US 20150313731A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2015/0313731 A1**

(43) **Pub. Date: Nov. 5, 2015**

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(54) **ARTIFICIAL BLOOD VESSEL USING DECELLULARIZED BLOOD VESSEL SHEET**

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(21) Appl. No.: **14/650,051**

(22) PCT Filed: **Dec. 17, 2013**

(86) PCT No.: **PCT/JP2013/083749**

§ 371 (c)(1),
(2) Date: **Jun. 5, 2015**

(30) **Foreign Application Priority Data**

Jan. 8, 2013 (JP) 2013-001033

Publication Classification

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

(52) **U.S. Cl.**
CPC ***A61F 2/82*** (2013.01); *A61F 2230/0069* (2013.01); *A61F 2240/002* (2013.01)

(57) **ABSTRACT**

An artificial blood vessel that can be transplanted to blood vessels with a small diameter, can be adjusted to an arbitrary size of a diameter, improves in invasiveness when a graft is taken, and overcomes the problem on the provision of a graft is provided. An artificial blood vessel prepared from a decellularized tubular structure, which is prepared by processing a decellularized, sheet-like blood vessel (decellularized blood vessel sheet) into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

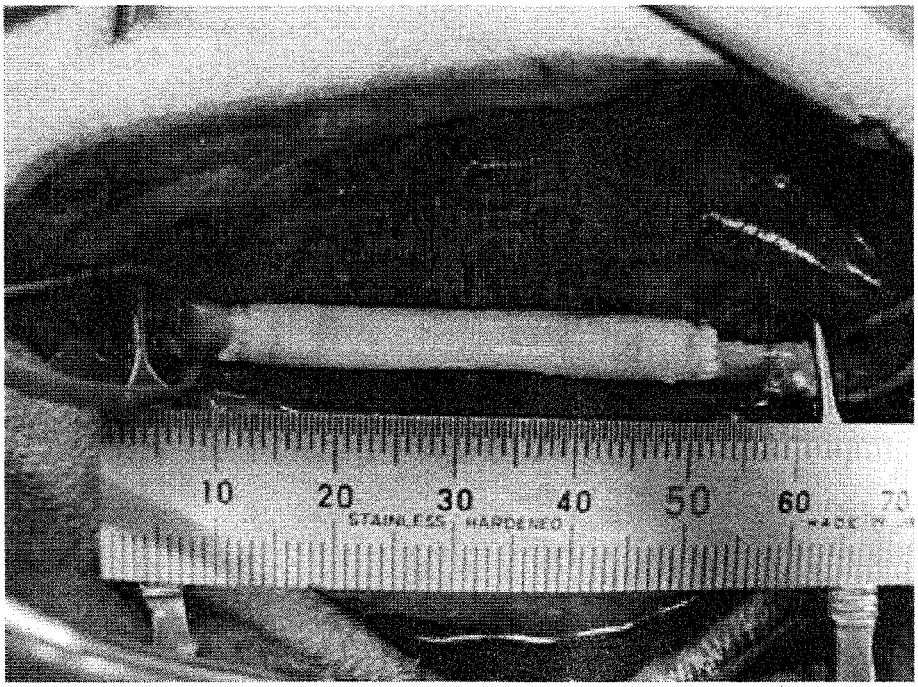


Fig. 1

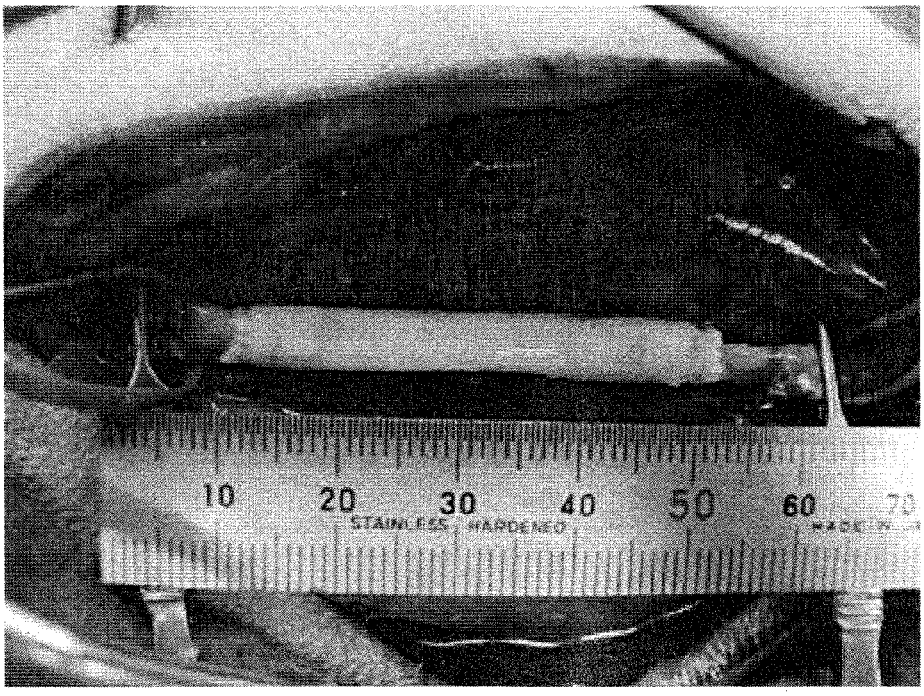
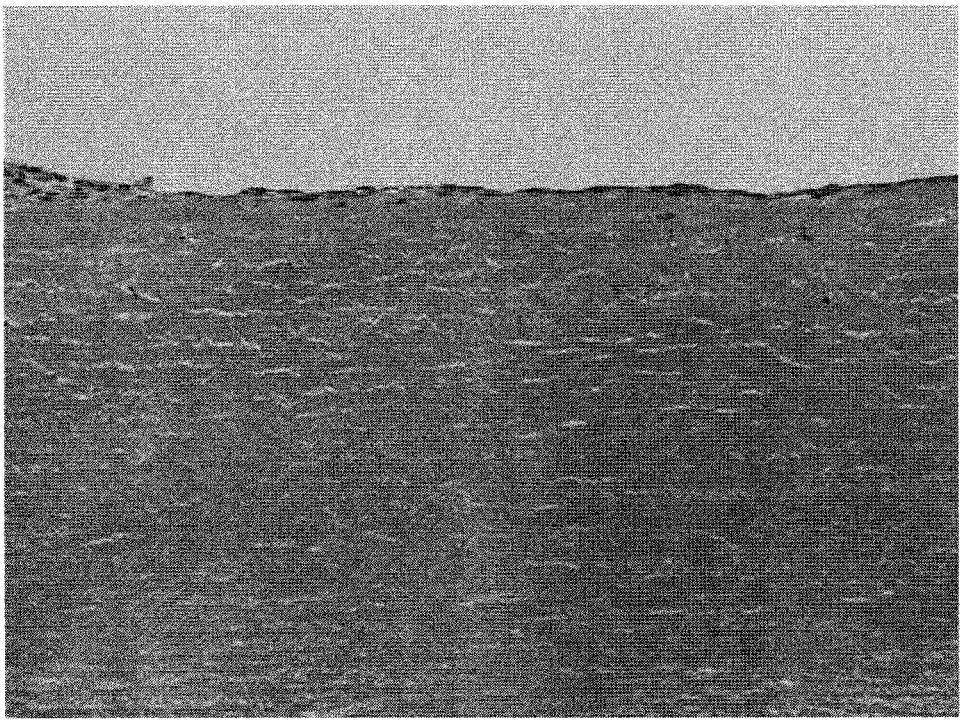


Fig. 2



ARTIFICIAL BLOOD VESSEL USING DECELLULARIZED BLOOD VESSEL SHEET

TECHNICAL FIELD

[0001] The present invention relates to an artificial blood vessel for use in graft of a blood vessel and a process for preparing the same.

BACKGROUND ART

[0002] For atherosclerosis of coronary arteries and peripheral blood vessels, therapy by surgical replacement or bypass surgery is performed. For affected parts with a diameter of 5 mm or less, an autologous blood vessel is a preferable graft for replacement wherein the most frequently used grafts are autologous internal mammary artery, radial artery and saphenous vein, which are known to have a good patency rate. However, there are problems such as unavoidable invasion for obtaining a graft, variability of its length or quality depending on each case, and unavailability of a graft in reoperation cases where a graft has already been used.

