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Original Research Article.

Safety and Effectiveness of Embolization Coils: A Comparison of Fibered, Non-Fibered, and Coated Designs

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ABSTRACT

In endovascular therapy, embolization coils serve as vital devices for preventing excessive circulation in many types of vascular diseases, including hemorrhages, arteriovenous malformations (AVMs), and aneurysms. The safety, thrombogenic effectiveness, mechanical characteristics, and economic viability of various embolization coil designs—including fibered, non-fibered, hydrogel-coated, and alternative fiber materials like hydrophobic cotton—as well as materials like platinum and nitinol are all examined in this review. The comparison of these coils' clotting efficiency, deployment control, migration risk, and radiopacity is based on current clinical and experimental research. Findings indicate that platinum fibered coils offer the best balance between safety, rapid thrombosis, and visibility under fluoroscopy. Hydrogel-coated coils show enhanced clot retention but at increased cost and complexity. Non-fibered and hydrophobic cotton coils lag in clotting efficiency and are less favorable for urgent or high-risk embolization. Nitinol coils, while offering shape memory and flexibility, suffer from poorer radiopacity compared to platinum. This review highlights the importance of coil selection tailored to the clinical scenario to optimize therapeutic outcomes.

Keywords: Arteriovenous Malformations (AVMs), Thrombogenic, Hydrogel-Coated Coil, Platinum, Nitinol, Nickel-Titanium Alloy, Hydrophobic Cotton Fibers.

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INTRODUCTION

As embolization techniques facilitate the precise closure of blood channels by minimally invasive endovascular techniques, they have completely changed the way vascular diseases are addressed. Following this improvement, there is now a reduced demand for open surgery that lowers patient morbidity and accelerates recovery. Originally developed to stop potentially fatal bleeding, embolization is now a vital treatment for a variety of vascular diseases. In order to manage severe bleeding in patients with coagulopathies, whereby earlier operations engaged significant dangers, coils were first utilized for embolization in the early 1970s[1]. Since then, ongoing advancements in coil design, composition of materials, and the distribution methods have improved the utility of and improving the safety and effectiveness of procedures.

In order to prevent rupture and possibly lethal subarachnoid hemorrhage, coils are now generally used to treat cerebral aneurysms. In the treatment of arteriovenous malformations (AVMs), which pose a serious risk of bleeding because of aberrant artery structure and flow dynamics, they are also essential. In addition to neurovascular applications, coils are essential for reducing tumor blood supply before surgery or as a palliative measure, as well as for controlling trauma-related hemorrhage[2]. The capacity of an embolization coil to quickly induce stable clot formation, hold its position after deployment, and be easily visible under fluoroscopy for precise placement are all necessary for its efficacy. Fibered platinum coils, which combine superior radiopacity with synthetic fibers that speed up thrombus, have emerged as the industry standard among the several designs.

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METHOD

The safety, effectiveness, and material characteristics of various e mbolization coil types-fibered, non-fibered, hydrogel-coated, and alternative fiber types like hydrophobic cotton-as well as the effects of coil material, particularly nitinol versus plat inum, are thoroughly compared in this review.

Literature Search Strategy

A comprehensive literature search was conducted using major medical databases, including PubMed, Scopus, and Google Scholar. Keywords used included “fibered embolization coil,” “non-fibered embolization coil,” “hydrogel-coated embolization coil,” “nitinol coil,” “platinum coil,” and “embolization coil safety and efficacy.”

Inclusion Criteria

- Studies published from 1965 to 2024, focusing on embolization coil materials, thrombogenicity, deployment techniques, and clinical outcomes.
- Both clinical trials and experimental studies comparing coil types and materials.

Data Extraction and Synthesis

Relevant data were extracted on coil design (fibered vs. non-fibered), material composition (platinum, nitinol, hydrogel, cotton), clinical applications, thrombogenicity, deployment control, radiopacity, cost considerations, and safety concerns such as non-target embolization and coil migration.

Data were then synthesized to compare:

1. The thrombogenic performance and clot formation speed of fibered vs. non-fibered coils.
2. The effectiveness of hydrophobic cotton fibers compared to synthetic fibers in coil design.
3. The advantages and disadvantages of nitinol versus platinum as coil materials.
4. The clinical efficacy and cost-benefit analysis of hydrogel-coated coils relative to fibered coils.

