of supervising physicians. The absence of supervising physicians significantly impacted complication rates in the 4 multifactorial risk factors marked with an asterisk. Acom, anterior communicating artery aneurysm; BA-bif, basilar artery bifurcation aneurysm; IC-PC, internal carotid artery-posterior communicating artery aneurysm

Conclusion

We performed a multifactorial assessment of complication risks in neuroendovascular therapy. Multifactorial assessment based on patient, procedural, and operator factors provides more reliable risk estimations and will help improve the clinical course.

Acknowledgments

We acknowledge the contributions of the JR-NET3 study group members who supported this research.

JR-NET3 study group:
Co-principal investigators:
Nobuyuki Sakai, Kobe City Medical Center General Hospital; Koji Iihara, Kyushu University; Tetsu Satow, National Cerebral and Cardiovascular Center.
Investigators:
Masayuki Ezura, Sendai Medical Center; Akio Hyodo, Dokkyo Medical University Saitama Medical Center; Shigeru Miyachi, Aichi Medical University; Susumu Miyamoto, Kyoto University; Yoji Nagai, Kobe University; Kunihiro Nishimura, National Cerebral and Cardiovascular Center; Kazunori Toyoda, National Cerebral and Cardiovascular Center.
Co-investigators:
Toshiyuki Fujinaka, Osaka Medical Center; Toshio Higashi, Fukuoka University; Masaru Hirohata, Kurume University; Akira Ishii, Kyoto University; Hiroshi Imamura, Kobe City Medical Center General Hospital; Yasushi Ito, Shinrakuen Hospital; Naoya Kuwayama, Toyama University; Hidenori Oishi, Juntendo University; Yuji Matsumaru, Tsukuba University; Yasushi Matsumoto, Konan Hospital; Ichiro Nakahara, Fujita Medical University; Chiaki Sakai, Hyogo College of Medicine; Kenji Sugiu, Okayama University; Tomoaki Terada, Showa University Fujigaoka Hospital; Shinichi Yoshimura, Hyogo College of Medicine; and Certified Specialists of Japanese Society of Neuroendovascular Therapy.

The authors acknowledge members of the JR-NET3 study group, who are listed as authors of this manuscript: Nobuyuki Sakai, Koji Iihara, Tetsu Satow, Shigeru Miyachi, Yasushi Matsumoto, and Chiaki Sakai, for their dual contributions as study investigators and manuscript authors.

Disclosure Statement

The first author and all co-authors declare no conflicts of interest.

Supplementary Information

Supplementary table

Overview of combination design. The combined risk factors for each AN site are comprehensively determined by evaluating whether each factor matches; a value of 1 indicates a match, while a value of 0 indicates that it does not matter whether the factor matches or not.

References

1) Chang SH, Shin S, Lee H, et al. Rebleeding of ruptured intracranial aneurysms in the immediate postoperative period after coil embolization. *J Cerebrovasc Endovasc Neurosurg* 2015; 17: 209–216.
2) Cho YD, Lee Y, Seo H, et al. Early recurrent hemorrhage after coil embolization in ruptured intracranial aneurysms. *Neuroradiology* 2012; 54: 719–726.
3) Molyneux A, Kerr R, Stratton I, et al. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. *Lancet* 2002; 360: 1267–1274.
4) White AC, Roark C, Case D, et al. Factors associated with rerupture of intracranial aneurysms after endovascular treatment: a retrospective review of 11 years experience at a single institution and review of the literature. *J Clin Neurosci* 2017; 44: 53–62.
5) Kim ST, Baek J, Lee W, et al. Causes of early rebleeding after coil embolization of ruptured cerebral aneurysms. *Clin Neurol Neurosurg* 2018; 174: 108–116.
6) Kocur D, Przybyłko N, Bażowski P, et al. Rupture during coiling of intracranial aneurysms: predictors and clinical outcome. *Clin Neurol Neurosurg* 2018; 165: 81–87.
7) McDougall CG, Spetzler R, Zabramski J, et al. The barrow ruptured aneurysm trial: clinical article. *J Neurosurg* 2012; 116: 135–144.
8) Wu TC, Tsui YK, Chen TY, et al. Rebleeding of aneurysmal subarachnoid hemorrhage in computed tomography angiography: risk factor, rebleeding pattern, and outcome analysis. *J Comput Assist Tomogr* 2012; 36: 103–108.
9) Johnston SC, Dowd C, Higashida R, et al. Predictors of rehemorrhage after treatment of ruptured intracranial aneurysms: the Cerebral Aneurysm Rerupture After Treatment (CARAT) study. *Stroke* 2008; 39: 120–125.

10) Sherif C, Gruber A, Schuster E, et al. Computerized occlusion rating: a superior predictor of aneurysm rebleeding for ruptured embolized aneurysms. *AJNR Am J Neuroradiol* 2012; 33: 1481–1487.
11) Jartti P, Isokangas JM, Karttunen A, et al. Early rebleeding after coiling of ruptured intracranial aneurysms. *Acta Radiol* 2010; 51: 1043–1049.
12) Sluzewski M, van Rooij WJ. Early rebleeding after coiling of ruptured cerebral aneurysms: incidence, morbidity, and risk factors. *AJNR Am J Neuroradiol* 2005; 26: 1739–1743.
13) Sluzewski M, van Rooij WJ, Beute G, et al. Late rebleeding of ruptured intracranial aneurysms treated with detachable coils. *AJNR Am J Neuroradiol* 2005; 26: 2542–2549.
14) Dumot C, Gasimov T, Hatipoglu Majernik G, et al. Nighttime treatment of ruptured intracranial aneurysms are associated with poor outcomes. *Neurosurgery* 2025; 96: 78–86.
15) Kang DH, Kim YS, Baik SK, et al. Acute serious rebleeding after angiographically successful coil embolization of ruptured cerebral aneurysms. *Acta Neurochir (Wien)* 2010; 152: 771–781.
16) Li K, Guo Y, Zhao Y, et al. Acute rerupture after coil embolization of ruptured intracranial saccular aneurysms: a literature review. *Interv Neuroradiol* 2018; 24: 117–124.
17) Larsen CC, Astrup J. Rebleeding after aneurysmal subarachnoid hemorrhage: a literature review. *World Neurosurg* 2013; 79: 307–312.
18) Sakai N, Uchida K, Iihara K, et al. Japanese surveillance of neuroendovascular therapy in JR-NET - part ii. Japanese registry of neuroendovascular treatment 3. main report. *Neurol Med Chir (Tokyo)* 2019; 59: 106–115.
19) Imamura H, Sakai N, Satow T, et al. Endovascular treatment for vasospasm after aneurysmal subarachnoid hemorrhage based on data of JR-NET3. *Neurol Med Chir (Tokyo)* 2018; 58: 495–502.
20) Imamura H, Sakai N, Satow T, et al. Factors related to adverse events during endovascular coil embolization for ruptured cerebral aneurysms. *J Neurointerv Surg* 2020; 12: 605–609.
21) Nishi H, Ishii A, Satow T, et al. Parent artery occlusion for unruptured cerebral aneurysms: results of the Japanese registry of neuroendovascular therapy 3. *Neurol Med Chir (Tokyo)* 2019; 59: 1–9.
22) Sato K, Matsumoto Y, Tominaga T, et al. Complications of endovascular treatments for brain arteriovenous malformations: a nationwide surveillance. *AJNR Am J Neuroradiol* 2020; 41: 669–675.
23) Satow T, Ikeda G, Takahashi J, et al. Coil embolization for unruptured intracranial aneurysms at the dawn of stent era: results of the Japanese registry of neuroendovascular therapy (JR-NET) 3. *Neurol Med Chir (Tokyo)* 2020; 60: 55–65.
24) Yamagami H, Hayakawa M, Inoue M, et al. Guidelines for mechanical thrombectomy in Japan, the fourth edition, March 2020: a guideline from the Japan Stroke Society, the Japan Neurosurgical Society, and the Japanese Society for Neuroendovascular Therapy. *Neurol Med Chir (Tokyo)*. 2021; 61: 163–192.
25) Sonobe S, Ishikawa T, Niizuma K, et al. Development and validation of machine learning prediction model for post-rehabilitation functional outcome after intracerebral hemorrhage. *Interdiscip Neurosurg* 2022; 29: 101560.
26) Chase BA, Krueger R, Pavelka L, et al. Multifactorial assessment of Parkinson's disease course and outcomes using trajectory modeling in a multiethnic, multisite cohort – extension of the LONG-PD study. *Front Aging Neurosci* 2023; 15: 1240971.
27) Randell R, Wright JM, Alvarado N, et al. What supports and constrains the implementation of multifactorial falls risk assessment and tailored multifactorial falls prevention interventions in acute hospitals? Protocol for a realist review. *BMJ Open* 2021; 11: e049765.
28) Singh P, Madanipour S, Fontalis A, et al. A systematic review and meta-analysis of trainee- versus consultant surgeon-performed elective total hip arthroplasty. *EFORT Open Rev* 2019; 4: 44–55.
29) Kauvar DS, Braswell A, Brown BD, et al. Influence of resident and attending surgeon seniority on operative performance in laparoscopic cholecystectomy. *J Surg Res* 2006; 132: 159–163.
30) Wilkiemeyer M, Pappas T, Giobbie-Hurder A, et al. Does resident post graduate year influence the outcomes of inguinal hernia repair? *Ann Surg* 2005; 241: 879–884; discussion, 882–884.