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(71) Applicants: **UNIVERSITE DE BORDEAUX** [FR/FR]; 35, place Pey Berland, 33000 Bordeaux (FR). **INSTITUT POLYTECHNIQUE DE BORDEAUX** [FR/FR]; 1, avenue du Docteur Albert Schweitzer, 33400 Talence (FR). **CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE** [FR/FR]; 3 rue Michel Ange, 75016 Paris (FR).

(72) Inventors: **DURRIEU, Marie-Christine**; 46, rue Emile Fourcand, 33000 Bordeaux (FR). **HEROGUEZ, Valérie**; 7, allée de Pagneau, 33700 Merignac (FR). **LOÏC, Pichavant**; 2, place de la Victoire, 33000 Bordeaux (FR). **CARRIE, Hélène**; 6, lieu dit Mayne Dalis, 33124 Brannens (FR).

(74) Agent: **CABINET BECKER ET ASSOCIES**; 25, rue Louis le Grand, 75002 Paris (FR).

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(54) Title: POLYMER PARTICLES AND BIOMATERIALS COMPRISING THE SAME

(57) Abstract: The present invention relates to polymer particles comprising antibiotics which are deliverable *in situ*, as well as a method of preparation thereof. The present invention also relates to bioactive biomaterials for the controlled delivery of antibiotics comprising support materials having such polymer particles on their surface. The invention also relates to implants, prostheses, stents, lenses or cements as well as any pharmaceutical composition comprising said biomaterials.

POLYMER PARTICLES AND BIOMATERIALS COMPRISING THE SAME

FIELD OF THE INVENTION

The present invention relates to polymer particles comprising antibiotics which are deliverable *in situ*, as well as a method of preparation thereof. The present invention also relates to bioactive biomaterials for the controlled delivery of antibiotics comprising support materials having such polymer particles on their surface. The invention also relates to implants, prostheses, stents, lenses or cements as well as any pharmaceutical composition comprising said biomaterials.

BACKGROUND OF THE INVENTION

The main gist of the present invention is to give the implantable devices the capacity to prevent and/or alleviate infectious processes which may follow their installation. In order to alleviate these effects, it has been proposed to administer a medicament by the general route and/or to administer antibiotics locally where installation of implants occurs during bone surgery.

Since 1970 cements with antibiotics have been used in prosthetic surgery locally. In France there are 2 preparations on the market using either gentamycin or a combination of erythromycin and colimycin. It is also possible to prepare "cement with antibiotics", particularly with vancomycin, in the operating theatre in non-standard conditions. The limiting factor of this method is the uncontrolled release (in terms of concentration and duration) of the active ingredients used. Actually, the kinetics of release of the active ingredient is not controlled since no device makes it possible to adjust its delivery and therefore to perpetuate its action over a predefined duration. Moreover, part of the active ingredient may not be released because it is trapped too deep in the cement.

In order to remedy these drawbacks, systems for delivery of active ingredients, so-called "drug delivery systems (DDS)" have been developed. The principle of these drug delivery systems is to deliver pharmacologically active substances *in situ*, in a prolonged and regular manner, in a sufficient and non-toxic quantity.

In that context, stimulable polymers, namely which are polymers sensitive to an external stimulus such a variation in pH or temperature, have already been described which exhibit reactive functions obtained by encapsulation or adsorption of the active ingredients directly in the material or in beads which are themselves adsorbed or

grafted on the material. However, adsorption does not allow a controlled release of the active ingredient. As regards encapsulation, when it can allow, on the one hand, a controlled release of the active ingredient, on the other hand, it proves incompatible with prolonged use and/or when the material is subjected to high stresses (flux, friction, etc.).

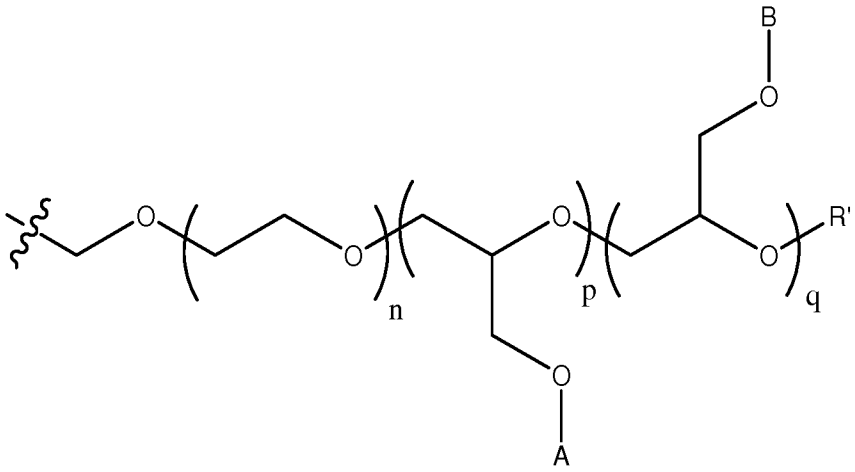
EP1771492 and EP1758621 patents disclose polymer particles having a reactive function, optionally engaged in a bond with an active ingredient or a biological molecule such as a protein, the said reactive function being covalently bonded to the said polymers is pH-sensitive. Such pH control presents the advantage to deliver the active ingredients only if necessary and the active ingredients kinetics are modulated by the pH decrease which typically occurs when infection rises. However, it would be useful to have polymer particles where the active ingredients comprised therein can be released in higher quantities at a specific location as to eradicate infections that can rise not only during the surgery to implant the device but also later on.

There is thus a need to have polymer particles or a biomaterial comprising the same where active ingredients comprised therein, and more specifically antibiotics, can be delivered in a tunable manner depending on the degree of infection and can potentially eradicate such infection efficiently and over a long period of time. There is also a need to provide polymer particles or a biomaterial comprising the same where at least two antibiotics can present satisfactory anti-bacteria properties for a wide range of bacteria spectra in a controlled and prolonged manner.

SUMMARY OF THE INVENTION

In this context, the inventors made up polymer particles and biomaterials comprising the same that contain one, two or more antibiotics (such as Ab1 or Ab2 as defined below) which can be delivered in different and controllable manners.

