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(54) Title: METHOD OF MAKING VASO-OCCLUSIVE COILS

(57) Abstract: Methods of making vaso-occlusive devices by varying the tension between the wire which forms the device and the winding mandrel are described.

METHOD OF MAKING VASO-OCCLUSIVE COILS

FIELD OF THE INVENTION

This invention is in the field of an implantable vaso-occlusive device. In particular, the invention includes methods of making such devices by varying the tension during winding of a wire to produce a primary coil configuration. The primary coil efficiently self-forms into a three-dimensional shape when deployed into a body cavity. Further, the variations in winding tension induce this three-dimensional formation in the desired directions and shapes.

BACKGROUND

Vaso-occlusion devices are surgical implements or implants that are placed within the vasculature of the human body, typically via a catheter, either to block the flow of blood through a vessel making up that portion of the vasculature through the formation of an embolus or to form such an embolus within an aneurysm stemming from the vessel. One widely used vaso-occlusive device is a helical wire coil having windings which may be dimensioned to engage the walls of the vessels. Other less stiff helically coiled devices have been described, as well as those involving woven braids.

U.S. Pat. No. 4,994,069, to Ritchart et al., describes a vaso-occlusive coil that assumes a linear helical configuration when stretched and a folded, convoluted configuration when relaxed. Vaso-occlusive coils having attached fibrous elements in a variety of secondary shapes are shown in U.S. Pat. No. 5,304,194, to Chee et al. Vaso-occlusive coils having little or no inherent secondary shape have also been described. For instance, co-owned U.S. Patent Numbers 5,690,666 and 5,826,587 by Berenstein et al., describes coils having little or no shape after introduction into the vascular space.

Further, there are a variety of ways of discharging shaped coils and linear coils into the human vasculature. In addition to those patents which apparently describe only the physical pushing of a coil out into the vasculature (e.g., Ritchart et al.), there are a number of other ways to release the coil at a specifically chosen time and site. U.S. Pat. No. 5,354,295 and its parent, U.S. Pat. No. 5,122,136, both to Guglielmi et al., describe an electrolytically detachable embolic device.

Production of vaso-occlusive coils typically involves winding an elongated wire

around a mandrel and annealing the wire-mandrel complex. Generally, during winding the wire is held stationary, for example, on a spool. The free end of the wire is affixed to the mandrel and the mandrel is turned such that the wire is released from the spool as it is wound about the mandrel. During winding, the tension between the wire and the mandrel does not change.

Thus, none of these documents disclose methods of making vaso-occlusive devices which involve varying the tension on the wire as it is wound around mandrel to form the vaso-occlusive coil.

SUMMARY OF THE INVENTION

Thus, this invention includes novel methods of making vaso-occlusive devices and devices made by these methods.

In one aspect, the invention includes a method of making a vaso-occlusive device comprising winding an elongated wire around a mandrel, wherein the tension on the wire is varied during said winding. The tension can be varied automatically or manually in a variety of ways (*e.g.*, by varying distance between the wire and mandrel; the rate of winding, and/or the angle of winding). Thus, in certain embodiments, the elongated wire is held in a holder and the tension is varied during winding of the wire by varying the distance between the holder and the mandrel. In other embodiments, the elongated wire is held in a holder and the tension is varied during winding of the wire by varying the rate of winding around the mandrel, for example using a magnetic brake or transducer. In yet other embodiments, the elongated wire is held in a holder and the tension is varied during winding of the wire by varying the angle between the wire and mandrel. One or more of these parameters can be varied in the methods described herein.

These and other embodiments of the subject invention will readily occur to those of skill in the art in light of the disclosure herein.

DESCRIPTION OF THE INVENTION

Vaso-occlusive devices, particularly coils, made by winding a wire around a mandrel at varying tensions are described herein. Varying the tension at which the wire is wound about the mandrel to form a primary coil can be achieved in any number of ways, for example by varying the angle between the wire and the mandrel; by varying the distance between the

wire holding device and the mandrel and/or by varying the rate at which the wire is wound about the mandrel (*e.g.*, using magnetic brakes and/or transducers). These and other parameters can be varied manually or using automated systems, for example using one or more computer programs linked to a winding device. Primary coils that have been produced using variable winding tensions exhibit particular characteristics, for example, the three-dimensional shape and the efficiency with which the three-dimensional shape is formed. Thus, vaso-occlusive devices made using these methods and methods of using these devices also form an aspect of this invention.

