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## Pipeline embolization device versus coiling for the treatment of large and giant unruptured intracranial aneurysms: a cost-effectiveness analysis

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### Abstract

**OBJECTIVE**—Rupture of large or giant intracranial aneurysms leads to significant morbidity, mortality, and health care costs. Both coiling and the Pipeline embolization device (PED) have been shown to be safe and clinically effective for the treatment of unruptured large and giant intracranial aneurysms; however, the relative cost-to-outcome ratio is unknown. The authors present the first cost-effectiveness analysis to compare the economic impact of the PED compared with coiling or no treatment for the endovascular management of large or giant intracranial aneurysms.

**METHODS**—A Markov model was constructed to simulate a 60-year-old woman with a large or giant intracranial aneurysm considering a PED, endovascular coiling, or no treatment in terms of neurological outcome, angiographic outcome, retreatment rates, procedural and rehabilitation costs, and rupture rates. Transition probabilities were derived from prior literature reporting outcomes and costs of PED, coiling, and no treatment for the management of aneurysms. Cost-effectiveness was defined, with the incremental cost-effectiveness ratios (ICERs) defined as difference in costs divided by the difference in quality-adjusted life years (QALYs). The ICERs < \$50,000/QALY gained were considered cost-effective. To study parameter uncertainty, 1-way, 2-way, and probabilistic sensitivity analyses were performed.

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Author Contributions

Conception and design: all authors. Acquisition of data: Wali, Park, Santiago-Dieppa, Murphy. Analysis and interpretation of data: all authors. Drafting the article: Khalessi, Wali, Park, Vaida, Murphy. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Khalessi. Statistical analysis: Wali, Park, Murphy. Administrative/technical/ material support: all authors. Study supervision: all authors.

Disclosures

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**RESULTS**—The base-case model demonstrated lifetime QALYs of 12.72 for patients in the PED cohort, 12.89 for the endovascular coiling cohort, and 9.7 for patients in the no-treatment cohort. Lifetime rehabilitation and treatment costs were \$59,837.52 for PED; \$79,025.42 for endovascular coiling; and \$193,531.29 in the no-treatment cohort. Patients who did not undergo elective treatment were subject to increased rates of aneurysm rupture and high treatment and rehabilitation costs. One-way sensitivity analysis demonstrated that the model was most sensitive to assumptions about the costs and mortality risks for PED and coiling. Probabilistic sampling demonstrated that PED was the cost-effective strategy in 58.4% of iterations, coiling was the cost-effective strategy in 41.4% of iterations, and the no-treatment option was the cost-effective strategy in only 0.2% of iterations.

**CONCLUSIONS**—The authors' cost-effective model demonstrated that elective endovascular techniques such as PED and endovascular coiling are cost-effective strategies for improving health outcomes and lifetime quality of life measures in patients with large or giant unruptured intracranial aneurysm.

### Keywords

cost-effectiveness; intracranial aneurysm; endovascular neurosurgery; Pipeline embolization device; coil embolization

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TREATMENT of large or giant intracranial aneurysms remains difficult despite advances in endovascular management.<sup>2,6</sup> Patients with a large intracranial aneurysm are subject to increased risk of spontaneous rupture with poor neurological outcome after subarachnoid hemorrhage.<sup>14,23</sup> With advances in endovascular technology, novel techniques to manage large or giant intracranial aneurysm have emerged. The role of the Pipeline embolization device (PED; Covidien) in the management of large or giant intracranial aneurysms has become increasingly established as retrospective and prospective studies demonstrate its clinical safety and efficacy.<sup>2,3</sup> A prior study comparing the efficacy of PED versus endovascular coiling, the standard endovascular technique to treat aneurysms, has demonstrated comparable neurological outcomes in patients.<sup>6</sup> Importantly, PED use in giant intracranial aneurysms may be associated with lower overall procedural cost and higher rates of complete angiographic occlusion.<sup>9</sup>

Although the comparative efficacy and procedural costs of these emerging endovascular techniques have been described, a cost-effectiveness analysis to demonstrate the lifetime health utility and economic impact of endovascular techniques compared with no treatment has not yet been conducted. We present the first cost-effectiveness model to directly compare PED, endovascular coiling, and no treatment to determine the cost-effectiveness of each strategy to manage large or giant intracranial aneurysms. Incremental cost-effectiveness ratios (ICERs) were used to assess the strategies. This model highlights the economic and quality of life (QOL) outcome of these novel endovascular treatment techniques.

## Methods

### Treatment Strategies

Our decision model captures the choice for a patient with an identified, nonsurgically resectable, large or giant intracranial aneurysm who is deciding between PED, coiling, and no treatment. We chose a nonsurgically resectable aneurysm to best evaluate the cost-effectiveness of endovascular aneurysm treatments. The treatment choices for a large, unruptured intracranial aneurysm were as follows: Strategy 1 was PED treatment; Strategy 2, endovascular coiling; and Strategy 3, no endovascular treatment.

### Decision Model

A decision-analysis Markov model was constructed to assess the cost-effectiveness of PED, endovascular coiling, and no treatment in patients with a confirmed large or giant intracranial aneurysm that was not amenable to resection. The decision-analytical model incorporated patient QOL, survival, and costs associated with each treatment. The base-case model simulates outcomes for a 60-year-old woman with a large or giant intracranial aneurysm (> 10 mm).<sup>2</sup> The Markov model was constructed with an annual cycle length, and it was run over a 50-year time horizon to capture the long-term implications of these 3 treatment strategies. Our model assumed a risk of death from the treatments, and a risk of aneurysm rupture (described further below), and it also assumed an underlying age-specific risk of death from other causes that was derived from the Centers for Disease Control and Prevention mortality data.<sup>1</sup> A simplified decision analysis model is illustrated in Fig. 1.

