—Review—

Petrous Internal Carotid Artery Aneurysm: A Systematic Review

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Objective: Petrous internal carotid aneurysm (PA) concomitant with a mass lesion and cranial nerve palsy is relatively rare. Flow-diverter stent implantation is now widely used as an alternative treatment for PA. However, alternative treatments sometimes cannot be used because of tortuosity of the carotid artery, allergies to contrast material, and high costs. The outcomes of different treatment methods should therefore be assessed. Here, we review the available literature on treatments for PA.

Methods: In a search using the terms "aneurysm", "carotid artery", and "petrous" on PubMed, MEDLINE, and databases such as OvidSP, 221 articles were identified. We also performed a literature review and discuss and compare the causes, symptoms, treatment methods, and clinical outcomes of PA.

Results and Conclusions: Onset of secondary aneurysm was generally heralded by bleeding ($p<0.001$), while onset of primary aneurysm was heralded by cranial nerve deficit ($p= 0.0014$). Outcomes after treatment of 34 cranial nerve palsies in 25 patients are reported. (J Nippon Med Sch 2020; 87: 172–183)

Key words: cerebral aneurysm, hypoglossal nerve, internal carotid artery, systematic review, petrous

Introduction

Extracranial, non-traumatic, non-dissecting saccular internal carotid artery (IC) aneurysms are usually located in the lower cervical region; aneurysms in the petrous portion of the IC are rare[1]. Extracranial IC dissection can cause hypoglossal nerve palsy[2,3], and concomitant incidence with IC dissection was reported in 5% of cases[4]. However, no case of hypoglossal nerve palsy due to saccular aneurysm in the petrous IC has been reported. In the largest series, which included 100 cases[5] of hypoglossal nerve palsy, nearly 50% of cases of hypoglossal nerve palsy were caused by tumors. Other causes[5] include trauma, stroke, multiple sclerosis, surgery, Guillain-Barré neuropathy, and infection. Hypoglossal nerve palsy resulting from extracranial aneurysm is rare[6,7].

Petrous IC aneurysm (PA) is relatively rare[8], has a wide variety of causes, including infection[9], trauma[10,11], and pseudoaneurysm[12], and has been studied since 2004[8]. In recent years, multiple treatments for PA, such as use of a flow diverter[9,13,14], have been reported; however, revascularization surgery remains an important strategy[10,15]. PA is often difficult to treat intravascularly, particularly in patients with infectious diseases[6,16], rupture[17], and pseudoaneurysm[16]. Furthermore, not all treatment strategies are available for all patients, as some patients are allergic to contrast agents or metals[18] and some have renal dysfunction. Another reason for the unavailability of a treatment may be its high cost. Therefore, the outcomes of available treatment methods need to be compared.

Studies of the symptoms of unruptured PAs commonly report cranial nerve symptoms[8,12,13,19,20]. Several studies have investigated the effects of treatment for cranial nerve symptoms of internal carotid artery-posterior communicating artery (ICPC) aneurysms[19,21,22] and cavernous carotid aneurysms[23]; however, few studies[8,19,24,25] have examined the effects of treatment for cranial nerve symptoms of PAs. Unlike ICPC and cavernous carotid aneurysms, PAs are partially surrounded by bone structure; therefore, the effect of decompression on the cranial nerve may be a characteristic of this lesion site. Further-

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more, because symptoms differ in relation to the cause of PA[8,26], even for aneurysms at the same location, we evaluated differences in symptoms between primary petrous carotid aneurysms and traumatic, infectious, and iatrogenic petrous aneurysms. For this purpose, we performed a systemic review of available studies on PAs. We also reviewed reports on PAs with different causes.

Systematic Review

To determine future treatment strategies for cranial nerve palsy due to PAs, we conducted a literature review of previously reported cases[6,7,9–16,19,20,24,25,27–89]. We searched for all reported case studies and clinical research studies of PAs that were published in English. PubMed, MEDLINE, and other databases, such as OvidSP, were searched by using keywords such as "petrous," "aneurysm," and "carotid artery." The initial search was completed at the end of July 2018 and yielded 221 articles; data for 107 patients (109 sides [2 cases of bilateral aneurysm]) from 79 studies[6,7,9–16,19,20,24,25,27–87] were reviewed. The exclusion criteria were (1) articles in a language other than English (n = 23); (2) review articles or clinical studies not related to petrous carotid aneurysm (n = 115); and (3) clinical studies with no data on the effects of the case study (n = 13).

