Influence of neurovascular embolic coil primary wind diameter on aneurysm packing density and case costs

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ABSTRACT

Aims: Endovascular coiling is a common modality for treating intracranial aneurysms; however, recanalization occurs in approximately 1 in 5 cases, with downstream consequences of regrowth and rupture. Aneurysm packing density >24% reduces recanalization risk; packing density can be increased by inserting additional coils or by using coils with larger volumetric filling. Coil volume depends on length and primary wind diameter (PWD). This study evaluated the influence of PWD on packing density and total case costs.

Materials and methods: Two hypothetical scenarios and one case study were analyzed. In scenario one, the number of coils required to achieve packing density >24% in a hypothetical aneurysm was determined for 0.012” vs. 0.010” PWD coils. In scenario two, the total length of 0.010” vs. 0.012” PWD coils required to achieve a packing density >24% was analyzed relative to aneurysm volume. In the case study, packing densities with one 0.012” PWD coil (actual scenario) and one 0.010” PWD coil (theoretical scenario) were compared.

Results: In scenario one, cost savings would be realized by using four 0.012” PWD coils vs. seven 0.010” PWD coils to achieve packing density >24%. In scenario two, greater volumetric filling of 0.012” vs. 0.010” PWD coils was correlated with lower total length of coil required. In the case study, a 0.012” PWD coil achieved packing density >24%, whereas an equivalent length 0.010” PWD coil would not.

Limitations: Theoretical modeling was used to explore the impact of coil PWD on aneurysm packing density. In clinical practice, packing density depends not only on PWD but on its length, shape, distribution within an aneurysm, and other recanalization risk factors.

Conclusions: Coil PWD influences packing density, the number of coils required to achieve a specific packing density, and total case costs. Using 0.012” PWD coils may provide cost and procedural efficiencies.

Introduction

Intracranial aneurysms occur in up to 2% of the general population, with an estimated 9 million Americans having unruptured intracranial aneurysms. Approximately 65,000 unruptured intracranial aneurysms are treated annually in the U.S., with the primary goals of preventing aneurysm rupture and consequent morbidity and mortality to patients. Aneurysm rupture results in roughly 27,000 new cases of subarachnoid hemorrhage each year. The devastating effects of subarachnoid hemorrhage include a mortality rate of 25–50% and permanent disability in nearly 50% of survivors, underscoring the importance of interventions to prevent hemorrhage recurrence or to prevent aneurysm rupture in the first place.

Two interventional modalities exist for the treatment of ruptured and unruptured intracranial aneurysms: (1) surgical management with craniotomy and clip ligation (i.e. clipping) and (2) endovascular management, which may include packing the aneurysm with detachable platinum coils (i.e. coiling), the use of flow-diverting stents, or the use of novel intrasaccular technology.

Coil embolization is the most common form of aneurysm treatment in the U.S., with patients experiencing significantly better survival and improved functional outcomes in cases of aneurysmal rupture and shorter hospitalizations compared with patients treated with surgical clipping. Despite these advantages, about 1 in 5 patients (21–24% of cases) treated with endovascular coiling experience aneurysm recanalization, thereby increasing the risk of rupture. An inverse correlation exists between aneurysm recanalization and how densely the aneurysm is packed with endovascular coils (i.e. packing density). Several studies have demonstrated that aneurysm packing densities...
exceeding 24% have lower rates of coil compaction and recanalization.16,17,19,20

As medical costs in the U.S. continue to rise, cost-efficient purchasing is one approach to optimize healthcare expenditures. In the context of endovascular coiling, the price of each embolic coil and the number of coils inserted drive the total materials cost in such procedures.9 Aneurysm packing density can be increased by either inserting more coils or using coils that occupy a larger volume, the latter of which may be a more cost-efficient approach.9,21–23

A coil’s volume is directly related to its length from end-to-end and its primary wind diameter (PWD) (Figure 1).18 The effect of coil length on cost efficiency has been demonstrated; however, studies that assess the relationship between coil PWD and cost efficiency are lacking. This study uses a hypothetical aneurysm model and a case study to evaluate the influence of PWD on packing density, the number of coils required to achieve a desired packing density, and the economic impact of PWD.

