US 20080177373A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2008/0177373 A1**

(43) **Pub. Date: Jul. 24, 2008**

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(54) **ENDOPROSTHESIS STRUCTURES HAVING SUPPORTING FEATURES**

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(21) Appl. No.: **12/016,077**

(22) Filed: **Jan. 17, 2008**

Related U.S. Application Data

(60) Provisional application No. 60/885,700, filed on Jan. 19, 2007.

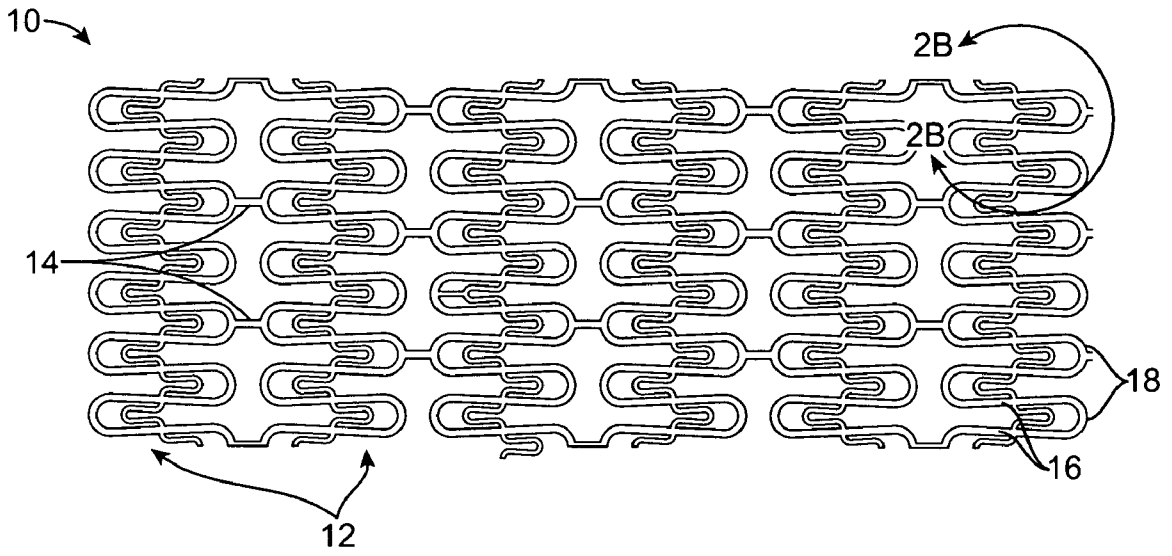
Publication Classification

(51) **Int. Cl.**
A61F 2/82 (2006.01)

(52) **U.S. Cl.** **623/1.15**

(57) **ABSTRACT**

An endoprosthesis includes a plurality of serpentine rings having supporting features which increase hoop strength, inhibit recoil, and provide an increased surface area. The supporting features may be formed between adjacent axial struts of the serpentine rings or may be positioned between axial lengths joining the serpentine rings together.



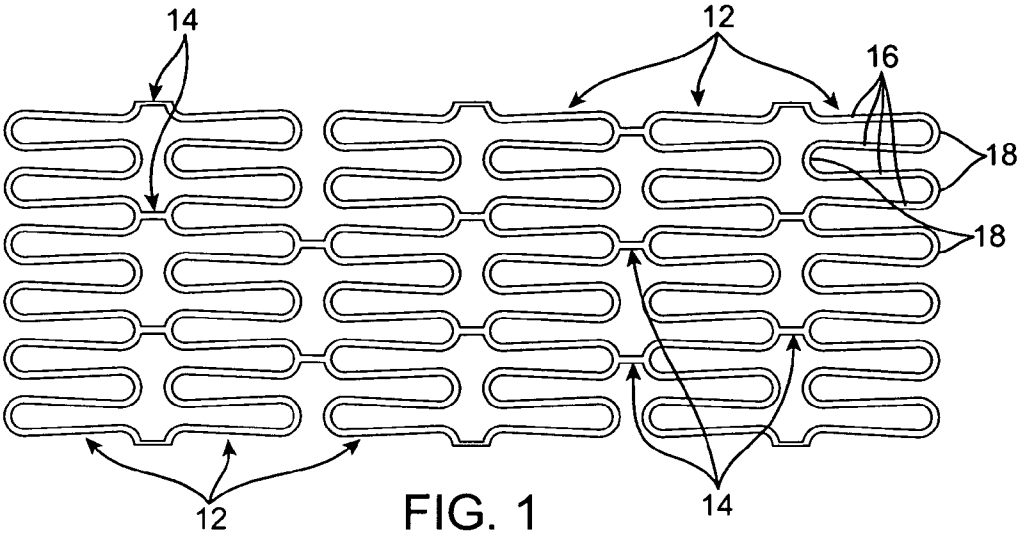


FIG. 1
(PRIOR ART)

