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Predictors and Treatment Strategies of Intraprocedural Rupture in Intracranial Aneurysms: A Single-Center Experience with 2302 Patients

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Abstract

Objective: Intraoperative rupture of an aneurysm is a known risk in the surgical management of intracranial aneurysms. The aim of the present study is to determine the risk factors for IPR.

Methods: This study retrospectively examined 2302 patients with intracranial aneurysms treated surgically between December 1996 and July 2019. These patients were categorized into two groups according to whether they exhibited IPR or not: i) The non-IPR group; and ii) the IPR group. Multiple factors, including sex, age, history of SAH, Hunt-Hess grade, Fisher score, operation timing, surgical approach, GOS, size, side, site, number, orientation, morphology and adhesion to surrounding tissue, were analyzed to identify factors associated with IPR.

Results: The overall rupture rate was 14.8%. Overall, the number of SAHs (1, ≥2) and aneurysm location (supraclinoid ICA and PICA) were found to be independent risk factors for IPR. This analysis revealed that in the MCA aneurysm database the risk for IPR decreased in patients aged >40 years. Furthermore, the present study identified a progressive increase in the risk of IPR with increasing H-H grade. Finally, in the ACOA aneurysm database the left pterional and coronal craniotomy approach increased the risk for IPR up to 1.99- and 15.153-fold, respectively, compared with the right pterional approach.

Conclusions: The number of SAHs (1, ≥2) and aneurysms site (supraclinoid ICA and PICA), age ≤40 years, higher H-H grade and surgical approach (left pterional and coronal craniotomy) seem to be important factors affecting the incidence of IPR.

1. Introduction

Intracranial aneurysms (IAs) are cerebral hemangiomatous abnormalities caused by the localized expansion of the intracranial arterial wall. IA is the third and first leading causes of cerebrovascular diseases and subarachnoid hemorrhage (SAH), respectively[22]. The incidence of IA is 3.6-6% with a mortality rate of 22–25% among patients with cerebrovascular disease[6]. According to the International Study on SAH, the case fatality rate following aneurysm rupture is approximately 40%[12,21]. Currently, treatment options for IAs mainly include microsurgical clipping and endovascular intervention. Intraprocedural rupture (IPR) has been reported as a complication during IA surgery. It has been demonstrated that endovascular interventions result in a lower IPR rate compared with microsurgical clipping, however, the mortality risk for patients undergoing endovascular interventions is increased when aneurysms rupture. The incidence of IPR ranges from 15–50% and affects patient survival and prognosis[1,9,18,24,27]. However, the factors influencing IPR remain to be determined. Therefore, the aim of the present study was to identify the risk factors for IPR, thereby reducing surgical complications and improving the prognosis and quality of life of patients. In addition, the findings of the present study may provide neurosurgeons with novel insights and treatment strategies to reduce the risk of IPR.

2. Materials And Methods

2.1 Patient selection

In the present study, 2,302 patients who underwent surgical clipping for IAs at the Affiliated Hospital of Qingdao University between December 1996 and July 2019 were retrospectively reviewed. The study protocol was approved by the Ethics Committee of the Affiliated Hospital of Qingdao University. The demographic and aneurysm characteristics of the study population are presented in Table 1.

Table 1
Demographics and characteristics of intracranial aneurysms and univariate analysis for IPR of aneurysms

Characteristic	Non-IPR (n = 1961)	IPR (n = 341)	P-Value
Age (years)			0.071
Mean ± SD	56.04 ± 10.331	54.94 ± 10.894	
Range	6–85	22–81	
Sex			0.288
Male	796 (40.6)	128 (37.5)	
Female	1165 (59.4)	213 (62.5)	
H-H grade at admission			<0.001
I	174 (8.9)	8 (2.3)	
II	1028 (52.4)	181 (53.1)	
III	565 (28.8)	97 (28.4)	
IV	177 (9.0)	47 (13.8)	
V	17 (0.9)	8 (2.3)	
Side			0.198
Left	1079 (55.0)	202 (59.2)	
Right	756 (38.6)	124 (36.4)	
Middle	126 (6.4)	15 (4.4)	
Fisher score			<0.001
I	175 (8.9)	8 (2.3)	
II	290 (14.8)	44 (12.9)	
III	1077 (54.9)	206 (60.4)	
Ⅳ	349 (17.8)	62 (18.2)	
V	70 (3.6)	21 (6.2)	
Size (mm)			0.265

Data presented as n (%). IPR, Intraprocedural Rupture; SD, Standard Deviation; H-H, Hunt-Hess; SAH, Subarachnoid Hemorrhage; ACOA, Anterior Communicating Artery; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; GOS, Glasgow Outcome Scale.