Methods

To analyze the effect of PWD on coil volume and subsequent packing density, a hypothetical aneurysm model was employed. The hypothetical aneurysms were filled with a set of embolic coils, and the resulting packing density was determined by first calculating the aneurysm volume and total sum of coil volumes. The volume of the hypothetical spherical aneurysm was calculated using the formula for the volume of a sphere \( \left( \frac{4}{3} \pi r^3 \right) \).

To assess the impact of PWD on packing density, an analysis was conducted using a set of coils that differed only by their PWD (i.e. cost per coil, coil lengths, and coil shape were the same). Coils in this analysis had a PWD of either 0.010” or 0.012”, and all coils were complex in shape. Coils with 0.010” PWD were selected as a comparator in these analyses because they represent the majority (~78%) of the unit market share for one embolic coil distributor (Cerenovus, data on file). The cost per coil used was $1,429, based on the mean cost of coils (in 2015–2016 U.S. dollars) described in a previous study, and a scenario analysis was conducted using a range of coil costs from other published literature sources ($1,295–1,695). The formula used to calculate coil volume was \( ((\pi)(PWD/2)^2)(\text{length}) \), and packing density was calculated by \( \left( \frac{\Sigma \text{ coil volumes/aneurysm volume}}{100}\% \right) \).

Two hypothetical scenarios were used to assess the influence of PWD on coil volume and packing density. In scenario one, the number of coils required to achieve a packing density >24% was compared for 0.010” and 0.012” PWD coils. The diameter of the spherical aneurysm was set at 6.7 mm in alignment with the mean aneurysm size reported in a recent analysis. In the second scenario, the total length of 0.010” and 0.012” PWD coils required to achieve a packing density >24% was analyzed as a function of aneurysm volume.

We also report a real-world application of this model by providing a case study. In this case, the dimensions of an ovoid-shaped, saccular aneurysm were determined using measurements from the 2D digital subtraction angiogram, with confirmation on the 3D computer reformatted images using Aneurysm Analysis software on a Siemens Syngo 4D workstation (Siemens Healthineers, Erlangen, Germany) (Figure 2). Aneurysm volume was calculated using the formula for an ovoid-shaped aneurysm \( (((\pi)(\text{width})(\text{depth})(\text{height})/6) \). The patient underwent an endovascular coiling procedure using one 0.012” PWD embolic coil, and the subsequent packing density was calculated.

Results

Scenario 1

In the first scenario, the number of coils required to achieve packing density >24% was analyzed. Whereas seven 0.010” PWD coils were required to achieve a packing density of 24.1%, only four 0.012” PWD coils were required to achieve a packing density of 24.6% (Table 1). The total cost of four 0.012” PWD coils was $5,716, compared with seven 0.010” PWD coils costing $10,00. Therefore, by using 0.012” PWD coils, the per patient cost was $4,287 less (a relative cost reduction of 43%). In this scenario, cost equivalence would be achieved if the 0.010” PWD coil were priced at $802 per coil compared with the price of $1,429 per 0.012” PWD coil.

Based on the results of scenario one, sensitivity analyses were performed to assess uncertainty related to coil costs, using the upper and lower bounds of a range of coil costs ($1,295–1,695). If a per-coil cost of $1,295 had been used, the total coil cost using 0.012” and 0.010” PWD coils would have been $5,180 and $9,065, respectively. In this case, the cost per patient was $3,885 less when using 0.012” PWD coils (a relative cost reduction of 43%). Had a cost of $1,695 per coil been used, the total coil cost using 0.012” and 0.010” PWD coils would have been $6,780 and $11,865, respectively. In this analysis, using 0.012” PWD coils resulted in a total case cost that was $5,085 less than if 0.010” PWD coils had been used.