[0003] On the other hand, an artificial blood vessel such as Dacron and ePTFE has been used for revascularization of peripheral arteries of limbs but cannot be used in blood vessels with a small diameter such as coronary arteries due to early formation of thrombus and hypertrophy of the tunica intima. In recent years, it has become possible to coat the lumen of an artificial blood vessel with vascular endothelial cells by seeding the cells within the artificial blood vessel with a tissue engineering technique to thereby prevent blood coagulation. However, before surgery, the bone marrow must be taken from patients, cultivated and engrafted to an artificial blood vessel, which takes time and is costly. In particular, in cases of urgency such as coronary artery bypass, its utility is low.

DISCLOSURE OF THE INVENTION

Technical Problem to be Solved by the Invention

[0004] The problem to be solved by the present invention is to provide an artificial blood vessel that can be transplanted to blood vessels with a small diameter, can be adjusted to an arbitrary size of a diameter, improves in invasiveness when a graft is taken, and overcomes the problem on the provision of a graft.

Means for Solving the Problems

[0005] The present inventors have earnestly studied in order to solve the aforementioned problems and as a result have found that an artificial blood vessel prepared by treating a decellularized blood vessel sheet so that a portion which is contacted with blood that flows consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media after removal of the tissue of the tunica intima, said decellularized blood vessel sheet being prepared either by processing a blood vessel from animals into a sheet followed by decellularization or by decellularizing a blood vessel from animals followed by processing the same into a sheet, and processing the decellularized blood vessel sheet into a roll structure with a tissue adhesive has an excellent pressure resistance and patency after grafting. Thereby the present invention has been completed.

[0006] Thus, the present invention may include an artificial blood vessel prepared from a decellularized tubular structure, which is prepared by processing a decellularized, sheet-like blood vessel (decellularized blood vessel sheet) into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

[0007] In addition, the present invention includes a process for preparing an artificial blood vessel comprising the steps (1) to (5) as follows:

(1) a step of preparing a decellularized blood vessel sheet of either (A) or (B):

[0008] (A) a step of processing a blood vessel from animals into a sheet to prepare a blood vessel sheet and a step of decellularizing the blood vessel sheet to prepare a decellularized blood vessel sheet, or

[0009] (B) a step of decellularizing a blood vessel from animals to prepare a decellularized blood vessel and a step of processing the decellularized blood vessel into a sheet to prepare a decellularized blood vessel sheet,

(2) a step of treating the decellularized blood vessel sheet so that a portion which is contacted with blood that flows within the artificial blood vessel when the sheet is processed into a roll structure consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media with the tissue of the tunica intima being removed,

(3) a step of applying a tissue adhesive to the overlap width of the decellularized blood vessel sheet,

(4) a step of processing the decellularized blood vessel sheet into a roll structure and pasting the overlap width together to prepare an artificial blood vessel, and

(5) a step of coating the circumferential surface of the resulting artificial blood vessel with a tissue adhesive.

[0010] Also, the present invention may include a kit for an artificial blood vessel comprising a decellularized blood vessel sheet or a decellularized tubular structure, which is prepared by processing the decellularized blood vessel sheet into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

Effects of the Invention

[0011] In accordance with the present invention, (1) it becomes possible to prepare an artificial blood vessel of a small diameter that can be transplanted to blood vessels with a small diameter; (2) it is possible to prepare a blood vessel of various diameters from the decellularized blood vessel sheet to thereby allow for preparing an artificial blood vessel fitted to blood vessels at the site of grafting; (3) in case that a blood vessel from heterologous animals is used, the problem on the provision of a graft or invasiveness into other tissues than affected parts are remedied; (4) even if a blood vessel from heterologous animals is used, the immunological rejection does not occur or is highly reduced since a scaffold is decel-

lularized; and (5) after grafting, the lumen is covered with the endothelium and the autologous tissue is taken into the scaffold to thereby provide an artificial blood vessel which has patency for a long period of time and is ideal close to an autologous blood vessel.

BRIEF DESCRIPTION OF DRAWINGS

[0012] FIG. **1** is a photograph of the artificial blood vessel of the present invention when grafted.

[0013] FIG. **2** is a photograph of the tissue of the vascular wall of the artificial blood vessel of the present invention three weeks after grafting.

BEST MODE FOR CARRYING OUT THE INVENTION

[0014] The present invention may include an artificial blood vessel prepared from a decellularized tubular structure, which is prepared by processing a decellularized, sheet-like blood vessel (decellularized blood vessel sheet) into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

[0015] As used herein, the tissue of the tunica media is a laminar tissue rich in the elastic lamina present under the tunica intima.