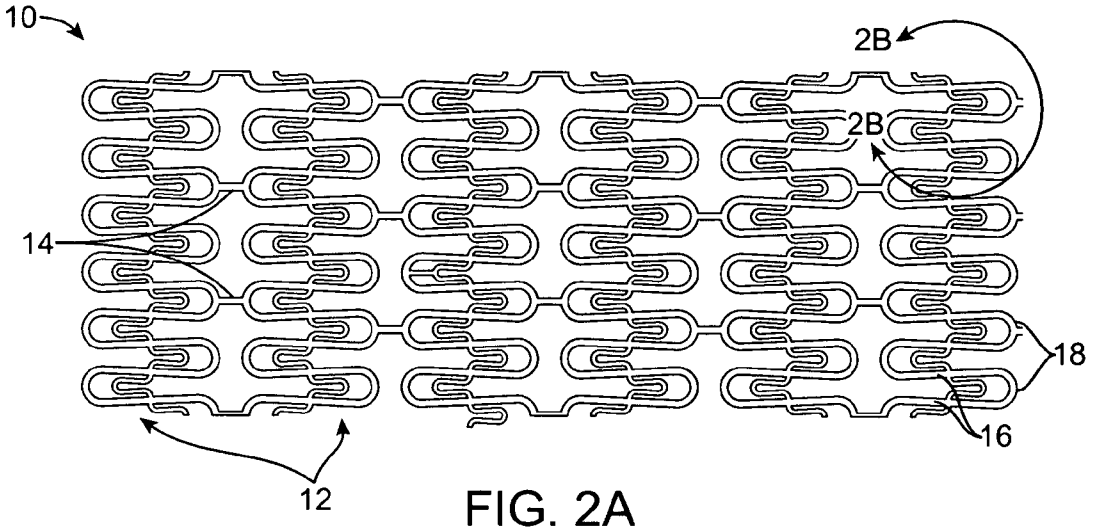


FIG. 2A

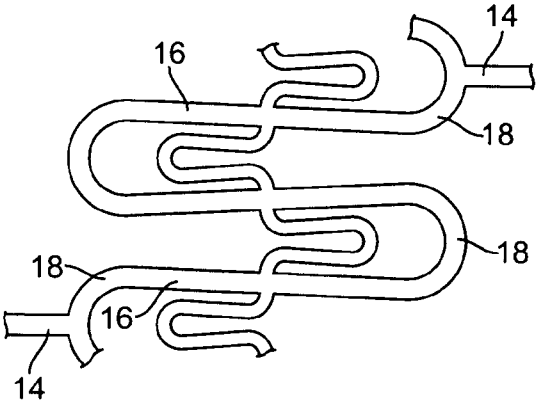


FIG. 2B

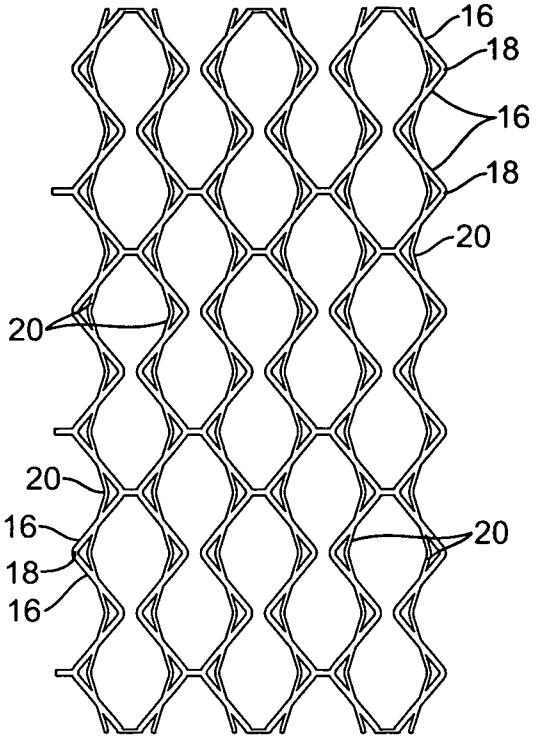


FIG. 3

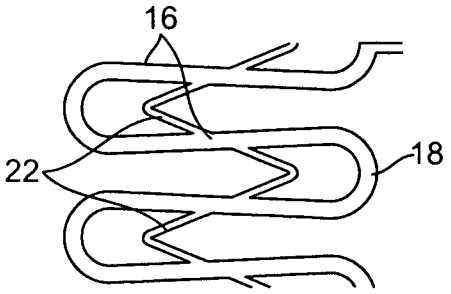


FIG. 4

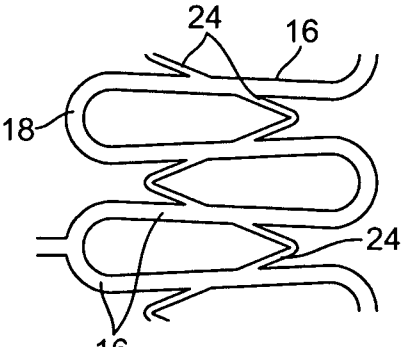


FIG. 5

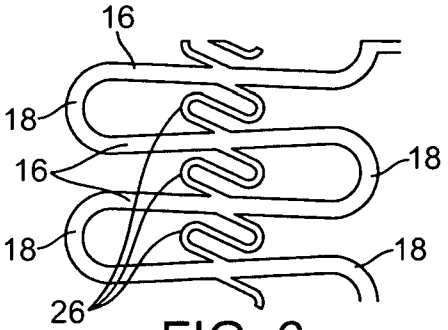


FIG. 6

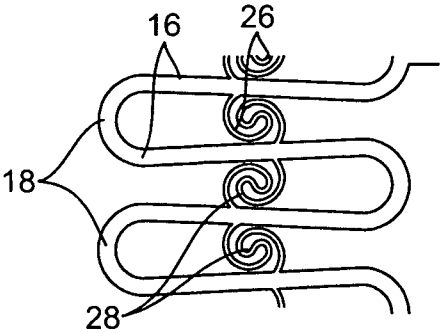


FIG. 7

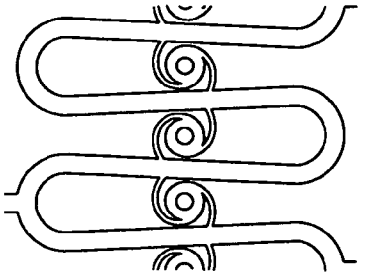


FIG. 8

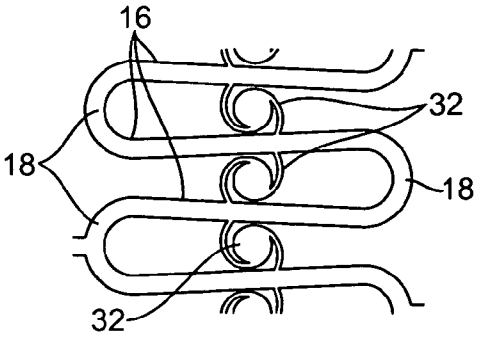


FIG. 9

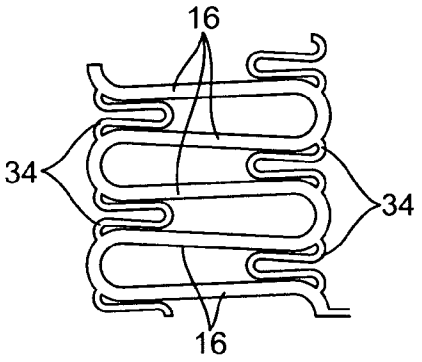


FIG. 10

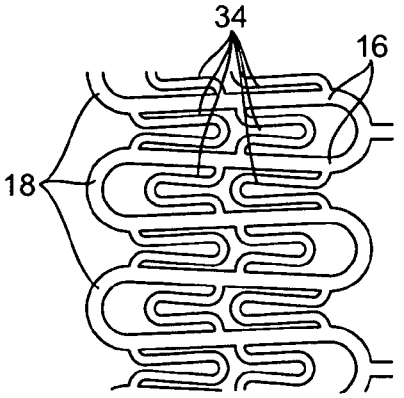


FIG. 11

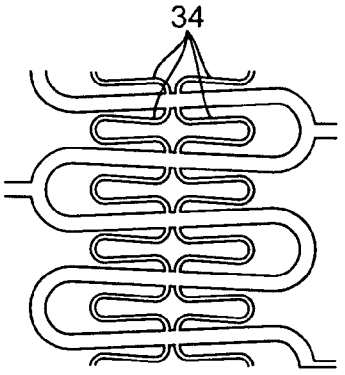


FIG. 12

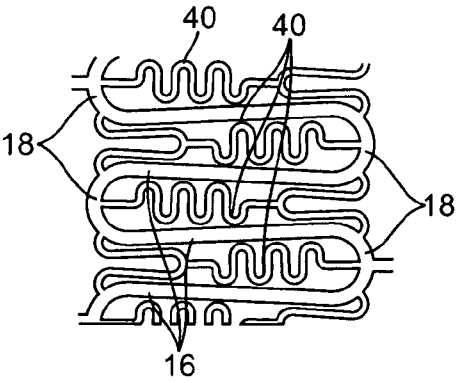


FIG. 13

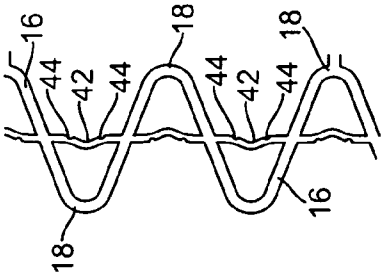


FIG. 15B

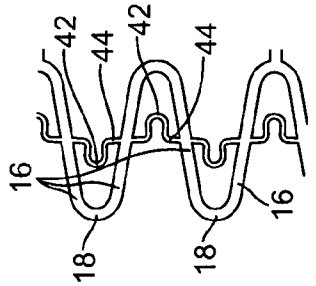


FIG. 15A

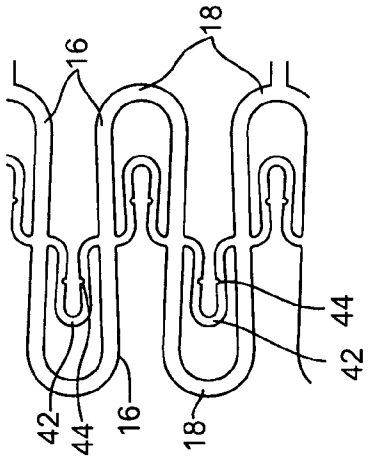


FIG. 14

