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**GB 2344053 A**

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UK CL (Edition X ) **A5R**  
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Other: **WPI, EPODOC**

(54) Abstract Title: **Shape memory stent producing non planar, swirling flow**

(57) A method of making a stent is described such that, when placed in the human body, it defines flow following a non-planar curve e.g. swirl or helical flow. The stent production method comprises providing a tubular, hollow shape memory material structure 6, modifying the structure such that it forms a non-planar curve (see Figure 3), heating the structure so that the shape is memorised, and cooling the resulting stent. Before heating, the shape of the shape memory structure may be modified by winding it around a mandrel tool 2 having a helical groove 4. A sleeve 8 may serve to constraint the structure 6 before heating in an inert (argon) atmosphere to 500 degrees C, followed by rapid cooling at 20 degrees C; further cooling to below 5 degrees C allows the finished stent to be manipulated into a collapsed state for delivery.

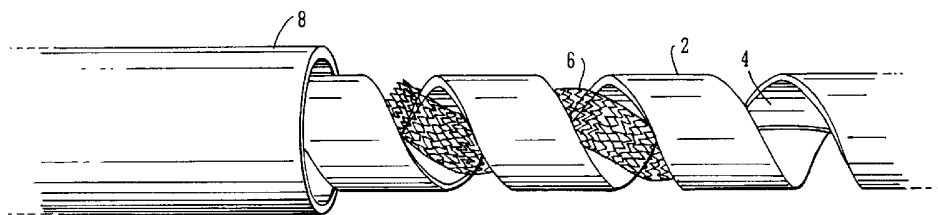


FIG. 2

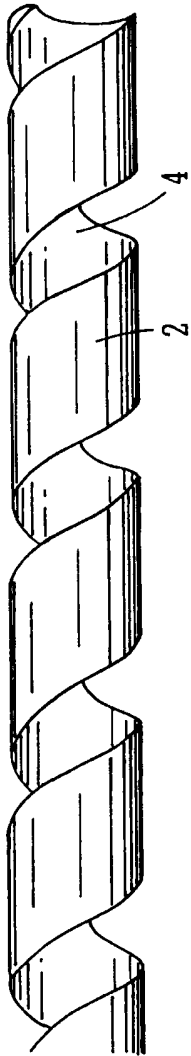


FIG. 1

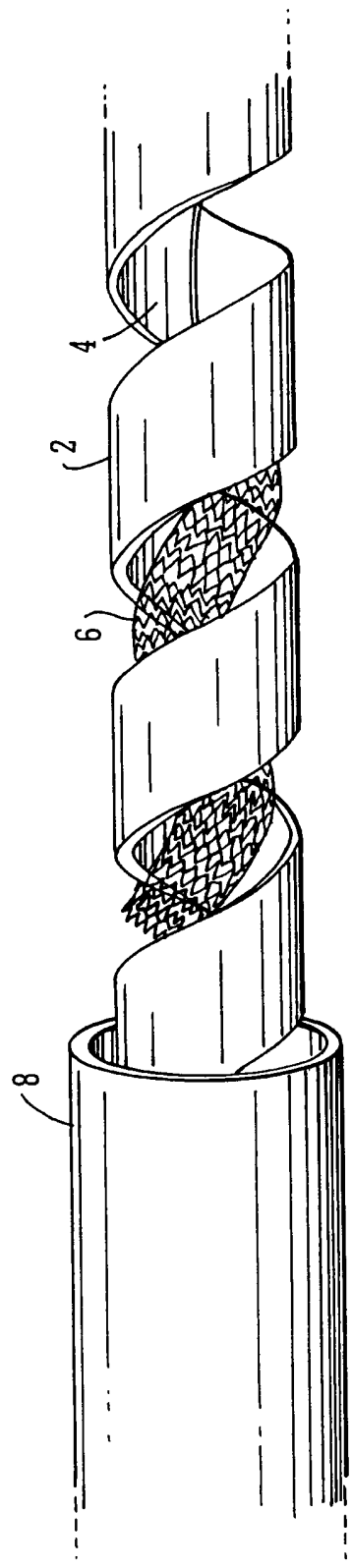


FIG. 2

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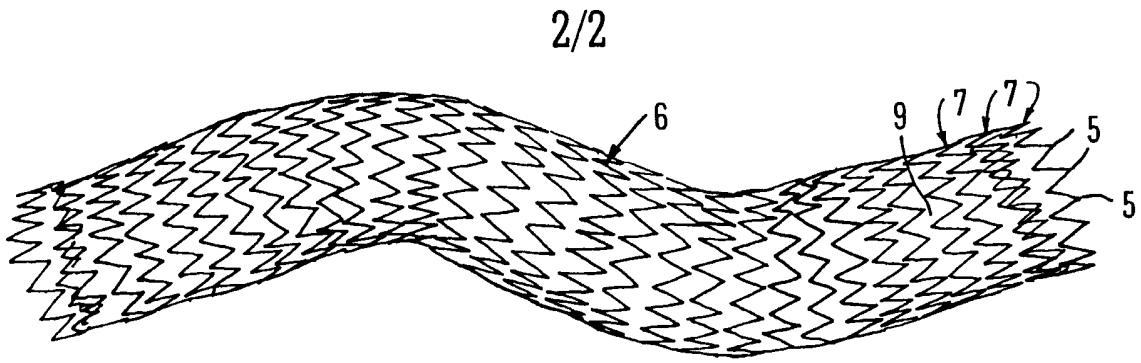