Advantages of the present invention include, but are not limited to, (i) ability to induce different three-dimensional shapes upon deployment, depending on which areas of the device have been wound at what tension; (ii) less rotation of the coil upon deployment; and (iii) rapid formation of three dimensional structures upon deployment into a body cavity. These advantages are achieved without the necessity of varying the diameter of the wire making up the coil. The devices described herein are useful whether the coils have mechanical or electrolytic detachment links at one or both ends.

All publications, patents and patent applications cited herein, whether supra or infra, are hereby incorporated by reference in their entirety.

It must be noted that, as used in this specification and the appended claims, the singular forms "a", "an", and "the" include plural referents unless the content clearly dictates otherwise. Thus, for example, reference to "a coil" includes a mixture of two or more such devices and the like.

Vaso-occlusive devices are typically formed by winding a wire (*e.g.*, a metallic wire) around a mandrel, for example winding the wire into a primary configuration, for example a helical coil. The primary coil can be wound into a secondary form or may self-form into a three-dimensional structure. The pattern and tension during winding on the mandrel provides the three dimensional shape of the invention at deployment. Once wound onto a mandrel, the assembly of mandrel and coil is typically heat treated. The secondary form is one which, when ejected from a delivery catheter, forms a generally three-dimensional shape, filling first the outer periphery of the three-dimensional shape and then the center region. Desirably, the vaso-occlusive device is of a size and shape suitable for fitting snugly within a vascular cavity (e.g., an aneurysm, or perhaps, a fistula).

Suitable winding mandrels may be a variety of shapes (*e.g.*, cylindrical, square,

spherical, circular, rectangular, etc.) and may be solid or hollow. Some exemplary shapes of mandrels are shown in co-owned U.S. Patent No. 5,957,948 to Mariant et al. As noted above, the winding mandrel is typically of sufficient heat resistance to allow a moderate annealing step. The mandrel may be made of a refractory material such as alumina or zirconia (for heat-treating devices made of purely metallic components) or may be made of a metallic material. Composite mandrels (*e.g.,* composites of conductive and non-conductive materials) described in co-owned U.S. Serial No. 09/637,470 may also be employed.

As noted above, varying the tension between the wire and the mandrel during winding can be achieved in any number of ways, including, but not limited to, varying the rate at which the wire is wound onto the mandrel and/or varying the distance between the mandrel and the wire-holder. In addition the angle between the wire and the mandrel can be used to vary the tension. Further, the use of magnetic brakes and/or transducers during winding can also be used to vary the tension of winding. Tension can be measured using standard techniques, for example using a force gauge, a transducer or the like. Such techniques are known to those of skill in the art. The variation in tension during winding can be anywhere from 2 gm to the deformation strength of the wire. The specific tensions will depend on the wire (*e.g.,* diameter, composition, etc.) and can readily be determined using known techniques in view of the teachings herein. For example, a 0.002 inch wire can be wound at tensions varying between about 5 gm to about 500 gm (and any integer therebetween), more preferably, between about 5 gm and 250 gm (and any integer therebetween).

Thus, the wire may be held stationary, for example, on a spool. The wire-holder can comprise any device which allows the wire to be fed onto a mandrel, for example a spool or other threading device. One end of the wire is then attached to a mandrel. The mandrel and/or the wire-holding device can rotate in any direction and both can optionally move laterally. In certain embodiments, rotation of the mandrel pulls the wire off the spool as the wire is wound around the mandrel. The pattern of winding is achieved by moving the mandrel and/or spool laterally during rotation of the mandrel. Moreover, the tension during winding may be varied by manually adjusting the rate at which the mandrel rotates. In addition, the tension can be varied automatically, for example by using a programmable device which drives rotation of the mandrel and/or unwinding of the wire from the spool. Suitable programmable microprocessors will be known to those of skill in the art. Alternatively, the rate at which the mandrel rotates can be adjusted manually.

In other embodiments, the tension is varied during winding by varying the distance between the wire-holder (*e.g.* spool) and the mandrel. In this way, tension can be increased by moving the wire-holder and the mandrel farther apart and decreased by moving the mandrel and wire-holder closer together. As above, the distance can be varied manually or using a microprocessor, *e.g.*, programmable device. One of skill in the art could readily vary these and other parameters to determine both the tension of winding and the winding pattern useful to achieve the desired coil type.

After winding, the mandrel and attached coil are typically annealed (*e.g.*, by heating). A typical annealing step for a platinum/tungsten alloy coil would involve a 1100°F heating step in air for about between about 15-20 minutes to about 6 hours. The primary coil is typically linear after it has been wound and annealed.