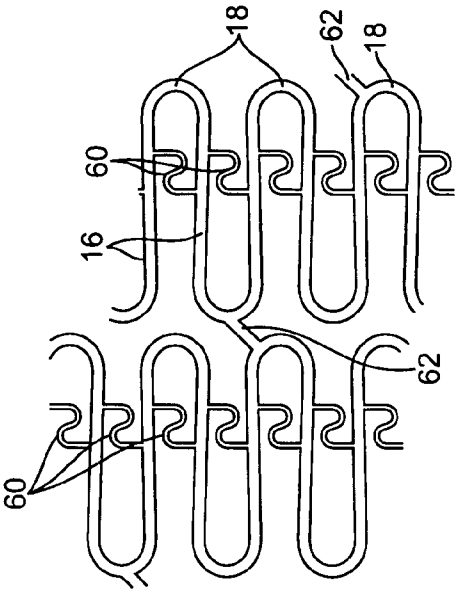


FIG. 17

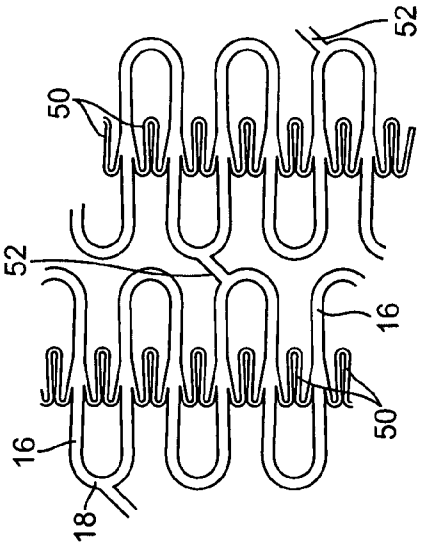


FIG. 16

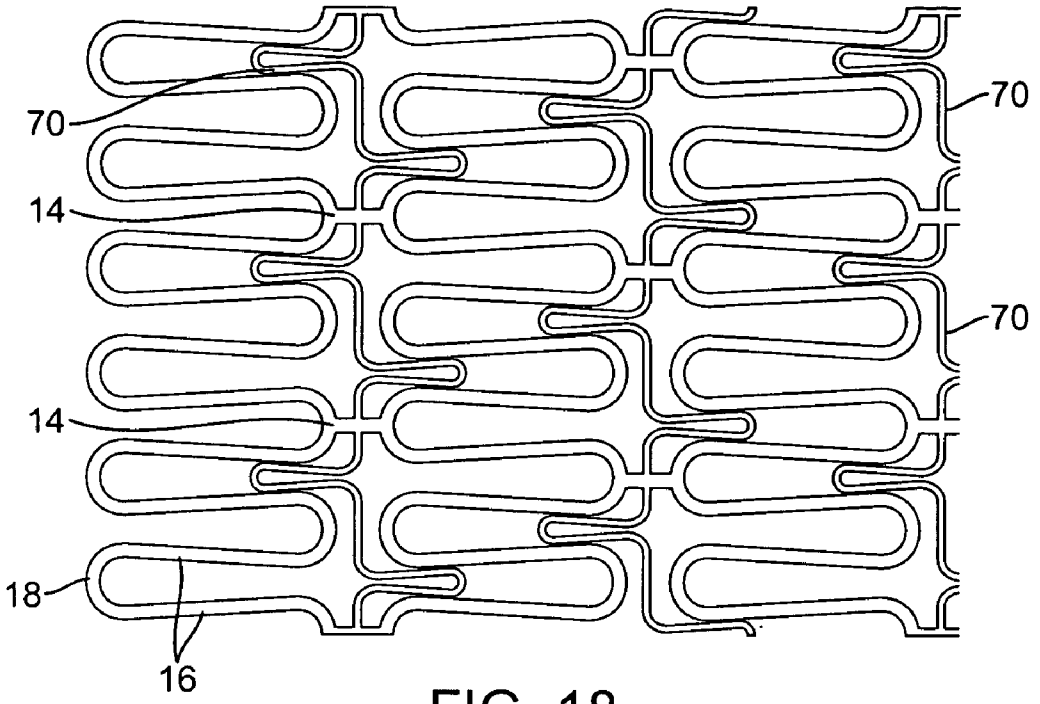


FIG. 18

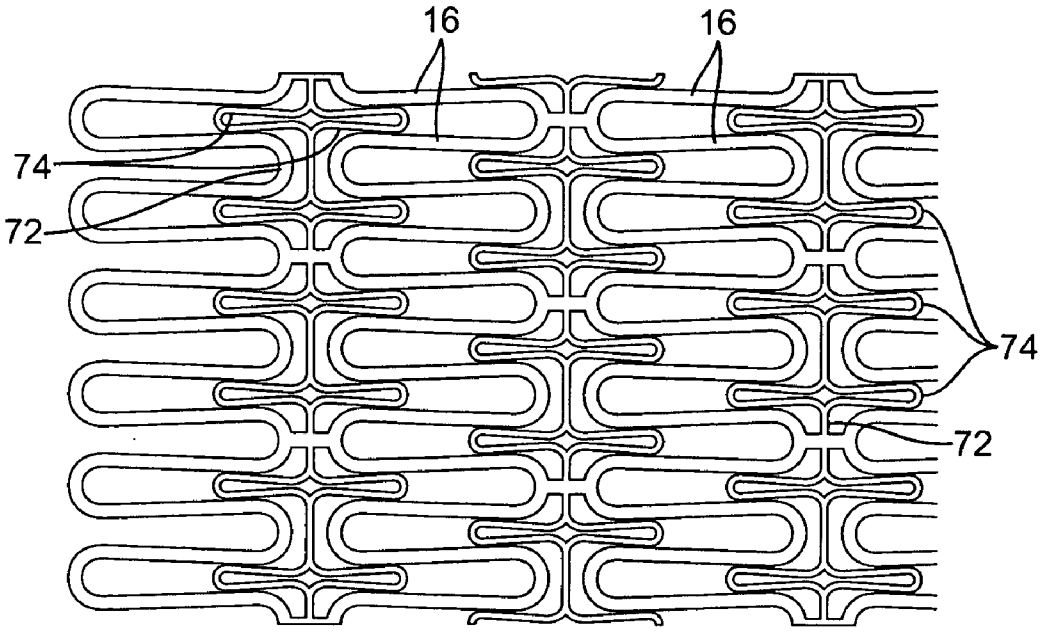


FIG. 19

ENDOPROSTHESIS STRUCTURES HAVING SUPPORTING FEATURES

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application claims the benefit of provisional application 60/885,700 (Attorney Docket No. 022265-000500US), filed on Jan. 19, 2007, the full disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to endoprosthesis designs, in particular biodegradable and non-biodegradable stents and grafts, which are adapted to be implanted into a patient's body lumen, such as coronary artery or other blood vessel or body lumen. Stents are particularly useful in the treatment of atherosclerotic stenosis in arteries and veins.