FIG. 3

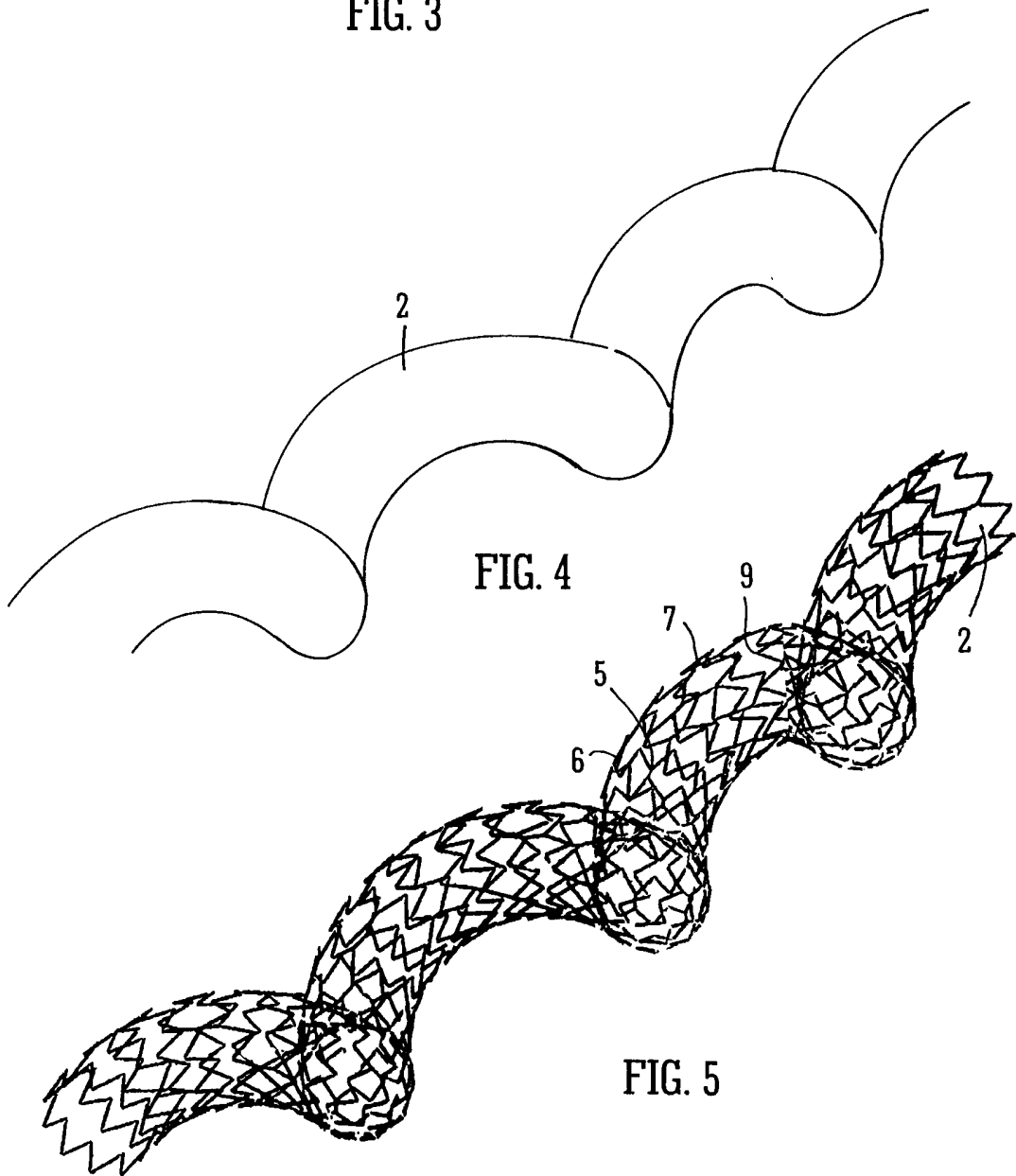


FIG. 4

FIG. 5

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Stent

5 This invention relates to methods of manufacturing stents for insertion in a fluid conduit of the human or animal body

Stents are generally tubular devices used for providing physical support to biological conduits, including blood vessels, i.e. they can be used to help prevent kinking or occlusion of conduits such as veins or arteries and to prevent their collapse after dilatation or other treatment.

10 Stents can be broadly divided into two main categories: balloon expandable stents and self-expanding stents. In the case of the former the material of the stent is plastically deformed through the inflation of a balloon, so that after the balloon is deflated the stent remains in the expanded shape. Such stents are manufactured in the "collapsed" condition, ready for delivery, and  
15 may be expanded to the expanded condition when inside the vessel or other fluid conduit

Self-expanding stents are also designed to be delivered in the collapsed condition and when released from a constraining delivery system the stent expands to its expanded condition of a predetermined size. This effect is  
20 achieved by using the elasticity of the material and/or a shape-memory or superelastic effect. In the case of shape-memory or superelastic stents a commonly used material is nitinol

Many different designs of stents are available on the market. They are made from a variety of materials providing corrosion resistance and  
25 biocompatibility, therapeutic opportunities such as the release of chemicals, ionizing radiation activity, and biodegradability. If metallic, they are made from sheet, round or flat wire or tubing. They are formed as a mesh and are generally cylindrical but also longitudinally flexible so as to conform to the curvature of the fluid conduit into which they are inserted

