

Description

HYDROPHILIC COPOLYMER AND MEDICAL DEVICE

Technical Field

[0001]

The present invention relates to a hydrophilic copolymer and a medical device having a surface lubricious layer containing the hydrophilic copolymer.

Background Art

[0002]

In recent years, diameters of catheters have been progressively reduced for accessing peripheral lesions. This leads to a significant decrease of the clearance between a catheter and the interior surface of a lumen in a living body to cause high frictional resistance on the surface of the catheter. Thus, there is a need for a coating for imparting lubricating property and durability (lubrication retaining property) to a surface of a catheter.

[0003]

In addition, when a coating is applied on a substrate of a catheter or the like, a solvent having low toxicity, such as water, an alcohol, or a water/alcohol mixed solvent, has to be selected as the solvent thereof in terms of compatibility

with biological materials and safety of the operator. Thus, the components of the coating are required to dissolve or disperse in such solvents (to have solvent solubility).

[0004]

ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498 (NPL 1) discloses as a surface modifier for biological materials a copolymer of 2-methacryloyloxyethyl phosphorylcholine (MPC) which is a polymerizable monomer having a phosphobetaine structure and 4-methacryloyloxybenzophenone (MBP) which is a polymerizable monomer having a photoreactive group.

Summary of Invention

[0005]

However, a surface lubricious layer containing the copolymer described in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498 cannot exhibit sufficient lubricating property and durability (lubrication retaining property).

[0006]

Accordingly, an object of the present invention is to provide a hydrophilic copolymer that can form a surface lubricious layer exhibiting superior lubricating property and durability (lubrication retaining property). Another object of the present invention is to provide a hydrophilic copolymer having good solvent solubility.

[0007]

The present inventors have made intensive and extensive studies for solving the above problems. As a result, they have found that the above objects can be achieved by a hydrophilic copolymer containing: structural units derived from a polymerizable monomer (A) having a sulfobetaine structure; structural units derived from a polymerizable monomer (B) having at least one group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof; and structural units derived from a polymerizable monomer (C) having a photoreactive group, completing the present invention.

Brief Description of Drawings

[0008]

Fig. 1 is a partial cross sectional view schematically illustrating a surface lamination structure of a typical embodiment of the medical device according to the present invention. In Fig. 1, 1 denotes a substrate layer, 2 denotes a surface lubricious layer, and 10 denotes a medical device (also referred to as "medical device").

Fig. 2 is a partial cross sectional view schematically illustrating a different configuration example of the surface lamination structure as an application of the embodiment of

Fig. 1. In Fig. 2, 1 denotes a substrate layer, 1a denotes a substrate layer core, 1b denotes a substrate surface layer, 2 denotes a surface lubricious layer, and 10 denotes a medical device.

Fig. 3 is a schematic diagram of a lubricating property and durability testing device (friction meter) used in Example 1-2 and Comparative Example 9-2. In Fig. 3, 12 denotes a petri dish, 13 denotes an HDPE terminal, 14 denotes a load, 15 denotes a moving table, 16 denotes an HDPE sheet (sample), 17 denotes water, and 20 denotes a friction meter.

Fig. 4 is a figure showing results of the lubricating property and durability test in Example 1-2 and Comparative Example 9-2.

Fig. 5 is a figure showing results of the lubricating property and durability test in Example 3-2, Example 5-2, Example 7-2, and Comparative Example 10-2.

Description of Embodiments

[0009]

An embodiment of the present invention will be described in detail below. Note that the present invention is not limited only to the embodiment. As used herein, "X to Y" which represents a range includes X and Y, that is, the phrase means "X or more and Y or less". Unless otherwise specified, operations and measurements of physical properties and the like

are made under conditions at room temperature (20 to 25°C) and a relative humidity of 40 to 60%.

[0010]

As used herein, the term "(meth)acryl" includes both of acryl and methacryl. Thus, for example, the term "(meth)acrylic acid" includes both of acrylic acid and methacrylic acid. Similarly, the "(meth)acryloyl" includes both of acryloyl and methacryloyl. Thus, for example, the term "(meth)acryloyl group" includes both of acryloyl group and methacryloyl group.

[0011]

Unless otherwise defined, the term "substituted", as used herein, refers to being substituted by a C1-C30 alkyl group, a C2-C30 alkenyl group, a C2-C30 alkynyl group, a C1-C30 alkoxy group, and alkoxycarbonyl group (-COOR, R is a C1-C30 alkyl group), a halogen atom (F, Cl, Br, or I atom), a C6-C30 aryl group, a C6-C30 aryloxy group, an amino group, a C1-C30 alkylamino group, a cyano group, a nitro group, a thiol group, a C1-C30 alkylthio group, or a hydroxyl group. Note that the substitution form in which a substituted structure after a group is substituted is further included in the definition before the substitution is excluded. For example, when an alkyl group is a substituent, the alkyl group as the substituent is not further substituted by another alkyl group.

[0012]

As used herein, the phrase "a structural unit is "derived from" a monomer" means that the structural unit is a divalent structural unit produced by cutting one bond of a polymerizable unsaturated double bond in the corresponding monomer.

[0013]

<Hydrophilic copolymer>

The hydrophilic copolymer according to the present invention is characterized by containing: structural units derived from a polymerizable monomer (A) having a sulfobetaine structure (hereinafter also referred to as "monomer A"); structural units derived from a polymerizable monomer (B) having at least one group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof (hereinafter also referred to as "monomer B"); and structural units derived from a polymerizable monomer (C) having a photoreactive group (hereinafter referred to as "monomer C"). The hydrophilic copolymer can form a surface lubricious layer exhibiting superior lubricating property and durability (lubrication retaining property). In addition, the hydrophilic copolymer has good solvent solubility. The mechanism of causing the effects has not been completely elucidated, but is supposed as follows.

[0014]

The photoreactive group contained in a structural unit

derived from the monomer C produces a reactive species by irradiation with an active energy ray, and reacts with a substrate layer surface to form a chemical bond. Thus, a surface lubricious layer containing the hydrophilic copolymer according to the present invention is strongly fixed on a substrate layer, thereby exhibiting superior durability (lubrication retaining property).

[0015]

In addition, the sulfobetaine structure contained in a structural unit derived from the monomer A is superior in lubricating property imparting effect as compared with other betaine structures, such as a phosphobetaine structure. Thus, a surface lubricious layer containing the hydrophilic copolymer according to the present invention (Example 1-2) can exhibit superior lubricating property as compared with a surface lubricious layer containing the copolymer described in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498 (Comparative Example 9-2) (Fig. 4). Homopolymers from monomers having a phosphobetaine structure are known to be soluble in water, whereas a study of the present inventors has revealed that homopolymers from the monomer A are soluble in aqueous NaCl solutions but do not or hardly dissolve in water and lower alcohols. The difference in the water solubility suggests a possibility of higher electrostatic interaction of sulfobetaine structures than that of phosphobetaine

structures. Thus, a strong cohesive force is caused inside a surface lubricious layer containing the hydrophilic copolymer according to the present invention. This results in enhancement of the strength of the surface lubricious layer so that the surface lubricious layer is hardly peeled and can maintain initial lubricating property even after repetitive slides. Accordingly, a surface lubricious layer containing the hydrophilic copolymer according to the present invention (Example 1-2) can also exhibit superior durability (lubrication retaining property) as compared with a surface lubricious layer containing the copolymer described in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498 (Comparative Example 9-2) (Fig. 4).

[0016]

However, the present inventors encountered the problem in that copolymers of the monomer A and the monomer C (in particular, a monomer having a benzophenone group) do not or hardly dissolve or disperse in various solvents, such as water, aqueous NaCl solutions, lower alcohols, and water/lower alcohols (that is, has extremely low solvent solubility) and therefore are difficult to apply to coatings. Regarding this problem, with an assumption that the problem may be caused by both the electrostatic interaction between the sulfobetaine structures and the hydrophobic interaction between the photoreactive groups simultaneously occurring between polymer

molecules, the present inventors focused on the monomer B as a third copolymerization component. A sulfonic acid group, a sulfuric acid group, a sulfurous acid group, or a group of a salt thereof contained in the structural unit derived from the monomer B is easily anionized in aqueous solvents. This causes electrostatic repulsion between polymer molecules to reduce the aforementioned interactions so that the polymer becomes likely to dissolve or disperse in aqueous solvents. Thus, the hydrophilic copolymer according to the present invention has superior solvent solubility. The effect of enhancing solvent solubility given by the monomer B is especially notable when the photoreactive group in the monomer C is a benzophenone group. A benzophenone group has plural aromatic rings and therefore is likely to associate due to the π - π interaction. Thus, a polymer containing a benzophenone group easily aggregates to become insoluble. Thus, when structural units derived from the monomer B are incorporated, electrostatic repulsion occurs as described above to suppress the association of benzophenone groups, thereby dramatically increasing solubility or dispersibility of the polymer.

[0017]

Note that the above mechanism is merely an assumption, and the present invention is not limited to the assumption.

[0018]

Polymerizable monomers constituting the hydrophilic

copolymer according to the present invention will be described below.

[0019]

[Polymerizable monomers]

(Monomer A)

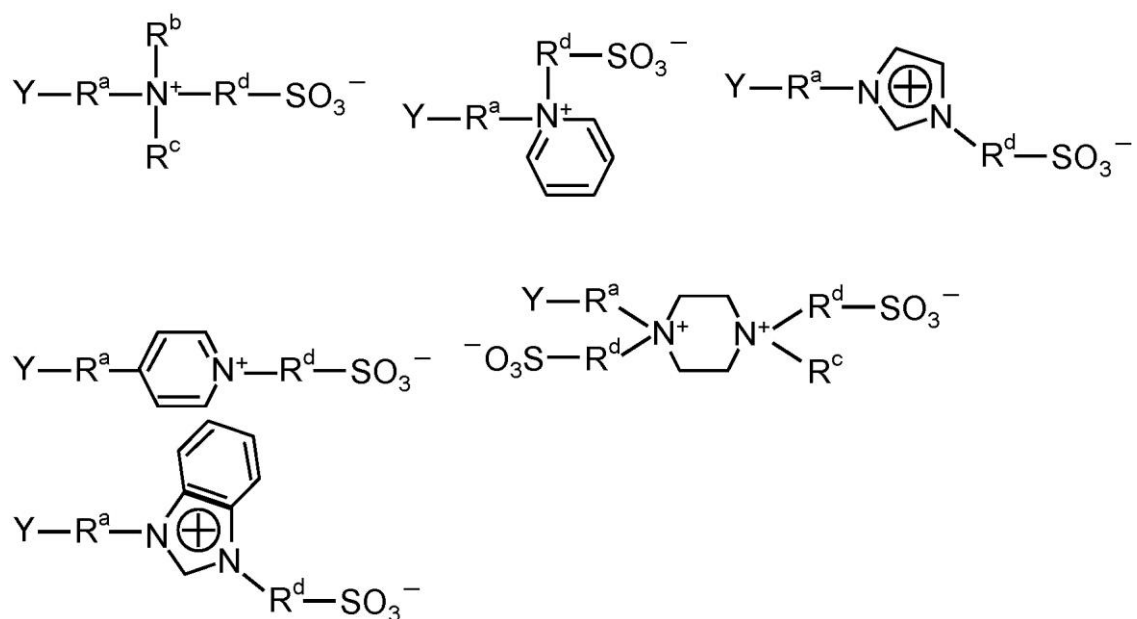
The monomer A is a polymerizable monomer having a sulfobetaine structure. The "sulfobetaine structure" as used herein refers to a structure where a positive charge and a negative charge containing a sulfur element are present at positions that are not adjacent to each other, an atom having a positive charge has no hydrogen atom that can be released, and the total sum of the charges is zero.

[0020]

Examples of the monomers A include, but not limited to, compounds represented by the following general formulae:

[0021]

[Chem. 1]



[0022]

In the above general formulae, R^a and R^d may each independently be an alkylene group having 1 to 30 carbon atoms which may be substituted or an arylene group having 6 to 30 carbon atoms which may be substituted, R^b and R^c may each independently be an alkyl group having 1 to 30 carbon atoms which may be substituted or an aryl group having 6 to 30 carbon atoms which may be substituted, and Y may be an ethylenically unsaturated group, such as an acryloyl group, a methacryloyl group, or a vinyl group. However, in the general formulae, the total sum of positive charges and negative charges is zero.

[0023]

Examples of alkylene groups having 1 to 30 carbon atoms include a methylene group, an ethylene group, a triethylene group, a propylene group, an isopropylene group, a butylene group, an isobutylene group, a sec-butylene group, a

tert-butylene group, and a pentylene group.

[0024]

Examples of arylene groups having 6 to 30 carbon atoms include a phenylene group, a naphthylene group, an anthracenylene group, a phenanthrenylene group, a pyrenylene group, a perylenylene group, a fluorenylene group, and a biphenylene group.

[0025]

Examples of alkyl groups having 1 to 30 carbon atoms include a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an isopentyl group, a tert-pentyl group, a neopentyl group, and an n-hexyl group.

[0026]

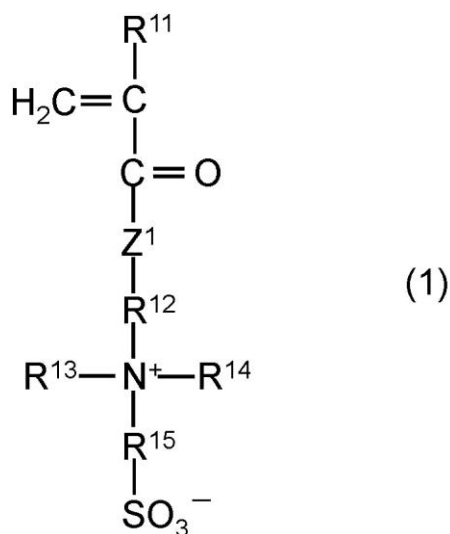
Examples of aryl groups having 6 to 30 carbon atoms include a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, and a biphenylenyl group.

[0027]

Among them, the monomer A is preferably a compound represented by the following formula (1) from the viewpoint of further enhancement of lubricating property and durability (lubrication retaining property):

[0028]

[Chem. 2]



[0029]

In the formula (1), R^{11} is a hydrogen atom or a methyl group. Z^1 is an oxygen atom (-O-) or -NH-, and preferably an oxygen atom (-O-).

[0030]

In the formula (1), R^{12} and R^{15} are each independently a straight chain or branched chain alkylene group having 1 to 20 carbon atoms from the viewpoint of further enhancement of lubricating property and durability (lubrication retaining property), preferably a straight chain or branched chain alkylene group having 1 to 12 carbon atoms, more preferably a straight chain or branched chain alkylene group having 1 to 8 carbon atoms, further preferably a straight chain or branched chain alkylene group having 1 to 6 carbon atoms, and particularly preferably a straight chain alkylene group having 1 to 3 carbon atoms (a methylene group, an ethylene group, or

a trimethylene group).

[0031]

In the formula (1), R^{13} and R^{14} are each independently a straight chain or branched chain alkyl group having 1 to 20 carbon atoms from the viewpoint of further enhancement of lubricating property and durability (lubrication retaining property), preferably a straight chain or branched chain alkyl group having 1 to 12 carbon atoms, more preferably a straight chain or branched chain alkyl group having 1 to 8 carbon atoms, further preferably a straight chain or branched chain alkyl group having 1 to 4 carbon atoms, and particularly preferably a methyl group.

[0032]

Examples of compounds represented by the formula (1) include

{2-[(meth)acryloyloxy]ethyl}dimethyl-(3-sulfopropyl) ammonium
hydroxide,

{2-[(meth)acryloyloxy]ethyl}dimethyl-(2-sulfoethyl) ammonium
hydroxide,

{2-[(meth)acryloyloxy]ethyl}diethyl-(2-sulfoethyl) ammonium
hydroxide,

{2-[(meth)acryloyloxy]ethyl}diethyl-(3-sulfopropyl) ammonium
hydroxide,

{3-[(meth)acryloyloxy]propyl}dimethyl-(2-sulfoethyl) ammonium
hydroxide,

{3-[(meth)acryloyloxy]propyl}dimethyl-(3-sulfopropyl) ammonium hydroxide, {3-[(meth)acryloyloxy]propyl}diethyl-(2-sulfoethyl) ammonium hydroxide, and {3-[(meth)acryloyloxy]propyl}diethyl-(3-sulfopropyl) ammonium hydroxide, and among them, {2-[(meth)acryloyloxy]ethyl}dimethyl-(3-sulfopropyl) ammonium hydroxide and [3-(methacryloylamino)propyl]dimethyl(3-sulfopropyl) ammonium hydroxide are preferred. The above compounds may be used alone or in combination of two or more thereof.

[0033]

The monomer A used may be either of a synthetic compound or a commercial product. A commercial product is available from Sigma-Aldrich Co. LLC., for example. When synthesized, A. Laschewsky, *Polymers*, 6, 1544-1601 (2014) may be referred, for example.

[0034]

The monomer A is not limited to the compound represented by the aforementioned general formulae, and may be a compound that has a form having a positive charge at an end thereof.

[0035]

In the hydrophilic copolymer of the present invention, the content of the structural units derived from the monomer A based on 100% by mole of the total of the structural units

derived from all monomers is preferably 0.05 to 99% by mole, more preferably 0.1 to 98% by mole, further preferably 0.1 to 95% by mole, and particularly preferably 0.1 to 90% by mole. In such a range, a good balance between the lubricating property and the solvent solubility is achieved. Note that the molar percentage is substantially equal to the proportion of the amount (moles) of the monomer A supplied based on the total amount (moles) of all the monomers supplied in production of the polymer.

[0036]

(Monomer B)

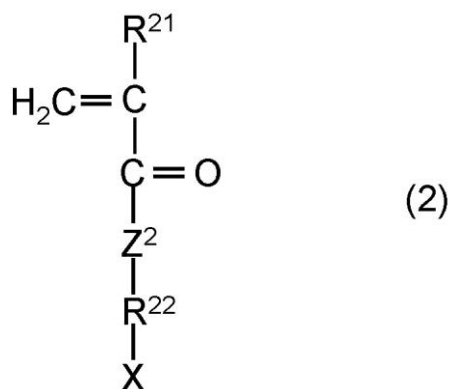
The monomer B is a polymerizable monomer having at least one group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof. With such a group incorporated, electrostatic repulsion occurs between hydrophilic copolymer molecules. Thus, the solvent solubility of the copolymer is enhanced. This effect of enhancement is particularly notable when the photoreactive group in the monomer C is a benzophenone group. Alternatively, also when the monomer C contains an ester group, the above effect of enhancement can be obtained well. The monomer B preferably has, in addition to the aforementioned groups, an ethylenically unsaturated group, such as a (meth)acryloyl group, a vinyl group, or an aryl group.

[0037]

Among them, from the viewpoint of further enhancement of the solvent solubility, the monomer B is preferably a compound represented by the following formula (2), (3), or (4), and more preferably a compound represented by the following formula (2).