### Model Inputs

**Neurological Outcomes**—The modified Rankin scale (mRS) represents the primary tool to measure neurological outcomes associated with the different treatment strategies. We converted the reported mRS values into health utility scores by using techniques described elsewhere.<sup>3</sup> Distributions of mRS outcomes for each endovascular treatment option including emergency coiling for a ruptured aneurysm were obtained from the current literature. The individual mRS outcomes for patients were grouped into good outcome (mRS Score 0–2), poor outcome (mRS Score 3–5), and death (mRS Score 6) based on reported conventions for outcome after aneurysm treatment by Chalouhi et al.<sup>6</sup> Postoperative complications such as procedural stroke, aneurysm rupture, or hemorrhage that caused permanent deficits were incorporated into our model if they caused long-term neurological deficits resulting in either poor mRS outcome or death. To model the proportions of patients who had a unique mRS score within the good and poor outcome groups, a negative binomial distribution was constructed to model the proportion of patients within each mRS state ranging from 0 to 6, and estimated the parameters separately for each study by using the maximum likelihood method.<sup>1,4</sup> The final health utility scores incorporated within the model correspond to the predicted probabilities of this negative binomial distribution (Table 1).

### Model Probabilities

**The mRS Outcomes by Type of Treatment**—At the initiation of the model prior to any intervention, all patients were assumed to have good baseline neurological status (mRS

Score 0–2). We incorporated the risk of aneurysmal rupture for untreated patients from large prospective randomized studies, which report an annual rupture rate of 7% for aneurysms > 10 mm and an annual rupture rate of 43% for aneurysms > 25 mm.<sup>14</sup> To capture the patient population assessed by Chalouhi et al. in which patients underwent either PED or endovascular coiling, and in which 20% of patients had aneurysms > 20 mm and 80% had aneurysms between 10 and 20 mm,<sup>9</sup> our model assumed a rupture rate of 13% for both groups within our base-case analysis.

Prior published data from Chalouhi et al. comparing PED with endovascular coiling to treat large, unruptured intracranial aneurysms reported a 92% probability of achieving a good mRS score, a 5.4% probability of achieving a poor mRS score, and a 2.6% probability of death at 8-month follow-up.<sup>6</sup> These findings were comparable to a larger prospective study by Becske et al. that assessed outcome rates at 3-year follow-up of PED management for large intracranial aneurysms in which 92% had good outcome, 3.5% had a poor outcome, and 4.5% died.<sup>3</sup> Given the comparable rates between these 2 studies, our model used the mRS outcomes from Chalouhi et al. as a similar study population to compare with the endovascular coiling group. For endovascular management, which included conventional coiling, stent-assisted coiling, and balloon-assisted coiling, Chalouhi et al. reported 94% of patients with a good outcome (mRS Score 0–2), 6% with a poor outcome (mRS Score 3–5), and 0 deaths at 15-month follow-up.<sup>9</sup> Other studies reported a 1.25% mortality rate associated with coiling for unruptured aneurysms.<sup>29</sup> To account for some probability of death within the model, we assumed that the final distribution of mRS scores after treatment with endovascular coiling was 94% with a good outcome, 4.75% with a poor outcome, and 1.25% with death.

Neurological outcome after spontaneous rupture of aneurysms that underwent subsequent emergency treatment was derived from the landmark International Subarachnoid Aneurysm Trial (ISAT), in which 76.5% of patients had mRS scores of 0–2, 15.5% had mRS scores of 3–5, and 8% died.<sup>21</sup> Although the ISAT did not emphasize the emergency treatment of large or giant aneurysms specifically, these outcome values are similar to the existing reports in the literature that describe mRS outcome at 1-year follow-up after rupture of a large or giant intracranial aneurysm with endovascular treatment, and thus are used within our model.<sup>11,12,16,17,19</sup> The probabilities of good outcome, poor outcome, and death after rupture of a previously treated aneurysm were also based on outcomes from the ISAT.<sup>20,21</sup> Our model assumed that patients with major disability (mRS Score 3–5) after initial treatment who had a subsequent aneurysm rupture either still had a poor outcome (mRS Score 3–5) or died—these patients had a 66% chance of remaining at mRS Score 3–5 and a 34% chance of death following rupture.<sup>20,27</sup>

**Angiographic Outcomes by Type of Treatment**—Chalouhi et al. reported that within the 1st year of treatment with either PED or endovascular coiling, 2.8% of those undergoing PED required additional treatment with coiling, whereas 37% of patients initially treated with coiling required subsequent recoiling.<sup>6</sup> Chalouhi et al. reported that 86% of patients treated with PED had complete angiographic occlusion at 7 months. Given that occlusion rates after PED treatment increased over time<sup>28</sup> and that the angiographic outcome reported by Chalouhi et al. was similar to complete occlusion rates at a follow-up of > 1 year, these

values were included within our model.<sup>3</sup> Chalouhi et al. report that, following endovascular coiling, 41% of patients attained complete occlusion at 12-month follow-up. Patients who had incomplete angiographic occlusion of their aneurysm were subject to an annual rupture risk of 4.3%.<sup>15</sup> Our model assumed that patients who had aneurysmal rupture and emergency endovascular coiling were subject to the same retreatment and angiographic occlusion rates as with elective coiling. Our model also assumed complete angiographic occlusion after emergency retreatment of a previously treated aneurysm. All probabilities, angiographic outcomes, rupture rates, and retreatment rates are detailed in Table 2.