The material used in constructing the vaso-occlusive member having enhanced areas of softness may be any of a wide variety of materials; preferably, the wire is a radio-opaque material such as a metal. Suitable metals and alloys for the wire making up the primary coil include the Platinum Group metals, especially platinum, rhodium, palladium, rhenium, as well as tungsten, gold, silver, tantalum, and alloys of these metals. These metals have significant radiopacity and in their alloys may be tailored to accomplish an appropriate blend of flexibility and stiffness. They are also largely biologically inert. Highly preferred is a platinum/tungsten alloy.

The wire may also be of any of a wide variety of stainless steels if some sacrifice of radiopacity may be tolerated. Very desirable materials of construction, from a mechanical point of view, are materials which maintain their shape despite being subjected to high stress. Certain "super-elastic alloys" include nickel/titanium alloys (48-58 atomic % nickel and optionally containing modest amounts of iron); copper/zinc alloys (38-42 weight % zinc); copper/zinc alloys containing 1-10 weight % of beryllium, silicon, tin, aluminum, or gallium; or nickel/aluminum alloys (36-38 atomic % aluminum). Particularly preferred are the alloys described in U.S. Pat. Nos. 3,174,851; 3,351,463; and 3,753,700. Especially preferred is the titanium/nickel alloy known as "nitinol". These are very sturdy alloys which will tolerate significant flexing without deformation even when used as a very small diameter wire. If a superelastic alloy such as nitinol is used in the device, the diameter of the coil wire may be significantly smaller than that used when the relatively more ductile platinum or platinum/tungsten alloy is used as the material of construction.

Generally speaking, when the device is formed of a metallic coil and that coil is a platinum alloy or a superelastic alloy such as nitinol, the diameter of the wire used in the production of the coil will be in the range of 0.0005 and 0.006 inches. The wire of such diameter is typically then wound into a primary coil having a primary diameter of between 0.005 and 0.035 inches. For most neurovascular indications, the preferable diameter is 0.010 to 0.018 inches. We have generally found that the wire may be of sufficient diameter to provide a hoop strength to the resulting device sufficient to hold the device in place within the chosen body cavity without distending the wall of the cavity and without moving from the cavity as a result of the repetitive fluid pulsing found in the vascular system.

The axial length of the primary coil will usually fall in the range of 0.5 to 100 cm, more usually 2.0 to 40 cm. Depending upon usage, the coil may well have 100-400 turns per centimeter, preferably 200-300 turns per centimeter. All of the dimensions here are provided only as guidelines and are not critical to the invention. However, only dimensions suitable for use in occluding sites within the human body are included in the scope of this invention.

The overall diameter of the device as deployed is generally between 2 and 20 millimeters. Most aneurysms within the cranial vasculature can be treated by one or more devices having those diameters. Of course, such diameters are not a critical aspect of the invention.

The primary coil may include or be made entirely from radiolucent fibers or polymers (or metallic threads coated with radiolucent or radiopaque fibers) such as Dacron (polyester), polyglycolic acid, polylactic acid, fluoropolymers (polytetrafluoro-ethylene), Nylon (polyamide), or even silk. Polymer materials may be filled with some amount of a known radiopaque material such as powdered tantalum, powdered tungsten, bismuth oxide, barium sulfate, and the like. Also contemplated in this invention is the attachment of various fibrous materials to the inventive coil for the purpose of adding thrombogenicity to the resulting assembly. The fibrous materials may be attached in a variety of ways. A series of looping fibers may be looped through or tied to coil and continue axially down the coil. Another variation is by tying the tuft to the coil. Tufts may be tied at multiple sites through the coil to provide a vast area of embolus forming sites. The primary coil may be covered by a fibrous braid. The method for producing the former variation is described in U.S. Pat. Nos. 5,226,911 and 5,304,194 to Chee. The method of producing the fibrous braid is described in

U.S. Pat. No. 5,382,259, issued Jan. 17, 1995, to Phelps and Van.

The coils described herein can also include additional additives, for example, any material that exhibits biological activity *in vivo*. Non-limiting examples of suitable bioactive materials are known to those of skill in the art. Preferably, these materials are added after annealing.

The inventive coils described herein may be associated with other materials, such as radioactive isotopes, bioactive coatings, polymers, fibers, etc., for example by winding, braiding or coating onto the device one or more of these materials, typically prior to introduction into the subject. Methods of associating polymeric materials with a solid substrate such as a coil are known to those of skill in the art, for example as described in U.S. Patent Nos. 5,522,822 and 5,935,145. In yet other embodiments, the solid substrate itself is made to be radioactive for example using radioactive forms of the substrate material (*e.g.*, metal or polymer). Thus, the solid substrates can be made to be radioactive after formation by deposition (*e.g.*, coating, winding or braiding), impregnantion (*e.g.*, ion-beam or electrodeposition) or other techniques of introducing or inducing radioactivity.