Scenario 2

In this scenario, the total length of 0.010” and 0.012” PWD coils required to achieve a packing density >24% (i.e. 24.1%) was analyzed as a function of spherical
aneurysm volume. The relationship between volumetric filling of coils and aneurysm size is illustrated in Figure 3. Regardless of aneurysm size, 0.012” PWD coils required less total length to achieve the target density >24%. Conversely, substantially more 0.010” PWD coil is needed to achieve this threshold.

Figure 2. (A) A 35-year-old woman presented with a subarachnoid hemorrhage from rupture of a 2.1 × 2.5 × 2.8 mm aneurysm located at the junction of the A1 and A2 divisions of the right anterior cerebral artery. Digital subtraction angiography (oblique view) was used to visualize the small, ovoid-shaped aneurysm. Three-dimensional computer reformatted images (B), along with Aneurysm Analysis Software, Siemens Syngo 4D workstation (Siemens Healthineers, Erlangen, Germany) (C, D), were used to confirm the dimensions of the ruptured aneurysm.

Table 1. Scenario one. Number of 0.012” vs. 0.010” PWD coils required to achieve packing density >24% in a 157.5-mm³ aneurysm.

| PWD (inches) | 0.012” | 0.010” |
|--------------|--------|--------|
| Number of coils inserted | 4<sup>b</sup> | 7 |
| Sum of coil lengths (cm) | 53 | 75 |
| Sum of coil volumes (mm³) | 38.7 | 38.0 |
| Coi length (cm per mm³ aneurysm) | 0.34 | 0.48 |
| Cost per coil (US$) | 1,429 | 1,429 |
| Total coil cost per aneurysm (US$) | 5,716 | 10,003 |
| Absolute cost difference per aneurysm (US$) (total cost 0.012” – total cost 0.010”) | –4,287 |
| Relative case cost reduction per aneurysm (%)<sup>c</sup> | 43 |
| Total cost (US$) per total coil volume | 148 | 263 |
| Cost for 0.010” PWD coil to achieve cost equivalence of 0.012” PWD coil (US$)<sup>d</sup> | 802 |
| Packing density (%) | 24.6 | 24.1 |

<sup>a</sup>Dimensions of coils (secondary wind diameter × length): coil 1: 6 mm × 20 cm; coil 2: 5 mm × 15 cm; coil 3: 4 mm × 10 cm; coil 4: 4 mm × 8 cm; coil 5: 3.5 mm × 8 cm; coil 6: 3 mm × 8 cm; coil 7: 3 mm × 6 cm.

<sup>b</sup>Coils 5, 6, and 7 were omitted.

<sup>c</sup>Total cost 0.010” PWD coils / total cost 0.012” PWD coils x 100%

<sup>d</sup>Cost for 0.010” PWD coil to achieve cost equivalence of 0.012” PWD coil (US$).

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Case study

A 35-year-old female patient was transferred to our institution with a Hunt & Hess Grade 4 subarachnoid hemorrhage. After appropriate resuscitation and stabilization in the neurocritical care unit, she was brought to the neurointerventional suite where angiography demonstrated a 2.1 \times 2.5 \times 2.8 \text{ mm} ruptured saccular aneurysm with an ovoid shape located at the junction of the A1 and A2 divisions of the right anterior cerebral artery (Figure 2). She underwent treatment using a single 2.5 \text{ mm} \times 3.5 \text{ cm} 0.012^{\text{\textregistered}} \text{ PWD embolic coil (ORBIT GALAXY, Cerenovus, SARL, Switzerland)} (Figure 4). Aneurysm volume was estimated to be 7.69 \text{ mm}^3, and the total volume of the inserted coil was 2.55 \text{ mm}^3. The packing density achieved was calculated to be 33.16% (Table 2). Had a 0.010^{\text{\textregistered}} \text{ PWD coil of the same length been used instead of the 0.012^{\text{\textregistered}} \text{ PWD coil, the resulting coil volume and packing density would have been 1.77 \text{ mm}^3 and 23.02\%, respectively. Absolute and relative packing density differences of 10.14\% and 44.04\%, respectively, were obtained in favor of the 0.012^{\text{\textregistered}} \text{ PWD coil. Because the number of coils inserted was assumed to be the same in the actual case and theoretical analysis, the total cost of coils was equivalent. Therefore, for the same cost, using a single 0.012^{\text{\textregistered}} \text{ PWD coil was estimated to achieve greater packing density compared with using a single 0.010^{\text{\textregistered}} \text{ PWD coil.}}
Discussion

In an era of increasing awareness of treatment costs, being mindful of cost efficiency when purchasing products may assist healthcare providers in offsetting expenses while optimizing patient care. In the U.S., coil embolization is the most common form of aneurysm treatment. With the number of endovascular coiling procedures performed annually on the rise, the cost efficiency of embolic coils is an important consideration. In this analysis, we evaluated the influence of a rise, the cost efficiency of embolic coils is an important consideration. In the U.S., coil embolization is the most common form of aneurysm treatment.

The results of scenario one demonstrated that, compared with 0.010” PWD coils, fewer 0.012” PWD coils were needed to achieve a packing density associated with lower recanalization risk (i.e., >24%) (Table 1). Because three fewer 0.012” PWD coils were needed to achieve the packing density threshold, a cost savings of $4,287 per patient (assuming one aneurysm per patient) was estimated. Although annual case volumes differ between centers, savings of $364,395 were estimated for an annual 85-patient cohort (assuming one aneurysm per patient). The total cost per total coil volume was lower for 0.012” PWD coils at $1429/mm³ compared with $1,429/mm³ for 0.010” PWD coils.

In scenario one, the unit price of 0.010” PWD coils would need to be reduced by $627 (i.e., 44%) to achieve cost equivalence with the 0.012” PWD coils (Table 1). In addition to the estimated cost savings, important clinical efficiencies may also be realized by inserting fewer coils, including shorter anesthesia time, reduced overall procedure time (and therefore, fewer potential complications), and lower radiation doses for the patient and healthcare team.

We hypothesized that because an embolic coil’s volume depends on its PWD and length, 0.012” PWD coils would afford greater volumetric filling than 0.010” PWD coils irrespective of aneurysm size. To test this, we performed analyses with aneurysms of increasing size while holding packing density steady at 24.1% (Figure 3). The results indicated that 0.012” PWD coils have greater volumetric efficiency than 0.010” PWD coils, irrespective of aneurysm size, and that the disparity between the required coil length increases along with increasing aneurysm size (Figure 3).

The superior packing density achieved by 0.012” PWD coils was further illustrated in the case study where a small, ruptured, ovoid-shaped aneurysm was packed with a single 0.012” PWD coil (Figures 2 and 4). Had this patient’s aneurysm been packed with a 0.010” PWD coil, the packing density would have been 23.02%, an absolute value of 10.14% less than what was achieved in the actual case (Table 2). The results of the case study also support the clinical and economic efficiencies of using 0.012” vs. 0.010” PWD coils. If a minimum packing density of 24% was required, an additional 0.010” PWD coil would need to be inserted (Table 2). With a typical cohort of 85 patients per year, the use of 0.012” PWD coils may result in one less coil inserted per case and, therefore, an annual cost savings of $121,465 compared with if 0.010” PWD coils were used. However, in the clinical setting, inserting additional coils is not always feasible or without consequent risks to the patient, particularly in the case of patients presenting with small, ruptured aneurysms. Thus, in this case study, the use of a larger volume coil may have minimized patient risk in addition to total procedural costs.

Clinical studies have also demonstrated that coils with larger PWD achieved greater packing density compared with coils with smaller PWD. In these studies, significantly greater packing density was achieved by complex-shaped 0.012” PWD coils compared with 0.010” PWD coils (helical or 3D). Because complex-shaped coils may allow for denser packing compared with helical coils, the superior packing density achieved in these clinical studies was likely due to a combination of coil shape and PWD. For the purpose of our analyses, we assumed all coils to be complex in shape to avoid introducing confounding factors and to highlight the impact of PWD on packing density.