Characteristic	Non-IPR (n = 1961)	IPR (n = 341)	P-Value
≤ 5	754 (38.4)	122 (35.8)	
5.1–10	938 (47.8)	165 (48.4)	
10.1–25	235 (12.0)	43 (12.6)	
> 25	34 (1.7)	11 (3.2)	
Number of SAH			<0.001
0	174 (8.9)	8 (2.3)	
1	1613 (82.3)	287 (84.2)	
≥ 2	174 (8.9)	46 (13.5)	
Operation timing (days)			0.095
<3	1213 (61.9)	219 (64.2)	
3–14	590 (30.1)	106 (31.1)	
>14	158 (8.1)	16 (7.6)	
Site			<0.001
ACOA	670 (34.2)	118 (34.6)	
ACA	79 (4.0)	13 (3.8)	
ICA Bifurcation	28 (1.4)	1 (0.3)	
AChA	86 (4.4)	10 (2.9)	
OphA	59 (3.0)	8 (9.9)	
Supraclinoid ICA	23 (1.2)	23 (6.7)	
PCOA	528 (26.9)	89 (26.1)	
MCA	446 (22.7)	64 (18.8)	
PCA	17 (0.9)	6 (1.8)	
PICA	13 (0.7)	8 (2.3)	
Others	12 (0.6)	1 (0.3)	
Number of aneurysms			0.417

Data presented as n (%). IPR, Intraprocedural Rupture; SD, Standard Deviation; H-H, Hunt-Hess; SAH, Subarachnoid Hemorrhage; ACOA, Anterior Communicating Artery; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; GOS, Glasgow Outcome Scale.

Characteristic	Non-IPR (n = 1961)	IPR (n = 341)	P-Value
1	1691 (86.2)	304 (89.1)	
2	224 (11.4)	32 (9.4)	
3	32 (1.6)	3 (0.9)	
4	12 (0.6)	1 (0.3)	
≥ 5	2 (0.1)	1 (0.3)	
GOS			<0.001
1–2	80 (4.1)	38 (11.1)	
3–5	1881 (95.9)	303 (88.9)	

Data presented as n (%). IPR, Intraprocedural Rupture; SD, Standard Deviation; H-H, Hunt-Hess; SAH, Subarachnoid Hemorrhage; ACOA, Anterior Communicating Artery; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; GOS, Glasgow Outcome Scale.

2.2 Patient eligibility

The inclusion criteria were as follows: i) Patients with IAs who underwent microsurgical clipping; and ii) patients with clear imaging and complete clinical data. The exclusion criteria were the following: i) Patients who succumbed unexpectedly; ii) patients who did not undergo microsurgical clipping treatment; and iii) patients with incomplete data.

The IPR consists of the following stages: The craniotomy; exposure and separation; and the clipping stage.

Finally, aneurysms may arise from the following sites: Anterior communicating artery (ACOA); anterior cerebral artery (ACA); supraclinoid carotid artery (Supraclinoid ICA); internal carotid artery bifurcation (ICA Bifurcation); anterior choroidal artery (AChA); ophthalmic artery (OphA); posterior communicating artery (PCOA); middle cerebral artery (MCA); posterior cerebral artery (PCA); posterior inferior cerebellar artery (PICA); and others.

2.3 Study design

The aneurysm and patient characteristics were recorded in the Affiliated Hospital of Qingdao University database until hospital discharge or loss to follow-up. A total of 2,302 patients were divided into two groups based on whether they exhibited IPR or not: i) The non-IPR group (n = 1,961); and ii) the IPR group (n = 341). Finally, sex, age, history of SAH, Hunt-Hess (H-H) grade, the occurrence of subarachnoid blood (Fisher score), timing of the operation (days), surgical approach, Glasgow outcome scale (GOS) and aneurysmal characteristics, including size (mm), side, site, number, orientation, morphology and adhesion to surrounding tissues, were analyzed to identify factors associated with IPR. Subsequently, aneurysms at each site were separately analyzed. (Fig. 1)

2.4 Statistical analysis

Descriptive, univariate and multivariate statistical analyses were performed using the commercially available software SPSS version 24.0 (IBM Corp., Armonk, NY, USA). Categorical and continuous variables are presented as count values and mean ± standard deviation (SD), respectively. Categorical variables were analyzed using the χ^2 test and the Fisher's exact test. Furthermore, continuous variables were assessed using a two independent sample t-test. Multivariate statistical analysis was used to evaluate the risk factors between non-IPR and IPR groups. Univariate predictors with $P < 0.20$ were included in a binary logistic regression (LR) model-building process.