The included studies are summarized in **Table 1**. Nine reports were added by requotation. Using these data, we compared primary and secondary petrous carotid aneurysms in relation to age, sex, side, and frequency of bleeding (**Table 2**). The incidences of complications and additional interventions in patients who underwent each type of treatment were also analyzed. Those who underwent additional treatment were regarded as having undergone 2 treatments. Because of the low radiological diagnostic and prognostic accuracy, all cases reported before 1970 were excluded. Two authors (Y.M. and K.S.) assessed and graded (modified Rankin scale score, 0-2 or not) postoperative complications reported in each study. Treatment methods were classified into 5 categories: (1) surgical or interventional carotid artery occlusion or trapping, without aneurysm embolization, (2) stenting, with or without coiling, (3) revascularization surgery, (4) aneurysm embolization with a coil or balloon, and (5) conservative or no treatment. All variables were evaluated by using JMP version 11.0.0 (SAS Institute Inc., Cary, NC, USA). A *P* value of less than 0.05 (Pearson analysis) was considered to indicate statistical significance.

All procedures performed involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments, or with comparable ethical standards.

Results of Systematic Review

The results of the analysis are shown in **Table 1**[6,7,9–16,19,20,24,25,27–88]. The characteristics of patients with primary and secondary (infectious, traumatic, radiation induced, or iatrogenic) petrous carotid aneurysm are shown in **Table 2**. The treatments selected are shown in **Table 3**. The average age of the reported patients was 41.4 years (range, 5-81 years). Among the 94 patients for which sex was reported, 54 were male and 40 were female (**Table 2**). Among the 95 patients for which the side of the aneurysm was reported, the aneurysm was located on the right side in 44 cases and on the left side in 51.

Thirty-nine patients developed 1 or more cranial nerve deficits (**Table 1, 4, 5**). Only a few studies reported the interval from symptom onset to treatment, so this variable was excluded from the present study. The most common sites of cranial nerve deficit were the eighth (n = 15), sixth (n = 13), seventh (n = 10), and fifth cranial nerves (n = 8) (**Table 4**). Thirty-five cranial nerve symptoms from 25 patients with a recorded post-treatment course were examined (**Table 4, 5**). Cranial nerve symptoms did not change in 9 cranial nerves, improved in 19 cranial nerves, and resolved in 7 cranial nerves.

There were 39 cases of bleeding from life-threatening otorrhagia or epistaxis (**Table 1, 2**). The cause was described in 45 of the 109 cases: 16 involved infectious diseases, including chronic otitis media, and 13 involved cervical trauma. Radiation therapy was performed for a cranio-cervical tumor in 10 patients, and the cause was characterized as iatrogenic in 6 patients.

Statistical analysis revealed that onset of secondary aneurysm was heralded by bleeding ($p<0.001$) and that onset of primary aneurysm was heralded by cranial nerve injury ($p=0.0014$) (**Table 2**). Factors associated with outcomes of treatment for injured cranial nerves were examined. The number of cases was insufficient to assess statistically the effect of individual treatments on each cranial nerve (**Table 5**). We also compared the incidences of complications and additional interventions, by treatment type, and studied 78 treatments performed for 75 cases and 10 patients undergoing conservative treatment (**Table 6**). Of the reported patients, 93.2% (82/88) were free of complications. There was no significant difference in the incidence of any complication. Four[51,70,71,83] cases of rebleeding after treatment were reported, and additional treatment was required in 3[17,51,83] of these 4 cases.

