



# Efficacy of pipeline endovascular device and Willis stent graft in the treatment of traumatic pseudo intracranial aneurysms



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## ABSTRACT

**Objective:** To investigate the advantages and effects of pipeline embolization device (PED) or Willis stent, in treating traumatic pseudoaneurysms. Traumatic pseudo intracranial aneurysms (TPIA) can be caused by either direct trauma or iatrogenic injuries, usually caused by direct arterial wall injury or shear due to acceleration. We describe a series of patients with TPIA who received a PED or Willis stent.

**Materials and methods:** Retrospective analysis was performed on nine patients with TPIA admitted to the southern hospital of Southern Medical University from December 2017 to June 2019, of whom four were treated with PED and five were implanted with six Willis covered stents. The occlusive rate and complication in the two kinds of stents were compared by postoperative follow-up and modified rankin score (MRS).

**Results:** After the implantation of PED, four patients showed an immediate stagnation of blood flow or a decreased filling in aneurysms, three out of four patients exhibited complete occlusion, and the remaining patient had nearly complete occlusion. Four out of five cases of Willis stent implantation were associated with immediate complete occlusion of aneurysms, and the modified rankin score of these patients ranged from 0 to 1. One patient died of unassociated complications.

**Conclusion:** For different types of TPIA in the internal carotid artery (ICA), PED and Willis stents provide significant advantages in treatment, with fewer postoperative complications and prognosis well.

## 1. Introduction

TPIAs are a rare high-risk subtype of cerebral aneurysms, accounting for about 1% of all intracranial aneurysms.<sup>1</sup> Although the incidence is low, it is a difficult problem in clinical diagnosis and treatment due to the high mortality and challenges associated with treatment. Pseudoaneurysm is characterized by a complete rupture of the arterial capsule wall, resulting in an extravascular hematoma containing only a thin layer of connective tissue.<sup>2,3</sup> The tissue morphology of these lesions is fragile, and can cause subarachnoid hemorrhage at any instance. The mortality rate of patients can reach 31–54%, therefore immediate and definitive treatments are often necessary.<sup>4</sup> TPIA is typically fragile, fusiform, lacks a real neck, and hence, it cannot be treated by surgical clamping.<sup>5</sup> In the past, open surgical treatment was mainly limited to the sacrifice of parent artery without bypass, which largely depended on the presence of enough collateral circulation. With the appearance of intravascular shunt stents, such as Tubridge; PED and Willis stents, which has become possible to protect the parent artery in pseudoaneurysm and promote endovascular remodeling.<sup>6</sup> TPIA can be caused by direct trauma and

iatrogenic injuries, usually caused by direct arterial wall injury or shear caused by acceleration. In this article, we describe a series of patients with TPIA of ICA who received surgical treatment by PED or Willis stents (Two typical cases see [Figs. 1 and 2](#)).

