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(54) **MEDICAL DEVICES WITH TUBULAR REINFORCEMENT**

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(21) Appl. No.: **18/339,039**

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Related U.S. Application Data

(63) Continuation of application No. PCT/US2021/065252, filed on Dec. 27, 2021.

(60) Provisional application No. 63/234,165, filed on Aug. 17, 2021, provisional application No. 63/131,767, filed on Dec. 29, 2020.

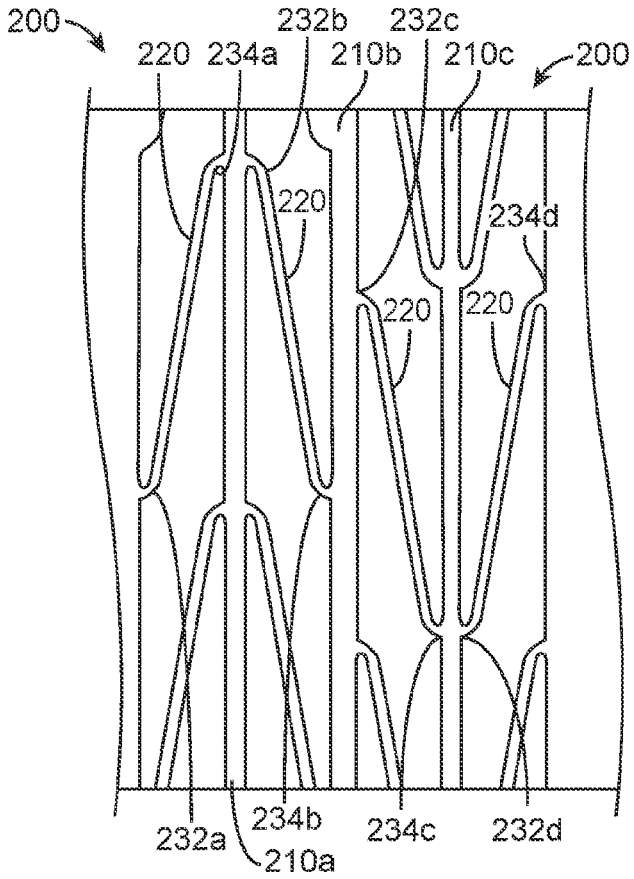
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(52) **U.S. Cl.**
CPC ***A61M 25/0051*** (2013.01); ***A61M 25/0013*** (2013.01); ***A61M 25/0054*** (2013.01); ***A61M 25/0068*** (2013.01); *A61M 25/0138* (2013.01)

(57) **ABSTRACT**

A catheter includes: a tubular structure having a longitudinal axis; wherein the tubular structure comprises first and second rings arranged in series along the longitudinal axis, the first and second rings being respective closed-loops, wherein the first ring lies within a first plane that is substantially perpendicular to the longitudinal axis; wherein the tubular structure comprises a first connecting member having a first end, a second end, and a member body; and a second connecting member comprises a first end, a second end, and a member body; and wherein the second end of the first connecting member and the first end of the second connecting member are connected to the first ring, and disposed across from each other, and wherein the second end of the second connective member is connected to the second ring, and wherein the respective member bodies are configured to rotate and/or bent.



