# Treatment of Large and Giant Intracranial Aneurysms: Cost Comparison of Flow Diversion and Traditional Embolization Strategies

*Nohra el-Chalouhi[1], Pascal M. Jabbour[1], Stavropoula I. Tjoumakaris[1], Robert M. Starke[1], Aaron S. Dumont[1], Haisong Liu[2], Robert Rosenwasser[1], Sedeek El Moursi[1], L. Fernando Gonzalez[1]*

**Key words**
- Aneurysm
- Coil
- Cost
- Pipeline embolization device

**Abbreviations and Acronyms**
**PED**: Pipeline embolization device
**MRA**: Magnetic resonance angiogram

*From the Departments of [1]Neurological Surgery and [2]Radiation Oncology, Thomas Jefferson University and Jefferson Hospital for Neuroscience, Philadelphia, Pennsylvania, USA*

*To whom correspondence should be addressed: L. Fernando Gonzalez, M.D. [E-mail: fernando.gonzalez@jefferson.edu]*

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**OBJECTIVE:** Flow diversion has emerged as a promising strategy for management of intracranial aneurysms. The purpose of this study was to determine whether treatment of large and giant aneurysms with the pipeline embolization device (PED) is more economical than traditional embolization strategies.

**METHODS:** We identified 30 consecutive aneurysms larger than 10 mm that were treated with PED at our institution. For each aneurysm treated with PED, theoretical coil embolization was performed by filling volume in a consistent, stepwise fashion until a packing density of 25% was reached. Prices of all equipment and implants were taken from price lists provided by each manufacturer.

**RESULTS:** Median aneurysm volume was 0.90 $cm^3$. Overall procedure cost was lower with the PED (mean, $23,911) vs. coiling ($30,522, $P = .06$). Above the median aneurysm volume, PED treatment was significantly less expensive than coiling even if multiple PEDs were used ($P = .006$). However, below the median aneurysm volume, PED treatment was significantly more expensive than coiling ($P = .009$). Treatment with multiple PEDs was not cost-beneficial compared with coiling, even above the median aneurysm volume. Potential savings associated with the PED were highly dependent on the type of embolic agent used.

**CONCLUSIONS:** The cost of initial treatment of large and giant aneurysms with PED is economically favorable compared to traditional embolization techniques. However, any potential cost benefit depends on aneurysm volume, coil type, and number of PEDs used. Accordingly, PED therapy is more expensive than coiling in aneurysms <0.9 $cm^3$ or when multiple devices are used.

## INTRODUCTION

Endovascular treatment of intracranial aneurysms with traditional embolic agents can be expensive. Compared with surgical clipping, endovascular treatment is associated with better clinical outcomes but higher hospital costs in both patients with ruptured and patients with unruptured aneurysms (4, 8). In addition, the total cost of endovascular treatment increases exponentially with aneurysm size. Consequently, endovascular treatment of large and giant aneurysms with traditional embolic agents can be cost prohibitive.

Flow diversion has recently emerged as a promising strategy for management of large and giant aneurysms. At an increasing number of institutions, the pipeline embolization device (PED), a dedicated flow diverter, has become a first-line treatment for aneurysms in various intracranial locations. Several recently published studies have demonstrated the relative safety and efficacy of this approach (1, 6, 9, 10, 14). Although the cost of each implant is much higher for PED compared with more traditional devices (coils and self-expanding stents), the number of implants used per procedure is smaller, resulting in significant cost savings, especially for large and giant aneurysms. A single study by Colby et al. (2) has compared the cost of aneurysm embolization with the PED vs. stent-assisted coiling and found a 25.7% procedural cost reduction with the PED. The authors, however, failed to control for decisive factors such as aneurysm volume, type of embolic agent, and number of PEDs used, all of which may significantly influence the total cost of the procedure. Their study also did not include a comparison to liquid embolic agents such as Onyx HD 500 (eV3, Irvine, California, USA).

The purpose of the current study was to determine whether treatment of large and giant aneurysms with the PED is more economical than traditional embolization strategies (coils or Onyx HD 500) using a matched-pair analysis. Cost comparison was also further stratified based on aneurysm volume, type of embolic agent, and number of PEDs used.

## MATERIALS AND METHODS

### Patient Selection

The study protocol was approved by the University Institutional Review Board. We identified 30 consecutive patients with aneurysms larger than 10 mm that were successfully treated with PED at our institution between 2011 and 2012. Previously treated aneurysms were excluded from the study.

### Aneurysm Volume Calculation

Thin-slice magnetic resonance angiogram (MRA) images of patients were imported into iPLAN RT Image 4.1 (BrainLAB AG, Feldkirchen, Germany). The aneurysm was identified by the senior author and contoured on the images slice by slice (Figure 1). The volume of the aneurysm was then calculated in iPLAN by accumulating the total voxels encompassed by the contours on all slices. The advantage of this method of measuring 3-dimensional volume is that it takes advantage of the 3-dimensional information from the axial thin-slice MRA scan; therefore, it is more accurate than the volumes rendered from 2-dimensional x-ray images. However, the disadvantage is that for some patients, it may be subject to interobserver uncertainties due to poor aneurysm visualization on MRA images. In that case, a reference angiography image is used to help identify the boundaries of the aneurysm.