30 The use of shape-memory alloys to make self-expanding stents is advantageous because a stent can be cooled for easy insertion into a restraining sleeve or other constraining delivery system. Once the stent is in position in the fluid conduit of the human or animal body the constraint is removed by the operator and the stent adopts the shape "programmed" into its memory at body  
35 temperatures, for example around 37°C for the human body. The expanded shape of the stent at body temperatures is usually a cylinder having a straight

longitudinal axis, but because of the resilience of the stent when deployed it is longitudinally flexible to conform to the curvature of the fluid conduit without kinking or collapsing.

5 We have previously proposed that the flow pattern in arteries including the swirling pattern induced by their non-planar geometry operates to inhibit the development of vascular diseases such as thrombosis, atherosclerosis and intimal hyperplasia

10 In WO 98/53764, there is disclosed a stent made of shape-memory alloy for supporting part of a blood vessel. The stent includes a supporting portion around which or within which part of a blood vessel intended for grafting can be placed so that the stent internally or externally supports that part. The supporting portion of the stent is shaped so that flow between graft and host vessel is caused to follow a non-planar curve. This generates a swirl flow, to provide a favourable blood flow velocity pattern which reduces the occurrence of vascular disease, particularly intimal hyperplasia

15 In WO 00/32241, there is disclosed another type of stent, in this case including a supporting portion around which or within which part of an intact blood vessel other than a graft can be placed. This supporting portion can prevent failure of the vessel through blockage, kinking or collapse. Again, the supporting portion of the stent is of a shape and/or orientation whereby flow within the vessel is caused to follow a non-planar curve. Favorable blood flow velocity patterns can be achieved through generation therein of swirl flow within and beyond the stent. Failures in blood vessels through diseases such as thrombosis, atherosclerosis, intimal hyperplasia can thereby be significantly reduced.