[0016] As used herein, the tissue of the tunica intima is a tissue consisting of the supporting tissue (basement membrane) of endothelial cells and mainly collagen fiber.

[0017] As used herein, a tissue adhesive is used for maintaining the shape of the artificial blood vessel and includes fibrin glue, a cyanoacrylate polymerizable adhesive and gelatin glue where gelatin and resorcinol are cross-linked with formalin. The use of fibrin glue as a tissue adhesive is particularly preferable.

[0018] When fibrin glue is used as a tissue adhesive, it is preferable for improving the pressure resistance of the artificial blood vessel of the present invention that, after fibrinogen is rubbed to an overlap width, thrombin and fibrinogen are applied.

[0019] The artificial blood vessel of the present invention may preferably be such that, when fibrin glue is used as a tissue adhesive, thrombin is applied at 1 U/mL to 160 U/mL.

[0020] The artificial blood vessel of the present invention may preferably be such that, when fibrin glue is used as a tissue adhesive, fibrinogen is applied at 4 mg/mL to 250 mg/mL.

[0021] The artificial blood vessel of the present invention may be prepared such that its size of an inner diameter may suitably be selected depending on a size of blood vessels at the grafting site. For instance, the artificial blood vessel with an inner diameter of about 1 mm to about 20 mm is selected.

[0022] The decellularized blood vessel sheet of the present invention may preferably be the one prepared by processing a blood vessel from animals into a sheet followed by decellularization or the one prepared by decellularizing a blood vessel from animals followed by processing into a sheet.

[0023] As used herein, blood vessels are preferably selected from arteries or veins. In particular, arteries may preferably be selected from the group consisting of the aorta, the carotid, the internal mammary artery, the radial artery and the gastro-epiploic artery.

[0024] The artificial blood vessel of the present invention may be such that a tissue adhesive is coated on its circumferential surface since the artificial blood vessel exerts the effect of improved pressure resistance and reduced tissue adhesion when the circumferential surface of the artificial blood vessel is coated with a tissue adhesive.

[0025] The pressure resistance of the artificial blood vessel of the present invention may suitably be altered depending on the grafting site and preferably is 400 mmHg or more.

[0026] The present invention includes a process for preparing an artificial blood vessel comprising the steps (1) to (5) as follows:

(1) a step of preparing a decellularized blood vessel sheet of either (A) or (B):

[0027] (A) a step of processing a blood vessel from animals into a sheet to prepare a blood vessel sheet and a step of decellularizing the blood vessel sheet to prepare a decellularized blood vessel sheet, or

[0028] (B) a step of decellularizing a blood vessel from animals to prepare a decellularized blood vessel and a step of processing the decellularized blood vessel into a sheet to prepare a decellularized blood vessel sheet,

(2) a step of treating the decellularized blood vessel sheet so that a portion which is contacted with blood that flows within the artificial blood vessel when the sheet is processed into a roll structure consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media with the tissue of the tunica intima being removed,

(3) a step of applying a tissue adhesive to the overlap width of the decellularized blood vessel sheet,

(4) a step of processing the decellularized blood vessel sheet into a roll structure and pasting the overlap width together to prepare an artificial blood vessel, and

(5) a step of coating the circumferential surface of the resulting artificial blood vessel with a tissue adhesive.

[0029] When fibrin glue is used as a tissue adhesive, the process for preparing the artificial blood vessel of the present invention preferably includes in step (3) a step of rubbing fibrinogen to an overlap width and a step of applying thrombin and fibrinogen to the overlap width.

[0030] The process for preparing the artificial blood vessel of the present invention may be such that the decellularization is selected from the group consisting of high hydrostatic pressure, a surfactant, an enzyme, hypertonic solution/hypotonic solution, and freeze-thawing.

[0031] The process for preparing the artificial blood vessel of the present invention may be such that the decellularization is the one where the structure of the basement membrane is maintained after decellularization.

[0032] The process for preparing the artificial blood vessel of the present invention may preferably further include a step of treating with DNase and/or a step of treating with an alcohol.

[0033] The present invention may include a kit for an artificial blood vessel comprising a decellularized blood vessel sheet or a decellularized tubular structure, which is prepared by processing the decellularized blood vessel sheet into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood

vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

[0034] The present invention is further explained in more detail by means of the following Examples but is not limited thereto.