In scenario one, we assumed an equivalent coil cost of $1,429 based on the mean cost per coil (in 2015–2016 U.S. dollars) described in a previous study. Although we acknowledge that coil prices may vary by brand and size, the
assumed cost of $1,429 is supported by other studies that noted a relatively flat pricing structure across the same brand, irrespective of coil size, and a price range of $1,295–$1,695 (assumed average retail price of $1,595) for 0.012” PWD coils. The results of the coil cost scenario analysis indicated that with a lower or higher cost per coil, cost savings are realized with 0.012” PWD coils compared with 0.010” PWD coils.

Taken together, the results of these analyses indicate that the PWD of an embolic coil is an important metric from both a clinical and an economic perspective. During coil selection, it is important for a neurointerventionalist to consider the relationship between a coil’s PWD and aneurysm packing density. However, other factors should be evaluated in coil selection such as the coil’s stiffness, which may influence its ability to be placed inside an aneurysm. Because coil stiffness is inversely proportional to PWD, coils with a larger PWD are softer and, therefore, more amenable to placement within an aneurysm. This underscores the importance of PWD during coil selection in clinical practice.

In scenario one, 0.012” PWD coils were more cost efficient than 0.010” PWD coils. Because this scenario focused strictly on the impact of PWD on coil volume and packing density, we assumed all coil lengths to be equal. In a recent analysis where coil efficiency was evaluated based on volume per cost, the length of an embolic coil was described as the most important contributor to volumetric efficiency. Although we agree that coil length influences volume and cost efficiency, we demonstrated that PWD is also an important consideration in determining a coil’s volumetric and cost efficiency, perhaps especially when inserting a longer-length coil is not clinically feasible.

The two scenarios described used theoretical modeling to explore the contribution of an embolic coil’s PWD to packing density. In clinical practice, packing density is dependent not only on PWD, but also coil length, coil shape, and the uniform distribution of coils within an aneurysm. It is not uncommon that a mixture of coils with varying PWD would be used to fill an aneurysm. For example, 0.015” or 0.018” PWD coils may provide structure and stability in endovascular coil procedures whereas coils with smaller PWD (e.g. 0.009”) are useful in filling remaining spaces within the coil mass. Packing density is also not independent of other recanalization risk factors including aneurysm diameter and neck size, coil permeability, local hemodynamics, vessel geometry, the presence of intraluminal thrombus, and the use of helical vs. complex coils. Regardless, packing density is an important metric to consider in terms of clinical outcomes and healthcare resource use. The results of this study underscore the importance of considering PWD in embolic coil selection to optimize packing density and total procedural costs.

Conclusions

The PWD of an embolic coil influences the total number of coils needed to fill an aneurysm, the overall packing density, and the total coil-related cost. Assuming equal coil length and unit cost, fewer 0.012” PWD coils were required to achieve a packing density >24% compared with 0.010” PWD coils. Regardless of aneurysm size, 0.012” PWD coils provide greater volumetric filling compared with 0.010” PWD coils. Using coils with a larger PWD per given length may provide cost and procedural efficiencies by limiting the number of coils required to achieve an aneurysm packing density with reduced recanalization risk. The results of this study emphasize the clinical and economic value in considering the PWD of an embolic coil in the treatment of intracranial aneurysms.

Transparency

Declaration of funding

This study was funded by Cerenovus, a subsidiary of Johnson & Johnson.

Declaration of financial/other relationships

RG is a consultant for Cerenovus, Medtronic Neurovascular, and Balt Neurovascular.

EK is an employee of Cerenovus, a subsidiary of Johnson & Johnson.

HLC and STK are paid consultants for Cerenovus.

PT is a consultant for Cerenovus, Medtronic Neurovascular, and Stryker.

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Author contributions

RG and PT contributed details pertaining to the case study. RG, EK, SK, and Kristin Kraus for their assistance in preparing the paper. All authors discussed the results and contributed to the final manuscript.

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