## 2. Materials and methods

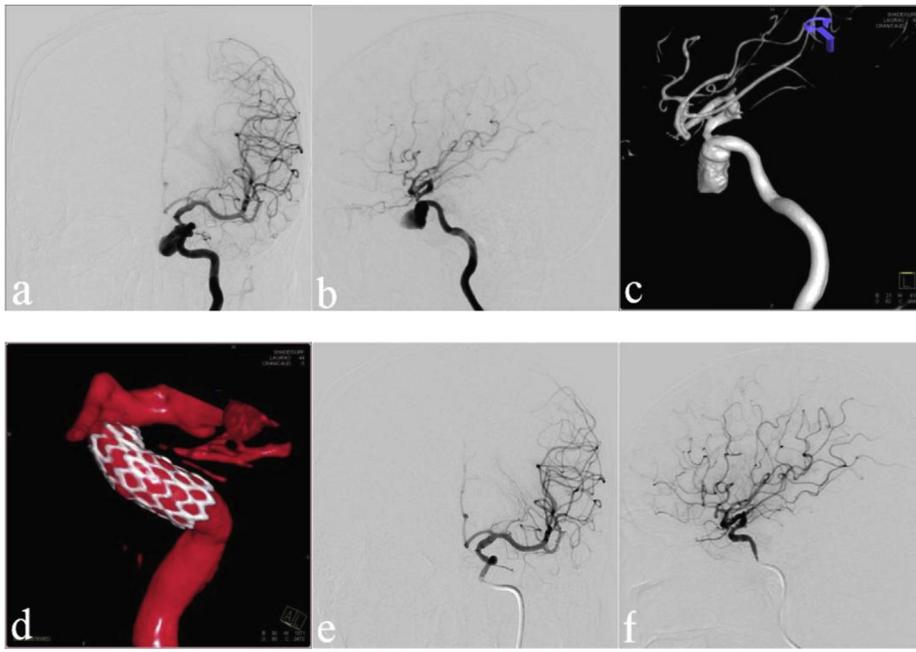
### 2.1. Patients

This study was approved by the Ethics Committee of Nanfang Hospital of Southern Medical University, and all patients provided written informed consent before undergoing endovascular surgery and related clinical data collection. Inclusion criteria included nine patients treated with Willis covered stents and PED, between December 2017 and June 2019, including iatrogenic pseudoaneurysm, which is usually considered traumatic. Exclusion criteria included pseudoaneurysm of unknown origin, or those not specifically associated with traumatic stimulation events. Among the nine patients, there were five males and four females, with an average age of  $41.6 \pm 9.1$  years (19–62 years). Among these, two

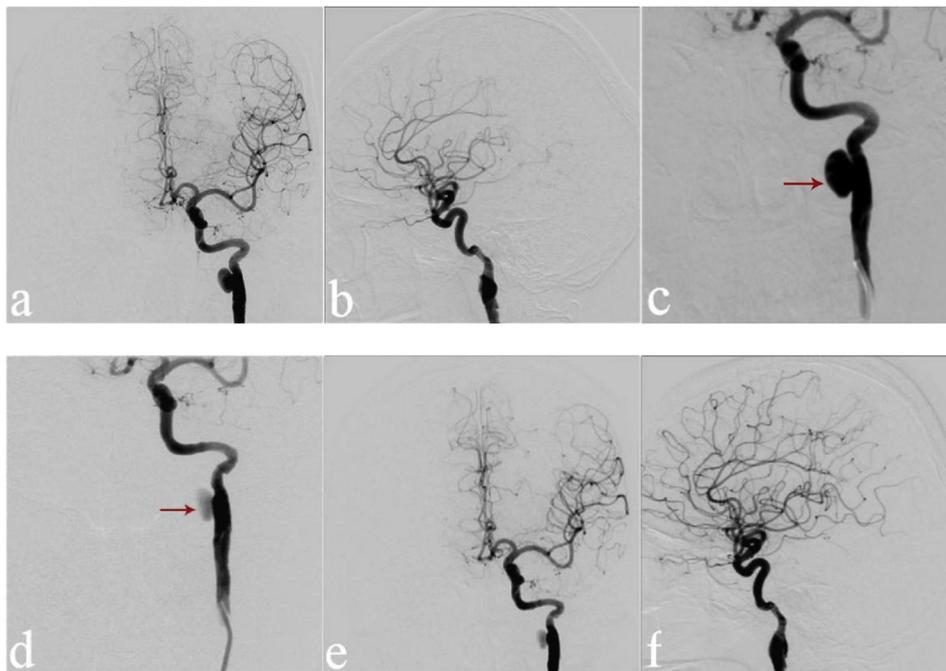
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**Fig. 1.** Traumatic pseudoaneurysm in cavernous segment of left internal carotid artery. a–b: Left internal carotid artery angiography positive and lateral positions indicating cavernous sinus with large pseudoaneurysm and rupture due to continuous ejection; c–d: The shape of pseudo aneurysm and three-dimensional reconstruction of Willis covered stent indicating good adhesion; e–f: The left internal carotid artery angiography showed disappearance of pseudoaneurysm and the parent artery reconstructed well.



**Fig. 2.** Treatment of traumatic pseudoaneurysm of left internal carotid artery with pipeline endovascular device. a–b: The left internal carotid artery angiography showing pseudo dissecting aneurysm of the cavernous sinus segment; c: Visible filling of blood flow before the treatment of pseudo-aneurysms; d: The filling of blood flow in this aneurysm decreased after treatment; e–f: postoperative follow-up of internal carotid artery DSA showing the aneurysm to be nearly completely occlusive.

cases were due to iatrogenic injury in ICA during transsphenoidal surgery, one was due to direct injury from mandibular sinus puncture, and the rest experienced blunt injuries, such as motorcycle collision, car accident, and fall from a considerable height. One patient was diagnosed with TPIA combined with bilateral internal carotid cavernous fistula, that could be cured using double Willis covered stents. After admission, all patients underwent digital subtraction angiography (DSA) to further confirm the diagnosis, along with the relationship between lesions and collateral vessels and the degree of ICA distortion. The diameter of the parent artery and the width of aneurysm neck were measured by three-dimensional DSA.

### 2.2. Procedure

We treated the newly diagnosed TPIAs within two weeks of the trauma. The appropriate stents were selected based on the results of angiography and three-dimensional reconstruction. The Willis covered stent must extend at least 2 mm above the neck of the bilateral aneurysm and is 0.5 mm larger in diameter compared to the target artery. A minimum extension of 5 mm is required for PED. Otherwise, stents need to be placed at the appropriate distal and proximal ends of the fistulas that merge with carotid cavernous fistulas. In this process, angiography needs to be carried out multiple times to determine the coverage of the stent to

the neck of the aneurysm. Aspirin (100 mg/d) and clopidogrel (75 mg/d) were administered orally before operation, and antiplatelet therapy was performed for three days. However, in patients with acute subarachnoid hemorrhage (SAH), special precautions were taken when using dual antiplatelet regimens, as aspirin and clopidogrel increase the risk of intracranial rebleeding in SAH patients. We have provided descriptions of two typical cases in the following sections.

### 2.3. Follow-up and assessment

Clinical evaluation and repeated cycles of angiography were performed to assess the presence of adequate shunt and flow in the mother vessel, distal branch, and associated perforations. Magnetic resonance imaging and CT scans were used to check whether the stent was displaced, and thrombotic elastograms were measured regularly in the outpatient clinic to evaluate the effects of antiplatelet therapy.

## 3. Results

TPIAs showed stagnation of blood flow or decrease in pseudoaneurysm filling immediately after PED implantation in four cases. At six months of follow-up, four cases of TPIAs showed complete occlusion on DSA. The remaining case showed nearly complete occlusion during 12 months of follow-up. In addition, four cases showed complete occlusion immediately after Willis stent implantation. One patient died of pressure balloon rupture due to acute rupture of iatrogenic pseudoaneurysm and severe cerebral vasospasm before operation. See Table 1 for details on TPIA and its physiological locations.

## 4. Discussion

The application of PED to treat TPIA reflects the latest technical progress in the field.<sup>7</sup> In the past, open surgical techniques were aimed at the sacrifice of parent arteries, including surgical clamping, wrapping, or parallel clamping with or without circulatory bypass. However, this technique is difficult to implement in patients with low tolerance for parent artery and collateral ischemia, or in invasive surgeries. In addition, due to the subtle conformational nature of most TPIAs, concerns about intraoperative ruptures are increasing. Standalone endovascular therapy initially uses a small invasive approach to directly operate on the coils and microcatheters in the cavity of fragile aneurysms, which is difficult to operate. Therefore, simple and practical PED and Willis covered stents have gradually become an alternative treatment for TPIA. PED is a flow shunt stent composed of 48 strands of grid (25% platinum

+ 75% nickel cobalt chromium alloy), which can provide 30–35% surface coverage in the target container. It changes the hemodynamics of the aneurysm, leads to stagnation of blood flow and thrombosis in the aneurysm, and keeps the parent artery unobstructed. PED acts as an endothelial reticular stent to promote endovascular reconstruction. The Willis covered stent consists of three parts, including bare stent, an expandable polytetrafluoroethylene (EPTFE) membrane, and a balloon catheter. The bare stent is made of a cobalt-chromium alloy steel wire with a diameter of 0.06 mm cut into sine wave by laser. The body of the stent is opaque and hence, easy to place with accuracy. The EPTFE film is very thin, about 30–50  $\mu\text{m}$  thick, in the shape of a tube and the conveying system is a fast exchange balloon catheter system. The mechanism of the Willis covered stent immediately excludes the aneurysm from the intracranial arterial circulation. The intracranial artery wall was reconstructed while keeping the parent artery unobstructed, and the mass effect was alleviated. Although Willis covered stents have a high rate of immediate aneurysm occlusion, intimal dilatation is still a common problem. The “endoleak” phenomenon refers to continuous perfusion between the stent and vascular wall, which usually develops immediately after stent implantation. It is the most common technical failure encountered in the process of intravascular repair. In our study, one out of five patients exhibited a transient “endoleak” phenomenon immediately after the first Willis stent implantation, which was eventually eliminated by balloon reinflation at the proximal and distal ends of the stent.<sup>8</sup> The potential causes of intimal dilatation after Willis stent implantation may include stent mismatch with parent artery diameter, uneven lumen, incomplete coverage of aneurysm orifice, transient vasospasm, stent migration, and rupture of the covered membrane. In our experience, if immediate DSA shows slow and weak filling speed of the aneurysm, and additional interventional therapy does not solve the problem of minor dilatation of the intima, the patient needs to be kept under further observation, since the residual channel will spontaneously eliminate the dilatation of the intima in case of slow filling.