25 Further aspects of how swirl flow is beneficial are explained in the above publications. It is further explained in Caro et al (1998) J Physiol 513P,2P how non-planar geometry of tubing inhibits flow instability. Further information on this topic is given in (2005) J Roy Soc Interface.

30 We have now found a way of producing an internal stent which facilitates flow within the stent supported fluid conduit to follow a non-planar curve, i.e. to swirl. We have realised that the shape-memory properties of a stent made from shape-memory material can be exploited to modify an existing cylindrical stent into one promoting swirl flow. This means that existing cylindrical stents made from shape-memory material can be used as a starting point in the new method, thereby avoiding complex geometric, mechanical or

structural modification of the wires or struts or other structural components forming the stent wall.

5 According to the invention there is provided a method of making a stent which, when the stent is inserted in a fluid conduit of the human or animal body defines a flow lumen following a non-planar curve, the method comprising providing a tubular hollow structure having a longitudinally extending cavity and made of a shape memory material, modifying the shape of the hollow structure into a shape in which its longitudinally extending cavity follows a non-planar curve, heating the modified hollow structure to a temperature such that  
10 the modified shape is memorised by the shape memory material, and cooling the hollow structure

Such a stent may be held in a constraining delivery system and when in place in the fluid conduit it will expand and seek to adopt its shape at body temperature, e.g. 37°C. It will thus define and impose a non-planar flow lumen  
15 therein. Flow within the fluid conduit supported by the stent can follow a non-planar curve, promoting swirl flow, the benefits of which are discussed above. Thus, considering the flow lumen of the conduit, as this extends in the longitudinal direction (x-axis) it curves in more than one plane (i.e. in both the y-axis and the z-axis). In other words, the flow lumen extends generally  
20 helically in the longitudinal direction.

The shape memory property of the stent is used not just to facilitate insertion in a delivery system and expansion to a much wider shape, as is conventional, but also to provide a flow lumen modified from the conventional linear shape  
25

The shape of the hollow structure may be modified by placing it along a flexible rod and twisting both the hollow structure and the rod so that both adopt a generally helical shape. Preferably, the shape of the hollow structure is modified by winding it round a tool, such as a mandrel. The tool is preferably substantially rigid. The tool may be a simple cylinder, but in order to provide  
30 control of the shape of the hollow structure (in particular the pitch and amplitude thereof) the tool may have a helical groove for receiving the hollow structure. Thus the shape of the hollow structure may for example be modified by placing it along a machined groove in a rod shaped tool. Advantageously, the hollow structure is constrained in contact with the tool, so that it does not return to the original cylindrical shape during heat treatment. This can be done using a wire  
35 along the inside of the hollow structure and/or a sleeve placed externally of the

hollow structure and rod. Thus, the hollow structure and tool may be together inserted in a suitable sleeve.

Another way of modifying the shape of the hollow structure would be to insert a tool inside the structure. Such a tool preferably has a helical shape, and may take the form of a helical rod. This method will generally not require the use of a sleeve or other constraint around the hollow structure and therefore has the advantage that the heating and cooling of the hollow structure can be carried out with greater uniformity and more rapidly. It is generally desirable to cool the hollow structure quickly, for example by quenching it in water, and this is facilitated by a method in which the rod or mandrel has a relatively small mass and the hollow structure is exposed directly to the cooling means. This method also provides superior constraint and improved control over the new helical set shape.