**Treatment Costs**—The costs of endovascular coiling (which averaged the costs of stent-assisted coiling, balloon-assisted coiling, and conventional coiling) and the costs for PED were derived from published literature describing the treatment of large or giant intracranial aneurysms.<sup>9</sup> The costs of PED and coiling were consistent with previously reported findings in the literature demonstrating that the overall procedural costs of PED were lower relative to elective coiling.<sup>7</sup> Costs of emergency coiling and associated hospitalization fees were derived from a prior cost-effectiveness study assessing the role of endovascular coiling in treating ruptured aneurysms.<sup>18</sup> The cost of endovascular retreatment after initial intervention was equivalent to the entire procedure cost associated with endovascular coiling. All interventional costs also consisted of additional procedural costs of intraoperative and postoperative angiograms.<sup>18</sup> Indirect costs to account for the management of functional disability were derived from a prior cost-effectiveness study on rehabilitation and special nursing facility costs associated with each mRS score.<sup>22</sup> All retrospectively obtained costs from the literature were converted to 2016 US dollars to account for inflation (<https://data.bls.gov/cgi-bin/cpicalc.pl>). All costs in the model are detailed in Table 3.

### Cost-Effectiveness Analysis

TreeAge Pro 2016 (TreeAge Software) was used to construct the decision analysis model. Our model discounted utilities and costs by 3% annually.<sup>13</sup> Cost-effectiveness between the different treatments was assessed using the ICER, which represents the difference in costs divided by the difference in quality-adjusted life years (QALYs) between the treatment arms. Results were considered cost-effective if the ICER was less than a willingness-to-pay cutoff of \$50,000/QALY—a convention used in cost-effectiveness analyses.<sup>5</sup> A strategy was considered dominant within this analysis if both the costs were more and the health utility outcomes were less than a competing strategy. The cost-effectiveness results are presented from a societal viewpoint.

The base-case analysis represents the cost-effectiveness analysis using our best estimation of all parameters in the model. In addition to the base-case analysis we conducted 1-way, 2-way, and probabilistic sensitivity analyses. The 1-way sensitivity analyses were performed on all variables in the model, although we present only variables that the model was most sensitive to, including changes in patient age, probability of spontaneous rupture, cost of PED, and cost of coiling. Probabilistic sensitivity analysis consisted of a Monte Carlo simulation that included 100,000 iterations, which sampled from model parameters fit to individual probability distributions.<sup>8</sup> In the probabilistic sensitivity analysis, age was modeled as a binomial distribution, costs were modeled by gamma distributions (constrained

between 0 and infinity), and probabilities and health utilities were modeled as beta distributions (constrained between 0 and 1). When possible, the standard deviation of each modeled variable was obtained from the literature, although when unavailable the standard deviation was assumed to be 20% of the mean value.

## Results

### Base-Case Analysis

Our base-case cost-effectiveness model demonstrated that elective PED and endovascular coiling were more effective than no treatment, yielding 12.72 QALYs in the PED group and 12.89 QALYs in the endovascular coiling group. Lifetime treatment and rehabilitation costs in the base-case scenario were \$59,800 for PED and \$79,000 for endovascular coiling. Patients who did not undergo elective treatment had an effectiveness of 9.7 QALYs, and costs of \$193,500. Our cost-effectiveness analysis showed that although endovascular coiling provided more QALYs over a lifetime, the increased costs incurred to achieve those QALYs yielded an ICER of \$123,600 per QALY gained (Fig. 2), indicating that PED was the more cost-effective option at a willingness-to-pay threshold of \$50,000 per QALY gained.

### One-Way Sensitivity Analysis

One-way sensitivity analysis demonstrated that the cost-effectiveness comparing PED and coiling was most sensitive to changes in cost of PED, cost of coiling, and probability of spontaneous death after PED (Table 4). As the initial cost of PED exceeded \$40,100, coiling became the more cost-effective option at a willingness-to-pay threshold of \$50,000/QALY. When the initial procedural cost of coiling decreased to \$21,200, coiling would be considered the more cost-effective option. As the probability of initial death after PED increased beyond 4%, coiling became the more cost-effective option. Across the ranges tested for treatment costs, none of the sensitivity analyses demonstrated the no-treatment arm to be a cost-effective strategy.

The PED remained the cost-effective strategy despite changes in the following variables at the range of values described: patient age from 18 to 80 years, spontaneous rupture rate of 7% (corresponding to aneurysms > 10 mm) to 43% (aneurysms > 25 mm), rate of achieving a good outcome with PED from 80% to 100%, rate of good outcome with coiling from 94% to 100%, rate of good angiographic outcome for coiling from 41% to 100%, retreatment rate for coiling from 5% to 37%, and rate of death with endovascular coiling from 0% to 1.25%.

### Two-Way Sensitivity Analysis

A 2-way sensitivity analysis was constructed to illustrate how the cost-effective strategy between PED and coiling transitioned across initial treatment costs ranging from \$5,000 to \$50,000 for either PED or coiling (Fig. 3). At a PED cost of < \$11,200, PED remained the cost-effective strategy compared with the cost of coiling ranging up to \$50,000. At a cost of endovascular coiling > \$44,900, PED was the cost-effective strategy ranging up to \$50,000.

## Probabilistic Sensitivity Analysis

Figure 4 demonstrates the results of the Monte Carlo probabilistic sensitivity analysis. This analysis found that the no-treatment option was unlikely to be cost-effective across a range of willingness-to-pay thresholds compared with the 2 treatment options. When comparing PED and coiling, the probabilistic sensitivity analysis demonstrated a moderate degree of uncertainty with regard to which treatment arm was more cost-effective. At a willingness-to-pay threshold of \$50,000/QALY, the PED was the cost-effective strategy in 58.4% of iterations, coiling was the cost-effective strategy in 41.4% of iterations, and the no-treatment option was the cost-effective strategy in 0.2% of iterations.