Table 1 Patient characteristics of reported petrous carotid aneurysm

Author & Year	Age	Sex	Side	Size (mm)	CN symptoms	Other symptoms	Treatment	CN post treatment	Post treatment ischemia	Cause
Barrett et al., 1960	26	M	L	NA	none	otalgia	CCA ligation	NA	none	infection
Guirguis et al., 1961	19	M	L	giant	6,7,8,9	headache	ligation	Dead	Dead	
Hiranandani et al., 1962	40	M	R	40	none	otalgia	none	NA	none	
Wemple et al., 1966	18	M	L	large	6,8	Horner	IC ligation	diplopia improved	none	
Allen et al., 1967	43	F	R	NA	8	none	conservative	NA	NA	iatrogenic
Busby et al., 1968	29	M	R	NA	6,7,8	epistaxis	ECA ligation	NA	none	trauma
Steffen et al., 1968	47	F	L	NA	none	tinnitus	NA	NA	none	
Conley et al., 1969	7	F	L	NA	NA		direct removal	NA	none	
Stallings et al., 1969	9	F	R	3	NA	purulent otorrhea	coating with fascia	NA	NA	
Anderson-1 et al., 1972	19	F	L	20	none	otorrhagia	trap (ligation and clip)	NA	none	
Anderson-2 et al., 1972	59	F	R	30	none	tinnitus, otorrhagia	trap (clip and clip)	NA	none	
Teal-1 et al., 1973	36	M	L	NA	none	none	conservative	NA	NA	trauma
Teal-2 et al., 1973	36	M	L	NA	none	headache	conservative	NA	NA	trauma
Morantz et al., 1976	34	F	R	NA	none	hyperacusis, tinnitus	IC ligation	NA	none	
Holtzman et al., 1979	35	M	L	5	none	otorrhagia	IC ligation	NA	none	infection
Glassock et al., 1983	9	M	L	18	NA	otalgia	end to end anastomosis	NA	none	iatrogenic
Lynch et al., 1983	28	F	L	50	8	ear pain	ligation	no change	none	
Kelly-1 et al., 1985	61	F	R	NA	7	none	conservative	NA	NA	
Kelly-2 et al., 1985	63	M	L	NA	6	none	NA	NA	NA	
DelBalso et al., 1986	50	F	L	large	none	transient ischemic attack	NA	NA	none	
McGrail et al., 1986	44	M	L	25	5,6	none	IC trap with balloon & STA- MCA	improve (months)	none	infection
Willinsky et al., 1987	35	F	L	5	none	epistaxes, ear pain	AN balloon emboli	NA	none	
Gibson et al., 1989	56	M	L	60	5	temporal pain	conservative	mild facial palsy	NA	
Frank et al., 1989	18	F	R	large	8	bruit	conservative	NA	none	neurofibromatosis
Halbach-1 et al., 1990	19	M	L	NA	5,7	bruit	IC ligation	5 resolved, 7 persistent	none	
Halbach-2 et al., 1990	7	M	L	NA	8	headache, amaurosis fugax	ICO with balloon	resolved	amaurosis fugax	
Halbach-3 et al., 1990	14	F	R	NA	8	headache, tinnitus, vertigo	IC trap with balloon	resolved	none	trauma
Halbach-4 et al., 1990	31	F	L	NA	8	none	IC trap with balloon	resolved	none	
Halbach-5 et al., 1990	62	F	L	NA	5	none	AN balloon emboli	resolved	none	
Halbach-6 et al., 1990	60	F	L	NA	none	headache	ICO with balloon	NA	none	
Halbach-7 et al., 1990	19	M	R	NA	3	none	ICO with balloon	resolved	none	
Costantino et al., 1991	37	F	R	NA	none	epistaxis, otorrhagia	ICO with balloon & coil	NA	temporal hemiparesis	infection
Tokimura et al., 1992	64	F	R	large	none	none	end to end anastomosis	none	none	
Umezu et al., 1993	21	M	L	20	7,8	otalgia	PAO with balloon → trap & STA- MCA	NA	none	