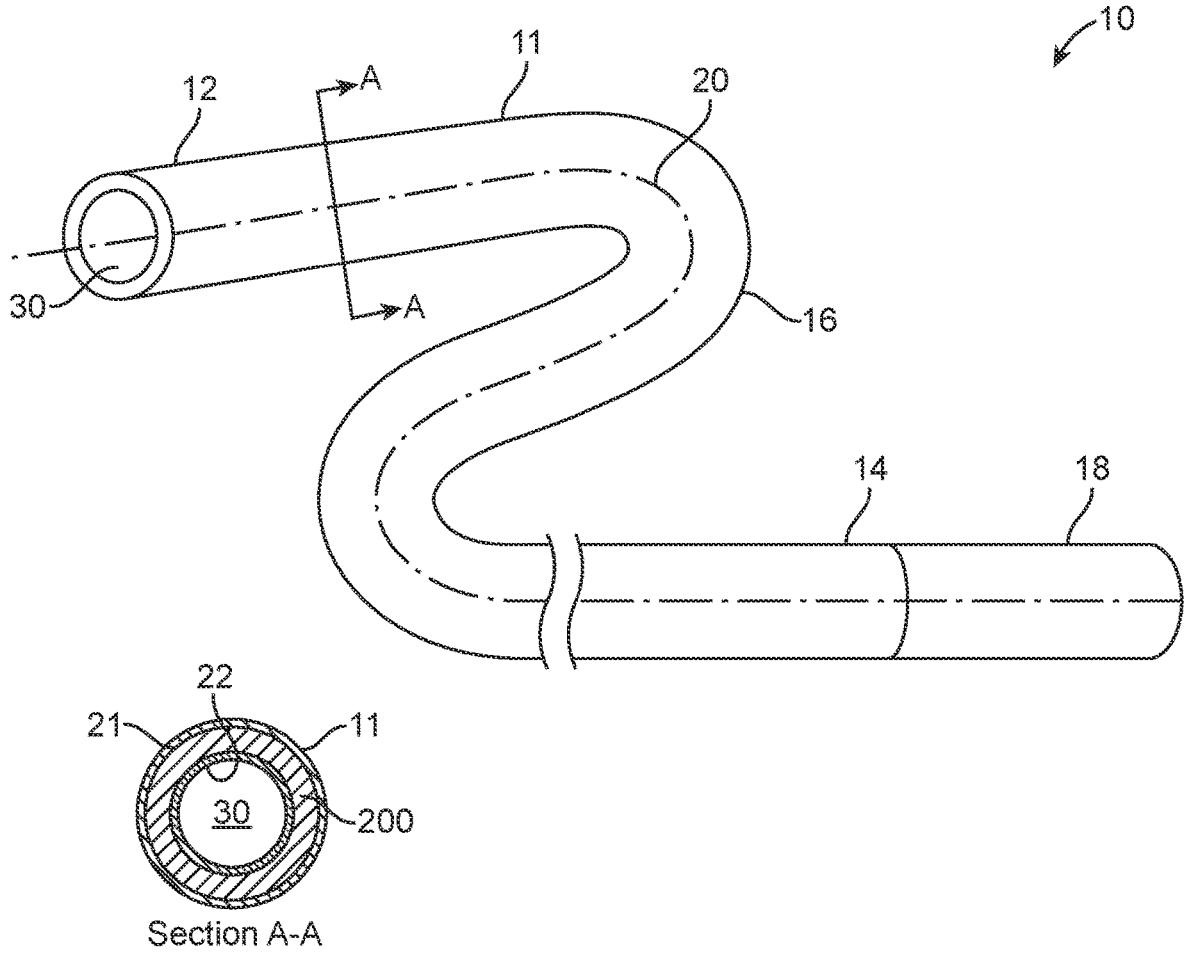


FIG. 1

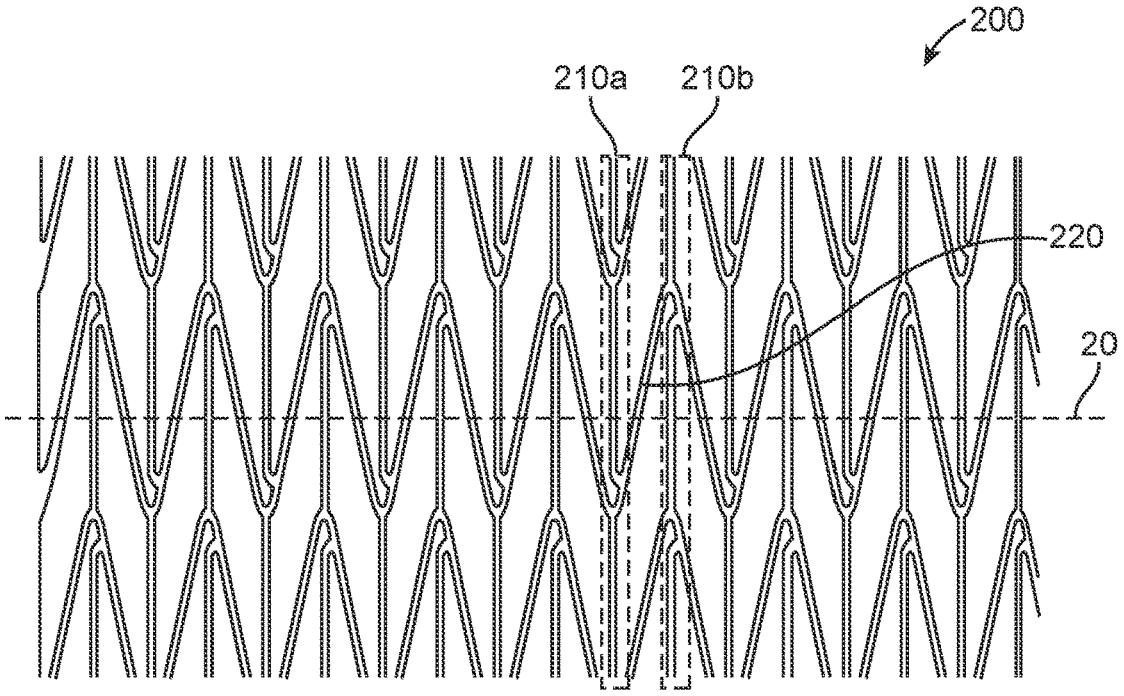

200
210a
210b
220
20

FIG. 2A

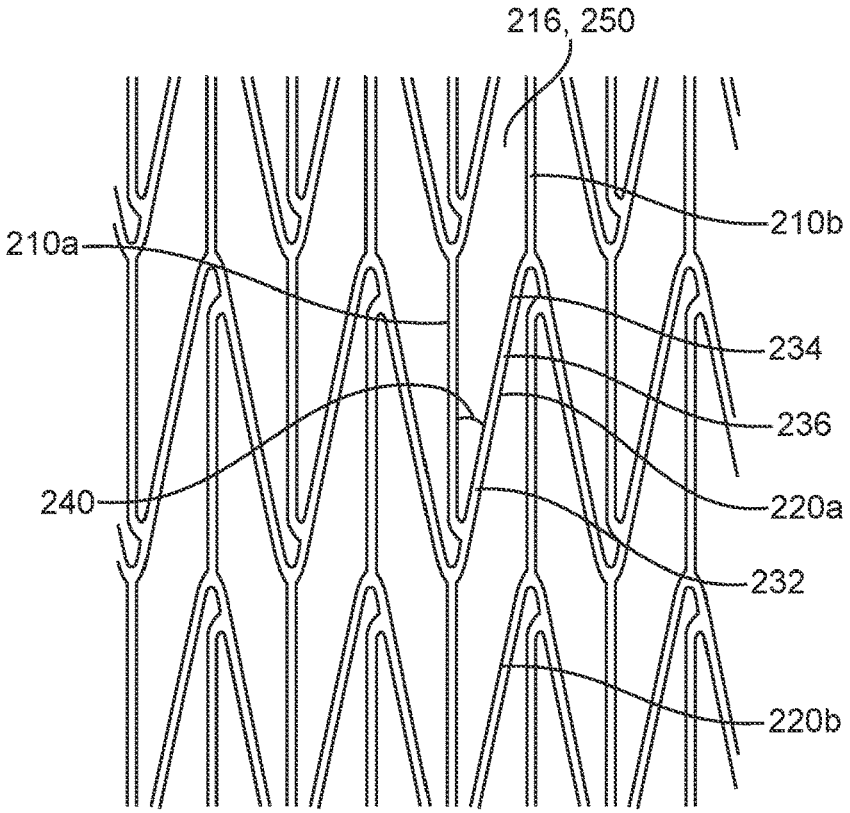

216, 250
210b
210a
234
236
240
220a
232
220b

FIG. 2B

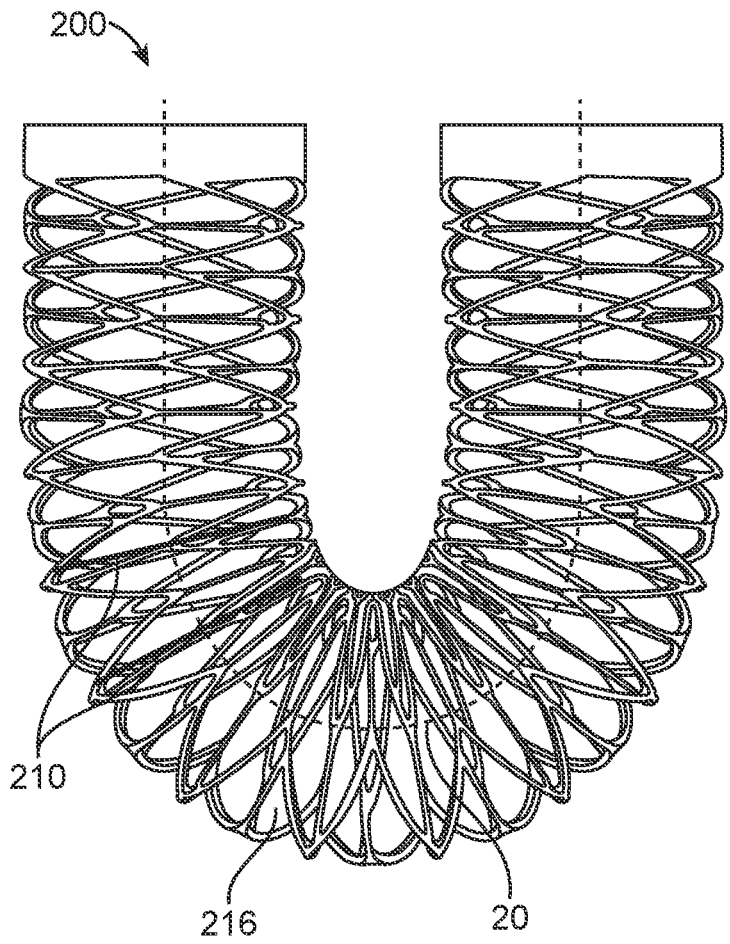


FIG. 3A

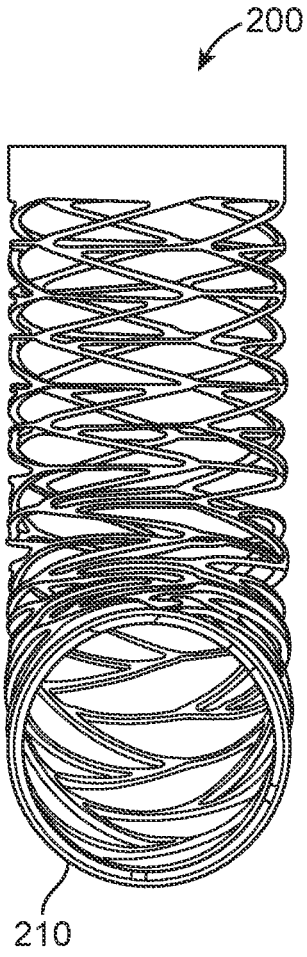


FIG. 3B

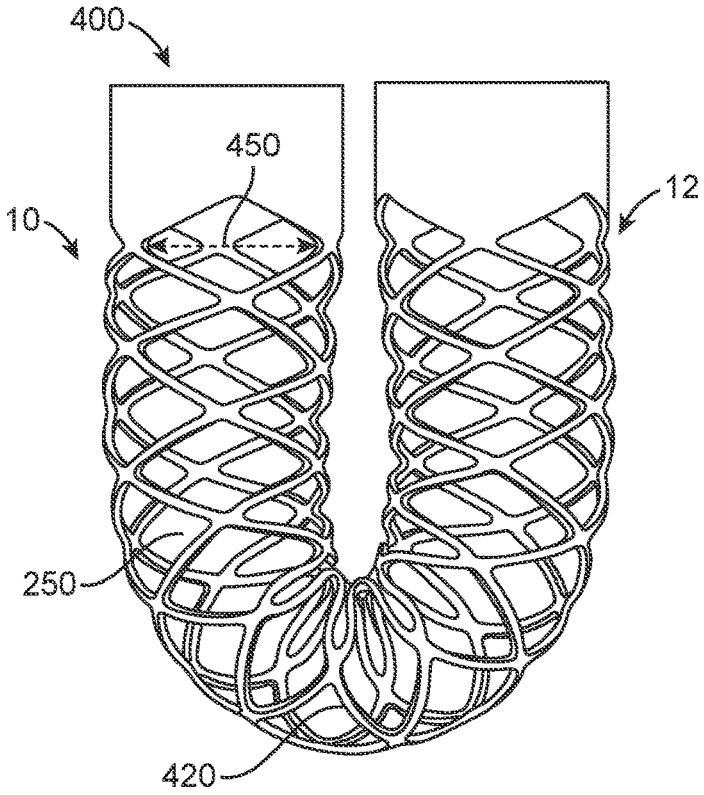


FIG. 4A

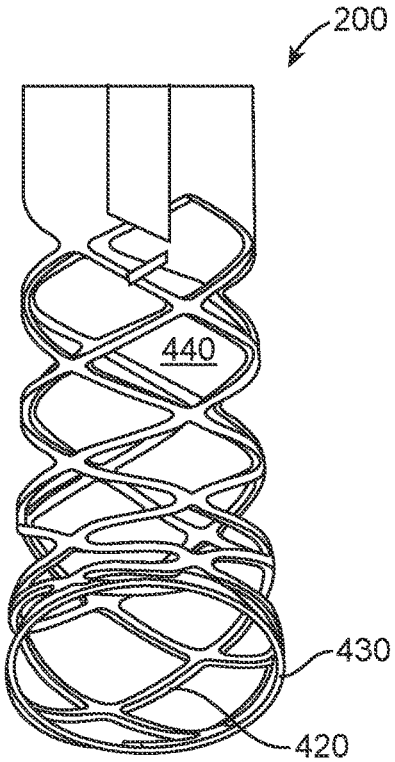


FIG. 4B

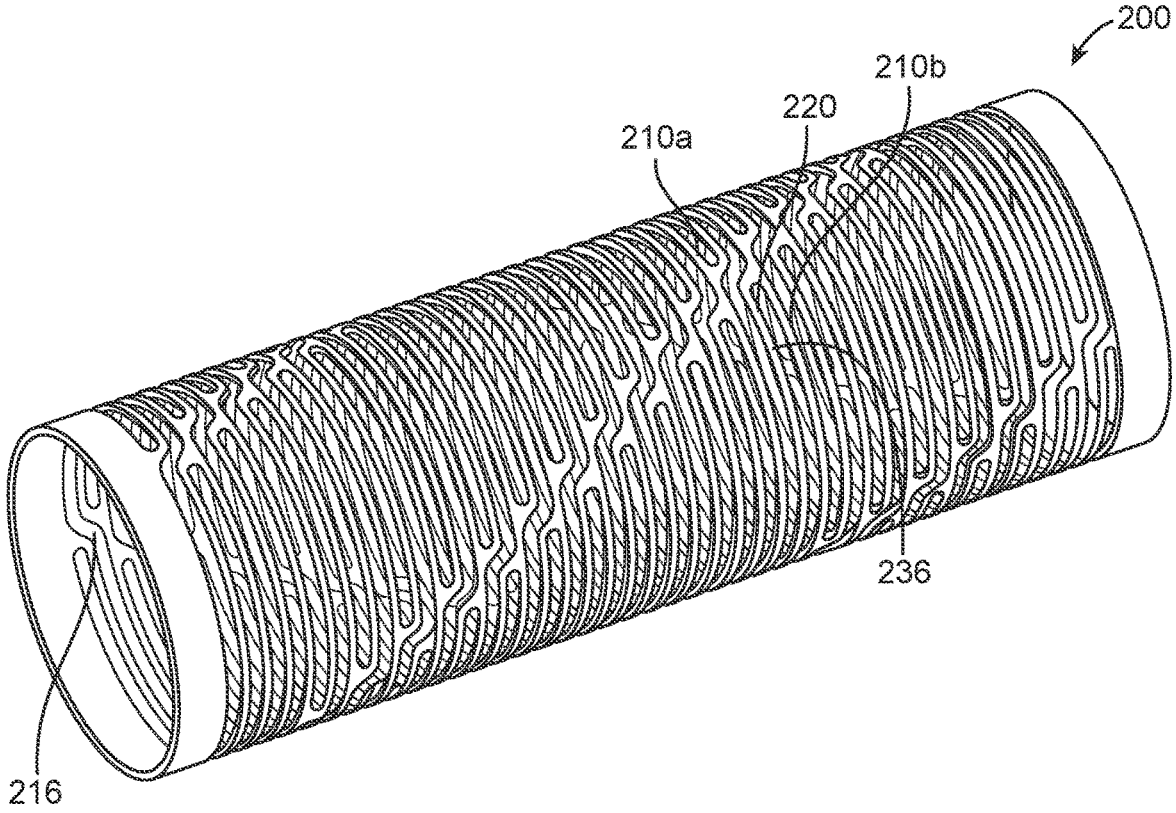


FIG. 5

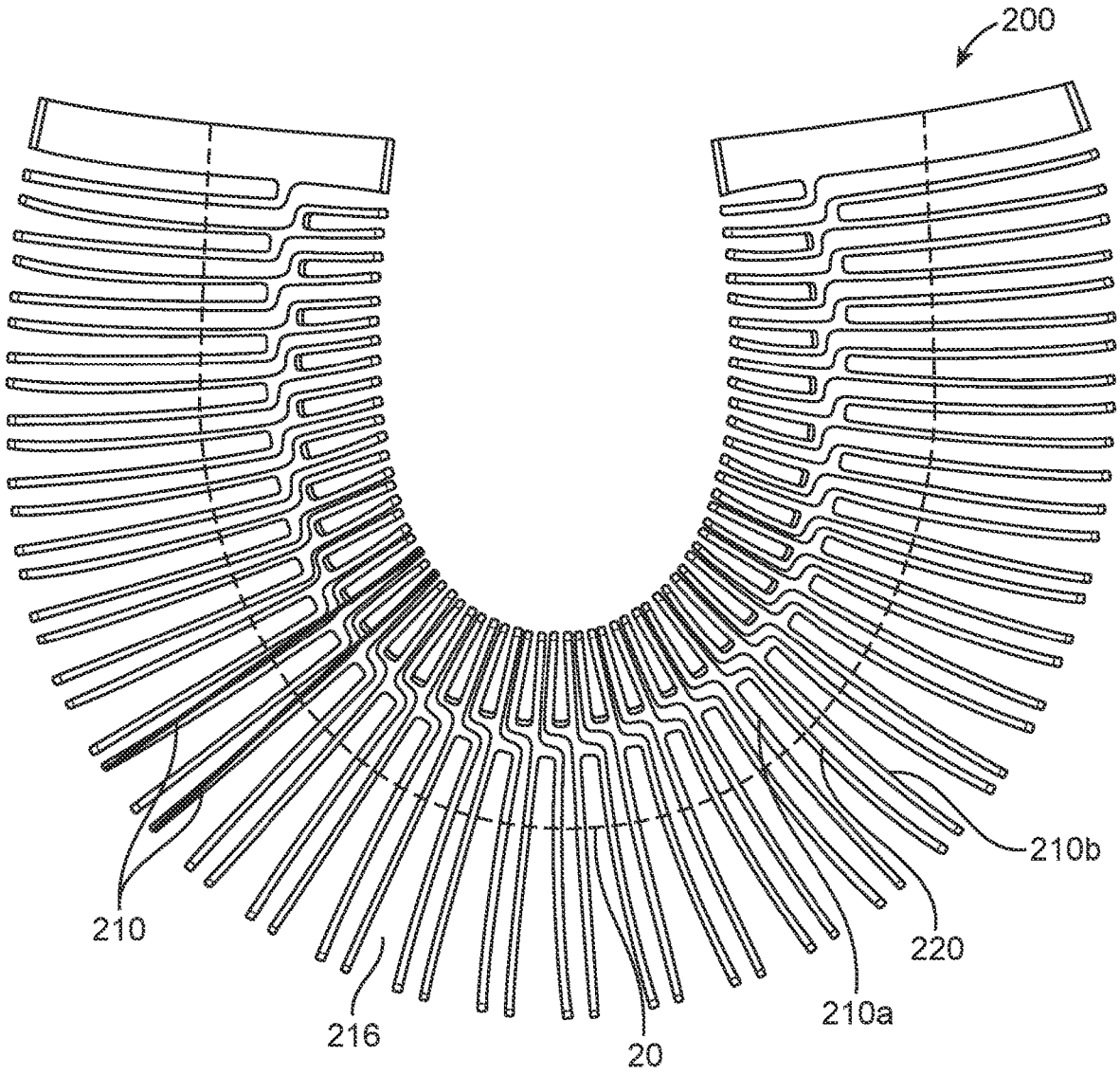


FIG. 6

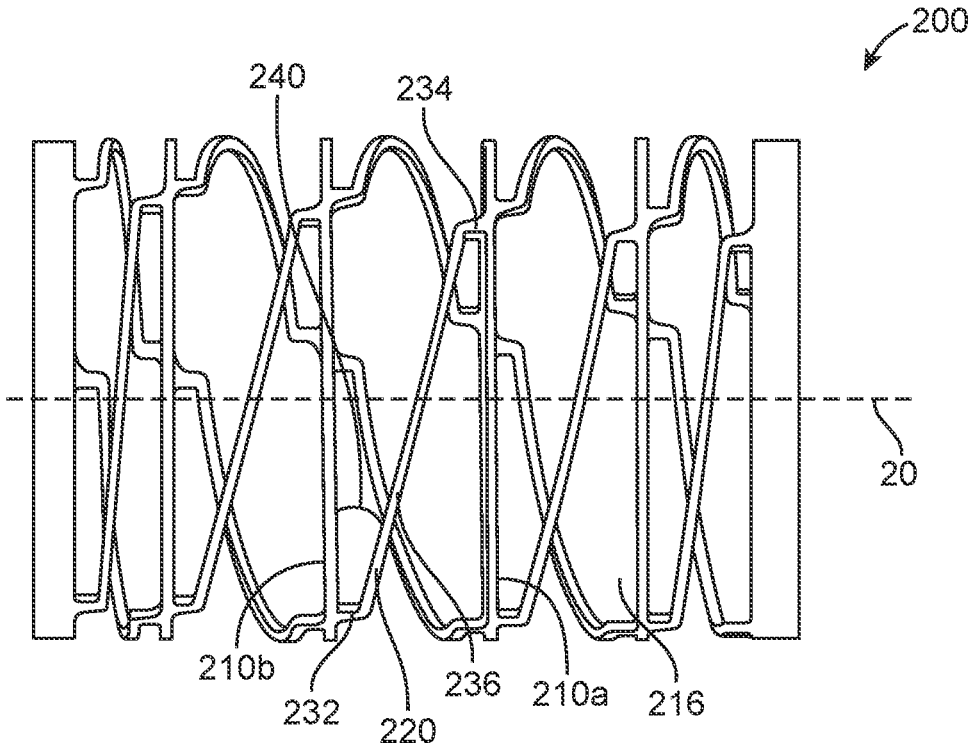


FIG. 7

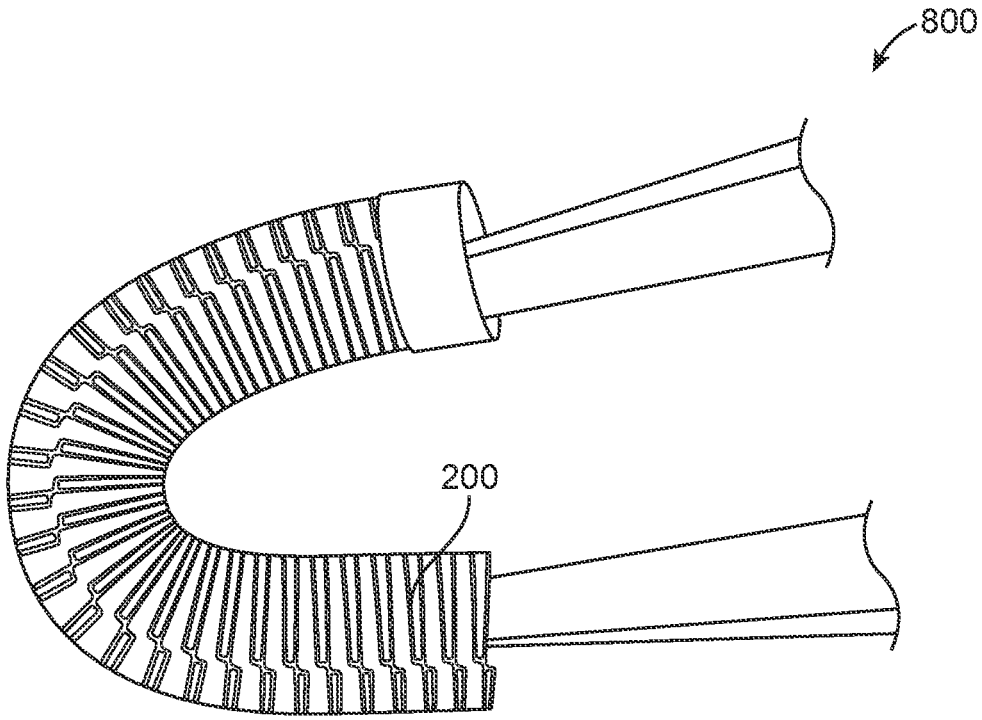


FIG. 8

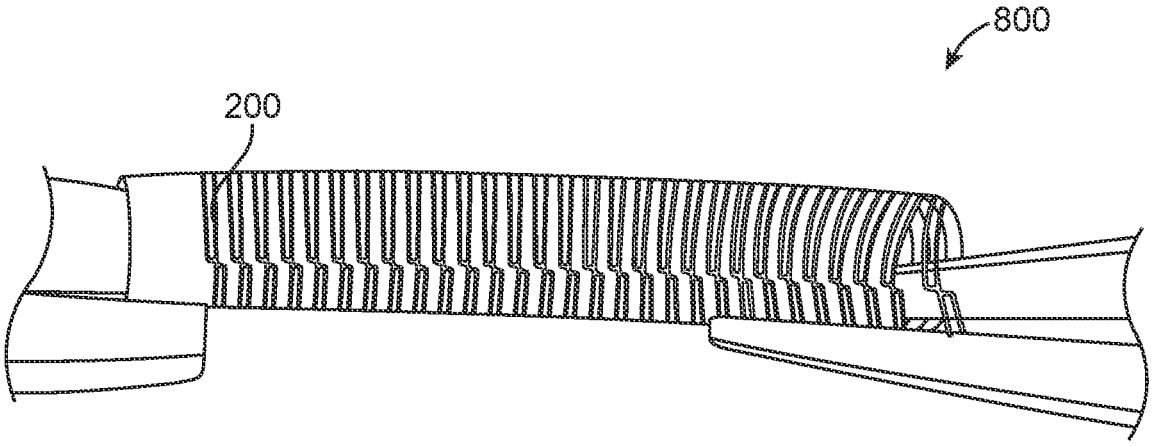


FIG. 9

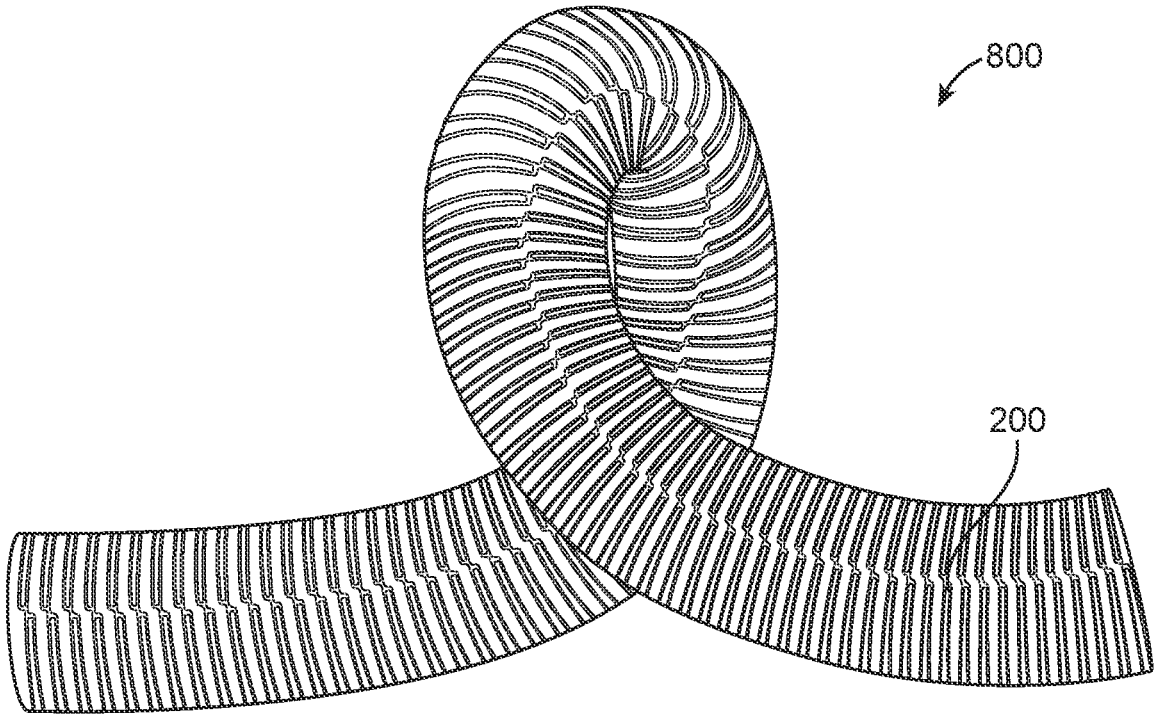


FIG. 10

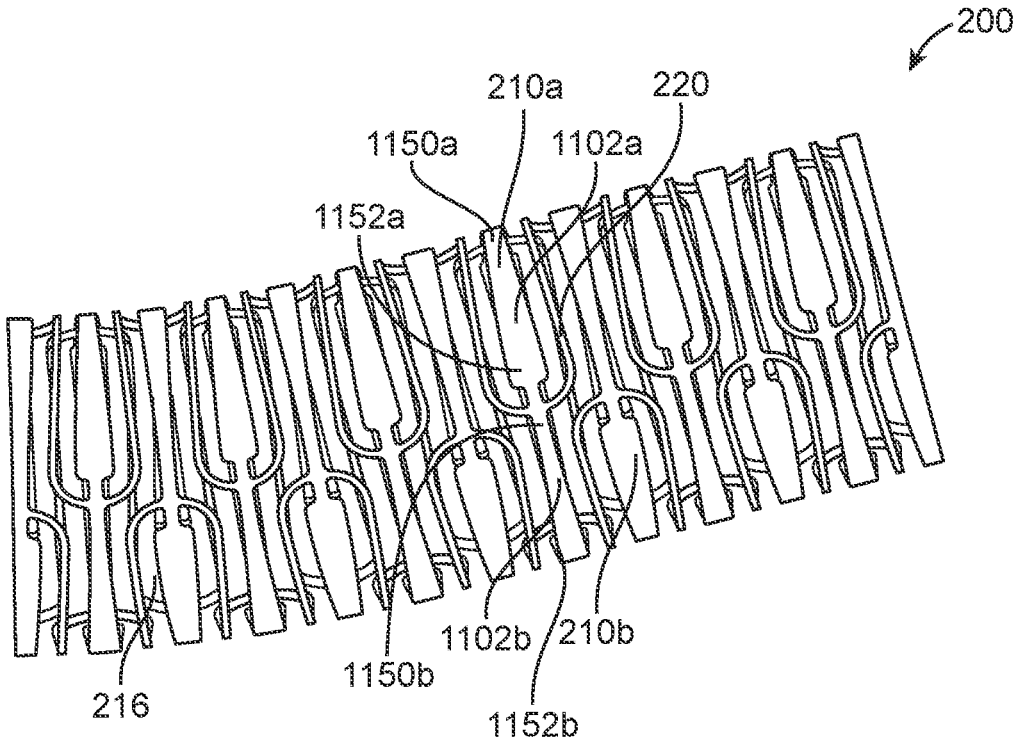

200
210a
220
1150a
1102a
1152a
1102b
210b
1150b
216
1152b

FIG. 11

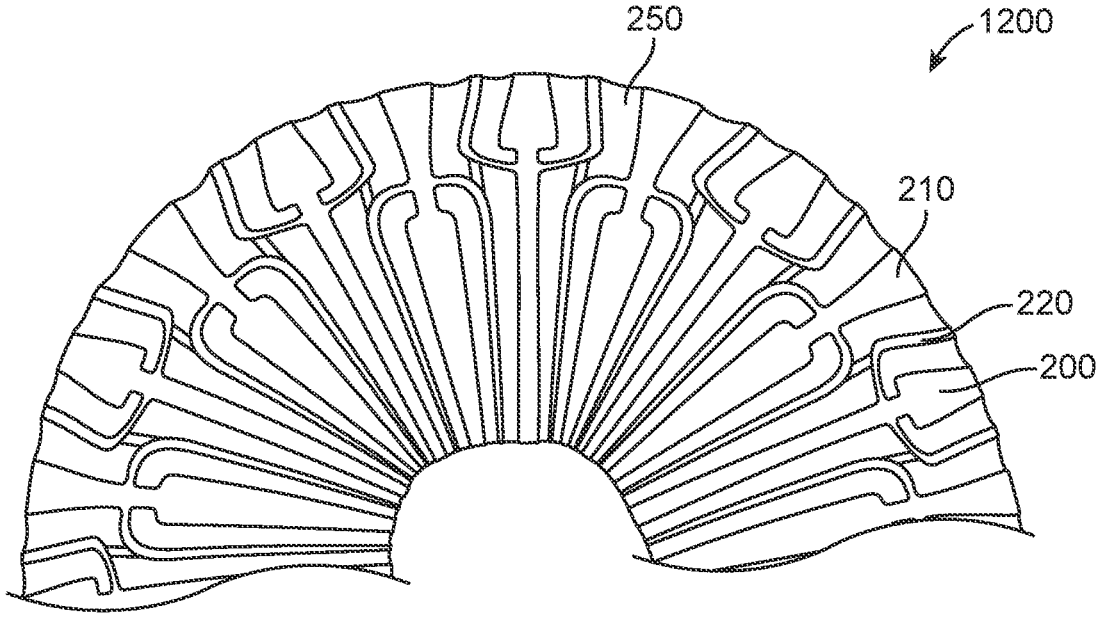

250
1200
210
220
200

FIG. 12

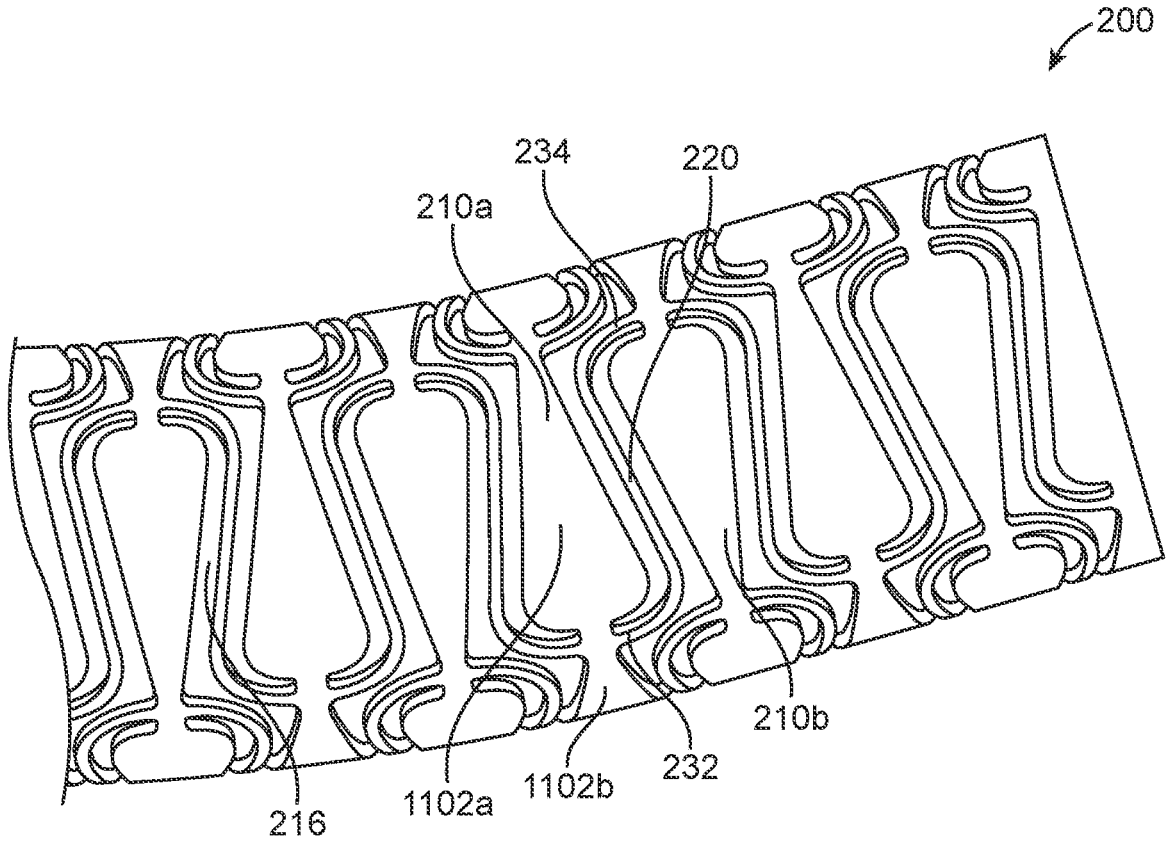


FIG. 13

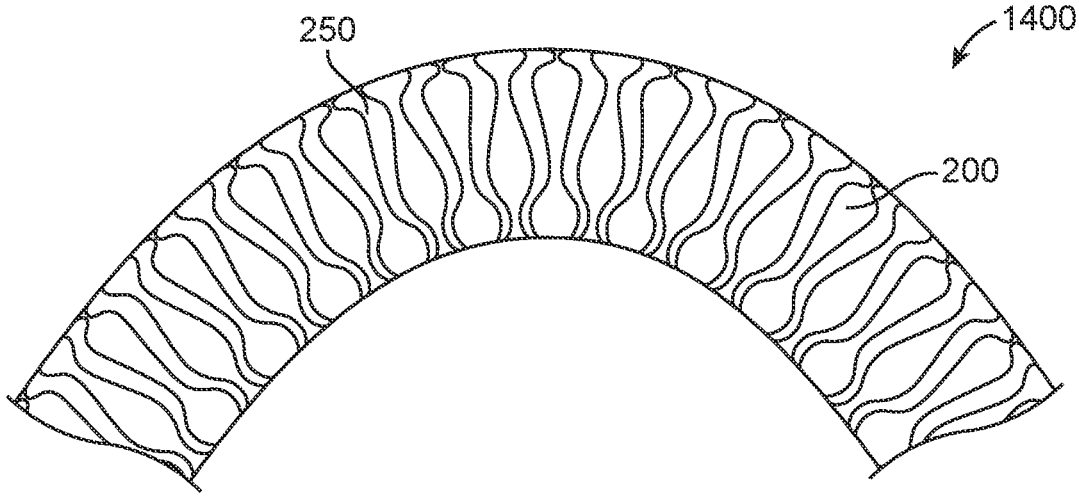


FIG. 14

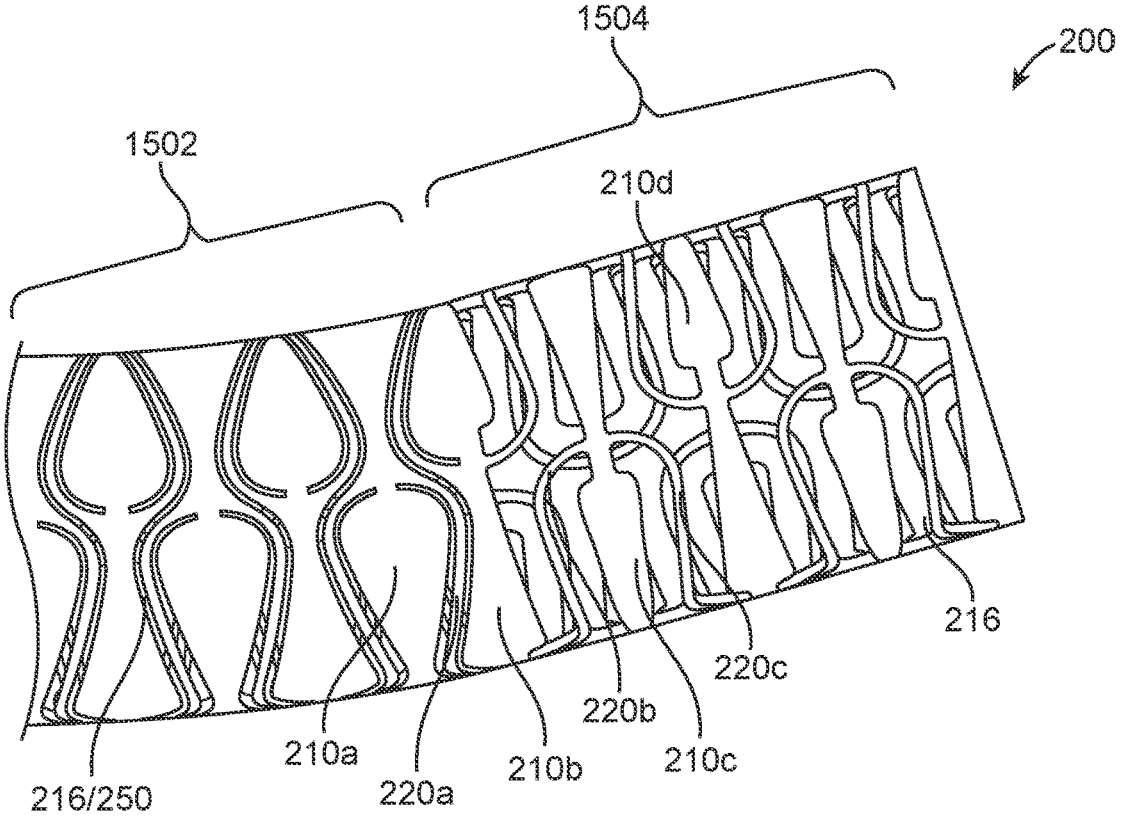

1504
200
1502
210d
216
220c
220b
210c
210a
210b
220a
216/250

FIG. 15

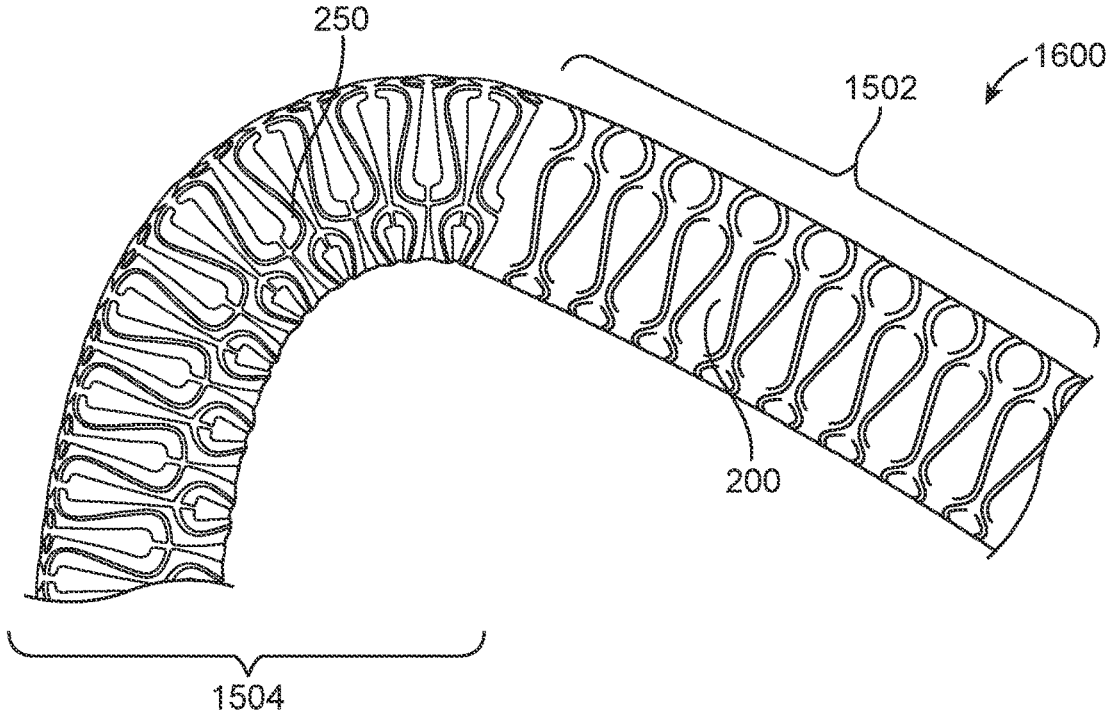

250
1600
1502
200
1504

FIG. 16

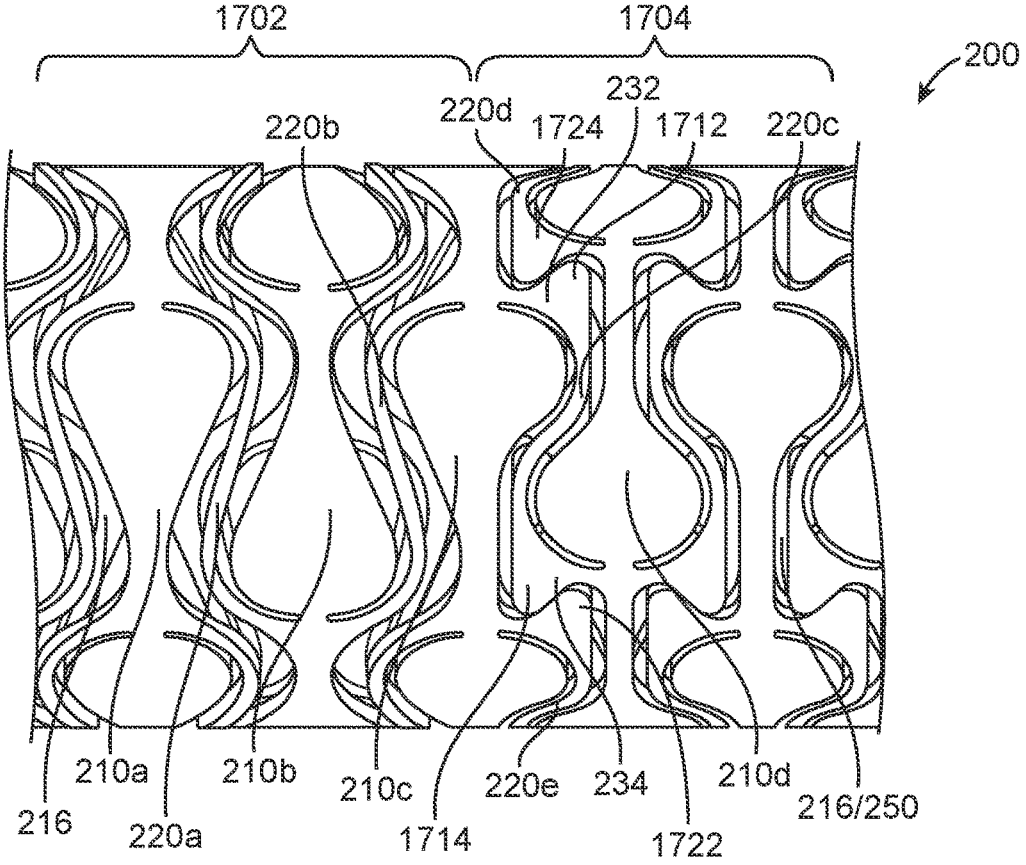

1702
1704
200
232
220b
220d
1724
1712
220c
216
210a
220a
210b
210c
1714
220e
234
1722
210d
216/250