Example 1

Preparation of Artificial Blood Vessel with Small Diameter with BOLHEAL and Decellularized Artery Sheet and Pressure Resistance Test

(1) Test Method

[0035] The swine aorta was made into a sheet. The tunica adventitia was peeled off overall and the tunica intima was peeled off in a range of ½ to ⅔. The sheet was treated under a high hydrostatic pressure and washed with a DNase solution for 7 days, with an alcohol for 3 days, and with a citrate buffer for 3 days. Water was wiped off from the surface of the decellularized swine aorta sheet as prepared. To the surface where the tunica intima was peeled off (the surface where the tunica media tissue was exposed), a fibrinogen solution (BOLHEAL) was rubbed and after 3 minutes a mixture of the fibrinogen solution and a 10-fold diluted thrombin solution (BOLHEAL) was applied. Using this surface as an overlap width, the sheet was crimped for 5 minutes into a roll structure wherein only the tunica intima tissue was exposed on the surface of the lumen of the artificial blood vessel the outside of which was covered with the tunica media tissue to form a double structure. The lumen was washed with a saline. To the circumference of the artificial blood vessel were sprayed a fibrinogen solution and a thrombin solution. The artificial blood vessel was immersed in a saline supplemented with 100 unit/mL of heparin sodium and was subject to sterilization under a high pressure. One end of the artificial blood vessel as prepared was clamped with a forceps and the other end was inserted with a cannula and ligated. To the cannula were connected a syringe and a manometer. A saline in the syringe was introduced into the lumen of the artificial blood vessel and a pressure at which the artificial blood vessel was ruptured was measured as pressure resistance.

(2) Results; Pressure Resistance

[0036] Pressure resistance of 375±61.2 mmHg was obtained (n=4).

Example 2

Graft Test in Goat of Artificial Blood Vessel with Small Diameter with BOLHEAL and Decellularized Artery Sheet

(1) Test Method

[0037] The right carotid of goat was exposed and partly removed under anesthesia and replaced with the artificial blood vessel prepared as in Example 1 (inner diameter: about 4 mm, length: about 5 cm) by anastomosis. To the anastomosed part was rubbed a fibrinogen solution and then were sprayed a fibrinogen solution and a thrombin solution. While treatment, a 5% glucose solution supplemented with heparin sodium was administered via instillation. Three minutes before clamping the carotid, 300 unit/kg of heparin sodium was administered intravenously in a single dose. No postoperative anticoagulant treatment was done. Three weeks after the treatment, the animal was subject to euthanasia and the treated part was sampled for pathological examination.

(2) Results

[0038] Autopsy: All the artificial blood vessels were in patency. The lumen showed a smooth surface with no sign of thrombus, obstruction or aneurysmal dilatation.
Pathological tissue examination: A layer of endothelial cells was observed in the lumen of the artificial blood vessel (FIG. **2**). The autologous tissue penetrated the vascular wall of the artificial blood vessel accompanied by capillary angiogenesis therein to form an autologous blood vessel-like structure.

INDUSTRIAL APPLICABILITY

[0039] The artificial blood vessel of the present invention can be used e.g. for the manufacture of material of medical application.

1. An artificial blood vessel prepared from a decellularized tubular structure, which is prepared by processing a decellularized, sheet-like blood vessel (decellularized blood vessel sheet) into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

2. The artificial blood vessel according to claim **1** wherein the tissue adhesive is fibrin glue.

3. The artificial blood vessel according to claim **1** wherein, after fibrinogen is rubbed to an overlap width, thrombin and fibrinogen are applied.

4. The artificial blood vessel according to claim **1** wherein thrombin is applied at 1 U/mL to 160 U/mL.

5. The artificial blood vessel according to claim **1** wherein fibrinogen is applied at 4 mg/mL to 250 mg/mL.

6. The artificial blood vessel according to claim **1** wherein the inner diameter of the artificial blood vessel is about 1 mm to about 20 mm.

7. The artificial blood vessel according to claim **1** wherein the decellularized blood vessel sheet is the one prepared by processing a blood vessel from animals into a sheet followed by decellularization or the one prepared by decellularizing a blood vessel from animals followed by processing into a sheet.

8. The artificial blood vessel according to claim **1** wherein the blood vessel is selected from arteries or veins.

9. The artificial blood vessel according to claim **8** wherein the blood vessel is selected from the group consisting of the aorta, the carotid, the internal mammary artery, the radial artery and the gastro-epiploic artery.