Table 1 Patient characteristics of reported petrous carotid aneurysm

Author & Year	Age	Sex	Side	Size (mm)	CN symptoms	Other symptoms	Treatment	CN post treatment	Post treatment ischemia	Cause
Papazian-1 et al., 1993	18	F	NA	NA	none	none	NA	none	NA	infection
Papazian-2 et al., 1993	49	M	NA	NA	none	headache	NA	none	NA	
Papazian-3 et al., 1993	52	F	NA	3.5	none	headache	NA	none	NA	
Cross et al., 1995	31	M	L	giant	none	epistaxis	IC trap with balloon	NA	none	infection
Patrick-1 et al., 1996	70	M	L	giant	none	none	conservative	NA	none	
Patrick-2 et al., 1996	43	F	L	giant	7	none	ICO with balloon with EC-IC bypass	7 persist	none	
Love et al., 1996	50	M	L	NA	7,8	tinnitus	ICO with balloon	7 persist, 8 lessened	none	
Goodman et al., 1996	22	M	R	large	8	Horner	ICO with balloon	8 improved	none	
Coley et al., 1998	15	M	L	giant	8	headache, Horner	ICO with balloon	NA	none	
Zander et al., 1998	45	M	R	5	none	headache, Horner	conservative	improve (18M)	none	
Lempert et al., 1998	36	M	L	8	5	NA	coiling	NA	none	trauma
Tanaka et al., 1998	37	F	R	30	12	headache	ICO with balloon & coil	NA	none	infection
Date et al., 1999	46	F	L	40	3,4,5,6	none	ICO with balloon	improve (2M)	none	
Reece et al., 1999	21	M	L	large	8	otalgia, tinnitus	ICO with balloon	persist	none	
Forshaw et al., 2000	20	M	L	30	none	otorrhagia	ICO with balloon	NA	none	
Couldwell et al., 2001	47	M	L	giant	6	headache	resection & SV graft	improve	none	
Scavée et al., 2001	53	M	R	13	NA	dizziness, neck pain	covered stent	NA	none	trauma
Cheng-1 et al., 2001	54	M	R	NA	none	epistaxis	ICO with coil	NA	none	radiation
Cheng-2 et al., 2001	35	M	R	small	none	otalgia	stent	NA	none	radiation
Vasama et al., 2001	5	NA	R	NA	none	epistaxis	coiling	NA	none	trauma
Alexander et al., 2002	42	F	R	6	none	otalgia	covered stent	NA	none	iatrogenic
Depauw et al., 2003	29	M	L	giant	none	cerebral ischemia	ICO with balloon	no ischemia	none	
Auyeung-1 et al., 2003	52	F	R	small	NA	none	epistaxis	covered stent	none	radiation
Auyeung-2 et al., 2003	52	M	L	large	none	epistaxis	covered stent	NA	none	radiation
Saatci-1 et al., 2004	48	F	R	31	none	headache	covered stent	NC	NC	trauma
Saatci-2 et al., 2004	25	M	L	7	none	none	covered stent	NA	NC	trauma
Saatci-3 et al., 2004	18	M	L	14	none	none	covered stent	NA	NC	trauma
Saatci-4 et al., 2004	22	M	R	9	none	none	covered stent	NA	NC	trauma
Saatci-5 et al., 2004	36	F	L	28	none	headache	covered stent	NA	NC	trauma
Horowitz et al., 2005	24	F	R	4	none	epistaxis	stent coil	NA	none	pseudoAN
Cohen et al., 2007	54	F	R	large	8	tinnitus, headache	covered stent	NA	CNVI palsy	fibromascular dysplasia
Singh et al., 2008	30	M	L	46	none	epistaxis, headaches	ligation	persist	none	
Schmerber et al., 2008	67	M	R	NC	none	otalgia, epistaxis	ICO with balloon	NA	none	iatrogenic