It is an object of the invention to provide polymer particles, the said particles being formed by polymer chains containing about 30 to 10000 monomer units, identical or different, derived from polymerization of monocyclic or polycyclic alkenes, wherein at least one of the said monomer units is substituted by a chain R comprising a polyethyleneglycol-polyglycidol chain of formula (I), wherein formula (I) is as follows:



(I),

formula (I) wherein:

n represents an integer from about 0 to 300, especially from 10 to 100, p represents an integer from about 0 to 300, q represents an integer from about 0 to 300, with n+p+q being from about 10 to 300,

A represents a hydrogen atom or a group of the following formula (II):
-CONHAb1, where Ab1 represents an antibiotic with extracellular action,

B represents a hydrogen atom or a group of the following formula (III):
-CH2CNAb2, wherein Ab2 represents an antibiotic with intracellular action,

R' represents a hydrogen atom, -CH2CNAb2 or -CONHAb1 as defined above,
with the proviso that when p is different from 0, then q is 0 and R' represents a hydrogen atom or -CONHAb1 as defined above, when q is different from 0, then p is 0 and R' represents a hydrogen atom or -CH2CNAb2, when p+q is not zero, at least one of the p or q moieties comprises the formula (II) or (III) respectively, and when said particles are formed by polymer chains with p+q is 0 exclusively, then at least one of said polymer chains presents a R chain comprising a polyethyleneglycol-polyglycidol chain of formula (I) where R' is -CONHAb1 as defined above,

 represents a covalent bond by which the polyethyleneglycol-polyglycidol chain is attached to the remainder of the R chain,

and wherein at least one of said monomer units, identical or different from the monomer units substituted by the R chain, is substituted by a group X, wherein X represents an alkyl or alkoxy chain with about 0 to 500 carbon atoms, preferably 1 to 500 carbon atoms, more preferably 40 to 400 carbon atoms, comprising a reactive function of the C=CH2, C≡CH, OH, OR''', wherein R''' represents an alkyl group, halogen, NH2, C(O)X1 type, wherein X1 represents a hydrogen atom, an alkyl group, a halogen atom, an OR" or NHR" group, in which R" represents a hydrogen atom or an alkyl group.

The invention also relates to biomaterials comprising a support material having on its support surface covalently bonded polymer particles as defined above.

The invention also relates to a monocyclic or polycyclic alkene based macromonomer, useful as a starting material for the preparation of particles as defined above.

The invention relates more specifically to particles that have generally a spherical form and have more preferably a diameter between 50 nm and 10 µm, preferably between 300 and 400 nm.

The invention also relates to the use of biomaterials as defined above for the preparation of implantable medical devices, in particular in the form of lenses, implants, prostheses, stents or cements, in particular in ocular, vascular, endovascular or bone surgery or treatment.

The invention also relates to medical devices, including implants, prostheses, stents, lenses or cements as well as any pharmaceutical composition, comprising biomaterials as defined above.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1: Size distributions of the PNb-PGLD particles measured by Dynamic light scattering (DLS) in EtOH/CH_2Cl_2 (65/35 %v/v) and in water

Figure 2: Distribution profiles of the particle size functionalized with carboxylic acid groups and Vancomycin measured by DLS in the reaction solvent (EtOH/CH_2Cl_2

mixture) and in DMF. For each solvent, the measure has been carried out three times (measures 1-3).

Figure 3: Scanning electron microscopy (SEM) observation of the titanium surface after grafting of particles functionalized with carboxylic acid groups and Vancomycin

Figure 4: Size distributions of polynorbornene-poly(ethylene oxide)-poly(ethylene oxide)-*bloc*-polyglycidol particles measured by DLS in the reaction medium ($EtOH/CH_2Cl_2$), in water and in DMF

Figure 5: Transmission electron microscopy (TEM) observations of the polynorbornene-poly(ethylene oxide)-poly(ethylene oxide)-*bloc*-polyglycidol particles

Figure 6: Size distributions of polynorbornene-poly(ethylene oxide)-poly(ethylene oxide)-*bloc*-polyglycidol particles functionalized with GS measured by DLS in the reaction medium ($EtOH/CH_2Cl_2$), in water and in DMF

Figure 7: MICs measurements were determined as the minimal concentration for which the lowest absorbance. Results are given for Vancomycin alone (Vanco), Macromonomer Vancomycin (Nb-PEO-Vanco; macro Vanco, as obtained by example 3.b)); particles grafted with Vancomycin as obtained by example 3 c) (Vanco particles); macro OH (equivalent to macro Vanco without Vancomycin), OH particles (equivalent to Vanco particles without Vancomycin)

DETAILED DESCRIPTION

The present invention relates therefore to polymer particles and biomaterials as defined above.

The term "alkyl" as used herein is a branched or unbranched saturated hydrocarbon group of 1 to 10 carbon atoms, for example, 1 to 8 carbon atoms, or 1 to 6 carbon atoms, such as methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, s-butyl, t-butyl, n-pentyl, isopentyl, s-pentyl, neopentyl, hexyl, heptyl, octyl, nonyl, decyl, and the like. The alkyl group can also be substituted (by halogen atoms or alkoxy groups for instance) or unsubstituted. For example, the term "halogenated alkyl" specifically refers to an alkyl group that is substituted with one or more halide, e.g., fluorine, chlorine, bromine, or iodine. The alkyl group can also be interrupted by one, two or

more heteroatoms, such as sulfur, nitrogen, or oxygen atoms. For example, the term "alkyl group" can specifically refer to polyoxyethylene or polyoxypropylene group.

The term " alkenyl" as used herein is a branched or unbranched hydrocarbon group with at least one ethylene bond (C=C) comprising from 2 to 10 carbon atoms, for example, 2 to 8 carbon atoms, or 2 to 6 carbon atoms.

The term "alkynyl" as used herein is a branched or unbranched hydrocarbon group with at least one acetylene bond (C≡C) comprising from 2 to 10 carbon atoms, for example, 2 to 8 carbon atoms, or 2 to 6 carbon atoms.

The terms "alkoxy" and "alkoxyl" as used herein to refer to an alkyl group as defined above bonded through an ether linkage (-O-). The term "alkoxyalkyl" specifically refers to an alkyl group that is substituted with one or more alkoxy groups, as described above.

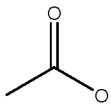
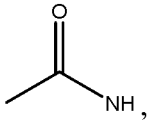
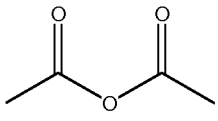
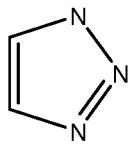
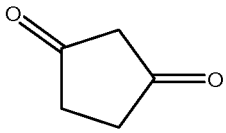
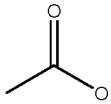
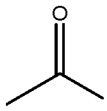
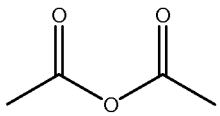
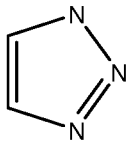
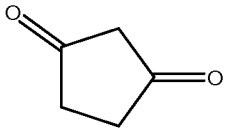
The term “halogen atom” includes chlorine, fluorine, iodine, or bromine.