3 Results

3.1 Risk factors for IPR of all aneurysms

In the present study, a total of 2,302 patients were enrolled between December 1996 and July 2019. The aneurysms and patients' characteristics are presented in Table 1. The total study population was divided into two categories based on whether they suffered from IPR or not (non-IPR, n = 1,961; IPR, n = 341). The study groups included 924 male and 1,378 female patients with a mean age of 55.88 ± 10.421 years (range, 6–85 years). The mean age of the non- IPR and IPR patients was 56.04 ± 10.331 and 54.94 ± 10.894 years, respectively. Among all aneurysms, 1,281 originated from the right side, 880 from the left side and the remaining 141 from the middle side of the arterial system. The diameter of aneurysms was ≤ 5 mm in 876 patients, 5.1–10 mm in 1,103 patients, 10.1–25 mm in 278 patients and > 25 mm in 45 patients. On admission, the H-H grade of patients was as follows: 182 patients in H-H grade I, 1,209 in grade II, 662 in grade III, 224 in grade IV and 25 patients in H-H grade V. Furthermore, the imaging results revealed that there were 183 cases of Fisher score I, 334 score II, 1,283 score III, 411 score IV and 91 cases of Fisher score V. Interestingly, the IPR group was associated with poorer prognosis compared with the non-IPR group. More specifically, the IPR group exhibited significantly higher H-H grade ($\chi2 = 28.297$, $P < 0.001$) and Fisher score ($\chi2 = 23.042$, $P < 0.001$), and larger number of SAH ($\chi2 = 22.260$, $P = 0.008$) compared with the non-IPR group. In addition, statistically significant differences were identified regarding the sites of the aneurysms between the two groups ($\chi2 = 64.066$, $P < 0.001$). However, no significant differences were observed in age, sex, side, size and number of aneurysms either for timing of the operation ($P \geq 0.05$) between non-IPR and IPR groups.

Predictors that were found to be associated with IPR ($P < 0.20$) were subsequently entered into a forward conditional binary LR model (Fig. 2). The number of SAHs (1, ≥ 2) and aneurysm location (supraclinoid ICA and PICA) were found to be independent risk factors for IPR (Table 2). The results indicated that the risk of IPR in patients with one and multiple (≥ 2) SAH increased up to 2.816- ($P = 0.015$, 95% CI: 1.219–6.503) and 3.960-fold ($P = 0.014$, 95% CI: 1.546–10.140), respectively. Furthermore, the rupture rate of aneurysms at the supraclinoid ICA and PICA (OR = 6.144 and 3.510, 95% CI: 3.249–11.618 and 1.381–

8.920, respectively) was significantly higher compared with other sites. The rupture rate of aneurysms at different sites was as follows: 50% for supraorbital ICA, 38.1% for PICA, 26.1% for PCA, 15% for ACOA, 14.4% for PCOA, 14.1% for ACA, 12.5% for MCA, 11.9% for OphA, 10.4% for AChA, 3.4% for ICA bifurcation and 7.7% for other sites.

Table 2
Multivariate logistic regression analysis for IPR of aneurysms

Predictor	P Value	β	Odds Ratio	95% Confidence Interval
Age (years)	0.111	-0.009	0.991	0.979–1.002
Number of SAH				
1	0.015	1.035	2.816	1.219–6.503
≥ 2	0.014	1.376	3.960	1.546–10.140
H-H grade at admission	0.242	0.107	1.113	0.930–1.332
Fisher score	0.460	0.071	1.074	0.889–1.297
Side				
Right	0.388	-0.115	0.891	0.686–1.115
Middle	0.098	-0.488	0.614	0.344–1.095
Site				
ACA	0.822	-0.073	0.930	0.494–1.750
ICA Bifurcation	0.154	-1.468	0.230	0.031–1.732
AChA	0.312	-0.359	0.698	0.348–1.401
OphA	0.953	0.024	1.024	0.466–2.253
Supraclinoid ICA	<0.001	1.815	6.144	3.249–11.618
PCOA	0.955	0.010	1.010	0.725–1.406
MCA	0.484	-0.125	0.882	0.621–1.253
PCA	0.147	0.728	2.071	0.773–5.547
PICA	0.008	1.256	3.510	1.381–8.920
Others	0.539	-0.648	0.523	0.066–4.124
Operation timing (days)				
3–14	0.638	0.063	1.065	0.818–1.388
>14	0.059	-0.535	0.586	0.336–1.020

IPR, Intraprocedural Rupture; SAH, Subarachnoid Hemorrhage; H-H, Hunt-Hess; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; β, Partial Regression Coefficient.