Table 1 Patient characteristics of reported petrous carotid aneurysm

Author & Year	Age	Sex	Side	Size (mm)	CN symptoms	Other symptoms	Treatment	CN post treatment	Post treatment ischemia	Cause
Ferroli et al., 2009	66	F	R	giant	6	headache	RA graft & IC ligation	persist	none	
Saylam et al., 2009	28	F	L	small	none	none	PAO with Balloon	NA	none	iatrogenic
Oyama et al., 2010	60	M	R	small	none	otalgia	coil & ligation trap & SV graft	NA	none	infection
Palacios et al., 2010	27	M	R	NC	5,6	tinnitus	NA	NA	NA	
Sun et al., 2010	6	M	L	30	none	none	conservative	NA	none	
Rose et al., 2010	33	M	R	NA	6	headache, Horner	conservative	NA	NA	
Endo et al., 2011	62	F	L	small	NA	epistaxis, headaches, SAH	IC trapping with coil & STA-MCA	NA	none	iatrogenic
Mangat et al., 2011	15	M	R	large	6	Horner	coil	improve (5M)	NA	
Lerat-1 et al., 2011	64	F	L	19	7	none	PED	improved	none	pseudoAN
Lerat-2 et al., 2011	64	F (bilateral)	R	15	none	none	PED	NA	none	
Kim et al., 2012	54	F	R	14	none	pulsatile tinnitus.	AN coil	tinnitus improve	none	
Rathore et al., 2012	30	NA	R	NA	3	NA	IC ligation	NA	none	
Bien et al., 2013	63	M	R	large	none	bloody otorrhea.	ICO with coil	NA	none	radiation
Chen et al., 2013	23	F	L	24	none	none	PAO with coil	NA	none	Ehlers-Danlos Synd
Hamamoto et al., 2013	77	F	R	large	7	none	coil	NA	none	
Kadkhodayan et al., 2013	50	F	L	small	none	otalgia	PED (rebleed additional coil)	NA	NA	infection
Shon et al., 2013	79	M	L	10	none	otalgia, cerebral embolism	conservative	NA	NA	infection
Kalani et al., 2014	51	M	L	NA	NA	NA	ICO with clip & STA-MCA bypass	NA	none	
Moon et al., 2014	64	M	L	16	2,5,6	none	PED with coil	improve	none	
Mascitelli et al., 2014	middle aged	NA	L	17	none	otalgia	coil → (rebleed) covered stent	NA	none	infection
Tsang-1 et al., 2015	40s	NA	R	1.2	NA	epistaxis	PED	NA	none	radiation
Tsang-2 et al., 2015	50s	NA	R	2.2	NA	epistaxis	PED	NA	Multiple CI	radiation
Tsang-3 et al., 2015	60s	NA	R	1.8	NA	epistaxis	PED with coil	NA	none	radiation
Tsang-4 et al., 2015	60s	NA	L	14	NA	epistaxis	PED with coil	NA	none	radiation
Tsang-5 et al., 2015	60s	NA	R	3.3	NA	epistaxis	PED	NA	delayed ICO (10M)	radiation
Baker et al., 2015	81	M	L	31	none	otalgia, trismus. CI	ICO with clip & bypass	NA	NA	infection
Lee et al., 2015	18	M	L	15	none	headache, nausea, tinnitus	stent coil	NA	none	neurofibromatosis
Mukher et al., 2016	64	M	R	NA	none	occipital infarction	SV bypass end to end	NA	temporal facial palsy	
Han et al., 2016	21	M	R	15	7	meningitis	covered stent	NA	none	infection

Table 1 Patient characteristics of reported petrous carotid aneurysm

Author & Year	Age	Sex	Side	Size (mm)	CN symptoms	Other symptoms	Treatment	CN post treatment	Post treatment ischemia	Cause
Akhtar et al., 2017	13	M	R	NA	none	otorrhagia	IC ligation & STA-MCA bypass	NA	none	trauma
Gross-1 et al., 2017	NA	NA	NA	17	none	tinnitus	Neuroform	tinnitus cone	none	
Gross-2 et al., 2017	NA	NA	NA	10	none	none	Enterprise coil	NA	none	
Gross-3 et al., 2017	NA	NA	NA	17	5,6	none	PED with coil	improve	none	
Gross-4 et al., 2017	NA	NA	NA	12	none	none	PED with coil	NA	none	
Gross-5 et al., 2017	NA	NA	NA	6	6	none	PED with coil	resolve	none	
Gross-6 et al., 2017	NA	NA	NA	10	none	none	Balloon coil	NA	none	
Németh-1 rt et al., 2017	68	F	R	NA	none	otalgia right	flow diverter	NA	NA	infection
Németh-2 lt et al., 2017	68	F (bilateral)	L	NA	none	otalgia left	flow diverter	NA	NA	infection
Hassania-1 et al., 2018	75	M	L	large	NA	otalgia, dysphonia, Horner	ICO with coil	NA	none	infection
Hassania-2 et al., 2018	60	M	R	NA	9,10,12	dysphonia, dysphagia	coil trap	NA	none	infection
Yu LB et al., 2018	58	M	R	giant	none	otorrhagia	coil → bypass & coil removal	NA	none	
Murai Y et al., 2018	64	F	L	28	11,12	none	IC ligation & RA graft	improve	none	

AN, aneurysm; CCA, common carotid artery; CI, cerebral ischemia; CN, cranial nerve; EC, external carotid artery; F, female; IC, internal carotid artery; ICO, internal carotid artery occlusion; M, male; MCA, middle cerebral artery; NA, not applicable or no data; PAO, parent artery occlusion; RA, radial artery; SAH, subarachnoid hemorrhage; STA, superficial temporal artery; SV, saphenous vein

Table 2 Clinical characteristics of reported petrous carotid aneurysm

All	Primary	Secondary	P Value
107 cases 109 side	64	45	
male:female 54:40	30:26	24:14	0.231
Side (rt:lt) 44:51	21:32	23:19	0.128
Age 41.37± 19.77	39.41± 19.74	44.02 ± 19.73	0.291
Hemorrhagic onset	11/56 (19.6%)	28/44 (63.6%)	**<0.0001**
mean size (mm) of aneurysm	21.7±15.0	13.8±10.4	0.089
Size (mm) range of aneurysm	3-60	1.2-31	
Cranial Nerve symptom	32/60 (53.3%)	7/35 (20%)	**0.0014**
Etiology	64	45	
		Infection	16
		Trauma	13
		Radiation	10
		Iatrogenic	6

Data are expressed as mean±SD
Variables showing significant difference by Pearsons analysis ($p<0.05$) are indicated by boldface.

Discussion

Treatment Strategies and Results of Literature Review

It was difficult, even in this systematic review, to examine the effects of different treatments for cranial nerves. Treatment outcomes for the cranial nerve were reported in only 25 cases[12,13,19,24,25,30,41,44,46,48,54,55,59,61,72,88], and only a few studies examined treatment with a flow-diverter stent[9,13,14,19,83]. The number of studies of flow diverters is

Table 3 Treatment selection of reported patients

Treatment			
Conservative or NA		19	
ICO without bypass		36	
	interventional PAO		16
	surgical ligation		10
	interventional trapping		8
	surgical trapping		2
AN embolization (coil or balloon)		8	
stent/ flow diverter		29	
Revascularization surgery		14	
	STA-MCA bypass		5
	anastomosis		2
	radial artery graft		3
	saphenous vein graft		3
	EC-IC bypass		1
Other		2	

AN, aneurysm; EC, external carotid artery; IC, internal carotid artery; ICO, internal carotid artery occlusion; MCA, middle cerebral artery; NA, not applicable or no data; PAO, parent artery occlusion; STA, superficial temporal artery

Table 4 Case number of cranial nerve disturbance and outcome

Cranial Nerve	Unknown	Unchanged	Improved	Resolved	Total
II	0	0	1	0	1
III	1	0	1	1	3
IV	0	0	1	0	1
V	1	1	4	2	8
VI	4	1	7	1	13
VII	6	3	1	0	10
VIII	6	3	3	3	15
IX	2	0	0	0	2
X	1	0	0	0	1
XI	0	1	0	0	1
XII	1	0	1	0	2

likely to increase, and this may aid in determining the treatment effects of flow diverters and parent artery occlusion and entrapment.

In this review, 36 patients[6,7,10,16,27,28,30,36,38,39,41,48,51,53–56,59,60,63,66,70–74,78,80–82,85,88] were treated with interventional or surgical parent-vessel occlusion only, without bypass (**Table 3**). Surgical revascularization was used in only 14 patients[10,40,44,50,51,54,61,72,74,78,85,89]. Among these, only 6 cranial nerve injuries in 5 patients were reported[44,54,61,72]. Of these, 4 cranial nerve injuries improved and 2 cranial nerve injuries were unchanged. Some patients with hemorrhagic PA required re-treatment. Mascitelli et al[17] described a patient requiring an additional covered stenting because of rebleeding after aneurysm coiling, and Umezu et al[51] reported a patient with rebleeding after treatment with balloon parent artery occlusion who needed additional trapping and STA-MCA anastomosis. Recently, Kadkhodayan et al[83] reported a patient who required additional interventional coil trapping of the IC artery because of rebleeding 12 days after placement of a pipeline embolization device.

In addition, Yu et al[15] reported a case in which the coil protruded into the external auditory canal after coiling; surgical extraction of the coil was required. These complications are characteristic of this type of lesion, as the coil is transported outside the body. These characteristics are not seen in the treatment of intracranial cerebral aneurysm. Therefore, treatment selection must consider

Table 5 Rates of recovery after the treatment of cranial nerve injuries according to the factors studied

Predictor	rate of recovery
All (n)	26/34 (76.5%)
Age	
<20	5/8 (62.5%)
21< <40	2/3 (66.7%)
41>	15/19 (78.9%)
Sex	
male	11/15 (73.3%)
female	6/9 (66.7%)
Size (mm)	
12>	1/1 (100%)
12< <25	9/12 (75%)
25<	9/13 (69.2%)
Treatment	
IC ligation or interventional occlusion	12/17 (70.5%)
Flow-diverter or stent w/wo coil	7/7 (100%)
revascularization surgery	4/6 (66.7%)
aneurysm embolization	2/2 (100%)
conservative or no treatment	1/2 (50%)