[0004] Stents are generally tubular-shaped devices which function to hold open or reinforce a segment of a blood vessel or other body lumen such as a coronary artery, carotid artery, saphenous vein graft, or femoral artery. They also are suitable to support and hold back a dissected arterial lining that can occlude the fluid passageway, to stabilize plaque, or to support bioprosthetic valves. Stents can be formed from various materials, particularly polymeric and/or metallic materials, and may be non-degradable, biodegradable, or be formed from both degradable and non-degradable components. Stents are typically delivered to the target area within the body lumen using a catheter. With balloon-expandable stents, the stent is mounted to a balloon catheter, navigated to the appropriate area, and the stent expanded by inflating the balloon. A self-expanding stent is delivered to the target area and released, expanding to the required diameter to treat the disease. Stents may also elute various drugs and pharmacological agents.

[0005] Referring to FIG. **1**, a common pattern employed in present cardiovascular stents comprises a plurality of serpentine rings **12** joined by short axial links **14**. The serpentine rings comprise axial struts **16**, where circumferentially adjacent struts are connected by crowns **18** which act as hinges in permitting circumferential expansion of the individual rings **12**. These patterns can be used for both degradable and non-degradable stents and other endoprostheses.

[0006] In the design of stents and other endoprostheses, a number of competing objectives must be addressed. For coronary artery stents, it is usually desirable to be able to collapse the stent to minimize the cross-sectional area for delivery while maximizing the surface area of the stent after expansion. A maximized surface area provides both enhanced wall support to reduce vessel recoil and a greater capacity to deliver drugs when employing drug-coated stents. A further design objective is to allow the stent to be compressed with a minimum force while still maintaining a good hoop strength after expansion to further resist vessel recoil.

[0007] Thus, what is needed is a stent design or stent material which enhances radial or hoop strength, reduces vessel recoil after implantation, provides an increased surface area while maintaining or reducing the size and mass of the stent. The present invention meets at least some of these requirements.

[0008] 2. Description of the Background Art

[0009] U.S. Pat. No. 6,773,455 describes a stent having serpentine rings axially connected via internal expansion elements. US 2003/0093143 describes a stent comprising box structures joined circumferentially by U-shaped connectors. US2003/0144729 describes a stent comprising axially spaced serpentine bands connected by wishbone connectors. See also U.S. Pat. No. 7,291,166 and U.S. Pat. No. 6,896,695.

SUMMARY OF THE INVENTION

[0010] The present invention provides an endoprosthesis, such as a stent, graft or other scaffold-like luminal prosthesis, that is used for treating vascular and other luminal conditions. The endoprosthesis includes supporting features or elements added to a base structure. The base structure of the stent is formed from a series of circumferential serpentine rings connected directly to each other or with at least one link or strut, generally as shown in FIG. **1** discussed above, where each ring comprises multiple expansion segments constructed from crowns and struts. In accordance with the present invention, the base structure is reinforced with supporting features which can increase radial strength and/or reduce recoil upon expansion of the stent compared to the structure without the supporting features. The supporting features can contain varying types of shapes such as an I-shape, C-shape, V-shape, U-shape, S-shape, Y-shape, M-shape, W-shape, Z-shape, spiral-shape or other types. In a first embodiment, the supporting features connect at least some of the adjacent struts. In another embodiment at least one supporting feature connects to at least one axially connecting link.

[0011] Thus, according to the present invention, an endoprosthesis comprises a plurality of circumferentially expandable serpentine rings, axial links joining the adjacent rings, and supporting features. The circumferentially expandable serpentine rings each include axial struts joined by crowns, where the crowns act as hinges allowing the struts to spread as the ring opens circumferentially. The axial links join the adjacent serpentine rings by connecting at least some of the crowns on the rings. The supporting features extend between at least some of the adjacent struts of at least some of the serpentine rings, where the supporting features elongate and the struts remain substantially undeformed as the ring circumferentially expands.

[0012] The endoprosthesis may be constructed from a variety of conventional stent materials and may be either balloon-expandable, self-expanding, or a combination of both. The serpentine rings of the self-expanding endoprostheses will be sufficiently elastic so that they can be constrained in a small cross-sectional area during delivery and released within the vasculature or other body lumens to assume a circumferentially expanded configuration. In contrast, the serpentine rings of the balloon-expandable endoprostheses will be sufficiently malleable so that they can be circumferentially expanded by applying a radially outward force from within the rings, typically using an inflatable balloon or other expandable structure. Particularly preferred stent materials include metals and alloys such as iron, zinc, steel, cobalt-chromium, nickel-titanium, as well as polymers such as poly lactides, polycaprolactone, polyethylene carbonate, copolymers of polylactide-glycolide, poly lactide-trimethylenecarbonates, and the like. Particular materials and fabrication methods are described in commonly owned application Ser. No. 11/_____ (Attorney Docket No. 022265-000520US), filed on the same day as the present application.

[0013] The supporting features may have a variety of specific configurations or patterns which are selected to elongate or otherwise expand as the serpentine rings of the endoprosthesis are expanded. Exemplary supporting feature configurations include U-shaped connectors, V-shaped connectors,

S-shaped connectors, spiral-shaped connectors, W-shaped connectors, N-shaped connectors, Z-shaped connectors, and the like. In order to increase or control the exposed surface area of the endoprosthesis, the supporting structures may have variable widths, for example the spiral-shaped connectors may include ring or disk-shaped cores to enhance or control the surface area. While the width and cross-sectional area of the supporting feature will usually be less than the width and cross-sectional area of the serpentine rings so that expansion of the supporting features does not deform or deflect the main ring structure, it will be possible to increase the area of the supporting feature by providing deflection points which allow the supporting feature to yield preferentially relative to the serpentine rings. For example, portions of the supporting feature may be notched so that they yield first as the endoprosthesis is expanded.

[0014] In some embodiments, one or more additional supporting features may be disposed between at least some of the adjacent struts. When a single supporting feature is employed, it will usually extend generally between the midpoints on the adjacent struts, but in other instances could be disposed closer to the ends of the struts which are not connected together with a crown. In cases where two or more supporting features are provided between adjacent pairs of struts, they may be located at any point along the length of the strut, typically with one being located near the midpoint and another being located near the free ends (i.e., ends which are not joined together with the crown).

[0015] The axial links will usually comprise short linear beams, where the linear beams are axially aligned with the axis of the endoprosthesis. In other cases, the linear beams may be aligned at a shallow angle relative to the axis, typically from zero degrees to 45 degrees.

[0016] Endoprostheses according to the present invention may comprise a plurality of circumferentially expandable serpentine rings joined by axial links, where the supporting features extend between at least some adjacent axial links between adjacent serpentine rings. These supporting features between the adjacent axial links elongate as the rings circumferentially expand. Exemplary supporting features which are connected between the adjacent axial links include serpentine connectors, usually where folded portions of the connectors extend into the region between adjacent axial struts. Alternatively, the connectors could comprise "box" connectors having symmetric extending lengths which project into the regions between axial struts.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** illustrates a conventional serpentine ring stent.

[0018] FIGS. **2**A and **2**B illustrate a first embodiment of the endoprostheses of the present invention having U-shaped connectors between adjacent axial struts in a serpentine ring.

[0019] FIG. **3** illustrates the stent structure of FIGS. **2**A and **2**B after expansion.

[0020] FIGS. **4** and **5** illustrate an exemplary V-shaped connector as the supporting feature where the connector can be oriented toward the crown (FIG. **4**) or away from the crown (FIG. **5**).

[0021] FIG. **6** illustrates an exemplary S-shaped connector as the supporting structure.

[0022] FIGS. **7-9** illustrate exemplary spiral-shaped supporting structures, where FIG. **7** illustrates an everting spiral, FIG. **8** illustrates a spiral having a ring core, and FIG. **9** illustrates a spiral having a disk core.

[0023] FIG. **10** illustrates an exemplary endoprosthesis structure having U-shaped connectors located near the open ends of the serpentine structure.

[0024] FIGS. **11** and **12** illustrate exemplary endoprosthesis structures having pairs of supporting features between adjacent axial struts.

[0025] FIG. **13** illustrates a complex supporting feature having both radially and axially aligned elongating portions.

[0026] FIGS. **14**, **15**A and **15**B illustrate a U-shaped supporting feature having notch-like yield points which control a two-stage expansion, as shown in FIGS. **15**A and **15**B.

[0027] FIGS. **16** and **17** illustrate exemplary endoprosthesis designs where adjacent serpentine rings are connected by angled axial links. FIG. **16** further illustrates an M-shaped connector as the supporting feature while FIG. **17**; illustrates a N-shaped connector as the supporting feature.

[0028] FIGS. **18** and **19** illustrate supporting features connecting adjacent axial links, where FIG. **18** illustrates a serpentine pattern, FIG. **19** illustrates a box pattern connector.

DETAILED DESCRIPTION OF THE INVENTION

[0029] The present invention provides an endoprosthesis, such as a stent, that is used for treating vascular or other luminal conditions with supporting features or elements added to a base stent structure. The base structure of the stent is formed from one or more serpentine rings. The rings may be interconnected directly or with at least one link. Each ring is composed of multiple expansion segments constructed from crowns and struts. The stent is then reinforced by supporting features that increase radial strength (e.g., hoop strength), increase surface area, and/or reduce recoil compared to the stent without the supporting features. The at least one supporting feature usually connects opposite sides of axial struts which expand (spread apart) about crowns (hinges). Alternatively, the supporting feature may connect axial links which join the serpentine rings. Upon expansion of the segment the supporting feature increases radial strength and/or reduces recoil. The stents may be non-degradable or degradable, where degradation includes biodegradation, bioerosion, bioabsorption, corrosion, and disintegration completely or partially in physiological environment. The supporting feature may undergo plastic deformation upon expansion to reinforce the base structure of the stent or alternatively may elastically expand to provide the reinforcement.

[0030] In one embodiment the at least one supporting feature undergoes deformation upon expansion and reinforces the base structure of the stent. Usually the at least one supporting feature increases the radial strength of the expanded stent by at least 15%, preferably by at least 50%, more preferably by at least 100% compared to the stent without the at least one supporting feature. In other embodiments the at least one supporting feature provides a stent which recoils after expansion by less than 15%, preferably by less than 7%, more preferably by less than 4%. In one instance, the at least one supporting feature provides a stent with recoil at least 28 days after expansion in a mammal of less than 20%, preferably less than 10%, more preferably less than 6%.

[0031] The supporting features will usually connect from strut to strut, but may alternatively or additionally from strut to crown, from strut to link, from link to link, from crown to crown, from crown to link, or from crown to same crown. Exemplary supporting features can contain varying types of

shapes such as C-shape, V-shape, U-shape, S-shape, Y-shape, M-shape, W-shape, Z-shape, spiral-shape or other types. These shapes may be continuous or discontinuous. At least one type of supporting feature per ring may be present.

[0032] The supporting feature thickness and/or width may be greater than, less than or approximately equal to the thickness of the adjacent expansion segment. In one embodiment the supporting feature thickness ranges from 0.125 mm (0.0005 in) to 2.5 mm (0.010 in), preferably 0.25 mm (0.001 in) to 1.25 mm (0.005 in), more preferably 0.5 mm (0.002 in) to 1 mm (0.004 in). In one embodiment the supporting feature width ranges from 0.125 mm (0.0005 in) to 2.5 mm (0.010 in), preferably 0.25 mm (0.001 in) to 1.25 mm (0.005 in), more preferably 0.5 mm (0.002 in) to 1 mm (0.004 in). In one embodiment the path length of the supporting feature ranges from 1.25 mm (0.005 in) to 25 mm (1 in), preferably 0.25 mm (0.010 in) to 0.75 mm (0.250 in), more preferably 0.5 mm (0.020 in) to 2.5 mm (0.100 in).

[0033] In one embodiment the angle at which the supporting feature connects to the expansion segment or link is approximately 90 degrees, but the angle may alternatively be less than 90 degrees or greater than 90 degrees. Usually, the angle at which the supporting feature connects to the axial strut or link ranges from 30 degrees to 150 degrees, preferably 45 to 135 degrees, more preferably 60 to 120 degrees.

[0034] The material of the supporting feature may be metallic, metal alloy, polymeric, composite, ceramic, or combination thereof, or other type of material, and can be of similar type as the expansion segment or link, or different type.

[0035] The increase in radial strength and/or reduction of recoil provided by these designs can be of particular benefit for biodegradable stents. The endoprosthesis designs and patterns are applicable to both biodegradable and non-biodegradable materials to provide an enhanced strength and/or increased elasticity. Exemplary biodegradable endoprosthesis materials include metallic, metallic alloy, polymeric, ceramic, composite, as well as other materials in combinations thereof. The yield strength for the biodegradable material(s) will usually be at least 50% of ultimate strength, preferably being at least 75% of ultimate strength, and more preferably being at least 90% of ultimate strength. For biodegradable polymeric stent materials, the yield strength can be measured in water at 37° C. The elastic modulus for biodegradable metallic stents will usually be at least 50 GPa, preferably being at least 100 GPa, and more preferably at least 150 GPa. The elastic modulus of biodegradable polymeric stents, in contrast, will be at least 0.5 GPa, preferably being at least 0.75 GPa, and more preferably being at least 1 GPa, measured in water at 37° C. Higher strain at yield may contribute to greater recoil of the stent. The yield strain for biodegradable polymeric stent materials will preferably be no more than 10% when measured in water at 37° C., preferably being no more than 5%, and more preferably being no more than 3%. The plastic strain for the biodegradable polymeric stent materials will preferably be at least 20%, more preferably being at least 30%, and still more preferably being at least 40%, when measured in water at 37° C., while the elastic recovery of the strained biodegradable polymeric stent material is at most 15%, preferably at most 10%, and more preferably at most 5%, when measured in water at 37° C.

[0036] The biodegradable stent materials may have a widely varying persistence. Usually, the material will substantially degrade within three years after implantation, more usually within one year, and still more usually within six months. When degrading under physiological conditions, such as vascular conditions, after one month the biodegradable stent will preferably retain at least 25% of the hoop strength, preferably maintaining at least 40%, and more preferably maintaining at least 70%.

[0037] The biodegradable polymeric stent materials may degrade by any of several known mechanisms, including bulk erosion, surface erosion, and combinations thereof. The biodegradable polymeric stent material usually degrades by at least one of hydrolytic degradation, enzymatic degradation, oxidative degradation, photo degradation, degradation under physiological environment or combination thereof.

[0038] Suitable the biodegradable polymeric stent material includes, but are not limited to, polyesters, polyanhydrides, polyamides, polyurethanes, poly(ester urethane), polyureas, polyethers, polyalkylene carbonates, polyacrylic acids, polyamines, polyester amides, polyester amines, polyvinylacetate, polyethylene imine, polycyanoacrylates, polyphosphazenes, polyphosphates, polyphosphonates, polyurethanes, polyureas, polysulfonates, polysulfonamides, polylactides, polyglycolides, regenerated cellulose, or biopolymers or blends, block polymers, copolymers or combinations thereof. Examples of these polymers include but are not limit to poly(L-lactic acid), poly(L/D-lactic acid), poly (L/DL-lactic acid), poly(glycolic acid), poly(lactide-co-glycolide), and copolymers and isomers, polydioxanone, poly (ethyl glutamate), poly(hydroxybutyrate), polyhydroxyvalerate and copolymer poly(3-hydroxy butyrate-co-hydroxy valerate), polycaprolactone, polyanhydride, poly(ortho esters); poly(ether esters), poly(trimethyl carbonate), Poly(L-lactic acid-co-trimethylene carbonate), Poly(L/D-lactic acid-co-trimethylene carbonate), Poly(L/DL-lactic acid-co-trimethylene carbonate), Poly(caprolactone-co-trimethylene carbonate), Poly(glycolic acid-co-trimethylene carbonate), Poly(glycolic acid-co-trimethylene carbonate-co-dioxanone), polyethylene carbonate, copolymers of polyethylene carbonate and poly(trimethylene carbonate), polypropylene carbonate, poly (iminocarbonates), poly(malic acid), modified poly(ethylene terephthalate), poly (butylene succinate), poly(butylene succinate adipate), poly (butylene succinate terephthalate), poly(butylene adipate-co-terephthalate), starch based polymers, hylaronic acid, oxidized or non-oxidized regenerated cellulose copolymers and other aliphatic polyesters, or suitable copolymers thereof. The biodegradable polymeric stent material in this invention can be homopolymers, copolymers, graft polymer, block polymers, polymers with special functional groups or end groups such as acidic or hydrophilic type or a blend of two or more homopolymers or copolymers.

[0039] The biodegradable polymeric stent material can have varying molecular architecture such as linear, branched, crosslinked, hyperbranched or dendritic. The biodegradable polymeric stent material in this invention can range from 10 KDa to 10,000 KDa in molecular weight, preferably from 100 KDa to 1000 KDa, more preferably 300 KDa to 600 KDa.

[0040] In certain embodiments, the biodegradable polymeric stent material incorporates at least one additive. The additives can affect strength, recoil, or degradation rate or combination thereof. Additives can also affect processing of biodegradable stent material, radiopacity or surface roughness or others. Additives can be biodegradable or non-biodegradable. The additives can be incorporated in to the biodegradable stent material by blending, extrusion, injection

moulding, coating, surface treatment, chemical treatment, mechanical treatment, stamping, or others or combinations thereof. The additives can be chemically modified prior to incorporation in to the biodegradable stent material.

[0041] In one embodiment, the weight percentage of the additives can range from 0.01% to 25%, preferably 0.1% to 10%, more preferably 1% to 5%. In one embodiment, the additive includes at least nanoclay, nanotubes, nanoparticles, exfoliates, fibers, whiskers, platelets, nanopowders, fullerenes, nanosperes, zeolites, polymers or others or combination thereof. Examples of nanoclay includes Montmorillonite, Smectites, Talc, or platelet-shaped particles or others or combination thereof. Clays can be intercalated or exfoliated. Example of clays include Cloisite NA, 93A, 30B, 25A, 15A, 10A or others or combination thereof. Examples of fibers include cellulose fibers such as Linen, cotton, rayon, acetate; proteins fibers such as wool or silk; plant fiber; glass fiber; carbon fiber; metallic fibers; ceramic fibers; absorbable fibers such as polyglycolic acid, polylactic acid, polyglyconate or others. Examples of whiskers include hydroxyapetite whiskers, tricalcium phosphate whiskers or others.

[0042] In another embodiment, the additives includes at least modified starch, soybean, hyaluronic acid, hydroxyapatite, tricarbonate phosphate, anionic and cationic surfactants such as sodium dococyl sulphate, triethylene benzylammonium chloride, pro-degradant such as D2W (from Symphony Plastic Technologies), photodegradative additives such as UV-H (from Willow Ridge Plastics), oxidative additives such as PDQ (from Willow Ridge Plastics), TDPA, family of polylactic acid and its random or block copolymers or others.

[0043] In another embodiment, the additive can induce degradation of non-degradable polymeric stent material. For example pro-degradant such as D2W (from Symphony Plastic Technologies), photodegradative additives such as UV-H (from Willow Ridge Plastics), oxidative additives such as PDQ (from Willow Ridge Plastics), TDPA or others or combination thereof can initiate degradation of non degradable stent materials such as polyethylene, polypropylene, polyethylene terephthalate or others. In still other embodiments, the additives include electroactive or electrolyte polymers, hydroscopic polymers, dessicants, or others. The additive may include an oxidizer such an acids, perchlorates, nitrates, permanganates, salts or other or combination thereof. The additive may include a monomer of the biodegradable polymeric stent material. For example glycolic acid is an additive to polyglycolic acid or its copolymer stent material. The additive may include water repellent monomers, oligomers or polymers such as bees wax, low MW polyethylene or others. In other embodiments, the additive can be water attractant monomers, oligomers or polymers such as polyvinyl alcohol, polyethylene oxide, glycerol, caffeine, lidocaine or other. In other embodiments, the additive can affect crystallinity of the biodegradable polymeric stent material. Example of additive of nanoclay to PLLA affects its crystallinity. In still other embodiments, the biodegradable polymeric stent material can have increased crystallinity upon exposure to radiation such as gamma or ebeam. The cumulative radiation dose can range from 1 Mrad to 100 Mrad, preferably 5 to 50 Mrad, more preferably 10 to 30 Mrad. The biodegradable stent material has increased crystallinity by increasing orientation of polymer chains with in the biodegradable stent material in radial and/or longitudinal direction by drawing, pressurizing and/or heating the stent material. In another embodiment, the drawing, pressurizing and/or heating the stent material occurs simultaneously or sequentially.

[0044] Specific methods for preparing biodegradable polymeric stents having the patterns disclosed herein are described in copending application Ser. No. 11/_____ (Attorney Docket No. 022265-000520US), filed on the same day as the present application, all disclosure of which is incorporated herein by reference.

[0045] In the present invention, the stent material may include pharmacological agents, such as immunomodulators, anti-cancer, anti-proliferative, anti-inflammatory, antithrombotic, antiplatelet, antifungal, antidiabetic, antihyperlipidimia, antiangiogenic, angiogenic, antihypertensive, healing promoting drugs, or other therapeutic classes of drugs or combination thereof. Illustrative immunomodulators agents include but are not limited to rapamycin, everolimus, ABT 578, AP20840, AP23841, AP23573, CCl-779, deuterated rapamycin, TAFA93, tacrolimus, cyclosporine, TKB662, myriocin, their analogues, pro-drug, metabolites, slats, or others or combination thereof.

[0046] Illustrative anticancer agents include acivicin, aclarubicin, acodazole, acronycine, adozelesin, alanosine, aldesleukin, allopurinol sodium, altretamine, aminoglutethimide, amonafide, ampligen, amsacrine, androgens, anguidine, aphidicolin glycinate, asaley, asparaginase, 5-azacitidine, azathioprine, *Bacillus* calmette-guerin (BCG), Baker's Antifol (soluble), beta-2'-deoxythioguanosine, bisantrene hcl, bleomycin sulfate, busulfan, buthionine sulfoximine, BWA 773U82, BW 502U83.HCl, BW 7U85 mesylate, ceracemide, carbetimer, carboplatin, carmustine, chlorambucil, chloroquinoxaline-sulfonamide, chlorozotocin, chromomycin A3, cisplatin, cladribine, corticosteroids, *Corynebacterium parvum*, CPT-11, crisnatol, cyclocytidine, cyclophosphamide, cytarabine, cytembena, dabis maleate, dacarbazine, dactinomycin, daunorubicin HCl, deazauridine, dexrazoxane, dianhydrogalactitol, diaziquone, dibromodulcitol, didemnin B, diethyldithiocarbamate, diglycoaldehyde, dihydro-5-azacytidine, doxorubicin, echinomycin, edatrexate, edelfosine, eflomithine, Elliott's solution, elsamitrucin, epirubicin, esorubicin, estramustine phosphate, estrogens, etanidazole, ethiofos, etoposide, fadrazole, fazarabine, fenretinide, filgrastim, finasteride, flavone acetic acid, floxuridine, fludarabine phosphate, 5-fluorouracil, Fluosol®, flutamide, gallium nitrate, gemcitabine, goserelin acetate, hepsulfam, hexamethylene bisacetamide, homoharringtonine, hydrazine sulfate, 4-hydroxyandrostenedione, hydrozyurea, idarubicin HCl, ifosfamide, interferon alfa, interferon beta, interferon gamma, interleukin-1 alpha and beta, interleukin-3, interleukin-4, interleukin-6,4-ipomeanol, iproplatin, isotretinoin, leucovorin calcium, leuprolide acetate, levamisole, liposomal daunorubicin, liposome encapsulated doxorubicin, lomustine, lonidamine, maytansine, mechlorethamine hydrochloride, melphalan, menogaril, merbarone, 6-mercaptopurine, mesna, methanol extraction residue of *Bacillus* calmette-guerin, methotrexate, N-methylformamide, mifepristone, mitoguazone, mitomycin-C, mitotane, mitoxantrone hydrochloride, monocyte/macrophage colony-stimulating factor, nabilone, nafoxidine, neocarzinostatin, octreotide acetate, ormaplatin, oxaliplatin, paclitaxel, pala, pentostatin, piperazinedione, pipobroman, pirarubicin, piritrexim, piroxantrone hydrochloride, PIXY-321, plicamycin, porfimer sodium, prednimustine, procarbazine, progestins, pyrazofurin, razoxane, sargramostim, semustine, spirogermanium, spiromustine, streptonigrin, streptozocin, sulofenur, suramin sodium,

tamoxifen, taxotere, tegafur, teniposide, terephthalamidine, teroxirone, thioguanine, thiotepa, thymidine injection, tiazofurin, topotecan, toremifene, tretinoin, trifluoperazine hydrochloride, trifluridine, trimetrexate, tumor necrosis factor, uracil mustard, vinblastine sulfate, vincristine sulfate, vindesine, vinorelbine, vinzolidine, Yoshi 864, zorubicin, QP-2, epothilone D, epothilone C Taxol, such as, paclitaxel, docetaxel, ABJ879, patupilone, MN-029, BMS247550, ecteinascidins such as ET-743, tetrahydroisoquinoline alkaloid, sirolimus, actinomycin, methotrexate, antiopeptin, vincristine, mitomycin, 2-chlorodeoxyadenosine or others, antifungal agents such as caspofungin, farnesylated dibenzodiazepinone, ECO-4601, fluconazole, or others, angiogenesis drugs such as follistatin, leptin, midkine, angiogenin, angiopoietin-1, becaplermin, Regranex, anti-angiogenesis drugs such as canstatin, angiostatin, endostatin, retinoids, tumistatin, vasculostatin, angioarrestin, vasostatin, bevacizumab, prinomastat, or others, antidiabetic drugs such as metformin, hypertension drugs such as candesartan, diovan, diltiazem, atenolol, adalat or others, anti-ischemia drugs such as ranolazine, isosorbide dinitrate, or others.

[0047] Illustrative antiinflammatory agents include classic non-steroidal anti-inflammatory drugs (NSAIDS), such as aspirin, diclofenac, indomethacin, sulindac, ketoprofen, flurbiprofen, ibuprofen, naproxen, piroxicam, tenoxicam, tolmetin, ketorolac, oxaprosin, mefenamic acid, fenoprofen, nambumetone (relafen), acetaminophen (Tylenol®), and mixtures thereof, COX-2 inhibitors, such as nimesulide, NS-398, flosulid, L-745337, celecoxib, rofecoxib, SC-57666, DuP-697, parecoxib sodium, JTE-522, valdecoxib, SC-58125, etoricoxib, RS-57067, L-748780, L-761066, APHS, etodolac, meloxicam, S-2474, and mixtures thereof, glucocorticoids, such as hydrocortisone, cortisone, prednisone, prednisolone, methylprednisolone, meprednisone, triamcinolone, paramethasone, fluprednisolone, betamethasone, dexamethasone, fludrocortisone, desoxycorticosterone, fluticasone propionate, piroxicam, celeoxib, mefenamic acid, tramadol, meloxicam, methyl prednisone, pseudopterosin, or others, hypercalcemia drugs such as zoledronic acid, alendronate or others, antithrombosis drugs like plavix, heparin, Arixtra and Fraxiparine or others or mixtures thereof.

[0048] Use of analogues, prodrugs, derivatives, precursors, fragments, salts, or other modifications or variations of pharmaceutical agents are all included.

[0049] Analogs, derivatives, prodrugs, salts, synthetic or biologic equivalents of these pharmaceutical agents can be released from the stents depending on the type of treatment needed, such as hyperproliferative diseases, stenosis, wound healing, cancer, aneurysm, diabetic disease, abdominal aortic aneurysm, angiogenesis, hypercalcemia, ischemia, fibrillation, arrhythmia or others.

[0050] The agents can be released from the implant using non-degradable, partially degradable, fully degradable coatings or a combination as disclosed in prior patent application which is referenced and incorporated in this application in its entirety. The agents can be incorporated as a matrix with the coating or applied on the stent and covered with the coating as a rate limiting barrier, or the drug agent directly coated onto the stent surface.

[0051] The solvent used to incorporate the agent and the coating on a stent can be an organic solvent such as dichloromethane, tetrahydrofuran, ethanol, or other solvents. In one embodiment, the solvent used to coat the agent and/or agent-polymer matrix does not affect the chemical or mechanical properties of the polymeric stent material.

[0052] In one embodiment, supercritical fluids such as supercritical carbon dioxide is used as a carrier solvent for the agent and/or the polymer and coats the stent with agent and/or agent-polymer matrix. The use of non-reactive gas such as carbon dioxide removes the need to use other organic solvents which can alter chemical and physical properties of the pharmacological agent.

[0053] In one embodiment the crystallinity of the pharmaceutical agent on the stent material is greater than 90%, preferably greater than 93%, more preferably greater than 95%.

[0054] In one embodiment, the pharmacological agent can be incorporated in the biodegradable polymeric stent material and extruded into stent tubing prior to laser cutting of the stent from the tubes. In another embodiment the agent is incorporated in a protective coating to prevent degradation of the agents during extrusion or laser cutting.

[0055] In one embodiment, the rate of agent release can be configured to be release at certain times and for certain durations corresponding to the degradation rate of the stent material or biological response events within the stent material environment. For example, an anti-inflammatory, antiproliferative, or immunomodulator drug or a combination of these can be made to release during the entire degradation period. Multiple drugs can be released to match the degradation rate of the coating and/or degradation rate of the implant. Antiplatelet or anti-thrombotic agents can be released in the initial phase and anti-inflammatory or antiproliferative or immunosuppressants can be released concurrently or at the later phase.

[0056] Referring now to FIGS. **2**A and **2**B, a stent **10** according to the present invention has the same base pattern as the stent illustrated in FIG. **1**, including a plurality of adjacent serpentine rings **12** joined by axial links **14**. As illustrated, the stent **10** includes six adjacent serpentine rings **12**, where each ring includes six serpentine segments comprising a pair of axial struts **16** joined by a hinge-like crown **18** at one end. The number of rings and segments may vary widely depending on the size of the desired size of the stent. According to the present invention, a supporting feature **20** is disposed between adjacent axial struts **16** and connected so that it will expand, usually elongate, circumferentially with the struts, as shown in FIG. **3**. The supporting features **20** are in a generally closed U-shaped configuration prior to expansion, as shown in FIGS. **2**A and **2**B, and open into a shallow V-shape along with the opening of the axial struts **16** about the crowns **18** during radial expansion of the serpentine rings **12**, as shown in FIG. **3**. Supporting features **20** enhance the hoop strength of the stent after radial expansion, help resist recoil after expansion is completed, and provide additional area for supporting the vascular or other luminal wall and optionally for delivering drugs into the luminal wall.

[0057] While U-shaped supporting feature **20** are illustrated in FIGS. **2**A and **2**B, a variety of other configurations may be utilized, as illustrated in FIGS. **4**-**17**. In FIG. **4**, V-shaped supporting features **22** are disposed between the adjacent axial struts **16**. The supporting features **24** of FIG. **5** are generally the same as those in FIG. **4**, except they are pointed in the opposite direction, i.e., away from the crowns **18** rather than toward the crowns. S-shaped connectors **26** are illustrated in FIG. **6**, while spiral-shaped connectors **28** are shown in FIG. **7**. FIG. **8** shows an alternative spiral-shaped

connector **30** having an open ring at its center, while FIG. **9** shows a similar supporting feature **32** having a disk at its center.

[0058] As shown thus far, the supporting features **20-32** have been connected to the adjacent axial struts **16** near the midpoints of said struts. Supporting features **34** may also be connected near the open ends of the axial struts **16**, as shown in FIG. **10**, or may be connected in pairs or in greater number, as shown in FIG. **11**. FIG. **12** illustrates a pair of connectors **34** joined near the midpoint, while FIG. **13** illustrates a complex supporting feature **40** joined between adjacent axial struts **16** at three points, two near the open end of the struts and a third on the inner side of the crown **18**.

[0059] Referring now to FIGS. **14**, **15**A and **15**B, the supporting features **42** may have deflection points **44** formed along their lengths in order to control expansion. For example, by placing notches **44** in the middle of the U-shaped connector **42**, the supporting features may be programmed to first open at the deflection points **44**, as illustrated in FIG. **15**A, and to later open at the crown of the connector, as shown in FIG. **15**B. Such programmed opening helps assure that the axial struts **16** may expand without being significantly hindered by the forces needed to expand the supporting features **42**.

[0060] Still further variations in the structure and positioning of the supporting features and axial links may be provided. As shown in FIG. **16**, the supporting features **50** may comprise N-shaped connectors while the axial links **52** may be angled relative to the axial direction of the endoprosthesis. Similarly, as shown in FIG. **17**, N-shaped supporting features **60** may be provided to join serpentine rings held together by angled axial links **62**.

[0061] Referring now to FIGS. **18** and **19**, the supporting features may also be connected between axial links **14** in the endoprostheses of the present invention. The supporting feature **70** has a generally serpentine configuration with a bent or folded portion extending into the region between adjacent axial struts **16**. The supporting feature **72** in the endoprosthesis of FIG. **19** is similar to **70**, except that the supporting feature includes a box region having a pair of projections **74** extending into the regions between adjacent axial struts **16**. In both cases, the supporting features **70** and **72** will both enhance the hoop strength of the serpentine ring after radial expansion, inhibit recoil, and provide an enhanced surface area for supporting tissue and delivering active agents.

[0062] While the above is a complete description of the preferred embodiments of the invention, various alternatives, modifications, and equivalents may be used. Therefore, the above description should not be taken as limiting the scope of the invention which is defined by the appended claims.

What is claimed is:

1. An endoprosthesis comprising:

a plurality of circumferentially expandable serpentine rings, each serpentine ring including axial struts joined by crowns, wherein the crowns act as hinges allowing the struts to spread as the ring opens circumferentially;

axial links joining at least some crowns on adjacent rings; and

supporting features extending between at least some adjacent struts of at least some of the serpentine rings, wherein the supporting features elongate and the struts remain substantially undeformed as the rings circumferentially expand.

2. An endoprosthesis as in claim **1**, at least partially comprising a biodegradable material.

3. An endoprosthesis as in claim **1**, at least partially comprising a metal.

4. An endoprosthesis as in claim **1**, wherein the serpentine rings are sufficiently elastic so that they can be constrained in a small cross-sectional area and released to assume a circumferentially expanded configuration.

5. An endoprosthesis as in claim **1**, wherein the serpentine rings are sufficiently malleable so that they can be circumferentially expanded by applying a radially outward force from within the ring.

6. An endoprosthesis as in claim **1**, wherein the supporting feature comprises a U-shaped connector.

7. An endoprosthesis as in claim **1**, wherein the supporting feature comprises a V-shaped connector.

8. An endoprosthesis as in claim **1**, wherein the supporting feature comprises an S-shaped connector.

9. An endoprosthesis as in claim **1**, wherein the supporting feature comprises a spiral-shaped connector.

10. An endoprosthesis as in claim **9**, wherein the spiral-shaped connector has a ring core.

11. An endoprosthesis as in claim **9**, wherein the spiral-shaped connector has a disk core.

12. An endoprosthesis as in claim **1**, wherein the supporting feature comprises a W-shaped connector.

13. An endoprosthesis as in claim **1**, wherein the supporting feature comprises an N-shaped connector.

14. An endoprosthesis as in claim **1**, further comprising at least one additional supporting feature extending between at least some of the adjacent struts.

15. An endoprosthesis as in claim **1**, wherein the supporting features extend between midpoints on the adjacent struts.

16. An endoprosthesis as in claim **1**, wherein the supporting features extend between points near the crowns on the adjacent struts.

17. An endoprosthesis as in claim **1**, wherein said supporting features extend between two points on adjacent axial struts and one point on the crown which joins the struts.

18. An endoprosthesis as in claim **1**, wherein said supporting features have a cross-sectional area which is less than the cross-sectional area of the axial struts.

19. An endoprosthesis as in claim **1**, wherein at least some of the supporting features have deflection points which preferentially yield when the serpentine rings is circumferentially expanded.

20. An endoprosthesis as in claim **19**, wherein the deflection points comprise notches.

21. An endoprosthesis as in claim **1**, wherein the axial links comprise linear beams.

22. An endoprosthesis as in claim **21**, wherein the linear beams are aligned axially.

23. An endoprosthesis as in claim **21**, wherein the linear beams are aligned at an angle relative to the axis.

24. An endoprosthesis comprising:

a plurality of circumferentially expandable serpentine rings, each serpentine ring including axial struts joined by crowns, wherein the crowns act as hinges allowing the struts to spread as the ring opens circumferentially;

axial links joining at least some crowns on adjacent rings; and

supporting features extending between at least some adjacent axial links between adjacent serpentine rings, wherein the supporting features elongate as the rings circumferentially expand.

25. An endoprosthesis as in claim **24**, wherein the supporting feature comprises a serpentine connector.

26. An endoprosthesis as in claim **24**, wherein the supporting feature comprises a box connector.

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