10. The artificial blood vessel according to claim **1** wherein the tissue adhesive is coated on the circumferential surface of the artificial blood vessel.

11. The artificial blood vessel according to claim **1** wherein the pressure resistance is 400 mmHg or more.

12. A process for preparing an artificial blood vessel comprising the steps (1) to (5) as follows:

(1) a step of preparing a decellularized blood vessel sheet of either (A) or (B):
(A) a step of processing a blood vessel from animals into a sheet to prepare a blood vessel sheet and a step of decellularizing the blood vessel sheet to prepare a decellularized blood vessel sheet, or
(B) a step of decellularizing a blood vessel from animals to prepare a decellularized blood vessel and a step of processing the decellularized blood vessel into a sheet to prepare a decellularized blood vessel sheet,
(2) a step of treating the decellularized blood vessel sheet so that a portion which is contacted with blood that flows within the artificial blood vessel when the sheet is processed into a roll structure consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media with the tissue of the tunica intima being removed,
(3) a step of applying a tissue adhesive to the overlap width of the decellularized blood vessel sheet,
(4) a step of processing the decellularized blood vessel sheet into a roll structure and pasting the overlap width together to prepare an artificial blood vessel, and
(5) a step of coating the circumferential surface of the resulting artificial blood vessel with a tissue adhesive.

13. The process according to claim **12** wherein the tissue adhesive is fibrin glue.

14. The process according to claim **12** wherein step (3) further includes a step of rubbing fibrinogen to an overlap width and a step of applying thrombin and fibrinogen to the overlap width.

15. The process according to claim **12** wherein thrombin is applied at 1 U/mL to 160 U/mL.

16. The process according to claim **12** wherein fibrinogen is applied at 4 mg/mL to 250 mg/mL.

17. The process according to claim **12** wherein the inner diameter of the artificial blood vessel is about 1 mm to about 20 mm.

18. The process according to claim **12** wherein the blood vessel is selected from arteries or veins.

19. The process according to claim **18** wherein the blood vessel is selected from the group consisting of the aorta, the carotid, the internal mammary artery, the radial artery and the gastro-epiploic artery.

20. The process according to claim **12** wherein the decellularization is selected from the group consisting of high hydrostatic pressure, a surfactant, an enzyme, hypertonic solution/hypotonic solution, and freeze-thawing.

21. The process according to claim **12** wherein the decellularization is the one where the structure of the basement membrane is maintained after decellularization.

22. The process according to claim **12** which further includes a step of treating with DNase and/or a step of treating with an alcohol.

23. The process according to claim **12** wherein the pressure resistance is 400 mmHg or more.

24. A kit for an artificial blood vessel comprising a decellularized blood vessel sheet or a decellularized tubular structure, which is prepared by processing the decellularized blood vessel sheet into a roll structure, and a tissue adhesive, wherein a portion which is contacted with blood that flows within the artificial blood vessel consists of the tissue of the tunica intima lined with the tissue of the tunica media whereas a portion of the sheet that overlaps when the sheet is processed into a roll structure (overlap width) consists of the tissue of the tunica media and wherein a tissue adhesive is applied to the overlap width.

25. The kit according to claim **24** wherein the tissue adhesive is fibrin glue.

26. The kit according to claim **24** wherein, after fibrinogen is rubbed to an overlap width, thrombin and fibrinogen are applied.

27. The kit according to claim **24** wherein thrombin is applied at 1 U/mL to 160 U/mL.

28. The kit according to claim **24** wherein fibrinogen is applied at 4 mg/mL to 250 mg/mL.

29. The kit according to claim **24** wherein the inner diameter of the artificial blood vessel is about 1 mm to about 20 mm.

30. The kit according to claim **24** wherein the decellularized blood vessel sheet is the one prepared by processing a blood vessel from animals into a sheet followed by decellularization or the one prepared by decellularizing a blood vessel from animals followed by processing into a sheet.

31. The kit according to claim **24** wherein the blood vessel is selected from arteries or veins.

32. The kit according to claim **31** wherein the blood vessel is selected from the group consisting of the aorta, the carotid, the internal mammary artery, the radial artery and the gastro-epiploic artery.

33. The kit according to claim **24** wherein the tissue adhesive is coated on the circumferential surface of the artificial blood vessel.

34. The kit according to claim **24** wherein the pressure resistance is 400 mmHg or more.

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