[0038]

[Chem. 3]



[0039]

In the formula (2), R^{21} is a hydrogen atom or a methyl group. Z^2 is an oxygen atom (-O-) or -NH-, and preferably -NH-.

[0040]

In the formula (2), R^{22} is a straight chain or branched chain alkylene group having 1 to 20 carbon atoms from the viewpoint of further enhancement of the solvent solubility, preferably a straight chain or branched chain alkylene group having 1 to 12 carbon atoms, more preferably a straight chain or branched chain alkylene group having 1 to 8 carbon atoms, further preferably a straight chain or branched chain alkylene

group having 1 to 6 carbon atoms, and particularly preferably a branched chain alkylene group having 3 to 5 carbon atoms. The branched chain alkylene group having 3 to 5 carbon atoms is a group represented by, for example, $-\text{CH}(\text{CH}_3)-\text{CH}_2-$, $-\text{C}(\text{CH}_3)_2-\text{CH}_2-$, $-\text{CH}(\text{CH}_3)-\text{CH}(\text{CH}_3)-$, $-\text{C}(\text{CH}_3)_2-\text{CH}_2-\text{CH}_2-$, $-\text{CH}(\text{CH}_3)-\text{CH}(\text{CH}_3)-\text{CH}_2-$, $-\text{CH}(\text{CH}_3)-\text{CH}_2-\text{CH}(\text{CH}_3)-$, $-\text{CH}_2-\text{C}(\text{CH}_3)_2-\text{CH}_2-$, or $-\text{C}(\text{CH}_3)_2-\text{CH}(\text{CH}_3)-$ (provided that, the order of linking of the above group in the formula (2) is not limited), and among them, a group represented by $-\text{C}(\text{CH}_3)_2-\text{CH}_2-$ is particularly preferred.

[0041]

In the formula (2), X is a group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof, and from the viewpoint of the degree of acid dissociation (that is, the degree of easiness of anionization) and in turn the solvent solubility of the copolymer, X is preferably a group selected from the group consisting of a sulfonic acid group, a sulfuric acid group, and groups of salts thereof, and in terms of the availability of the monomer, X is more preferably a sulfonic acid group or a group of a salt thereof.

[0042]

Examples of compounds represented by the formula (2) include 2-(meth)acrylamide-2-methyl-1-propanesulfonic acid,

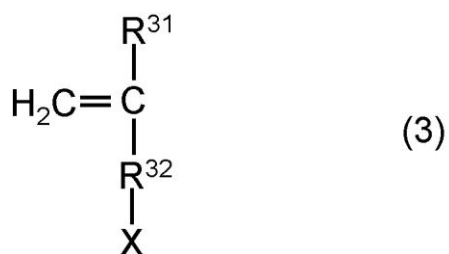
1-[(meth)acryloyloxymethyl]-1-propanesulfonic acid,
 2-[(meth)acryloyloxy]-2-propanesulfonic acid,
 3-[(meth)acryloyloxy]-1-methyl-1-propanesulfonic acid,
 2-sulfoethyl (meth)acrylate, 3-sulfopropyl (meth)acrylate,
 and salts thereof. The compounds may be used alone or in
 combination of two or more thereof.

[0043]

The compound represented by the formula (2) used may be
 either of a synthetic compound or a commercial product, and
 a commercial product may be available, for example, from Tokyo
 Chemical Industry, Co., Ltd.

[0044]

[Chem. 4]



[0045]

In the formula (3), R^{31} is a hydrogen atom or a methyl
 group.

[0046]

In the formula (3), R^{32} is a single bond or a straight
 chain or branched chain alkylene group having 1 to 20 carbon
 atoms, and preferably a single bond or a straight chain or
 branched chain alkylene group having 1 to 12 carbon atoms, more

preferably a single bond or a straight chain or branched chain alkylene group having 1 to 8 carbon atoms, further preferably a single bond or a straight chain or branched chain alkylene group having 1 to 4 carbon atoms, and particularly preferably a single bond. Specific examples of alkylene groups here are the same as in the formula (2) and therefore the description is omitted here.

[0047]

In the formula (3), X is a group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof, and from the viewpoint of the degree of acid dissociation (that is, the degree of easiness of anionization) and in turn the solvent solubility of the copolymer, X is preferably a group selected from the group consisting of a sulfonic acid group and a sulfuric acid group, and groups of salts thereof, and in terms of the availability of the monomer, X is more preferably a sulfonic acid group or groups of salts thereof.

[0048]

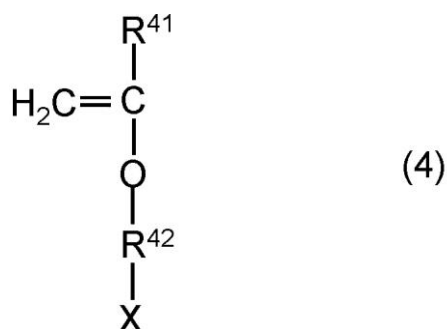
Examples of compounds represented by the formula (3) include vinylsulfonic acid, allylsulfonic acid, methallylsulfonic acid, and salts thereof. The compounds may be used alone or in combination of two or more thereof.

[0049]

The compound represented by the formula (3) used may be either of a synthetic compound or a commercial product, and a commercial product may be available from, for example, Asahi Kasei Finechem Co., Ltd., or Tokyo Chemical Industry, Co., Ltd.

[0050]

[Chem. 5]



[0051]

In the formula (4), R^{41} is a hydrogen atom or a methyl group.

[0052]

In the formula (4), R^{42} is a straight chain or branched chain alkylene group having 1 to 20 carbon atoms, preferably a straight chain or branched chain alkylene group having 1 to 12 carbon atoms, more preferably a straight chain or branched chain alkylene group having 1 to 8 carbon atoms, and further preferably a straight chain or branched chain alkylene group having 1 to 6 carbon atoms. Specific examples of alkylene groups here are the same as in the formula (2), and therefore the description is omitted here.

[0053]

In the formula (4), X is a group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof, and from the viewpoint of the degree of acid dissociation (that is, the degree of easiness of anionization) and in turn the solvent solubility of the copolymer, X is preferably a group selected from the group consisting of a sulfonic acid group, a sulfuric acid group, and groups of salts thereof, and in terms of the availability of the monomer, X is more preferably a sulfonic acid group or a group of a salt thereof.

[0054]

Examples of compounds represented by the formula (4) include 2-sulfoxyethyl vinyl ether, 3-sulfoxy-n-propyl vinyl ether, 2-propene-1-sulfonic acid, 2-methyl-2-propene-1-sulfonic acid, and salts thereof. The compounds may be used alone or in combination of two or more thereof.

[0055]

The compound represented by the formula (4) used may be either of a synthetic compound or a commercial product. As a commercial product, 2-methyl-2-propene-1-sulfonic acid sodium salt from Tokyo Chemical Industry, Co., Ltd. may be used.

[0056]

In the hydrophilic copolymer of the present invention,

the content of the structural units derived from the monomer B based on 100% by mole of the total of the structural units derived from all monomers is preferably 0.1 to 99% by mole, more preferably 0.2 to 99% by mole, further preferably 0.5 to 99% by mole, and particularly preferably 1 to 99% by mole, and in particular, the content is preferably 20 to 99% by mole, and above all, the content is preferably 25 to 99% by mole, and most preferably 28 to 99% by mole. In this range, a good balance of the lubricating property and the solvent solubility is achieved. Note that the molar percentage is substantially equal to the proportion of the amount (moles) of the monomer B supplied based on the total amount (moles) of all the monomers supplied in production of the polymer.

[0057]

(Monomer C)

The monomer C is a polymerizable monomer having a photoreactive group. As used herein, the "photoreactive group" refers to a group that generates a reactive species, such as a radical, a nitrene, or a carbene when irradiated with an active energy ray, and can react with a substrate layer to form a chemical bond. Thus, a surface lubricious layer containing the hydrophilic copolymer according to the present invention is strongly fixed on a substrate surface. Accordingly, the surface lubricious layer can exhibit superior durability (lubrication retaining property). In addition,

the monomer C preferably has, in addition to the photoreactive group, an ethylenically unsaturated group, such as a (meth)acryloyl group, a vinyl group, or an allyl group.

[0058]

Examples of photoreactive groups include an azide group, a diazo group, a diazirine group, a ketone group, and a quinone group.

[0059]

Examples of azide groups include aryl azide groups, such as phenyl azide and 4-fluoro-3-nitrophenyl azide; acyl azide groups, such as benzoyl azide and p-methylbenzoyl azide; azideformate groups, such as ethyl azideformate and phenyl azideformate; sulfonyl azide groups, such as benzenesulfonyl azide; and phosphoryl azide groups, such as diphenylphosphoryl azide and diethylphosphoryl azide.

[0060]

Examples of diazo groups include groups derived from, for example, diazoalkanes, such as diazomethane and diphenyldiazomethane; diazoketones, such as diazoacetophenone and 1-trifluoromethyl-1-diazo-2-pentanone; diazoacetates, such as t-butyl diazoacetate and phenyl diazoacetate; and β -keto- α -diazoacetatoacetates, such as t-butyl- α -diazoacetoacetate.

[0061]

Examples of diazirine groups include groups derived from, for example, 3-trifluoromethyl-3-phenyldiazirine.

[0062]

Examples of ketone groups include groups having a structure, such as acetophenone, benzophenone, anthrone, xanthine, or thioxanthone.

[0063]

Examples of quinone groups include groups derived from, for example, anthraquinone.

[0064]

The photoreactive group is appropriately selected according to the type of the substrate layer of the medical device, and the like. For example, when the substrate layer is formed of a polyolefin resin, such as polyethylene resin, a polyamide resin, a polyurethane resin, a polyester resin, or the like, the photoreactive group is preferably a ketone group or a phenyl azide group, and in terms of the availability of the monomer, it is more preferably a group having a benzophenone structure (a benzophenone group).

[0065]

Examples of the monomers C include 2-azidoethyl (meth)acrylate, 2-azidopropyl (meth)acrylate, 3-azidopropyl (meth)acrylate, 4-azidobutyl (meth)acrylate, 4-(meth)acryloyloxybenzophenone, 4-(meth)acryloyloxyethoxybenzophenone,

4-(meth)acryloyloxy-4'-methoxybenzophenone,
4-(meth)acryloyloxyethoxy-4'-methoxybenzophenone,
4-(meth)acryloyloxy-4'-bromobenzophenone,
4-(meth)acryloyloxyethoxy-4'-bromobenzophenone,
4-styrylmethoxybenzophenone, and
4-(meth)acryloyloxythioxanthone.

[0066]

The monomer C used may be either of a synthetic compound or a commercial product, and a commercial product may be available, for example, from MRC UNITEC Co., Ltd.

[0067]

In the hydrophilic copolymer of the present invention, the content of the structural units derived from the monomer C based on 100% by mole of the total of the structural units derived from all monomers is preferably 0.1 to 40% by mole, more preferably 0.1 to 30% by mole, further preferably 0.1 to 25% by mole, and particularly preferably 0.1 to 20% by mole, and in particular, the content is preferably 0.5 to 15% by mole, and above all, the content is preferably 0.8 to 12% by mole, and most preferably 1 to 10% by mole. In the range, the hydrophilic copolymer can sufficiently bind to the substrate layer, and therefore the surface lubricious layer containing the hydrophilic copolymer can be strongly fixed to the substrate layer. In addition, in the range, sufficient amounts of the other monomers (the monomers A and B) can exist,

and therefore the hydrophilic copolymer can be effectively improved in the lubricating property and durability by the monomer A and the solvent solubility by the monomer B. Note that the molar percentage is substantially equal to the proportion of the amount (moles) of the monomer C supplied based on the total amount (moles) of all the monomers supplied in production of the polymer.

[0068]

The hydrophilic copolymer of the present invention may contain any structural units derived from other polymerizable monomers than the monomer A, the monomer B, and the monomer C (hereinafter also referred to as "other monomers") to the extent that the effects of the present invention are not impaired. In the hydrophilic copolymer of the present invention, the content of the structural units derived from other monomers based on 100% by mole of the total amount of structural units derived from all the monomer is preferably less than 10% by mole, more preferably less than 5% by mole, further preferably less than 1% by mole (lower limit: 0% by mole). Preferably, the hydrophilic copolymer of the present invention is consisting of the monomer A, the monomer B, and the monomer C. Note that the molar percentage is substantially equal to the proportion of the amount (moles) of the other monomers supplied based on the total amount (moles) of all the monomers supplied in production of the polymer.

[0069]

The ends of the hydrophilic copolymer according to the present invention are not limited and appropriately defined according to the type of the material used. The ends are typically hydrogen atoms. The structure of the copolymer is not limited and may be any of a random copolymer, an alternating copolymer, a periodical copolymer, and a block copolymer.

[0070]

[Physical properties of hydrophilic copolymer]

The hydrophilic copolymer according to the present invention is superior in solvent solubility, and in particular, is superior in solubility in water, lower alcohols, or mixed solvents of water and a lower alcohol. As used herein, the "lower alcohol" refers to an alcohol having 1 to 3 carbon atoms, that is, methanol, ethanol, n-propanol, or isopropanol. This enables one to apply the solvents having low toxicity to a coating liquid, ensuring the safety of operators. In addition, solvents containing a lower alcohol can be quickly removed from the coated film because of their high vaporization speed. Thus, a drying step in coating of a medical device can be simplified and a coating operation can be performed quickly. Note that the "superior in solvent solubility" means that the copolymer dissolves or disperses in the above solvents preferably in an amount of 1% by weight or more. The time required for dissolving or dispersion here is preferably within 2 hours.

[0071]

The copolymer preferably has a weight average molecular weight of several thousands to several millions. The "weight average molecular weight" adopted in the present invention is a value measured by gel permeation chromatography (GPC) using polyethylene glycol as a standard.

[0072]

[Method of producing hydrophilic copolymer]

The method of producing the hydrophilic copolymer according to the present invention is not limited and known polymerization methods, such as radical polymerization, anion polymerization, and cation polymerization may be adopted, but radical polymerization, which allows for easy production, is preferably used.

[0073]

A polymerization method that is typically adopted is a method in which the monomer A, the monomer B, and the monomer C, and the other monomers as needed, are copolymerized by stirring and heating them together with a polymerization initiator in a polymerization solvent.

[0074]

The polymerization temperature is preferably, but not limited to, 25 to 100°C, and more preferably 30 to 80°C. The polymerization time is preferably, but not limited to, 30 minutes to 24 hours, and more preferably 1 hour to 5 hours.

[0075]

The polymerization solvent is preferably aqueous solvents, for example, water; alcohols, such as methanol, ethanol, propanol, n-butanol, and 2,2,2-trifluoroethanol; and polyhydric alcohols, such as ethylene glycol, diethylene glycol, propylene glycol, and dipropylene glycol. From the viewpoint of dissolving raw materials used in the polymerization, one of the solvents may be used alone or two or more thereof may be used in combination.

[0076]

The concentrations of the polymerizable monomers are preferably, but not limited to, 0.05 to 1 g/mL, and more preferably 0.1 to 0.5 g/mL in terms of the total solid amount (g) of the polymerizable monomers relative to the polymerization solvent (mL). Preferred proportion of the amount (moles) of each monomer supplied based on the total amount (moles) of all the monomers supplied are as described above.

[0077]

The reaction solution containing the polymerizable monomers may be degassed before addition of a polymerization initiator. Degassing may be performed, for example, by bubbling an inert gas, such as nitrogen gas or argon gas, in the reaction solution for about 0.5 to 5 hours. In degassing, the reaction solution may be heated to about 30 to 100°C.

[0078]

In production of the polymer, a traditionally known polymerization initiator may be used, and examples of polymerization initiators that can be used include, but not limited to, azo-based polymerization initiators, such as 2,2'-azobisisobutyronitrile, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile), 4,4'-azobis(4-cyanovaleric acid), and 2,2'-azobis(2,4-dimethylvaleronitrile); and redox-type polymerization initiators in which an oxidant, for example, a persulfate, such as potassium persulfate (KPS), sodium persulfate, or ammonium persulfate, or a peroxide, such as hydrogen peroxide, t-butyl peroxide, or methyl ethyl ketone peroxide, is combined with a reductant, for example, sodium sulfite, sodium hydrogen sulfite, or ascorbic acid.

[0079]

The amount of the polymerization initiator incorporated based on the total amount (moles) of the polymerizable monomers is preferably 0.01 to 10% by mole, and more preferably 0.1 to 5% by mole.

[0080]

A chain transfer agent, a polymerization rate modifier, a surfactant, and other additives may also be appropriately used, as required, in polymerization.

[0081]

The atmosphere in the polymerization reaction is not limited, and the polymerization may be performed in the ambient air, or under an atmosphere of an inert gas, such as nitrogen gas or argon gas. The reaction liquid may be stirred in the polymerization reaction.

[0082]

The copolymer may precipitate in the polymerization reaction. The copolymer after polymerization can be purified by a common purification method, such as reprecipitation, dialysis, ultrafiltration, or extraction.

[0083]

The copolymer after purification may be dried by any method, such as lyophilization, vacuum drying, spray drying, or heat drying, but from the viewpoint of small influence on the physical properties of the polymer, lyophilization or vacuum drying is preferred.

[0084]

The proportion of the structural units derived from each polymerizable monomer in the obtained copolymer can be determined by analyzing peak intensities of groups contained in the structural units using a known means such as NMR or IR.

[0085]

The amount of unreacted monomers contained in the obtained copolymer is preferably 0.01% by weight or less based on the entire copolymer. A smaller amount of unreacted

monomers is preferred (lower limit: 0% by weight). The content of remaining monomers can be measured by a known means, for example, high performance liquid chromatography.

[0086]

<Medical device>

The present invention also provides a medical device including a substrate layer and a surface lubricious layer that is formed on at least a part of the surface of the substrate layer and that contains the hydrophilic copolymer.

[0087]

A preferred embodiment of the medical device according to the present invention will be described below with reference to the accompanying drawings.

[0088]

Fig. 1 is a partial cross sectional view schematically illustrating a surface lamination structure of a typical embodiment of the medical device of the present invention (hereinafter also referred to as merely "medical device"). Fig. 2 is a partial cross sectional view schematically illustrating a different configuration example of the surface lamination structure as an application of the embodiment. Note that, in Fig. 1 and Fig. 2, 1 denotes a substrate layer, 1a denotes a substrate layer core, 1b denotes a substrate surface layer, 2 denotes a surface lubricious layer, and 10 denotes a medical device.

[0089]

As shown in Fig. 1 and Fig. 2, a medical device 10 of the embodiment includes a substrate layer 1 and a surface lubricious layer 2 that is fixed on at least a part of the substrate layer 1 (the figures show an example in which the surface lubricious layer 2 is fixed on all of the surface (the entire surface) of the substrate layer 1 in the figures) and that contains a hydrophilic copolymer. The surface lubricious layer 2 binds to the substrate layer 1 via a photoreactive group of the hydrophilic copolymer.

[0090]

The components of the medical device of the embodiment will be described below.

[0091]

[Substrate layer (substrate)]

The substrate layer used in the embodiment may be constituted of any material that can react with photoreactive group contained in the hydrophilic copolymer to form a chemical bond. Specific examples of materials for constituting (forming) the substrate layer 1 include metal materials, polymer materials, and ceramics. Regarding the substrate layer 1, the entire substrate layer 1 (all of the substrate layer 1) may be constituted (formed) of any one of the materials as shown in Fig. 1, or the substrate layer 1 may have a structure in which the surface of the substrate layer core 1a which is

constituted (formed) of any one of the materials is covered (coated) with another one of the materials by a suitable method to constitute (form) a substrate surface layer 1b as shown in Fig. 2. Examples of the latter cases include a case where the surface of the substrate layer core 1a formed of a resin material and the like is covered (coated) with a metal material by a suitable method (a traditionally known method, such as plating, metal vapor deposition, or sputtering) to form the substrate surface layer 1b; and a case where the surface of the substrate layer core 1a formed of a hard reinforcing material, such as a metal material or a ceramic material, is covered (coated) with a polymer material which is softer than a reinforcing material, such as metal material, by a suitable method (a traditionally known method, such as dipping, spray, or application/printing), or a reinforcing material of the substrate layer core 1a and a polymer material of the substrate surface layer 1b are combined into a composite (with a suitable reaction treatment), to form the substrate surface layer 1b. Accordingly, the substrate layer core 1a may be a multilayer structure in which multiple different materials are laminated, or a structure in which members formed of different materials for the respective parts of a medical device are joined (complex). Another layer, i.e., a middle layer (not shown) may further be formed between the substrate layer core 1a and the substrate surface layer 1b. The substrate surface layer

1b may also be a multilayer structure in which multiple different materials are laminated or a structure in which members formed of different materials for the respective parts of a medical device are joined (complex).

[0092]

Among the materials constituting (forming) the substrate layer 1, the metal material is not limited and metal materials that are commonly used in medical devices, such as catheters, stents, and guide wires are used. Specific examples include various stainless steels (SUS), such as SUS304, SUS316, SUS316L, SUS420J2, and SUS630, gold, platinum, silver, copper, nickel, cobalt, titanium, iron, aluminum, tin, and various alloys, such as nickel-titanium (Ni-Ti) alloys, nickel-cobalt (Ni-Co) alloys, cobalt-chromium (Co-Cr) alloys, and zinc-tungsten (Zn-W) alloys. One of the metal materials may be used alone or two or more thereof may be used in combination. The metal material may be appropriately selected to be most suitable for the substrate layer of a catheter, stent, guide wire, or the like, which is the use target.

[0093]

Among the materials constituting (forming) the substrate layer 1, the polymer material is not limited and polymer materials that are commonly used in medical devices, such as catheters, stents, and guide wires are used. Specific examples include polyamide resins, polyolefin resins, such as

polyethylenes, for example, straight chain low density polyethylenes (LLDPE), low density polyethylenes (LDPE), and high density polyethylenes (HDPE), and polypropylene, and polyester resins, such as polyethylene terephthalate, styrol resins, such as polystyrene, cyclic polyolefin resins, modified polyolefin resins, epoxy resins, urethane resins, diallylphthalate resins (allyl resins), polycarbonate resins, fluororesins, amino resins (urea resins, melamine resins, benzoguanamine resins), acrylic resins, polyacetal resins, vinyl acetate resins, phenol resins, vinyl chloride resins, silicone resins (silicon resins), polyether resins, and polyimide resins. One of the polymer materials may be used alone or two or more thereof may be used in combination. The polymer material may be appropriately selected to be most suitable for the substrate layer of a catheter, stent, guide wire, or the like, which is the use target.

[0094]

The shape of the substrate layer is not limited and appropriately selected according to the use form, such as a sheet form, a liner form (wire), or a tubular form.

[0095]

[Method of producing medical device]

The method of producing the medical device according to the present invention (method of forming the surface lubricious layer on a substrate layer) is not limited as long as the method

uses the hydrophilic copolymer, and a known method may be applied as it is or with appropriate modification. In an example of preferred methods, the hydrophilic copolymer according to the present invention is dissolved in a solvent to prepare a coating liquid, which is then applied on a substrate layer of a medical device. According to such a method, lubricating property and durability (lubrication retaining property) can be imparted to a surface of a medical device.

[0096]

(Application step)

In the above method, as a solvent used for dissolving the hydrophilic copolymer, solvents described in the section [Physical properties of hydrophilic copolymer] are suitable from the viewpoint of safety of the operation (low toxicity).

[0097]

The concentration of the hydrophilic copolymer in the coating liquid preferably, but not limited to, 0.01 to 50% by weight, more preferably 0.05 to 40% by weight, and further preferably 0.1 to 30% by weight. In the range, applicability of the coating liquid is good and the obtained surface lubricious layer is superior in the lubricating property and durability (lubrication retaining property). In addition, since a uniform surface lubricious layer having a desired thickness can be easily obtained through a single coating, such a concentration is preferred in terms of production efficiency.

Note that when the concentration of the hydrophilic copolymer is less than 0.01% by weight, a sufficient amount of the hydrophilic copolymer may not be fixed on a substrate layer surface. When the concentration of the hydrophilic copolymer exceeds 30% by weight, the viscosity of the coating liquid is so high that a surface lubricious layer having a uniform thickness may not be obtained. However, a concentration outside the range may be sufficiently applicable to the extent that the functions and effects of the present invention are not influenced.

[0098]

The substrate layer surface may be previously subjected to a UV irradiation treatment, a plasma treatment, a corona discharge treatment, a flame treatment, an oxidation treatment, a silane coupling treatment, or a phosphate coupling treatment before application of a coating liquid. When the solvent of a coating liquid is only water, it is difficult to apply the coating liquid on a hydrophobic substrate layer surface. However, a plasma treatment of the substrate layer surface hydrophilizes the substrate layer surface. This leads to enhancement of wettability of a coating liquid to a substrate layer surface, making it possible to form a uniform surface lubricious layer. In addition, application of the treatments on a substrate layer surface of a material having no C-H bond, such as a metal or a fluororesin, makes it possible to form

a covalent bond to the photoreactive group of the hydrophilic copolymer.

[0099]

The method of applying a coating liquid to a substrate layer surface is not limited, and a traditionally known method, such as an application/printing method, a dipping or dip-coating method, a spraying method, a spin coating method, or a mixed solution-impregnated sponge coating method can be applied. Among them, a dipping or dip-coating method is preferred.

[0100]

Note that, when a surface lubricious layer is formed on a thin and narrow interior surface of a catheter, a stent, a guide wire, or the like, the pressure of the system may be reduced for degassing while dipping the substrate layer in a coating liquid. Degassing by reducing the pressure allows a solution to quickly permeate the thin and narrow interior surface to facilitate the formation of the surface lubricious layer.

[0101]

When the surface lubricious layer is to be formed on only a part of a substrate layer, only a part of the substrate layer is dipped in a coating liquid to coat the part of the substrate layer with the coating liquid. A surface lubricious layer can thus be formed on a desired surface part of a substrate layer.

[0102]

When it is difficult to dip only a part of a substrate layer in a coating liquid, a part of the substrate layer surface where a surface lubricious layer is not required to be formed is previously protected (for example, covered) with a suitable removable (detachable) member or material, then the substrate layer is dipped in a coating liquid to coat the substrate layer with the coating liquid, and thereafter the protecting member (material) on the part of the substrate layer surface where a surface lubricious layer is not required to be formed is removed, followed by a reaction through a heating operation or the like. In this manner, a surface lubricious layer can be formed on a desired part of a substrate layer surface. However, the present invention is not limited to the above formation methods at all, and a traditionally known method can be appropriately used to form a surface lubricious layer. For example, when it is difficult to dip only a part of a substrate layer in a mixed solution, in place of a dipping method, another coating method (for example, a method of applying a coating liquid to a desired part of a surface of a medical device with an applicator, such as a spray apparatus, a bar coater, a die coater, a reverse coater, a comma coater, a gravure coater, a spray coater, or a doctor knife) may be applied. Note that, when both of the outer surface and the inner surface of a cylindrical medical device have to have a surface lubricious

layer due to the structure of the medical device, a dipping method is preferably used since both the outer surface and the inner surface can be coated at once.

[0103]

(Drying step)

It is preferred that a substrate layer is dipped in a coating liquid containing the hydrophilic copolymer of the present invention as described above, then the substrate layer is taken out of the coating liquid, and the coating film is dried. The drying conditions are not limited as long as the solvent can be removed from the coating film, and a hot air treatment with a dryer or the like or a natural drying may be adopted. The pressure condition in drying is also not limited, and the drying may be performed at normal pressure (the atmospheric pressure), or at an increased or decreased pressure. As a drying means (device), for example, an oven or a vacuum dryer may be used. In the case of natural drying, no drying means (device) is needed.

[0104]

(Fixing step)

The coating film after the drying step is irradiated with an active energy ray. This activates the photoreactive group of the hydrophilic copolymer in the coating film to form a chemical bond between the photoreactive group and the substrate layer. More specific description is made for a case of

combination of a photoreactive group having a benzophenone structure and a polyethylene substrate layer. When the hydrophilic copolymer contains a photoreactive group having a benzophenone structure, two radicals are generated in the photoreactive group by irradiation with a UV ray. One radical thereof withdraws a hydrogen atom from the polyethylene substrate layer, and instead, one radical is generated on the polyethylene substrate layer. Then, the remaining radical in the photoreactive group is bound to the radical on the polyethylene substrate layer to thereby form a covalent bond between the photoreactive group and the polyethylene substrate layer. This mechanism allows the surface lubricious layer containing the hydrophilic copolymer having a photoreactive group to be strongly fixed to the substrate layer surface. Thus, the surface lubricious layer can exhibit superior durability (lubrication retaining property).

[0105]

Examples of active energy rays include UV rays, electron rays, and gamma rays. The active energy ray is preferably a UV ray or an electron ray, and in view of influence on human bodies, it is more preferably a UV ray. When a UV ray is used, any wavelength that can activate a photoreactive group can be appropriately selected as the irradiation wavelength. The irradiation intensity of the UV ray is preferably, but not limited to, 1 to 5000 mW/cm². The integrated light quantity

of the UV ray is preferably, but not limited to, 50 to 5000 mJ/cm², and more preferably 100 to 1000 mJ/cm². Examples of the device for the UV ray irradiation include high pressure mercury lamps, low pressure mercury lamps, metal halide lamps, xenon lamps, and halogen lamps.

[0106]

After the irradiation with the active energy ray, the substrate layer surface may be washed with a solvent (for example, a solvent used in preparing a coating liquid) to remove the unreacted hydrophilic copolymer.

[0107]

The fixation of the coating film (surface lubricious layer) onto the substrate layer can be checked using a known analysis means, such as FT-IR or XPS. For example, the fixation can be checked by comparing the ratio of a peak of a bond formed through the irradiation with the active energy ray and a peak of an unchanged bond using FT-IR measurement before and after the irradiation with an active energy ray.

[0108]

According to the method, in the medical device according to the present invention, a surface lubricious layer containing the hydrophilic copolymer of the present invention is formed on a surface. Thus, the medical device according to the present invention can exhibit superior lubricating property and durability (lubrication retaining property).

[0109]

[Use of medical device]

The medical device 10 according to the present invention is used in contact with body fluid or blood, and the surface has a lubricating property in an aqueous solution such as body fluid or a saline, being capable of enhancing operability and reducing damage of tissue mucosa. Specific examples include catheters, stents, and guide wires which are used in blood vessels. That is, a medical device according to one embodiment of the present invention is a catheter, a stent, or a guide wire. Besides the above, the following medical devices may be mentioned.

[0110]

(a) Catheters to be orally or nasally inserted or allowed to indwell in a digestive organ, such as stomach tube catheters, digestive catheters, and tubes for enteric nutrients

(b) Catheters to be orally or nasally inserted or allowed to indwell in a respiratory tract or trachea, such as oxygen catheters, oxygen cannulas, tubes and cuffs of tracheal tubes, tubes and cuffs of tracheotomy tubes, and tracheal aspiration catheters

(c) Catheters to be inserted or allowed to indwell in a urethra or ureter, such as urethra catheters, urinary catheters, and catheters and balloons of urethra balloon catheters

(d) Catheters to be inserted or allowed to indwell in various lumens, organs, and tissues, such as suction catheters, drain catheters, and rectum catheters

(e) Catheters to be inserted or allowed to indwell in a blood vessel, such as indwelling needles, IVH catheters, thermodilution catheters, angiography catheters, vasodilation catheters, and dilators or introducers, or guide wires, stylets, and the like for the catheters

(f) Artificial tracheae, artificial bronchi, and the like

(g) Medical devices for extracorporeal circulation therapy (artificial lungs, artificial hearts, artificial kidneys, etc.) and circuits therefor. Examples

[0111]

The present invention will be described specifically below with respect to examples, but the present invention is not to be limited to the examples. Note that the parts and % in the examples are all by weight. Hereinafter, unless otherwise defined, the conditions for allowing to stand at room temperature are all at 23°C/55% RH.

[0112]

<Production of copolymer>

[Production Example 1]

In 10 mL of a methanol/water (9/1 v/v) mixed solvent were dissolved 1.95 g (7.0 mmol) of

[2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl) ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.410 g (2.0 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid (AMPS) from Tokyo Chemical Industry, Co., Ltd., and 0.266 g (1.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 31 mg (0.10 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation, and the obtained insoluble matter was dissolved in 1 mL of a methanol/water (7/3 v/v) mixed solvent. The solution was subjected to reprecipitation in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0113]

[Production Example 2]

In 1 mL of a methanol/water (9/1 v/v) mixed solvent were dissolved 0.251 g (0.9 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl) ammonium hydroxide (MSPB) from Sigma-Aldrich and 0.027 g (0.1 mmol) of

4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0114]

[Production Example 3]

In 1 mL of a methanol/water (9/1 v/v) mixed solvent were dissolved 0.276 g (0.99 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich and 0.003 g (0.01 mmol) 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization

proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0115]

[Production Example 4]

In 1 mL of methanol were dissolved 0.167 g (0.6 mmol) of

[2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.043 g (0.3 mmol) of butyl methacrylate (BMA) from Tokyo Chemical Industry, Co., Ltd., and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0116]

[Production Example 5]

In 1 mL of methanol were dissolved 0.167 g (0.6 mmol) of

[2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.039 g (0.3 mmol) of 2-methoxyethyl acrylate (MEA) from Wako Pure Chemical Corporation, and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0117]

[Production Example 6]

In 1 mL of methanol were dissolved 0.167 g (0.6 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.034 g (0.3 mmol) of N-isopropylacrylamide (NIPAAm) from Wako Pure Chemical Corporation, and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution

was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0118]

[Production Example 7]

In 1 mL of methanol were dissolved 0.167 g (0.6 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.030 g (0.3 mmol) of N,N-dimethylacrylamide (DMAAm) from Tokyo Chemical Industry, Co., Ltd., and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization

proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0119]

[Production Example 8]

In 1 mL of methanol were dissolved 0.167 g (0.6 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl) ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.090 g (0.3 mmol) of poly(ethylene glycol) methyl ether methacrylate (PEGMEA, number average molecular weight 300) from Sigma-Aldrich, and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0120]

[Production Example 9]

In 1 mL of methanol were dissolved 0.167 g (0.6 mmol)

of

[2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.035 g (0.3 mmol) of N-(2-hydroxyethyl)acrylamide (HEAAM) from Tokyo Chemical Industry, Co., Ltd., and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 15 mL centrifuge tube, oxygen was removed by sufficient nitrogen bubbling, 3.1 mg (0.01 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. As the polymerization proceeded, insoluble matter precipitated and settled down. Next, the solvent was removed by decantation to obtain the insoluble matter (copolymer).

[0121]

[Production Example 10]

In 10 mL of a methanol/water (9/1 v/v) mixed solvent were dissolved 2.07 g (7.0 mmol) of 2-methacryloyloxyethyl phosphorylcholine (MPC) from Tokyo Chemical Industry, Co., Ltd., 0.414 g (2.0 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid (AMPS) from Tokyo Chemical Industry, Co., Ltd., and 0.266 g (1.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd.

to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 31 mg (0.10 mmol) of a polymerization initiator, 2,2'-azobis(4-methoxy-2,4-dimethylvaleronitrile) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 50°C for 2 hours. Next, the obtained polymerization liquid was subjected to reprecipitation in the 5-fold amount of THF/methanol (9/1 v/v), and the supernatant was removed by decantation, followed by washing twice with THF/methanol (9/1 v/v), to obtain a copolymer.

[0122]

[Production Example 11]

In 10 mL of a 2,2,2-trifluoroethanol/water (9/1 v/v) mixed solvent were dissolved 1.95 g (7.0 mmol) of [3-(methacryloylamino)propyl]dimethyl(3-sulfopropyl)ammonium hydroxide (MSPBa) from Sigma-Aldrich, 0.580 g (2.8 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid (AMPS) from Tokyo Chemical Industry, Co., Ltd., and 0.053 g (0.2 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and

polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0123]

[Production Example 12]

In 10 mL of a 2,2,2-trifluoroethanol/water (9/1 v/v) mixed solvent were dissolved 2.07 g (7.0 mmol) of 2-methacryloyloxyethyl phosphorylcholine (MPC) from Tokyo Chemical Industry, Co., Ltd., 0.580 g (2.8 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid (AMPS) from Tokyo Chemical Industry, Co., Ltd., and 0.053 g (0.2 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0124]

[Production Example 13]

In 10 mL of a 2,2,2-trifluoroethanol/water (9/1 v/v)

mixed solvent were dissolved 1.95 g (7.0 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.580 g (2.8 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid (AMPS) from Tokyo Chemical Industry, Co., Ltd., and 0.053 g (0.2 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0125]

[Production Example 14]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 2.76 g (9.89 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.023 g (0.1 mmol) 2-acrylamide-2-methyl-1-propanesulfonic acid sodium salt (AMPS(Na)) from Sigma-Aldrich, and 0.003 g (0.01 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution

was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0126]

[Production Example 15]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 1.96 g (7.0 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.458 g (2.0 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid sodium salt (AMPS(Na)) from Sigma-Aldrich, and 0.266 g (1.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing

twice with methanol, to obtain a copolymer.

[0127]

[Production Example 16]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 1.68 g (6.0 mmol) [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.458 g (2.0 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid sodium salt (AMPS(Na)) from Sigma-Aldrich, and 0.532 g (2.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0128]

[Production Example 17]

In 10 mL of a 2,2,2-trifluoroethanol/water (9/1 v/v) mixed solvent were dissolved 0.003 g (0.01 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 2.05 g (9.89 mmol) of

2-acrylamide-2-methyl-1-propanesulfonic acid (AMPS) from Tokyo Chemical Industry, Co., Ltd., and 0.027 g (0.1 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0129]

[Production Example 18]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 1.96 g (7.0 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.685 g (2.99 mmol) of 2-acrylamide-2-methyl-1-propanesulfonic acid sodium salt (AMPS(Na)) from Sigma-Aldrich, and 0.003 g (0.01 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical

Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0130]

[Production Example 19]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 1.96 g (7.0 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.465 g (2.0 mmol) of 3-sulfopropylacrylate potassium salt (SPA(K)) from Tokyo Chemical Industry, Co., Ltd., and 0.266 g (1.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0131]

[Production Example 19]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 1.96 g (7.0 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.465 g (2.0 mmol) of 3-sulfopropylacrylate potassium salt (SPA(K)) from Tokyo Chemical Industry, Co., Ltd., and 0.266 g (1.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd. to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0132]

[Production Example 20]

In 10 mL of a 2,2,2-trifluoroethanol/water (8/2 v/v) mixed solvent were dissolved 1.96 g (7.0 mmol) of [2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl)ammonium hydroxide (MSPB) from Sigma-Aldrich, 0.493 g (2.0 mmol) of 3-sulfopropylmethacrylate potassium salt (SPMA(K)) from Sigma-Aldrich, and 0.266 g (1.0 mmol) of 4-methacryloyloxybenzophenone (MBP) from MRC UNITEC Co., Ltd.

to prepare a reaction solution. Next, the reaction solution was put in a 30 mL eggplant-shaped flask, oxygen was removed by sufficient nitrogen bubbling, 28 mg (0.10 mmol) of a polymerization initiator (V-501 from Wako Pure Chemical Corporation) was added, followed by immediate sealing, and polymerization was carried out in a water bath at 80°C for 2 hours. Next, reprecipitation was performed in acetone, and the supernatant was removed by decantation, followed by washing twice with methanol, to obtain a copolymer.

[0133]

The compositions of the copolymers obtained in the Production Examples 1 to 20 were shown in Table 1-1 and Table 1-2. Here, the copolymers of Production Examples 1, 11, and 13 to 20 correspond to the hydrophilic copolymer according to the present invention, and the copolymers of Production Examples 10 and 12 correspond to the copolymer disclosed in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498.

[0134]

[Table 1-1]

	Structural unit ratio (% by mole)									
	MSPB	MPC	AMPS	BMA	MEA	NIPAAm	DMAAm	PEGMA	HEAAm	MBP
Production Example 1	70		20							10
Production Example 2	90									10
Production Example 3	99									1
Production Example 4	60			30						10
Production Example 5	60				30					10
Production Example 6	60					30				10
Production Example 7	60						30			10
Production Example 8	60							30		10
Production Example 9	60								30	10
Production Example 10		70	20							10

[0135]

[Table 1-2]

	Structural unit ratio (% by mole)							
	MSPB	MSPBa	MPC	AMPS	AMPS (Na)	SPA (K)	SPMA (K)	MBP
Production Example 11		70		28				2
Production Example 12			70	28				2
Production Example 13	70			28				2
Production Example 14	98.9				1			0.1
Production Example 15	70				20			10
Production Example 16	60				20			20
Production Example 17	0.1			98.9				1
Production Example 18	70				29.9			0.1
Production Example 19	70					20		10
Production Example 20	70						20	10

[0136]

In Table 1-1 and Table 1-2, the abbreviations represent the followings:

MSPB:

[2-(methacryloyloxy)ethyl]dimethyl-(3-sulfopropyl) ammonium hydroxide (corresponding to monomer A)

MSPBa:

[3-(methacryloylamino)propyl]dimethyl(3-sulfopropyl) ammonium hydroxide (corresponding to monomer A)

MPC: 2-methacryloyloxyethyl phosphorylcholine

AMPS: 2-acrylamide-2-methyl-1-propanesulfonic acid (corresponding to monomer B)

AMPS(Na): 2-acrylamide-2-methyl-1-propanesulfonic acid sodium salt (corresponding to monomer B)

SPA(K): 3-sulfopropylacrylate potassium salt (corresponding to monomer B)

SPMA(K): 3-sulfopropylmethacrylate potassium salt (corresponding to monomer B)

BMA: butyl methacrylate

MEA: 2-methoxyethyl acrylate

NIPAAm: N-isopropylacrylamide

DMAAm: N,N-dimethylacrylamide

PEGMA: poly(ethylene glycol) methyl ether methacrylate

HEAAm: N-(2-hydroxyethyl)acrylamide

MBP: 4-methacryloyloxybenzophenone (corresponding to

monomer C).

[0137]

<Solvent solubility test of copolymer>

[Examples 1-1 to 10-1, Comparative Examples 1-1 to 10-1]

The copolymers obtained in Production Examples 1 to 20 were evaluated for the solubility in water, methanol, and water/methanol mixed solvents having different mixing ratios. Specifically, solubility tests were performed under conditions of a temperature of 25°C, a concentration of 1% by weight, and a testing time of 2 hours, and the solubility was determined according to the following determination criteria:

o: dissolve or disperse

x: not dissolve nor disperse.

[0138]

The results are shown in Table 2. The copolymers of Production Examples 1, 11, and 13 to 20 (corresponding to the hydrophilic copolymer according to the present invention) showed good solubility in water or water/methanol mixed solvents (Examples 1-1 to 10-1). On the other hand, the copolymers of Production Examples 2 to 9, which contained no structural unit derived from the monomer B (AMPS) did not dissolve in water/methanol solvents of any mixing ratios (Comparative Examples 1-1 to 8-1). Based on the results, it is considered that the structural unit derived from the monomer B contributes to the solvent solubility of the copolymers.

This is supposedly because the electrostatic repulsion between sulfonic acid groups contained in the structural units derived from the monomer B possibly contributes to dispersion of the copolymer. Note that the copolymer of Production Examples 10 and 12 (corresponding to the copolymer disclosed in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498) showed solubility in water/methanol of any mixing ratio (Comparative Example 9-1, Comparative Example 10-1).

[0139]

[Table 2]

	Production Example	Solubility or dispersibility in water/methanol (v/v)						
		10/0	9/1	7/3	5/5	3/7	1/9	0/10
Example 1-1	Production Example 1	o	o	o	o	o	×	×
Comparative Example 1-1	Production Example 2	×	×	×	×	×	×	×
Comparative Example 2-1	Production Example 3	×	×	×	×	×	×	×
Comparative Example 3-1	Production Example 4	×	×	×	×	×	×	×
Comparative Example 4-1	Production Example 5	×	×	×	×	×	×	×
Comparative Example 5-1	Production Example 6	×	×	×	×	×	×	×
Comparative Example 6-1	Production Example 7	×	×	×	×	×	×	×
Comparative Example 7-1	Production Example 8	×	×	×	×	×	×	×
Comparative Example 8-1	Production Example 9	×	×	×	×	×	×	×
Comparative Example 9-1	Production Example 10	o	o	o	o	o	o	o
Example 2-1	Production Example 11	o	o	o	o	o	×	×
Comparative Example 10-1	Production Example 12	o	o	o	o	o	o	o
Example 3-1	Production Example 13	o	o	o	o	o	×	×
Example 4-1	Production Example 14	o	×	×	×	×	×	×
Example 5-1	Production Example 15	o	o	o	o	o	×	×
Example 6-1	Production Example 16	×	×	×	×	o	×	×
Example 7-1	Production Example 17	o	o	o	o	o	o	o
Example 8-1	Production Example 18	o	o	o	o	×	×	×
Example 9-1	Production Example 19	o	o	o	o	×	×	×
Example 10-1	Production Example 20	o	o	o	o	×	×	×

[0140]

<Slide and durability test>

[Example 1-2]

The copolymer obtained in Production Example 1 (corresponding to the hydrophilic copolymer according to the present invention) was dissolved in methanol/water (7/3 v/v) at 10% by weight to prepare a coating liquid. Next, an HDPE sheet (12.5 mm × 100 mm) was dipped in the coating liquid and was taken out at a speed of 15 mm/sec. Next, the HDPE sheet was dried with a dryer for 30 seconds to remove the solvent. Next, the HDPE sheet was irradiated with UV under conditions of a wavelength of 365 nm, a lamp power of 1 kW, an irradiation distance of 200 mm, and a sample transporting rate of 2 m/min (integrated light quantity: 230 mJ/cm²). UVC-1212/1MNLC3-AA04 (high pressure mercury lamp) manufactured by Ushio Inc. was used as a UV irradiation device. [0141]

Next, the obtained sample was evaluated for the lubricating property and durability (lubrication retaining property) using a friction meter (Handy Tribo Master TL201 manufactured by Trinity-Lab Inc.) 20 shown in Fig. 3 according to the following method. [0142]

That is, the sample 16 was fixed in a petri dish 12, and was dipped in water 17 with such a height that the entire sample 16 soaked therein. The petri dish 12 was placed on a moving table 15 of the friction meter 20 illustrated in Fig. 3. An HDPE terminal (ϕ 10 mm, R 1 mm) 13 was brought into contact

with the sheet, and a load 14 of 450 g was applied on the terminal. While the moving table 15 was subjected to 50 horizontal reciprocations under a sliding distance set to 20 mm and a sliding speed set to 16.7 mm/sec, the sliding resistance (gf) was measured. During the reciprocations from the first time to 50th time, an average of the sliding resistance for each reciprocation was taken and plotted on a graph as a test force to thereby evaluate the variation of the sliding resistance during the 50 repeated slides.

[0143]

[Example 3-2]

The copolymer obtained in Production Example 13 (corresponding to the hydrophilic copolymer according to the present invention) was dissolved in methanol/water (7/3 v/v) at 10% by weight to prepare a coating liquid. Next, a nylon sheet (12.5 mm × 100 mm) was dipped in the coating liquid and was taken out at a speed of 5 mm/sec. Next, the nylon sheet was dried with a dryer for 30 seconds to remove the solvent. Next, the nylon sheet was irradiated with UV under conditions of a wavelength of 365 nm, a lamp power of 1 kW, an irradiation distance of 200 mm, and a sample transporting rate of 250 m/min (integrated light quantity: 1000 mJ/cm²). UVC-1212/1MNLC3-AA04 (high pressure mercury lamp) manufactured by Ushio Inc. was used as a UV irradiation device.

[0144]

Next, the obtained sample was evaluated for the lubricating property and durability (lubrication retaining property) using a friction meter (Handy Tribo Master TL201 manufactured by Trinity-Lab Inc.) 20 shown in Fig. 3 according to the following method

[0145]

That is, the sample 16 was fixed in a petri dish 12, and was dipped in water 17 with such a height that the entire sample 16 soaked therein. The petri dish 12 was placed on a moving table 15 of the friction meter 20 illustrated in Fig. 3. An HDPE terminal (ϕ 10 mm, R 1 mm) 13 was brought into contact with the sheet, and a load 14 of 450 g was applied on the terminal. While the moving table 15 was subjected to 100 horizontal reciprocations under a sliding distance set to 20 mm and a set sliding speed of 16.7 mm/sec, the sliding resistance (gf) was measured. During the reciprocations from the first time to 50th time, an average of the sliding resistance for each reciprocation was taken and plotted on a graph as a test force to thereby evaluate the variation of the sliding resistance during the sliding repeated 100 times.

[0146]

[Example 5-2]

Production of the sample and measurement of sliding resistance were performed in the same manner as in Example 3-2 except for using the copolymer obtained in Production Example

15 in place of the copolymer obtained in Production Example 13.

[0147]

[Example 7-2]

Production of the sample and measurement of sliding resistance were performed in the same manner as in Example 3-2 except for using the copolymer obtained in Production Example 17 in place of the copolymer obtained in Production Example 13.

[0148]

[Comparative Example 9-2]

Production of the sample and measurement of sliding resistance were performed in the same manner as in Example 1-2 except for using the copolymer obtained in Production Example 10 (corresponding to the copolymer disclosed in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498) in place of the copolymer obtained in Production Example 1.

[0149]

The results of Example 1-2 and Comparative Example 9-2 are shown in Fig. 4. The sample of Example 1-2 had a significantly lower initial sliding value as compared with the sample of Comparative Example 9-2. The sliding resistance of the sample of Comparative Example 9-2 increases from 0 to 10th sliding, which suggests the possibility of wear of the surface of the surface lubricious layer. On the other hand, the sample

of Example 1-2 did not present such a phenomenon that the sliding resistance increases as the sliding time increases. The above fact indicates that the surface lubricious layer formed using the hydrophilic copolymer according to the present invention has higher film strength as compared with the surface lubricious layer formed using the copolymer disclosed in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498, and this is suggested to be attributable to the strong electrostatic interaction of the sulfobetaine structure.

[0150]

It was found from the above results that the surface lubricious layer containing the hydrophilic copolymer according to the present invention can exhibit superior lubricating property and durability (lubrication retaining property).

[0151]

[Comparative Example 10-2]

Production of the sample and measurement of sliding resistance were performed in the same manner as in Example 3-2 except for using the copolymer obtained in Production Example 12 (corresponding to the copolymer disclosed in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498) in place of the copolymer obtained in Production Example 13.

[0152]

The results of Example 1-2 and Comparative Example 9-2

are shown in Fig. 4. The sample of Example 1-2 had a significantly low initial sliding value as compared with the sample of Comparative Example 9-2. The sliding resistance of the sample of Comparative Example 9-2 increases from 0 to 10th sliding, which suggests the possibility of wear of the surface of the surface lubricious layer. On the other hand, the sample of Example 1-2 did not present such a phenomenon that the sliding resistance increases as the sliding time increases. The above fact indicates that the surface lubricious layer formed using the hydrophilic copolymer according to the present invention has higher film strength as compared with the surface lubricious layer formed using the copolymer disclosed in ACS Appl. Mater. Interface, 2015, 7(31), pp 17489-17498, and this is suggested to be attributable to the strong electrostatic interaction of the sulfobetaine structure.

[0153]

The results of Example 3-2, Example 5-2, Example 7-2, and Comparative Example 10-2 are shown in Fig. 5. The samples of Example 3-2, Example 5-2, and Example 7-2 had significantly low initial sliding values as compared with the sample of Comparative Example 10-2. Based on the above, it is considered that the surface lubricious layer formed using the hydrophilic copolymer according to the present invention has superior slidability and durability as compared with the surface lubricious layer formed using the copolymer disclosed in ACS

Appl. Mater. Interface, 2015, 7(31), pp 17489-17498.

[0154]

It was found from the above results that the surface lubricious layer containing the hydrophilic copolymer according to the present invention can exhibit superior lubricating property and durability (lubrication retaining property).

[0155]

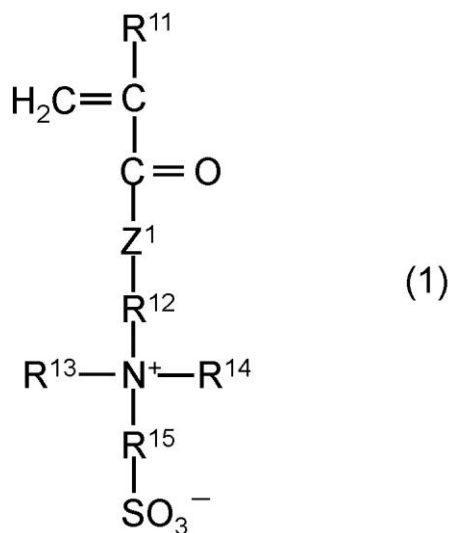
The present application is based on Japanese Patent Application No. 2016-164815 filed on August 25, 2016, and the entire disclosure is incorporated herein by reference.

Claims

1. A hydrophilic copolymer comprising: structural units derived from a polymerizable monomer (A) having a sulfobetaine structure; structural units derived from a polymerizable monomer (B) having at least one group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof; and structural units derived from a polymerizable monomer (C) having a photoreactive group.

2. The hydrophilic copolymer according to claim 1, wherein the polymerizable monomer (A) is represented by the following formula (1):

[Chem. 1]



wherein

R^{11} is a hydrogen atom or a methyl group,

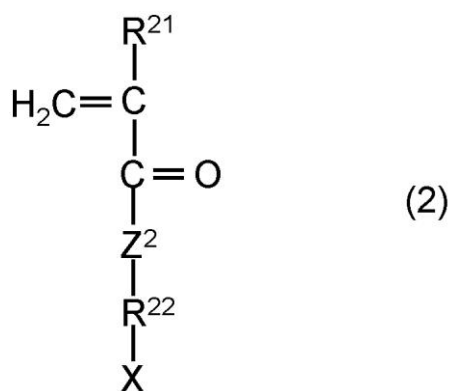
Z^1 is an oxygen atom or $-\text{NH}-$,

R¹² and R¹⁵ are each independently a straight chain or branched chain alkylene group having 1 to 20 carbon atoms, and

R¹³ and R¹⁴ are each independently a straight chain or branched chain alkyl group having 1 to 20 carbon atoms.

3. The hydrophilic copolymer according to claim 1 or 2, wherein the polymerizable monomer (B) is represented by the following formula (2), (3), or (4):

[Chem. 2]



wherein

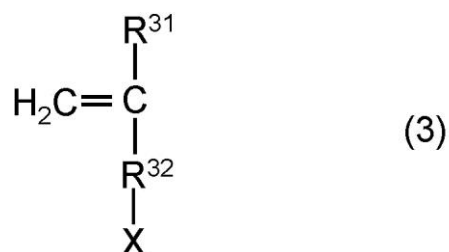
R²¹ is a hydrogen atom or a methyl group,

Z² is an oxygen atom or -NH-,

R²² is a straight chain or branched chain alkylene group having 1 to 20 carbon atoms, and

X is a group selected from the group consisting of a sulfonic acid group (-SO₃H), a sulfuric acid group (-OSO₃H), a sulfurous acid group (-OSO₂H), and groups of salts thereof;

[Chem. 3]



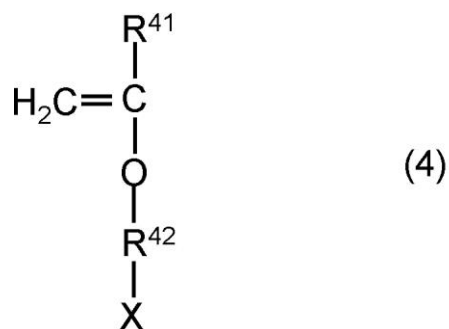
wherein

R^{31} is a hydrogen atom or a methyl group,

R^{32} is a single bond or a straight chain or branched chain alkylene group having 1 to 20 carbon atoms, and

X is a group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof; and

[Chem. 4]



wherein

R^{41} is a hydrogen atom or a methyl group,

R^{42} is a straight chain or branched chain alkylene group having 1 to 20 carbon atoms, and

X is a group selected from the group consisting of a sulfonic acid group ($-\text{SO}_3\text{H}$), a sulfuric acid group ($-\text{OSO}_3\text{H}$), a sulfurous acid group ($-\text{OSO}_2\text{H}$), and groups of salts thereof.

4. A medical device comprising:

a substrate layer; and

a surface lubricious layer that is formed on at least a part of a surface of the substrate layer and that contains the hydrophilic copolymer according to any one of claims 1 to 3.

5. The medical device according to claim 4, which is a catheter, a stent, or a guide wire.