FIG. 17

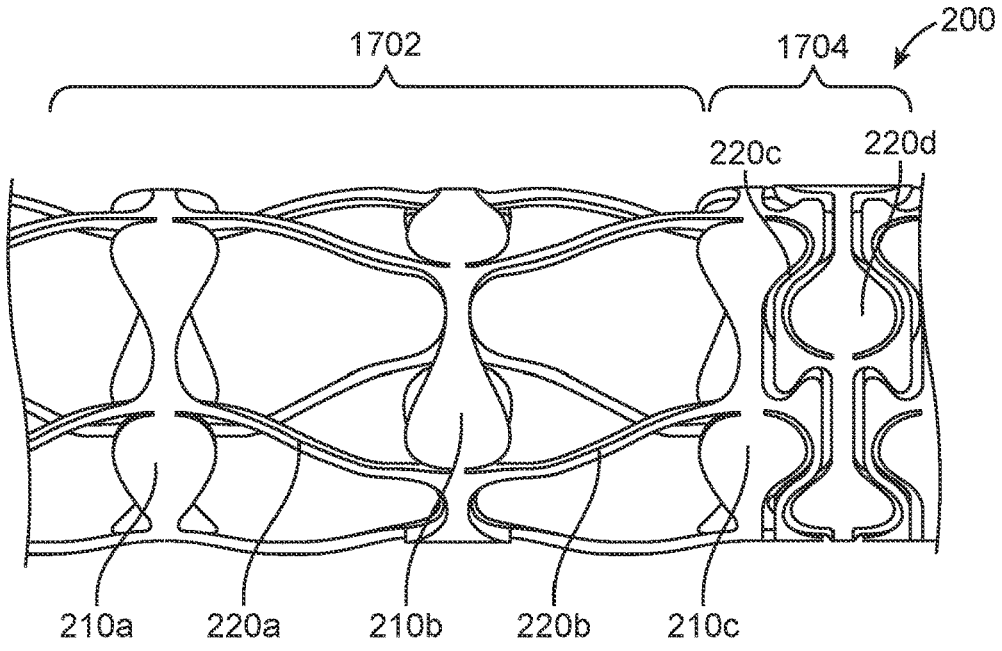

1702
1704
200
220c
220d
210a
220a
210b
220b
210c

FIG. 18

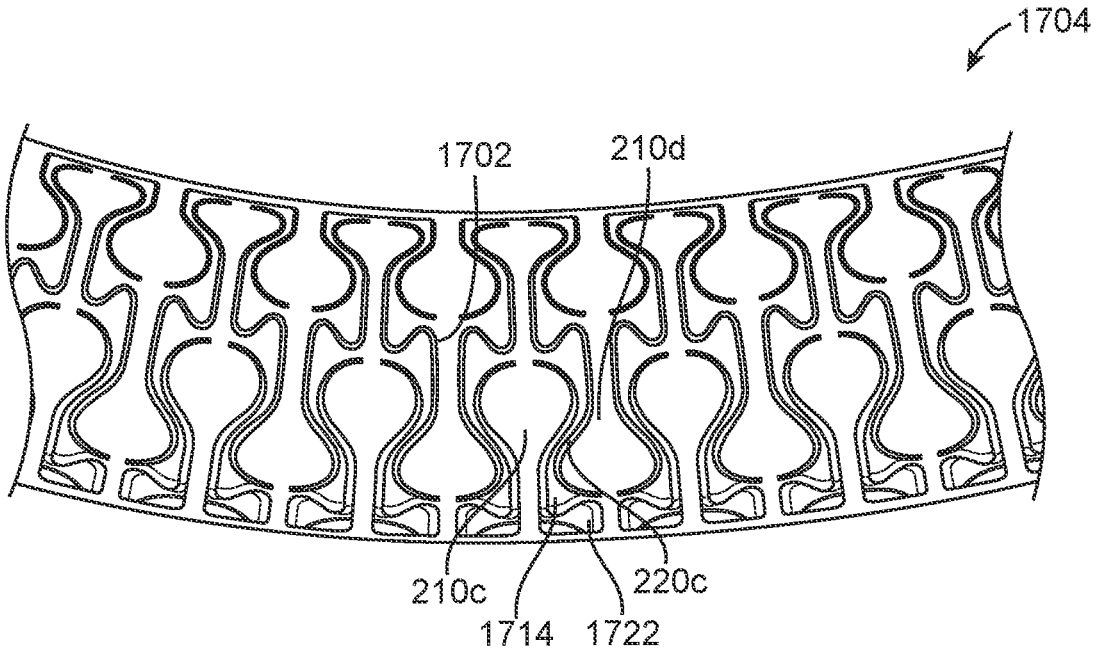


FIG. 19

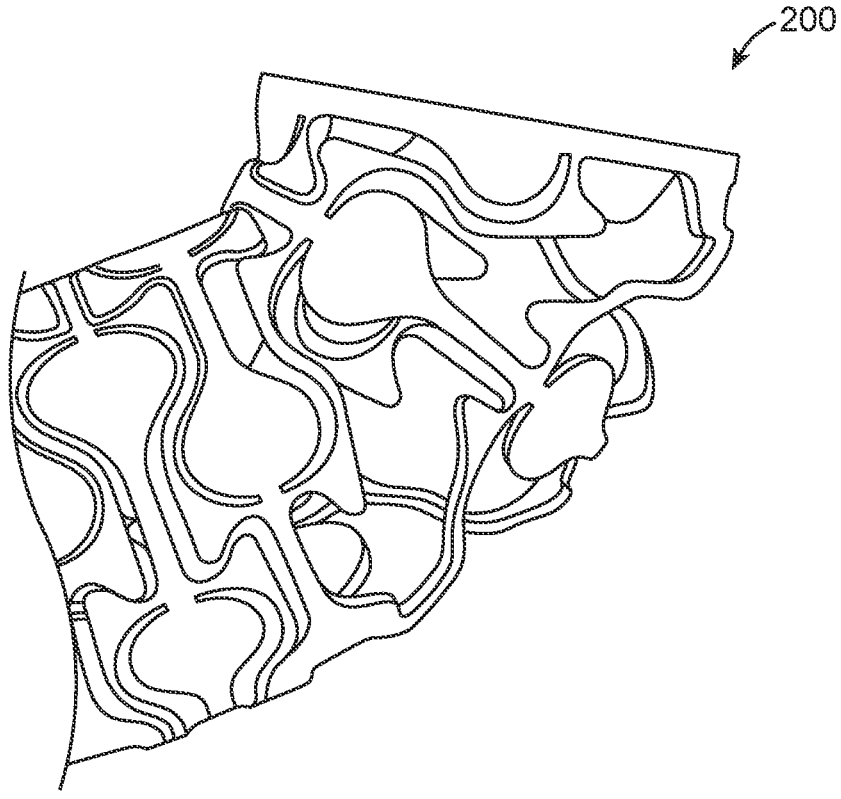


FIG. 20

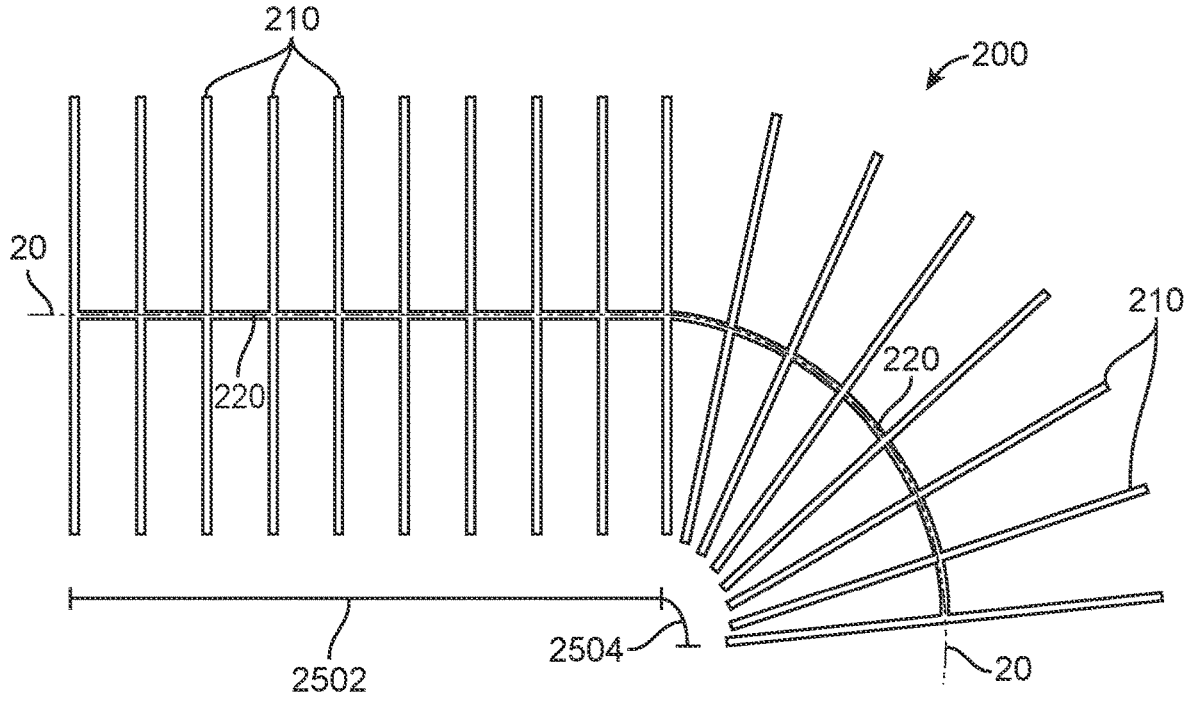


FIG. 21A

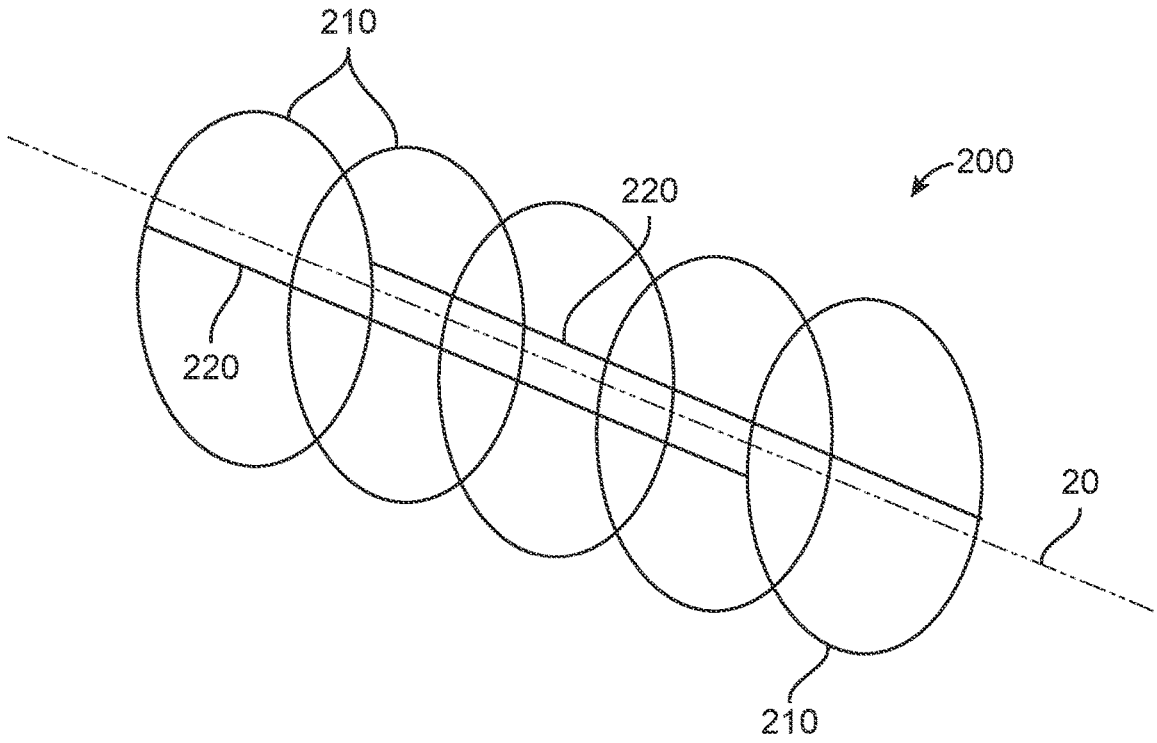


FIG. 21B

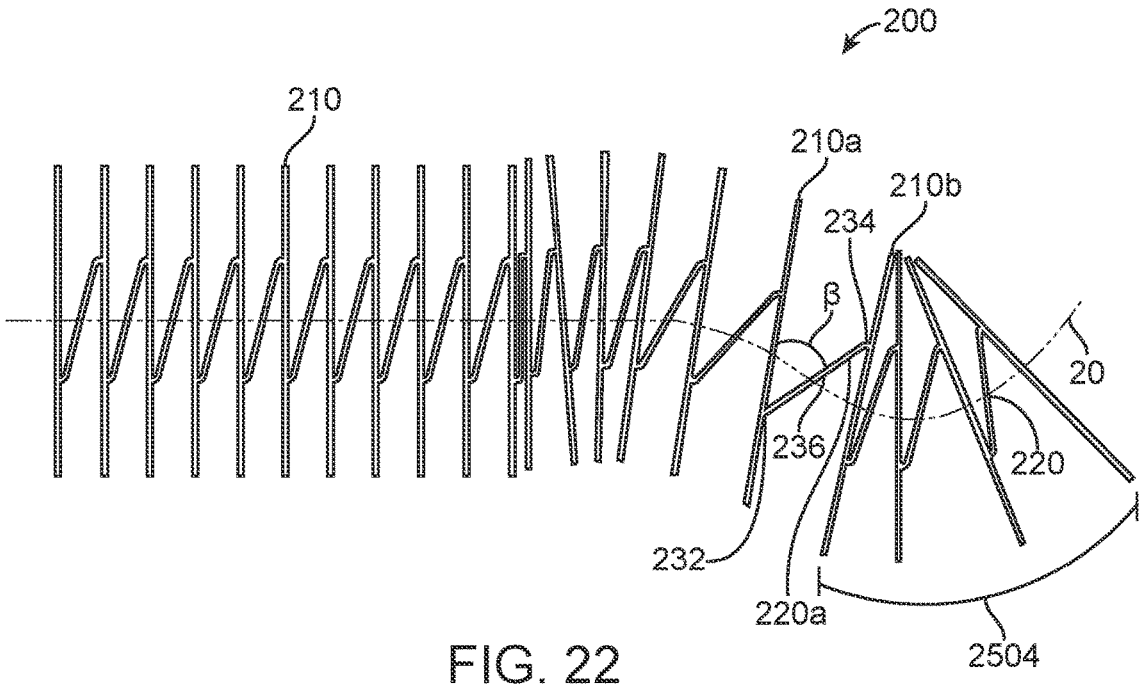

200
210
210a
210b
234
β
20
236
220
232
220a
2504

FIG. 22

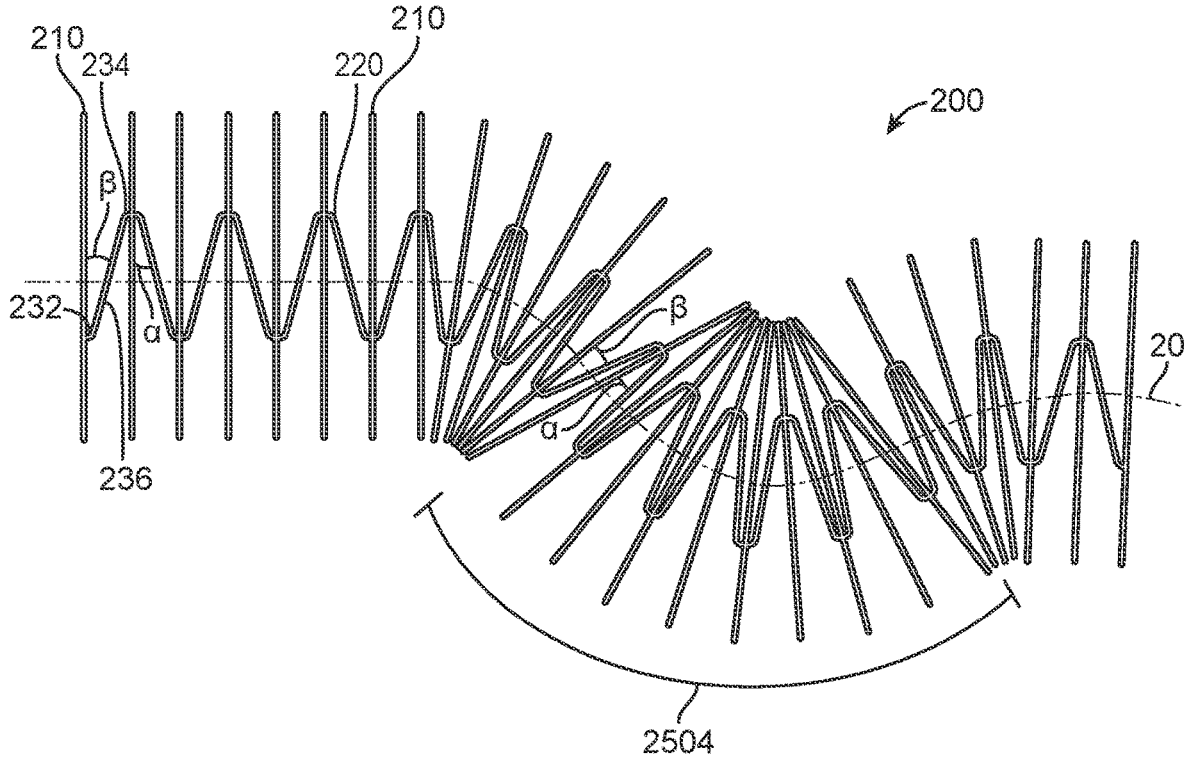

210
234
210
220
200
β
232
α
β
20
α
236
2504

FIG. 23

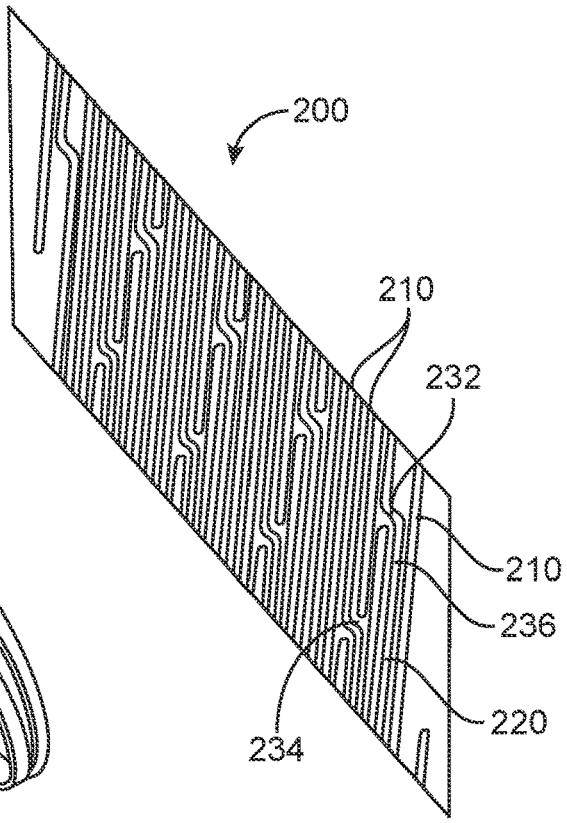


FIG. 24A

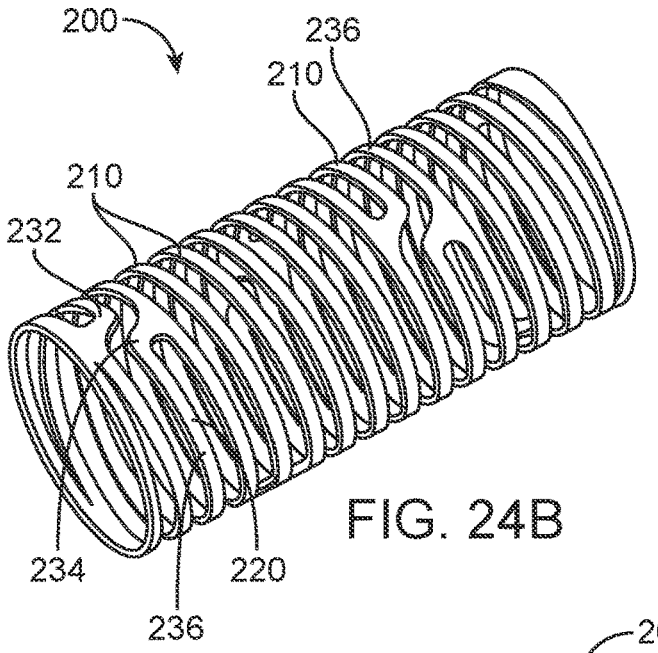


FIG. 24B

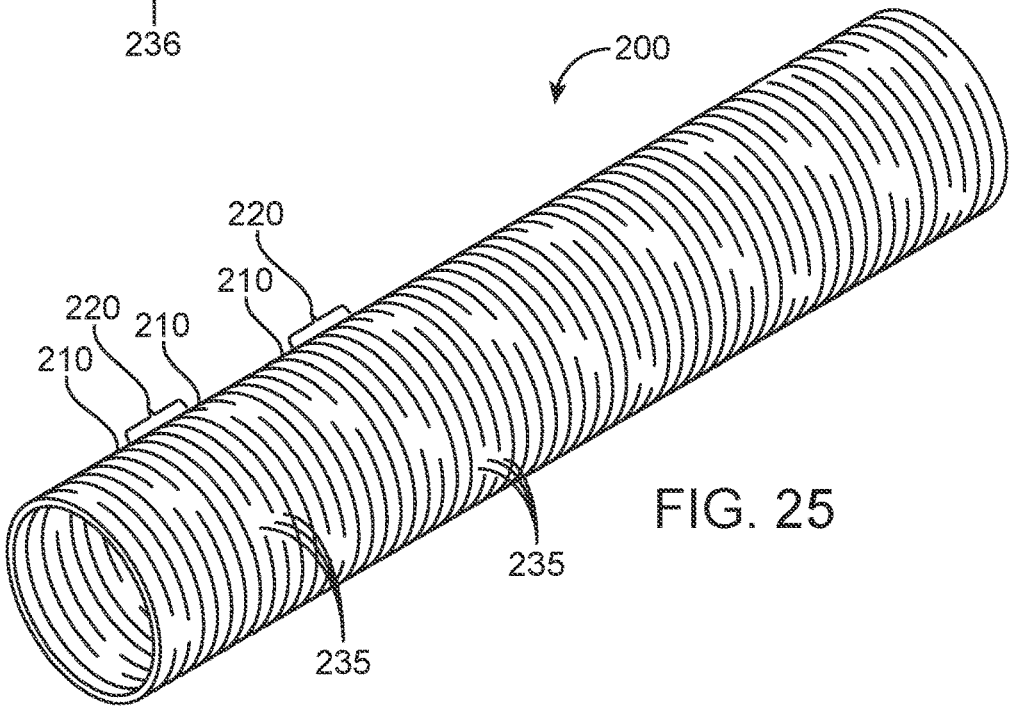


FIG. 25

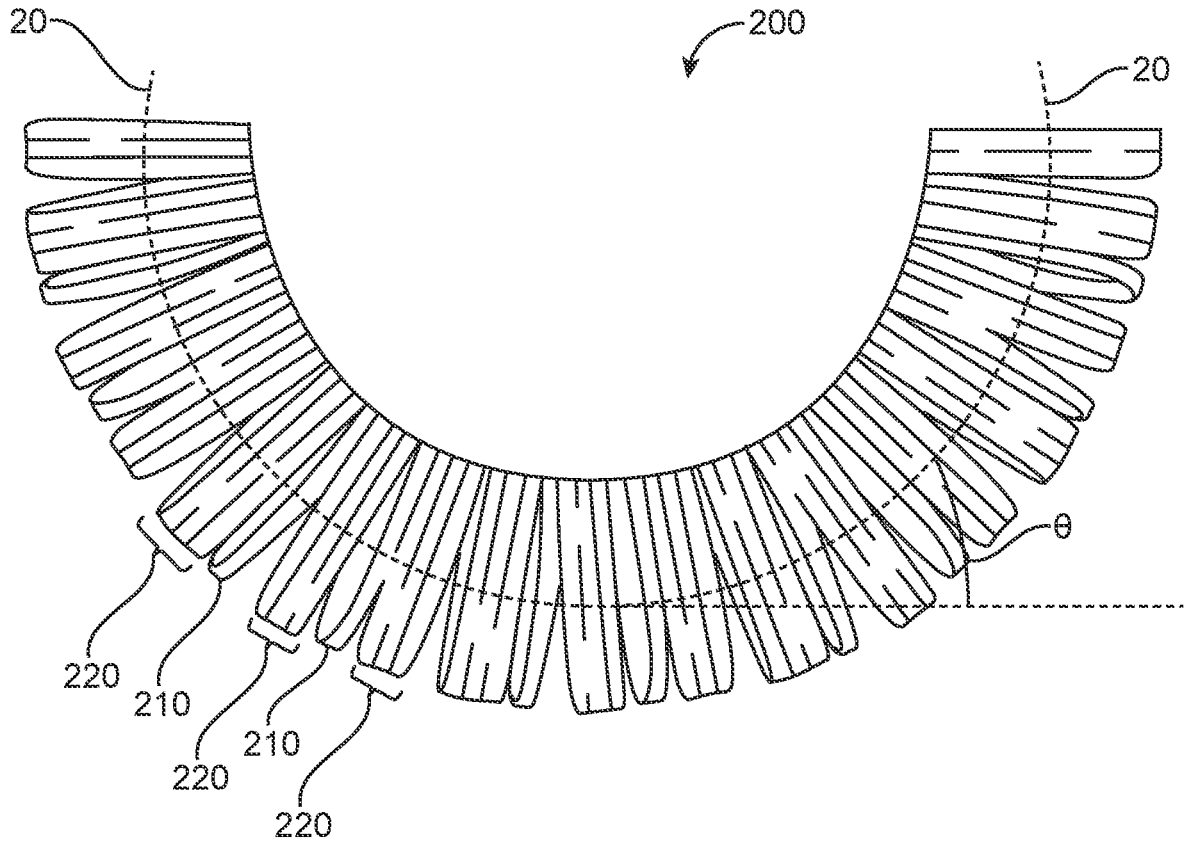


FIG. 26

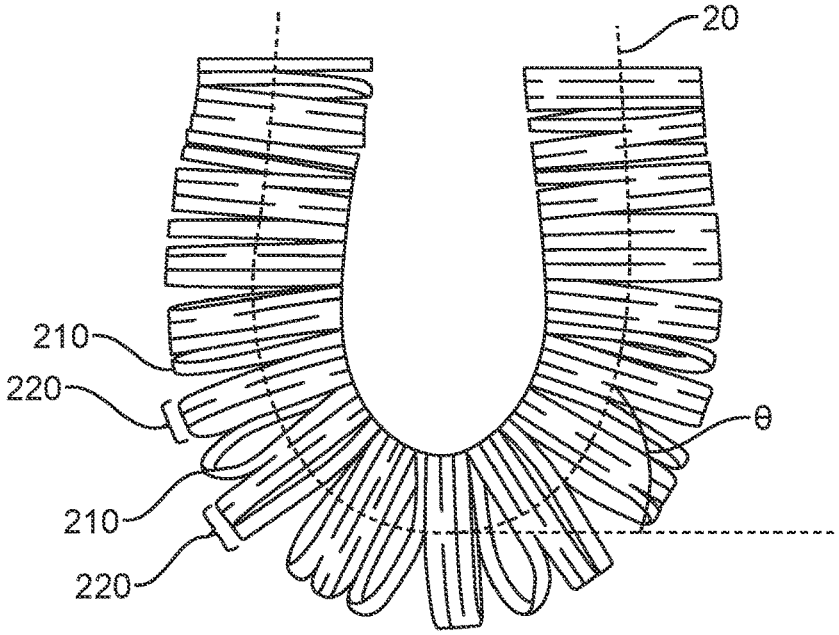


FIG. 27

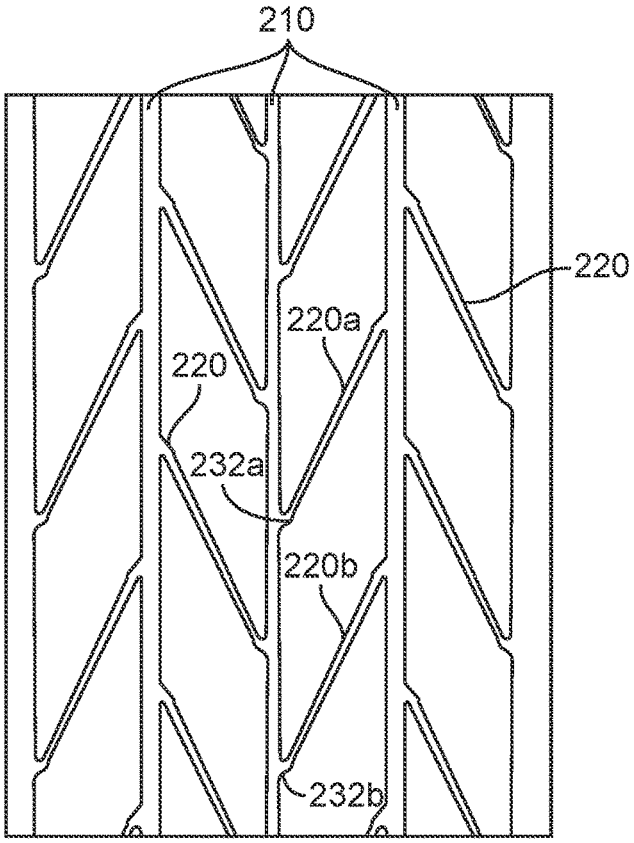


FIG. 28A

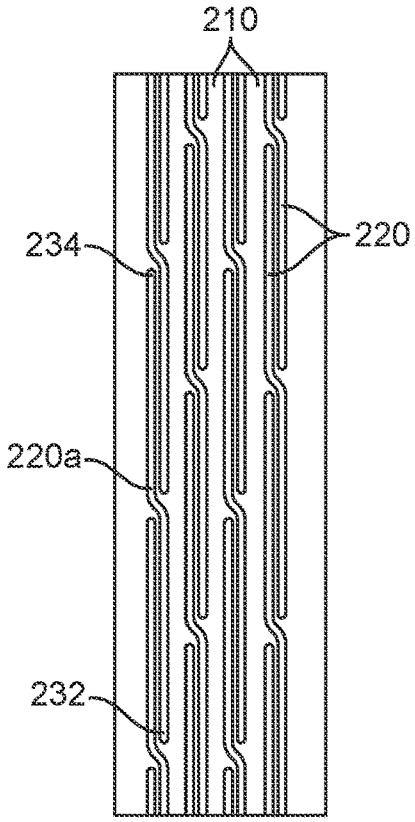


FIG. 28B

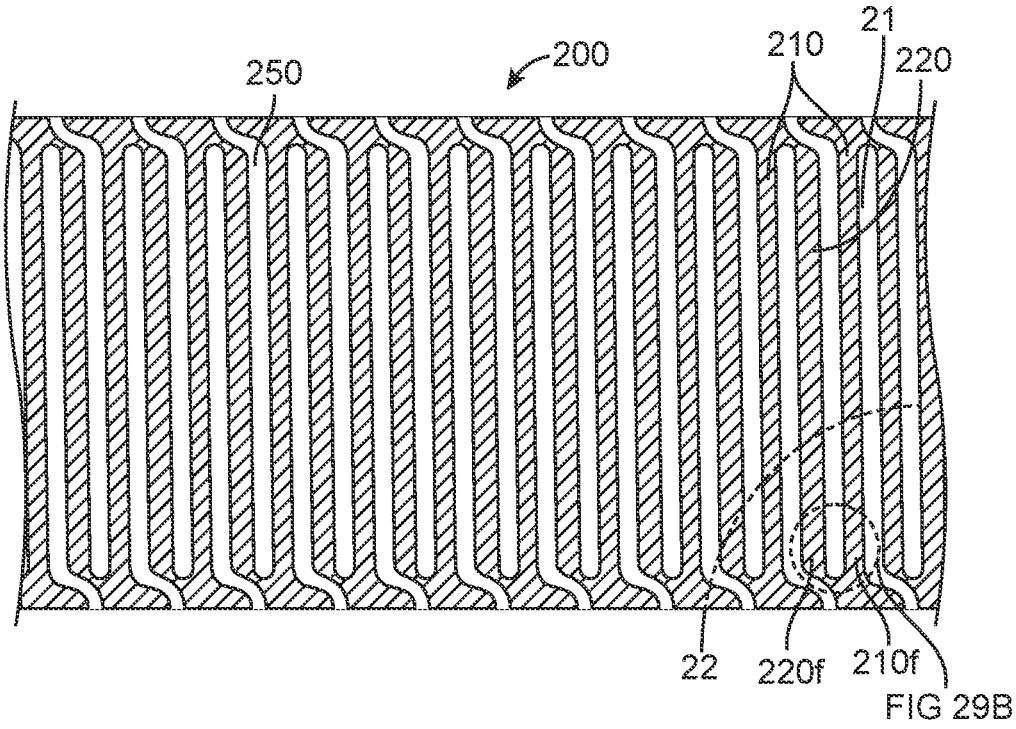


FIG. 29A

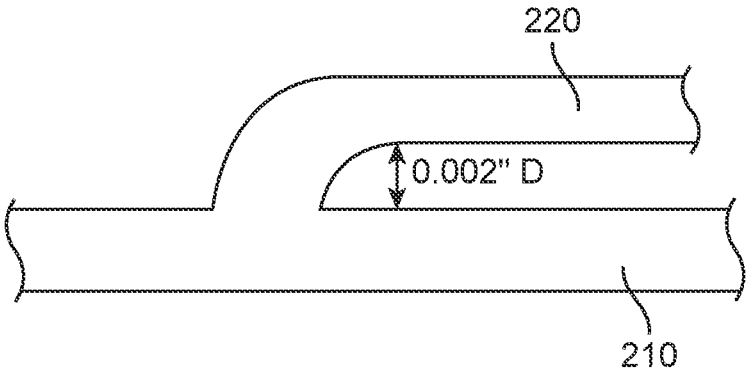


FIG. 29B

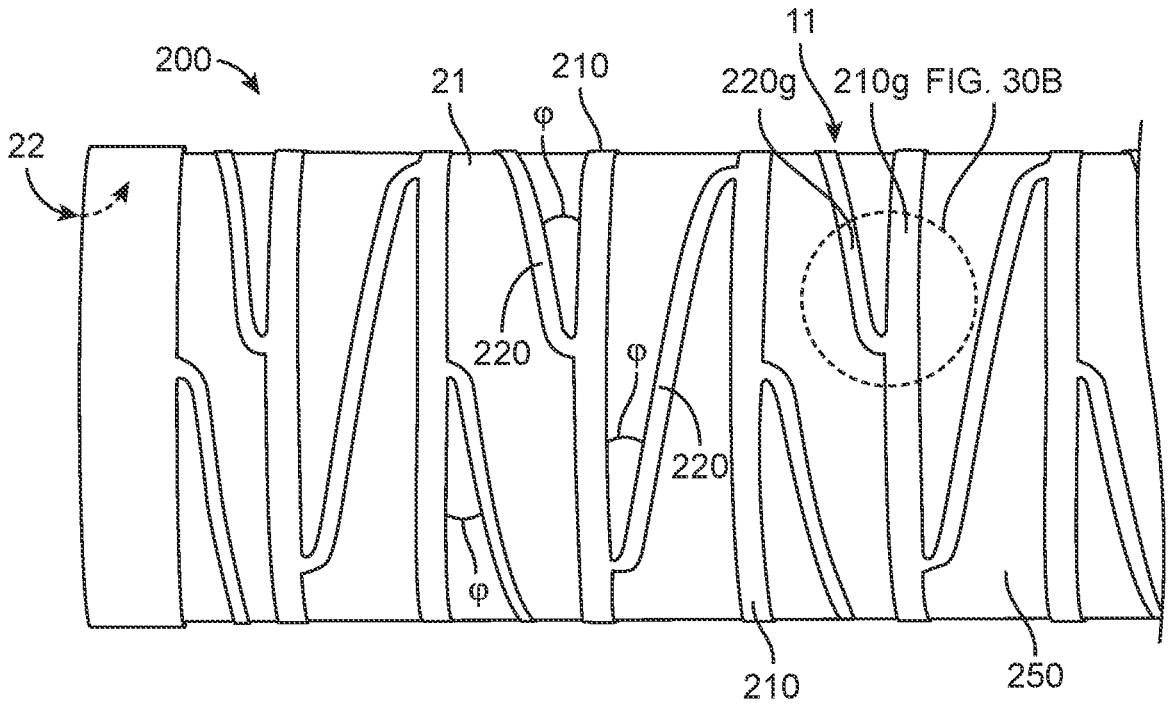


FIG. 30A

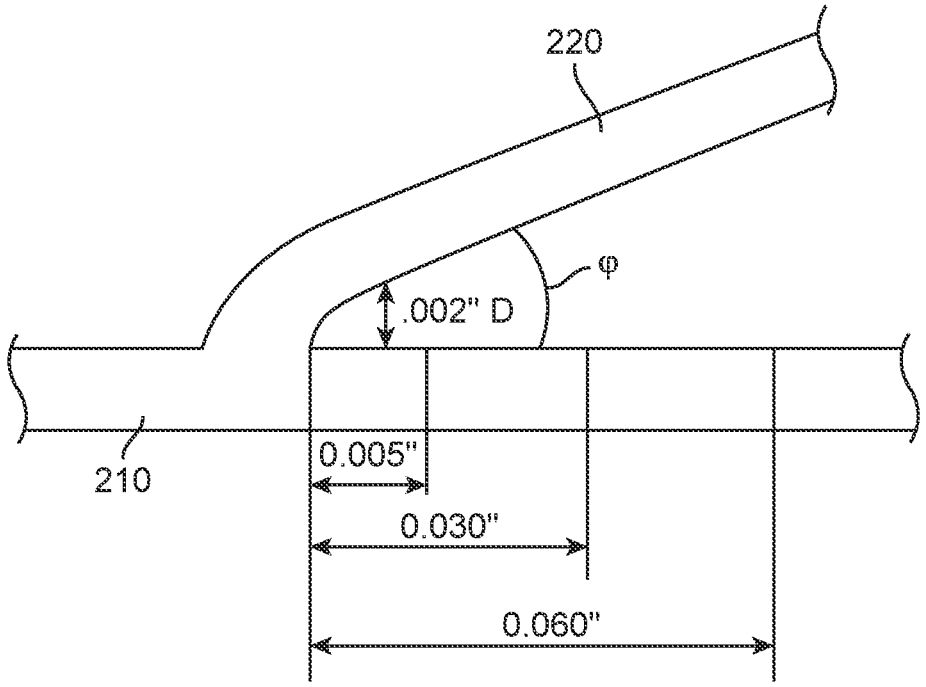


FIG. 30B

Angle φ	radians	Length 0.005 away	% strain 0.005 away	length 0.030 away	% strain 0.030 away	length 0.060 away	% strain 0.060 away
0	0	0.002	0%	0.002	0%	0.002	0%
2	0.034907	0.002174	9%	0.003047	52%	0.004094	105%
4	0.069813	0.002349	17%	0.004093	105%	0.006185	209%
6	0.10472	0.002523	26%	0.005136	157%	0.008272	314%
8	0.139626	0.002696	35%	0.006175	209%	0.01035	418%
10	0.174533	0.002868	43%	0.007209	260%	0.012419	521%
12	0.20944	0.00304	52%	0.008237	312%	0.014475	624%
14	0.244346	0.00321	60%	0.009258	363%	0.016515	726%
16	0.279253	0.003378	69%	0.010269	413%	0.018538	827%
18	0.314159	0.003545	77%	0.011271	464%	0.020541	927%
20	0.349066	0.00371	86%	0.012261	513%	0.022521	1026%

FIG. 31

Angle φ	radians	Length 0.005 away	% strain 0.005 away	length 0.030 away	% strain 0.030 away	length 0.060 away	% strain 0.060 away
10	0.174533	0.002868	0%	0.007209	0%	0.012419	0%
12	0.20944	0.00304	6%	0.008237	14%	0.014475	17%
14	0.244346	0.00321	12%	0.009258	28%	0.016515	33%
16	0.279253	0.003378	18%	0.010269	42%	0.018538	49%
18	0.314159	0.003545	24%	0.011271	56%	0.020541	65%
20	0.349066	0.00371	29%	0.012261	70%	0.022521	81%
22	0.383972	0.003873	35%	0.013238	84%	0.024476	97%
24	0.418879	0.004034	41%	0.014202	97%	0.026404	113%
26	0.453786	0.004192	46%	0.015151	110%	0.028302	128%
28	0.488692	0.004347	52%	0.016084	123%	0.030168	143%
30	0.523599	0.0045	57%	0.017	136%	0.032	158%