3.2 Risk factors for IPR of aneurysms at different sites

The aneurysms at each site are analyzed in Table 3, S1- S11. In the ACOA aneurysm database, only surgical approaches were significantly associated with IPR (χ^2 = 18.853, P = 0.008). In the MCA aneurysm database, statistically significant differences in age (t = 3.058), number of SAHs (χ^2 = 14.909), Fisher score (χ^2 = 12.272) and H-H grade (χ^2 = 27.530) between the two groups were observed. In addition, age was associated with IPR risk (P = 0.042) in the OphA aneurysm group. Interestingly, shorter operation timing was associated with increased IPR risk (χ^2 = 6.801, P = 0.004). Furthermore, in the supraclinoid ICA aneurysm database the IPR group presented a significantly increased number of aneurysmal SAHs (χ^2 = 8.000, P = 0.004) and reduced aneurysm size (χ^2 = 9.310, P = 0.020) compared with the non-IPR group. Additionally, in the AChA aneurysm database the diameter of the aneurysms was significantly smaller in the IPR group (χ^2 = 18.381, P = 0.022). Finally, statistically significant differences were also recorded in several aneurysm characteristics between the non-IPR and IPR groups.

Table 3
Univariate analysis for IPR of aneurysms at different sites

Site	Characteristic	Non-IPR	IPR	P-Value
ACOA		n = 670	n = 118	
	Surgical approach			0.001
	Right pterional	447	59	
	Left pterional	217	57	
	Coronal craniotomy	1	2	
	Right supraorbital	4	NA	
	Left supraorbital	1	NA	
AChA		n = 86	n = 10	
	Size (mm)			0.022
	≤ 5	42	5	
	5.1–10	37	3	
	10.1–25	7	NA	
	> 25	NA	2	
OphA		n = 59	n = 8	
	Age (years)			0.042
	Mean ± SD	53.68 ± 8.549	60.50 ± 10.240	
	Operation timing (days)			0.020
	＜3	23	7	
	3–14	26	1	
	＞14	10	NA	
Supraclinoid ICA		n = 23	n = 23	
	Number of SAH			0.004
	0	4	NA	
	1	19	19	

IPR, Intraprocedural Rupture; SD, Standard Deviation; H-H, Hunt-Hess; SAH, Subarachnoid Hemorrhage; ACOA, Anterior Communicating Artery; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; NA, Not Applicable.

Site	Characteristic	Non-IPR	IPR	P-Value
	≥ 2	NA	4	
	Size (mm)			0.020
	≤ 5	2	9	
	5.1–10	16	7	
	10.1–25	3	6	
	> 25	2	1	
MCA		n = 446	n = 64	
	Age (years)			0.002
	Mean ± SD	56.00 ± 9.343	52.11 ± 10.630	
	Number of SAH			□0.001
	0	74	1	
	1	347	54	
	≥ 2	25	9	
	H-H grade at admission			□0.001
	I	73	1	
	II	217	30	
	III	103	13	
	IV	49	16	
	V	4	4	
	Fisher score			0.015
	I	74	1	
	II	63	11	
	III	165	25	
	□	111	18	
	V	33	9	

IPR, Intraprocedural Rupture; SD, Standard Deviation; H-H, Hunt-Hess; SAH, Subarachnoid Hemorrhage; ACOA, Anterior Communicating Artery; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; NA, Not Applicable.

Site	Characteristic	Non-IPR	IPR	P-Value
ACA	NA			
ICA Bifurcation	NA			
PCOA	NA			
PCA	NA			
PICA	NA			
Others	NA			
IPR, Intraprocedural Rupture; SD, Standard Deviation; H-H, Hunt-Hess; SAH, Subarachnoid Hemorrhage; ACOA, Anterior Communicating Artery; ACA, Anterior Cerebral Artery; ICA, Internal Carotid Artery; AChA, Anterior Choroidal Artery; OphA, Ophthalmic Artery; PCOA, Posterior Communicating Artery; MCA, Middle Cerebral Artery; PCA, Posterior Cerebral Artery; PICA, Posterior Inferior Cerebellar Artery; NA, Not Applicable.				

All predictors with $P < 0.20$ were entered into a forward conditional binary LR model (Fig. 1). This analysis revealed that in the MCA aneurysm database (Table 4) the risk for IPR was decreased 0.387- and 0.267-fold in patients aged from 41 to 60 and > 60 years, respectively. Furthermore, the present study identified a progressive increase in the risk of IPR with increasing H-H grade (OR = 8.633, 7.286, 21.225 and 67.168, P = 0.036, 0.051, 0.004 and 0.001, respectively). Finally, in the ACOA aneurysm database (Table 5) the left pterional and coronal craniotomy approach increased the risk for IPR up to 1.99- and 15.153-fold, respectively, compared with the right pterional approach.

Table 4
Multivariate logistic regression analysis for IPR of MCA aneurysms

Predictor	P Value	β	Odds Ratio	95% Confidence Interval
Age (years)				
41–60	0.034	-0.951	0.387	0.160–0.932
[illegible]60	0.009	-1.321	0.267	0.099–0.717
H-H grade at admission				
[illegible]	0.036	2.156	8.633	1.150-64.816
[illegible]	0.051	2.057	7.826	0.995–61.576
[illegible]	0.004	3.055	21.225	2.713-166.056
[illegible]	0.001	4.207	67.168	5.904-764.099
IPR, Intraprocedural Rupture; MCA, Middle Cerebral Artery; β, Partial Regression Coefficient.				

Table 5
Multivariate logistic regression analysis for IPR of ACOA aneurysms

Predictor	P Value	β	Odds Ratio	95% Confidence Interval
Surgical approach				
Left pterional	0.001	0.688	1.990	1.336–2.964
Coronal craniotomy	0.027	2.718	15.153	1.353-169.682
Right supraorbital	0.999	-19.178	NA	NA
Left supraorbital	1.000	-19.178	NA	NA

IPR, Intraprocedural Rupture; ACOA, Anterior Communicating Artery; β, Partial Regression Coefficient; NA, Not Applicable.

4 Discussion

Microsurgical clipping is widely used in neurosurgery. Although, the incidence of IPR is significantly reduced compared with the non-microscopy era, IPR complications cannot be prevented. IPR often leads to blurred vision, which in turn presents great obstacles to neurosurgeons. Thus, IPR remains a potentially catastrophic event that may lead to a poor outcome. However, the results of several studies regarding the risk factors for IPR are controversial. The present study sought to elucidate the risk factors and identify appropriate treatment strategies for IPR.

4.1 Risk factors:

4.1.1 Age:

There are very few comprehensive analyses addressing the effect of age on IRP in the literature. Kunz *et al* demonstrated a statistically significant correlation between age and IPR. In this study the average age of the IPR and non-IPR groups were 57 and 52 years, respectively[17]. In the present study the average age of IPR group was 54.94 and 56.04 years for the non-IPR group, however, no statistically significant difference in age between the two groups was observed. Moreover, age was correlated with IPR in the aneurysm sites. Thus, in OphA aneurysms, the average age was 60.5 and 53.68 years in the IPR and non-IPR groups, respectively. In addition, in MCA aneurysms the mean age of the IPR group was 52.11, whereas the mean age of the non-IPR group was 56 years. Additionally, a 0.387- and 0.267-fold decreased risk for IPR was detected in middle-aged (41 to 60 years) and elder patients (age > 60 years), respectively. Finally, the mean age in the IPR group was lower compared with the non-IPR group. The association between increased IPR risk and age is perplexing, as the results are inconsistent with previous studies possibly due to the small sample size.

4.1.2 Size:

The association between IPR and the size of aneurysm remains controversial. Several studies have reported increased IPR risk in large aneurysms[10,19], while others have indicated that there is no significant correlation between these factors[2,7]. The results of the present study showed that there was no association between IPR and aneurysm size. However, the size of the aneurysm was associated with its location, particularly with AChA and supraclinoid ICA. When the diameter of the aneurysms at the AChA and supraclinoid ICA was < 5 mm, the IPR rate was significantly increased by 10.6 and 81.8%, respectively (Video 1). Although increased aneurysm diameter makes its exposure and occlusion difficult, especially in areas with atherosclerotic plaque, more attention should be paid to the smaller ones at AChA and supraclinoid ICA. During the clamping process the artery walls are usually thinner, therefore, uneven force may easy cause IPR.

4.1.3 Location:

Although the studies by Sundt *et al.*[28] and Giannotta *et al.*[24] have shown that there is no correlation between aneurysm location and IPR, the majority of studies indicate a strong association between them[7,11,14,29]. Thus, Schramm *et al* revealed that the IPR incidence rate was increased in ACoA and ACA (approximately 36.9%)[14]. In addition, Sandalcioglu *et al.* reported that the IPR incidence rate of ACOA and ICA aneurysms were 39.1 and 31.2%, respectively[11]. Consistent with the previous studies, Ragonovic *et al.* demonstrated an IPR rate for ACA and ICA aneurysms of 40 and 16.7%, respectively[29]. In the present study, a significant correlation between IPR incidence rate and supralinioid ICA (50%) and PICA (38.1%) aneurysms was identified. The overall rupture rate was 14.8%. The rupture rates of aneurysms at different sites were as follows: 50% for supraorbital ICA, 38.1% for PICA, 26.1% for PCA, 15% for ACOA, 14.4% for PCOA, 14.1% for ACA, 12.5% for MCA, 11.9% for OphA, 10.4% for AChA, 3.4% for ICA bifurcation and 7.7% for other sites. Supracervical ICA aneurysms are usually caused by thin artery walls. PICA is very complex and tortuous, and surgery for aneurysms in this site is challenging due to the deep location. The dome of ACOA and POCA aneurysms mainly points to various directions, thus they easily adhere to the surrounding tissues. When the aneurysm neck is exposed, the aneurysm wall is easily pulled, leading to rupture.

4.1.4 H-H grade and Fisher score:

Although, several studies have shown that the IPR incidence is not associated with H-H grade[25,27], Elijovich *et al.* indicated that lower H-H grade was correlated with increased IPR risk[15]. However, the majority of studies have suggested that patients with higher H-H grade are more likely to experience IPR[8,11]. Thus, Sandalcioglu *et al.* reported that the IPR incidence rate was 19.6 and 30.8% in H-H grade I-III and IV-V patients, respectively[11]. The results of the present study showed that the IPR incidence rate was 4.4% in H-H grade I, 15% in II, 14.7% in III, 21% in IV and 32% in grade Ⅴ patients. Increased H-H grade is often accompanied by intracranial hematoma, brain swelling and intracranial pressure. Thus, it is difficult to separate and clip the aneurysm during surgery, while it is easy to rupture the aneurysm by pulling the hematoma. Furthermore, the IPR incidence rate was 4.4% in Fisher score I, 15% in II, 14.7% in III, 21% in IV and 32% in Fisher score Ⅴ patients. Overall, increased Fisher score was associated with more severe intracranial hemorrhage, edema and swelling symptoms. The results suggested that the successful implementation of aneurysm clipping is challenging, indicating H-H grade and Fisher score as risk factors to predict IPR occurrence.

4.1.5 Number of SAH

As expected, the ruptured aneurysms exhibited a significantly increased IPR incidence compared with that noted to the unruptured aneurysms. It has been reported that the IPR incidence rate of unruptured and ruptured aneurysms is 1.2 and 10.7%, respectively[1,7,27]. These findings were consistent with the results of the present study, in which the IPR incidence rate of unruptured and ruptured aneurysms was 4.4 and 15.7%, respectively. Moreover, the present results suggested that the elevated IPR risk was associated with increased SAH incidence. Following aneurysm rupture, the hematoma expands, resulting in its adhesion to the vessel wall. In addition, the aneurysm separation process may lead to its rupture. Moreover, it has been shown that in patients with multiple ruptures, the blood vessel walls are usually thinner and less elastic, further increasing risk of IPR.

4.1.6 Operation time

Several studies have suggested that early surgical treatment may minimize the risk of rebleeding[7,20,29]. However, the clinical data indicated that the timing of the operation was not associated with the incidence of IPR[11,25,27,28]. Thus, the results of the present study were consistent with previous studies, as no significant correlation was detected between the timing of operation and the occurrence of IPR. Nevertheless, in patients with OphA aneurysms, a shorter operation timing was found to increase the risk of rupture. It has been reported that in the early stages of aneurysm formation the blood clot is fragile. However, in the late stages of aneurysm formation peripheral vasospasm, hydrocephalus and adhesion with surrounding tissues may be induced, which may increase the risk of IPR.

4.1.7 Surgical approach

Only few studies have evaluated the association between surgical approach and IPR incidence. Kang *et al* indicated that the incidence rate of IPR in supratentorial aneurysms treated with the supraorbital keyhole approach was higher compared with those treated with the pterional approach[23]. The pterional approach, as a classic surgical process, is widely used for treating the majority of aneurysms. Analysis of ACOA aneurysms revealed increased risk of rupture in patients treated with the left pterional and coronal craniotomy approaches, whereas it was significantly reduced when the supraorbital approach was performed. However, further studies with a larger sample size are required to confirm these findings. When the top of the aneurysm is pointing somewhat anteriorly lower, it often spreads to the anterior fossa or optic chiasmata. In addition, when the frontal lobe is lifted, the aneurysm wall may easily rupture. Furthermore, clinical studies have shown that the supraorbital approach has several advantages in terms of small incision, small bone window, shorter operation time and less bleeding. Additionally, this approach does not affect the intracranial pressure, thus preventing the occurrence of IPR[3,4,13].

4.1.8 Others

In the present study, no significant correlation between IPR incidence rate and sex, aneurysm side, number, direction and morphology were observed. Although irregular morphology and complex direction of aneurysms may increase the difficulty of the surgery, the aforementioned results indicated that they were not associated with the occurrence of IPR. In addition, several studies have suggested that intraoperative controlled hypotension may reduce the incidence rate of IPR[8,11,16].

4.2 Treatment strategies

4.2.1 Announcements

According to imaging data, the aneurysm location, size, shape and its association with peripheral tissues, blood vessels and nerves should be assessed from various angles. Thus, the choice of the operative approach, the clipping of the aneurysm and lowering the occurrence rate of IPR are of great importance. There has been controversy regarding the control of blood pressure preoperatively. Thus, blood pressure should be maintained at normal levels, as lower levels may lead to adverse effects. Furthermore, temporary occlusion of the parent artery may significantly reduce the incidence of IPR[5,9,27]. However, the clipping could inevitably cause damage to the blood vessel wall during temporary occlusion. In addition, attention should be paid to patients with atherosclerosis. When a temporary occlusion clip is used, the atherosclerotic plaque may be easily detached, leading to cerebral infarction and vasospasm. Therefore, when the temporary occlusion approach is performed to clamp the artery, healthy or less sclerotic artery segments should be selected and the temporary occlusion time should not exceed 20 min. Additionally, the intracranial pressure should be reduced by releasing the cerebrospinal fluid during the procedure. Finally, the available operating space may facilitate the procedure, as the aneurysm is adequately exposed.

4.2.2 Treatment after IPR

First of all, we should have a strong psychology, and don't feel nervous when IPR happens. Secondly, it is necessary to compress the ICA and temporarily block the carrier artery to reduce the bleeding rate. At the same time, the double aspirator method is used to quickly clean up the blood in the surgical field. Then, we should find and clipping the aneurysm neck. If necessary, the electric coagulation break can be selected according to the situation[26](Video 1).

5. Conclusion

The present study showed that the number of SAHs (1, ≥ 2) and aneurysms site (supraclinoid ICA and PICA) were independent risk factors for IPR in all aneurysm databases. In addition, in the MCA and ACOA aneurysm databases, age ≤ 40 years and higher H-H grade, and left pterional and coronal craniotomy approaches, respectively, were identified as independent risk factors for IPR. Overall, the surgical treatment strategy of aneurysms should include preoperative evaluation, intraoperative coping strategies and postoperative treatment, in order to ensure satisfactory efficient therapeutic effects.

Declarations

Acknowledgement:

Not applicable

Authors' contributions:

LHJ and FYG conceived of the study, and participated in its design and coordination.

LHJ and LDL collected the data from Affiliated Hospital of Qingdao University, performed the statistical analysis, and contributed to draft the manuscript.

LY and KXY helped to draft the manuscript and revised the manuscript carefully.

All authors read and approved the final version of the manuscript.

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Ethics approval and consent to participate:

This study was approved by the Ethics Committee of the Affiliated Hospital of Qingdao University, and has been exempted from the application for informed consent.

Consent for publication:

Written informed consent for publication was obtained from all participants

Abbreviations

IAs: Intracranial aneurysms; SAH:Subarachnoid hemorrhage; IPR:Intraprocedural rupture; ACOA:Anterior communicating artery; ACA:Anterior cerebral artery; ICA:Internal carotid artery; AChA:Anterior choroidal artery; OphA:Ophthalmic artery; PCOA:Posterior communicating artery; MCA:Middle cerebral artery;

PCA:Posterior cerebral artery; PICA:Posterior inferior cerebellar artery; H-H:Hunt-Hess; GOS:Glasgow outcome scale.