Comparisons were contextualized using clinical outcomes from case studies, experimental models, and technical evaluations found in the reviewed literature.

1. Comparison between Fibered and Non-Fibered Embolization Coils

Fibered embolization coils are composed of a metal core integrated with synthetic fibers, while non-fibered coils consist solely of plain metallic material. The presence of fibers in fibered coils enhances their thrombogenicity by providing a scaffold that facilitates rapid blood clot formation.

Although fibered coils may be slightly more challenging to navigate and deploy within the vessel due to their increased bulk, they achieve vessel occlusion more efficiently. In contrast, non-fibered coils are easier to deliver but rely solely on the metal surface to initiate clotting, resulting in a slower and less robust thrombotic response[4].

2. Fibered Embolization Coils vs. Hydrophobic Cotton Fibered Embolization Coils

Fibered embolization coils, typically made with synthetic fibers, are designed to actively promote blood clot formation by enhancing the surface area and encouraging platelet aggregation. In contrast, coils incorporating hydrophobic cotton fibers demonstrate significantly lower thrombogenicity.

Due to the water-repelling nature of hydrophobic cotton, these coils impede effective interaction with blood components, resulting in delayed or even absent clot formation[5]. As a result, hydrophobic cotton-based coils are considerably less effective in achieving timely vessel occlusion, particularly in critical or emergency settings.

3. Nitinol vs. Platinum as Embolization Coil Materials

Nitinol and platinum are two commonly used materials in embolization coils, each with distinct properties[6]. Nitinol is known for its super elasticity and shape memory, allowing it to return to its pre-set shape once deployed, which can aid in precise placement within tortuous vessels.

However, its lower radiopacity compared to platinum makes it harder to visualize under fluoroscopy. On the other hand, platinum is highly radiopaque and flexible, allowing for excellent visualization and trackability during procedures.

Despite lacking shape memory, platinum remains the preferred choice for most embolization coils due to its predictable behavior and superior visibility in imaging[7].

4. Hydrogel-Coated vs. Fibered Embolization Coils

Hydrogel-coated fibered embolization coils and synthetic fibered coils both aim to induce vessel occlusion but differ in mechanism and effectiveness[8]. Hydrogel-coated coils expand upon contact with blood, providing a larger surface area and physical volume for thrombus formation, which enhances their ability to seal vessels effectively. Synthetic fibered coils, while also thrombogenic, rely primarily on fiber insertion with blood components to promote clotting. Although hydrogel-coated coils generally achieve more complete and rapid occlusion, they are significantly more expensive. Fibered coils, by contrast, offer a cost-effective and practical alternative, making them widely suitable for various clinical settings[9].

RESULTS

Fibered vs. Non-Fibered Embolization Coils

Fibered coils incorporate synthetic fibers that enhance thrombogenicity by increasing surface area and facilitating clot formation. Non-fibered coils, lacking such scaffolds, depend solely on their metallic surface, resulting in slower clot formation. Despite easier navigation, non-fibered coils are less effective in time-sensitive cases.

Fibered Coils vs. Hydrophobic Cotton Coils

Hydrophobic cotton coils, though designed to be thrombogenic, exhibit poor clotting efficiency due to their water-repellent nature, which impedes interaction with blood elements. Synthetic fibered coils outperform them significantly in thrombus formation.

Nitinol vs. Platinum Coils

Platinum coils offer superior radiopacity and are preferred for most procedures. Nitinol, with its shape-memory property, allows flexibility in tortuous vessels but is less visible under fluoroscopy, limiting its precision during placement.

Hydrogel-Coated vs. Fibered Coils

Hydrogel-coated coils expand upon blood contact, enhancing clot volume and reducing migration risk. While they offer superior occlusion, their cost is significantly higher compared to synthetic fibered coils, which remain effective in most general scenarios.