FIG. 32

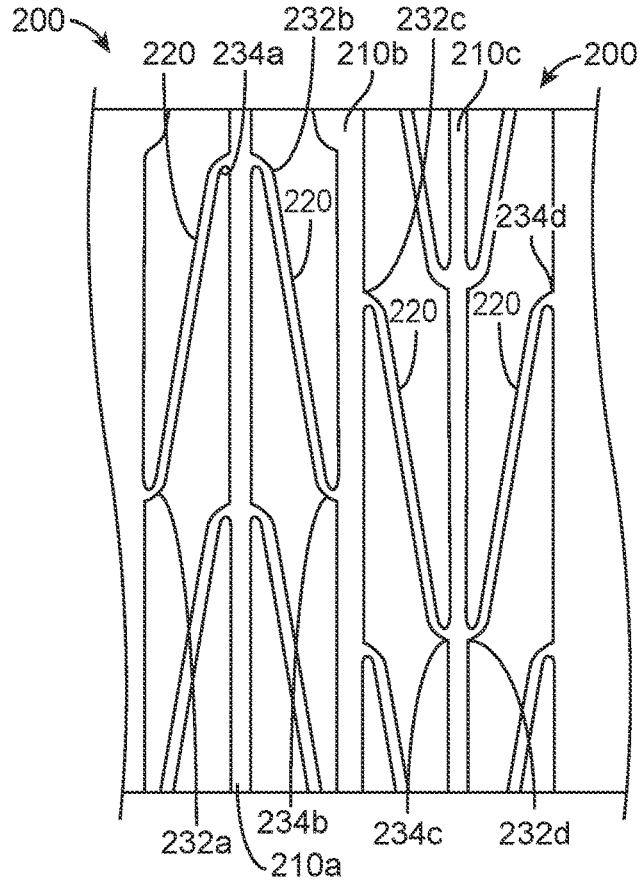

200
232b
232c
220
234a
210b
210c
200
220
234d
220
220
232a
234b
210a
234c
232d

FIG. 33

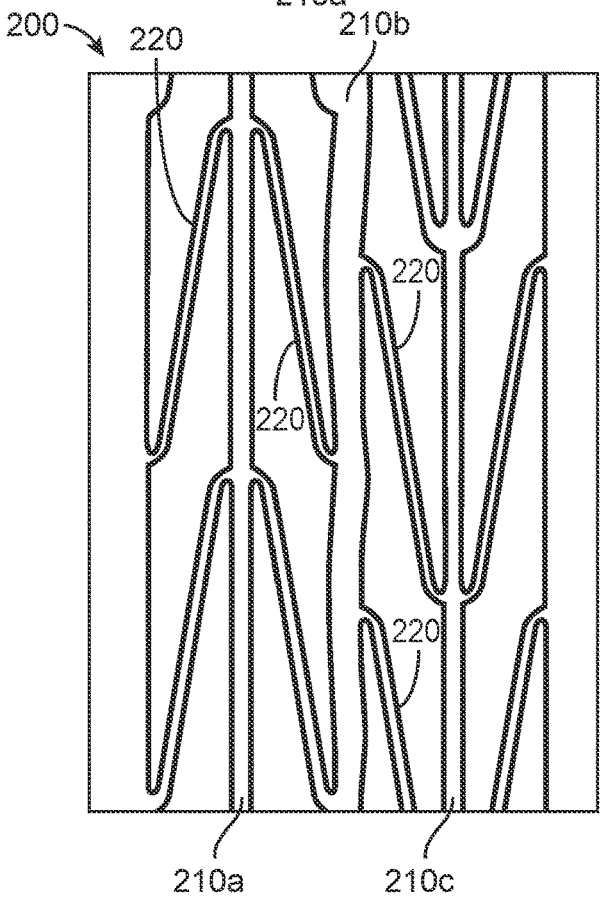

200
220
210b
220
220
220
210a
210c

FIG. 34

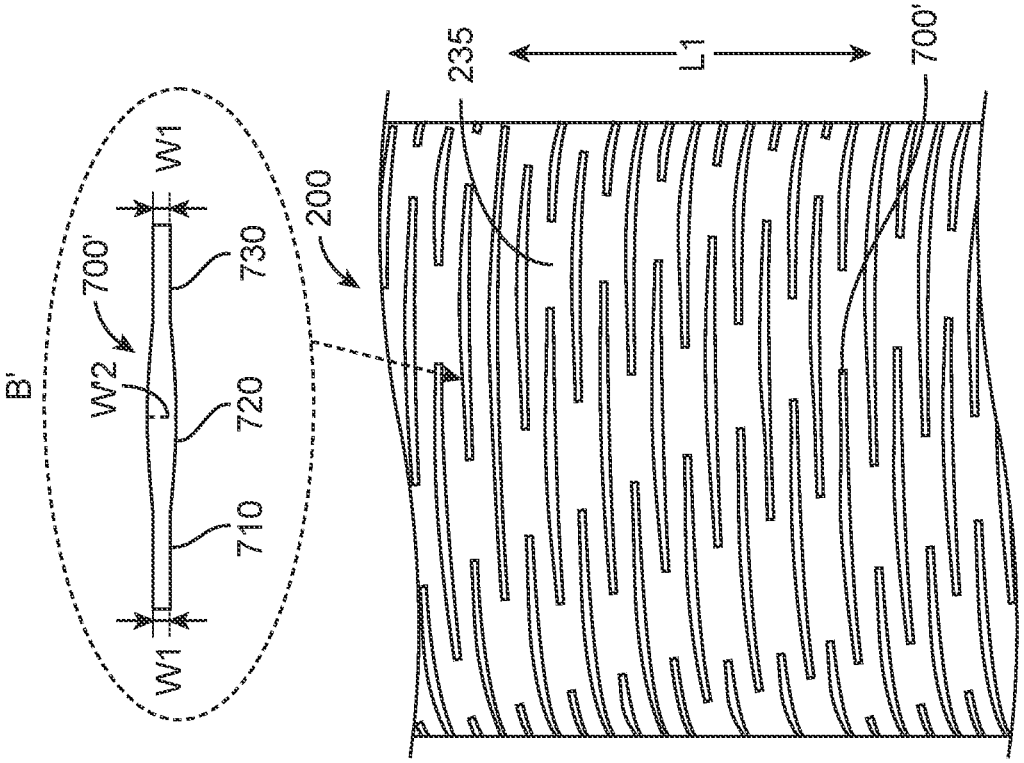


FIG. 35B

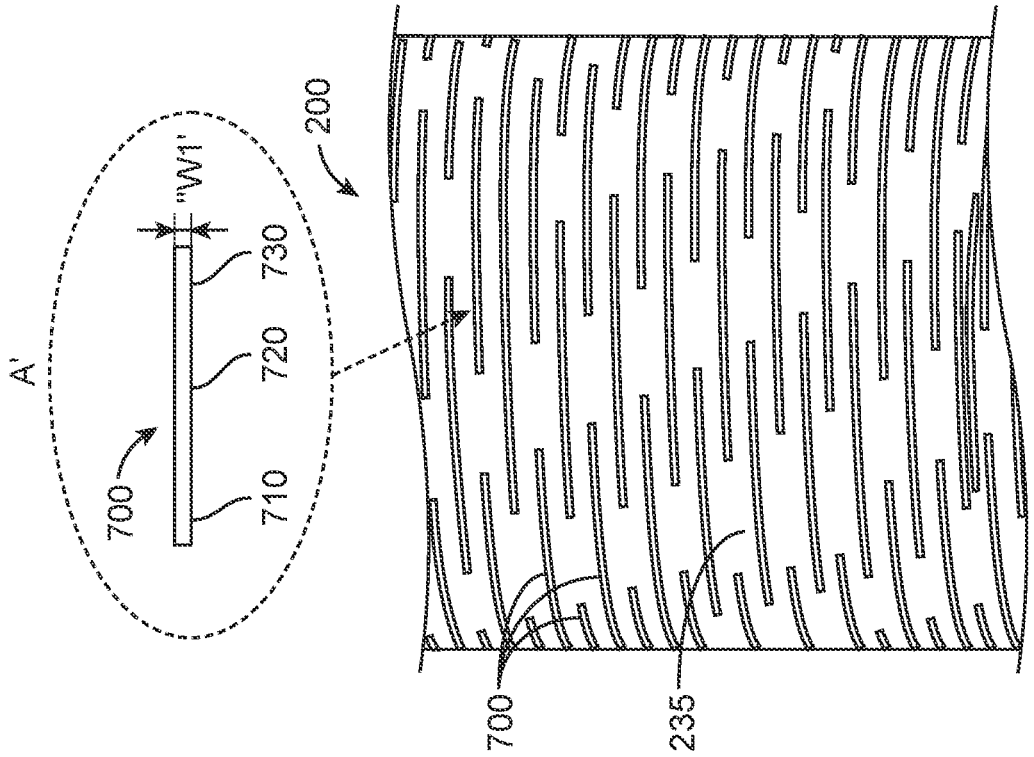


FIG. 35A

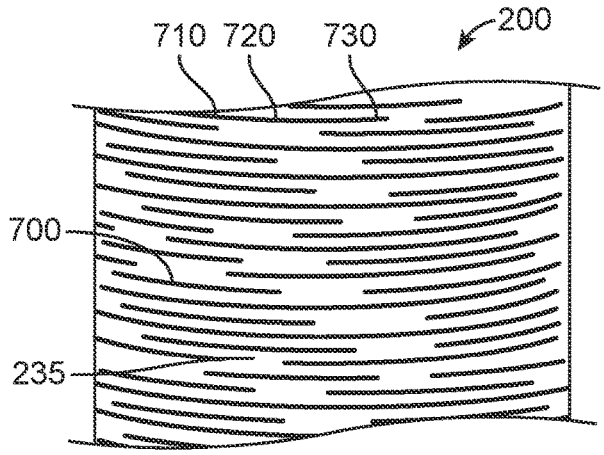


FIG. 36A

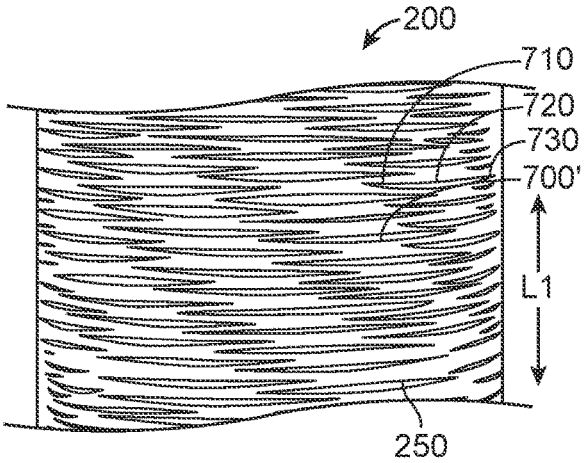


FIG. 36B

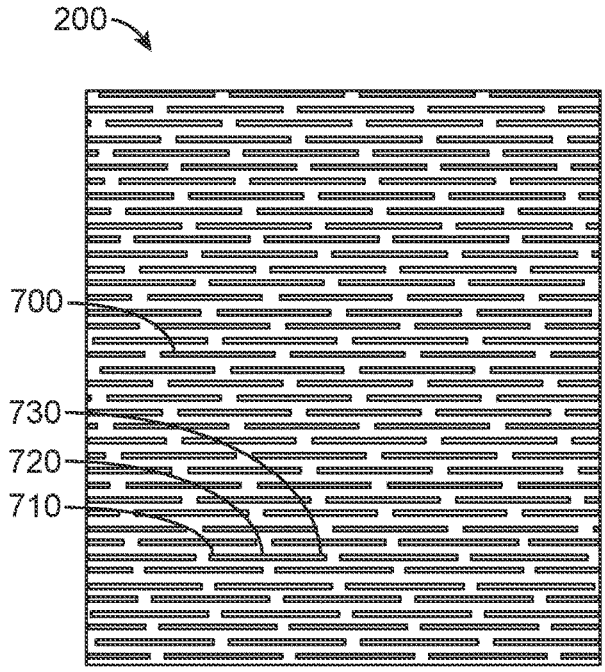


FIG. 37A

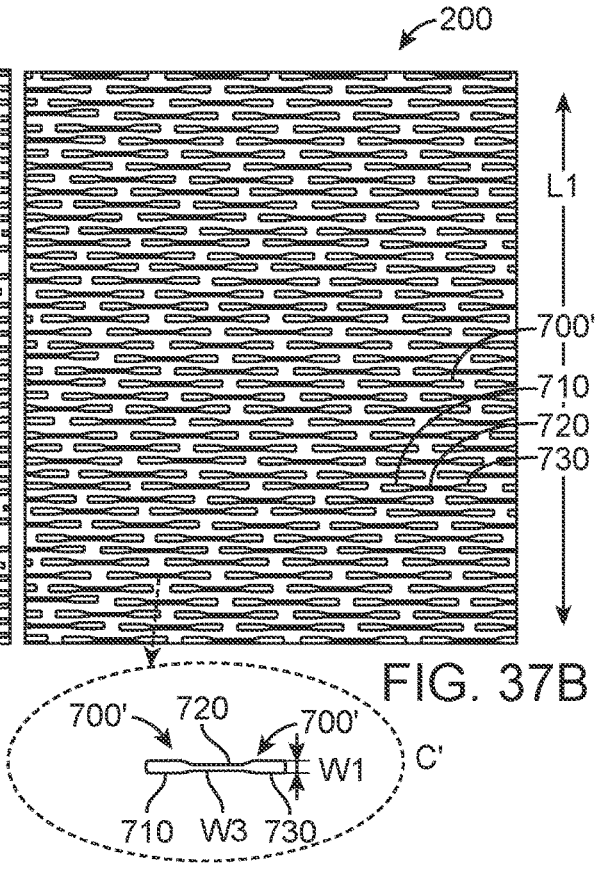


FIG. 37B

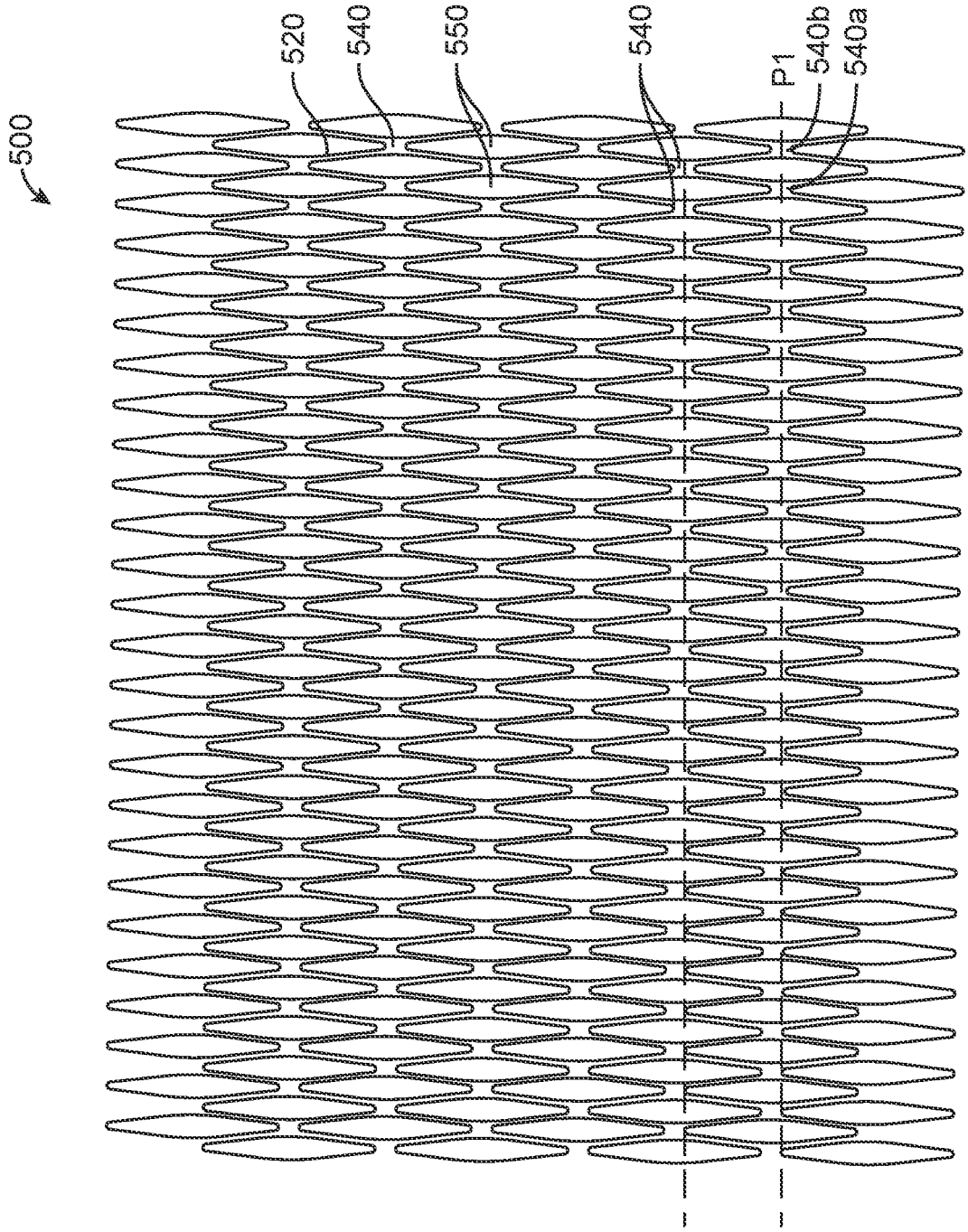


FIG. 38A

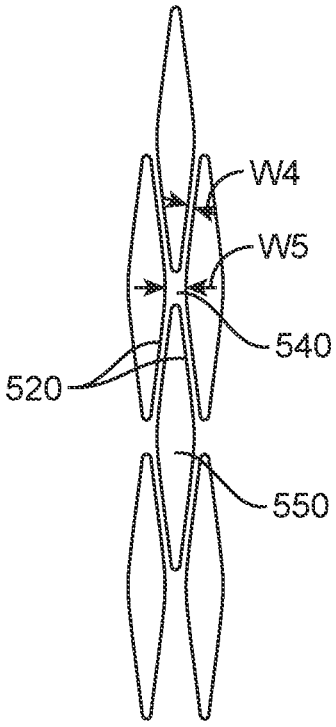


FIG. 38B

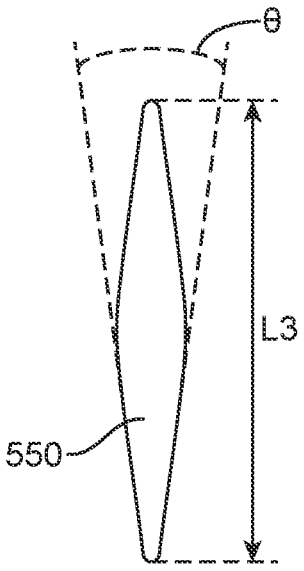


FIG. 38C

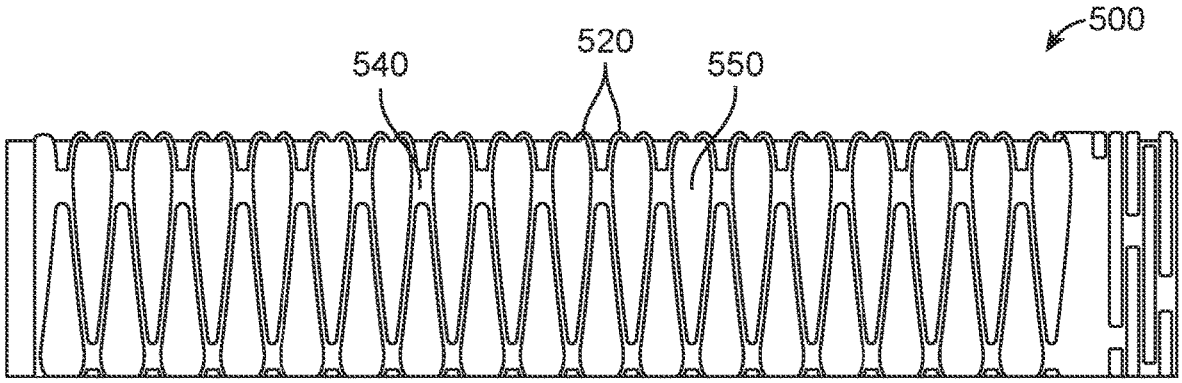


FIG. 38D

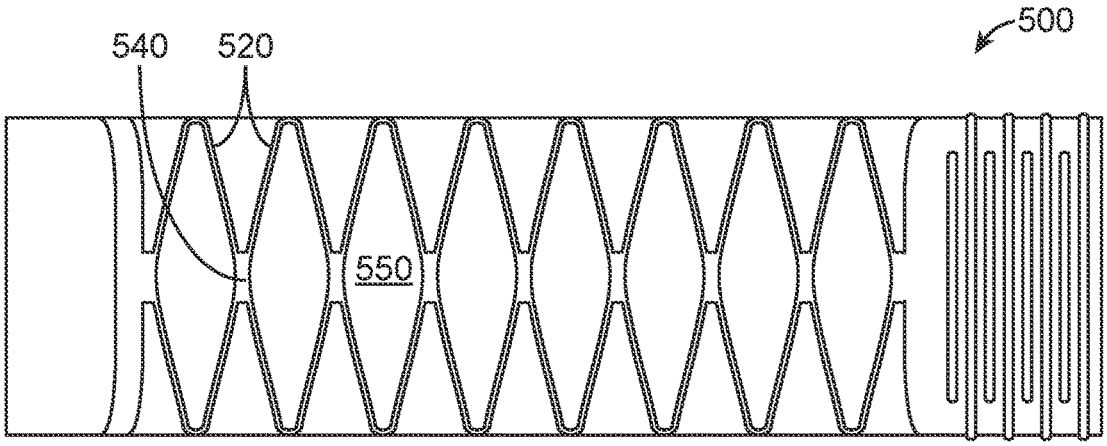


FIG. 38E

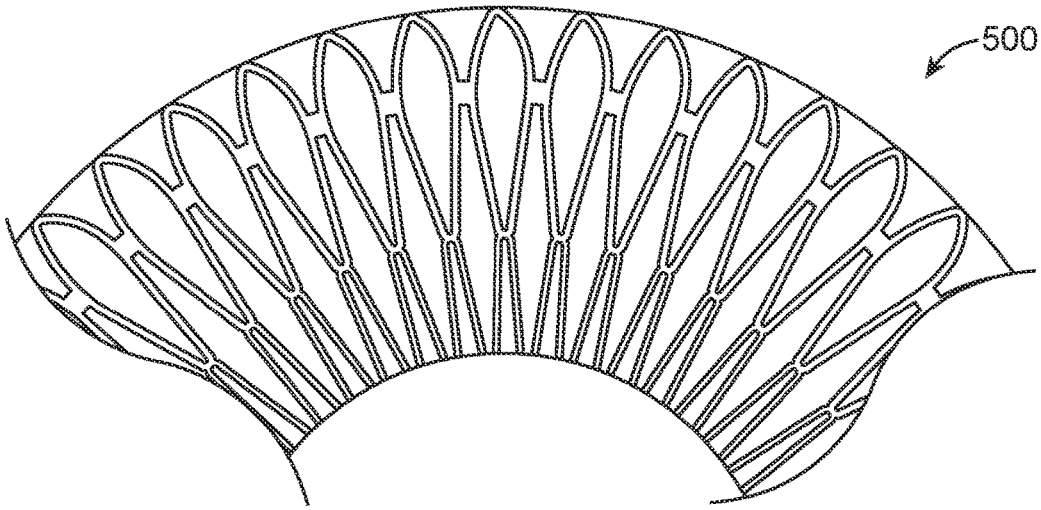


FIG. 38F

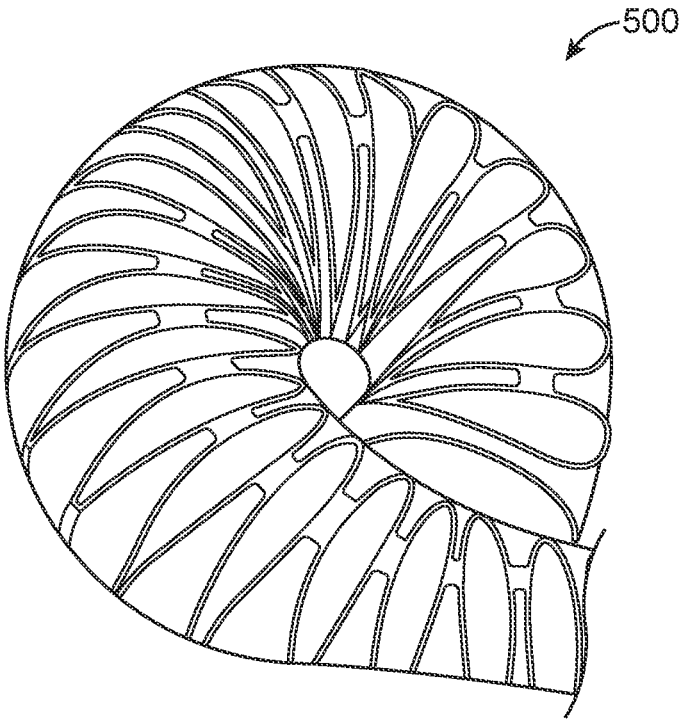


FIG. 38G

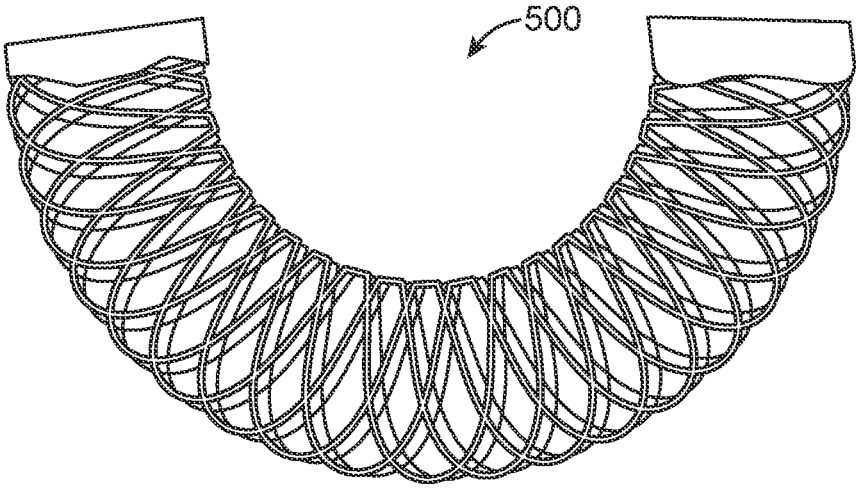


FIG. 38H

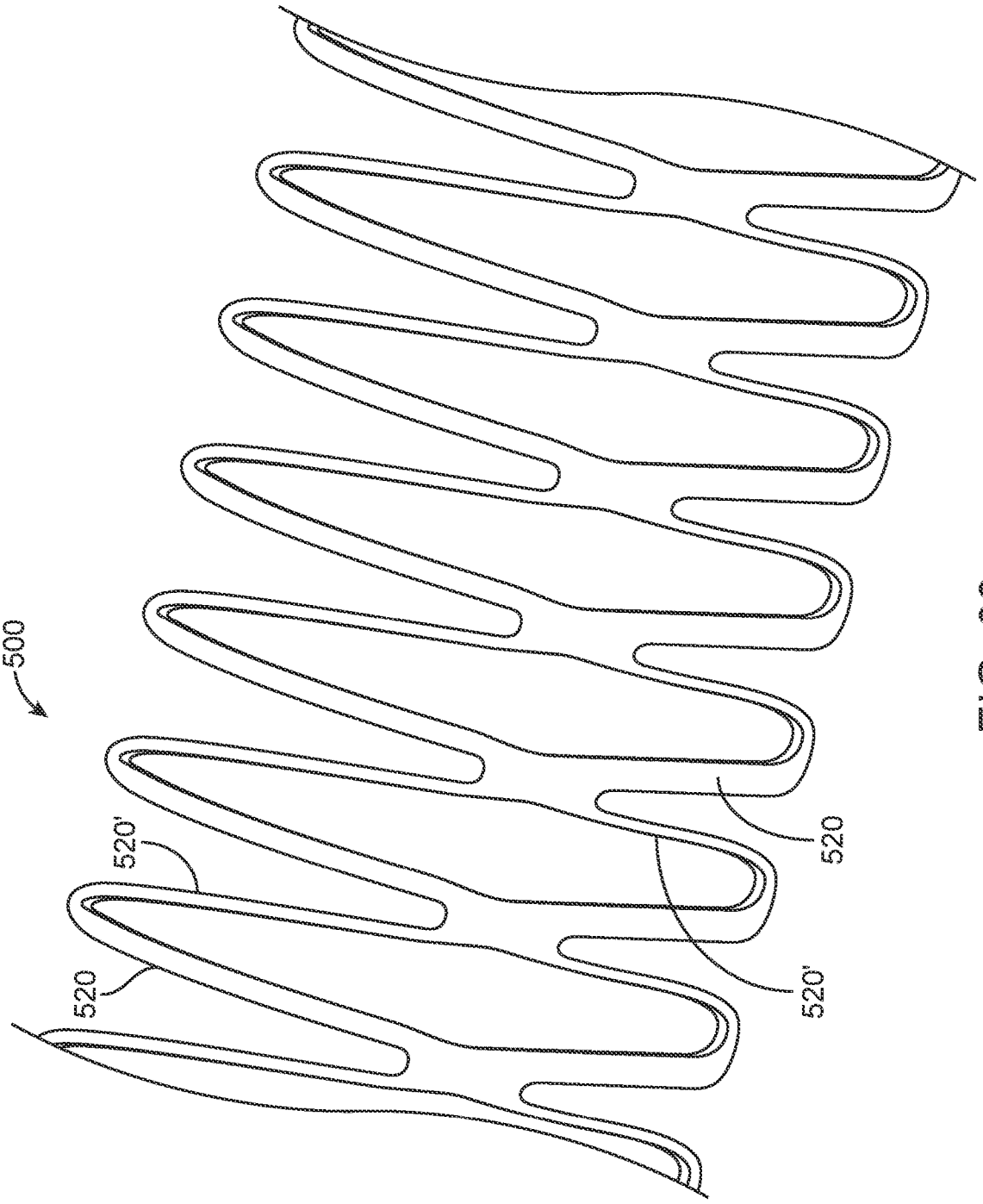


FIG. 39

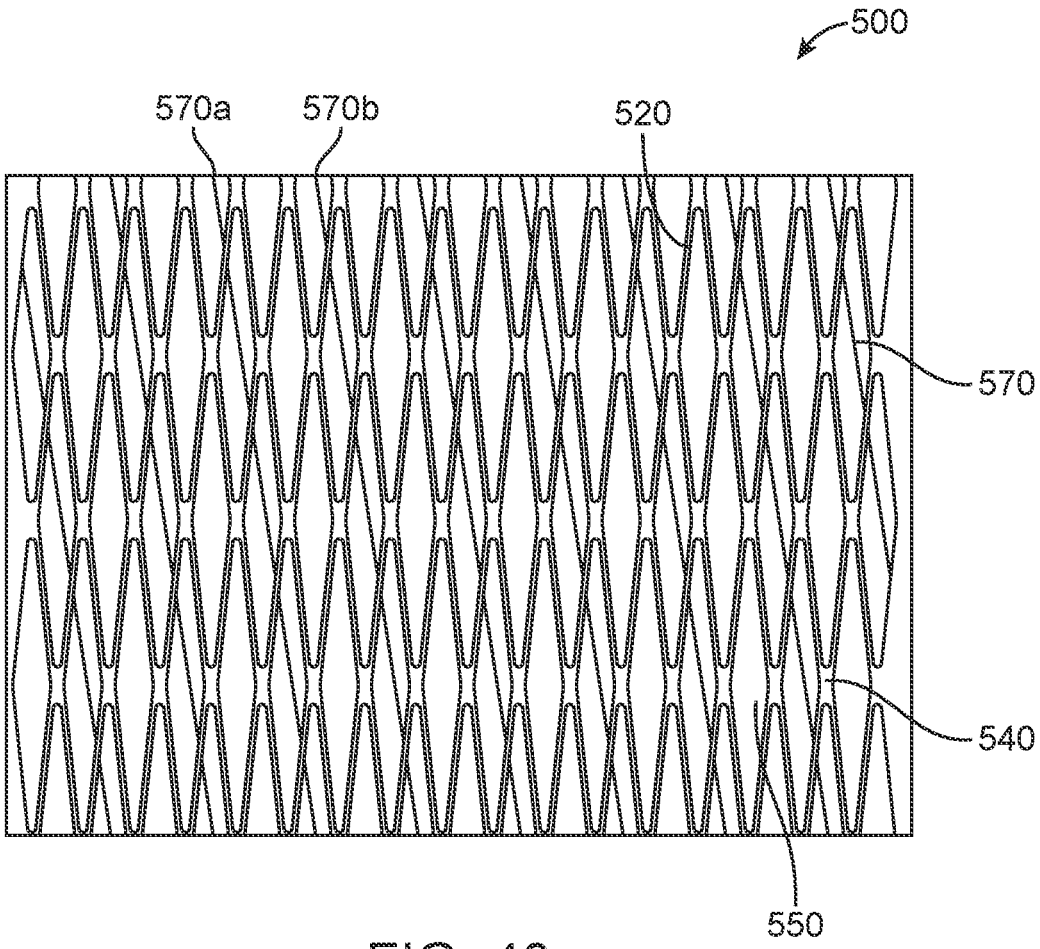


FIG. 40

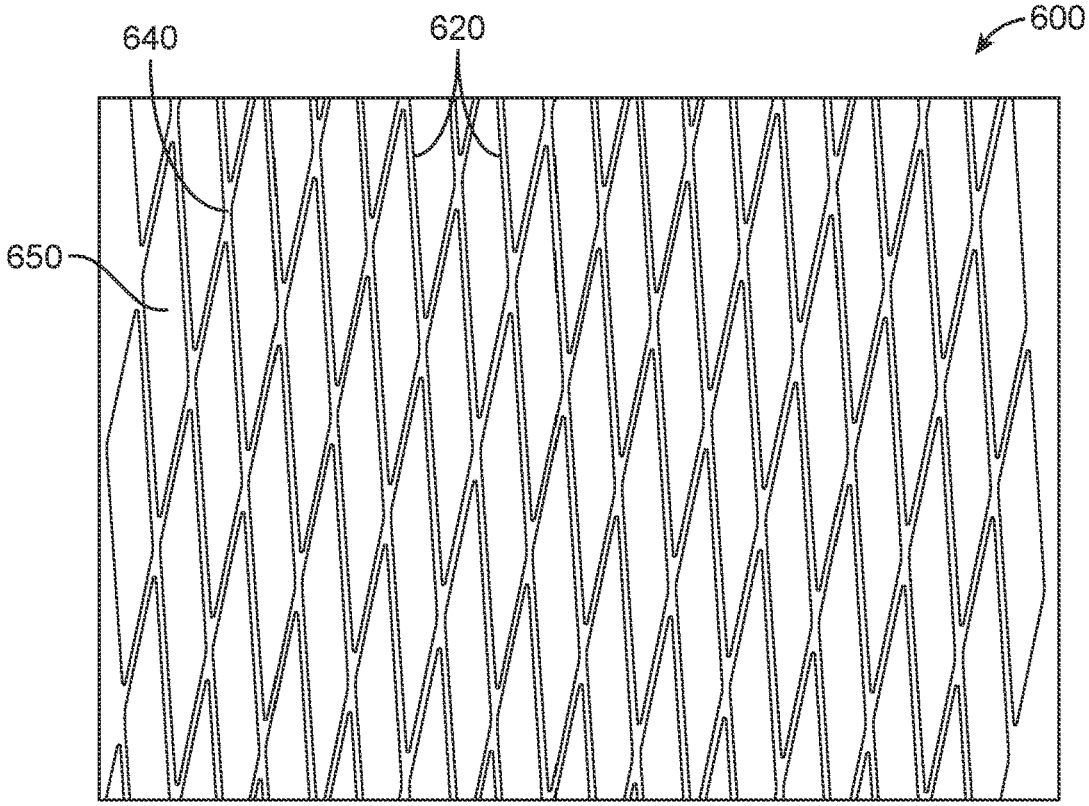


FIG. 41A

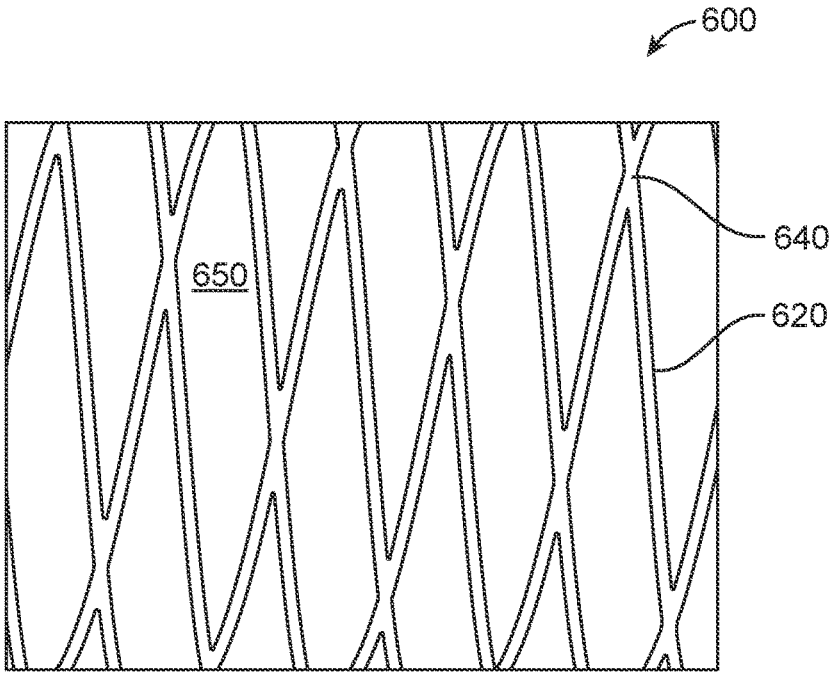


FIG. 41B

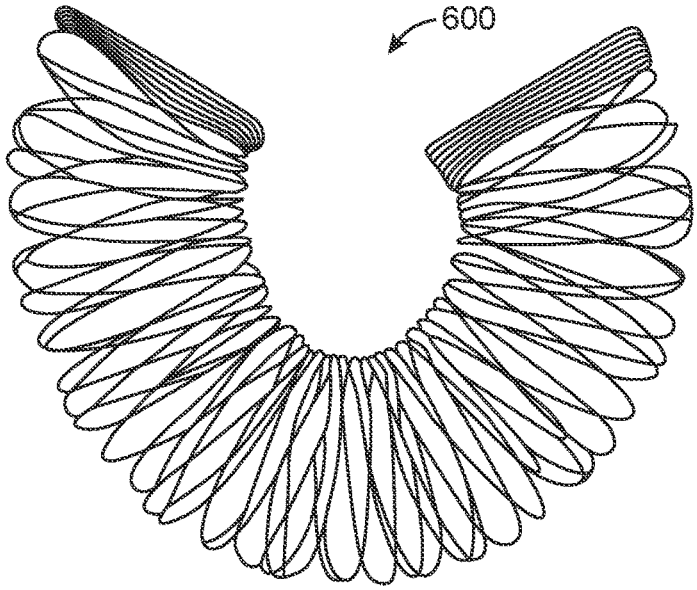


FIG. 41C

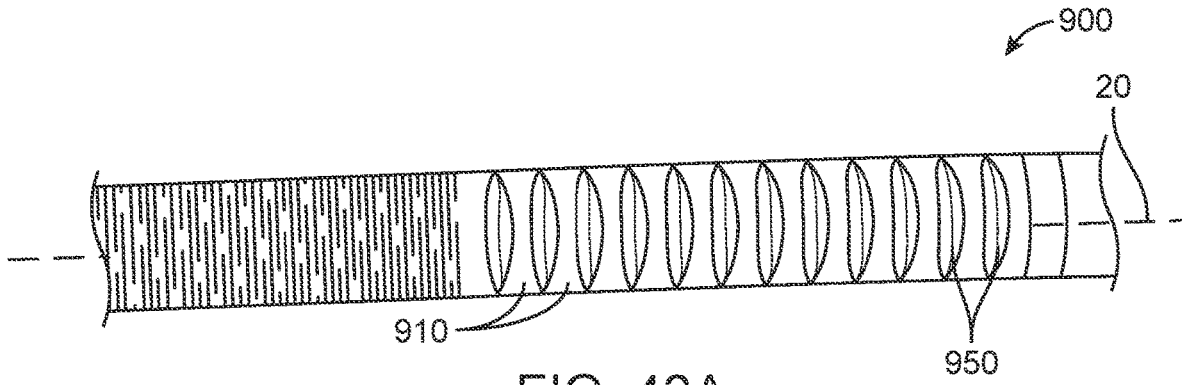


FIG. 42A

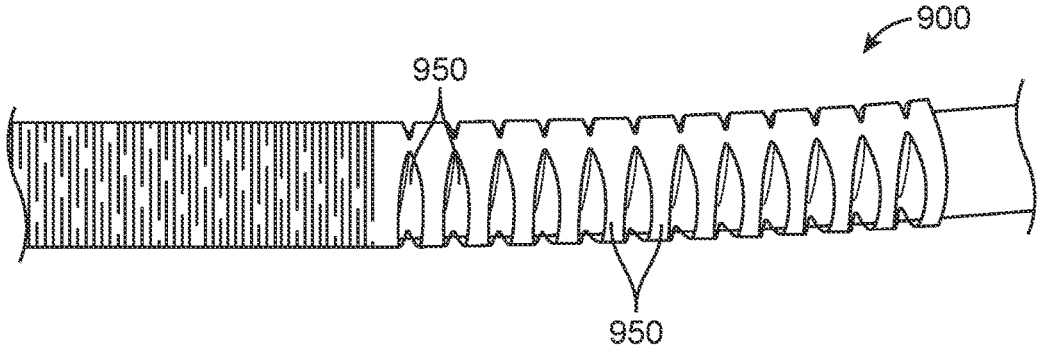


FIG. 42B

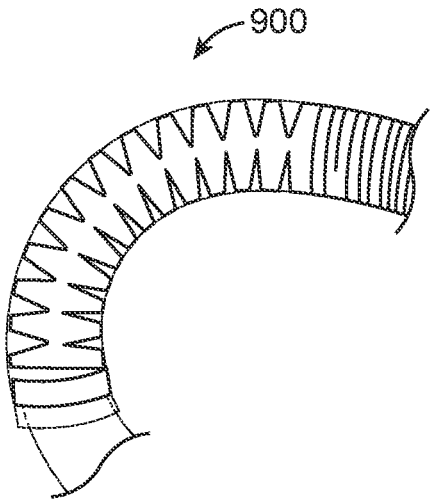


FIG. 42C

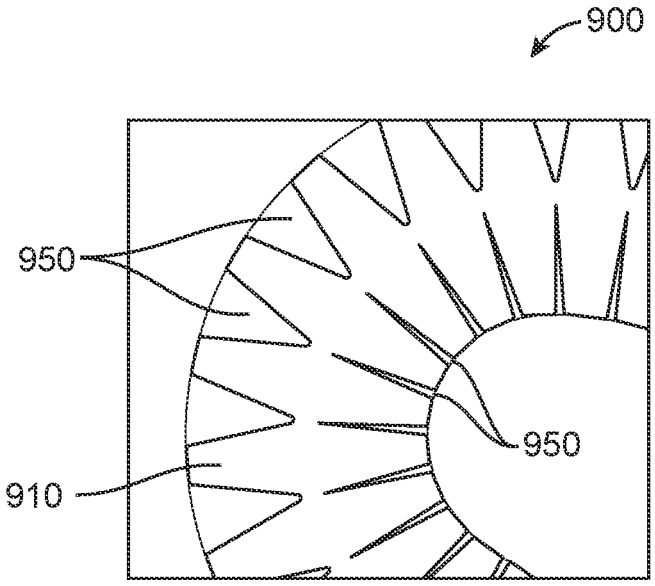


FIG. 42D

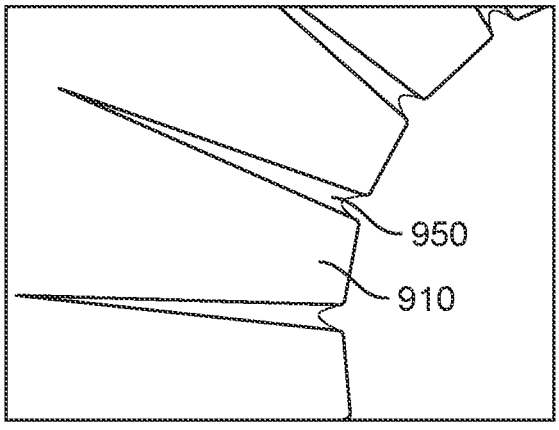


FIG. 42E

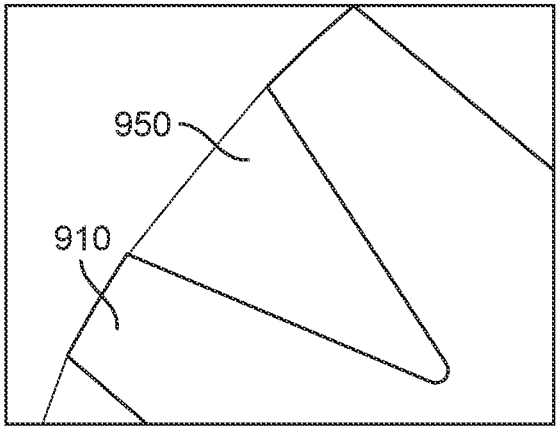


FIG. 42F

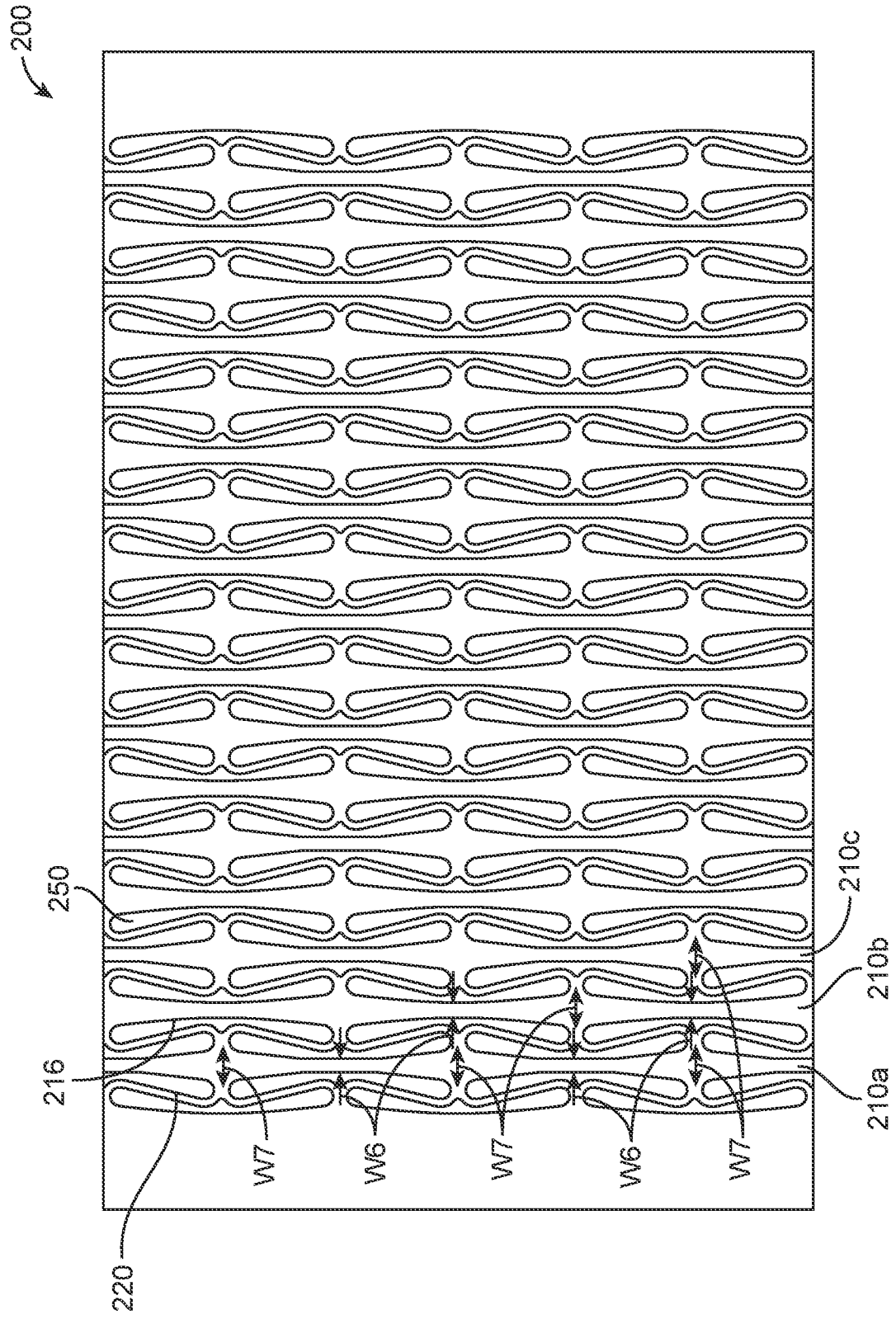


FIG. 43

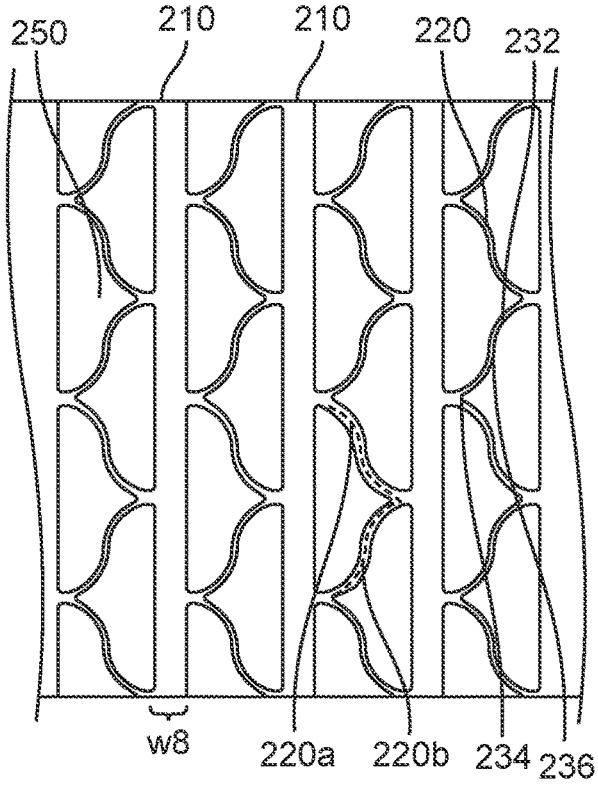


FIG. 44A

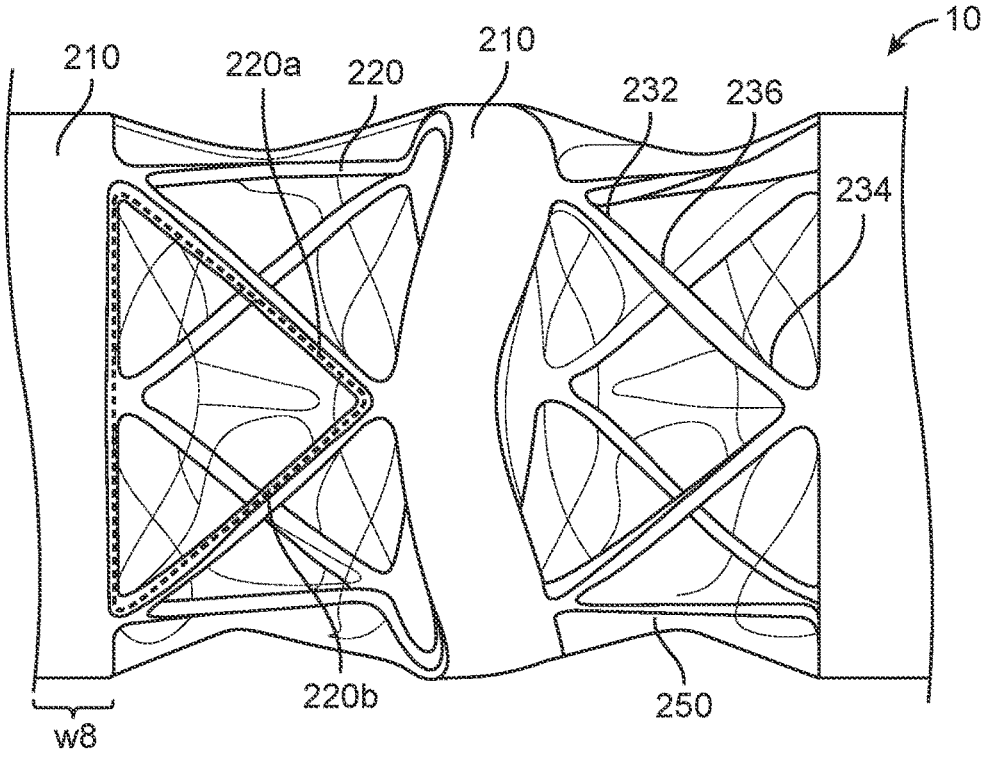


FIG. 44B

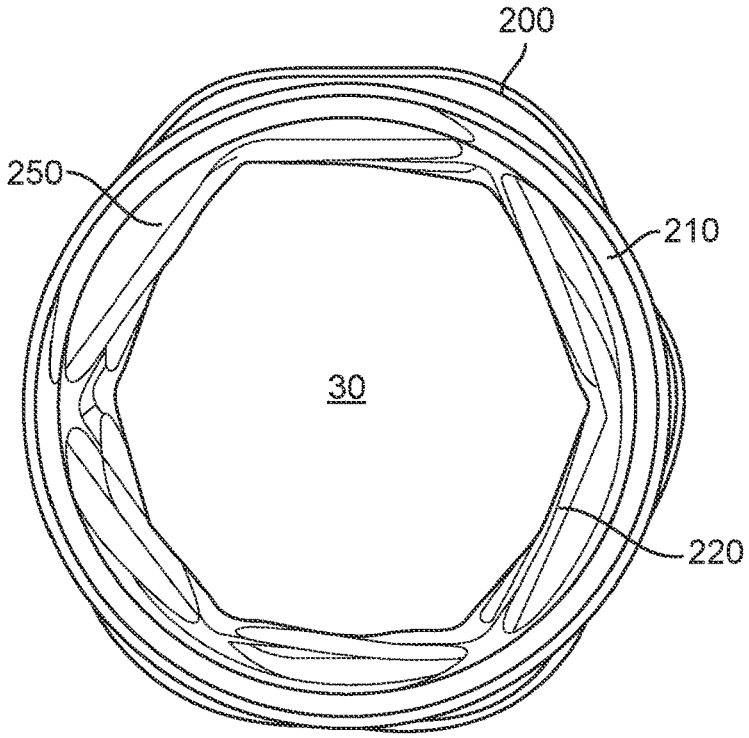


FIG. 44C

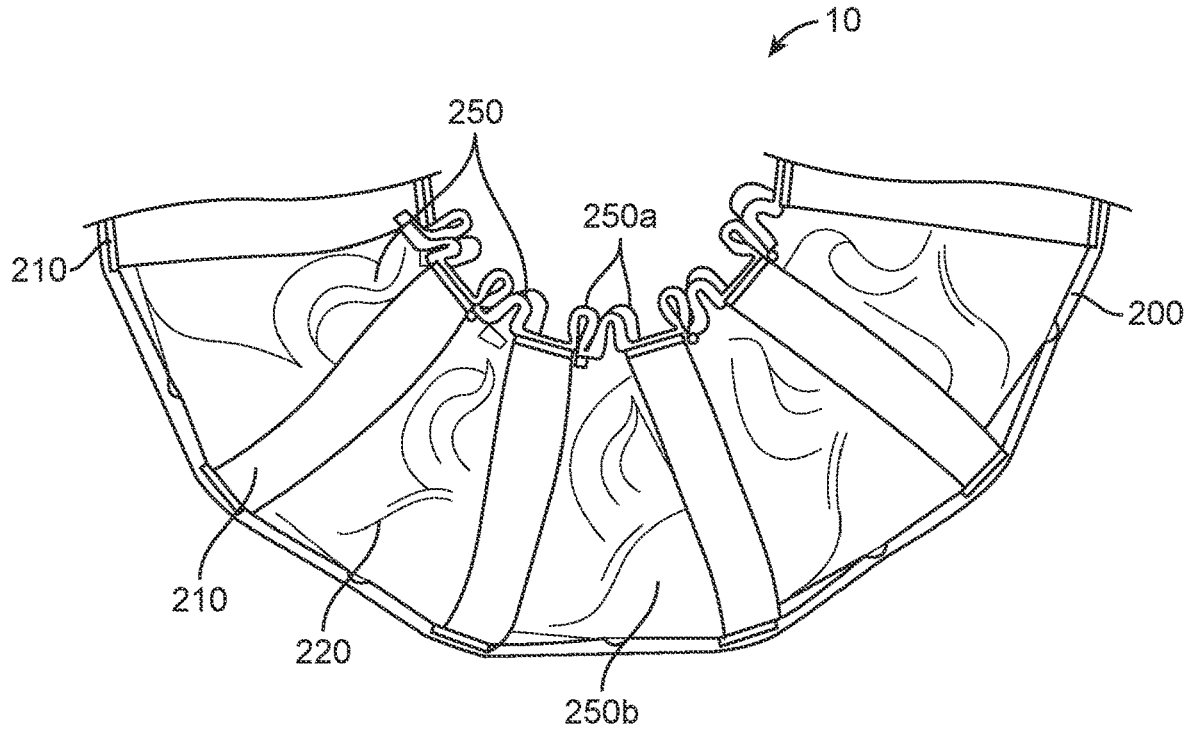


FIG. 44D

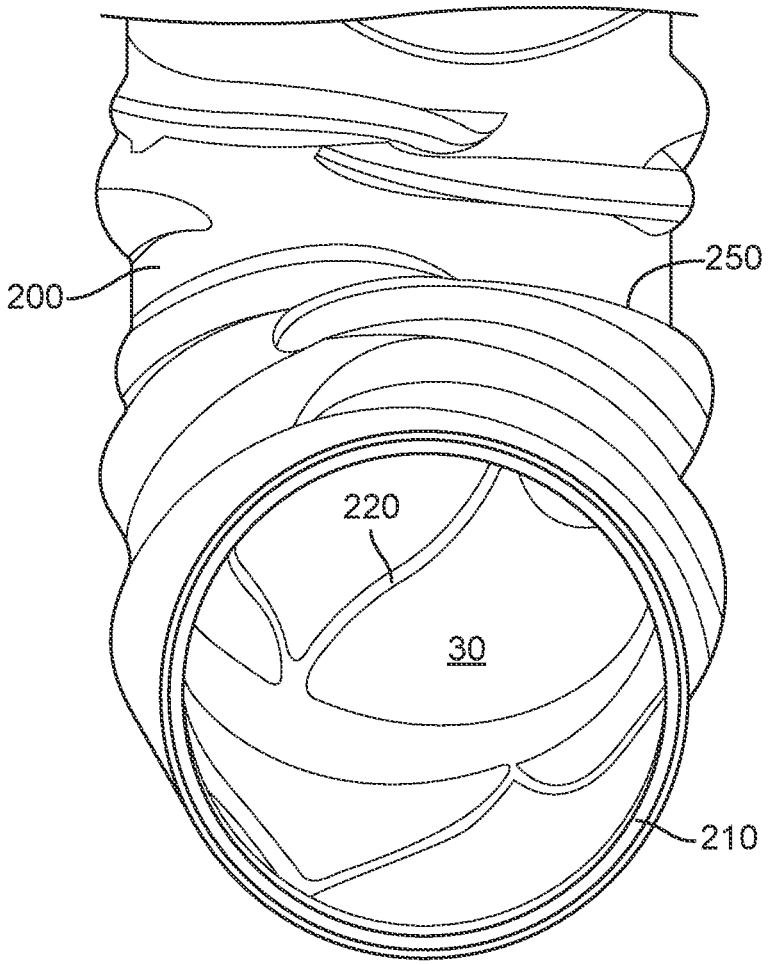


FIG. 44E

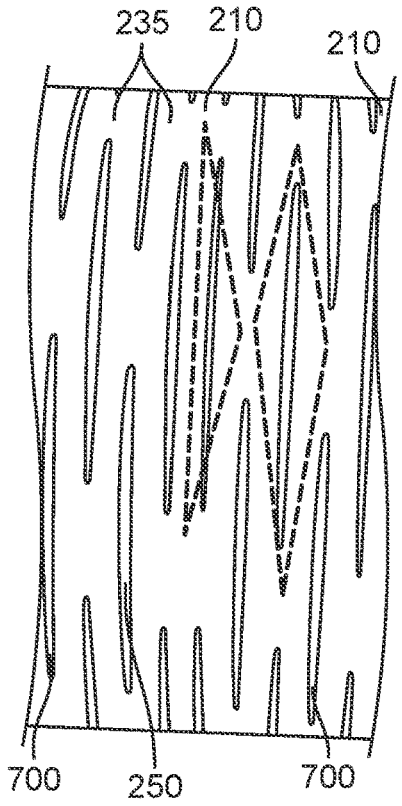


FIG. 45A

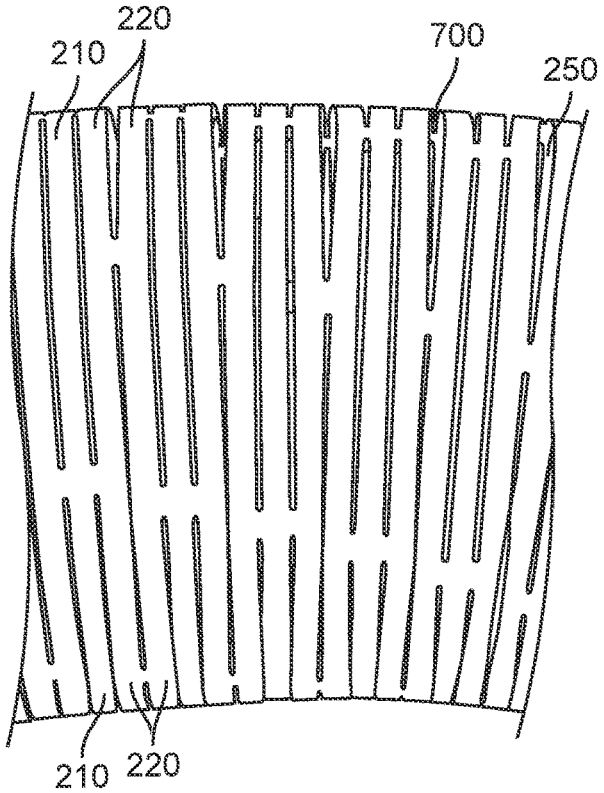


FIG. 45B

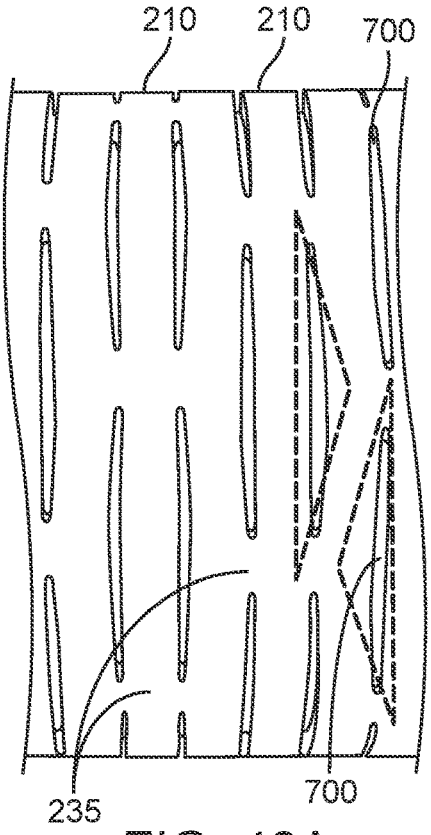


FIG. 46A

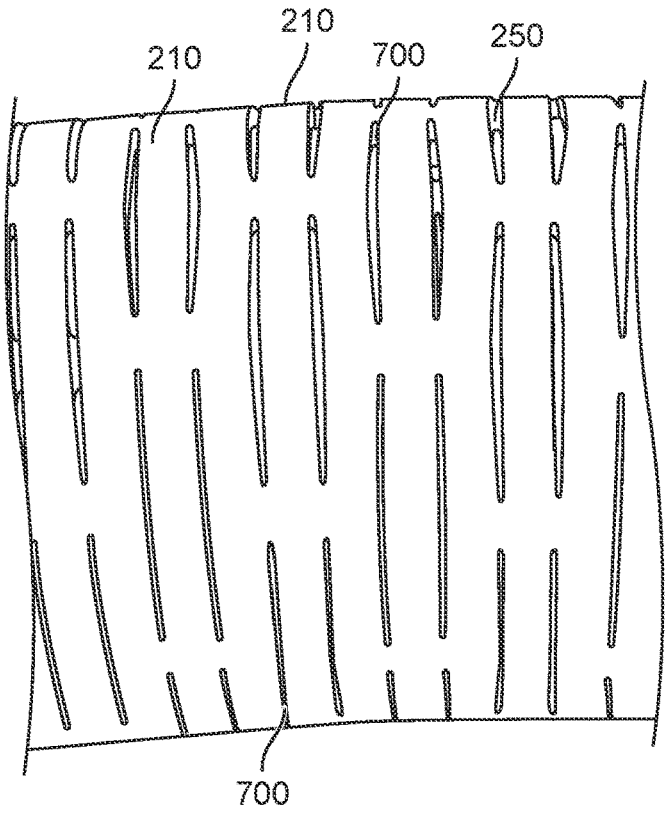


FIG. 46B

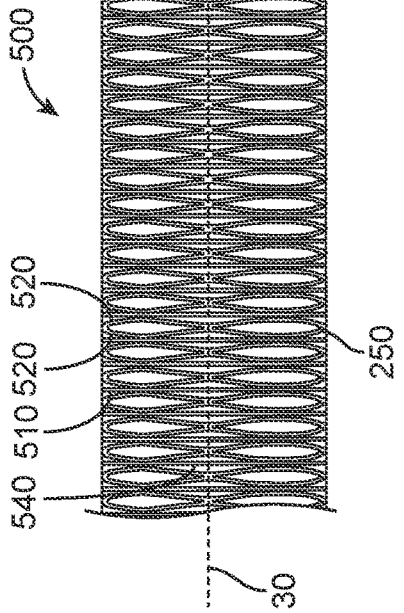


FIG. 47B

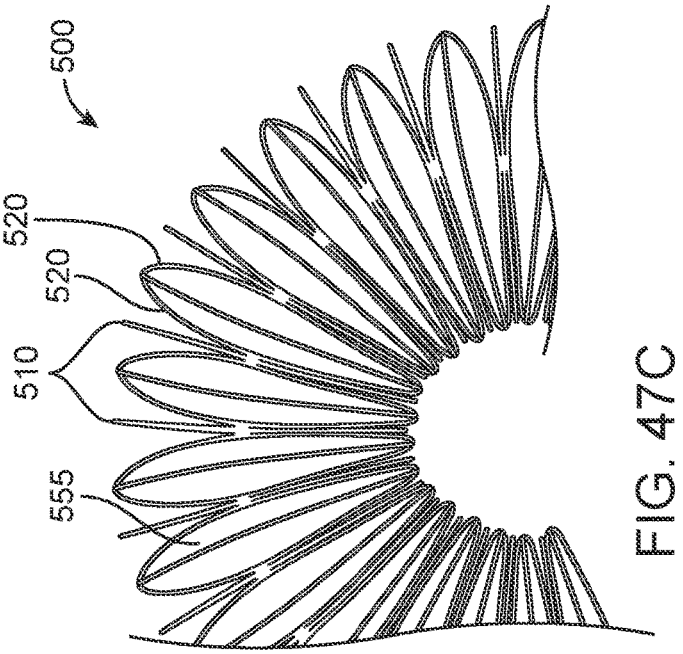


FIG. 47C

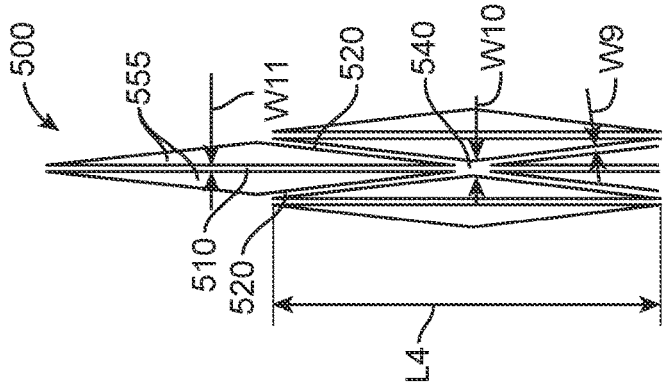


FIG. 47A

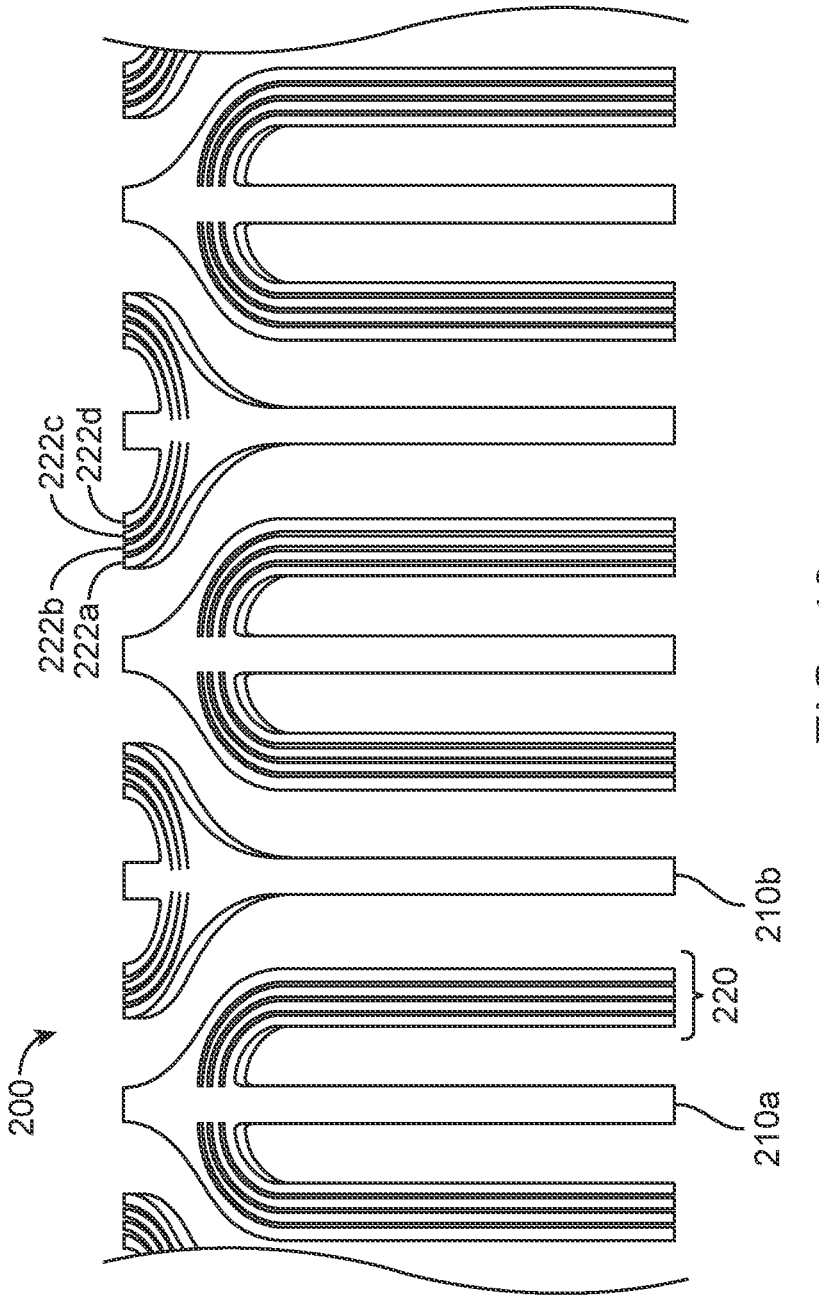

200
210a
210b
220
222a
222b
222c
222d

FIG. 49

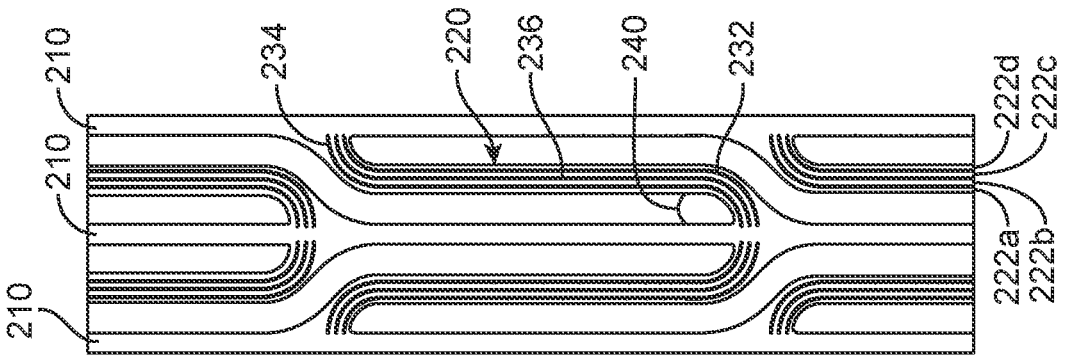

210
210
210
234
220
236
240
232
222a
222b
222d
222c

FIG. 48

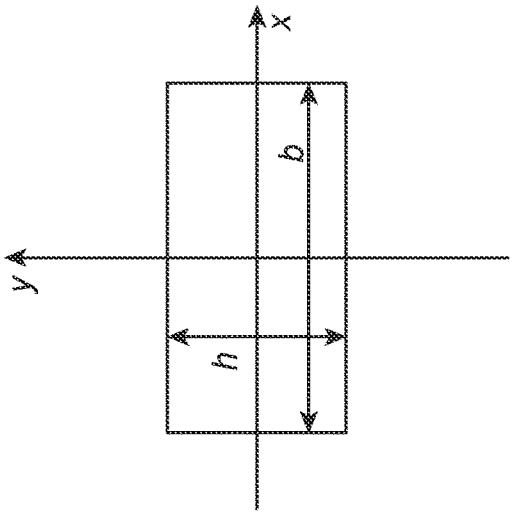


FIG. 52

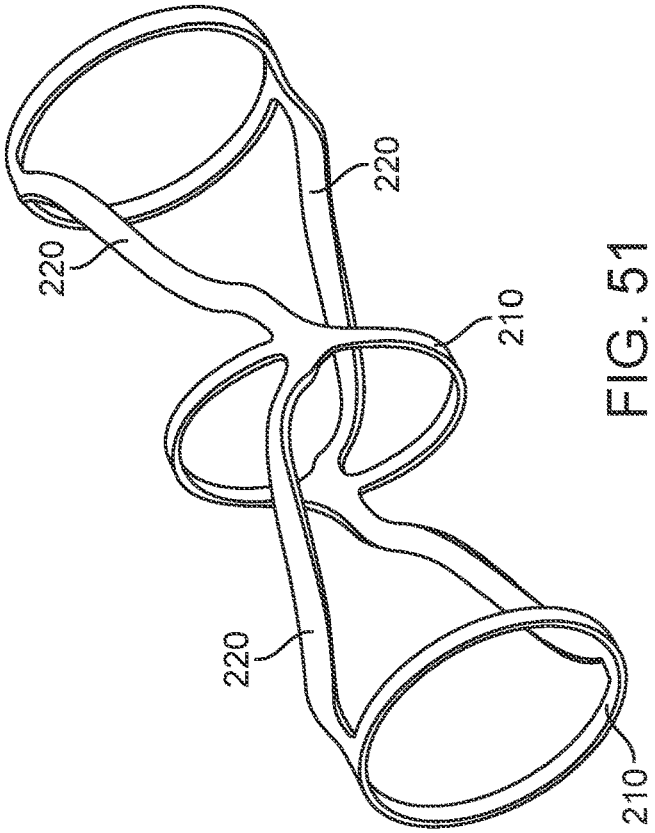


FIG. 51

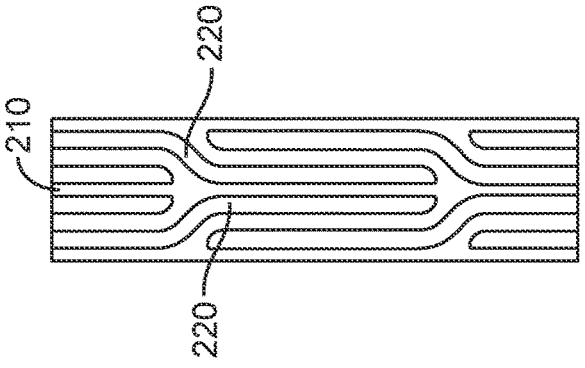


FIG. 50

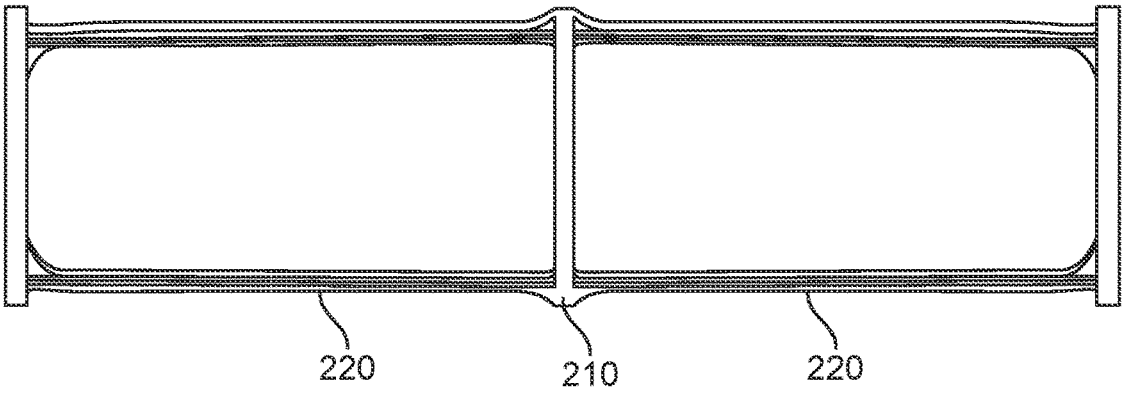


FIG. 53

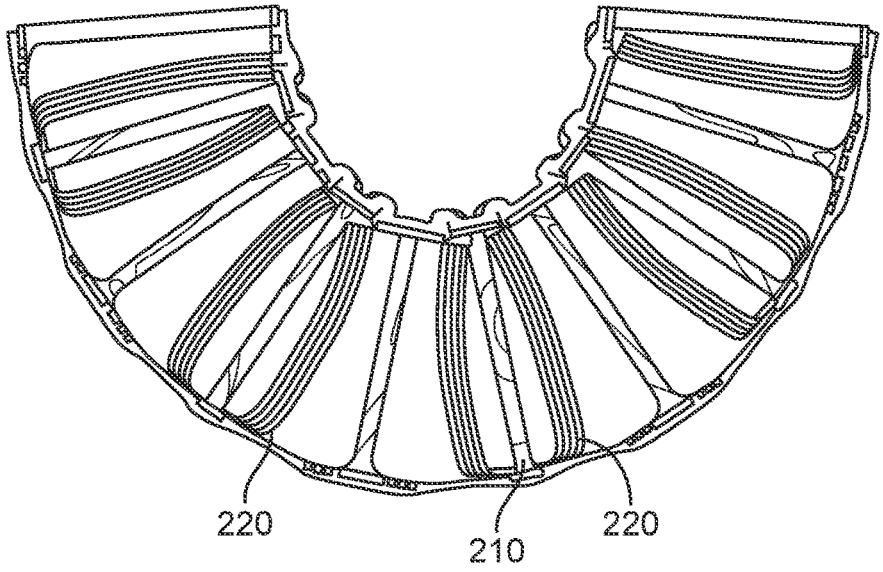


FIG. 54

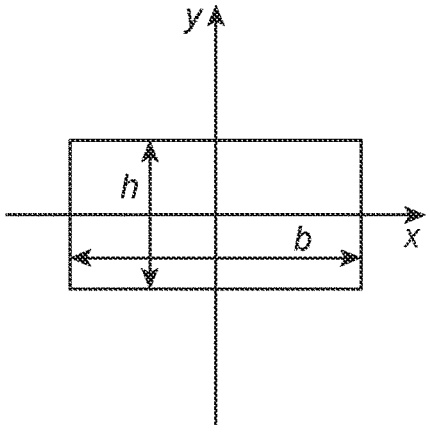


FIG. 55

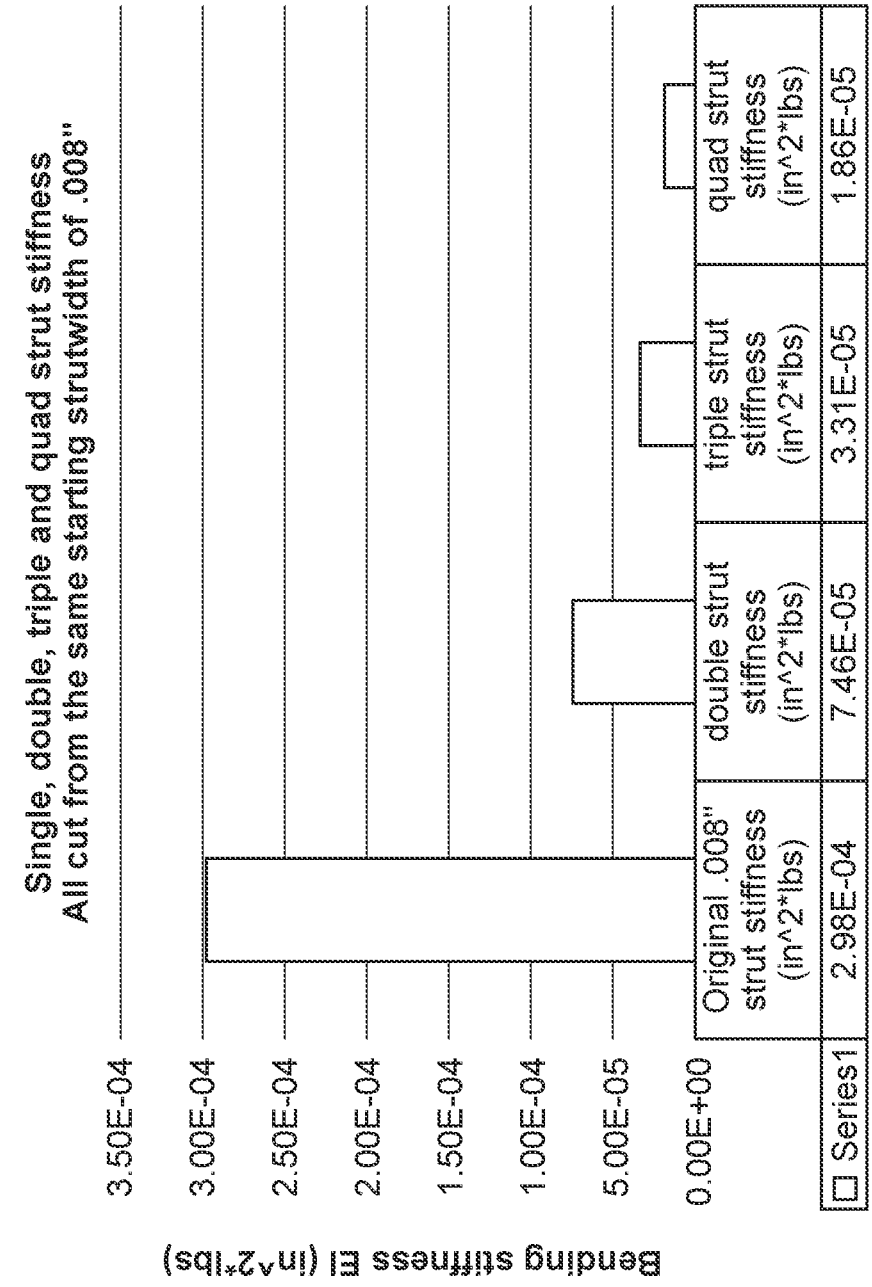

Single, double, triple and quad strut stiffness
All cut from the same starting strutwidth of .008"
Bending stiffness EI (in^2*lbs)
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
Original .008" strut stiffness (in^2*lbs)
double strut stiffness (in^2*lbs)
triple strut stiffness (in^2*lbs)
quad strut stiffness (in^2*lbs)
Series1
2.98E-04
7.46E-05
3.31E-05
1.86E-05

FIG. 56

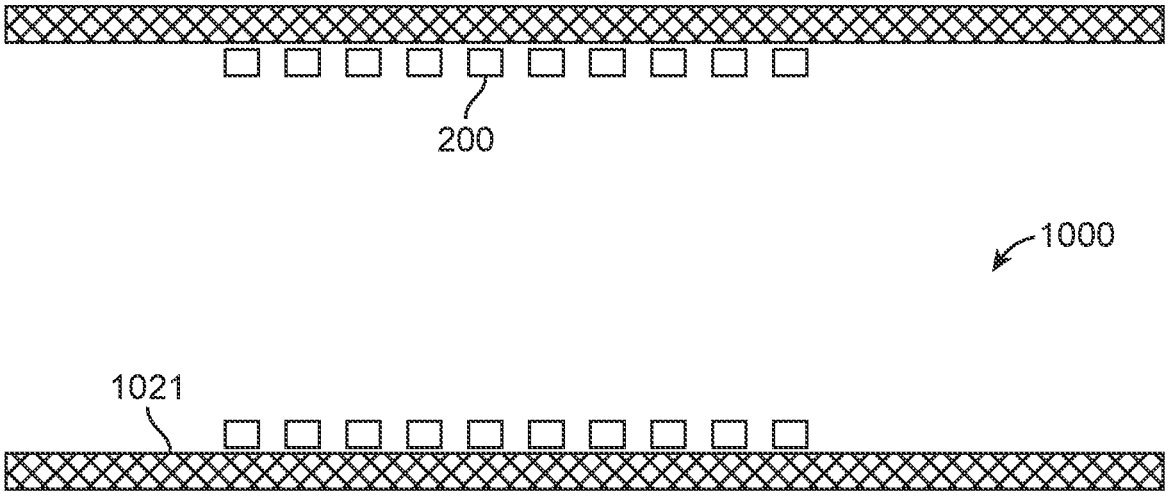


FIG. 57A

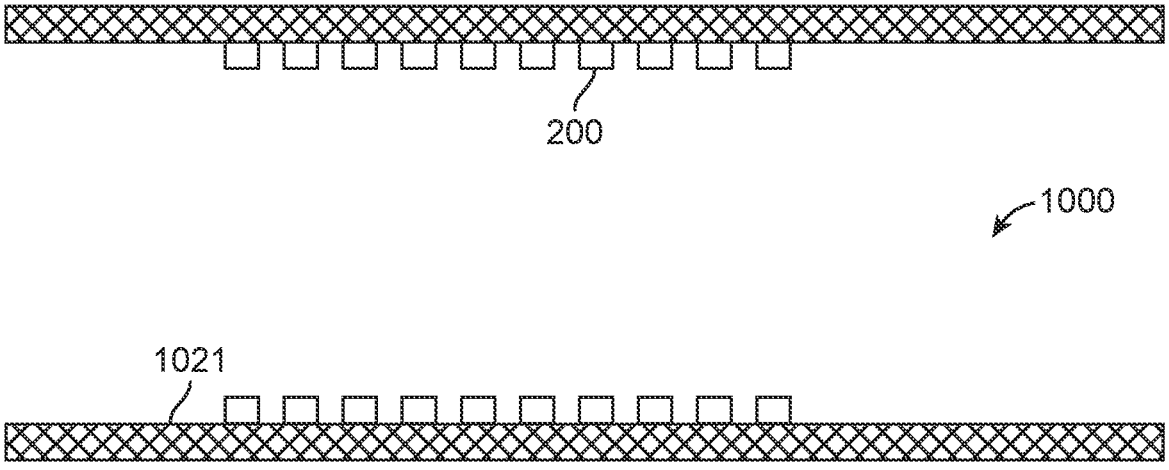


FIG. 57B

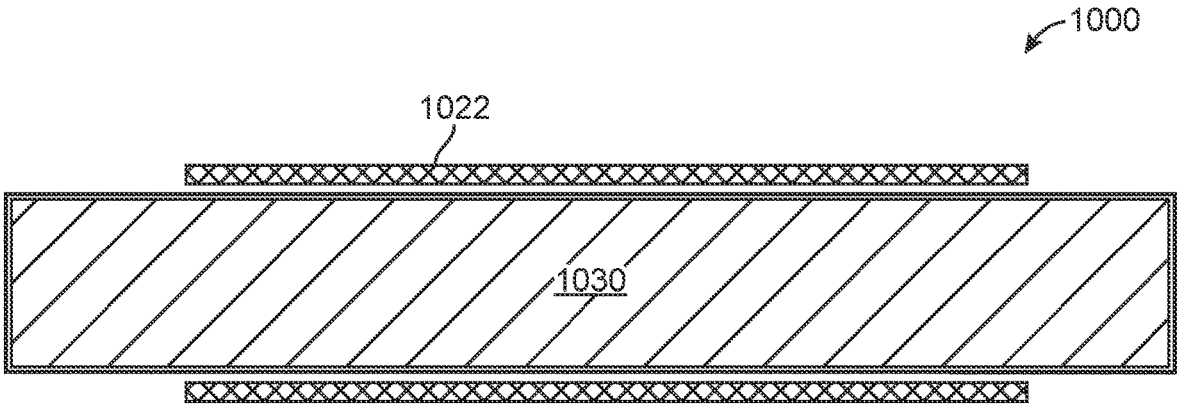


FIG. 57C

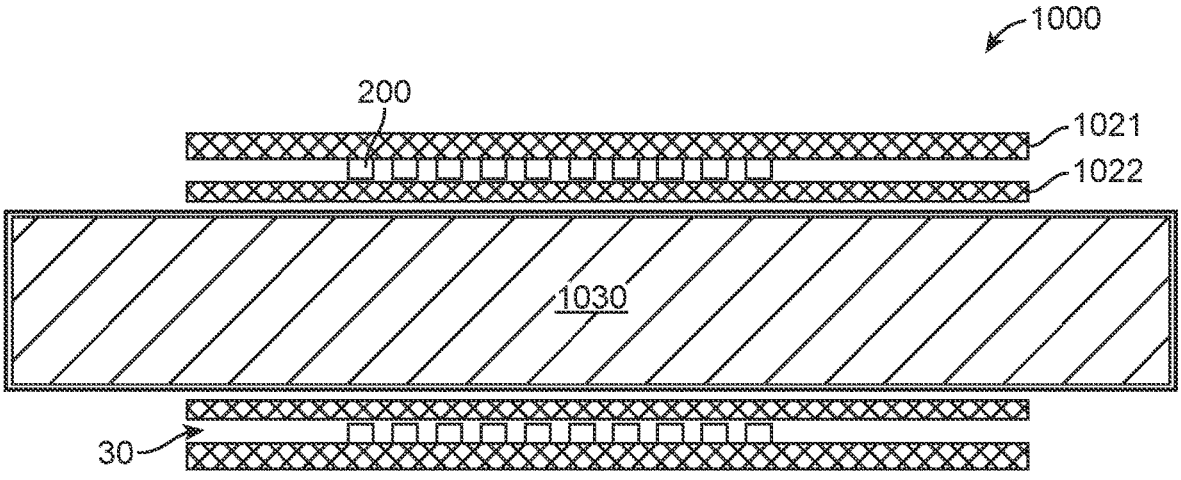


FIG. 57D

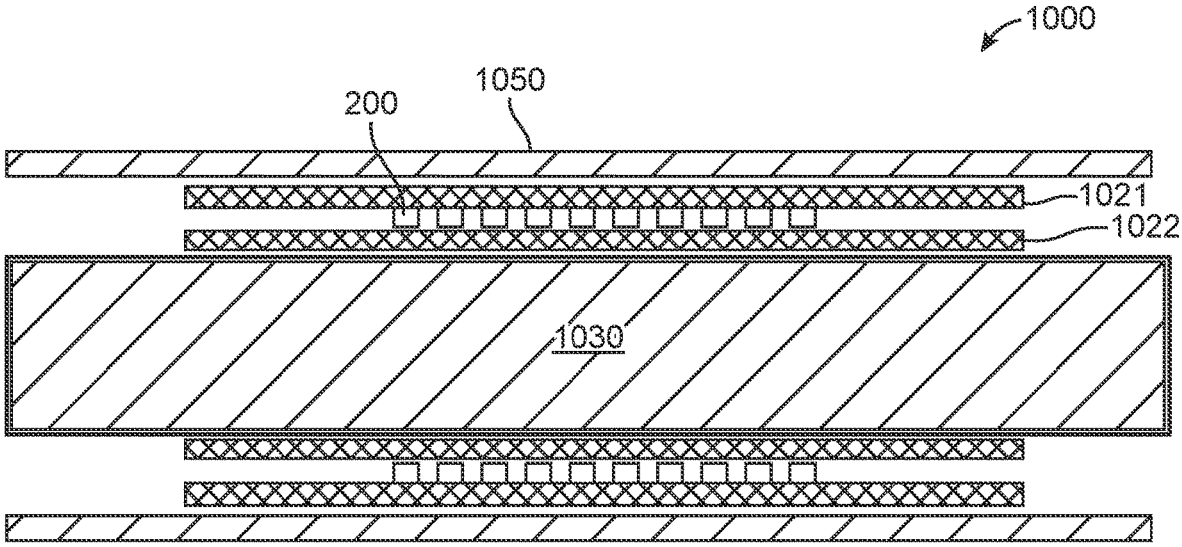


FIG. 57E

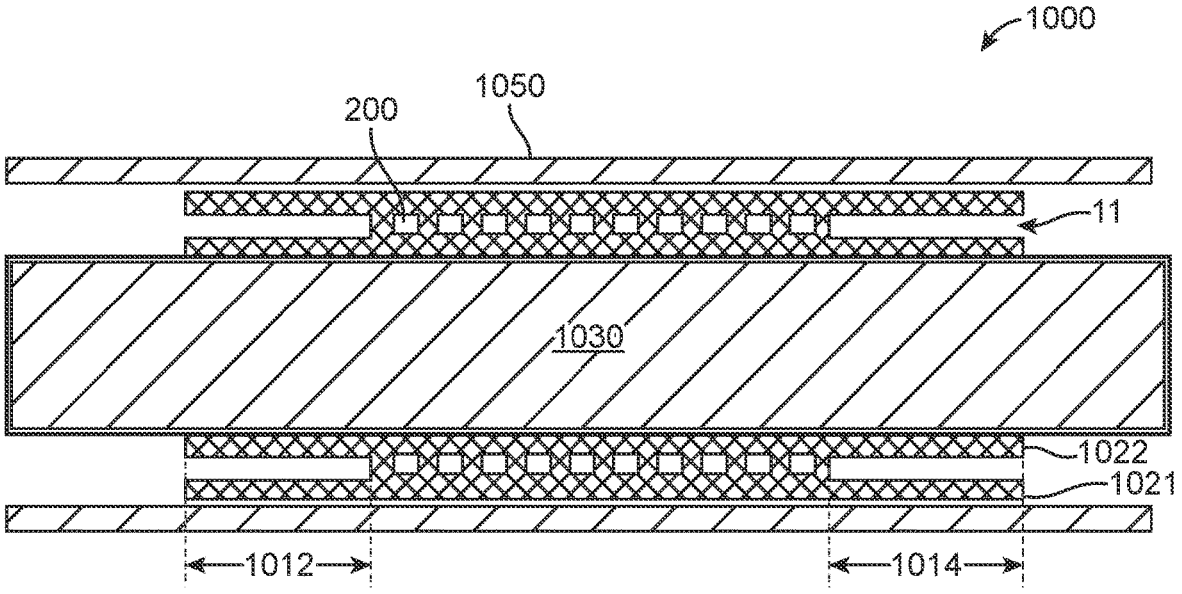


FIG. 57F

MEDICAL DEVICES WITH TUBULAR REINFORCEMENT

RELATED APPLICATION DATA

[0001] This application is a continuation of International Patent Application No. PCT/US2021/065252, filed on Dec. 27, 2021, which claims priority to U.S. Provisional Patent Application No. 63/234,165, filed Aug. 17, 2021, and U.S. Provisional Patent Application No. 63/131,767, filed Dec. 29, 2020, the disclosures of all of which are hereby incorporated herein by reference in their entirety into the present application.

FIELD

[0002] The present disclosure relates generally to minimally invasive medical devices, and more specifically to catheters.

BACKGROUND

[0003] The use of intravascular catheters for accessing and treating various types of diseases, such as vascular defects, is well-known. For example, a suitable intravascular catheter may be inserted into the vascular system of a patient. Commonly used vascular application to access a target site in a patient involves inserting a guidewire through an incision in the femoral artery near the groin, and advancing the guidewire until it reaches the target site. Then, a catheter is advanced over the guidewire until an open distal end of the catheter is disposed at the target site. Simultaneously or after placement of the distal end of the catheter at the target site, an intravascular implant is advanced through the catheter via a delivery wire.

[0004] In certain applications, such as neurovascular treatment, the catheters are required to navigate tortuous and intricate vasculature. By using an appropriately sized device having the requisite performance characteristics, such as "pushability" "steerability", "torqueability" and most important, distal tip flexibility, virtually any target site in the vascular system may be accessed, including that within the tortuous cerebral and peripheral vasculature. Further, the forces applied at the proximal end of these catheters should be transferred to the distal ends for suitable pushability (axial rigidity) and torqueability (rotation). Achieving a balance between these features is highly desirable, but difficult.

[0005] Also, a catheter may have a lumen with a certain cross-sectional shape. During use, the catheter may be bent. For example, tensioning wire may be operated to bend the catheter, and/or the catheter may be bent via guidewire or by a curvature of an anatomy. The bending of the catheter causes a compression on one side of the catheter and tension on an opposite side of the catheter. In some cases, due to the compression associated with the bending of the catheter, the catheter may kink, thereby collapsing the lumen of the catheter. Designing a catheter to resist such kinking while achieving certain bending flexibility and torsional rigidity is very difficult to accomplish.

SUMMARY

[0006] A catheter includes: a tubular structure having a distal end, a proximal end, and a body extending between the distal end and the proximal end, the tubular structure having a longitudinal axis; wherein the tubular structure comprises a plurality of ring elements arranged in series along the longitudinal axis, the ring elements being respective closed-loops, wherein the ring elements comprise a first ring element and a second ring element, wherein the first ring element lies within a first plane that is substantially perpendicular to the longitudinal axis of the tubular structure, and wherein the second ring element lies within a second plane that is substantially perpendicular to the longitudinal axis of the tubular structure; wherein the tubular structure further comprises connecting members, the connecting members comprising a first connecting member connected between the first ring element and the second ring element, wherein the first connecting member comprises a first member end, a second member end, and a member body between the first member end and the second member end; and wherein the first member end of the first connecting member is connected to the first ring element, wherein the second member end of the first connecting member is connected to the second ring element, and wherein the member body is configured to rotate and/or bent relative to the first ring element and the second ring element in response to a bending and/or axial-loading of the tubular structure.

[0007] Optionally, the catheter comprises a lumen having a cross-sectional shape when the catheter is in a relaxed state, and wherein the tubular structure is configured to maintain the cross-sectional shape of the lumen during bending of the catheter.

[0008] Optionally, the tubular structure is configured to provide axial stiffness and/or torsional stiffness for the catheter.

[0009] Optionally, the first member end of the first connecting member and the second member end of the first connecting member define a line that is non-parallel to the longitudinal axis of the tubular structure.

[0010] Optionally, the first plane and the second plane remain substantially perpendicular to the longitudinal axis when the tubular structure is being bent and/or being axially-loaded.

[0011] Optionally, the first ring element has an uniform cross-section.

[0012] Optionally, the first ring element has different cross-sectional dimensions along a length of the first ring element.

[0013] Optionally, the first ring element has multiple segments connected together, each of the multiple segments having a paddle-shape.

[0014] Optionally, a majority of the first connecting member lies in a third plane that is parallel to the first plane when the tubular structure is in a relaxed state.

[0015] Optionally, at least a portion of the first connecting member has a curvilinear configuration.

[0016] Optionally, the first ring elements comprises a first ring segment and a second ring segment; wherein the first ring segment has a first end and a second end that is larger than the first end; wherein the second ring segment has a first end and a second end that is larger than the first end of the second ring segment; and wherein the first end of the second ring segment is connected to the second end of the first ring segment.

[0017] Optionally, the first connecting member extends from the first end of the second ring segment.

[0018] Optionally, the connecting members also comprise a second connecting member, and wherein both the first and

second connecting members are located between the first ring element and the second ring element.

[0019] Optionally, the first and second connecting members comprise respective interlocks that are in abutment engagement with respect to each other to limit an amount of bending and/or stretching of the tubular structure.

[0020] Optionally, the connecting members also comprise a second connecting member, wherein the first and second connecting members are connected to a same location at the first ring element.

[0021] Optionally, the ring elements and the connecting members are integrally formed together.

[0022] Optionally, the ring elements and the connecting members are parts of a cut tube.

[0023] Optionally, a portion of the first ring element and a portion of the first connecting member are separated from each other to define a first space, and wherein the catheter further comprises a filler located in the space.

[0024] Optionally, the portion of the first connecting member is separated from the second ring to define a second space, wherein the first space and the second space has a same width.

[0025] Optionally, the catheter further includes a layer disposed on an outer surface or an inner surface of the tubular structure.

[0026] Optionally, the layer of the catheter includes a material that extends into a spacing to form a filler between a portion of the first ring element and a portion of the first connecting member.

[0027] Optionally, the tubular structure and the layer are configured to cooperate with each other by sharing tensile load and/or bending load.

[0028] Optionally, the connecting members of the catheter also include a second connecting member and a third connecting member, and wherein the first connecting member, the second connecting member, and the third connecting member are coupled between the first ring element and the second ring element.

[0029] Optionally, the connecting members include three pairs of connecting members or more, and wherein the first connecting member, the second connecting member, and the third connecting member are respectively in the three pairs of the connecting members.

[0030] Optionally, the first connecting member has a width that is less than 0.005 inch.

[0031] Optionally, the filler comprises a polymeric material.

[0032] Optionally, the first connecting member comprises a plurality of sub-connecting members.

[0033] Optionally, majority parts of the respective sub-connecting members are substantially parallel to each other.

[0034] Optionally, the plurality of sub-connecting members comprises 2, 3, or 4 sub-connecting members.

[0035] Optionally, the sub-connecting members are parts of a structure that is cut to form the sub-connecting members.

[0036] Optionally, at last one of the sub-connecting members has a cross-sectional shape with a thickness and a width, wherein the thickness is measured along a radial direction extending from the longitudinal axis of the tubular structure, wherein the width is measured along a direction that is perpendicular to the radial direction, and wherein the width is greater than the thickness.

[0037] Optionally, at last one of the sub-connecting members has a cross-sectional shape with a thickness and a width, wherein the thickness is measured along a radial direction extending from the longitudinal axis of the tubular structure, wherein the width is measured along a direction that is perpendicular to the radial direction, and wherein the width is greater than the thickness.

[0038] A catheter includes: a tubular structure having a distal end, a proximal end, and a body extending between the distal end and the proximal end; wherein the tubular structure comprises a configuration shown in any of the FIGS. **2-3** and **5-20**.

[0039] Other and further aspects and features of embodiments will become apparent from the ensuing detailed description in view of the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

[0040] FIG. **1** illustrates a catheter in accordance with some embodiments.

[0041] FIGS. **2**A-**2**B illustrate a part of a tubular structure of the catheter of FIG. **1**.

[0042] FIGS. **3**A-**3**B illustrate a bending of the tubular structure of FIG. **2**.

[0043] FIGS. **4**A-**4**B illustrate a bending of another tubular structure that is different from the tubular structure of FIG. **2**.

[0044] FIG. **5** illustrates another tubular structure.

[0045] FIG. **6** illustrates a bending of the tubular structure of FIG. **5**.

[0046] FIG. **7** illustrates a tensioning of the tubular structure of FIG. **5**.

[0047] FIG. **8** illustrates a tube segment having the tubular structure of FIG. **5**, particularly showing the tube segment being bent.

[0048] FIG. **9** illustrates the tube segment of FIG. **8**, particularly showing the tube segment being tensioned.

[0049] FIG. **10** illustrates the tube segment of FIG. **8**, particularly showing the tube segment being tested for kink resistance.

[0050] FIG. **11** illustrates another tubular structure.

[0051] FIG. **12** illustrates a tube segment having the tubular structure of FIG. **11**.

[0052] FIG. **13** illustrates another tubular structure.

[0053] FIG. **14** illustrates a tube segment having the tubular structure of FIG. **13**.

[0054] FIG. **15** illustrates another tubular structure.

[0055] FIG. **16** illustrates a tube segment having the tubular structure of FIG. **15**.

[0056] FIG. **17** illustrates another tubular structure.

[0057] FIG. **18** illustrates a tensioning of the tubular structure of FIG. **17**.

[0058] FIG. **19** illustrates a section of the tubular structure of FIG. **17**, particularly showing the section undergoing bending.

[0059] FIG. **20** illustrates the tubular structure of FIG. **17**, particularly showing some of the interlocks being disengaged during bending of the tubular structure.

[0060] FIGS. **21**A-**21**B illustrate a side and perspective view of another tubular structure.

[0061] FIG. **22** illustrates another tubular structure with a section being bent.

[0062] FIG. **23** illustrates another tubular structure a section being bent.

[0063] FIGS. **24**A-**24**B illustrate another tubular structure and a 2D pattern of the same.

[0064] FIG. **25** illustrates another tubular structure.

[0065] FIG. **26** illustrates a bending of the tubular structure of FIG. **25**.

[0066] FIG. **27** illustrates a further bending of the tubular structure of FIG. **5**.

[0067] FIGS. **28**A-**28**B illustrate 2D patterns of the others tubular structure.

[0068] FIGS. **29**A-**29**B illustrate another tubular structure and detailed section thereof.

[0069] FIGS. **30**A-**30**B illustrate another tubular structure and detailed section thereof.

[0070] FIG. **31** illustrates a data table of stretching percentage of a polymer of the tubular structure of FIG. **29**A-**29**B.

[0071] FIG. **32** illustrates illustrates a data table of stretching percentage of a polymer of the tubular structure of FIG. **30**A-**30**B.

[0072] FIG. **33** illustrates another tubular structure 2D pattern.

[0073] FIG. **34** illustrates a variation of the tubular structure 2D pattern of FIG. **33**.

[0074] FIGS. **35**A-**35**B illustrate another tubular structure in respective relaxed and stretched configurations.

[0075] FIGS. **36**A-**36**B illustrate another tubular structure in respective relaxed and stretched configurations.

[0076] FIGS. **37**A-**37**B illustrate another tubular structure in respective relaxed and stretched configurations.

[0077] FIGS. **38**A-**38**H illustrate another tubular structure and various bending of the same.

[0078] FIG. **39** illustrates a variation of the tubular structure of FIGS. **38**A-**38**H.

[0079] FIG. **40** illustrates another variation of the tubular structure of FIGS. **38**A-**38**H.

[0080] FIGS. **41**A-**41**C illustrates another tubular structure and bending of the same.

[0081] FIGS. **42**A-**42**F illustrate another tubular structure and bending of the same.

[0082] FIG. **43** illustrates another tubular structure.

[0083] FIGS. **44**A-**44**E illustrate another tubular structure, stretching and bending of the same.

[0084] FIGS. **45**A-**45**B illustrate another tubular structure having cut pattern and loading configuration.

[0085] FIGS. **46**A-**46**B illustrate a tubular structure having another cut pattern and loading configuration.

[0086] FIGS. **47**A-**47**C illustrate another tubular structure and bending of the same.

[0087] FIG. **48** illustrates another 2D pattern of a tubular structure.

[0088] FIG. **49** illustrates of the tubular structure of FIG. **48**.

[0089] FIG. **50** illustrates another 2D pattern of a tubular structure.

[0090] FIG. **51** illustrates the tubular structure of FIG. **50** in a stretched configuration.

[0091] FIG. **52** illustrates a cross-sectional shape of the connecting member of FIGS. **50-51**.

[0092] FIG. **53** illustrates the tubular structure of FIGS. **48-49** in a stretched configuration.

[0093] FIG. **54** illustrates a bending of the tubular structure of FIGS. **48-49**.

[0094] FIG. **55** illustrates a cross-sectional shape of a structural member, and associated moments of inertial with respect to two different axes.

[0095] FIG. **56** is a table comparing stiffness of different connecting members.

[0096] FIGS. **57**A-**57**F illustrate cross-sectional views of a method of manufacturing the catheter of FIG. **1**.

DETAILED DESCRIPTION

[0097] Various embodiments are described hereinafter with reference to the figures. It should be noted that the figures are not drawn to scale and that elements of similar structures or functions are represented by the same reference numerals throughout the figures. It should also be noted that the figures are only intended to facilitate the description of the embodiments. They are not intended as an exhaustive description of the invention or as a limitation on the scope of the invention. In addition, an illustrated embodiment needs not have all the aspects or advantages shown. An aspect or an advantage described in conjunction with a particular embodiment is not necessarily limited to that embodiment and can be practiced in any other embodiments even if not so illustrated, or if not so explicitly described.

[0098] For the following defined terms, these definitions shall be applied, unless a different definition is given in the claims or elsewhere in this specification.

[0099] All numeric values are herein assumed to be modified by the term "about," whether or not explicitly indicated. The term "about" generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (i.e., having the same function or result). In many instances, the term "about" may include numbers that are rounded to the nearest significant figure. In some cases, the term "about" may refer to a range of values that are within +/−10% of a value. For example, a value of 2 or a value of about 2 may refer to any value that is within the range of 2+/−10% (=2+/−0.2=1.8 to 2.2).

[0100] The recitation of numerical ranges by endpoints includes all numbers within that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5).

[0101] 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. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

[0102] FIG. **1** illustrates a catheter **10** in accordance with some embodiments. The catheter **10** includes a tube **11** having a distal end **12**, a proximal end **14**, and a tube body **16** extending between the distal end **12** and the proximal end **14**. The catheter **10** also includes a handle **18** attached to the proximal end **14** of the tube **11**.

[0103] The distal end **12** of the catheter **10** is more flexible than the tube body **16** and the proximal end **14**, and the proximal end **14** is stiffer and typically less flexible than the tube body **16**. Although the distal end **12**, the proximal end **14**, and the tube body **16** may be considered as distinct sections of the catheter **10**, the transition between these sections is smooth and substantially gradual. Usually, the typical dimensions of the catheter **10** are: overall length: 125-200 cm; proximal end **14**: 50-150 cm; tube body **16**: 5-100 cm; and distal end **12**: 2-30 cm. It should be appre-

ciated that these dimensions are only guidelines and are selected as a function of the condition to be treated and its site within the body.

[0104] The tube **11** includes an outer surface **21**, and inner surface **22**, and a lumen **30** defined by the inner surface. The tube **11** also includes a tubular structure **200** configured to provide certain stiffness for the tube **11**. As shown in the figure, the tubular structure **200** is disposed between the outer surface **21** and the inner surface **22** of the tube **11**, so that the tubular structure **200** is embedded within a wall of the tube **11**. In other embodiments, the tubular structure **200** may be on the outer surface **21**, or on the inner surface **22** of the tube **11**. The tubular structure **200** has a distal end, a proximal end, and a body extending between the distal end and the proximal end. The tubular structure **200** also has a longitudinal axis **20** defined by the distal end and the proximal end of the tubular structure **200**.

[0105] In the illustrated embodiments, the lumen **30** of the catheter **10** has a cross-sectional shape when the catheter **10** is in a relaxed state. The tubular structure **200** is configured to maintain the cross-sectional shape of the lumen **30** (Section A-A) during bending of the catheter **10**, so that the catheter **10** will not kink. Optionally, the tubular structure **200** may also be configured to provide axial stiffness (e.g., tension/compression along the longitudinal axis **20**) and/or torsional stiffness (e.g., bending) for the catheter **10**.

[0106] Any of the tubular structures **200** and/or further embodiments of the tubular structure disclosed herein or combination thereof, are configured to be disposed at the distal end **12**, the tube body **16** and/or the proximal end **14** of the catheter **10** depending on the desired flexibility, stiffness, and other features, such as tracking, pushability, among others.

[0107] The outer surface **21** and/or the inner surface **22** of the tube **11** may be formed by a filler. Any of the tubular structures **200** and/or further embodiments of the tubular structure disclosed herein or combination thereof, the filler and the tubular structure behave as a composite by sharing tensile and bending loads between the filler and tubular structure, as it will be described in further detail below.

[0108] In some embodiments, the filler forming part of the tube **11** may have a modulus of elasticity that is lower than the modulus of elasticity of the tubular structure **200**. For example, the filler may have a modulus of elasticity that is less than 50%, or more preferably less than 30%, or more preferably less than 20%, or more preferably less than 10%, or more preferably less than 5%, or more preferably less than 1%, of that of the tubular structure **200**. In one implementation, the filler may have a modulus of elasticity that is less than 15 Mpa (e.g., 10 Mpa or less).

[0109] Also, the filler forming part of the tube **11** may have the ability to undergo significant elongation before break point. For example, in some embodiments, the filler may be capable of having a strain (defined as an amount of elongation of the material divided by the length of the material) of at least: 20%, 40%, 60%, 80%, 100%, 200%, 300%, 400%, 500%, 600%, 700%, 800%, 900%, 1000%, or greater.

[0110] Various materials may be utilized as the filler. The filler may be made from polymer, plastic, foam, polymeric solution or any of other elastic materials. By means of non-limiting examples, the filler material may include polyurethane, polyurethane-based material, silicon-based material, any material having polyurethane dispersion or silicon-based dispersion, etc. Examples of filler material that may be used include CD102® or AD111® from Covestro, Gelest Ex-sil50® from Gelest, etc.

[0111] In some embodiments, because the filler is significantly softer than the material of the tubular structure **200**, the resulting tube **11** will have one or more mechanical properties that are contributed predominantly (e.g., more than 50%, more than 60%, more than 70%, more than 80%, more than 90%, more than 95%, more than 99%, etc.) by the tubular structure **200**. By means of non-limiting examples, the one or more mechanical properties may be a bending stiffness, an axial stiffness, a torsional stiffness, a shear stiffness, or any combination of the foregoing.

[0112] In one or more embodiments, the tube **11** may optionally further include a lubricious coating (e.g. hydrophilic or any other suitable coating) that is disposed on the exterior surface of the tube **11** and/or on the interior surface of the tube **11**. In some cases, an initial coating material may first be applied on the tubular structure **200** to fill the openings at the wall of the tubular structure **200**, and optionally to cover the exterior and/or interior surface of the tubular structure **200**. Then the lubricious coating is applied over the initial coating material.

[0113] Constructing the tube **11** using the tubular structure **200** (providing a majority of the mechanical properties), and using the very soft filler material, is advantageous because it prevents the distal end of the tube **11** from being too stiff, and because it allows design of catheter to be easier with resulting behavior of the catheter being more predictable (because computational modeling of the catheter may be made based on the tubular structure design only).

[0114] FIGS. **2**A-**2**B illustrate a part of a tubular structure **200** of the catheter **10** of FIG. **1**. The tubular structure **200** has a plurality of ring elements **210** arranged in series along the longitudinal axis **20**. In the illustrated embodiments, the ring elements **210** are respective closed-loops. In FIGS. **2**A-**2**B, two of the ring elements **210** are identified (e.g., a first ring element **210***a* and a second ring element **210***b*). The ring elements **210** lie within respective planes that are arranged in series along the longitudinal axis **20**. The planes in which the ring elements **210** lie are substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**, when the tubular structure **200** is in a relaxed state. In some embodiments, a ring element **210** may be considered as lying within a plane if at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90% (e.g., 100%), of a circumferential length of a part of the ring element **210** lies within a plane.

[0115] The tubular structure **200** also includes connecting members **220** connected between adjacent ones of the ring elements **210**. As shown in FIG. **2**B, the tubular structure **200** includes multiple connecting members **220***a*, **220***b* connected between adjacent ring elements **210***a*, **210***b*. The connecting member **220***a* includes a first member end **232**, a second member end **234** opposite from the first member end **232**, and a member body **236** extending between the first member end **232** and the second member end **234**. The member body **236** forms an acute angle **240** with respect to the ring element **210***a*. In some cases, the angle **240** may be measured with the tubular structure **200** being "un-rolled" to a flat configuration. Also, the first member end **232** of the connecting member **220***a* and the second member end **234** of

the connecting member **220***a* define a line that is non-parallel to the longitudinal axis **20** of the tubular structure **200**.

[0116] In the illustrated embodiments, the connecting member **220** has a rectilinear configuration. In other embodiments, at least a part of the connecting member **220** may have a curvilinear configuration.

[0117] In other embodiments, the tubular structure **200** may include more than two connecting members **220** between adjacent ring elements **210**. In further embodiments, the tubular structure **200** may include only one connecting member **220** between adjacent ring elements **210**.

[0118] In other embodiments, the ring elements **210** and/or connecting member **220** may have variations in length, width and thickness to adjust flexibility and kink resistance of the tubular structure **200**.

[0119] In some embodiments, the member body **236** of each connecting member **220** rotates and/or bends relative to the adjacent ring element **210** as the tubular structure **200** is being axially loaded (e.g., tensioned or compressed). Accordingly, the angle **240** changes as the tubular structure **200** is being axially loaded. In addition, as the tubular structure **200** is being axially loaded to change (e.g., to increase or decrease) a spacing between adjacent ring elements **210**, the cross-sectional shape of the ring elements **210** are maintained.

[0120] Also, in some embodiments, the member body **236** of each connecting member **220** rotates and/or bends relative to the adjacent ring element **210** as the tubular structure **200** is being bended. Accordingly, the angle **240** changes as the tubular structure **200** is being bended. In addition, as the tubular structure **200** is being bended, the cross-sectional shape of the ring elements **210** is maintained.

[0121] In some embodiments, filler **250** may be disposed in the spacing **216** defined between the ring elements **210** and the connecting members **220**. The filler **250** provides a seal to prevent fluid from passing across a wall of the tubular structure **200**. Additionally, the filler **250** behaves as a composite when integrated with the tubular structure **200** by sharing tensile and bending loads between the filler **250** and tubular structure **200**, as it will be described in further detail below.

[0122] FIGS. **3**A-**3**B illustrate a bending of the tubular structure **200** of FIG. **2**. As shown in FIG. **3**A, when the tubular structure **200** is being bent, the ring elements **210** stay substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**. The connecting members **220** are configured to move relative to the ring elements **210** in correspondence with the bending of the tubular structure **200**. This allows the connecting members **220** to conform to a change in a spacing distance between adjacent ring elements **210** due to the bending of the tubular structure **200**. As shown in FIG. **3**B, the tubular structure **200** is advantageous because the close-loop ring elements **210** prevents the tubular structure **200** from collapsing radially inward. Thus, the cross-sectional shape of the ring elements **210** are maintained even during bending of the tubular structure **200**, and kinking of the catheter **10** is prevented.

[0123] FIGS. **4**A-**4**B illustrate a bending of another tubular structure **400** that is different from the tubular structure **200** of FIGS. **2**A-**2**B. The tubular structure **400** comprises members **420** that are arranged in crisscross configuration. Unlike the tubular structure **200**, the tubular structure **400** does not have any closed-loop ring elements that lie in respective planes. As shown in FIG. **4**B, during bending of the tubular structure **400**, the tubular structure **400** may be "squished" due to one side of the tubular structure **400** being in compression from the bending. As a result, if the tubular structure **400** defines a circular cross-section lumen while in a relaxed state, the "squished" tubular structure **400** may result in the lumen having an elliptical shape **430**. A catheter constructed using the tubular structure **400** will be easily kinked during use.

[0124] Although the "squished" tubular structure **400** of FIG. **4**B may result in the lumen having an elliptical shape **430**, the members **420** arranged in crisscross configuration form relative large diamond cells **440** (e.g., range from 1 to 4 mm of cell width **450**) that are configured to distribute the load on the catheter **10** while preventing tearing of the filler **250** during bending. Without the relative large diamond cells **440**, attempts to shape the distal end **12** would tear the filler **250** damaging the catheter **10**. By preventing the filler **250** from tearing, the overall kink radius of the tube **11** is smaller (e.g., 0.2 mm), enabling the distal end **12** to be formed into a desired shape (i.e., pre-shape), to have shape retention, and to improve trackability. Additionally, the relative large diamond cells **440** of the tubular structure **400** are configured to increase flexibility of the distal end **12** of the catheter **10** forming a flexible end tip (e.g., ultra-soft tip), allowing bending and deflecting the catheter **10** in tortuous body lumens.

[0125] In other embodiments, instead of having the acute angle **240** shown in the above example of FIGS. **2**A-**2**B, the member bodies **236** of the connecting members **220** and their respective adjacent ring elements **210** of the tubular structure **200** may form other non-zero acute angles when the tubular structure **200** is in a relaxed state. Also, in other embodiments, the member bodies **236** of the connecting members **220** may be parallel with their respective adjacent ring elements **210**.

[0126] FIG. **5** illustrates another tubular structure **200**. The tubular structure **200** is similar to that of FIGS. **2**A-**2**B, except that a majority of the body **236** of each connecting member **220** is parallel to an adjacent ring element **210** when the tubular structure **200** is in a relaxed state. In particular, a majority of each connecting member **220** lies in a plane that is parallel to the plane in which an adjacent ring element **210** lies when the tubular structure **200** is in a relaxed state.

[0127] The tubular structure **200** of FIG. **5** may be considered as a variation of the tubular structure **200** of FIGS. **2**A-**2**B.

[0128] FIG. **6** illustrates a bending of the tubular structure **200** of FIG. **5**. As shown in FIG. **6**, when the tubular structure **200** is being bent, the ring elements **210** stay substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**. The connecting members **220** are configured to move (e.g., flex and/or rotate) relative to the ring elements **210** in correspondence with the bending of the tubular structure **200**. This allows the connecting members **220** to conform to a change in a spacing distance between adjacent ring elements **210** due to the bending of the tubular structure **200**. As similarly discussed, the tubular structure **200** is advantageous because the closed-loop ring elements **210** prevent the tubular structure **200** from collapsing radially inward. Thus, the cross-sectional shape of the ring

elements **210** are maintained even during bending of the tubular structure **200**, and kinking of the catheter **10** is prevented.

[0129] FIG. **7** illustrates a tensioning of the tubular structure **200** of FIG. **5**. As the tubular structure **200** is being tensioned, the planes in which the respective ring elements **210** (e.g., ring elements **210***a*, **210***b*) lie remain substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**. The connecting members **220** between adjacent pairs of the ring elements **210** elastically flex in correspondence with axial movement of the ring elements **210** as the tubular structure **200** is being tensioned. As shown in the figure, the member body **236** of each connecting member **220** rotates and/or bends relative to the adjacent ring element **210** so that the angle **240** changes as the tubular structure **200** is being tensioned. In addition, as the tubular structure **200** is being tensioned to change a spacing between adjacent ring elements **210**, the cross-sectional shape of the ring elements **210** are maintained.

[0130] FIG. **8** illustrates a tube segment **800** having the tubular structure **200** of FIG. **5**, particularly showing the tube segment **800** being bent. The tube segment **800** may be a part of the catheter **10** of FIG. **1** in some embodiments. As shown in FIG. **8**, the tube segment **800** with the tubular structure **200** can undergo very tight bending to have a bent shape with small radius of curvature. Through the entire length of the bend, the gaps between respective pairs of adjacent ring elements **210** remain substantially even (e.g., the gaps between different pairs of adjacent ring elements **210** do not vary by more than 10%). This is the case for both the gaps on the tension side, and the gaps on the compression side, of the bent tube segment **800**.

[0131] FIG. **9** illustrates the tube segment **800** of FIG. **8**, particularly showing the tube segment **800** being tensioned. While the tube segment **800** is being tensioned, the gaps between respective pairs of adjacent ring elements **210** remain substantially even (e.g., the gaps between different pairs of adjacent ring elements **210** do not vary by more than 10%).

[0132] FIG. **10** illustrates the tube segment **800** of FIG. **8**, particularly showing the tube segment **800** being tested for kink resistance. As shown in FIG. **10**, the tube segment **800** with the tubular structure **200** can undergo 360-degree bending to have a bent shape with small radius of curvature. Through the entire length of the bent, the gaps between respective pairs of adjacent ring elements **210** remain substantially even (e.g., the gaps between different pairs of adjacent ring elements **210** do not vary by more than 10%). This is the case for both the gaps on the tension side, and the gaps on the compression side, of the bent tube segment **800**. As shown in the figure, even with such extreme bending, the tube segment **800** forms no kink, and the structural integrity of the tube segment **800** is maintained.

[0133] In the above embodiments, the tubular structure **200** is illustrated as having ring elements **210**, wherein each ring element **210** has an uniform cross-section along the circumferential length of the ring element **210**. In other embodiments, a ring element **210** may have a varying cross-section along the circumferential length of the ring element **210**.

[0134] FIG. **11** illustrates another tubular structure **200**. The tubular structure **200** is similar to that of FIG. **5**, except that each ring element **210** has a varying cross-section along the circumferential length of the ring element **210**. Also, the connecting members **220** have a much smaller cross-sectional dimension compared to that of the ring elements **210**. In some embodiments, the connecting member **220** may have a cross-sectional dimension that is less than 50%, or less than 40%, or less than 30%, or less than 20% or less than 10%, of a cross-sectional dimension (e.g., the largest cross-sectional dimension, the smallest cross-sectional dimension, or the average cross-sectional dimension) of the ring element **210**. The tubular structure **200** of FIG. **11** may be considered as a variation of the tubular structure **200** of FIG. **5** or FIGS. **2**A-**2**B.

[0135] The configuration of the tubular structure **200** of FIG. **11** is advantageous because it provides increased spacing (compared to the tubular structure **200** of FIG. **5**) between the ring elements **210** and the connecting members **220**. This allows more filler material to be disposed between the ring elements **210** and the connecting members **220**. By configuring an amount of filler material that is placed between the ring elements **210** and the connecting members **220**, a stiffness and/or a degree of maximum bending (for a medical device incorporating the tubular structure **200**) can be tailored. For example, if it is desirable to make the catheter **10** more flexible so that it can be bent more, the spacing between the ring elements **210** and the connecting members **220** can be increased. On the other hand, if it is desirable to make the catheter **10** less flexible so that it cannot bend as much, the spacing between the ring elements **210** and the connecting members **220** can be decreased.

[0136] As shown in FIG. **11**, two of the ring elements **210** are being identified (i.e., ring element **210***a*, and ring element **210***b*). The ring element **210***a* includes different cross-sectional dimensions along a length of the ring element **210***a*. In particular, the ring element **210***a* has multiple ring segments **1102** (e.g., first ring segment **1102***a*, second ring segment **1102***b*) connected together, each of the multiple ring segments **1102** having a paddle-shape. In the illustrated embodiments, the first ring segment **1102***a* of the ring element **210***a* has a first end **1150***a* and a second end **1152***a* opposite from the first end **1150***a*, wherein the second end **1152***a* is larger in cross-section compared to the first end **1150***a*. Similarly, the second ring segment **1102***b* has a first end **1150***b* and a second end **1152***b* opposite from the first end **1150***b*, wherein the second end **1152***b* is larger in cross-section compared to the first end **1150***b*. The first end **1150***b* of the second ring segment **1102***b* is connected to the second end **1152***a* of the first ring segment **1102***a*. The connecting member **220** extends from the first end **1150***b* of the second ring segment **1102***b*.

[0137] In other embodiments, the segments **1102** may have other shapes (e.g., non-rectangular shape). Also, in other embodiments, instead of the segments **1102** of each ring element **210** having the same shape, the segments **1102** of each ring element **210** may have different respective shapes.

[0138] FIG. **12** illustrates a tube segment **1200** having the tubular structure of FIG. **11**, particularly showing the tube segment **1200** being bent. The tube segment **1200** also includes filler **250** disposed in the space that is between the ring elements **210** and the connecting members **220**. The tube segment **1200** may be a part of the catheter **10** of FIG. **1** in some embodiments. As shown in FIG. **12**, the tube segment **1200** with the tubular structure **200** can undergo very tight bending to have a bent shape with small radius of curvature. Through the entire length of the bent, the spacing

between pairs of adjacent ring elements **210** remain substantially even (e.g., the gaps between different pairs of adjacent ring elements **210** do not vary by more than 10%). This is the case for both the gaps on the tension side, and the gaps on the compression side, of the bent tube segment **800**.

[0139] Increasing the width of the ring element **210** (e.g., at certain part(s) of the ring element **210**) is advantageous. This is because polymers have stretch limit, which can limit the bend radius of a tube formed using polymers. This effect is useful since limiting the bend radius can result in more support for pushing the tube. By increasing the width of the ring elements **210**, the amount of space available for the filler **250** becomes reduced, which in turn changes the distance the polymer can stretch within the space **216**. Accordingly, the tube behavior (e.g., bending stiffness, bending limit, torsional stiffness, torsional strain limit, axial stiffness, axial strain limit, etc., or any combination of the foregoing) may be selectively adjusted without the added complexity of changing polymer formulation (chemistry). This is especially beneficial to medical devices where each material change requires an enormous amount of paperwork, testing, validation, etc.

[0140] FIG. **13** illustrates another tubular structure **200**. The tubular structure **200** is the same as that shown in FIG. **11**, except that the tubular structure **200** of FIG. **13** has ring elements **210** (e.g., ring elements **210***a*, **210***b*) that are wider. The wider ring elements **210** occupy more space, thereby reducing an amount of space that is between the ring elements **210** and the connecting members **220**. As a result, less filler **250** will be disposed in the space **216** that is between the ring elements **210** and the connecting members **220** (compared to thinner ring elements **210** having the same center-to-center distance), and the resulting tube formed by such tubular structure **200** will be stiffer compared to that of FIG. **11**.

[0141] FIG. **14** illustrates a tube segment **1400** having the tubular structure **200** of FIG. **13**, particularly showing the tube segment **1400** being bent. The tube segment **1400** also includes filler disposed in the space that is between the ring elements **210** and the connecting members **220**. The tube segment **1400** may be a part of the catheter **10** of FIG. **1** in some embodiments. As shown in FIG. **14**, the tube segment **1400** with the tubular structure **200** can undergo very tight bending to have a bent shape with small radius of curvature. Through the entire length of the bent, the spacing between pairs of adjacent ring elements **210** remain substantially even (e.g., the gaps between different pairs of adjacent ring elements **210** do not vary by more than 10%). This is the case for both the gaps on the tension side, and the gaps on the compression side, of the bent tube segment **800**. The tube segment **1400** of FIG. **14** is stiffer, and can undergo less bending, compared to the tube segment **1200** of FIG. **12** because the tube segment **1400** has less amount of filler **250** between the ring elements **210** and the connecting members **220**.

[0142] FIG. **15** illustrates another tubular structure **200**. The tubular structure **200** has a first section **1502** and a second section **1504**. The first section **1502** and the second section **1504** have different respective stiffness. In the illustrated embodiments, the first section **1502** has a pattern that is similar to the embodiments of FIG. **13**, except that the spacing between the ring elements **210** and the adjacent connecting elements **220** is smaller. The second section **1504** has the same pattern as that of the embodiments of FIG. **11**. As shown in FIG. **15**, the spacing between the connecting member **220***a* and its adjacent ring elements **210***a*, **210***b* in the first section **1502** is less than the spacing between the connecting member **220***c* and its adjacent ring elements **210***c*, **210***d* in the second section **1504**. Such configuration allows more filler **250** be placed in the space **216** among the ring elements **210** and connecting members **220** in the second section **1504** than in the space **216** among the ring elements **210** and connecting members **220** in the first section **1502**. Since the filler **250** contributes the flexibility of the medical device, the second section **1504** with more filler **250** will be more flexible (having lower stiffness) than the first section **1504**.

[0143] In the illustrated embodiments, the first section **1502** has a first bending stiffness, and the second section **1504** has a second bending stiffness, wherein the first bending stiffness is higher than the second bending stiffness. FIG. **16** illustrates a tube segment **1600** having the tubular structure of FIG. **15**, and filler **250** disposed among the ring elements **210** and the connecting members **220**. As shown in the figure, the section of the tube segment **1600** with the second section **1504** of the tubular structure **200** is more flexible, allowing the tube segment **1600** to undergo more bending, compared to the section of the tube segment **1600** with the first section **1502**.

[0144] In some embodiments, the first section **1502** of the tubular structure **200** has a first axial stiffness, and the second section **1504** has a second axial stiffness, wherein the first axial stiffness is higher than the second axial stiffness.

[0145] Also, in some embodiments, the first section **1502** of the tubular structure **200** has a first torsional stiffness, and the second section **1504** has a second torsional stiffness, wherein the first torsional stiffness is higher than the second torsional stiffness.

[0146] In some embodiments, the transition between the first section **1502** and the second section **1504**, may be a gradual transition by adjusting the pattern of the tubular structure **200** and/or the size of the spacing between the connecting members **220**. A gradual transition between the first section **1502** and the second section **1504** of the tubular structure **200** is configured to have a higher tracking performance of the catheter **10**.

[0147] FIG. **17** illustrates another tubular structure **200**. The tubular structure **200** has a first section **1702** and a second section **1704**. The first section **1702** and the second section **1704** are the same (and they have patterns that are similar to the embodiments of FIG. **13**), except that the second section **1704** has interlocks (e.g., interlocks **1712**, **1714**, **1722**, **1724**). The interlocks are configured to keep at least some of the adjacent ring elements **210** from moving too far away from each other during axial loading (e.g., tensioning and/or compression), and/or bending of the tubular structure **200**.

[0148] As shown in FIG. **17**, the first section **1702** of the tubular structure **200** includes ring element **210***a* and adjacent ring element **210***b*. The first section **1702** of the tubular structure **200** also includes connecting member **220***a* connected between the ring element **210***a* and the ring element **210***b*. The second section **1704** of the tubular structure **200** includes ring element **210***c* and adjacent ring element **210***d*. The second section **1704** of the tubular structure **200** also includes connecting member **220***c* connected between the ring element **210***c* and the ring element **210***d*. The tubular

structure **200** also includes connecting member **220***b* connected between the ring element **210***b* and the ring element **210***c*.

[0149] The second section **1704** of the tubular structure **200** includes interlocks **1714**, **1722** in abutment engagement with each other, and also interlocks **1712**, **1724** in abutment engagement with each other. The interlock **1712** is implemented at the first end **232** of the connecting member **220***c*, and the interlock **1714** is implemented at the second end **234** of the connecting member **220***c*. The interlock **1712** at the end **232** of the connecting member **220***c* that is connected to (or extend from) the ring element **210***c* is configured to engage with another interlock **1724** at an end of connecting member **220***d*. Similarly, the interlock **1714** at the end **234** of the connecting member **220***c* that is connected to (or extend from) the ring element **210***d* is configured to engage with another interlock **1722** at an end of connecting member **220***e*. In the illustrated embodiments, the connecting members **220***c*, **220***d*, **220***e* are connected between adjacent ring elements **210***c*, **210***d*, and are arranged in a same row. Thus, connecting members **220** in the same row between adjacent ring elements **210** are all connected to the same ring element **210** (e.g., ring element **210***c*) at first respective ends **232** of the connecting members **220**, and are all connected to the same adjacent ring element **210** (e.g., ring element **210***d*) at second respective ends of the connecting members **220**. Also, each of the first ends **232** of the connecting members **220** in the same row are in engagement with the second end **234** of the connecting member **220** next in the series along the circumference in the same row.

[0150] FIG. **18** illustrates a tensioning of the tubular structure **200** of FIG. **17**. As shown in the figure, because the first section **1702** of the tubular structure **200** has no interlocks, the first section **1702** can deform more in response to axial loading (e.g., tensioning). Without any interlocks locking adjacent ring elements **210***a*, **210***b* with respect to each other, the ring elements **210***a*, **210***b* in the first section **1702** can move relative to each other (at least more so compared to the second section **1704**) when the tubular structure **200** is being tensioned. On the other hand, the interlocks in the second section **1704** maintain the ring elements **210***c*, **210***d* in close proximity relative to each other, and prevent the ring elements **210***c*, **210***d* from moving too far from each other (e.g., within a certain distance threshold) when the tubular structure **200** is being tensioned.

[0151] In some embodiments, the interlocks can also prevent the adjacent ring elements **210***c*, **210***d* in close proximity relative to each other, and prevent the ring elements **210***c*, **210***d* from moving too far from each other (within a certain distance threshold) when the tubular structure **200** is being bent. FIG. **19** illustrates the second section **1704** of the tubular structure **200** of FIG. **17**, particular showing the second section **1704** undergoing bending. As shown in the figure, the interlocks (e.g., interlocks **1714**, **1722**) are in abutment engagement with each other as the section **1704** of the tubular structure **200** is being bent. This prevents the ring elements **210** (e.g., ring elements **210***c*, **210***d*) from moving too far away (e.g., past a certain distance threshold) from each other during bending of the section **1704**.

[0152] In the embodiments of FIG. **17**, each pair of interlocks has respective curvilinear sides at the interlocks that allow them to rotate relative to each other as the connecting members **220** rotate relative to the adjacent ring elements **210**. Also, the interface between the pair of interlocks is oriented at a certain angle A so that the interlocks will uncouple and slide off from each other if the relative rotation between the interlocks exceeds a certain limit. The relative rotation between the interlocks may be due to axial-loading and/or bending of the tubular structure **200**, which causes the connecting members **220** (with the interlocks at opposite ends of the connecting members **220**) to flex and/or rotate. In the illustrated embodiments, the angle A is about 45 degrees (e.g., 45+/−5 degrees). In other embodiments, the angle A may have other values. FIG. **20** illustrates the second section **1704** of the tubular structure **200** of FIG. **17**, particularly showing some of the interlocks being disengaged during bending of the tubular structure **200**.

[0153] FIGS. **21**A-**21**B illustrates yet another tubular structure **200**. The tubular structure **200** has a plurality of ring elements **210** arranged in series along the longitudinal axis **20**. The ring elements **210** lie within respective planes, substantially parallel to each adjacent ring element **210** when the tubular structure **200** is in a relaxed state. Further, the planes in which the ring elements **210** lie are substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**, when the tubular structure **200** is in a relaxed state. In the illustrated embodiments, the ring elements **210** are respective closed-loops; better appreciated in FIG. **21**B, which illustrates a perspective view of a portion of the tubular structure **200**.

[0154] The tubular structure **200** of FIGS. **21**A-**21**B may be considered as a variation of the tubular structure **200** of FIGS. **2**A-**2**B. The tubular structure **200** of FIGS. **21**A-**21**B are similar to that of FIGS. **2**A-**2**B, except that the connecting members **220** are substantially perpendicular between adjacent ring elements **210** and/or substantially parallel to the longitudinal axis **20**, when the tubular structure **200** is in a relaxed state, as shown in section **2502**.

[0155] In the embodiments of FIGS. **21**A-**21**B, the tubular structure **200** includes a pair of connecting members **220** between adjacent ring elements **210**. The pair of connecting members **220** have a rectilinear configuration and are disposed substantially at π distance (e.g. 0 and 180 degrees) of a respective ring element **210** of the tubular structure **200**, as shown in FIG. **21**B. In further embodiments, the tubular structure **200** may include only one connecting member **220** between adjacent ring elements **210**.

[0156] FIG. **22** illustrates another tubular structure **200**. The tubular structure **200** of FIG. **22** is similar to, and may be considered a variation of FIGS. **2**A-**2**B and FIGS. **21**A-**21**B. Similarly to FIGS. **2**A-**2**B and FIGS. **21**A-**21**B, the tubular structure **200** of FIG. **22** has a plurality of closed-loops ring elements **210** arranged in series along the longitudinal axis **20** and substantially parallel to each adjacent ring element **210** when the tubular structure **200** is in a relaxed state. Another similitude to FIGS. **2**A-**2**B is that the connecting members **220** of FIG. **22** includes a first member end **232**, a second member end **234** opposite from the first member end **232**, and a member body **236** extending between the first member end **232** and the second member end **234**.

[0157] A difference with FIGS. **2**A-**2**B is that the tubular structure **200** of FIG. **22** includes a pair of connecting members **220** between adjacent ring elements **210**. A difference with FIGS. **21**A-**21**B is that the each pair of connecting members **220** of FIG. **22** forms an obtuse angle β

with respect to the ring element **210** proximately disposed to another adjacent ring element **210** (e.g., angle β between **210***a* and **210***b*, as the angle is measured with respect to **210***a* as the base). For example, the member body **236** forms an obtuse angle α with respect to the ring element **210***a*. In some cases, the angle α may be measured with the tubular structure **200** being "un-rolled" to a flat configuration. In view of the angle α, the first member end **232** of the connecting member **220***a* and the second member end **234** of the connecting member **220***a* define a line that is non-parallel to the longitudinal axis **20** of the tubular structure **200**. Further, first member end **232** and the second member end **234** include an arcuate configuration while the member body **236** includes a rectilinear configuration.

[0158] FIG. **23** illustrates an alternative embodiment to the tubular structure **200** of FIG. **22**. Similar to FIG. **22**, tubular structure **200** of FIG. **23** includes a plurality of closed-loops ring elements **210** arranged in series along the longitudinal axis **20** and substantially parallel to each adjacent ring element **210** when the tubular structure **200** is in a relaxed state. FIG. **23** includes a pair of connecting members **220** between adjacent ring elements **210**. Also, the connecting members **220** of FIG. **23** includes a first member end **232**, a second member end **234** opposite from the first member end **232**, and a member body **236** extending between the first member end **232** and the second member end **234**. Further, first member end **232** and the second member end **234** include an arcuate configuration while the member body **236** includes a rectilinear configuration.

[0159] A difference with FIG. **22** is that each pair of connecting members **220** in FIG. **23** forms alternating acute a and obtuse **13** angles with respect to the ring element **210** proximately disposed to another adjacent ring element **210**. The alternating angles α and β illustrate a zig-zag configuration of the connecting members **220** of the tubular structure **200**, as shown in FIG. **23**.

[0160] FIG. **21**, FIG. **22** and FIG. **23** further illustrates respective bending sections **2504** of the tubular structures **200**. As shown by sections **2504**, when the tubular structure **200** is being bent, the ring elements **210** stay substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**. The connecting members **220** are configured to move (e.g., flex, bend, and/or translate) relative to the ring elements **210** in correspondence with the bending of the tubular structure **200**. This allows the connecting members **220** to conform to a change in a spacing distance between adjacent ring elements **210** due to the bending of the tubular structure **200**. As similarly discussed, the tubular structure **200** is advantageous because the closed-loop ring elements **210** prevent the tubular structure **200** from collapsing radially inward. Thus, the cross-sectional shape of the ring elements **210** are maintained even during bending of the tubular structure **200**, and kinking of the catheter **10** is prevented. For example, a circular inner diameter cross-section of tubular structure **200** is substantially maintain when the tubular structure **200** is subjected to tension and/or bending forces, while avoiding and/or minimizing ovalization of the circular inner diameter.

[0161] FIGS. **24**A-**24**B illustrate another tubular structure **200**. FIG. **24**A depicts the pattern of the ring elements **210** and connecting members **220** in a 2D configuration (e.g., cutting pattern on a sheet of material), while FIG. **24**B depicts the tubular structure **200** formed with the FIG. **24**A pattern (e.g. cut sheet is rolled and ends are coupled to form the tubular structure **200**). The tubular structure **200** of FIG. **24**B is similar to and may be considered a variation of FIG. **5**, such as the majority of the body **236** of each connecting member **220** is parallel to an adjacent ring element **210** when the tubular structure **200** is in a relaxed state. A difference of the tubular structure **200** of FIGS. **24**A-**24**B with respect to FIG. **5** is that a ratio of ring elements **210** to connecting members **220** is higher (e.g. 2:1) than in FIG. **5** (e.g. 1:1). Another difference of the tubular structure **200** of FIG. **24**B with respect to FIG. **5** is that the first member end **232** and the second member end **234** of a connecting member **220** are substantially parallel to each other, since the body **236** of each connecting member **220** forms a substantially complete circumference, as shown in FIG. **24**B.

[0162] FIG. **25** illustrates another tubular structure **200**. FIG. **25** depicts a pattern of cuts in the tubular structure **200**, wherein the cuts are created in a high frequency sinusoidal wave pattern forming interrupted articulation sections **235** between ring elements **210** in the tubular structure **200**. The cut pattern as shown in FIG. **25** is configured to balance the forces exerted in the tubular structure **200** when it bends, as shown in FIG. **26** and FIG. **27**. The high frequency sinusoidal wave cuts of FIG. **25** creates a ratio of at least 1:3 of ring elements **210** to connecting members **220**, as better appreciated in FIG. **26** and FIG. **27**.

[0163] FIG. **26** and FIG. **27** illustrate bending of the tubular structures **200** of FIG. **25**. FIG. **26** shows the tubular structure **200** having a bending angle θ of 30 degrees (e.g., +/−10 degrees) with respect to the longitudinal axis **20**, and FIG. **27** shows the tubular structure **200** having the bending angle θ at 60 degrees (e.g., +/−10 degrees) with respect to the longitudinal axis **20**. When the tubular structure **200** is being bent, the ring elements **210** stay substantially perpendicular (e.g., 90 degrees+/−10 degrees) to the longitudinal axis **20**. The connecting members **220** are configured to move (e.g., flex, bend, and/or translate) relative to the ring elements **210** in correspondence with the bending of the tubular structure **200**. The connecting members **220** are configured to move in a set of three, as shown in FIG. **26** and FIG. **27**, according to the cut pattern shown in FIG. **25**, and the ring elements **210** maintain hoop strength allowing the tubular structure **200** to resist kinking while preventing and/or minimizing ovalization of the circular inner diameter of the tubular structure **200**.

[0164] FIGS. **28**A-**28**B illustrate patterns of ring elements **210** and connecting members **220** in 2D configurations (e.g., cutting patterns on sheets of material) to form other embodiments of the tubular structure **200**. FIG. **28**A is similar to FIGS. **2**A-**2**B, except that the first member ends **232** and second member ends **234** of respective connecting members **220** are offset (e.g., first member ends **232***a* and **232***b* of respective connecting members **220***a* and **220***b*, as shown in FIG. **28**A). FIG. **28**A may be considered as a variation of FIGS. **2**A-**2**B. FIG. **28**B is similar to FIG. **24**A, except that in in FIG. **28**B, the first member end **232** and the second member end **234** of a connecting member **220** (e.g., **220***a*) are offset, and not substantially parallel to each other, as shown in FIG. **24**B. FIG. **28**B may be considered as a variation of FIG. **24**A.

[0165] FIG. **29**A illustrates another tubular structure **200** with a pattern similar to the one disclosed in FIG. **28**B. FIG. **29**B illustrates a detailed section of FIG. **29**A. As shown in FIG. **29**A, the tubular structure **200** includes ring elements **210** and connecting members **220**, where each connecting

member **220** is parallel to an adjacent ring element **210** when the tubular structure **200** is in a relaxed state. The tubular structure **200** is encapsulated in a biocompatible polymer creating a fluid seal and smooth outer surface **21** and inner surface **22** of tube **11**, as described in FIG. **1**. The detailed section of the tubular structure **200** of FIG. **29**B illustrates a portion of a connecting member **220***f* parallel to an adjacent ring element **210***f* and having a distance "D" of 0.002" in between.

[0166] FIG. **30**A illustrates another tubular structure **200** with a pattern similar to the one disclosed in FIG. **28**A. FIG. **30**B illustrates a detailed section of FIG. **30**A. As shown in FIG. **30**A, the tubular structure **200** includes ring elements **210** and connecting members **220**, where the tubular structure **200** is encapsulated in filler **250** (e.g., polymer, plastic, foam, polymeric solution or any of other elastic materials) creating a fluid seal and smooth outer surface **21** and inner surface **22** of tube **11** of catheter **10**, as described in FIG. **1**. The filler **250** and the tubular structure **200** behave as a composite by sharing tensile and bending loads between the filler **250** and tubular structure **200**. The tubular structure **200** having ring elements **210** and connecting members **220** is configured to evenly distribute the loads in the filler **250**, such that peak stresses (e.g., quantified by percent of elongation) in the filler **250** are minimized, which ensures higher tensile strength and resistance to rupture of the filler **250**. For example, when the tubular structure **200** is elongated (e.g., in tension or in bending), the filler **250** elongation can be more evenly distributed, which allows for an effective load distribution between the filler **250** and tubular structure **200** of the tube **11**. Some of these advantages are achieved by having an angle φ between the connecting members **220** and the ring elements **210** (FIGS. **30**A-**30**B) that creates uniform strains in the filler **250** during elongation/bending of the tubular structure **200**. The angle φ of the connecting members **220** relative to their respective ring elements **210** is about 10 degrees (e.g., +/−5 degrees) and can be increased or decreased to allow compliance of the filler **250** in order to match the compliance of the tubular structure **200**. The detailed section of the tubular structure **200** of FIG. **30**B illustrates a portion of a connecting member **220***g* forming the angle φ of about 10 degrees with respect to an adjacent ring element **210***g* and having a distance "D" of about 0.002" in between. The angle φ of the connecting members **220** relative to their respective ring elements **210** is configured to increase the tensile strength of the tube **11**. For example, variations of the angle φ may increase the peak tensile strength of the tube **11** to at least 200% (e.g., prior to filler **250** failure, break, rupture or the like). The composite effects of sharing tensile and bending loads between the filler **250** and tubular structure **200** may be adjusted (e.g., increase or decrease) by for example, a) varying the angle φ between the connecting members **220** and their respective ring elements **210**, b) varying the width and/or the radius of the ring elements **210** and/or connecting members **220**, and/or c) varying the amount of connecting members **220** with respect to their respective ring elements **210**, among other suitable variations.

[0167] In some embodiments, the space between the ring elements **210** and the connecting members **220** may be increased or decrease by varying the length of the connecting members **220**, such as to tailor the space to the properties of the filler **250**.

[0168] FIG. **31** and FIG. **32** depict data tables with the percentage in length change of the filler **250** as the connecting members **220** of the tubular structure **200** of their respective FIGS. **29**A-**29**B and FIGS. **30**A-**30**B extends, bends or rotates. The data shown in FIG. **31** and FIG. **32** reflects the percent of elongation (i.e., stretching) of the filler **250** as their respective tubular structure **200** are stretched causing their respective connecting members **220** to deflect a total of 20 degrees from their starting neutral position (i.e., tubular member **200** in a relaxed state). The elongation of the filler **250** is calculated at 0.005", 0.030" and 0.060" away from a vertex between the connecting members **220** and the ring elements **210**. The connecting members **220** of FIG. **29**A-**29**B usually form a non-uniform elongation of the filler **250** versus the connecting members **220** of FIG. **30**A-**30**B. For example, at 20 degrees of total connecting members **220** deflection, the tubular structure **200** of FIG. **29**A-**29**B shows a minimum of 86% elongation and a maximum percent elongation of 1026%, which is above the predicted rupture point of most elastomeric polymers. In contrast, at 20 degrees of total connecting members **220** deflection, the tubular structure **200** of FIG. **30**A-**30**B shows a minimum elongation of 57% and maximum elongation of 158%, such as evenly distributing the strain load and the peak strains (i.e., elongation) are well below the rupture point of most elastomeric polymers.

[0169] FIG. **33** illustrates a pattern of ring elements **210** and connecting members **220** in a 2D configuration (e.g., cutting patterns on sheets of material) to form another embodiment of the tubular structure **200**. The pattern of FIG. **33** is similar to the one disclosed in FIG. **28**A, except that some of the first member ends **232** and some of the second member ends **234** of respective connecting members **220** are substantially parallel to each other (e.g., **234***a* with **232***b*, and **234***c* with **232***d*) and some of them are offset (e.g., **234***b* with **232***c*). Having the connecting members **220** coupled around the ring elements **210** in a parallel and offset pattern, as shown in FIG. **33**, is configured to improve the flexibility of the tubular structure **200** when subjected to tensile or bending forces. Further, the ring elements **210** of FIG. **33** have substantially the same length, width and thickness throughout the tubular structure **200** (e.g., **210***a*, **210***b*, **210***c*). FIG. **33** may be considered as a variation of FIG. **28**A.

[0170] FIG. **34** illustrates a pattern of ring elements **210** and connecting members **220** in a 2D configuration to form another embodiment of the tubular structure **200**. The pattern of FIG. **34** is similar to the one disclosed in FIG. **33**, except that some of the ring elements **210** of FIG. **34** varied in width and thickness (e.g., **210***b*). As shown in FIG. **34**, the ring element **210***b* includes an increased width and/or thickness compared to the ring element **210***a*. Further, the ring element **210***b* includes curvatures between connecting members **220**. The curved and increased width/thickness of the ring element **210***b* is configured to balance and counteract tensile forces and avoid deformation or ovalization of the ring elements **210** and the tubular structure **200**. It should be appreciated that one or more curved thicker ring elements **210** may be disposed throughout the tubular structure **200**. FIG. **34** may be considered as a variation of FIG. **33**.

[0171] FIGS. **35**A-**37**B illustrate other tubular structures **200**. FIGS. **35**A-**35**B and **36**A-**36**B depict patterns of cuts made in the tubular structure **200** similar to FIG. **25**, wherein the cuts are created in a high frequency sinusoidal wave

pattern forming interrupted articulation sections **235** between ring elements **210** in the tubular structure **200**. FIGS. **37**A-**37**B depict a pattern of cuts made in the tubular structure **200** similar to FIG. **29**A, except that the cuts have a higher frequency and are offset to each adjacent cut, as shown in FIGS. **37**A-**37**B.

[0172] The cut patterns made in the tubular structures **200** of FIGS. **35**A-**37**B creates slits **700** (e.g., kerfs, slots or their like). Each slit **700** have a first end portion **710**, a middle portion **720** and a second end portion **730**. The tubular structure **200** of FIG. **35**A, FIG. **36**A and FIG. **37**A are in relaxed state and the tubular structure **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B are longitudinally stretched, as shown by arrows L**1**. The slits **700** of the tubular structure **200** in FIG. **35**A, FIG. **36**A and FIG. **37**A have a uniform configuration, such as having a substantially constant width W**1** along their respective first end portion **710**, middle portion **720** and second end portion **730**. For example, as shown in detailed and enlarged view A' of a single slit **700** of FIG. **35**A. In contrast, the slits **700'** of the tubular structure **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B have a non-uniform configuration, due to the longitudinally stretching of the tubular structure **200**. For example, the slits **700'** have a substantially constant width W**1** along the first end portion **710** and the second end portion **730**, having a larger width W**2** along the middle portion **720**; as shown in detailed and enlarged view B' of a single slit **700'** of FIG. **35**B. In another example, the slits **700'** have a substantially constant width W**1** along the first end portion **710** and the second end portion **730**, having a reduced width W**3** along the middle portion **720**; as shown in detailed and enlarged view C' of a single slit **700'** of FIG. **37**B.

[0173] In the embodiments of FIG. **35**B, FIG. **36**B and FIG. **37**B, the tubular structures **200** are created by longitudinally stretching and heat setting the respective tubular structures **200** of FIG. **35**A, FIG. **36**A and FIG. **37**A. In some embodiments, the tubular structures **200** of FIG. **35**A, FIG. **36**A and FIG. **37**A are composed of super-elastic Nitinol, such that when stretched and heat set, results in the tubular structures **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B having wider slits **700'**. It should be appreciated that the tubular structures **200** of FIG. **35**A, FIG. **36**A and FIG. **37**A may be composed of any other suitable metal, alloy, polymer, and/or material configured to maintain a stretched or plastic deformed configuration by heat setting, shot-peening or laser shock peening or any other suitable techniques.

[0174] The tubular structures **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B having wider slits **700'**, due to stretching and heat set configuration, allow tighter bend radius of the tubular structures **200** without fully closing the slits **700'** (e.g., 'crashing' adjacent ring elements). The condition called crashing is produced when tubular structures have narrow slits (e.g., about 15 microns), since such narrow slits allow limited bending of tubular structures before the slits on the inside of the bend fully close at their center points. Additionally, the narrow slits exacerbate the stiffening of the tubular structures, which along with the crashing condition; limit the performance of tubular structures manufacture with a cost-effective interrupted-helix slit pattern.

[0175] The slits **700'** in the tubular structures **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B are manufactured by stretching tubular structures **200** such as to open and/or widen of the slits **700** of FIG. **35**A, FIG. **36**A and FIG. **37**A to about 100%. For example, slits **700** having a width of 15 microns each are opened to form the slits **700'** having a width of 30 microns each, by the widening of about 100% of slits **700**. Further, it should be appreciated that the widening of the slits **700** may range from 50% to 150%, or any other suitable stretching, opening or widening, to avoid or minimize crashing condition and allow tighter bend radius in a flexible section of the tubular structures **200**.

[0176] Additionally, the tubular structure **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B may be encapsulated in filler **250** (e.g., polymer, plastic, foam, polymeric solution or any of other elastic materials) creating a fluid seal and smooth outer surface (not shown); where the wider slits **700'** are configured to reduce the degree of stiffening of the filler **250** when the tubular structure **200** is subjected to bending forces. As such, when the tubular structure **200** having wider slits **700'** bend laterally through a curve, the filler **250** spanning the slits **700'** stretch allowing the slits **700'** on the outside of the curve to open. The wider slits **700'** are configured to lower the strain percentage required in the filler **250** to allow the slots to open.

[0177] Some of the further advantages of the wider slits **700'** in the tubular structures **200** of FIG. **35**B, FIG. **36**B and FIG. **37**B, are: a) improvement in the wicking of adhesive from the exterior to the interior of the tubular structures **200**, flow of laminate or dip coat, and ability to visually confirm the extent of adhesive wicking, flow of laminate or dip coat, b) improvement in the UV light penetration to the interior diameter of the tubular structures **200** for the purpose of curing UV adhesives, and c) avoid or minimize entrapment of air inside the slits **700'** of the tubular structures **200** in the coating process.

[0178] FIGS. **38**A-**38**H illustrate another tubular structure **500**. FIG. **38**A illustrates part of the tubular structure **500** and FIGS. **38**B-**38**C illustrate enlarged sections of FIG. **38**A. The tubular structure **500** comprises elongated members **520** that are arranged in crisscross configuration. The tubular structure **500** further comprises articulation sections **540** coupling the elongated members **520** and defining diamond-shaped cells **550**. Each member **520** is coupled to an adjacent member **520** by an articulation section **540**. Adjacent articulation sections **540** of the tubular structure **500** are disposed in the same longitudinal plane, as shown in FIG. **38**A, as for example the adjacent articulation sections **540***a* and **540***b* under longitudinal plane P**1**. In the embodiment of FIGS. **38**A and **38**B, each articulation section **540** comprises four members **520** forming respective cells **550**, as better appreciated in FIG. **38**A-**38**C. Unlike the tubular structure **200**, the tubular structure **500** does not have any closed-loop ring elements that lie in respective planes.

[0179] In some embodiments, the members **520** may have a width W**4** that ranges between 0.002 to 0.003 inches and the articulation sections **540** may have a width W**5** that ranges between 0.005 to 0.017 inches, as shown in FIG. **38**B. In other embodiments, the members **520** may have a width that is less than 0.01 inches or less than 0.005 inches. Also, in other embodiments, the articulation section **540** may have any width that is larger than the width of the member **520**. In further embodiments, the articulation section **540** may have a width that is larger than 0.017 inches. The cells **550** may have a length L**3** that ranges between 0.0618 and 0.127 inches and an angle θ that ranges between 13 to 15 degrees in a relaxed configuration, as shown in FIG. **38**C. It should be appreciated that variation and/or combinations of dimensions of the elements of the tubular struc-

ture **500** may be desired. For example, FIG. **39** illustrates an alternative embodiment of the tubular structure **500**, comprising members **520** having a width of 0.003 inches and members **520'** having a width of 0.002 inches.

[0180] FIG. **38**D illustrates the tubular structure **500** comprising elongated members **520**, articulation sections **540** and defining diamond-shaped cells **550** in a relaxed configuration and FIG-**38**E illustrates the tubular structure **500** in a longitudinal stretched configuration. FIGS. **38**F-**38**H illustrate various bending of the tubular structure **500**, configured to be flexible and kink resistance during bending.

[0181] FIG. **40** illustrates an alternative embodiment of the tubular structure **500** of FIGS. **38**A-**38**H. The tubular structure **500** comprises the elongated members **520** and articulation sections **540** defining diamond-shaped cells **550**, and further comprises one or more tensile members **570** helically wound around the tubular structure **500**. The tensile members **570** are configured to intersect some cells **550**, and are offset from each adjacent tensile member **570**, as shown in FIG. **40**, for example in the tensile members **570***a* and **570***b*. The tensile members **570** are configured to increase flexibility and improve load distribution of the tubular structure **500**.

[0182] FIGS. **41**A-**41**C illustrate another tubular structure **600**. FIG. **41**A illustrates part of the tubular structure **600**, FIG. **41**B illustrates an enlarged section of FIG. **41**A, and FIG. **41**C illustrates the bending of the tubular structure **600**. Similar to the tubular structure **500** of FIGS. **38**A-**38**H, the tubular structure **600** comprises elongated members **620** and articulation sections **640** coupling the elongated members **620**, except that the articulation sections **640** are off-set (i.e., not in the same longitudinal plane) and define cells **650** comprising a parallelogram shape (i.e., off-set diamond shape). The parallelogram-shaped cells **650** are configured to increase flexibility of the tubular structure **600**.

[0183] FIGS. **42**A-**42**F illustrate another tubular structure **900**. The tubular structure **900** comprises a plurality of diamond-shaped ring elements **910** and V-cuts **950** along a longitudinal axis **20**. As shown in FIG. **42**A, the tubular structure **900** is in a relaxed configuration and in FIG. **42**B where the tubular structure **900** is in a longitudinally stretched configuration. FIGS. **42**C-**42**F illustrate the bending and bending sections of the tubular structure **900**. It should be appreciated that the frequency and dimensions of the cuts **950** may vary to increase flexibility of the tubular structure **900**.

[0184] FIG. **43** illustrates another tubular structure **200**. The tubular structure **200** is similar to that of FIGS. **11**-**13**, except that the tubular structure **200** of FIG. **43** comprises ring elements **210** that alternate width along the respective length of each ring (e.g. width W**7** wider than width W**6** along the length of ring **210***a*) and with respect to each adjacent ring (e.g., ring element **210***a* wider width W**7** is laterally disposed to adjacent ring element **210***b* narrower width W**6**, and ring element **210***b* narrower width W**6** is laterally disposed to adjacent ring element **210***c* wider width W**7**). The alternating narrower width W**6** and wider width W**7** of the ring elements **210** occupy alternating more and less space, as shown in FIG. **43**, thereby reducing or augmenting the amount of space that is between the ring elements **210** and the connecting members **220**. As a result, more or less filler **250** will be disposed in the space **216** that is between the ring elements **210** and the connecting members **220**, depending on the width of the ring elements **210**. By configuring an alternating amount of filler material that is placed between the ring elements **210** and the connecting members **220**, stiffness, flexibility and/or degree of maximum bending (for a medical device incorporating the tubular structure **200**) can be tailored.

[0185] FIGS. **44**A-E illustrate another tubular structure **200**. Particularly, FIG. **44**A illustrates the tubular structure **200** in a relaxed configuration, FIGS. **44**B-**44**C illustrate the tubular structure **200** in a longitudinally stretched configuration and FIGS. **44**D-**44**E illustrate the tubular structure **200** in a curved or bent configuration. The tubular structure **200** is similar to that of FIG. **43**, except that the tubular structure **200** of FIGS. **44**A-E comprises ring elements **210** having a constant width W**8**. The tubular structure **200** of FIGS. **44**A-E further comprises connecting members **220** and filler **250**.

[0186] As shown in FIG. **44**A, the tubular structure **200** has a plurality of connecting members **220** (e.g., three pairs of connecting members **220***a*/**220***b*) between respective ring elements **210**. The ring elements **210** comprise a width W**8** in a range of 0.1 to 1.0 mm. In some embodiments, the number of connecting members **220** and the width W**8** may vary. Such variations may depend on the needs and requirements of the catheter **10**.

[0187] Each connecting member **220** includes a first member end **232**, a second member end **234** opposite from the first member end **232**, and a member body **236** extending between the first member end **232** and the second member end **234**. Each connecting members **220** from their respective first member end **232** to the second member end **234** have an arcuate configuration, such that a pair of connecting members (e.g., **220***a*, **220***b*) form a V-shaped furcular or parenthesis-like configuration, as shown in dashed-line in FIG. **44**A. The arcuate configuration of the connecting members **220** allow longitudinal stretching and further degrees of freedom to the connecting members **220** when the tubular structure **200** is longitudinally stretched, translated, bent, or moved. Further, the arcuate configuration of the connecting members **220** avoids or minimizes relative rotation of adjacent ring elements **210**.

[0188] When the tubular structure **200** is longitudinally stretched and subjected to tensile loads, the connecting members **220** stretched out of their arcuate configuration, such that the pair of connecting members **220***a*, **220***b* form a triangle-like loading configuration with their respective ring element **210**, as shown in dashed-line in FIG. **44**B. The triangle-like loading configuration of the stretched connecting members **220** and ring elements **210** with the filler **250**, allow for tensile load sharing between the tubular structure **200** and the filler **250** avoiding or minimizing compression of the tubular structure **200** (e.g., collapsing of the catheter). FIG. **44**C illustrate a down-the-barrel view of the longitudinally stretched tubular structure **200** of FIG. **44**B, where the lumen **30** is opened (e.g., no collapsed catheter maintaining patency of the lumen).

[0189] FIGS. **44**D-**44**E illustrate the tubular structure **200** in a curved configuration when subjected to bending loads. The composite interaction of the tubular structure **200** and the filler **250** increases bending load sharing between the tubular structure **200** and the filler **250**, allowing the filler **250** to compress (e.g., wrinkle filler **250***a* in the inner curvature) and to expand (e.g., stretched filler **250***b* in the outer curvature), as shown in FIG. **44**D. The composite interaction of the tubular structure **200** and the filler **250**

during bending is configured to avoid or minimize kinking of catheter **10** when subjected to bending loads. FIG. **44**E illustrate a down-the-barrel and perspective view of the curved tubular structure **200** of FIG. **44**D, where the lumen **30** is opened (e.g., no collapsed catheter maintaining patency of the lumen).

[0190] FIGS. **45**A-**45**B illustrate yet another tubular structure **200**. FIGS. **45**A-**45**B depict a pattern of cuts made in the tubular structure **200** similar to FIG. **25**, FIG. **35**A, and/or FIG. **36**A, wherein the cuts are created in a sinusoidal wave pattern forming interrupted articulation sections **235** between ring elements **210** in the tubular structure **200**. The cut pattern made in the tubular structures **200** creates slits **700** (e.g., kerfs, slots or their like). The sinusoidal wave cuts of FIGS. **45**A-**45**B create a ratio of at least 1:4 of ring elements **210** to connecting members **220**, such as, forming a tubular structures **200** having a ring element **210** every five slits **700**.

[0191] When the tubular structure **200** is longitudinally stretched and subjected to tensile loads, the connecting members **220** form alternating triangle and diamond loading configurations with their respective ring element **210**, as shown in dashed-line in FIG. **45**A. The triangle and diamond loading configuration of the connecting members **220** and ring elements **210** along with the filler **250**, allow for tensile load sharing between the tubular structure **200** and the filler **250** avoiding or minimizing compression of the tubular structure **200** (e.g., collapsing of the catheter).

[0192] FIGS. **46**A-**46**B illustrate another tubular structure **200**. FIGS. **46**A-**46**B depict a pattern of cuts made in the tubular structure **200** similar to FIGS. **45**A-**45**B having interrupted articulation sections **235** between ring elements **210** in the tubular structure **200**. The cut pattern made in the tubular structures **200** of FIGS. **46**A-**46**B creates slits **700** (e.g., kerfs, slots or their like) forming a tubular structure **200** having a ring element **210** every two slits **700**.

[0193] When the tubular structure **200** of FIGS. **46**A-**46**B is longitudinally stretched and subjected to tensile loads, the connecting members **220** form triangle loading configurations with their respective ring element **210**, as shown in dashed-line in FIG. **46**A. The triangle loading configurations of the connecting members **220** and ring elements **210** along with the filler **250**, allow for tensile load sharing between the tubular structure **200** and the filler **250** avoiding or minimizing compression of the tubular structure **200**.

[0194] The cut patterns of FIGS. **45**A-**45**B and FIGS. **46**A-**46**B are configured to balance the forces exerted in the tubular structure **200** when it translates and/or bends. Additionally, the cut patters are configured to optimize kink resistance and tensile strength of their respective tubular structures **200** and fillers **250**. Depending on the slits **700** (e.g., quantity, spacing and further features of the slits) between the ring elements **210** and connecting members **220**, either a combination of triangle and diamond loading configurations (FIGS. **45**A-**45**B) or only triangle loading configuration (FIGS. **46**A-**46**B) are formed.

[0195] The triangle loading configuration is stiffer than the diamond loading configuration. The triangle loading configuration is less flexible in bending and tension (e.g., elongation of connecting members **220** occurs when subjected to tension and bending loads). The diamond loading configuration is more flexible in bending and tension (e.g., no need for elongation of connecting members **220** when subjected to tension and bending loads).

[0196] FIGS. **47**A-**47**C illustrate another tubular structure **500**. FIG. **47**A illustrates part of the pattern to produce the tubular structure **500**. The pattern depicted in FIG. **47**A is similar to the pattern of FIG. **38**B except that the tubular structure **500** of FIGS. **47**A-**47**C defines triangular-shaped cells **555** and comprises ring elements **510**.

[0197] The tubular structure **500** comprises elongated members **520** that are arranged in crisscross configuration and ring elements **510** disposed between respective elongated members **520**. The tubular structure **500** further comprises articulation sections **540** coupling the elongated members **520** to the ring elements **510**, defining triangular-shaped cells **555**. Adjacent articulation sections **540** of the tubular structure **500** are disposed in the same longitudinal plane, as shown in FIG. **47**B (e.g., along the longitudinal axis **30**).

[0198] In some embodiments, the members **520** may have a width W**9** that ranges between 0.002 to 0.003 inches, the articulation sections **540** may have a width W**10** that ranges between 0.005 to 0.017 inches and the ring elements **510** may have a width W**11** that ranges between 0.002 to 0.003 inches, as shown in FIG. **47**A. The cells **555** may have a length L**4** that ranges between 0.0700 and 0.151 inches. It should be appreciated that variation and/or combinations of dimensions of the elements of the tubular structure **500** may be desired.

[0199] FIG. **47**B illustrates the tubular structure **500** comprising elongated members **520**, ring elements **510**, articulation sections **540**, all defining triangle-shaped cells **555** in a relaxed configuration and FIG-**47**C illustrates bending of the tubular structure **500**.

[0200] The tubular structure **500** of FIGS. **47**A-**47**C is configured to be flexible and kink resistance during bending. Additionally, the ring elements **510** are configured to provide hoop strength, avoid or minimize ovalization of the tubular structure **500** while bending to preserve lumen patency. In some embodiments, the ring elements **510** may have the width W**11** larger than 0.003 inches. In other embodiments, the width W**11** of the ring elements **510** may vary along the length of the tubular structure **500**. For example, the width W**11** may be larger than 0.003 inches, decreasing the flexibility of the tubular structure **500** and gradually the width W**11** may decrease, increasing the flexibility of the tubular structure **500**. In some embodiments the width W**9** of the members **520** should be similar to the width of the filler **250** to maximize tensile force. Additionally, the number of cells **555** can be varied to increase or decrease stiffness and kink of the tubular structure **500**.

[0201] FIG. **48** illustrates a two-dimensional (2D) pattern of another tubular structure. In particular, FIG. **48** shows a pattern of ring elements **210** and connecting members **220** in a 2D configuration (e.g., cutting patterns on sheets of material) to form another embodiment of the tubular structure **200** (shown in FIG. **49**). The connecting members **220** are disposed between adjacent ring elements **210**, such as the ring elements **210***a* and **210***b* shown in FIG. **49**. The connecting members **220** include first member ends **232**; second member ends **234** opposite from the first member ends **232**, and member bodies **236** extending between the respective first member ends **232** and second member ends **234**. The member bodies **236** form an acute angle **240** (e.g., any angle that is less than 90 degrees, such as 0 degree) with respect to the ring element **210**. In some cases, the angle **240** may be measured with the tubular structure **200** being "un-rolled" to a flat configuration, as in FIG. **48**.

[0202] In the illustrated embodiments of FIGS. **48-49**, the connecting members **220** have curvilinear configurations at their respective first member ends **232** and second member ends **234**, and a rectilinear configuration at the member bodies **236**. In other embodiments, the bodies **236** may each have a curvilinear configuration.

[0203] The tubular structure of FIGS. **48-49** may be considered as a variation of that shown in FIG. **33**. In particular, the tubular structure of FIGS. **48-49** is similar to the one disclosed in FIG. **33**, except that one or more of the connecting members **200** comprise a plurality of sub-connecting members **222***a*-**222***d*. In the embodiments of FIGS. **48-49**, each connecting member **220** has at least four sub-connecting members **222***a*-**222***d* in which their respective member bodies are substantially parallel (e.g., forming an angle that is less than 5 degrees, such as 0 degree) to each other. The cross-sectional shapes of the respective sub-connecting members **222***a*-**222***d* are the same (i.e., they have the same width and thickness). In other embodiments, at least two of the sub-connecting members **222***a*-**222***d* may have respective cross-sectional shapes that are different from each other (i.e., they have different widths and/or different thicknesses). Also, in other embodiments, the connecting member **220** may include more than four sub-connecting members **222** or fewer than four (e.g., three or two) sub-connecting members **222** between adjacent ring elements **210**. As shown in the figure, majority parts of the respective sub-connecting members **222** are substantially parallel to each other. In other cases, majority parts of the respective sub-connecting members **222** may form acute angle with respect to each other. The sub-connecting members **222** may be parts of a structure that is cut to form the sub-connecting members **222**.

[0204] The tubular structure of FIGS. **48-49** with the connecting member **220** having multiple sub-connecting members **222***a*-**222***d* is advantageous over a tubular structure in which the connecting member **220** has a single elongated body. FIG. **50** illustrates a 2D pattern of another tubular structure, which comprises the ring elements **210** and connecting members **220**. The tubular structure of FIG. **50** is similar to that of FIG. **48**, except that each connecting member **220** has a single elongated body (i.e., each connecting member **220** in the tubular structure of FIG. **50** does not have multiple sub-connecting members **222** like that of FIG. **48**).

[0205] In the case of FIG. **50**, the tensile strength of each connecting member **220** is related to the width and wall thickness of the connecting members **220**. For example, assuming the width of each connecting member **220** is b, and the wall thickness of each connecting member **220** is h (see FIG. **52**), the tensile strength of the connecting member **220** is a function of the area of the cross-sectional shape, which area is b×h. If the connecting member **220** has no shear stress, the connecting member **220** can withstand a maximum tensile loading that is based on b×h. On the other hand, during use of the tubular structure, the tubular structure may undergo bending and/or twisting, which causes the connecting member **220** to twist (as shown in FIG. **51**). The direction of twisting of the connecting member **220** depends on the dimensions of the thickness h and width b of the cross-sectional shape of the connecting member **220**. In the illustrated example, the width b is larger than h, and the connecting member **220** twists in the manner shown in FIG. **51**. The twisting imposes shear stress on the connecting members **220** and can lead to poor clinical performance such as early fracture, poor tensile performance, and/or undesirable deflected geometries of the tubular structure **200**.

[0206] Having the connecting members **220** comprise a plurality of sub-connecting members (e.g. **222***a*-**222***d* in FIGS. **48-49**) improves flexibility and pushability of the tubular structure **200** when subjected to tensile or bending forces. Also, the plurality of sub-connecting members (e.g. **222***a*-**222***d*) of the connecting members **220** are configured to move (e.g., flex, bend, and/or translate) relative to the ring elements **210** in correspondence with the flexing, bending, and/or translation of the tubular structure **200**, as shown in FIG. **53** and FIG. **54**. The plurality of sub-connecting members (e.g., **222***a*-**222***d*) eliminates or reduces the sheer stress of the connecting members **220** when the tubular member **200** is deflected, since the plurality of sub-connecting members (e.g. **222***a*-**222***d*) are allowed to move (e.g., translate, slide, etc.) relative to each other. Since sheer stress is reduced or eliminated, the sub-connecting members **222** of the connecting member **220** can withstand higher tensile stress (compared to the scenario in which the connecting member **220** has no sub-connecting members **222** and has higher shear stress). Reducing shear stress in a structural member can allow the structural member to withstand higher tensile stress because the structural member's structural capacity can be utilized to handle other stress (e.g., tensile stress). For example, if a structural member has stress capacity C, the structural member can handle a combined stress (e.g., tensile stress TS, shear stress SS, etc.) that is equal to C. If shear stress SS and tensile stress TS are present, the combined stress demand on the structural member is TS+SS, and the structural member will fail when TS+SS>C. This means that the structural member can withstand tensile stress TS=C−SS. On the other hand, if shear stress is eliminated, then the structural member will fail when TS>C. In this case, the structural member can withstand tensile stress TS=C.

[0207] In addition, each sub-connecting member **222** of FIGS. **48-49** has a smaller cross-sectional width b compared to the connecting member **220** of FIG. **50**. For example, the cross-section width b of the connecting member **220** of FIG. **50** may be X, and the cross-sectional width b of each of the sub-connecting members **222***a*-**222***d* of FIG. **48** may be X/4. Despite the total cross-sectional area (A=4×h×X/4=hX) of all of the sub-connecting members **222** of FIGS. **48-49** being equal to the cross-sectional area (A=hX) of the connecting member **220** of FIG. **50**, the combined shear stress in all of the sub-connecting members **222***a*-**222***d* of the connecting member **220** of FIG. **48** is smaller than the shear stress in the connecting member **220** of FIG. **50** (given the same force-loading condition and same wall thicknesses for both devices) because the sub-connecting members **222** can move relative to each other as discussed. The plurality of sub-connecting members **222** of FIGS. **48-49** further allows the sub-connecting members **222** to collectively handle higher tensile stress (see FIG. **53**) compared to the connecting member **220** of FIG. **50**, because the sub-connecting members **222** have less shear stress compared to the connecting member of FIG. **50** (assuming with the same loading conditions), as discussed. The sub-connecting members **222** also increases flexibility of the tubular structure **200** as shown in FIG. **54**, compared to the embodiments of FIGS. **50-51**.

[0208] In the embodiments of FIGS. **48-49** and FIGS. **53-54**, the wall thickness h of each sub-connecting member **222** is smaller than the width b of the connecting member **222**. In other embodiments, the wall thickness h of each sub-connecting member **222** may be larger than the width b of the connecting member **222**. In some cases, the thickness h is measured in a radial direction extending from a longitudinal axis of the tubular member **200**. The thickness h may also be the wall thickness of the tubular member **200**. In some cases, the width may be measured along a direction that is perpendicular to the radial direction.

[0209] Additionally, having the connecting member **220** comprising a plurality of sub-connecting members (e.g. sub-connecting members **222***a*-**222***d* in FIGS. **48-49**) allows the connecting member **220** to have reduced bending stiffness compared to the connecting member **220** in FIG. **50**, because the sum of the cross-sectional stiffnesses of the sub-connecting members **222** of the connecting member **220** in FIG. **48** is less than the cross-sectional stiffness of the single connecting member **220** in FIG. **50**. In particular, the bending stiffness of a member is based on a cross-sectional stiffness of the member, and the cross-sectional stiffness of the member is in turn based on a moment of inertia of the cross-sectional shape of the member. The moment of inertia I of the cross-sectional shape of a member is a function of the width of the member raised to the third power (see FIG. **55**). For example, a connecting member **220** including two sub-connecting members **222** having a width b of 0.004" each, would have a stiffness of $K\times(0.004)^3=K\times6.4E-8$ per sub-member **222**, where K is a constant. Thus, the total bending stiffness of the connecting member **220** with two sub-connecting members **222** is $2K\times6.4E-8=K\times12.8E-8$. On the other hand, a single connecting member **220** having a width of 0.008" would have a stiffness of $K\times(0.008)^3=K\times51.2E-8$. Therefore, the stiffness of a connecting member **220** with two sub-connecting members **222** would be four times more flexible (i.e., less stiff) that a connecting member **220** without sub-connecting members **222** (e.g. 51.2E-8/12.8E-8=4). As a result, the overall structural stiffness of the tubular structure **200** can be adjusted by configuring a number of the sub-connecting members **222**. Exemplary data table comparing the stiffness of a connecting member **220** (without sub-connecting members **222**) to stiffnesses of connecting members **220** with double, triple or quadruple sub-connecting members **222**, respectively, having the same base geometry is shown in FIG. **56**.

[0210] In some embodiments, when sub-connecting members **222** are being created, such as by laser cutting, some materials may be removed by the laser. For example, if the width of the connecting member **220** is 0.008 inch, and if one laser cut is applied to the middle to create two sub-connecting members **222**, each sub-connecting member **222** may have a width that is less than 0.004 inch (=0.008/2 inch). For example, the laser cut may remove a width of 0.0008 inch. In such cases, the width of each of the two sub-connecting members **222** may be (0.008-0.0008)/2=0.0036 inch.

[0211] In any of the embodiments of the tubular structure **200** described herein, the tubular structure **200** may be made from a raw tube. The raw tube may be a metal tube, an alloy tube, a plastic tube, a polymeric tube, or a tube made from any of other materials. The raw tube is then cut to form the ring elements **210** and connecting members **220**. In such cases, the ring elements **210** and the connecting members **220** are parts of a cut tube. The cutting of the raw tube may be performed using laser cutting in some embodiments. For example, an electronic file storing geometric information (e.g., shape information, dimension information, etc.) regard the tubular structure **200** to be formed may be created. The electronic file may be provided to a processing unit of a laser cutting machine. The processing unit processes the electronic file to operate a laser cutter of the laser cutting machine to cut geometric pattern(s) defined by the information in the electronic file. In some embodiments, the laser cutting may be performed on the raw tube. In other embodiments, instead of a raw tube, a raw sheet of material may be provided, and the laser cutting may be performed on the raw sheet. After the laser cutting is performed, the cut sheet may be rolled to form the tubular structure **200**. Edges (that are parallel to the longitudinal axis) of the rolled sheet may be connected together to form a closed loop tube. Other techniques involve forming the desired pattern into a sheet or a tube by chemical etching or electrical discharge machining.

[0212] In other embodiments, the ring elements **210** and the connecting members **220** may be integrally formed together. For example, a mold having a rod with protrusions on the surface of the rod may be provided. The protrusions correspond with the space **216** to be formed between the ring elements **210** and the connecting members **220**. Then the material for forming the ring elements **210** and the connecting members **220** is deposited onto the mold. The material is then cured to form the ring element **210** and the connecting members **220**.

[0213] In further embodiments, the ring elements **210** and the connecting members **220** may be separately formed, and are then connected to each other after they are formed. In one implementation, a plurality of ring elements **210** may be provided. Then a tubular mesh may be used to connect the ring elements **210** in series. In particular, the ring elements **210** in spaced-away configuration may be disposed over the tubular mesh, and are arranged in series along a longitudinal axis of the tubular mesh. The ring elements **210** may then be secured to the tubular mesh, such as via an adhesive, glue, weld, etc. Parts of the tubular mesh between the ring elements **210** become and function as the connecting members **220**.

[0214] As discussed, the tubular structure **200** described herein may be utilized to form a tube of a catheter. For example, filler **250** may be disposed in the space (e.g., gaps) **216** between the ring elements **210** and the connecting members **220**. In some embodiments, the tubular structure **200** may be dipped into a polymeric solution to allow the polymeric solution to fill the space **216**. The polymeric solution may then be cured to form the filler **250**. Excess filler material may be removed using agent, by cutting, sanding, etc.

[0215] Also, in some embodiments, the filler **250** occupying the space **216** may have the same thickness as the thickness of the wall of the tubular structure **200**. In other embodiments, the filler **250** may be thicker than the thickness of the wall of the tubular structure **200**.

[0216] In addition, in some embodiments, the material of the filler **250** may extend pass the exterior surface of the tubular structure **200**. In some cases, the material of the filler **250** may be disposed on the exterior surface of the tubular structure **200** to form an outer layer covering the tubular structure **200**. The outer layer may be formed integrally together with the filler **250** in the space **216**. In other

embodiments, the outer layer may be formed separately from the filler **250**, and is disposed on the exterior surface of the tubular structure **200** after the filler **250** is disposed (e.g., formed) in the space **216**. In such cases, the outer layer may be made from the same material as the filler **250**, or may be made from a material that is different from the filler **250**.

[0217] Similarly, in some embodiments, the material of the filler **250** may extend pass the inner surface of the tubular structure **200**. In some cases, the material of the filler **250** may be disposed on the inner surface of the tubular structure **200** to form an inner layer covering the inner wall of the tubular structure **200**. The inner layer may be formed integrally together with the filler **250** in the space **216**. In other embodiments, the inner layer may be formed separately from the filler **250**, and is disposed on the inner surface of the tubular structure **200** after the filler **250** is disposed (e.g., formed) in the space **216**. In such cases, the inner layer may be made from the same material as the filler **250**, or may be made from a material that is different from the filler **250**.

[0218] The filler **250** is not limited to being polymeric material, and may be made from other materials in other embodiments. For example, in other embodiments, the filler **250** may be made from plastic, foam, or any of other elastic materials.

[0219] In any of the embodiments of the tubular structure **200** (or any of the further tubular structures described herein), the filler **250** and the tubular structure **200** behave as a composite by sharing tensile and bending loads between the filler **250** and tubular structure **200**. The tubular structures **200** having ring elements **210** and connecting members **220** is configured to evenly distribute the loads in the filler **250**, such that peak stresses (e.g., quantified by percent of elongation) in the filler **250** are minimized, which ensures higher tensile strength and resistance to rupture of the filler **250**. For example, when the tubular structure **200** is elongated (e.g., in tension or in bending), the filler **250** elongation can be more evenly distributed, which allows for an effective load distribution between the filler **250** and tubular structure **200** of the catheter **10**. Some of these advantages are achieved by having an angle between the connecting members **220** and the ring elements **210** that creates uniform strains in the filler **250** during elongation/bending of the tubular structure **200**. The angle of the connecting members **220** relative to their respective ring elements **210** is about 10 degrees (e.g., +/−5 degrees) and can be increased or decreased to allow compliance of the filler **250** in order to match the compliance of the tubular structure **200**. Further advantages of the composite effects of sharing tensile and bending loads between the filler **250** and tubular structure **200** are achieve by varying the width and/or the radius of the ring elements **210** and/or connecting members **220**, such as for example, having thicker ring elements **210** avoids or minimize the bending of the rings when the catheter **10** is subjected to bending loads. Further advantages of the composite effects of sharing tensile and bending loads between the filler **250** and tubular structure **200** are achieve by varying and/or increasing the ratio of connecting members **220** to their respective ring elements **210** (e.g., ratio of connecting members per ring, such as 3:1, 4:1, 5:1, 6:1, etc.). It should be appreciated that the patterns of the tubular structures disclosed herein are produced to optimize the interaction with the filler, such that the tubular structures and the filler act in a composite, combined and compounded manner sharing tensile and bending loads. The composite interaction between the tubular structures and the filler increases tensile and bending load sharing while reducing compression of the catheter. The composite interaction between the tubular structures and the filler further increases trackability of the catheter (e.g., advancing the catheter within a body lumen without a guidewire).

[0220] In other embodiments, the catheter **10** may not include filler **250**. Instead, the catheter **10** may include an outer sheath and an inner sheath, with the tubular structure **200** sandwiched there-between. Other techniques of sealing the space **216** may be employed. For example, in other embodiments, a filler may be applied to the tubular structure **200** to seal the space **216**.

[0221] In addition, in some embodiments, the ring elements **210** may have the same thickness as the connecting members **220**. In other embodiments, the ring elements **210** and the connecting members **220** may have different thicknesses. For example, in other embodiments, the ring elements **210** may have a first thickness, and the connecting members **220** may have a second thickness, wherein the first thickness may be larger or smaller than the second thickness.

[0222] Tube Manufacturing Processes

[0223] Various techniques may be employed to make the tube **11** having the tubular structure **200**. In some embodiments, a filler may be applied so that the material is disposed in the openings of the tubular structure **200** and forms an outer layer covering the exterior surface of the tubular structure **200**. The filler and tubular structure **200** forms the tube **11**. In other embodiments, the filler may encapsulate the tubular structure **200** to form the tube **11**. In such cases, the filler covers the exterior surface of the tubular structure, covers the interior surface of the tubular structure, as well as filling the openings (e.g., slots, kerf, slits) through the wall of the tubular structure **200**.

[0224] In some embodiments, the filler forming part of the tube **11** may have a modulus of elasticity that is lower than the modulus of elasticity of the tubular structure **200**. For example, the filler may have a modulus of elasticity that is less than 50%, or more preferably less than 30%, or more preferably less than 20%, or more preferably less than 10%, or more preferably less than 5%, or more preferably less than 1%, of that of the tubular structure **200**. In one implementation, the filler may have a modulus of elasticity that is less than 15 Mpa (e.g., 10 Mpa or less).

[0225] Also, the filler forming part of the tube **11** may have the ability to undergo significant elongation before break point. For example, in some embodiments, the filler may be capable of having a strain (defined as an amount of elongation of the material divided by the length of the material) of at least: 20%, 40%, 60%, 80%, 100%, 200%, 300%, 400%, 500%, 600%, 700%, 800%, 900%, 1000%, or greater.

[0226] Various materials may be utilized as the filler material. The filler may be made from polymer, plastic, foam, polymeric solution or any of other elastic materials. By means of non-limiting examples, the filler material may include polyurethane, polyurethane-based material, silicon-based material, any material having polyurethane dispersion or silicon-based dispersion, etc. Examples of filler material that may be used include CD102® or AD111® from Covestro, Gelest Ex-sil50® from Gelest, etc.

[0227] In some embodiments, because the filler is significantly softer than the material of the tubular structure **200**,

the resulting tube **11** will have one or more mechanical properties that are contributed predominantly (e.g., more than 50%, more than 60%, more than 70%, more than 80%, more than 90%, more than 95%, more than 99%, etc.) by the tubular structure **200**. By means of non-limiting examples, the one or more mechanical properties may be a bending stiffness, an axial stiffness, a torsional stiffness, shear stiffness, or any combination of the foregoing.

[0228] In one or more embodiments, the tube **11** may optionally further include a lubricious coating (e.g., hydrophilic or any other suitable coating) that is disposed on the exterior surface of the tube **11** and/or on the interior surface of the tube **11**. In some cases, an initial coating material may first be applied on the tubular structure **200** to fill the openings at the wall of the tubular structure **200**, and optionally to cover the exterior and/or interior surface of the tubular structure **200**. Then the lubricious coating is applied over the initial coating material.

[0229] Constructing the tube **11** using the tubular structure **200** (providing a majority of the mechanical properties), and using the very soft filler, is advantageous because it prevents the distal end of the tube **11** from being too stiff, and because it allows design of catheter to be easier with resulting behavior of the catheter being more predictable (because computational modeling of the catheter may be made based on the tubular structure design only).

[0230] Various techniques may be employed to apply the filler to the tubular structure **200** in different embodiments. For example, in some embodiments, a deposition technique may be employed to deposit the filler onto the tubular structure **200**. In other embodiments, a dipping process may be utilized to apply the filler onto the tubular structure **200**.

[0231] Dipping Process

[0232] In some embodiments, when using a dipping technique to apply the filler onto the tubular structure **200**, a barrier may be provided inside the central lumen of the tubular structure **200** to prevent the filler from entering into the central lumen. For example, in some embodiments, the interior surface of the tubular structure **200** may be masked to prevent the filler from outside the tubular structure **200** from flowing into the central lumen through the openings at the wall of the tubular structure **200**. In other embodiments, a tube or rod may be placed inside the central lumen of the tubular structure **200** to act a barrier for preventing the filler from entering into the central lumen. The tube or the rod may be made from PTFE, HDPE, stainless steel, or any of other suitable materials.

[0233] The tubular structure **200** may then be placed into a reservoir of the filler in liquid or viscous form. The filler may be tailored to have certain specific viscosity to assist with the filler/coating process. In some cases, the tubular structure **200** may be placed vertically into the reservoir with the longitudinal axis of the tubular structure **200** forming an angle that is 90°+/−25° with respect to a top surface of the liquid in the reservoir. In other cases, the tubular structure **200** may be placed horizontally into the reservoir with the longitudinal axis of the tubular structure **200** forming an angle that is 0°+/−25° with respect to a top surface of the liquid. In other embodiments, the tubular structure **200** may be placed into the reservoir at other angles that are different from the above examples.

[0234] In some embodiments, the tubular structure **200** may be inserted into the reservoir at a certain rate, such as anywhere from 0.01 cm/sec to 5 cm/sec. In other embodiments, the tubular structure **200** may be inserted at a rate that is slower or faster than the above range of rates. Also, in some embodiments, as the tubular structure **200** is inserted into the reservoir, the tubular structure **200** may be rotated at a certain rate, such as 2-10 rotations per minute. The rotational speed may be slower or faster than 2-10 rotations per minute in other embodiments. In further embodiments, the tubular structure **200** may not be rotated as it is being inserted into the reservoir.

[0235] After the tubular structure **200** is dipped into the reservoir of the filler, the tubular structure **200** may then be removed from the reservoir. In some embodiments, the tubular structure **200** may be removed from the reservoir at a certain rate, such as anywhere from 0.01 cm/sec to 10 cm/sec. In other embodiments, the tubular structure **200** may be removed from the reservoir at a rate that is slower or faster than the above range of rates. Also, in some embodiments, as the tubular structure **200** is removed from the reservoir, the tubular structure **200** may be rotated at a certain rate, such as 2-10 rotations per minute. The rotational speed may be slower or faster than 2-10 rotations per minute in other embodiments. In further embodiments, the tubular structure **200** may not be rotated as it is being removed from the reservoir of the filler.

[0236] As a result of dipping the tubular structure **200** into the reservoir and removing it from the reservoir, a first layer of filler is disposed on the exterior surface of the tubular structure **200**. The filler also spans and fills up the openings at the wall of the tubular structure **200**.

[0237] After the tubular structure **200** is removed from the reservoir, the tubular structure **200** with the filler is held at certain time and at certain temperature to solidify the filler. The time for the filler to solidify may be anywhere from 1 minute to 120 minutes. In other embodiments, the solidifying time may be faster than 1 minute, or longer than 120 minutes. Also, in some embodiments, the temperature for solidifying the filler may be anywhere from 20° C. to 100° C. In other embodiments, the temperature for solidifying the filler may be less than 20° C. or higher than 100° C.

[0238] In some embodiments, the insertion of the tubular structure **200** into the reservoir, and the removing of the tubular structure **200** from the reservoir, may be repeated one or more times (e.g., anywhere from 1 additional time to 30 additional times, or more) until a desired thickness for the filler is achieved. In some embodiments, the thickness of the filler created on the exterior surface of the tubular structure **200** may be anywhere from 0.0001 inch to 0.003 inch, or greater.

[0239] In some embodiments, the applying of the filler onto the tubular structure **200** may be performed in a vacuum. For example, in some embodiments, the reservoir of filler may be placed in a vacuum chamber, and the dipping and removing of the tubular structure **200** may be performed inside the vacuum chamber. The solidifying of the filler may also occur inside the vacuum chamber.

[0240] In some embodiments, after the filler is solidified, a hydrophilic coating may be applied on the solidified coating. The application of the hydrophilic coating may be performed using a dipping technique that is similar to that described above. In other embodiments, the hydrophilic coating may be applied on the solidified coating using a deposition technique. The hydrophilic coating may be applied to the exterior surface of the tube **11** and/or to the

interior surface of the tube **11**. In some cases, the hydrophilic coating may be considered to be a part of the tube **11**.

[0241] It should be noted that the processing of coating the tubular structure **200** is not limited to the examples described above, and that the tubular structure **200** may be coated using other techniques, or variations of the techniques described. For example, in other embodiments, a barrier may not be provided inside the central lumen of the tubular structure to prevent the filler from entering into the central lumen. Instead, filler is allowed to flow into the central lumen during the dipping process. In such case, after the tubular structure **200** is removed from the reservoir, and before the filler in the central lumen of the tubular structure **200** solidifies, a plunger may be placed inside the central lumen and be moved longitudinally through the tubular structure **200** to remove excess material inside the central lumen. In some embodiments, all filler inside the central lumen is removed so that there is no filler disposed on the interior surface of the tubular structure **200**. In other embodiments, some but not all of the filler inside the central lumen is removed so that a layer of the filler remains on the interior surface of the tubular structure **200**. In further embodiments, the removing of the excess filler inside the central lumen of the tubular structure **200** may be removed using a cutter after the filler has been solidified.

[0242] In other embodiments, before the tubular structure **200** is inserted into the reservoir of filler, a rod or a tube (smaller than a size of the central lumen of the tubular structure **200**) may be placed inside the central lumen of the tubular structure **200**. The rod or the tube has an exterior surface that is spaced away from the inner surface of the tubular structure **200**. This allows the filler to fill the space between the rod/tube and the interior surface of the tubular structure **200**, thereby creating a layer of coating on the interior surface of the tubular structure **200**. The filler also fills the openings at the wall of the tubular structure **200**, and extends to outside the tubular structure **200** to create a layer of coating on the exterior surface of the tubular structure **200**.

[0243] In further embodiments, instead of using the dipping technique, the filler may be pumped to encapsulate the tubular structure **200** at certain flow rates to create a desired thickness of the coating.

[0244] Thermal Process

[0245] Alternative techniques may be employed to apply the filler to the tubular structure **200** in different embodiments. In some embodiments, thermal recovery and/or expansion properties of polymeric material (e.g., stretched or non-stretched fluoropolymers) may be used to create an integral polymer or fluoropolymer filler for the tubular structure **200**.

[0246] In some embodiments, the filler may be implemented using one or more layers that encapsulate the tubular structure **200** to form the tube **11**. In such cases, the layer(s) may cover the exterior surface of the tubular structure **200** defining the outer surface **21**, may cover the interior surface of the tubular structure **200** defining the inner surface **22**, and may fill the openings (e.g., slots, kerf, slits) through the wall of the tubular structure **200**. In this embodiment, the layer(s) may be composed of one or more of the materials previously disclosed. In other embodiments, the filler may be implemented using one or more layers that cover the exterior surface of the tubular structure **200** (not the interior surface of the tubular structure **200**). In such cases, the material of the layer(s) may or may not fill the openings through the wall of the tubular structure **200**. In further embodiments, the filler may be implemented using one or more layers that cover the interior surface of the tubular structure **200** (not the exterior surface of the tubular structure **200**). In such cases, the material of the layer(s) may or may not fill the openings through the wall of the tubular structure **200**.

[0247] In other embodiments, different materials may be used for the filler. For example, in other embodiments, the exterior surface of the tubular structure **200** may be covered using a first material (e.g., Pebax) to form the outer surface **21** or jacket); the interior surface of the tubular structure **200** may be covered using a second material (e.g., PTFE) to form the inner surface **22** or liner, wherein the liner and/or jacket may fill the openings (e.g., slots, kerf, slits) through the wall of the tubular structure **200**.

[0248] Referring now to FIGS. **57**A-**57**F, a method **1000** of manufacturing the tube **11** using a thermal process that forms an integral polymeric (e.g., fluoropolymer or other polymer) filler for the tubular structure **200**, will be described. FIGS. **57**A-**57**F illustrate the method depicting cross-sectional view of the tubular structure **200**, filler and other elements, comprising the followings steps: First, a heat-shrink tube **1021** is disposed over the tubular structure **200** (FIG. **57**A). The heat-shrink tube **1021** may be composed of FEP, PFA, PVDF, or any other non-PTFE polymeric material. In other embodiments, the heat-shrink tube **1021** may be composed of PTFE polymeric material. The heat-shrink tube **1021** may have a central lumen with a cross-sectional dimension that is larger than the outer cross-sectional dimension of the tubular structure **200**. Then, the heat-shrink tube **1021** is heated such that the heat-shrink tube **1021** contacts the outer surface **21** of the tubular structure **200** to form a jacket (FIG. **57**B).

[0249] Before, during or after the steps of FIGS. **57**A-**57**B, a tube **1022** may be inserted into the tubular structure **200** for implementing a liner for the tubular structure **200**. For example, as shown in FIG. **57**C, in some embodiments, the tube **1022** may be inserted over a barrier rod **1030**, and the barrier rod **1030** wand the tube **1022** may then be inserted into the tubular structure **200** (FIG. **57**D). The barrier rod **1030** may be a tube, a cylinder, or the like. The barrier rod **1030** may be composed of any material, such as, PTFE. The barrier rod **1030** is configured to prevent any material from entering into the lumen **30** of the tubular structure **200**. In some embodiments, the barrier rod **1030** and/or the tube **1022** may be stretched before being inserted into the tubular structure **200**. In one implementation, the barrier rod **1030** and the tube **1022** may be stretched at room temperature (approximately 22° C.). The barrier rod **1030** and the tube **1022** may be stretched together after the tube **1022** is disposed over the barrier rod **1030**. Alternatively, the barrier rod **1030** may be stretched first, then the tube **1022** is disposed over the stretched barrier rod **1030**, and the tube **1022** is then stretched. In further alternative, the barrier rod **1030** may be stretched, and the tube **1022** may be stretched, and then the stretched tube **1022** is disposed over the stretched barrier rod **1030**. In other embodiments, the stretching of the barrier rod **1030** and/or the stretching of the tube **1022** is not required. The tube **1022** may be made from any suitable material, such as a non-PTFE polymer.

[0250] Next, referring to FIG. **57**E, a heat-shrink tubing **1050** may be disposed over the heat-shrink tube jacket **1021**.

Then, all of the elements previously described and depicted in FIG. **57**E are heated (e.g., to a temperature that is above room temperature), As a result of the heating, the barrier rod **1030** expands to compress the liner **1022** towards the inner surface of the tubular structure **200**. As a result of the heating and compression, the liner **1022** and heat-shrink tube jacket **1021** melt into the openings of the tubular structure **200**, fusing the liner **1022** and the jacket **1021** through the openings of the tubular structure **200** (FIG. **57**F). In this embodiment, the filler comprises the fused liner **1022** and jacket **1021**. In some embodiments, in order to prevent air bubbles between the liner **1022** and the jacket **1021**, the heating may optionally be performed by a localized heat source traveling from one end of the liner **1022**/jacket **1021** to the other end, or the heating may be performed in a vacuum chamber (not shown). In some embodiments, the heating may be performed by a heat source that is a part of a laminator.

[0251] After the filler is formed in the openings of the tubular structure **200**, the heat-shrink tubing **1050** is removed (e.g., stripped from the outer surface **21** of the tubular structure **200**), and the barrier rod **1030** is removed (e.g., by pulling or pushing it out from the inner surface **22** of the tubular structure **200**, and optionally also by stretching the barrier rod **1030** before pulling or pushing it). As a result, the tubular structure **200** is encapsulated by the liner **1021** and the jacket **1022**, and the openings of the tubular structure **200** is filled with liner materials that are composed of material of the liner **1021**, material of the jacket **1022**, or both.

[0252] In the above embodiments using the barrier rod **1030**, it should be appreciated that when the barrier rod **1030** that is disposed within the lumen of tubular structure **200** is heated, the barrier rod **1030** expands to occlude the central lumen of the tubular structure **200**. Expansion of the barrier rod **1030** also compresses the liner **1022** against the inner surface of the tubular structure **200**, covering the openings at the wall of the tubular structure **200**. This technique is insensitive to the dimension of the openings at the wall of the tubular structure **200**, to the thickness of the liner, and/or tolerances of the cross-sectional dimensions of the various components. Therefore, there is no need to accommodate tolerance stack up, and the inner diameter (ID) of the lumen of the tube **11** (e.g., catheter) may be maximized.

[0253] Additionally, the step of heating the barrier rod **1030** and/or heat-shrink tubing **1050** (as shown in FIG. **57**F) is advantageous because it ensures intimate contact and secure fusion between the liner **1022**, the tubular structure **200**, and outer jacket **1021**, forming the tube **11**.

[0254] In some embodiments, the end portions (e.g., distal end **1012** and/or proximal end **1014** of FIG. **57**F) of the tube **11** may be trimmed, cut or reduced as desired. In other embodiments, the method **1000** may be applied to discrete portions or sections of the tubular structure **200** to create band or markers. In some embodiments, the method **1000** may be applied with a variety of materials and/or width of materials allowing variations on flexibility and/or stiffness at different sections of the tube **11**

[0255] In some embodiments, the liner **1022** and the jacket **1021** may be formed of respective materials having lower melting temperature(s) than the material of the barrier rod **1030** and the material of the heat-shrink tubing **1050**, allowing the liner **1022** and the jacket **1021** to melt and/or fuse prior any melting of the barrier rod **1030** and the heat-shrink tubing **1050**. For example, in some embodiments, the liner **1022** and the jacket **1021** may be formed of respective non-PTFE materials (e.g., FEP, PFA, PVDF or any other suitable polymer), the barrier rod **1030** may be formed of a PTFE material, and the heat-shrink tubing **1050** may be formed of a PTFE material, wherein the non-PTFE material of the liner **1022** and the non-PTFE material of the barrier rod **1030** may have lower melting temperature(s) than the PTFE barrier rod **1030** and the PTFE heat-shrink tubing **1050**. In some cases, FEP melting point is 260° C., PFA melting point is 306° C., PVDF melting point is 177° C., and PTFE 'melting' point is 327° C.

[0256] It should be appreciated that the steps of manufacturing described herein may be performed simultaneously or sequentially, as suitable, and not necessarily in the order previously described.

[0257] In an alternative embodiment of the method **1000** of manufacturing the tube **11**, the steps are similar as those described with reference to FIGS. **57**A-**57**F, except that the liner **1022** (shown in FIG. **57**C) includes an outer layer configured to adhere to an inner surface of the tubular structure **200**. In some cases, the outer layer of the liner **1022** is heat and/or compression activated, such that when the liner **1022** is heated and/or compressed towards the tubular structure **200**, the outer layer secures the liner **1022** relative to the tubular structure **200**. In some embodiments, the outer layer of the liner **1022** may be made from non-PTFE polymer. In other embodiments, the outer layer of the liner **1022** may be made from PTFE polymer. Also, other part(s) of the liner **1022** may be made from non-PTFE polymer or PTFE polymer.

[0258] Also, in other embodiments, the tube **11** may be formed without having the jacket **1021**, such that the liner **1022** would form the filler of the tubular structure **200**. In further embodiments, a coating may be applied over the outer diameter (OD) of the tubular structure **200** without the jacket **1021**. For example, a Parylene coating chamber may apply conformal Parylene (e.g., Parylene C) to create a uniform conformal layer on the OD of the tubular structure **200**, extending across the openings of the tubular structure **200**. In some cases, material of the conformal layer may migrate towards the liner **1022**, and may attach to the liner **1022**. Also, in some embodiments, material of the conformal layer may attach the liner **1022** to the tubular structure **200**.

[0259] In further embodiments, if the liner **1022** is provided, the liner **1022** may be non-stretched (i.e., the step of stretching the liner **1022** may be omitted). In such cases, the non-stretched liner **1022** may be disposed within the tubular structure **200**. The liner **1022** may then be heated to expand the liner **1022** so that it contacts the inner surface of the tubular structure **200**.

[0260] In yet another alternative embodiment of the thermal process, the tube/jacket **1021** and/or the liner **1022** is not needed. Instead, a coating (e.g., external lamination) may be applied to fill some or all of the openings of the tubular structure **100**. In this alternative embodiment, the barrier rod **1030** (e.g., composed of PTFE) is stretched and disposed within the lumen of the tubular structure **200**. Heat is then applied to expand the barrier rod **1030** so that the rod contacts the inner surface of the tubular structure **200** and seals the lumen. Then, a coating of suitable material is applied over the tubular structure **200** filling and sealing the openings at the wall of the tubular structure **200**, and

forming the filler. Lastly, heat is applied to remove the barrier rod **1030** from the lumen of the tubular structure **200**.

[0261] As used in this specification, the term "relaxed state" (e.g., a relaxed state of the tubular structure, a relaxed state of the catheter, etc.) refers to a state of an object in which no external force is applied against the object (other than the force due to gravity). For example, a relaxed state of a catheter may refer to a state of the catheter that is placed on a surface without having bending force, axial force, and torsional force applied to the catheter.

[0262] Although particular embodiments have been shown and described, it will be understood that it is not intended to limit the claimed inventions to the preferred embodiments, and it will be obvious to those skilled in the art that various changes and modifications (e.g., the dimensions and/or shapes of various parts) may be made without department from the spirit and scope of the claimed inventions. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense. The claimed inventions are intended to cover alternatives, modifications, and equivalents.

What is claimed is:

1. A catheter comprising:

a tubular structure having a distal end, a proximal end, and a body extending between the distal end and the proximal end, the tubular structure having a longitudinal axis;

wherein the tubular structure comprises a plurality of ring elements arranged in series along the longitudinal axis, the ring elements being respective closed-loops, wherein the ring elements comprise a first ring element and a second ring element, wherein the first ring element lies within a first plane that is substantially perpendicular to the longitudinal axis of the tubular structure, and wherein the second ring element lies within a second plane that is substantially perpendicular to the longitudinal axis of the tubular structure;

wherein the tubular structure further comprises connecting members, the connecting members comprising a first connecting member, connected between the first ring element and the second ring element, wherein the first connecting member comprises a first end, a second end, and a member body between the first end and the second end of the first connecting member; and

wherein a second connecting member comprises a first end, a second end, and a member body between the first end and second end of the second connecting member; and

wherein the second end of the first connecting member and the first end of the second connecting member are connected to the first ring element, and disposed across from each other, and wherein the second end of the second connecting member is connected to the second ring element, and wherein the member body of the second connective member is configured to rotate and/or bent relative to the first ring element and the second ring element in response to a bending and/or axial-loading of the tubular structure.

2. The catheter of claim **1**, wherein the catheter comprises a lumen having a cross-sectional shape when the catheter is in a relaxed state, and wherein the tubular structure is configured to maintain the cross-sectional shape of the lumen during bending of the catheter.

3. The catheter of claim **1**, wherein the tubular structure is configured to provide axial stiffness and/or torsional stiffness for the catheter.

4. The catheter of claim **1**, wherein the first end and the second end of the first connecting member define a line that is non-parallel to the longitudinal axis of the tubular structure.

5. The catheter of claim **1**, wherein the first plane and the second plane remain substantially perpendicular to the longitudinal axis when the tubular structure is being bent and/or being axially-loaded.

6. The catheter of claim **1**, wherein the first ring element has a uniform cross-section.

7. The catheter of claim **1**, wherein the first ring element has different cross-sectional dimensions along a length of the first ring element.

8. The catheter of claim **1**, wherein at least a portion of the second connecting member has a curvilinear configuration.

9. The catheter of claim **1**, wherein a majority of the first connecting member lies in a third plane that is parallel to the first plane when the tubular structure is in a relaxed state.

10. The catheter of claim **1**, wherein at least a portion of the first connecting member has a curvilinear configuration.

11. The catheter of claim **1**, wherein the connecting members also comprise a third connecting member, and wherein the first, second and third connecting members are located between the first ring element and the second ring element.

12. The catheter of claim **1**, wherein the first and second connecting members are connected to a same location at the first ring element.

13. The catheter of claim **1**, wherein the ring elements and the connecting members are integrally formed together.

14. The catheter of claim **1**, wherein the ring elements and the connecting members are parts of a cut tube.

15. The catheter of claim **1**, wherein a portion of the first ring element and a portion of the first connecting member are separated from each other to define a first space, and wherein the catheter further comprises a filler located in the space.

16. The catheter of claim **15**, wherein the portion of the first connecting member is separated from the second ring to define a second space, wherein the first space and the second space has a same width.

17. The catheter of claim **1**, further comprising a layer disposed on an outer surface or an inner surface of the tubular structure.

18. The catheter of claim **17**, wherein the layer comprises a material that extends into a spacing to form a filler between a portion of the first ring element and a portion of the first connecting member.

19. The catheter of claim **17**, wherein the tubular structure and the layer are configured to cooperate with each other by sharing tensile load and/or bending load.

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