Rate of injured cranial nerve recovery = number of recovered cranial nerves/total number of injured cranial nerves × 100%

Table 6 Treatment results and complications

Selected Treatment	ratio of mRS 0-2	Details of complications
parent artery occlusion or trapping (surgical and interventional)	28/29 (96.6%)	ischemia rebleeding (additional trapping and bypass) rebleeding (conservative) ischemia
flow diverter or stent w/wo coil	23/26 (88.5%)	ischemia rebleeding (additional IC coil occlusion)
revascularization surgery	14/14 (100%)	facial palsy for 2 months
aneurysm embolization (coil or balloon)	8/ 9 (88.9%)	extraction of protruded coil rebleeding (additional covered stent)
conservative or no treatment	9/10 (90%)	ischemia
Total	82/ 88 (93.2%)	

features not found in intracranial cerebral aneurysm, especially in patients with sudden onset of epistaxis or otorrhagia.

Future studies are likely to report treatment outcomes for flow diverters. However, flow diverters cannot be used for all patients, including those with tortuous carotid arteries, allergies to contrast agent, and difficulties in angiographic access. In addition, flow diverters are not available in all countries because of their high cost. When considering treatment strategies from a global perspective, revascularization procedures and parent-vessel occlusion are important for treating patients with hemorrhagic PAs requiring emergency surgery who cannot undergo a balloon occlusion test.

Cranial Nerve Symptoms

The mechanism underlying cranial nerve palsy is aneurysm expansion, which causes mechanical compression of adjacent structures, in particular the hypoglossal and glossopharyngeal nerves, and subsequently results in nerve palsy[90]. The hypoglossal nerve emerges from the

anterior condylar canal in the skull base and passes downward between the IC and jugular vein. The glossopharyngeal nerve leaves the skull through the jugular foramen and again passes downward between the IC and internal jugular vein.

With regard to endovascular options, we considered a covered stent with coil embolization or a flow-diverter stent for patients with unruptured aneurysms. Endovascular stents are effective, but coil embolization may also be needed[19,68,87]. Additionally, as this portion was circumscribed by the cranial bone, coil embolization may have worsened aneurysm compression and nerve palsy[21,22]. A flow-diverter stent is a good option and was reported[13,14,19] to be effective for extracranial IC aneurysm. However, placement of the stent in this portion is technically difficult and is associated with high risk because the petrous segment is located near the curved portion of the IC. Additionally, as the aneurysm is circumscribed by the petrous bone, recovery of cranial nerve palsy is uncertain. Moon et al[19] reported that pipeline embolization improved cranial neuropathy of the second, third, fifth, and sixth nerves, but there are no reports of extracranial aneurysm with lower cranial nerve palsy.

In open surgery for lower cervical extracranial saccular aneurysm, aneurysmectomy with direct end-to-end anastomosis or an interposition graft is recommended[91]. However, the aneurysm was located from the petrous portion to the higher cervical portion; thus, a direct surgical approach would have been difficult because of the anatomical characteristics[92,93]. Proximal ligation of the IC is an effective treatment for unruptured cervical IC aneurysm, although direct clipping may be difficult[94]. We safely performed treatment with proximal ligation and a radial artery graft for unruptured intracranial IC aneurysm in the cavernous portion[23]. Proximal ligation and EC-IC bypass changes blood flow, and flow alteration promotes aneurysm thrombosis. Thus, EC-IC bypass and proximal ligation might be more effective than endovascular treatment for PA. Recovery of lower cranial nerve palsy due to aneurysmal compression is not well understood. However, in patients with oculomotor nerve palsy and posterior communicating artery aneurysm, clipping tends to result in faster, more complete recovery than coiling, and duration of recovery ranges from 0 to 250 days postoperatively[21].

Limitations

A limitation of our literature review is the lack of statistical power to examine the effects of particular treatments. Although all patients had petrous IC artery aneurysm, the causes and incidence rates of hemorrhage were different. Furthermore, progress and changes in endovascular treatment devices during the past decade affected the results. Therefore, we were unable to develop a general treatment strategy.

Conclusions

Treatment of extracranial saccular aneurysm with cranial nerve palsy remains controversial, and the proper treatment must be chosen for each aneurysm. EC-IC bypass and proximal ligation is an effective alternative to endovascular surgery for treatment of petrous carotid aneurysm with cranial nerve palsy. Further studies of patients with aneurysm and cranial nerve palsy are needed.

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