In addition one or more metals, the occlusive devices may optionally include a wide variety of synthetic and natural polymers, such as polyurethanes (including copolymers with soft segments containing esters, ethers and carbonates), ethers, acrylates (including cyanoacrylates), olefins (including polymers and copolymers of ethylene, propylene, butenes, butadiene, styrene, and thermoplastic olefin elastomers), polydimethyl siloxane-based polymers, polyethyleneterephthalate, cross-linked polymers, non-cross linked polymers, rayon, cellulose, cellulose derivatives such nitrocellulose, natural rubbers, polyesters such as lactides, glycolides, caprolactones and their copolymers and acid derivatives, hydroxybutyrate and polyhydroxyvalerate and their copolymers, polyether esters such as polydioxinone, anhydrides such as polymers and copolymers of sebacic acid, hexadecandioic acid and other diacids, orthoesters may be used. In a preferred embodiment, the polymeric filament comprises the materials of the present invention or other suture materials that have already been approved for use in wound heating in humans.

Methods of Use

The coils prepared by varying the tension during winding as described above are typically removed from the winding mandrel and loaded into a carrier for introduction into

the delivery catheter. The devices are preferably first introduced to the chosen site using the procedure outlined below. This procedure may be used in treating a variety of maladies. For instance, in treatment of an aneurysm, the aneurysm itself may be filled with the mechanical devices prior to introducing the inventive composition. Shortly after the devices are placed within the aneurysm, an emboli begins to form and, at some later time, is at least partially replaced by neovascularized collagenous material formed around the vaso-occlusive devices.

In using the occlusive devices, a selected site is reached through the vascular system using a collection of specifically chosen catheters and guide wires. It is clear that should the site be in a remote site, e.g., in the brain, methods of reaching this site are somewhat limited. One widely accepted procedure is found in U.S. Patent No. 4,994,069 to Ritchart, et al. It utilizes a fine endovascular catheter such as is found in U.S. Patent No. 4,739,768, to Engelson. First of all, a large catheter is introduced through an entry site in the vasculature. Typically, this would be through a femoral artery in the groin. Other entry sites sometimes chosen are found in the neck and are in general well known by physicians who practice this type of medicine. Once the introducer is in place, a guiding catheter is then used to provide a safe passageway from the entry site to a region near the site to be treated. For instance, in treating a site in the human brain, a guiding catheter would be chosen which would extend from the entry site at the femoral artery, up through the large arteries extending to the heart, around the heart through the aortic arch, and downstream through one of the arteries extending from the upper side of the aorta. A guidewire and neurovascular catheter such as that described in the Engelson patent are then placed through the guiding catheter as a unit. Once the tip of the guidewire reaches the end of the guiding catheter, it is then extended using fluoroscopy, by the physician to the site to be treated using the vaso-occlusive devices of this invention. During the trip between the treatment site and the guide catheter tip, the guidewire is advanced for a distance and the neurovascular catheter follows. Once both the distal tip of the neurovascular catheter and the guidewire have reached the treatment site, and the distal tip of that catheter is appropriately situated, e.g., within the mouth of an aneurysm to be treated, the guidewire is then withdrawn. The neurovascular catheter then has an open lumen to the outside of the body. The devices of this invention are then pushed through the lumen to the treatment site. They are held in place variously because of their shape, size, or volume. These concepts are described in the Ritchart et al patent as well as others. Once the vaso-occlusive devices are situated in the vascular site, the embolism forms.

The mechanical or solid vaso-occlusion device may be used as a kit with the inventive polymeric composition.

Modifications of the procedure and device described above, and the methods of using them in keeping with this invention will be apparent to those having skill in this mechanical and surgical art. These variations are intended to be within the scope of the claims that follow.

CLAIMS

What is claimed is:

1. A method of making a vaso-occlusive device comprising winding an elongated wire around a mandrel, wherein the tension on the wire is varied during said winding.

2. The method of claim 1, wherein the tension is varied automatically.

3. The method of claim 1, wherein the tension is varied manually.

4. The method of any of claims 1 to 3, wherein the elongated wire is held in a holder and wherein the tension is varied during winding of the wire by varying the distance between the holder and the mandrel.

5. The method of any of claims 1 to 3, wherein the elongated wire is held in a holder and wherein the tension is varied during winding of the wire by varying the rate of winding around the mandrel.

6. The method of any of claims 1 to 3, wherein the elongated wire is held in a holder and wherein the tension is varied during winding of the wire by varying the angle between the wire and mandrel.

7. The method of any of claims 1 to 6, wherein the tension is varied using a magnetic brake.

8. The method of any of claims 1 to 6, wherein the tension is varied using a transducer.