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Figures

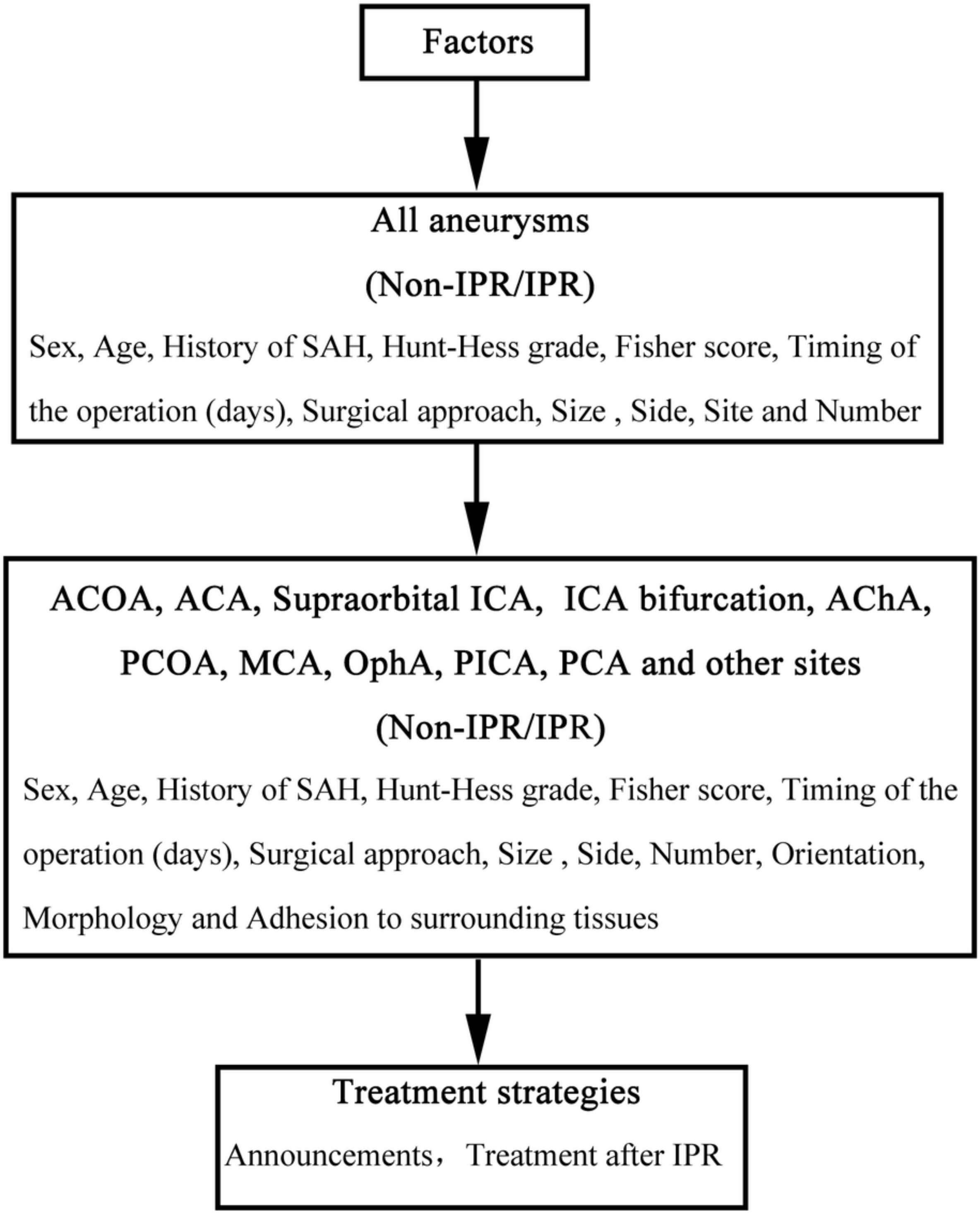

Figure 1

Flow Chart

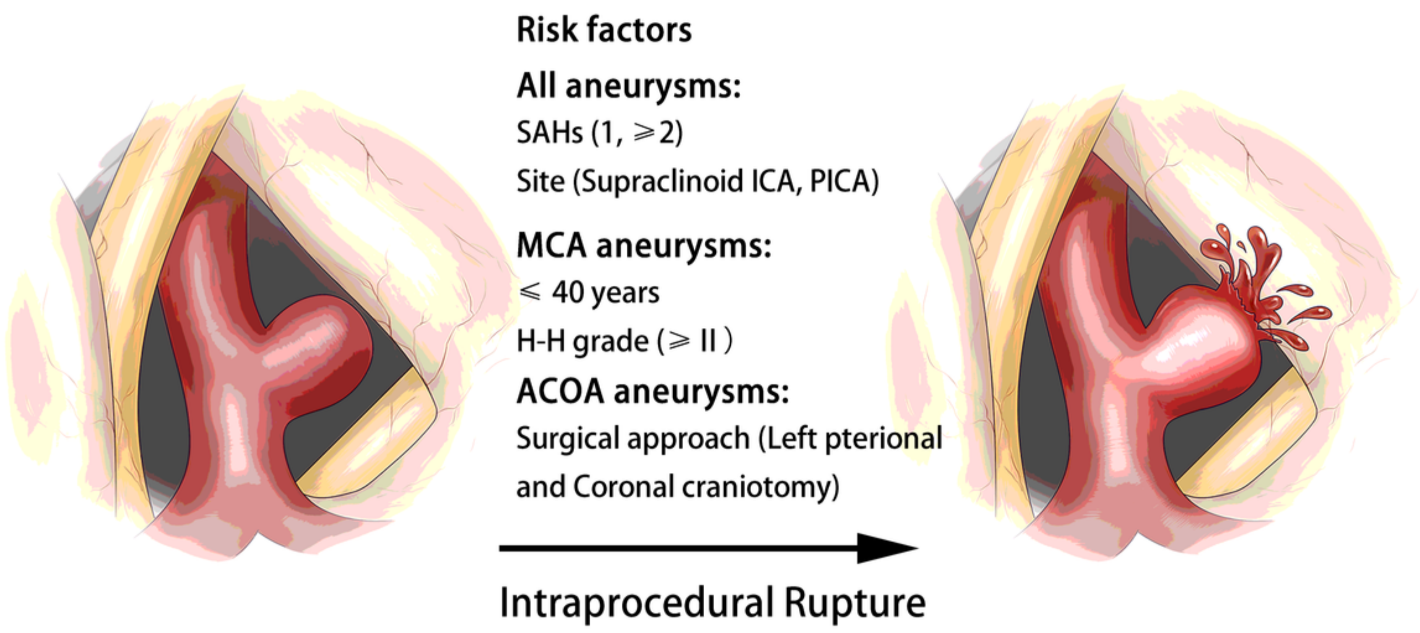

Figure 2

Risk factors for IPR of aneurysms

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