In addition, the clinical application of Willis covered stent has some limitations. Because of the composition and structure of the Willis stent, rigidity is the main disadvantage of this stent.<sup>9</sup> The Willis covered stent is not flexible enough to be completely molded to the structure of the curved target artery, resulting in poor connection between the stent and the vessel wall, especially in the curved siphon section of the ICA. In addition, covered stents are used in endovascular treatment of traumatic intracranial atherosclerosis, but the significant stiffness of these stents are often incompatible with the distortion of intracranial vessels, and a completely covered membrane design would increase the risk of perforating artery occlusions. Therefore, PED implantation may be more

**Table 1**

Demographic information and the pseudo intracranial aneurysms treated with pipeline endovascular device or Willis sent.

Case	Age/ sex	Etiology	Location(ICA)	Clinical feature	Size (mm <sup>2</sup> )	Pseudo occlusion	PostMRS	Complications
1	54/F	Iatrogenic after recent transphenoidal surgery	Left cavernous sinus segment	SAH Comatose state	4.0×10	Complete occlusion	1	no
2	62/F	Open surgery	Left rear traffic section	SAH Comatose state	3.5×10	Complete occlusion	6	Balloon rupture
3	35/F	Puncture injury in maxillary sinus	Left cavernous sinus segment	Hemorrhagic shock	4.5×10	Complete occlusion	0	no
4	42/M	Car accident	Bilateral cavernous sinus segment	Bilateral epistaxis	4.0×10	Complete occlusion	1	no
5	19/M	Car accident	Lower end of left petrous bone	Headache, dizziness	6.0×35	Complete occlusion	0	no
6	22/M	Head trauma	Proximal to origin of ophthalmic artery	Dizziness blurred vision	5.5×35	Complete occlusion	1	no
7	31/M	Motorcycle collision	Right proximal cavernous sinus	Nosebleedlethargy	4.5×10	Complete occlusion	0	Incomplete adhesion
8	26/M	Motorcycle collision	Left middle cavernous sinus	Vague ness of consciousness	4.5×30	Complete occlusion	0	no
9	36/F	Skull base fracture	Right upper rock segment	congestionnosebleed	5.0×30	Complete occlusion	0	no

effective in the treatment of TPIA, due to large curvature of the parent artery and associated important branch arteries (such as ophthalmic, posterior communicating, and anterior choroidal arteries). Brzezicki et al. reported the application of PED in the treatment of high and skull base carotid artery anatomy.<sup>10</sup> Among the 11 patients, four cases were complicated with traumatic dissecting pseudoaneurysm, of which two cases showed partial residual filling, and the rest were cured. Menta published a case report of iatrogenic aneurysm of the petrous segment of the ICA after sinus surgery.<sup>11</sup> Complete occlusion of pseudoaneurysm was achieved within four months of PED implantation. Giorginni et al., described a male patient with two traumatic pseudoaneurysms in anterior communicating artery where complete occlusion could be achieved after PED released.<sup>12</sup> Kim et al., reported that a TPIA of the fundus internal carotid artery disappeared immediately after the implantation of PED, The visual acuity of the patient remained unaffected after 12 months of follow-up.<sup>13</sup> Hasan et al., successfully treated a case of traumatic anterior choroidal artery pseudoaneurysm caused by endoscopic transphenoidal surgery with PED.<sup>14</sup>

## 5. Conclusions

With the progress of existing technology, we predict that the treatment of TPIA will become increasingly simple and effectively. For TPIAs associated with hemorrhagic shock or acute traumatic rupture, we recommend early implantation of Willis covered stents, which can effectively reduce the risk of rebleeding. In the long term follow-up, it was found that the incidence of stent stenosis, thromboembolism complications, and perforator occlusion was lower after PED implanted, which was found suitable for TPIA with dissection and chronic stable phase. In addition, patient selection and experience in operating is crucial for optimizing the treatment.

## Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

## Declaration of competing interest

The authors declare that they have no competing interests.

## Abbreviations

DSA	Digital subtraction angiography
ICA	Internal carotid artery
MRS	Modified rankin score
TPIA	Traumatic pseudo intracranial aneurysms
PED	Pipeline endovascular device
SAH	Subarachnoid hemorrhage

## Ethics declarations

Ethics approval and consent to participate: The study was approved

by the Ethics Committee of Nanfang Hospital of Southern Medical University.

## Funding

None.

## Authors' contributions

DQ wrote the manuscript. WF managed patient care and edited the manuscript. All authors read and approved the final manuscript.

## Consent for publication

The patients provided written informed consent before undergoing endovascular surgery and related clinical data collection.

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