## Discussion

As novel endovascular techniques emerge and become increasingly prevalent in the elective management of unruptured large or giant intracranial aneurysm, it is imperative for health care decision makers and patients to be informed on the cost-effectiveness of these treatment techniques. Patients who have large or giant intracranial aneurysms are at a very high risk of rupture, ranging from 7% to 43% annually, which results in expensive emergency treatment, a high mortality rate, and a high potential for severe neurological disability.<sup>14</sup>

Whereas prior cost-effectiveness models have assessed neurosurgical clipping compared with endovascular coiling for emergency treatment of ruptured aneurysms,<sup>18</sup> the present work is the first cost-effectiveness study to examine the elective endovascular management of large or giant intracranial aneurysms. Our model demonstrates that both elective PED and endovascular coiling are efficacious in dramatically improving lifetime QALYs, resulting in lifetime QALYs of 12.72 and 12.89, respectively, compared with QALYs of 9.7 in the no-treatment (observation) cohort. Although not undergoing treatment may be cost saving initially due to avoiding procedural costs, the high annual rupture rate associated with large or giant aneurysms and the subsequent ramifications, including higher costs of emergency intervention, lifetime rehabilitation, and severe neurological disability as well as elevated risk of death argue decisively in favor of aneurysm treatment provided using endovascular techniques.

Our model was sensitive to changes in the cost of PED and coiling, respectively. Chalouhi et al. reported a large variance in the cost of PED ( $\$24,995.46 \pm \$12,531.70$ ) and endovascular coiling ( $\$31,906.29 \pm \$24,861.65$ ).<sup>9</sup> The costs of PED and endovascular coiling vary depending on the characteristics of the aneurysm, such as its size.<sup>7</sup> Our model demonstrated that the more cost-effective endovascular treatment strategy between PED and coiling depended on the price of each procedure across a comparable range of costs. Using the mean procedural costs in the literature, our model indicated that PED may be slightly more cost-effective than coiling over a lifetime, possibly due to the decreased incidence of retreatment and higher rates of angiographic occlusion.

Notably, endovascular coiling generated 0.15 more QALYs over a lifetime compared with the PED, which would largely be ascribed to the higher initial mortality of 2.6% with the PED compared with a procedural mortality of 1.25% with endovascular coiling. Complications associated with the PED, including parent vessel thrombosis, still only



represent a small fraction of patients, and the incidence of morbidity and mortality associated with the PED may decrease as technical skill and management of these patients continue to improve.<sup>3,10</sup> Moreover, the probabilistic sensitivity analysis demonstrated that the PED was the dominant strategy in 58% of 100,000 iterations of our model compared with endovascular coiling dominating in 41% of iterations. These rates are similar due to the comparable neurological outcomes associated with both treatment techniques. The probabilistic sensitivity analysis demonstrates slight favorability of PED over coiling given the trend toward lower procedural costs, decreased need for retreatment, and improved angiographic outcomes. The no-treatment strategy was cost-effective in only 0.2% of iterations, demonstrating the urgent and important need to electively treat an identified large or giant aneurysm to improve both QOL and decrease health care costs across a lifetime.

This model has several limitations—the primary outcomes of this study are based on the assumptions of prior studies. Given that large or giant intracranial aneurysms may not always be amenable to surgical clipping, vessel sacrifice, and bypass, surgical options were not included in this model and were beyond the scope of this analysis. Most of the model inputs were data obtained from retrospective single-center studies, due to the lack of randomized prospective data comparing the different endovascular techniques. The procedural costs in this model were derived from a single-center study and may not reflect costs in different clinical settings. However, our model addressed this limitation using 1- and 2-way sensitivity analyses to adjust procedural costs from \$5000 to \$50,000, and aggregated the costs of endovascular coiling with balloon-assisted coiling and stent-assisted coiling. Probabilities of technical success may also differ across surgeons and centers; we also addressed this using a 1-way sensitivity analysis. Our model does not include additional costs associated with endovascular complications, such as femoral hematoma, vessel vasospasm related to catheter procedures, or thromboembolic stroke.<sup>25</sup> However, to address this limitation, our model captured complications as affecting QOL if they caused long-term disability or death. Although our model derived all neurological outcome probabilities and costs from the single existing comparative study assessing PED and endovascular coiling for large or giant aneurysm, these variables were consistent with those in larger, prospective studies comparing the efficacy of these techniques individually. Future cost-effectiveness studies comparing endovascular techniques may benefit from additional data on procedural costs, neurological and angiographic outcomes, and complication and retreatment rates from larger, prospective multicenter settings.

Despite these limitations, our model is the first cost-effectiveness analysis that directly compares the elective endovascular management of large or giant intracranial aneurysms and provides an important perspective on the impact of aneurysm treatment on cost and health utilities. These findings should be considered in the setting of competing procedural options for a patient with a large or unruptured intracranial aneurysm to guide an informed decision that optimizes QOL and minimizes costs of intervention and rehabilitation.

## Conclusions

Large or giant intracranial aneurysms pose a high risk of rupture—leading to expensive emergency treatments, reduction in QOL due to neurological disability, and a higher risk of

death. Our cost-effectiveness model demonstrates that elective endovascular techniques such as PED and endovascular coiling are cost-effective strategies for improving health outcomes and lifetime QOL measures in patients with large or giant unruptured intracranial aneurysm.

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## ABBREVIATIONS

<b>ICER</b>	incremental cost-effectiveness ratio
<b>ISAT</b>	International Subarachnoid Aneurysm Trial
<b>mRS</b>	modified Rankin scale
<b>PED</b>	Pipeline embolization device
<b>QALY</b>	quality-adjusted life year
<b>QOL</b>	quality of life

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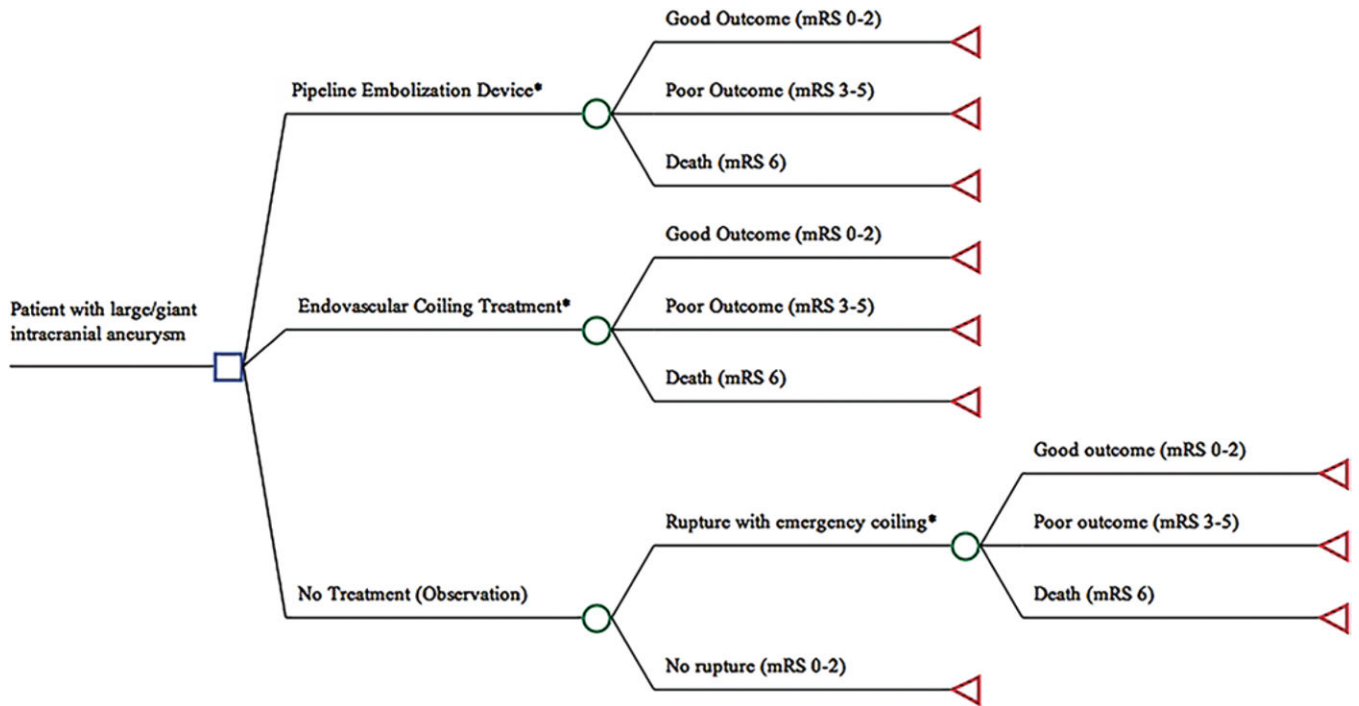
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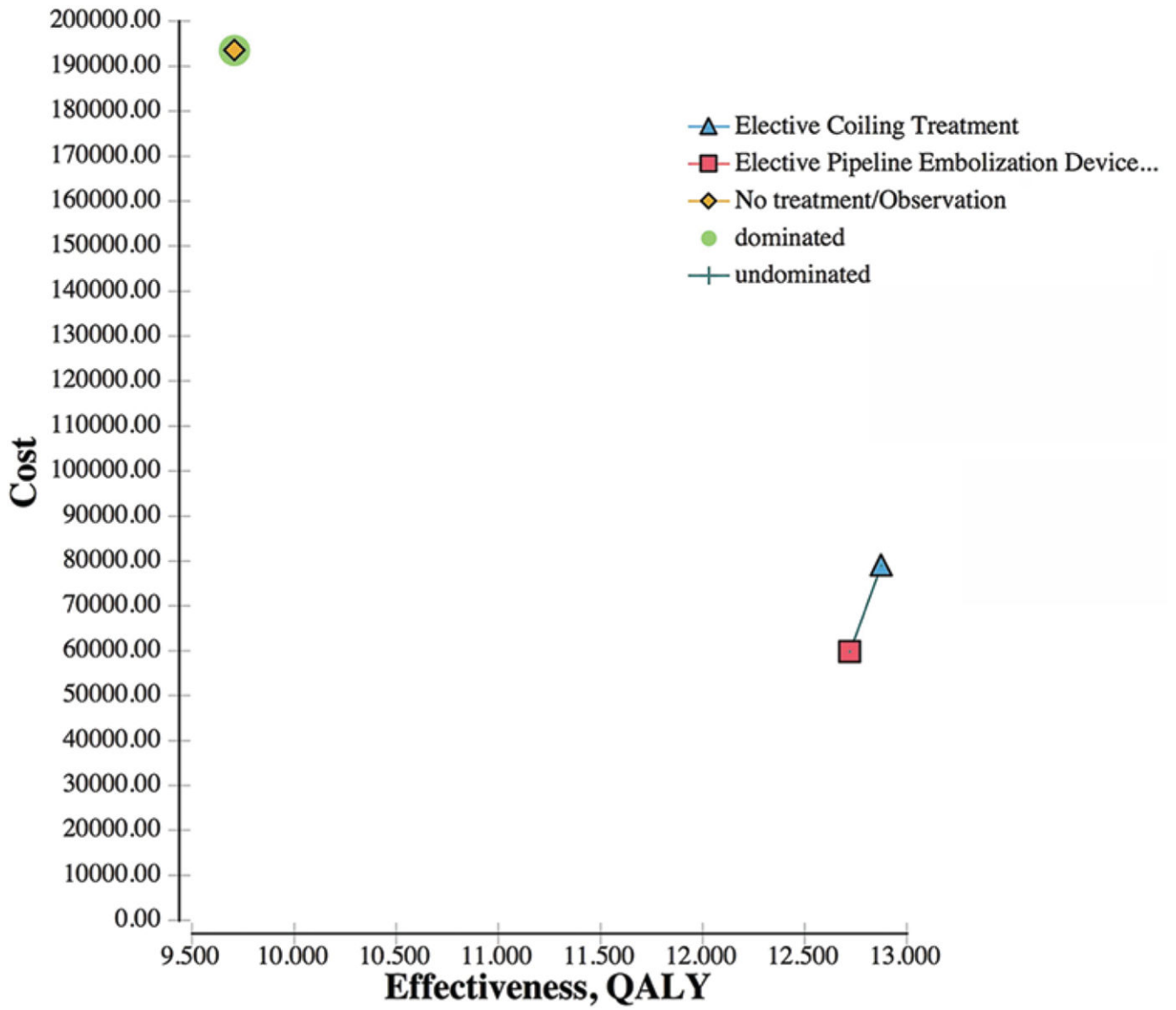
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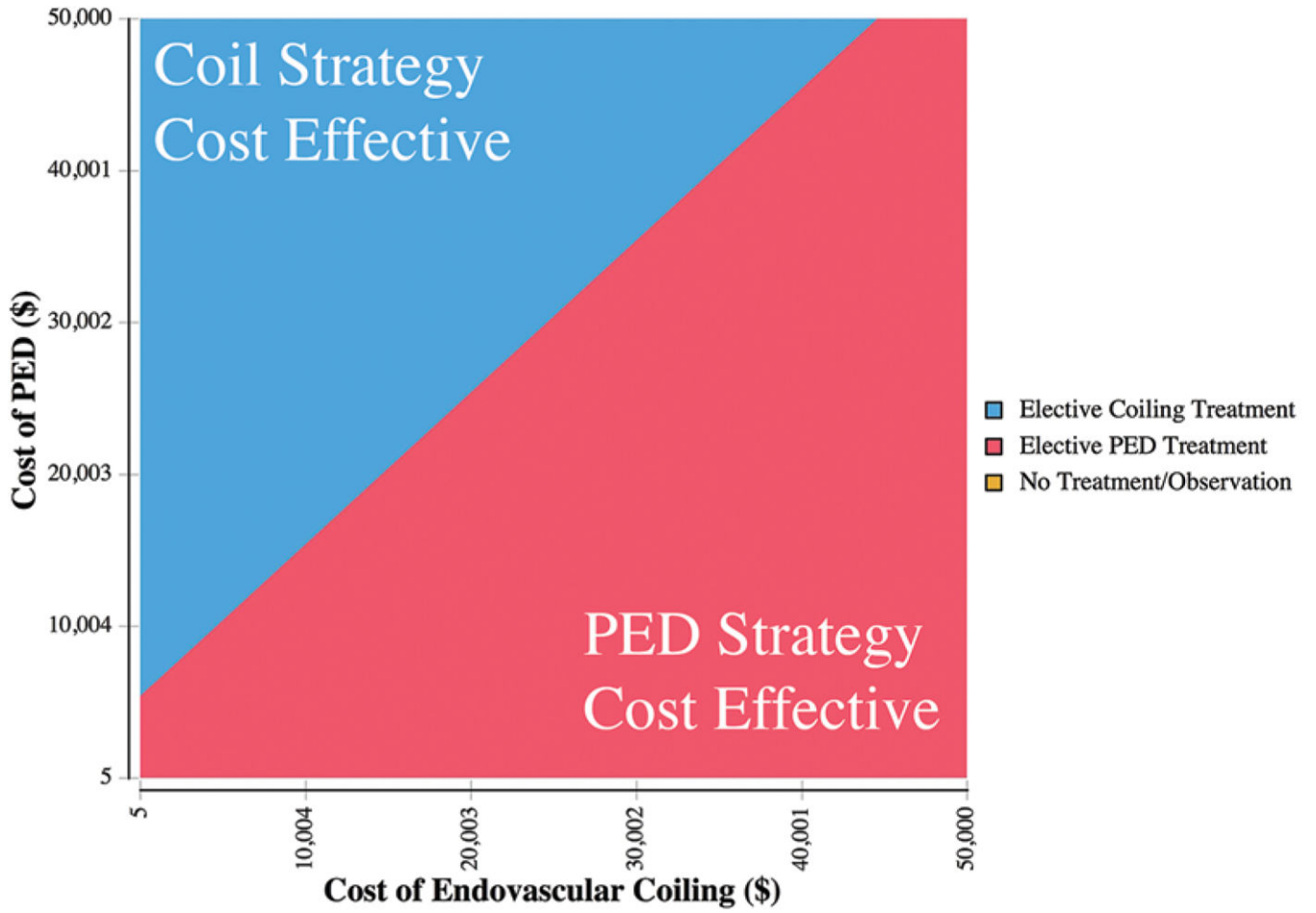
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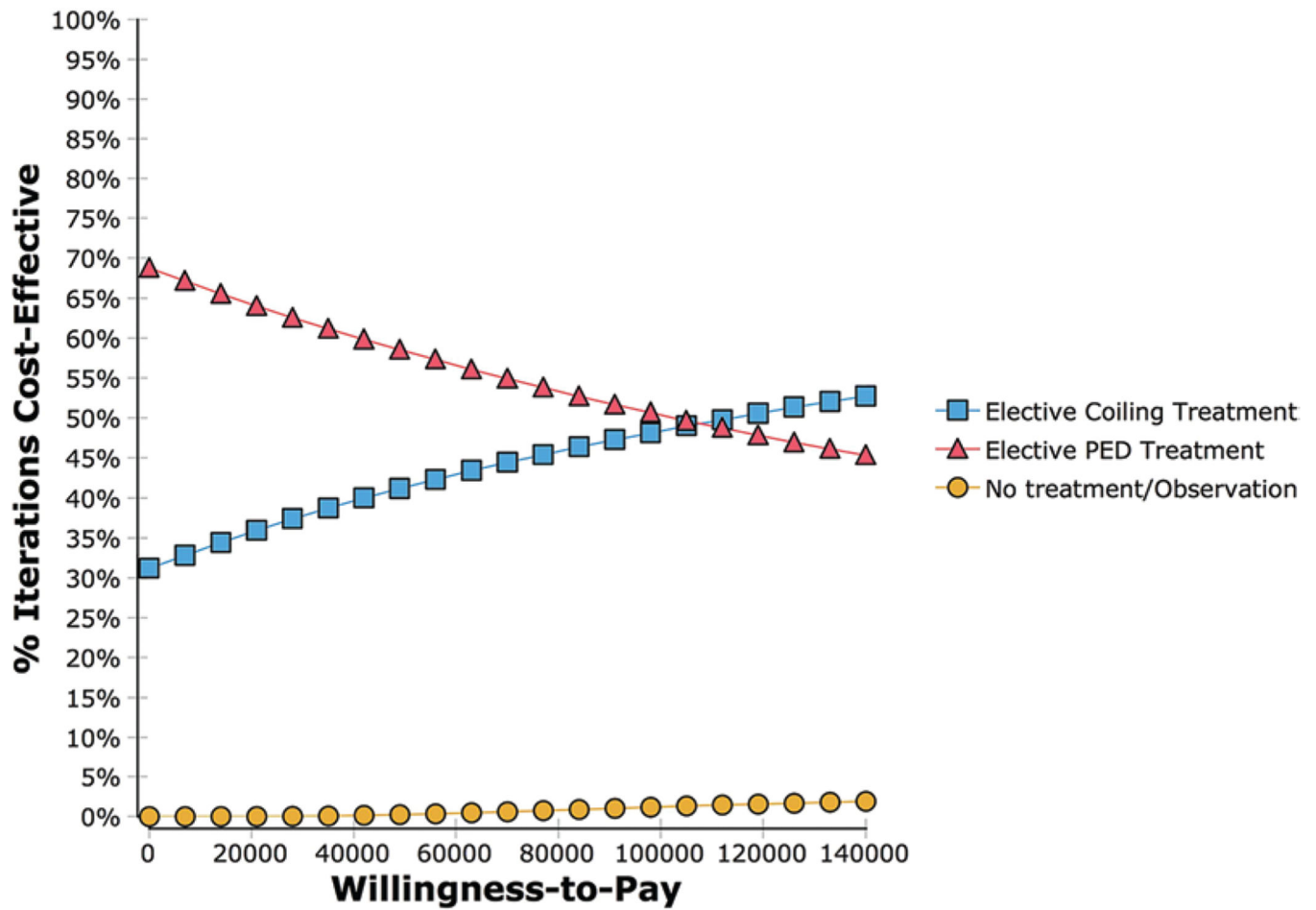
**FIG. 1.** Decision analysis model with competing strategies for endovascular management of a patient with a large or giant intracranial aneurysm. The *square* decision node indicates the 3 options: to undergo Pipeline embolization of the aneurysm, to undergo endovascular coiling of the aneurysm, or to undergo no treatment and be subject to risk of spontaneous rupture. The *asterisks* denote that, after undergoing either elective or emergency intervention, patients may require subsequent retreatment, which would contribute to additional procedural costs. Patients also may have either complete or incomplete angiographic occlusion. Patients with incomplete angiographic occlusion despite initial treatment are at risk for rupture.



**FIG. 2.** Graph showing cost-effectiveness analysis demonstrating the cost and overall QALY for the competing strategies. The no-treatment strategy (*yellow*, highlighted in *green*) is shown to be dominated by elective PED and coiling treatment. The PED and coiling treatment demonstrated 12.72 QALYs and 12.89 QALYs, respectively, with an ICER of \$123,600 per QALY gained, indicating that PED was the more cost-effective strategy.



**FIG. 3.** Graph showing 2-way sensitivity analysis for the base-case scenario of PED treatment versus endovascular coiling versus no treatment as management plan for large or giant unruptured intracranial aneurysm.



**FIG. 4.** Graph showing cost-effectiveness acceptability curve demonstrating that as the willingness to pay increases, PED is cost-effective in 58.4% of iterations, coiling is cost-effective in 41.4% of iterations, and the no-treatment option is cost-effective in 0.2% of iterations.



**TABLE 1.**

Neurological outcome (mRS score) by health utility score (QALYs) in reports of patients with large or giant unruptured aneurysms

<b>Variable Name</b>	<b>Health Utility</b>	<b>SD</b>	<b>Distribution</b>	<b>Authors &amp; Year</b>
mRS Score 0–2, PED/coil	0.851	0.18	Beta	Rivero-Arias et al., 2010; Chalouhiet al., 2013
mRS Score 3–5, PED/coil	0.478	0.24	Beta	Rivero-Arias et al., 2010; Chalouhi et al, 2013
mRS Score 0–2, emergency treatment	0.81	0.21	Beta	Molyneux et al., 2005
mRS Score 3–5, emergency treatment	0.41	0.32	Beta	Molyneux et al., 2005

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Decision analysis model probabilities and patient characteristics in reports of large or giant unruptured aneurysms

TABLE 2.

Variable Value	Value	SD	Distribution	Authors & Year
Patient age in yrs	60	10	Binomial	Chalouhi et al., 2013
<b>Aneurysm rupture rates</b>				
Annual rupture risk for large or giant aneurysm w/o treatment	13%	2.6%	Beta	Ishibashi et al., 2009
Annual rupture risk w/ incomplete angiographic occlusion	4.3%	0.9%	Beta	Johnston et al., 2008
Good outcome (mRS Score 0–2) after spontaneous rupture w/ good mRS baseline	0.765	0.153	Beta	Molyneux et al., 2005
Poor outcome (mRS Score 3–5) after spontaneous rupture w/ good mRS baseline	0.155	0.414	Beta	Molyneux et al., 2005
Death (mRS Score 6) after spontaneous rupture w/ good mRS baseline	0.08	0.016	Beta	Molyneux et al., 2005
Poor outcome (mRS Score 3–5) after spontaneous rupture w/ poor mRS baseline	0.66*	0.13	Beta	Molyneux et al., 2005
Death (mRS Score 6) after spontaneous rupture w/ poor mRS baseline	0.34*	0.06	Beta	Molyneux et al., 2005
<b>PED treatment</b>				
Good outcome (mRS Score 0–2) after PED	0.92	0.184	Beta	Chalouhi et al., 2013
Poor outcome (mRS Score 3–5) after PED	0.053	0.01	Beta	Chalouhi et al., 2013
Death (mRS Score 6) after PED	0.026	0.005	Beta	Chalouhi et al., 2013
Probability of PED requiring endovascular retreatment	0.028	0.005	Beta	Chalouhi et al., 2013
Probability of complete angiographic occlusion w/ PED	0.86	0.172	Beta	Chalouhi et al., 2013
<b>Endovascular coiling</b>				
Good outcome after endovascular coiling	0.94	0.02	Beta	Chalouhi et al., 2013; Yue, 2011
Poor outcome after endovascular coiling	0.047	0.007	Beta	Chalouhi et al., 2013; Yue, 2011
Death after endovascular coiling	0.012	0.005	Beta	Chalouhi et al., 2013; Yue, 2011
Probability of coiling requiring endovascular retreatment	0.37	0.074	Beta	Chalouhi et al., 2013
Probability of complete angiographic occlusion w/ coiling	0.41	0.082	Beta	Chalouhi et al., 2013

\* Refers to estimated values at which patients who had prior poor neurological status and who had aneurysm rupture would either remain at their poor neurological status or die.

Costs incorporated within the model in reports of patients with large or giant unruptured aneurysms\*

TABLE 3.

Costs	Value	SD	Distribution	Authors & Year
Elective Pipeline embolization	\$24,995.46	\$12,531.70	Gamma	eI-Chalouhi et al., 2014
Elective endovascular coiling	\$31,906.29	\$24,861.65	Gamma	eI-Chalouhi et al., 2014
Emergency endovascular intervention & hospitalization	\$41,838.13	\$8,367.63	Gamma	Maud et al., 2009
Elective endovascular coiling retreatment	\$31,906.29	\$24,861.65	Gamma	eI-Chalouhi et al., 2014
Angiogram	\$894.98	\$179.00	Gamma	Maud et al., 2009
Rehabilitation—mRS Score 0–2 for coil/PED cohort	\$1,251.43	\$250.29	Gamma	Nelson et al., 2011; Chalouhi et al., 2013
Rehabilitation—mRS Score 3–5 for coil/PED cohort	\$14,405.76	\$2,881.15	Gamma	Nelson et al., 2011; Chalouhi et al., 2013
Rehabilitation—mRS Score 0–2 for emergency treatment cohort	\$1,630.06	\$326.01	Gamma	Nelson et al., 2011; Chalouhi et al., 2013
Rehabilitation—mRS Score 3–5 for emergency treatment cohort	\$57,534.23	\$11,506.85	Gamma	Nelson et al., 2011; Chalouhi et al., 2013

\* Costs are expressed in 2016 US dollars.

One-way sensitivity analysis demonstrating changes in ICER in patients with large or giant unruptured aneurysms

TABLE 4.

Parameter	Value Used for Sensitivity Analysis	ICER for PED	ICER for Coiling	ICER for No Treatment	Dominant Strategy
Initial procedural cost of PED	\$5,000	0	\$286,194.57	Dominated	PED
	\$14,000	0	\$224,866.85	Dominated	PED
	\$23,000	0	\$163,539.13	Dominated	PED
	\$32,000	0	\$102,211.41	Dominated	PED
	\$41,000	0	<b>\$40,883.69</b>	Dominated	Coil
	\$50,000	Dominated	0	Dominated	Coil
Initial procedural cost of endovascular coiling	\$5,000	Dominated	0	Dominated	Coil
	\$14,000	0	<b>\$3,530.54</b>	Dominated	Coil
	\$23,000	0	\$64,858.98	Dominated	PED
	\$32,000	0	\$126,185.98	Dominated	PED
	\$41,000	0	\$187,513.70	Dominated	PED
	\$50,000	0	\$248,841.42	Dominated	PED
Probability of initial death after PED treatment	0%	0	Dominated	Dominated	PED
	1%	0	Dominated	Dominated	PED
	2%	0	\$241,895.12	Dominated	PED
	3%	0	\$93,779.80	Dominated	PED
	4%	0	\$59,327.01	Dominated	PED
	5%	0	<b>\$43,981.67</b>	Dominated	Coil

An ICER corresponding to 0 refers to a nondominated base value. An ICER is dominated if another treatment option can provide more QALYs at lower cost. Nondominated ICERs < \$50,000 were deemed cost-effective. Boldface type indicates cost-effectiveness.