Table 1: Comparison between Fibered and Non-Fibered Coils

Feature	Fibered Coils	Non-Fibered Coils
Structure	Metal coil with synthetic fibers	Plain metal coil
Clotting Ability	Rapid thrombus formation	Delayed clotting
Vessel Occlusion Speed	Faster	Slower
Deployment Control	Moderate (bulkier)	Easy
Radiopacity	High (with platinum)	Varies
Non-Target Embolization Risk	Slightly higher	Lower

Table 2: Fibered vs. Hydrophobic Cotton Fibered Coils

Feature	Synthetic Fibered Coils	Hydrophobic Cotton Coils
Fiber Type	Synthetic polymer	Natural cellulose-based (cotton)
Thrombogenicity	High	Low
Clot Formation Speed	Fast	Delayed
Clinical Use	Recommended	Not recommended
Cost	Economical	Low, but performance-limited

Table 3: Nitinol vs. Platinum Embolization Coils

Feature	Nitinol Coils	Platinum Coils
Material	Nickel-Titanium Alloy	Pure Platinum
Flexibility	High (shape memory)	Moderate
Radiopacity	Low	Excellent
Deployment Control	Self-expanding	Catheter-controlled
Use Case	Complex vessel navigation	General embolization

Table 4: Hydrogel-Coated vs. Fibered Coils

Feature	Hydrogel-Coated Coils	Fibered Coils
Material	Polymer hydrogel + fiber	Synthetic fiber only
Clotting Performance	Very high	High
Migration Risk	Very low (due to swelling)	Depends on sizing
Cost	High	Moderate
Preferred Use	Large aneurysms, high-risk procedures	General embolization

DISCUSSION

This study demonstrates that fibered embolization coils composed of platinum provide superior efficacy and safety in clinical practice. Fibered coils exhibit significantly greater performance than non-fibered variants due to their enhanced ability to rapidly promote thrombus formation—a critical factor in emergency embolization procedures (Kawakami, O., 2005). In contrast, non-fibered coils, which consist solely of metal, facilitate clot formation at a slower rate and may be less suitable for time-sensitive interventions.

However, the volume of synthetic fibers in fibered coils may increase the risk of non-target embolization, particularly when coils are improperly sized. Hydrophobic cotton fibered coils, despite being designed to encourage thrombosis, have proven less effective in promoting rapid thrombus formation, limiting their clinical utility.

In terms of material properties, platinum coils offer excellent radiopacity, enabling precise intra-procedural visualization and accurate deployment—both essential for procedural success. Nitinol coils, while beneficial for their shape memory and self-expanding characteristics, possess lower radiopacity, which may hinder optimal positioning during placement.

Hydrogel-coated fibered coils demonstrate superior thrombus entrapment efficiency and a markedly reduced risk of migration, attributed to the hydrogel's expansion upon blood contact. However, the substantially higher cost associated with these coils limits their broader clinical adoption.

LIMITATIONS

Due to the wide variety of coil designs and the differing methodologies used across studies, there is inherent heterogeneity in the available data. Consequently, the conclusions of this review were drawn while carefully considering the variability in clinical contexts, patient conditions, and coil deployment techniques.

CONCLUSION

Fibered embolization coils composed of platinum and synthetic fibers represent the most favorable option in terms of safety, efficacy, and clinical applicability. Their capacity to facilitate rapid and reliable thrombus formation renders them particularly effective in acute and emergency interventions. In contrast, non-fibered coils, though easier to deploy, are associated with delayed thrombogenesis and reduced effectiveness in time-sensitive scenarios.

The use of hydrophobic cotton fibers is not recommended due to their suboptimal clotting performance and increased risk of coil migration. Platinum remains the material of choice for embolization coils, owing to its excellent radiopacity and malleability, which allow for accurate placement and conformation within the vasculature. Although nitinol offers benefits such as shape memory and self-expansion, its lower radiographic visibility under fluoroscopy may hinder precise deployment.

Hydrogel-coated fibered coils demonstrate superior clot entrapment and enhanced positional stability due to hydrogel expansion upon blood contact. Nevertheless, their substantially higher cost limits their use to select clinical situations where maximum occlusive efficacy is required.

In summary, fibered platinum embolization coils offer the most balanced combination of performance, procedural control, and cost-effectiveness, supporting their continued preference in a broad range of embolization procedures.

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