### Theoretical Treatment with Coils

For each aneurysm treated with PED, theoretical coil embolization was performed by filling volume in a consistent stepwise fashion until a packing density of 25% was reached. Theoretical coiling of 5 aneurysms was performed by representatives from each coil manufacturer under the supervision of the senior author, and the remaining 25 aneurysms were coiled using the same methodology. Briefly, the longest possible coil was initially selected (taking into account aneurysm diameter), followed by coils of the next smallest diameter available, and so on until the target packing density was achieved. This process was done for each of the coil brands, namely Cordis (Codman Neurovascular, Raynham, Massachusetts), eV3 (eV3, Irvine, California), Microvention (Microvention, Aliso Viejo, California), Penumbra (Penumbra, Alameda, California), and GDC (Boston Scientific, Natick, Massachusetts). Although we did not mix different coil brands, coils of different sizes and configurations were selected within each group. A packing density of 25% was chosen because this is the volume above which aneurysm recurrences are thought to be less common (12). The Angiocalc software (available at http://www.angiocalc.com) was used to determine the length and number of coils needed to fill up to 25% of aneurysm volume.

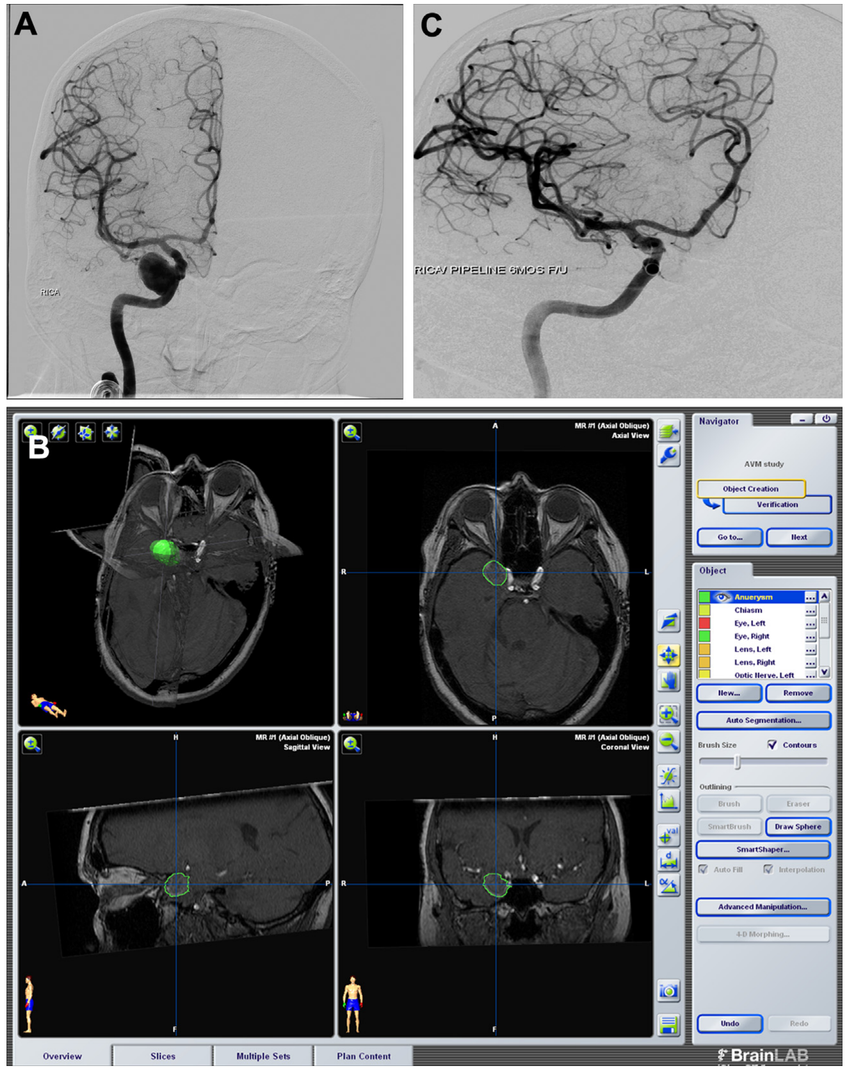


**Figure 1.** (**A**) Frontal view of digital subtraction angiography showing a giant cavernous aneurysm measuring 24 × 19 mm. (**B**) Aneurysm volume (2.857 cm$^3$) was calculated by importing magnetic resonance angiogram images into iPLAN RT Image 4.1. Four pipeline embolization devices were needed to induce contrast stasis inside the aneurysm and eliminate the inflow jet. (**C**) Follow-up angiogram at 6 months showing complete aneurysm occlusion.

### Equipment and Implant Cost

Prices of PEDs, coils, stents, balloons, and equipment (proximal access catheters, guide catheters, microcatheters, and microwires) were taken from price lists provided by each manufacturer. The cost of PED treatment varied widely depending on the number of PEDs that were used during the actual embolization procedure. The cost of adjunctive coils was also added, if any had been used during the actual procedure. For theoretical coiling, the cost of a stent ($5000) was added to the cost of coils and equipment only for wide-necked aneurysms (dome-to-neck ratio <2 or neck >4 mm).