Certain preferred embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 shows a mandrel for use in the method of the invention,

Figure 2 shows a hollow structure inserted into a groove in the mandrel,

Figure 3 shows the hollow structure after it has been removed from the mandrel;

Figure 4 shows another form of mandrel, and

Figure 5 shows a hollow structure with the mandrel of Figure 4 inserted therein.

A tool in the form of a mandrel 2 is made from stainless steel and is formed with a helical groove 4 extending along its length. The groove 2 has a diameter suitable to receive a hollow structure 6, as seen in Figure 2. The hollow structure is a conventional cylindrical stent made of shape memory alloy, which is deformed from its usual linear shape to a shape following the helical groove of the mandrel.

Figure 4 shows another form of mandrel 8, in the form of a stainless steel rod having a helical shape. This rod is designed to be inserted inside the hollow structure 6 of a conventional shape memory alloy stent, so as to modify the longitudinal cavity of the hollow structure to conform to the shape of the helical rod. This is seen in Figure 5.

#### 35 **EXAMPLE 1**

A nitinol stent was used, having an outside diameter of 8 mm. The stent was placed in the groove 4 of the mandrel 2 as shown in Figure 2. In order to prevent the stent from springing out of the groove it was restrained by a steel sleeve (8). It was placed in a hot furnace heated to 500°C in an inert (oxygen free) atmosphere (argon) for 15 minutes. The mandrel, hollow structure and sleeve were then immersed in water at a temperature of 20°C so as to be rapidly cooled.

The sleeve was removed and the stent was separated from the mandrel. When the stent so made is cooled to below 5°C, for example by being placed in iced water, it is easily manipulated and so can be readily placed in a collapsed condition constrained by an appropriate delivery system. When the stent is deployed in a fluid conduit of the human or animal body, it expands to a helical shape, so as to define a flow lumen following a non-planar curve.

It is expected that the modification process applied to the stent will have no adverse physiological effects.

### **EXAMPLE 2**

The mandrel of Figure 4 was inserted in a the same type of stent as described in Example 1. The stent and mandrel were placed in a hot furnace heated to 500°C in an inert (oxygen free) atmosphere (argon) for 15 minutes. They were then immersed in water at a temperature of 20°C so as to be rapidly cooled. The stent and mandrel were separated and the stent had adopted a helical shape. By cooling this stent to below 5°C it can be easily constrained in a delivery system. When it is deployed in a fluid conduit of a human or animal body it defines a flow lumen following a non-planar curve.

**Claims**

- 1        A method of making a stent which, when the stent is inserted in a fluid  
conduit of the human or animal body defines a flow lumen following a non-  
5        planar curve, the method comprising providing a tubular hollow structure having  
a longitudinally extending cavity and made of a shape memory material,  
modifying the shape of the hollow structure into a shape in which its  
longitudinally extending cavity follows a non-planar curve, heating the modified  
hollow structure to a temperature such that the modified shape is memorised by  
10        the shape memory material, and cooling the hollow structure.
2.        A method as claimed in claim 1, wherein the shape of the hollow  
structure is modified by winding it round a tool
- 15        3        A method as claimed in claim 2, where the tool has a helical groove for  
receiving the hollow structure.
- 4        A method as claimed in claim 2 or 3, comprising constraining the hollow  
structure in contact with the tool.  
20
- 5        A method as claimed in claim 4, wherein a sleeve is used to constrain the  
hollow structure in contact with the tool.
- 6        A method as claimed in claim 1, comprising inserting a tool inside the  
25        hollow structure to modify its shape



INVESTOR IN PEOPLE

Application No: GB0508859.6

Examiner: Matthew Males

Claims searched: 1

Date of search: 18 August 2005

### Patents Act 1977: Search Report under Section 17

#### Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1	GB 2344053 A IMPERIAL COLLEGE - whole document but see abstract; page 3, lines 5 - 8 and line 25 - page 4, line 2; page 7, lines 17 - 25; Figures 6A - 6C.

#### Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

#### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>x</sup> :

A5R

Worldwide search of patent documents classified in the following areas of the IPC<sup>07</sup>

A61F

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC