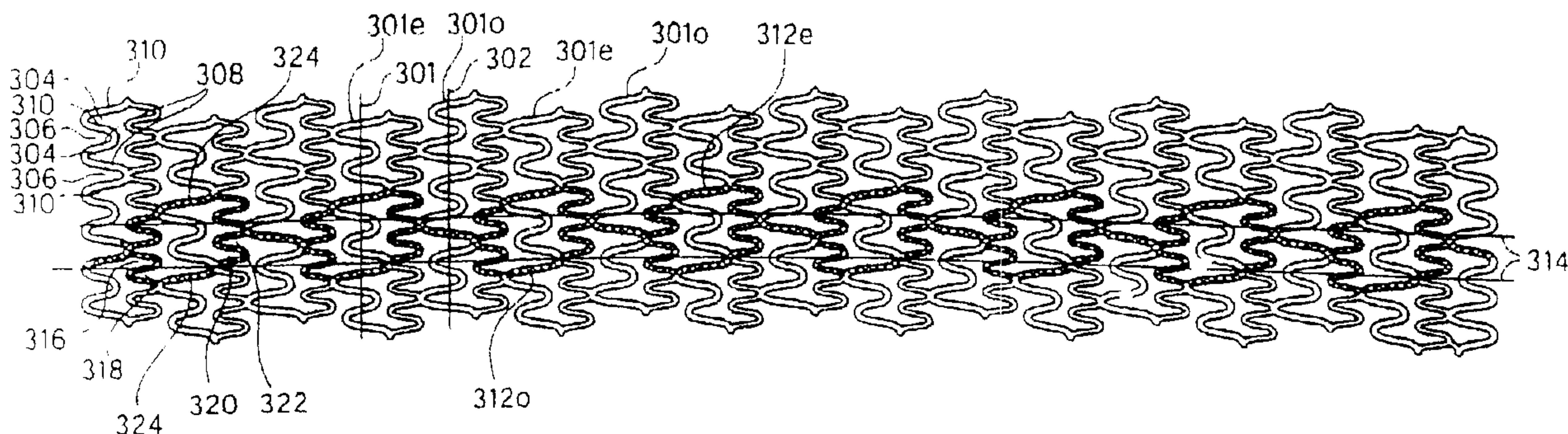




(22) Date de dépôt/Filing Date: 2001/02/27  
 (41) Mise à la disp. pub./Open to Public Insp.: 2001/09/01  
 (45) Date de délivrance/Issue Date: 2010/08/31  
 (62) Demande originale/Original Application: 2 338 782  
 (30) Priorités/Priorities: 2000/03/01 (US09/516,753);  
 2000/05/08 (US60/202,723)

(51) Cl.Int./Int.Cl. *A61F 2/90* (2006.01)  
 (72) Inventeurs/Inventors:  
 PINCHASIK, GREGORY, IL;  
 RICHTER, JACOB, IL  
 (73) Propriétaire/Owner:  
 MEDINOL LTD., IL  
 (74) Agent: KIRBY EADES GALE BAKER

(54) Titre : TUTEUR FLEXIBLE LONGITUDINALEMENT  
 (54) Title: LONGITUDINALLY FLEXIBLE STENT



(57) Abrégé/Abstract:

A stent for widening a vessel in the human body comprises a plurality of first meander patterns and a plurality of second meander patterns. The second meander patterns are intertwined with the first meander patterns to form triangular cells.

ABSTRACT

A stent for widening a vessel in the human body comprises a plurality of first meander patterns and a plurality of second meander patterns. The second meander  
5 patterns are intertwined with the first meander patterns to form triangular cells.

**LONGITUDINALLY FLEXIBLE STENT**

This is a division of co-pending Canadian Patent Application No. 2,338,782 filed on February 27, 2001.

FIELD OF THE INVENTION

5           The present invention relates generally to stents, which are endoprostheses implanted into vessels within the body, such as blood vessels, to support and hold open the vessels, or to secure and support other endoprostheses in the vessels. In particular, the  
10 present invention relates to a stent which is longitudinally flexible before and after expansion.

BACKGROUND OF THE INVENTION

Various stents are known in the art. Typically stents are generally tubular in shape, and are expandable  
15 from a relatively small, unexpanded diameter to a larger, expanded diameter. For implantation, the stent is typically mounted on the end of a catheter, with the stent being held on the catheter at its relatively small, unexpanded diameter. By the catheter, the unexpanded  
20 stent is directed through the lumen to the intended implantation site. Once the stent is at the intended implantation site, it is expanded, typically either by an internal force, for example by inflating a balloon on the inside of the stent, or by allowing the stent to  
25 self-expand, for example by removing a sleeve from around a self-expanding stent, allowing the stent to expand outwardly. In either case, the expanded stent resists the tendency of the vessel to narrow, thereby maintaining the vessel's patency.

U.S. Patent No. 5,733,303 to Israel et al. ("303"), shows a unique stent formed of a tube having a patterned shaped which has first and second meander patterns having axes extending in first and second directions. The  
5 second meander patterns are intertwined with the first meander patterns to form flexible cells. Stents such as this one are very flexible in their unexpanded state such that they can be tracked easily down tortuous lumens. Upon expansion, these stents provide excellent radial  
10 support, stability, and coverage of the vessel wall. These stents are also conformable, in that they adapt to the shape of the vessel wall during implantation.

One feature of stents with a cellular mesh design such as this one, however, is that they have limited  
15 longitudinal flexibility after expansion, which may be a disadvantage in particular applications. This limited longitudinal flexibility may cause stress points at the end of the stent and along the length of the stent. Conventional mesh stents like that shown in U.S. Patent  
20 No. 4,733,665 may simply lack longitudinal flexibility, which is illustrated by Figure 1, a schematic diagram of a conventional stent 202 in a curved vessel 204.

To implant a stent, it may be delivered to a desired site by a balloon catheter when the stent is in an  
25 unexpanded state. The balloon catheter is then inflated to expand the stent, affixing the stent into place. Due to the high inflation pressures of the balloon -- up to 20 atm -- the balloon causes the curved vessel 204 and even a longitudinally flexible stent to straighten when  
30 it is inflated. If the stent, because of the configuration of its mesh is or becomes relatively rigid

after expansion, then the stent remains or tends to remain in the same or substantially the same shape after deflation of the balloon. However, the artery attempts to return to its natural curve (indicated by dashed lines) in Figure 1 with reference to a conventional mesh stent. The mismatch between the natural curve of the artery and the straightened section of the artery with a stent may cause points of stress concentration 206 at the ends of the stent and stress along the entire stent length. The coronary vasculature can impose additional stress on stents because the coronary vasculature moves relatively significant amounts with each heartbeat. For illustration purposes, the difference between the curve of the vessel and the straightened stent has been exaggerated in Figure 1.

U.S. Patent No. 5,807,404 to Richter, shows another stent which is especially suited for implantation into curved arterial portions or osteal regions. This stent can include sections adjacent the end of the stent with greater bending flexibility than the remaining axial length of the stent. While this modification at the end of the stent alleviates the stress at the end points, it does not eliminate the stress along the entire length of the stent.

Various stents are known that retain longitudinal flexibility after expansion. For example, U.S. Patent Nos. 4,886,062 and 5,133,732 to Wiktor ("the Wiktor '062 and '732 patents") show various stents formed of wire wherein the wire is initially formed into a band of zig-zags forming a serpentine pattern, and then the zig-zag band is coiled into a helical stent. The stents

are expanded by an internal force, for example by inflating a balloon.

The coiled zig-zag stents that are illustrated in Figures 1 through 6 of the Wiktor '062 and '732 patents  
5 are longitudinally flexible both in the expanded and unexpanded condition such that they can be tracked easily down tortuous lumens and such that they conform relatively closely to the compliance of the vessel after deployment. While these stents are flexible, they also  
10 have relatively unstable support after expansion. Furthermore, these stents leave large portions of the vessel wall uncovered, allowing tissue and plaque prolapse into the lumen of the vessel.

Thus, it is desired to have a stent which exhibits  
15 longitudinal flexibility before expansion such that it can easily be tracked down tortuous lumens and longitudinal flexibility after expansion such that it can comply with the vessel's natural flexibility and curvature while still providing continuous, stable  
20 coverage of a vessel wall that will minimize tissue sag into the lumen.

#### OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, an object of the invention is to provide a stent that is longitudinally flexible before  
25 expansion so that it can easily be tracked down tortuous vessels and remains longitudinally flexible after expansion such that it will substantially eliminate any stress points by complying with the vessel's flexibility and assuming the natural curve of the vessel.

Another object of the present invention is to provide a stent that is longitudinally flexible after delivery such that it flexes during the cycles of the heartbeat to reduce cyclic stress at the ends of the stent and along the stent.

Another object of the present invention is to provide a stent with a closed cell pattern such that it provides good coverage and support to a vessel wall after expansion.

Other advantages of the present invention will be apparent to those skilled in the art.

In accordance with one aspect of the present invention there is provided a stent for widening a vessel in the human body comprising: a plurality of first meander patterns; a plurality of second meander patterns intertwined with the first meander patterns to form triangular cells.

In accordance with another aspect of the present invention there is provided a stent for holding open a lumen, comprising: a plurality of even and odd vertical meander patterns, the odd vertical meander patterns being located between every two even vertical meander patterns and being out of phase with the even vertical meander patterns; a plurality of even and odd horizontal meander patterns, the odd horizontal meander patterns being located between every two even horizontal meander patterns; wherein the vertical meander patterns are intertwined with the horizontal meander patterns to form a plurality of triangular cells.

In accordance with yet another aspect of the present invention there is provided a stent for widening a vessel in the human body comprising: a) a plurality of first meander patterns; b) a plurality of second meander patterns intertwined with the first meander patterns to form triangular cells, said first meander patterns and said second meander patterns disposed and adapted to cooperate so that after expansion of said stent, when said stent is disposed in a curved vessel, cells on the outside of the curve open in length, but narrow circumferentially whereas cells on the inside of the curve shorten in length but widen circumferentially; and c) the second meander patterns compensate for foreshortening of the first meander patterns when the stent is expanded such that the widths of the first meander patterns are smaller expanded than compressed, and the width of the second meander patterns are greater expanded than compressed.

In accordance with still yet another aspect of the present invention there is provided a stent for holding open a lumen, comprising: a) a plurality of even and odd vertical meander patterns, the odd vertical meander patterns being located between every two even vertical meander patterns and being out of phase with the even vertical meander patterns; b) a plurality of even and odd horizontal meander patterns, the odd horizontal meander patterns being located between every two even horizontal meander patterns; c) wherein the vertical meander patterns are intertwined with the horizontal meander patterns to form a plurality of triangular cells;



d) wherein said horizontal meander patterns and said vertical meander patterns are disposed and adapted to cooperate so that after expansion of said stent, when said stent is disposed in a curved lumen, cells on the outside of the curve open in length, but narrow circumferentially whereas cells on the inside of the curve shorten in length but widen circumferentially; and e) said horizontal meander patterns and said vertical meander patterns form a high and a low frequency loop section, wherein the high frequency loop section compensates for foreshortening of the low frequency loop section when the stent is expanded such that width of the low frequency loop section is smaller when expanded than compressed and width of the higher frequency loop section is larger when expanded than compressed.

A stent according to the invention retains the longitudinal flexibility associated with the '303 cellular stent in its unexpanded state, and has increased longitudinal flexibility in the expanded state. The stent does so without sacrificing scaffolding -- i.e. coverage of the vessel wall -- or radial support.

BRIEF DESCRIPTION OF THE DRAWINGS

- Figure 1 shows a schematic diagram of a conventional rigid stent deployed in a curved lumen;
- Figure 2 shows a schematic diagram of a stent of the present invention deployed in a curved lumen;
- Figure 3 shows a pattern for a stent made in accordance with the present invention;
- Figure 4 shows an enlarged view of one cell of the pattern of Figure 3;
- Figure 5 shows a pattern for a stent made in accordance with the present invention;
- Figure 6 shows an enlarged view of one cell of the pattern of Figure 5;
- Figure 7 shows a pattern for a stent made in accordance with the present invention;
- Figure 8 shows an enlarged view of one cell used in the pattern of Figure 7;
- Figure 9 shows an enlarged view of another cell used in Figure 7;
- Figure 10 shows a schematic comparison of a four cornered or "square cell" and a three cornered or "triangular" cell of the present invention.
- Figure 11 shows a pattern for a stent constructed according to the principles of the invention which has variable geometry along its length.
- Figure 12 shows another pattern for a stent constructed according

to the principles of the invention.

Figure 13 shows another pattern for a stent constructed according to the principles of the invention.

5

DETAILED DESCRIPTION OF THE INVENTION

Figure 2 shows a schematic diagram of a longitudinally flexible stent 208 of the present invention. The stent 208 may be delivered to a curved vessel 210 by a balloon catheter, and  
10 implanted in the artery by inflating the balloon. As described before, the balloon causes the artery to straighten upon inflation of the balloon. However, upon deflation of the balloon, the stent 208 assumes the natural curve of the vessel 210 because it is and remains longitudinally flexible after  
15 expansion. This reduces any potential stress points at the ends of the stent and along the length of the stent. Furthermore, because the stent is longitudinally flexible after expansion, the stent will flex longitudinally with the vessel during the cycles caused by a heartbeat. This also reduces any cyclic stress at  
20 the ends of the stent and along the length of the stent.

Figure 3 shows a pattern of a stent according to the present invention. This pattern may be constructed of known materials, and for example stainless steel, but it is particularly suitable to be constructed from NiTi. The pattern  
25 can be formed by etching a flat sheet of NiTi into the pattern shown. The flat sheet is formed into a stent by rolling the

etched sheet into a tubular shape, and welding the edges  
of the sheet together to form a tubular stent. The  
details of this method of forming the stent, which has  
certain advantages, are disclosed in U.S. Patent  
5 Nos. 5,836,964 and 5,997,703. Other methods known  
to those of skill in the art such as laser cutting a tube or  
etching a tube may also be used to construct a stent which uses  
the present invention. After formation into a tubular shape, a  
NiTi stent is heat treated, as known by those skilled in the art,  
10 to take advantage of the shape memory characteristics of NiTi and  
its superelasticity.

The pattern 300 is formed from a plurality of each of  
two orthogonal meander patterns which patterns are intertwined  
with each other. The term "meander pattern" is taken herein to  
15 describe a periodic pattern about a center line and "orthogonal  
meander patterns" are patterns whose center lines are orthogonal  
to each other.

A meander pattern 301 is a vertical sinusoid having a  
vertical center line 302. A meander pattern 301 has two loops 304  
20 and 306 per period wherein loops 304 open to the right while  
loops 306 open to the left. Loops 304 and 306 share common  
members 308 and 310, where member 308 joins one loop 304 to its  
following loop 306 and member 308 joins one loop 306 to its  
following loop 304.

25 A meander pattern 312 (two of which have been shaded  
for reference) is a horizontal pattern having a horizontal center

line 314. A horizontal meander pattern 312 also has loops labeled 316, 318, 320, 322, and between the loops of a period is a section labeled 324.

Vertical meander pattern 301 is provided in odd and even (o and e) versions which are 180° out of phase with each other. Thus, each left opening loop 306 of meander pattern 301o faces a right opening loop 304 of meander pattern 301e and a right opening loop 304 of meander pattern 301o faces a left opening loop 306 of meander pattern 301e.

The horizontal meander pattern 312 is also provided in odd and even forms. The straight sections 324 of the horizontal meander pattern 312e intersect with every third common member 310 of the even vertical meander pattern 301e. The straight sections 324 of the horizontal meander pattern 312o also intersect with every third common member 310 of the odd vertical meander pattern 301.

Upon expansion of the stent, the loops of the vertical meander patterns 301 open up in the vertical direction. This causes them to shorten in the horizontal direction. The loops in the horizontal meander pattern 312 open up both in the vertical direction and the horizontal direction, compensating for the shortening of the loops of the vertical meander patterns.

A stent formed from the pattern of Figure 3 and made of NiTi is particularly well suited for use in the carotid artery or other lumens subject to an outside pressure. One reason is that because the stent is formed of NiTi, it is reboundable, which is

a desirable property for stents placed in the carotid artery. The other reason is that the stent of Figure 3 offers excellent scaffolding, which is particularly important in the carotid artery. Scaffolding is especially important in the carotid artery because dislodged particles in the artery may embolize and cause a stroke.

Figure 4 is an expanded view of one flexible cell 500 of the pattern of Figure 3. Each flexible cell 500 includes: a first member 501 having a first end 502 and a second end 503; a second member 504 having a first end 505 and a second end 506; a third member 507 having a first end 508 and a second end 509; and a fourth member 510 having a first end 511 and a second end 512. The first end 502 of the first member 501 is joined to the first end 505 of the second member 504 by a first curved member 535 to form a first loop 550, the second end 506 of the second member 504 is joined to the second end 509 of the third member 508 by a second curved member 536, and the first end 508 of the third member 507 is joined to the first end 511 of the fourth member 510 by a third curved member 537 to form a second loop 531. The first loop 550 defines a first angle 543. The second loop 531 defines a second angle 544. Each cell 500 also includes a fifth member 513 having a first end 514 and a second end 515; a sixth member 516 having a first end 517 and a second end 518; a seventh member 519 having a first end 520 and a second end 521; an eighth member 522 having a first end 523 and a second end 524; a ninth member 525 having a first end 526 and a second end 527; and a

tenth member having a first end 529 and a second end 530. The first end 514 of the fifth member 513 is joined to the second end 503 of the first member 501 at second junction point 542, the second end 515 of the fifth member 513 is joined to the second end 518 of the sixth member by a curved member 539 to form a third loop 532, the first end 517 of the sixth member 516 is joined to the first end 520 of the seventh member 519 by a fifth curved member 548, the second end 521 of the seventh member 519 is joined to the second end 524 of the eighth member 522 at third junction point 540 to form a fourth loop 533, the first end 523 of the eighth member 522 is joined to the first end 526 of the ninth member 525 by a sixth curved member 549, the second end 526 of the ninth member 525 is joined to the second end 530 of the tenth member 528 by a seventh curved member 541 to form a fifth loop 534, and the first end 529 of the tenth member 528 is joined to the second end 512 of the fourth member 510. The third loop 532 defines a third angle 545. The fourth loop 533 defines a fourth angle 546. The fifth loop 534 defines a fifth angle 547.

In the embodiment shown in Fig. 4, the first member 501, the third member 507, the sixth member 516, the eighth member 522, and the tenth member 528 have substantially the same angular orientation to the longitudinal axis of the stent and the second member 504, the fourth member 510, the fifth member 513, the seventh member 519, and the ninth member 525 have substantially the same angular orientation to the longitudinal axis of the stent. In the embodiment shown in Figure 4, the

lengths of the first, second, third and fourth members 501, 504, 507, 510 are substantially equal. The lengths of the fifth, sixth, seventh, eighth, ninth and tenth members 513, 516, 519, 522, 525, 528 are also substantially equal. Other embodiments, where lengths of individual members are tailored for specific applications, materials of construction or methods of delivery are also possible, and may be preferable for them.

Preferably, the first, second, third, and fourth members 501, 504, 507, 510 have a width that is greater than the width of the fifth, sixth, seventh, eighth, ninth, and tenth members 513, 516, 519, 522, 525, 528 in that cell. The differing widths of the first, second, third, and fourth members and the fifth, sixth, seventh, eighth, ninth, and tenth members with respect to each other contribute to the overall flexibility and resistance to radial compression of the cell. The widths of the various members can be tailored for specific applications. Preferably, the fifth, sixth, seventh, eighth, ninth, and tenth members are optimized predominantly to enable longitudinal flexibility, both before and after expansion, while the first, second, third, and fourth members are optimized predominantly to enable sufficient resistance to radial compression to hold a vessel open. Although specific members are optimized to predominantly enable a desired characteristic, all the portions of the cell interactively cooperate and contribute to the characteristics of the stent.

Figures 5 and 6 show a pattern and an expanded view of



one cell of an embodiment of the present invention which is specially adapted for a stent made of stainless steel. The pattern is similar to the pattern of Figures 3 and 4, and the same reference numerals are used to indicate the generally  
5 corresponding parts.

In this embodiment of the invention, for example, the second loops 531 are made stronger by shortening the third and fourth members 507, 510. This helps assure that the second loops do not "flare out" during delivery of the stent through tortuous  
10 anatomy. This "flaring out" is not a concern with NiTi stents which are covered by a sheath during delivery.

Furthermore, the length of the members in this embodiment may be shorter than the length of the corresponding members in the embodiment illustrated in Figures 3 and 4.  
15 Typically, the amount of strain allowed in a self-expanding NiTi stent may be around 10%. In a stainless-steel stent, the amount of strain allowed typically may be 20% or greater. Therefore, to facilitate stents made of NiTi and stents made of stainless steel expanding to comparable diameters, the members of the NiTi stent  
20 may be longer than the members of a stainless steel stent.

Figure 7 illustrates another aspect of the present invention. The stent of Figure 7 is also constructed from orthogonal meander patterns 301, 302. The meander patterns form a series of interlocking cells 50, 700 of two types. The first  
25 type of cell 50 is taught by U.S. Patent No. 5,733,303. These cells are arranged so that they form alternating bands 704 of

first type of cells 50 and bands 706 of the second type of cells 700.

As seen in Figure 8 and particularly with respect to the cell labeled for ease of description, each of the '303 cells 50 has a first longitudinal apex 100 and a second longitudinal end 78. Each cell 50 also is provided with a first longitudinal end 77 and a second longitudinal apex 104 disposed at the second longitudinal end 78. Each cell 50 also includes a first member 51 having a longitudinal component having a first end 52 and a second end 53; a second member 54 having a longitudinal component having a first end 55 and a second end 56; a third member 57 having a longitudinal component having a first end 58 and a second end 59; and a fourth member 60 having a longitudinal component having a first end 61 and a second end 62. The stent also includes a first loop or curved member 63 defining a first angle 64 disposed between the first end 52 of the first member 51 and the first end 55 of the second member 54. A second loop or curved member 65 defining a second angle 66 is disposed between the second end 59 of the third member 57 and the second end 62 of the fourth member 60 and is disposed generally opposite to the first loop 63. A first flexible compensating member (or a section of a longitudinal meander pattern) 67 having curved portion and two legs with a first end 68 and a second end 69 is disposed between the first member 51 and the third member 57 with the first end 68 of the first flexible compensating member 67 joined to and communicating with the second end 53 of the first

member 51 and the second end 69 of the first flexible  
 compensating member 67 joined to and communicating with the first  
 end 58 of the third member 57. The first end 68 and the second  
 end 69 are disposed a variable longitudinal distance 70 from each  
 5 other. A second flexible compensating member (or, a section of a  
 longitudinal meander pattern) 71 having a first end 72 and a  
 second end 73 is disposed between the second member 54 and the  
 fourth member 60. The first end 72 of the second flexible  
 compensating member 71 is joined to and communicates with the  
 10 second end 56 of the second member 54 and the second end 73 of  
 the second flexible compensating member 71 is joined to and  
 communicates with the first end 61 of the fourth member 60. The  
 first end 72 and the second end 73 are disposed a variable  
 longitudinal distance 74 from each other. In this embodiment,  
 15 the first and second flexible compensating members, and  
 particularly the curved portion thereof, 67 and 71 are arcuate.

The second type of cell 700 is illustrated in Figure 9  
 and the same reference numerals are used to indicate generally  
 corresponding areas of the cell. The apices 100, 104 of the  
 20 second type of cell 700 are offset circumferentially. Also, each  
 flexible compensating member 67, 71 includes: a first portion or  
 leg 79 with a first end 80 and a second end 81; a second portion  
 or leg 82 with a first end 83 and a second end 84; and a third  
 portion or leg 85 with the first end 86 and a second end 87, with  
 25 the second end 81 and the second end 84 being joined by a curved  
 member and the first end 83 and the first end 86 being joined by

a curved member. The first end of a flexible compensating member 67, 71 is the same as the first end 80 of the first portion 79, and the second end of a flexible compensating member 67, 71 is the same as the second end 87 of the third portion 85. A first  
5 area of inflection 88 is disposed between the second end 81 of the first portion 79 and the second end 84 of the second portion 82 where the curved portion joining them lies. A second area of inflection 89 is disposed between the first end 83 of the second portion 82 and the first end 86 of the third portion 85 where the  
10 curved portion joining them lies.

While Figure 7 illustrates a pattern of alternating bands of cells, the stent may be optimized for a particular usage by tailoring the configuration of the bands. For example, the middle band of the second type of cells 700 may instead be formed  
15 of cells 50, or vice versa. The second type of cells in Figure 7 may also utilize the cell configurations described with respect to Figures 4 and 6. The cell configurations of Figures 4 and 6 provide the advantage that they will not cause any torque of one portion of the cell relative to another portion of the cell about  
20 the longitudinal axis of the stent upon expansion, which may happen when the second type of cells 700 expand, a torque which could cause a stent to deform, and stick out.

As illustrated in Figure 7, all of the flexible compensating members are arranged so that the path of the  
25 flexible compensating members, from left to right, travels in a generally downward direction. The cells 700 can also be arranged

so that the flexible compensating members in one band are arranged in a generally upward direction, and the flexible compensating members in an adjacent band are arranged in a generally downward direction. One skilled in the art can easily  
 5 make these modifications.

Figure 10 is a schematic representation comparing the cells 804 of the present invention, which have three points where the intertwined first and second meander patterns meet and are in that sense three cornered or triangular cells, with cells 802 of  
 10 the '303 stent which have four points where the intertwined first and second meander patterns meet and are in that sense four cornered or square cells. More particularly, on the left side of Figure 10, a pair of vertical meander patterns 806, 826 are joined by members 808, 810, 812 (which are sections of  
 15 longitudinal meander patterns) to form a plurality of three cornered or triangular cells 804. By triangular cell, it is meant that there are three sections 810, 812, 814, each having loop portions and three associated points 816, 818, 820 of their joining, forming each cell.

20 On the right side of Figure 10, a pair of vertical meander patterns 822, 824 are joined together compensating members 828, 830, 832, 834 (which are sections of a longitudinal meander) to form a plurality of square cells 804. By square cell, it is meant that there are four sections, each having loop  
 25 portions, and four associated points of their joining, forming each cell. For example, the shaded cell 802 is formed from four

sections 832, 836, 830, 838, with four associated points of their joining 840, 842, 844, 846.

Both the square cell and the triangular cell have two kinds of sections with loops. The first kind of loop containing section is formed from a vertical meander pattern and is optimized predominantly to enable radial support. The second kind of loop containing section is optimized predominantly to enable flexibility along the longitudinal axis of the stent. Although each loop containing section is optimized predominantly to enable a desired characteristic of the stent, the sections are interconnected and cooperate to define the characteristics of the stent. Therefore, the first kind of loop containing section contributes to the longitudinal flexibility of the stent, and the second kind of loop containing section contributes to the radial support of the stent.

In the square cell 802, it can be seen that the second kind of loop containing sections 830, 832 each have one inflection point 848, 850. In the triangular cell, the loop containing sections 810, 812 each have two inflection point areas 852, 854, 856, 858. The higher number of inflection points allows more freedom to deform after expansion of the stent and distributes the deformation over a longer section, thus, reducing the maximal strain along these loop containing sections.

Furthermore, it can be seen that a square cell 802 is generally more elongated along the longitudinal axis of the stent than a triangular cell 804, which is generally more elongated

along the circumference of the stent. This also contributes to higher flexibility after expansion.

If the first meander patterns 806, 822, 824, 826 of both types of cells are constructed identically and spaced apart  
5 by the same amount, the area of a triangular cell 804 is the same as a square cell 802. This can be more readily understood with reference to a band of cells around the circumference of a stent. Each band will encompass the same area, and each band will have the same number of cells. Accordingly, the area of each cell in  
10 one band formed of square cells will be the same as the area of each cell in another band formed of triangular cells.

Although the areas of the cells are equal, the perimeter of the triangular cell is larger than the perimeter of the square cell. Therefore, in comparison to a square cell, a  
15 triangular cell offers increased coverage of a vessel wall.

In the particular embodiments described above, the stent is substantially uniform over its entire length. However, other applications where portions of the stent are adapted to provide different characteristics are also possible. For  
20 example, as shown in Figure 11, a band of cells 850 may be designed to provide different flexibility characteristics or different radial compression characteristics than the remaining bands of cells by altering the widths and lengths of the members making up that band. Or, the stent may be adapted to provide  
25 increased access to a side branch lumen by providing at least one cell 852 which is larger in size than the remaining cells, or by

providing an entire band of cells 854 which are larger in size than the other bands of cells. Or, the stent may be designed to expand to different diameters along the length of the stent. The stent may also be treated after formation of the stent by coating the stent with a medicine, plating the stent with a protective material, plating the stent with a radiopaque material, or covering the stent with a material.

Figures 12 and 13 show alternative patterns for a stent constructed according to the principles of the present invention. The stent shown in Fig. 12 has two bands of cells 856 located at each of the proximal end 860 and distal end 862. The cells that form the bands of cells 856 located at the ends of the stent are '303 type cells. The remaining cells in the stent are the same as described with respect to the cells 500 depicted in Fig. 6. The stent shown in Fig. 13 has alternating bands of cells 864, 866, 868. The first type of band of cells 864 is composed of '303 type cells. The second and third types of bands of cells 866, 868 are formed of the cells described with respect to the cells 500 depicted in Fig. 4. Of course, any various combination of cells may be used in the present invention.

Thus, what is described is a longitudinally flexible stent that utilizes a closed cell structure to provide excellent coverage of the vessel wall. The general concepts described herein can be utilized to form stents with different configurations than the particular embodiments described herein. For example, the general concepts can be used to form bifurcated



stents. It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described above. Rather, the scope of the present invention is defined by the claims which follow.

CLAIMS

1. A stent for widening a vessel in the human body comprising:

5 a plurality of first meander patterns each formed of a single, continuous, generally sinusoidal pattern of loops about the circumference of the stent occurring at a first frequency;

10 a plurality of second meander patterns each formed of a single, continuous, generally sinusoidal pattern of loops about the circumference of the stent occurring at a second frequency higher than the first frequency, alternating with the first meander patterns for at least two repetitions;

15 wherein said first and second meander patterns are connected directly to each other without intervening materials to form triangular cells.

2. A stent according to claim 1, wherein the first meander patterns are comprised of:

20 even first meander patterns; and  
odd first meander patterns which are 180° out of phase with the even first meander patterns, the odd first meander patterns occurring between every two even first meander patterns.

3. A stent according to claims 1 or 2, wherein the 25 second meander patterns are comprised of:

even second meander patterns; and  
odd second meander patterns occurring between every two even second meander patterns.

4. A stent according to claim 1, wherein each of the triangular cells is comprised of a first loop containing section, a second loop containing section, and a third loop containing section.
- 5 5. A stent according to claim 4, wherein the first loop containing section is formed by a portion of a first meander pattern and the second and third loop containing sections are formed by portions of a second meander pattern.
- 10 6. A stent according to claim 4, wherein the first loop containing section includes at least one leg of a free loop which is shorter than other legs of loops in the loop containing section.
- 15 7. A stent according to claim 4, wherein the first loop containing section is wider than the second and third loop containing sections.
8. A stent according to claim 4, wherein the first meander pattern has two loops per period.
- 20 9. A stent according to claim 4, wherein the second meander pattern has four loops per period.
10. A stent according to claim 4, wherein the first loop containing section has two loops opening toward the interior of the cell.

11. A stent according to claims 4 or 8, wherein the second and third loop containing sections together have three loops opening toward the interior of the cell.

12. A stent according to claims 4, 8 or 11, wherein the loops of the second and third loop containing sections are adapted to compensate for the tendency of the loops of the first loop containing section to foreshorten when the stent is expanded.

13. A stent according to claims 4, 8 or 11, wherein one of the loops of the first loop section is a free loop which is shorter than the other loop of the first loop section.

14. A stent for holding open a lumen comprising:  
a plurality of even and odd first vertical meander patterns having loops occurring at a first frequency, the odd first vertical meander patterns being located between every two even first vertical meander patterns and being out of phase with the even first vertical meander patterns;

a plurality of second vertical meander patterns having loops occurring at a second frequency higher than said first frequency, said second vertical meander patterns alternating with each even and odd first vertical meander pattern;

wherein each vertical meander pattern is a single, continuous, generally sinusoidal pattern of loops;

wherein the even and odd first vertical meander patterns are connected directly with each adjacent second vertical meander pattern without intervening materials to form a plurality of triangular cells.

5 15. A stent according to claim 14, wherein the triangular cells are formed by a first loop containing section, a second loop containing section connected to the first loop containing section, and a third loop containing section connected to the first and second loop  
10 containing section.

16. A stent according to claim 15, wherein the first loop containing section is formed from a portion of a first vertical meander pattern.

17. A stent according to claim 16, wherein the second  
15 and third loop containing sections are formed from a portion of a second vertical meander pattern.

18. A stent according to claim 17, wherein members forming the first loop containing section are wider than members forming the second and third loop containing  
20 sections.

19. A stent according to claim 18, wherein the first loop containing section forms two loops opening toward the interior of the cell.

20. A stent according to claim 19, wherein the second loop containing section and third loop containing section together form three loops opening toward the interior of the cell.
- 5 21. A stent according to one of claims 14 and 15, wherein the stent is made of stainless steel.
22. A stent according to claim 15, wherein the first loop containing section includes one free loop.
23. A stent according to claim 22, wherein one leg of  
10 the free loop is shorter than the other leg of the loop.
24. A stent according to claim 15, wherein the length of the second loop containing section is equal to the length of the third loop containing section.
25. A stent according to claim 14, wherein each  
15 triangular cell of the stent encompasses the same area.
26. A stent according to claim 15, wherein the width of members forming the second loop containing section and the width of members forming the third loop containing section are the same.
- 20 27. A stent for widening a vessel in the human body comprising:  
a) a plurality of first meander patterns each forming a single, continuous, generally sinusoidal pattern of loops occurring at a first frequency;

b) a plurality of second meander patterns each forming a single, continuous, generally sinusoidal pattern of loops occurring at a second frequency higher than the first frequency, alternating with the first  
5 meander patterns for at least two repetitions;

wherein said first and second meander patterns are connected directly to each other without intervening materials to form triangular cells;

c) said first meander patterns and said second  
10 meander patterns disposed and adapted to cooperate so that after expansion of said stent when said stent is disposed in curved vessel, cells on the outside of the curve open in length, but narrow circumferentially whereas cells on the inside of the curve shorten in  
15 length but widen circumferentially.

28. A stent according to claim 27, wherein the second meander patterns compensate for foreshortening of the first meander patterns when the stent is expanded such that the widths of the first meander patterns are smaller  
20 expanded than compressed, and the width of the second meander patterns are greater expanded than compressed.

29. A stent according to claim 28, wherein said stent is coated with medicine and said compensation results in more even dose being applied to the inside wall of the  
25 lumen.

30. A stent for holding open a lumen, comprising:
- a) a plurality of even and odd first vertical meander patterns having loops occurring at a first frequency, the odd first vertical meander patterns being  
5 located between every two even first vertical meander patterns and being out of phase with the even first vertical meander patterns;
  - b) a plurality of second vertical meander patterns having loops occurring at a second frequency higher than  
10 said first frequency, said second vertical meander patterns alternating with each even and odd first vertical meander pattern;
  - c) wherein the even and odd first vertical meander patterns are connected directly with each adjacent second  
15 vertical meander pattern without intervening materials to form a plurality of triangular cells;
  - d) wherein each vertical meander pattern is a single, continuous generally sinusoidal pattern of loops;
  - e) wherein said even and odd first vertical meander  
20 patterns and said second vertical meander patterns are disposed and adapted to cooperate so that after expansion of said stent, when said stent is disposed in curved lumen, cells on the outside of the curve open in length, but narrow circumferentially whereas cells on the inside  
25 of the curve shorten in length but widen circumferentially; and
  - f) wherein the second vertical meander patterns compensate for foreshortening of the even and odd first vertical meander patterns when the stent is expanded such  
30 that the widths of the even and odd first vertical meander patterns are smaller when expanded than



compressed and the widths of the second vertical meander patterns are larger when expanded than compressed.

31. A stent according to claim 30, wherein compensation, which occurs when cells on the outside of the curve open  
5 in length, but narrow circumferentially and cells on the inside of the curve shorten in length but widen circumferentially, results in a more constant density of stent element area between the inside and the outside of the curve than if the cells on the outside only  
10 lengthened and cells on the inside only shortened.

32. A stent according to claim 31, wherein said stent is coated with medicine and said compensation results in a more even dose being applied to the inside wall of the lumen.

15 33. A stent according to claim 30, wherein compensation, which occurs when cells on the outside of the curve open in length but narrow circumferentially and cells on the inside of the curve shorten in length but widen circumferentially results in more constant stent cell  
20 area between the inside and the outside of the curve than if the cells on the outside only lengthened and cells on the inside only shortened.

34. A stent according to claim 33, wherein said stent is coated with medicine and said compensation results in a  
25 more even dose being applied to the inside wall of the lumen.

35. A multicellular stent for widening a vessel in the human body comprising:

(a) a plurality of first circumferential bands containing a single, continuous, generally sinusoidal pattern of loops at a first frequency;

(b) a plurality of second circumferential bands containing a single, continuous, generally sinusoidal pattern of loops at a second frequency higher than said first frequency, alternating with said first circumferential bands and connected directly thereto without intervening materials to form cells;

(c) wherein loops in said bands are disposed and adapted to cooperate so that, when the expanded stent is in a curved lumen, cells on the outside of the curve open in length, but narrow circumferentially whereas cells on the inside of the curve shorten in length but widen circumferentially.

36. A multicellular stent according to claim 35, the second circumferential bands compensate for foreshortening of the first circumferential bands when the stent is expanded such that the widths of the first circumferential bands are smaller expanded than compressed, and the widths of the second circumferential bands are greater expanded than compressed.

37. A multicellular stent according to claim 36, wherein said stent is coated with a medicine and said compensation results in a more even dose being applied to the inside wall of the lumen.

38. A stent for widening a vessel in the human body comprising:

5 a plurality of first circumferential bands containing a single, continuous, generally sinusoidal pattern of loops at a first frequency;

10 a plurality of second circumferential bands containing a single, continuous, generally sinusoidal pattern of loops at a second frequency higher than said first frequency, alternating with said first circumferential bands for at least two repetitions and connected directly thereto without intervening materials to form cells.

39. A stent according to claim 38, wherein the first circumferential bands containing a pattern of loops are  
15 comprised of:

even first circumferential bands containing a pattern of loops; and

20 odd first circumferential bands containing a pattern of loops which are  $180^\circ$  out of phase with the loops of the even first circumferential bands, an odd first circumferential band occurring between every two even first circumferential bands.

40. A stent according to claim 39, wherein each cell includes two loops of one of said plurality of first  
25 circumferential bands and three loops of one of said plurality of second circumferential bands.

41. A stent according to claim 39, wherein each cell includes a number of loops of said first circumferential band corresponding to two cycles of said first frequency and a number of loops of said second circumferential band  
5 corresponding to three cycles of said second frequency.

42. A stent according to claim 39, wherein the first circumferential bands have loops that are wider than the loops in said second circumferential bands.

43. A stent according to claim 42, wherein the relative  
10 widths of said loops is such that when said stent is crimped for insertion into a lumen of a blood vessel, the loops of said second circumferential bands are crimpable to essentially the same diameter as the loops of said first circumferential bands.

15 44. A stent according to claim 42, wherein the higher frequency of the loops in said second circumferential bands provide improved flexibility.

45. A stent according to claim 39, wherein the first circumferential bands have loops forming two cycles per  
20 period.

46. A stent according to claim 39, wherein the second circumferential bands have loops forming three cycles per period.

47. A coronary stent comprising:

(a) a first loop containing section having loops, said first loop containing section oriented in the circumferential direction, the loops in said first loop containing section occurring at a first frequency;

(b) a second loop containing section having loops, said second loop containing section oriented in the circumferential direction, the loops in said second loop containing section also occurring at said first frequency;

(c) said first and second loop containing sections formed of a single, continuous, generally sinusoidal pattern; and

(d) a third loop containing section having loops, said third loop containing section formed of a single, continuous, generally sinusoidal pattern also oriented about a circumferential axis and, the loops in said third loop containing section occurring at a second frequency that is higher than said first frequency, each said third loop containing section disposed in the generally circumferential space between each of said first and second loop containing sections to form consecutive repeating patterns along the longitudinal axis of the stent for at least two repetitions and wherein the third loop containing sections are alternately joined to said adjacent first and second loop containing sections at a first junction without intervening materials between the first and third loop containing sections and a second junction without intervening materials between the second and third loop containing sections, wherein at least two loops of the third loop containing section are disposed

between each said first and second junction, said first, second and third loop containing sections forming a uniform pattern of flexible cells;

(e) the loops in said first, second and third loop  
5 containing sections being disposed and adapted to cooperate so that, components of said third loop containing section contribute to the cell's elongating or shortening when the stent is flexed; and

(f) the loops of the first, second and third loop  
10 containing sections further include struts having a thickness in the radial direction and width in the circumferential direction, wherein the struts of the first and second loop containing sections are wider than the width of the struts of the third loop containing  
15 section.

48. A stent according to claim 47, wherein said stent is coated with a medicine.

49. A coronary stent comprising:

(a) a plurality of first circumferential bands,  
20 each formed of a single, continuous, generally sinusoidal pattern of loops at a first frequency;

(b) a plurality of second circumferential bands, each containing a single, continuous, generally sinusoidal pattern of loops at a second frequency higher  
25 than said first frequency, said sinusoid in said second circumferential band oriented about a circumferential axis, each said first circumferential band alternating with each said second circumferential band to form consecutive patterns along the longitudinal axis of the

stent for at least two repetitions, said second bands periodically coupled directly to said first bands without intervening materials to form cells, wherein each second circumferential band has at least two loops between each  
5 coupling;

(c) patterns of loops in said bands being disposed and adapted to cooperate so that second circumferential bands contribute more than first circumferential bands to deformation during flexing of the stent: and

10 (d) the loops of the first and second bands further include struts having a thickness in the radial direction and a width in the circumferential direction, wherein the struts of the first bands are wider than the width of the struts of the second bands.

15 50. A stent according to claim 49, wherein said stent is coated with a medicine.

1/12

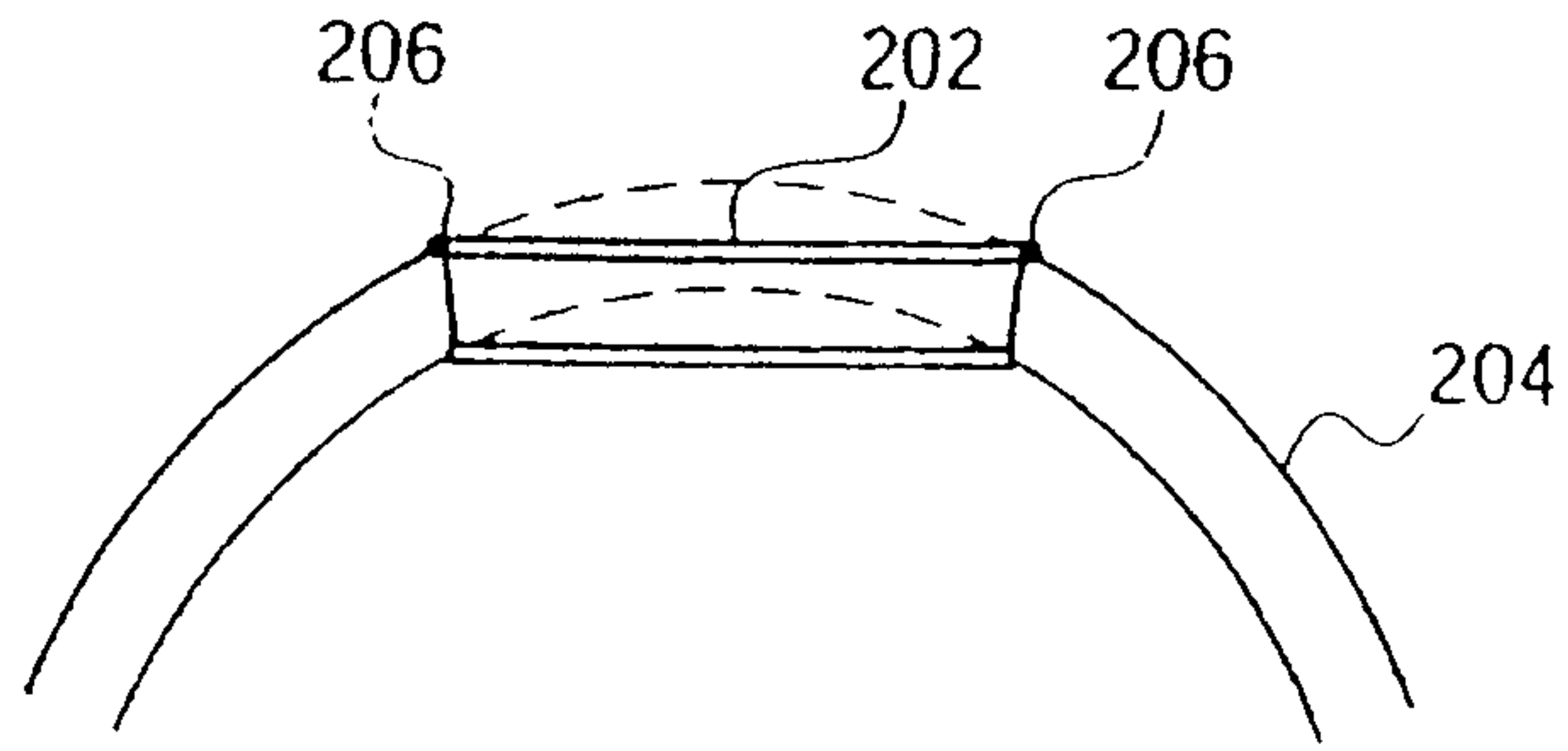


FIG. 1

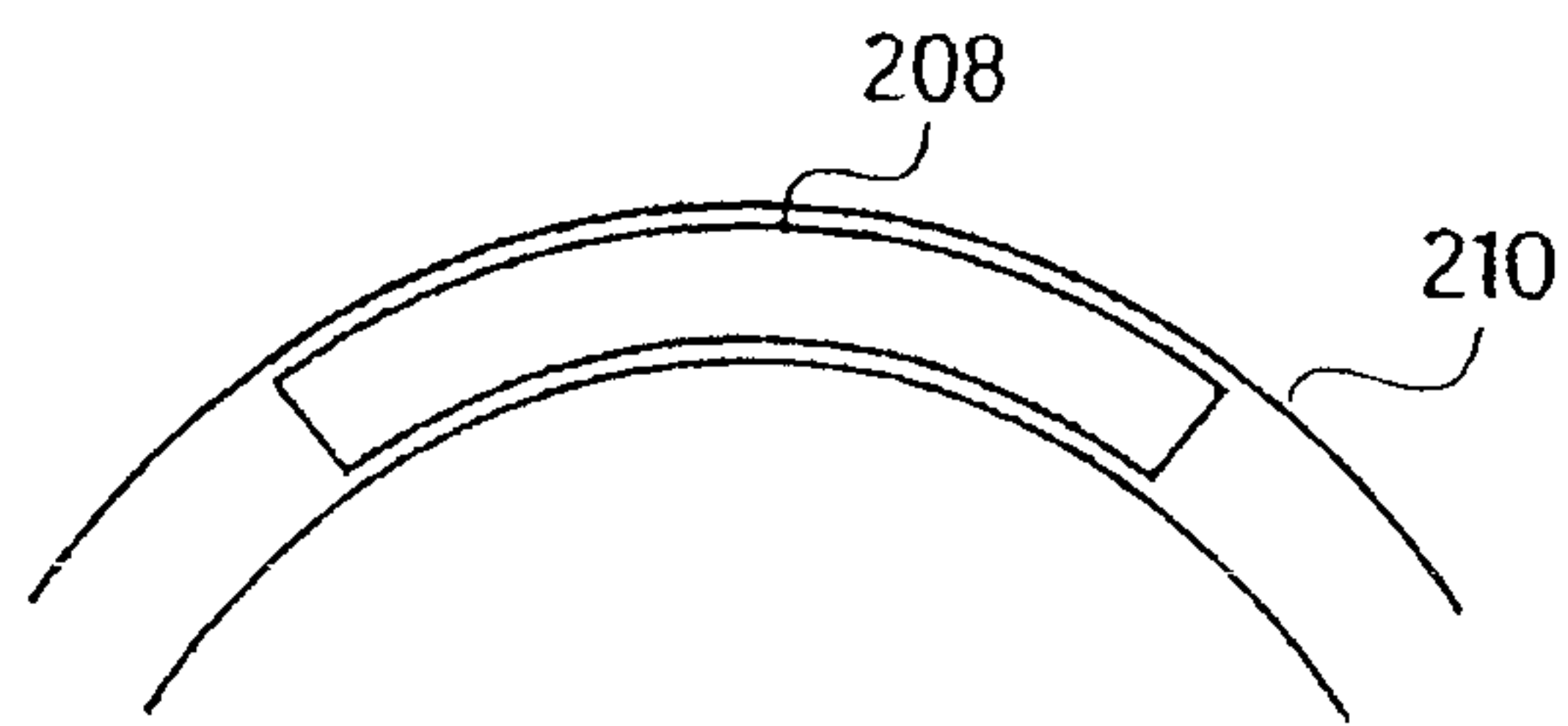


FIG. 2



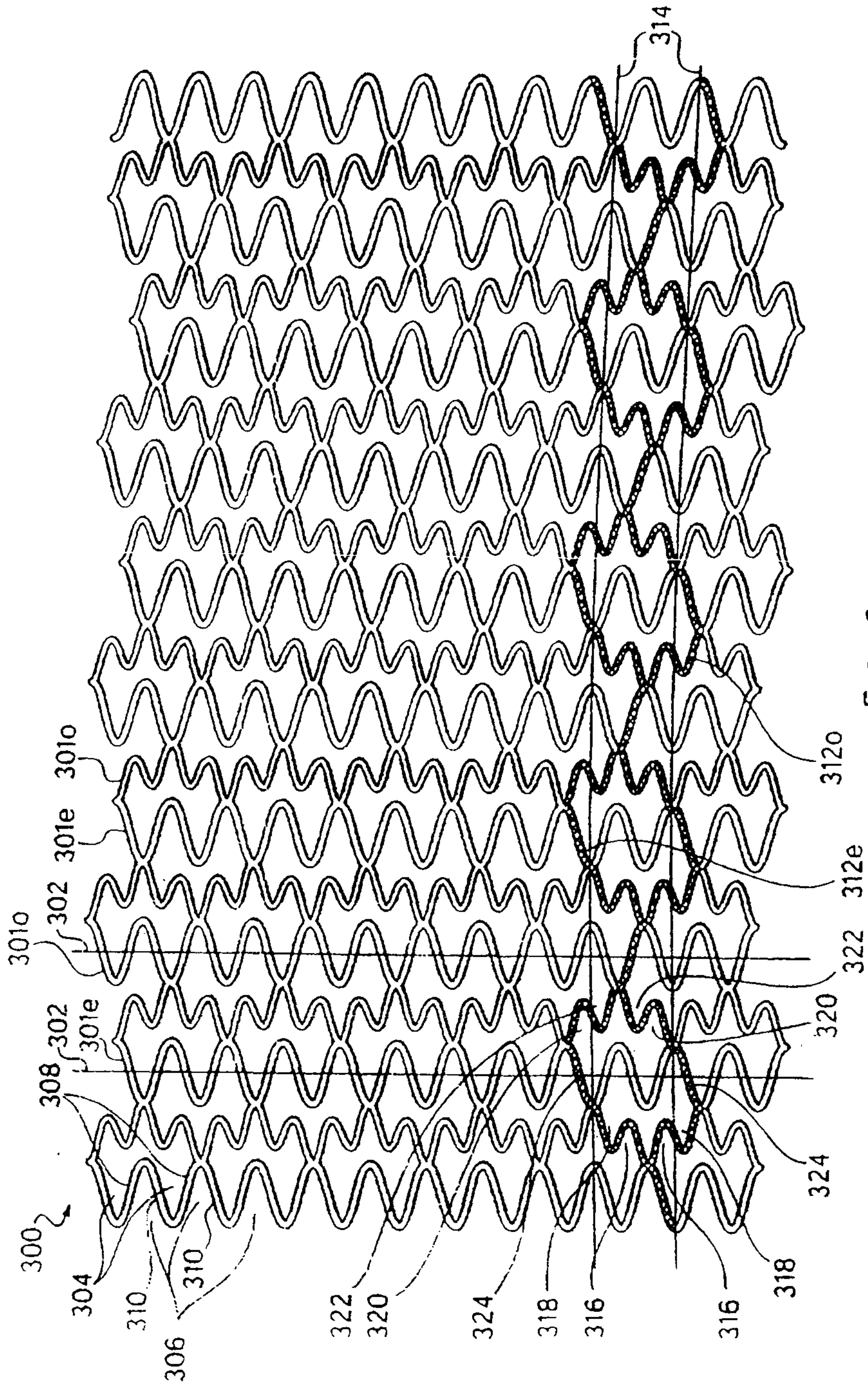


FIG. 3

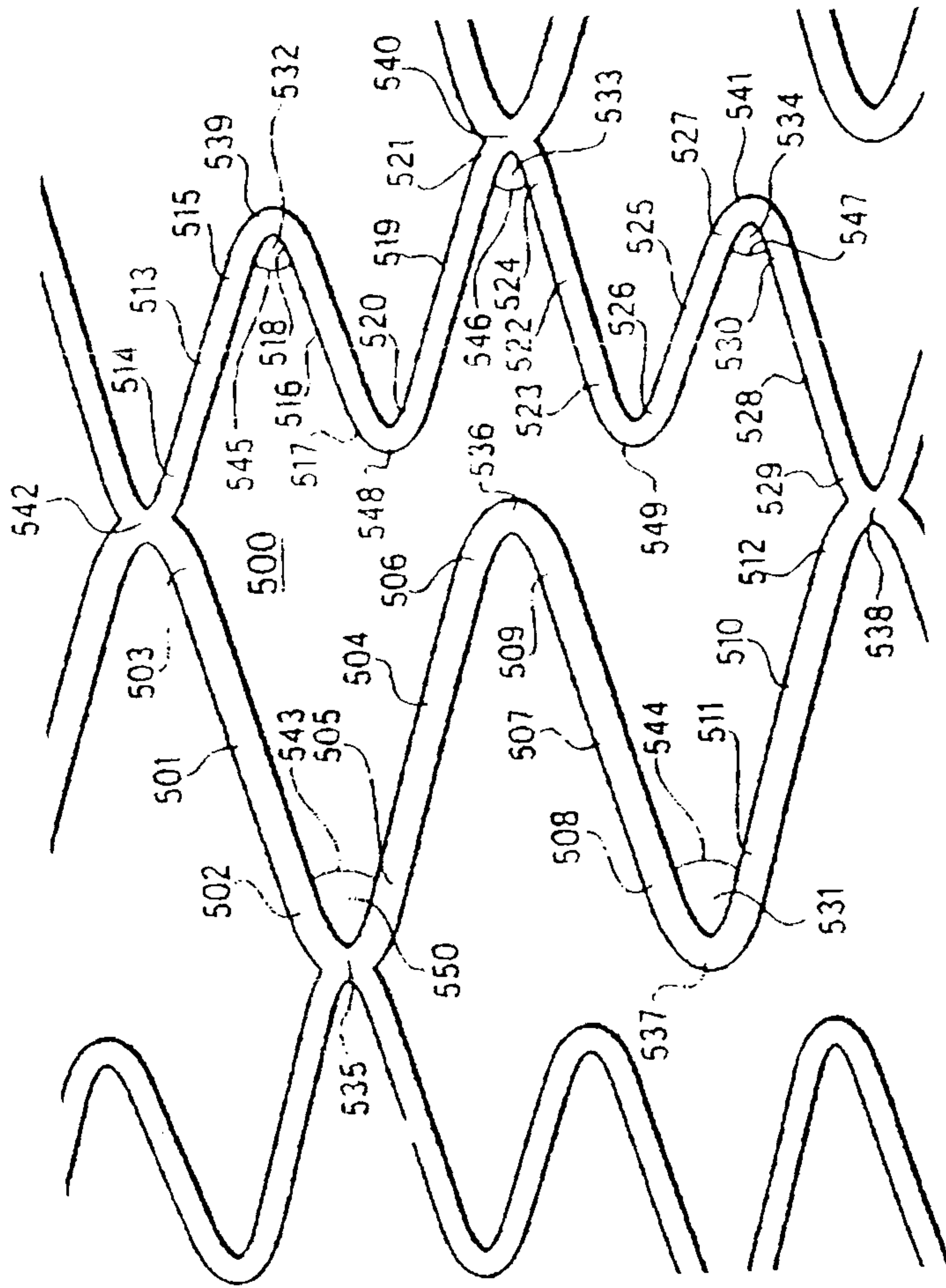


FIG. 4

4/12

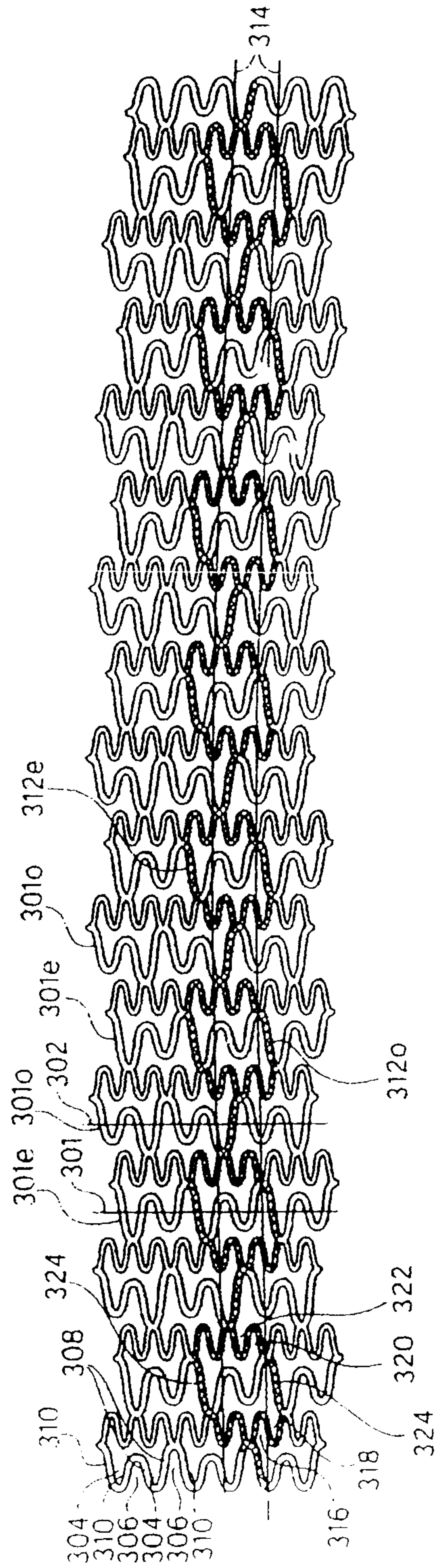


FIG. 5

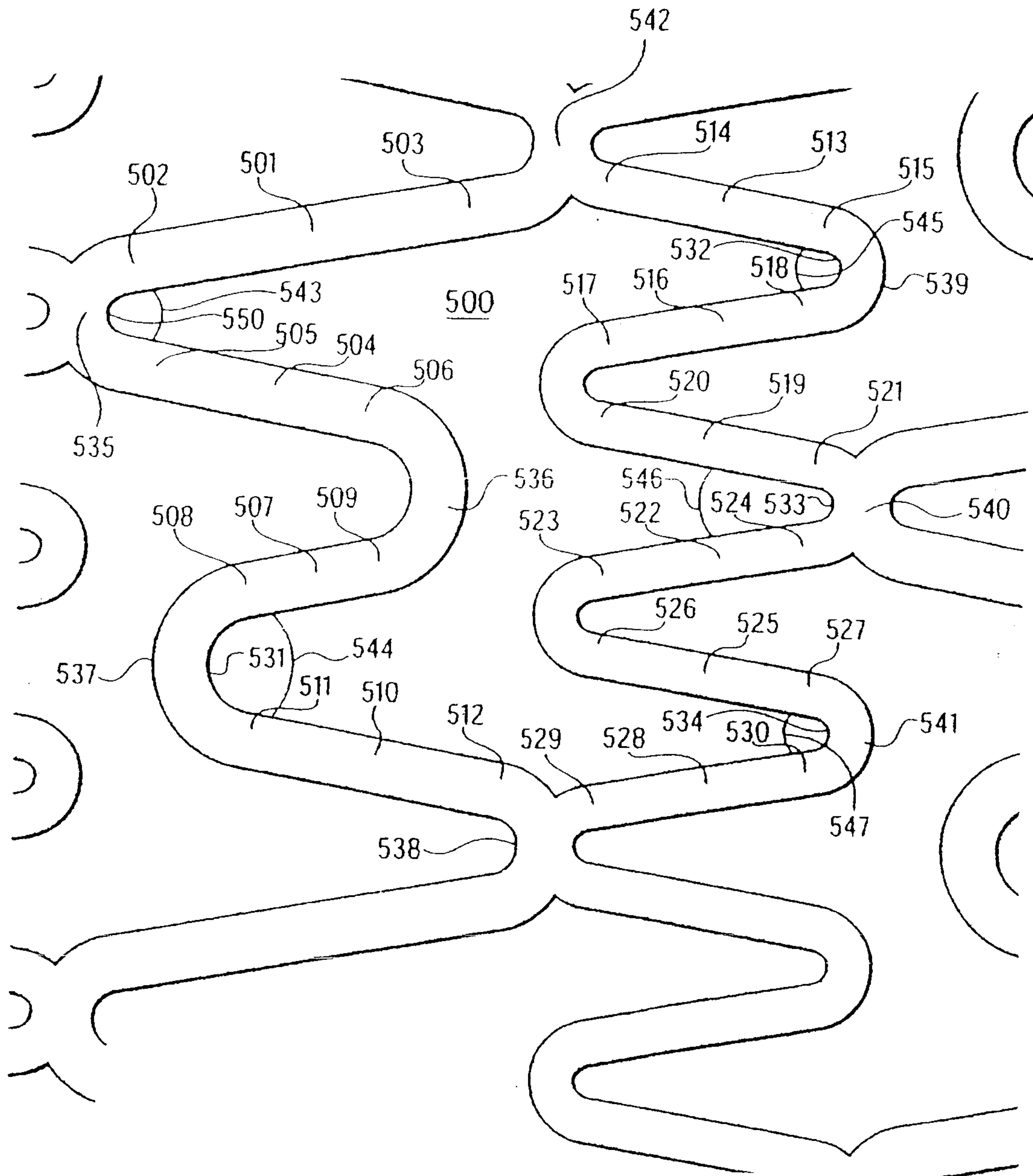


FIG. 6

6/12

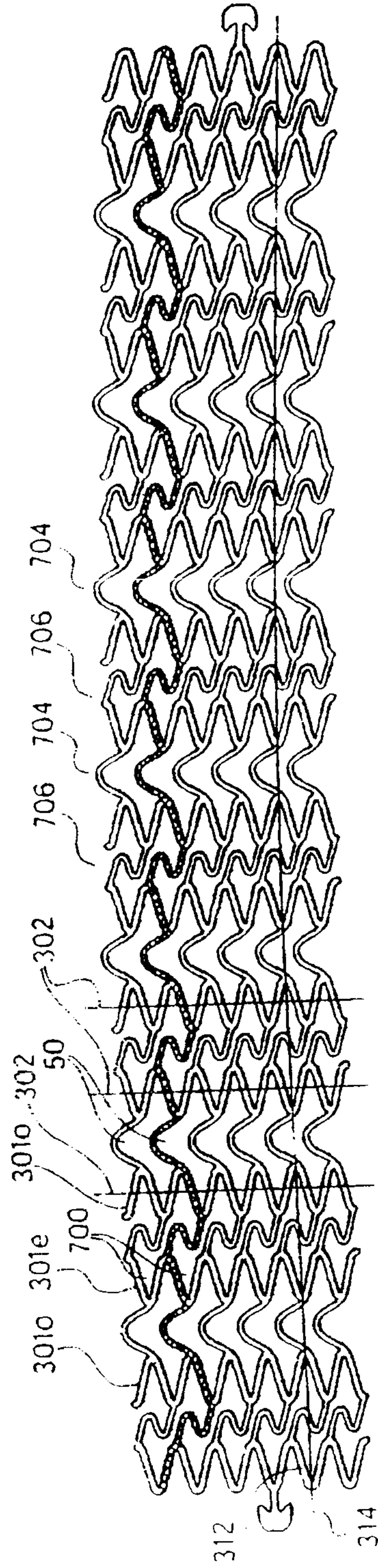


FIG. 7

7/12

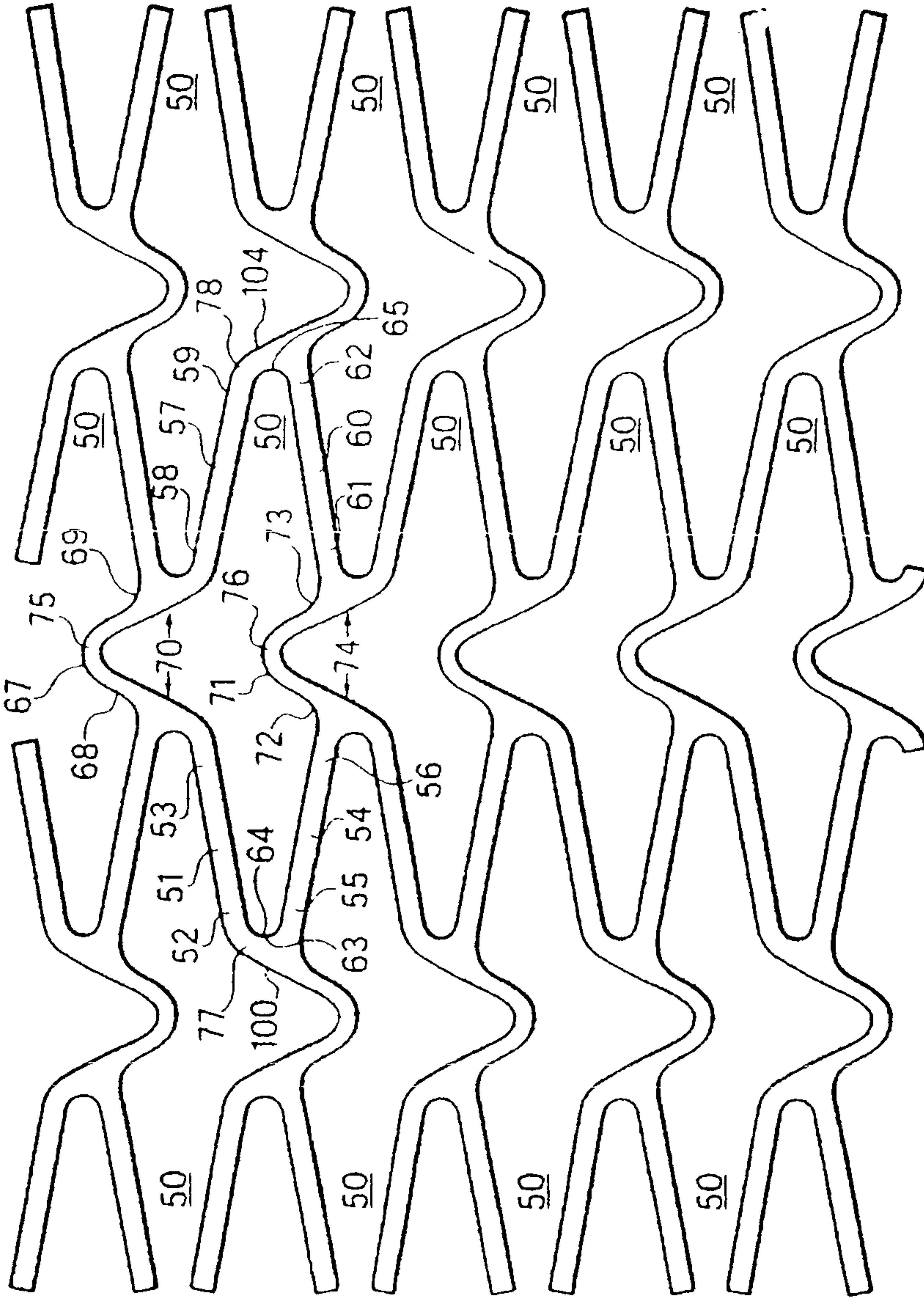


FIG. 8

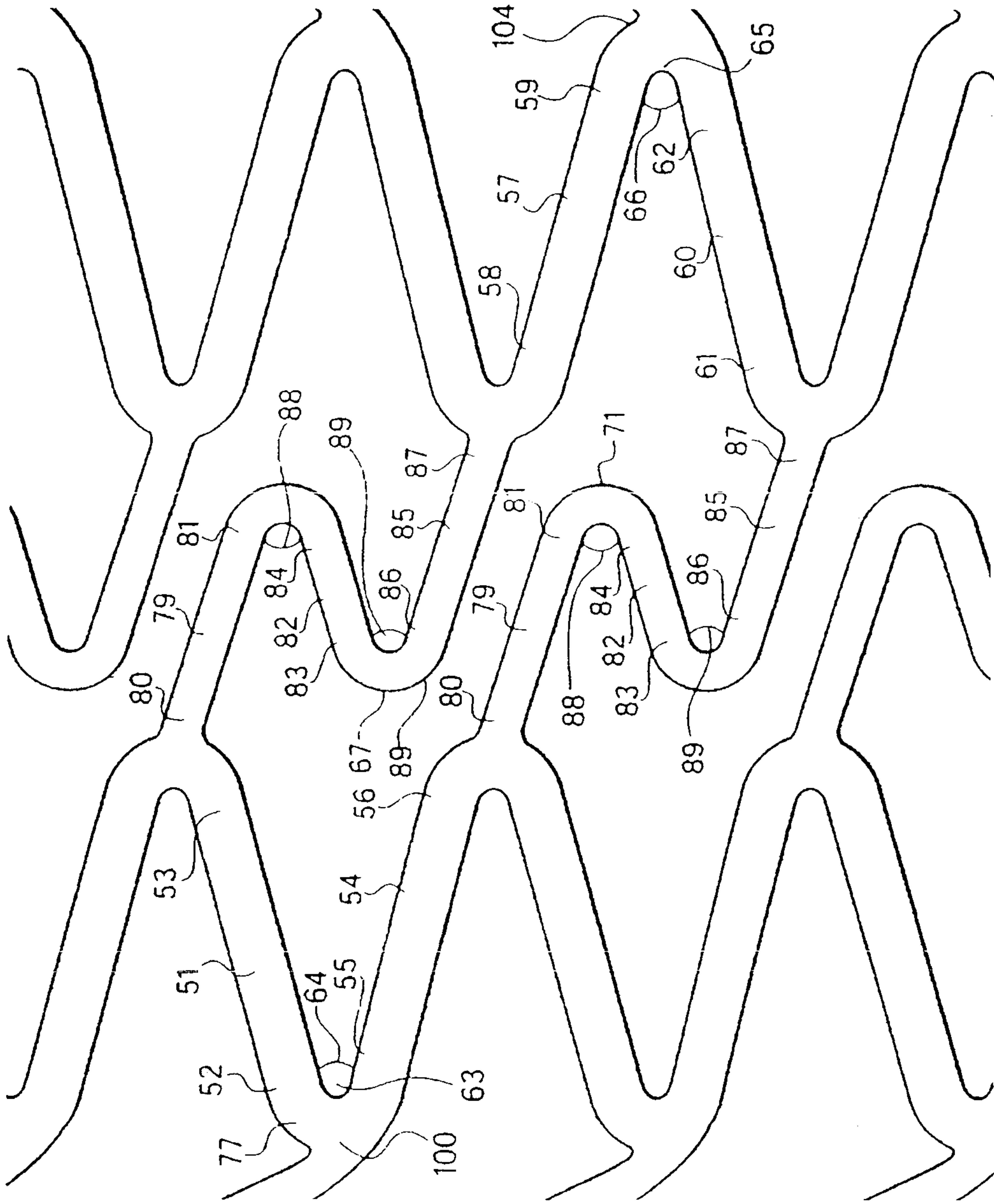


FIG. 9

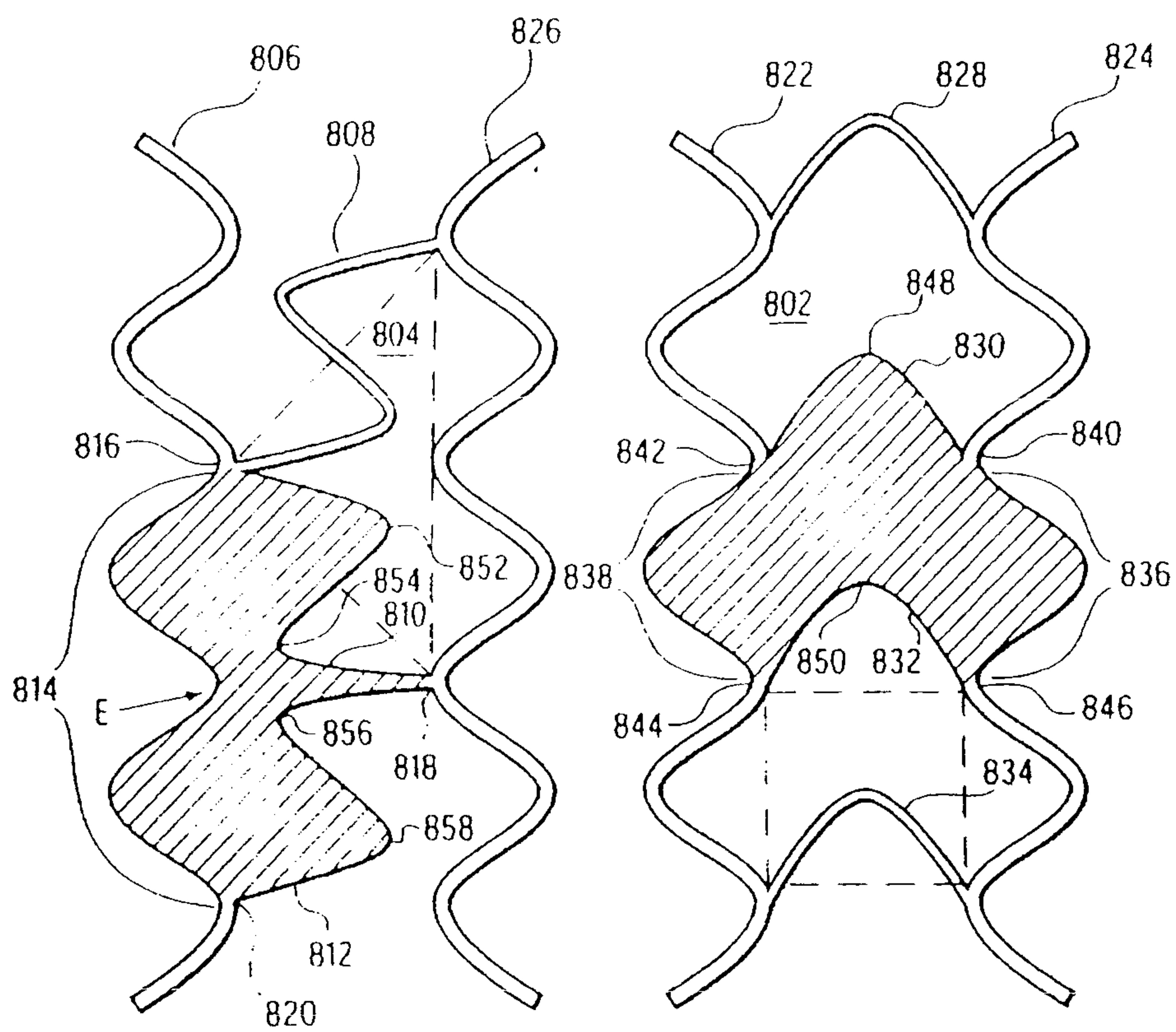


FIG. 10



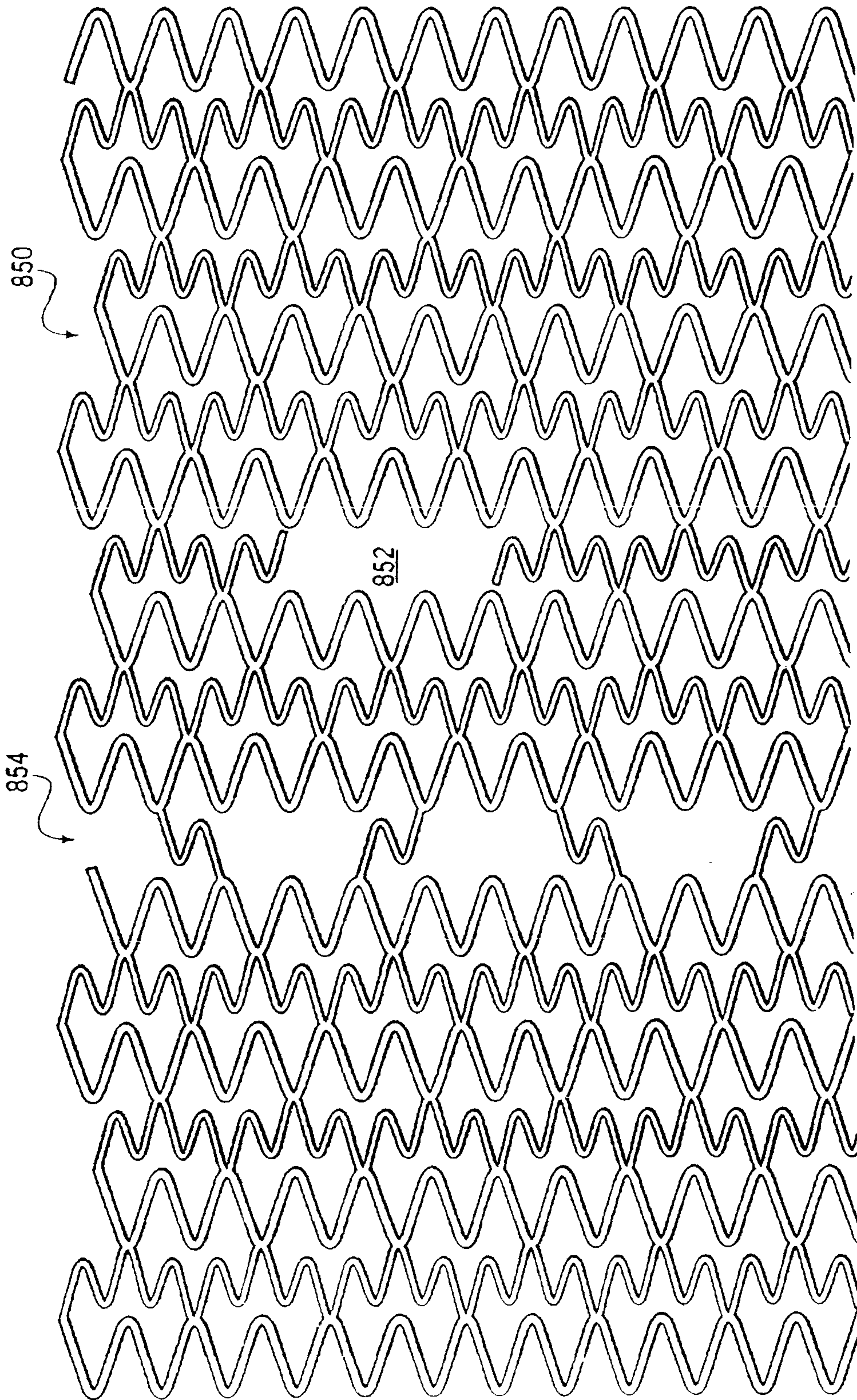


FIG. 11

11/12

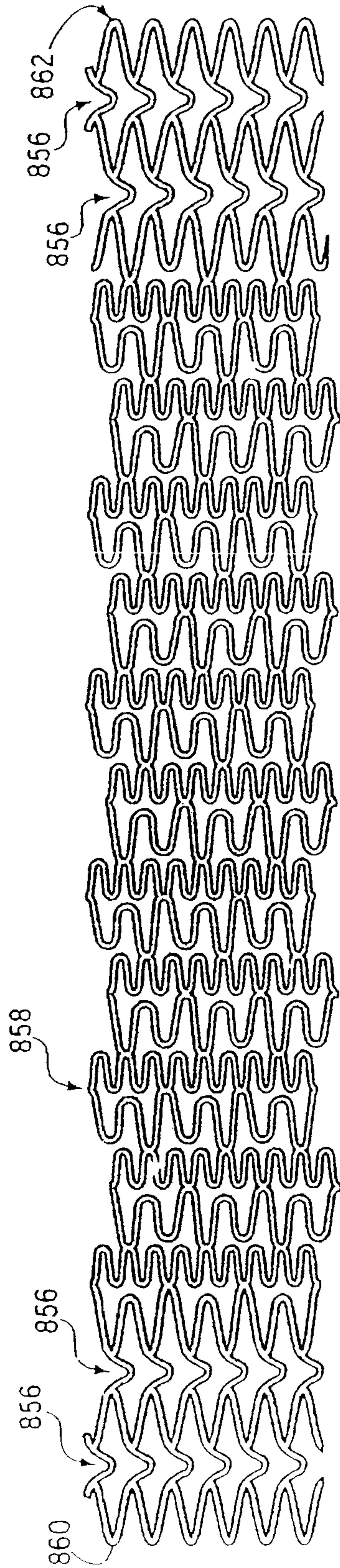


FIG. 12

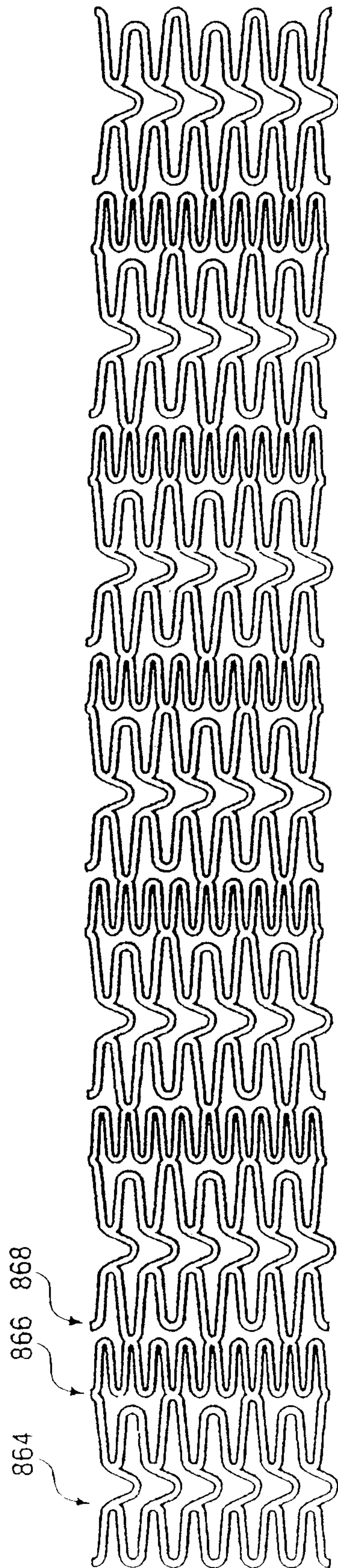


FIG. 13