The terms “the remainder of the R chain” refer to the part of the R chain that is covalently linked to the polyethyleneglycol-polyglycidol chain of formula (I). It may refer to a group of atoms situated between the said at least one of the monomer units (deriving from polymerization of a monocyclic or polycyclic alkene) and the polyethyleneglycol-polyglycidol chain of formula (I).

In an embodiment, the remainder of the R chain does not exist and the polyethyleneglycol-polyglycidol chain of formula (I) is covalently linked to the monocyclic or polycyclic alkene moiety through the  bond.

In another embodiment, the remainder of the R chain is an alkyl, alkenyl or alkynyl chain, preferably an alkyl chain.

In another embodiment, the remainder of the R chain comprises at least one chemical group appropriate for linking the monomer unit (deriving from polymerization of a monocyclic or polycyclic alkene) and the polyethyleneglycol-polyglycidol chain of formula (I). For instance, said chemical group may be selected from the group consisting of ether, ester, amide, anhydride, triazole, thiolene and cyclopentane-dione groups. Preferably, the remainder of the R chain is an alkyl chain comprising from 1 to 10, preferably from 1 to 5, carbon atoms, which is terminated and/or interrupted by at least one group selected from the group consisting of ketone =O, ether -O- , ester

 , amide  , anhydride  , triazole  , thiolene -S- and cyclopentane-1,3-dione  groups. In a preferred embodiment, the group selected from the group consisting of ketone =O, ether -O- , ester  , amide  , anhydride  , triazole  , thiolene -S- and cyclopentane-1,3-dione  groups, is directly bonded to the monocyclic or polycyclic alkene moiety.

Said alkyl chain may be interrupted by at least one aromatic or heteroaromatic ring, such as a phenyl ring.

In another embodiment, at least part of the remainder of the R chain forms a ring with at least one other substituent of the monomer unit (deriving from polymerization of a monocyclic or polycyclic alkene), for instance a succinimide, cyclopropyl or dihydrofuran-2,5-dione ring.

As used herein, the term "about" will be understood by a person of ordinary skill in the art and will vary to some extent on the context in which it is used. If there are uses of the term which are not clear to persons of ordinary skill in the art given the context in which it is used, "about" will mean up to plus or minus 10% of the particular term.

According to the invention, the term "comprise(s)" or "comprising" (and other comparable terms, e.g., "containing," and "including") is "open-ended" and can be generally interpreted such that all of the specifically mentioned features and any optional, additional and unspecified features are included. According to specific embodiments, it can also be interpreted as the phrase "consisting essentially of" where the specified features and any optional, additional and unspecified features that do not

materially affect the basic and novel characteristic(s) of the claimed invention are included, or the phrase "consisting of" where only the specified features are included, unless otherwise stated.

According to a specific embodiment, the monocyclic alkene presents a number of carbon atoms constituting the ring of about 4 to 12 or the polycyclic alkene presents a number of carbon atoms constituting the rings of about 6 to 20.

The invention relates more specifically to particles or biomaterials as defined above, wherein the monomer units are derived from the polymerization of monocyclic alkenes and are of the following formula (Z1):

=[CH-R1-CH]= (Z1)

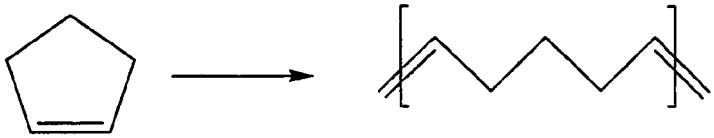
wherein R1 represents a hydrocarbon chain with 2 to 10 carbon atoms, saturated or unsaturated and at least one of the monomer units is optionally substituted by a chain R or a group X, as mentioned above.

The invention relates more specifically to particles or biomaterials as defined above, wherein the monocyclic alkenes from which the monomer units are derived are:

cyclobutene leading to a polymer comprising monomer units of formula (Z1a) below:

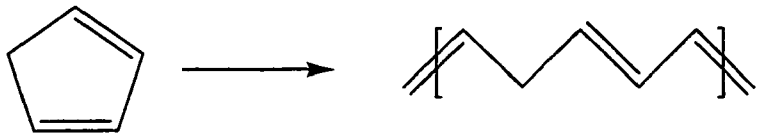
Z1a

cyclopentene leading to a polymer comprising monomer units of formula (Z1b) below:



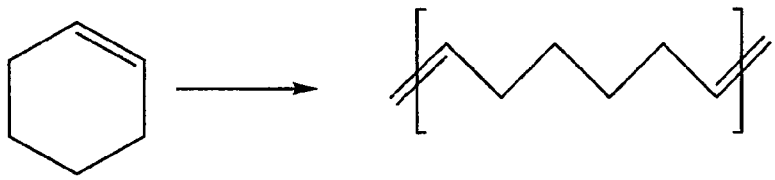
Z1b

cyclopentadiene leading to a polymer comprising monomer units of formula (Z1c) below:



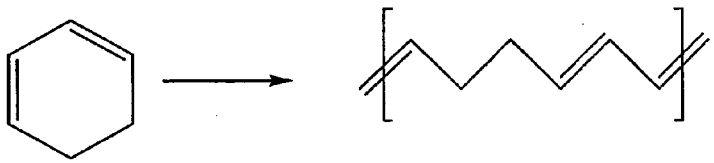
Z1c

cyclohexene leading to a polymer comprising monomer units of formula (Z1d) below:



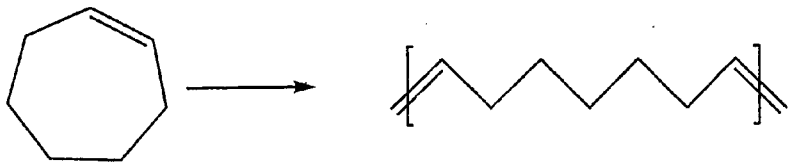
Z1d

cyclohexadiene leading to a polymer comprising monomer units of formula (Z1e) below:



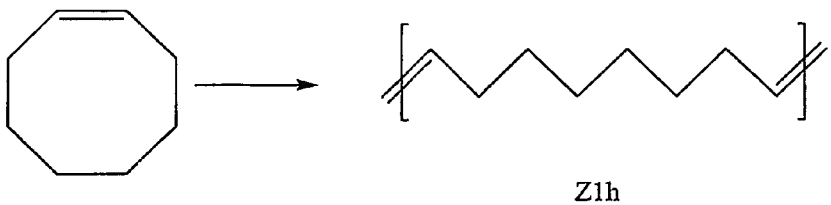
Z1e

cycloheptene leading to a polymer comprising monomer units of formula (Z1f) below:



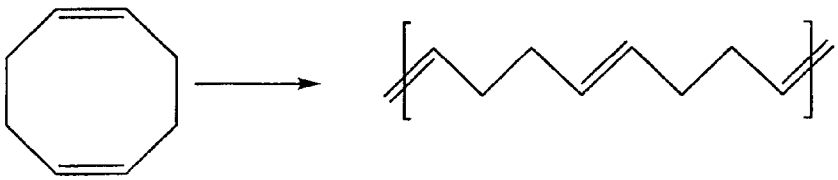
Z1f

cyclooctene leading to a polymer comprising monomer units of formula (Z1h) below:



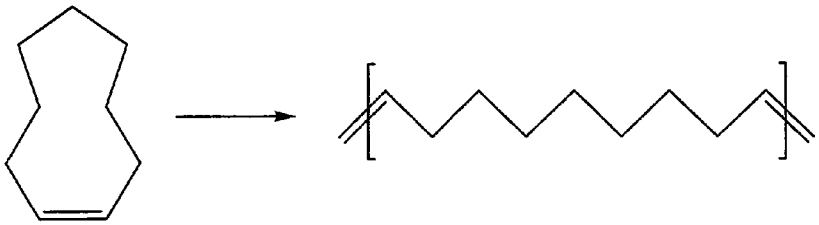
Z1h

cyclooctapolyene, especially cycloocta-1,5-diene, leading to a polymer comprising monomer units of formula (Z1i) below:



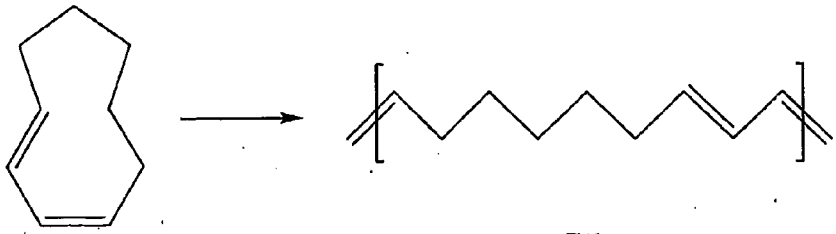
Z1i

cyclononene leading to a polymer comprising monomer units of formula (Z1j) below:



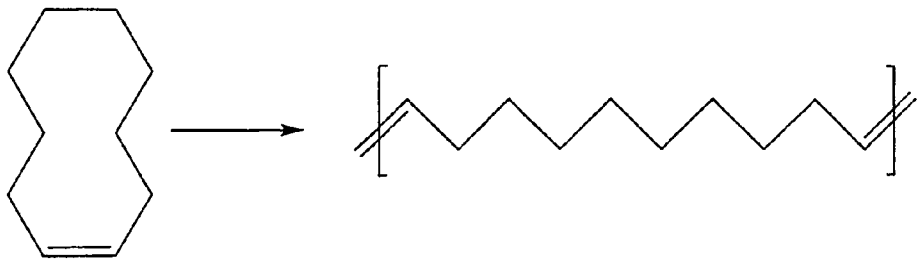
Z1j

cyclononadiene leading to a polymer comprising monomer units of formula (Z1k) below:



Z1k

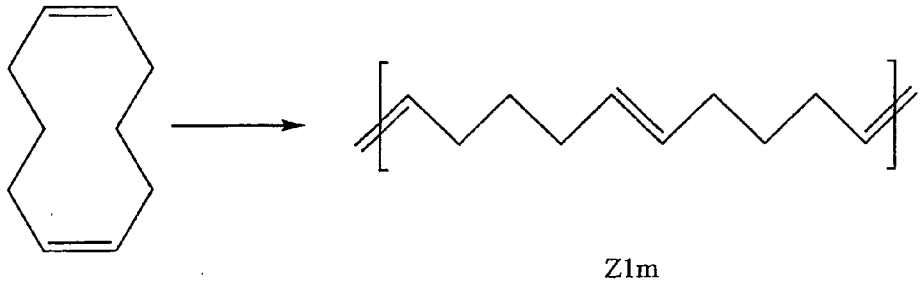
cyclodecene leading to a polymer comprising monomer units of formula (Z1l) below:



Z1l

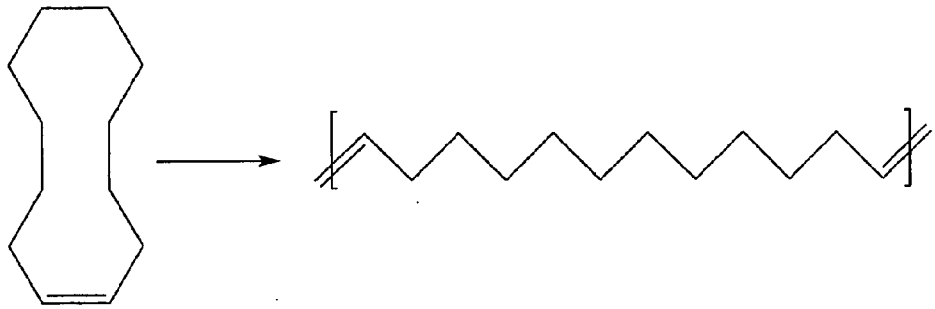
cyclodeca-1,5-diene leading to a polymer comprising monomer units of formula (Z1m)

below:



Z1m

cyclododecene leading to a polymer comprising monomer units of formula (Z1n) below:



Z1n

or also 2,3,4,5-tetrahydrooxepin-2-yl acetate, cyclopentadecene, paracyclophane, ferrocenophane.

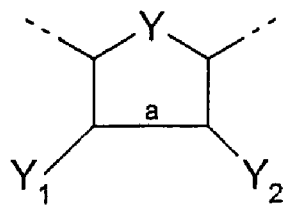
The invention also relates to particles or biomaterials as defined above, wherein the monomer units are derived from the polymerization of polycyclic alkenes and are:

- of formula (Z2) below:

=[CH-R2-CH]= (Z2)

wherein R2 represents:

* a ring of formula



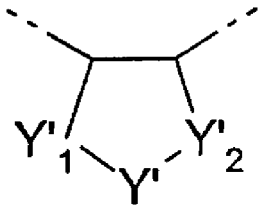
wherein:

Y represents -CH2-, or a heteroatom, or a -CHR- group , or a -CHX- group, R chain and X being as defined above,

Y1 and Y2, independently of one another, represent H, or a chain R, or a group X, as mentioned above, or form in association with the carbon atoms bearing them a ring with 4 to 8 carbon atoms, this ring being optionally substituted by a chain R or a group X as mentioned above, and this ring being optionally interrupted by at least one heteroatom, such as a N or O atom,

a represents a single or double bond,

* or a ring of formula

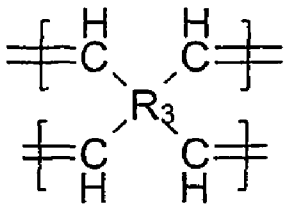


wherein:

Y' represents -CH2-, or a heteroatom, or a -CHR- group, or a -CHX- group, R and X being as defined above,

Y'1 and Y'2 independently of one another represent -CH2-, or a -C(O) group, of a -COR group, or a -C-OX group, R and X being as defined above,

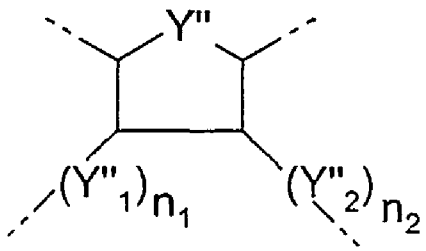
- of formula (Z3) below:



(Z3)

in which R3 represents:

* a ring of formula



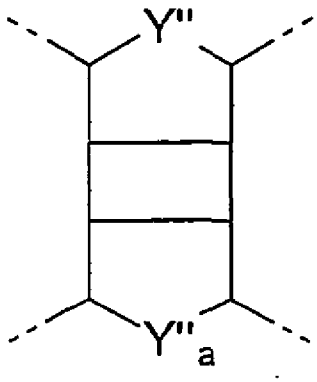
wherein:

n1 and n2, independently of one another, represent 0 or 1,

Y'' represents -CH2-, or a -CHR- group, or a -CHX- group, R and X being as defined above,

Y''1 and Y''2 independently of one another represent a hydrocarbon chain with 0 to 10 carbon atoms,

*or a ring of formula

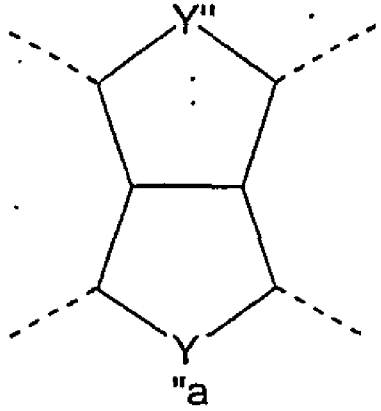


wherein Y'' and Y''a independently of one another represent -CH2-, or a -CHR- group,

or

a -CHX- group, R and X being as defined above,

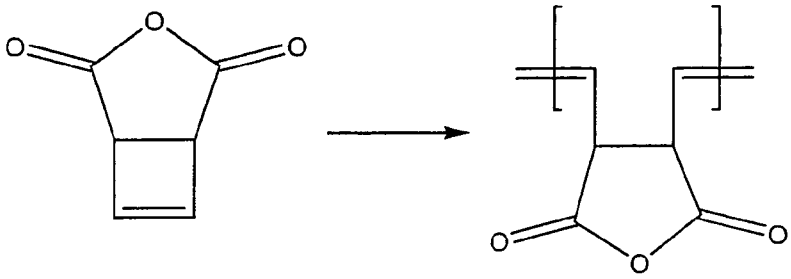
* or a ring of formula



wherein Y" and Y"a independently of one another represent -CH2-, or a -CHR- group, or a -CHX- group, R and X being as defined above.

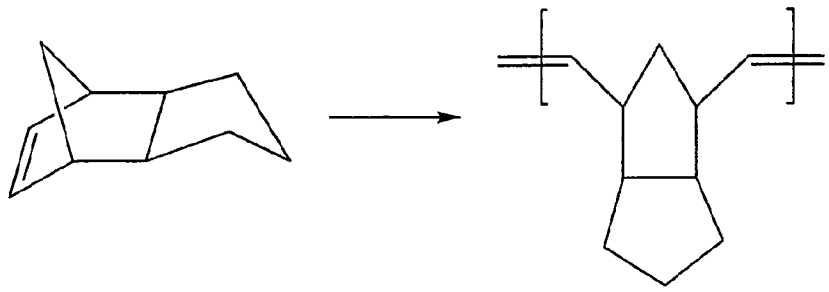
The invention relates more specifically to particles as defined above, wherein the polycyclic alkenes from which the monomer units are derived are:

- monomers containing a cyclobutene ring leading to a polymer comprising monomer units of formula (Z2a) below:



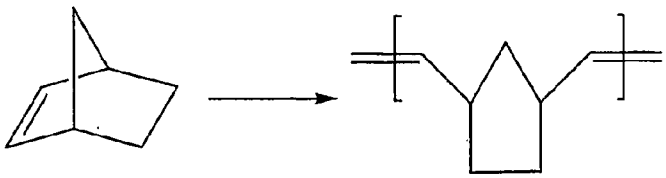
(Z2a)

- monomers containing a cyclopentene ring leading to a polymer comprising monomer units of formula (Z2b) below:



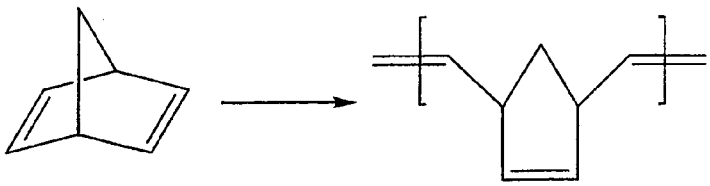
(Z2b)

- (bicyclo[2.2.1]hept-2-ene)norbornene leading to a polymer comprising monomer units of formula (Z2c) below:



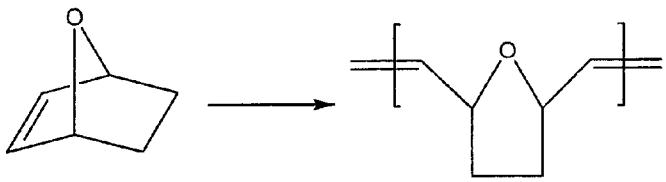
(Z2c)

- norbornadiene leading to a polymer comprising monomer units of formula (Z2d) below:



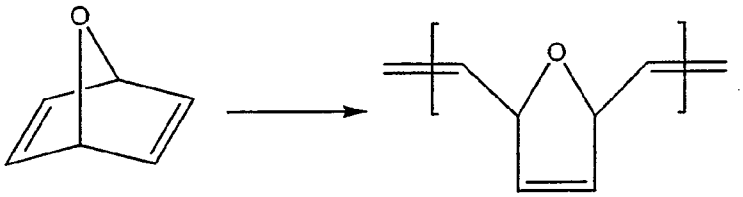
(Z2d)

- 7-oxanorbornene leading to a polymer comprising monomer units of formula (Z2e) below:



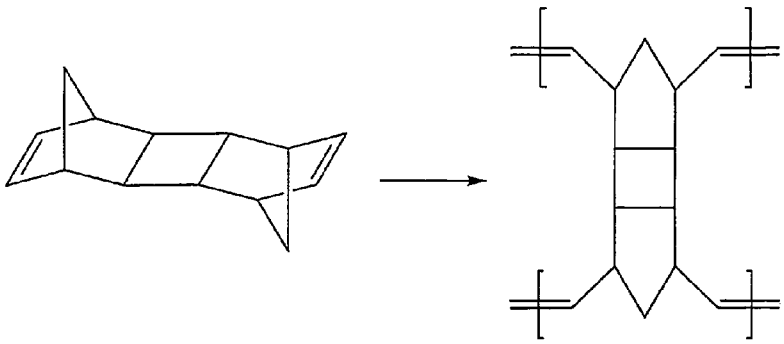
(Z2e)

- 7-oxanorbornadiene leading to a polymer comprising monomer units of formula (Z2f) below:



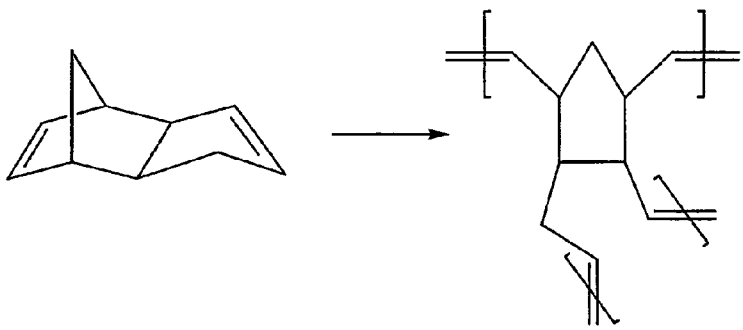
(Z2f)

- the dimer of norbornadiene leading to a polymer comprising monomer units of formula (Z3a) below:



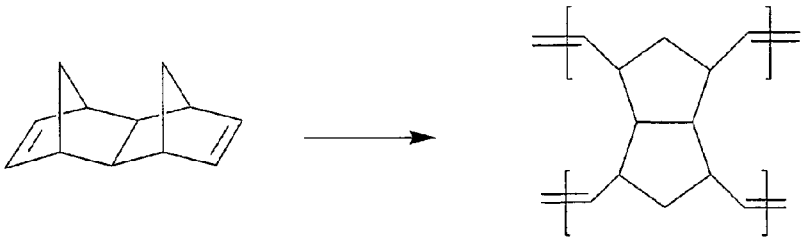
(Z3a)

- dicyclopentadiene leading to a polymer comprising monomer units of formula (Z3b) below:



(Z3b)

- tetracyclododecadiene leading to a polymer comprising monomer units of formula (Z3c) below:



(Z3c)

or bicyclo[5.1.0]oct-2-ene, bicyclo[6.1.0]non-4-ene.

The invention relates more specifically to preferred particles or biomaterials as defined above, wherein the monocyclic or polycyclic alkenes from which the monomer units are derived are:

norbornene (bicyclo[2.2.1]hept-2-ene) leading to a polymer comprising monomer units of formula (Z2c),

tetracyclododecadiene leading to a polymer comprising monomer units of formula (Z3c),

dicyclopentadiene leading to a polymer comprising monomer units of formula (Z3b),

the dimer of norbornadiene leading to a polymer comprising monomer units of formula (Z3a),

cycloocta-1,5-diene leading to a polymer comprising monomer units of formula (Z1i),

preferably the monocyclic or polycyclic alkenes from which the monomer units are derived is:

norbornene (bicyclo[2.2.1]hept-2-ene) leading to a polymer comprising monomer units of formula (Z2c).

Advantageously the particles or biomaterials as defined above are characterized in that at least 0.5% up to 100% of the monomer units are substituted by a chain R as defined above, the said chain R being identical or different for these monomers.

The invention relates more specifically to particles or biomaterials as defined above, characterized in that they comprise:

between about 0.5% and 99.5% of monomer units substituted by a chain R as defined above, the said chain R being identical for these monomers, and between about 0.5%

and 99.5% of monomer units substituted by a chain R as defined above, the said chain R of these monomers being different from the chain R of the preceding monomers (for instance, one chain R can comprise groups of formula (II) and the other chain R can comprise groups of formula (III)), and between 0.0% and about 99% of unsubstituted monomer units, optionally at least one of the monomer units substituted by a chain R is also substituted by a group X,

and/or between about 0.5% and 99.5% of monomer units substituted by a chain R as defined above, the said chain R being identical or different for these monomers, and between about 0.5% and 99.5% of unsubstituted monomer units, optionally at least one of the monomer units substituted by a chain R is also substituted by a group X,

and/or between about 0.5% and 99.5% of monomer units substituted by a group X as defined above, and between about 0.5% and 99.5% of monomer units substituted by a chain R as defined above, the said chain R being identical or different for these monomers, and between 0.0% and about 99.0% of unsubstituted monomer units,

the total of the percentages of the monomers mentioned above being 100%.

According to a specific embodiment, when particles of the invention are formed by polymer chains with p+q is 0 exclusively, then at least one of said polymer chains presents a R chain comprising a polyethyleneglycol-polyglycidol chain of formula (I) where R' is -CONHAb1 as defined above. This embodiment includes for instance particles where a polymer chain comprises at least one of the monomer units substituted by a chain R comprising a polyethyleneglycol-polyglycidol chain of formula (I) where p+q is 0 with R'=CH2CNAb2, then another polymer chain of said particles may comprise monomer units substituted by a chain R comprising a polyethyleneglycol-polyglycidol chain of formula (I) where p+q is different from 0 or monomer units substituted by a chain R comprising a polyethyleneglycol-polyglycidol chain of formula (I) where p+q is 0 and R' is CONHAb1.

The invention relates more specifically to particles or biomaterials as defined above, wherein the chain or chains R substituting the monomers comprise the formula (I) as defined above, more specifically wherein at least one, or all (if compatible), of the following specific embodiments are fulfilled:

n+p+q is from 10 to 100; and/or
n is from 35 to 70, more specifically n is from 40 to 60 (e.g. n=45); and/or
either p or q is from 1 to 300.

According to the invention, the term "p moiety" represents the glycidol moiety in the parenthesis of formula (I) where p is the number of said units.
According to the invention, the term "q moiety" represents the glycidol moiety in the parenthesis of formula (I) where q is the number of said units.
According to the invention, when p+q is not zero, at least one of the p or q moieties comprises the formula (II) or (III) respectively, this embodiment includes polymer particles where Ab1 or Ab2 is present, preferably Ab2 is present, more preferably is gentamicin, or both Ab1 and Ab2 are present. When both Ab1 and Ab2 are present, this entails that at least two different R chains are present in the polymer particles of the invention, ones with Ab1 and other ones with Ab2.

According to a specific embodiment, the particles or biomaterials are as defined above, wherein the chain of formula (I) is of the following formula:

,

wherein R' is -CONHAb1 and n is as defined above, and preferably n is from 1 to 300, more preferably from 10 to 100, or Ab1 is preferably vancomycin or a salt thereof.
According to another specific embodiment, the particles or biomaterials are as defined above, wherein R' in formula (I) is a hydrogen atom.
According to another specific embodiment, the particles or biomaterials are as defined above, wherein R' in formula (I) is a hydrogen atom and q is 0. According to another specific embodiment, the particles or biomaterials are as defined above, wherein R' in formula (I) is a hydrogen atom and p is 0.

Such particles or materials are especially advantageous since they permit a controlled action of the antibiotics, e.g. vancomycin and/or gentamicin, in an effective amount to prevent and/or alleviate infectious processes which may occur for instance during surgery of the implants or later on.

Where B represents a group of the following formula (III), the particles according to the invention are stimulable particles, that is to say they are sensitive to a stimulus such as a variation in pH, which then allows the release of the antibiotics Ab2 (such as gentamycin) bonded onto these particles.

The biomaterials according to the invention as defined above are advantageously materials wherein the support material is chosen from:

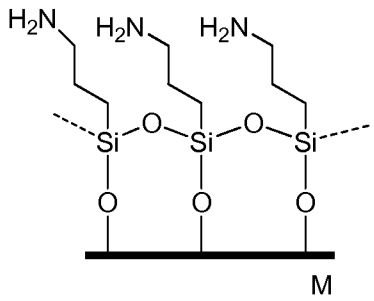
- metals or oxides thereof, preferably titanium or TiO2,
- metal alloys, in particular alloys with or without shape memory such as Ni-Ti alloys, Ti-6Al-4V alloys,
- polymers, such as polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE), polyvinylidine fluoride (PVDF), polyether etherketone (PEEK), polycarbonate-urethane (PCU), polyhydroxyethylmethacrylate (PHEMA), polymethylmethacrylate (PMMA), poluethylmethacrylate (PEMA), poly(4-hydroxystyrene),
- copolymers, such as the copolymer ethylene vinyl acetate (EVA), the copolymer vinylidene fluoride-hexafluoropropylene P(VDF-HFP), poly(lactic acid)-co-poly(glycolic acid) (PLA-PGA), copolymers of polymethylmethacrylate (PMMA) and poluethylmethacrylate (PEMA),
- ceramics, such as hydroxyapatites, or compounds of hydroxyapatites and tricalcium phosphate in varied proportions, in particular in the proportions 50/50.

The invention also relates to biomaterials as defined above, wherein the reactive function situated on the support material in order to ensure the covalent bond between the said material and the said particles by reacting the reactive function of these latter of the OH, halogen, NH2, C(O)X1 type, wherein X1 represents a hydrogen atom, a halogen atom, an OR" or NHR" group, wherein R" represents a hydrogen atom or an alkyl group, with a reactive function of the material in order to form a bond of the -O-C(O)-, -NH-C(O)-, -C(O)-NH-, -C(O)O- or –C(O)OC(O)- type, or a type of bond that can be obtained by click chemistry (bioorthogonal reaction), such as via azide/cycloalkyne reaction, chloro-oxime/norbornene reaction, tetrazine/cyclooctene reaction, thiol/alkene reaction, thiol/maleimide reaction, or tetrazole/alkene reaction.

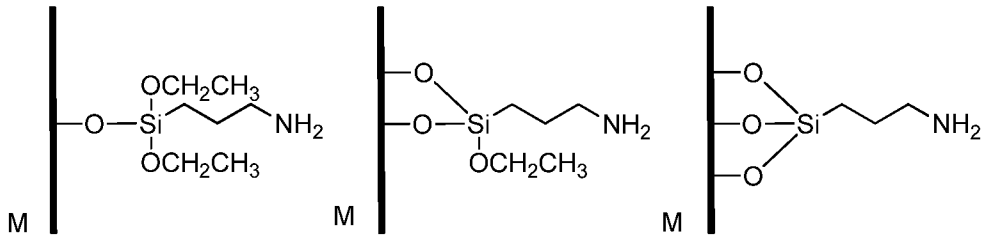
The invention relates more particularly to biomaterials as defined above, wherein the reactive function of the support material is situated on an alkyl chain having about 1 to 10 carbon atoms grafted on said material, substituted or unsubstituted, and optionally comprising one or several heteroatoms, in particular O and/or Si, in said chain.

The invention relates more particularly to biomaterials as defined above, wherein:
the reactive function of the material is an NH_2 function situated on an aminopropyltriethoxysilane (APTES) molecule grafted on the material (M) according to the following formulae:

A)



B)



A) APTES functionalization (aqueous conditions), B) APTES functionalization (anhydrous conditions), wherein M represents a metal oxide or a ceramic such as hydroxyapatite or any other polymer having OH sites on its surface (naturally or due to prefunctionalisation),
the reactive function of the material is an NH_2 function situated on a surface which is coupled to COOH groups present onto particles, using for instance NHS/DCC (i.e., N-hydroxysuccinimide/Dicyclohexylcarbodiimide).

The antibiotics used in the invention are more specifically the following:

- the antibiotics with extracellular action (Ab1) are generally those that target the bacterial cell wall (such as penicillins and cephalosporins) or the cell membrane (such as polymyxins),
- the antibiotics with intracellular action (Ab2) are generally those that interfere with essential bacterial enzymes (such as rifamycins, lipiarmycins, quinolones, and sulfonamides) or those that target protein synthesis (such as macrolides, lincosamides and tetracyclines).

Among the antibiotics Ab1, one can cite the following classes: cephalosporins, including those from first to the fifth generations, such as cefalexin, cefuroxim, ceftriaxone, cefepime, ceftobiprole; carbacephem, such as Loracarbef; carbapenems, such as imipenem; glycopeptides, such as vancomycin, teicoplanin or ramoplanin; lipopeptides, such as daptomycin; monobactams, such as aztreonam; penicillins, such as amoxicillin; or polymyxins, such as polymyxin B.
According to a specific embodiment, Ab1 is a glycopeptide, preferably vancomycin or a salt thereof (such as hydrochloride).

Among the antibiotics Ab2, one can cite the following classes: aminoglycosides, including gentamicin, neomycin, and streptomycin; anzamycins, such as rifaximin; lincosamides, such as clindamycin; macrolides, such as azithromycin; nitrofuranes, such as furazolidone; oxazolidinones, such as linezolid; quinolones or fluoroquinolones, such as nalidixic acid, ofloxacin, ciprofloxacin, or levofloxacin; sulfonamides, such as sulfacetamide, furosemide; tetracyclines, such as doxycycline.
According to a specific embodiment, Ab2 is an aminoglycoside, preferably gentamicin or any salt thereof (such gentamicin sulfate).

The polymer particles and biomaterials, according to a particular embodiment of the invention, comprise vancomycin and/or gentamicin, or any salt thereof (such as gentamicin sulfate)

The invention also relates to the use of biomaterials as defined above for the preparation of implantable medical devices, in particular in the form of implants, prostheses, stents, lenses or cements, in particular in vascular, endovascular or bone surgery or treatment.

The invention also relates to medical devices, more specifically implants, prostheses, stents or cements as well as any pharmaceutical composition, comprising biomaterials as defined above. It can be for instance ocular lenses, dental, ligament, valve or bone prostheses, implants, stents or cements.

The invention also relates to a pharmaceutical composition comprising particles or biomaterials as defined above, wherein said particles or biomaterials comprise antibiotics Ab1 and/or Ab2, preferably vancomycin or/and gentamicin, or any salt thereof, optionally in association with a pharmaceutically acceptable carrier, in particular for use in parenteral form.

The polymer particles, biomaterials, implants, prostheses, stents or cements as well as the pharmaceutical composition according to the invention are useful as medicines, they are more particularly for a use in the treatment of bacterial infections.

The invention also relates to a method of preparation of particles as defined above, wherein it comprises a step of polymerization of a monocyclic or polycyclic alkene as defined above substituted by a chain R as defined above, optionally in the presence of:

- one or several monocyclic or polycyclic alkenes as defined above, identical to or different from the foregoing, and substituted by a chain R as defined above, the said chain R being different from that substituting the aforementioned monocyclic or polycyclic alkene (for instance, one chain R can comprise groups of formula (II) -with antibiotic Ab1- and the other chain R can comprise groups of formula (III) –with antibiotic Ab2),
- and/or one or several monocyclic or polycyclic alkenes as defined above, identical to or different from the foregoing, and substituted by a group X as defined above,
- and/or one or several monocyclic or polycyclic alkenes as defined above, identical to or different from the foregoing, the said alkenes being unsubstituted,

the said polymerization being carried out while stirring in the presence of a transition metal complex as initiator of the reaction chosen in particular from amongst those in groups IV or VI or VII, such as ruthenium, osmium, molybdenum, tungsten, iridium,

titanium, in a polar or apolar medium, particularly with the aid of the following ruthenium-based complexes: RuCl3, RuCl2(PCy3)2CHPh.

The polymerization step is preferably a ROMP reaction (Ring-opening metathesis polymerization), which can implement a wide variety of metals and range from a simple $RuCl_3$/alcohol mixture to Grubbs' catalyst.

The preparation of the particles is carried out in one step and allows the antibiotics comprised therein to be effective and/or particles having efficient kinetics of release of antibiotics depending on the envisioned uses thereof.

The invention also relates to a method of preparation of biomaterials as defined above, wherein it comprises the step as defined above, followed by a step of fixing said particles obtained in the previous step on a support material as defined above by placing the said particles in the presence of the said material, this latter having been optionally functionalized with a reactive function as defined above capable of ensuring the covalent bond between the said material and the said particles by reacting with the reactive function of the said particles.

The use of the particles makes it possible to introduce several chemical functions and antibiotics easily on the surface of the biomaterial.

Schematically, the production of the proposed device can be divided into three distinct steps:

1-The functionalization of the biomaterial

2-The synthesis of the bioactive particles (as described above)

3-The fixing of the particles on the biomaterial (as described above)

1-The Functionalization of the Biomaterial

In terms of materials, the development of a bioactive prosthesis necessitates control of the interfaces between materials and molecules or between materials and biomolecules.

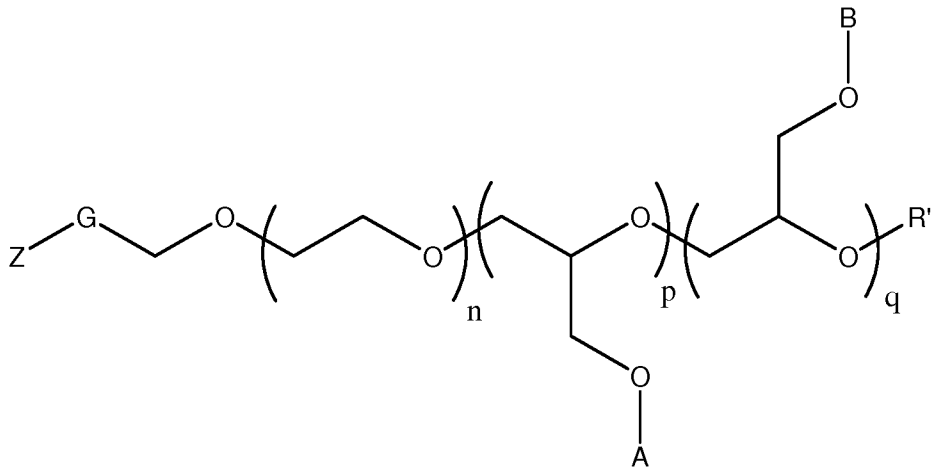
Grafting is a technique which allows one or several molecules chosen for their specific properties to be fixed by covalent bonding to the surface of any type of

material. The technique of functionalization can be carried out under anhydrous conditions with controlled atmosphere, temperature and pressure, which enables perfect control of the grafting conditions. In an alternative embodiment, the technique can be carried out in an aqueous solution. The technique employed comprises a modification of the functionality at the surface of the biomaterial in order to render it more reactive. Said technique is known to one skilled in the art.

The invention also relates to monocyclic or polycyclic alkenes substituted by a chain R or a group X as defined above.

The preferred monocyclic or polycyclic alkenes as defined above are chosen from amongst those mentioned above.

The invention also relates to a monocyclic or polycyclic alkene based macromonomer of formula (VI):



formula (VI) wherein:

n represents an integer from about 0 to 300, especially from 10 to 100, p represents an integer from about 0 to 300, q represents an integer from about 0 to 300, with n+p+q is from about 10 to 300,

A represents a hydrogen atom or a group of the following formula (II):

-CONHAb1, where Ab1 represents an antibiotic with extracellular action,

B represents a hydrogen atom or a group of the following formula (III):

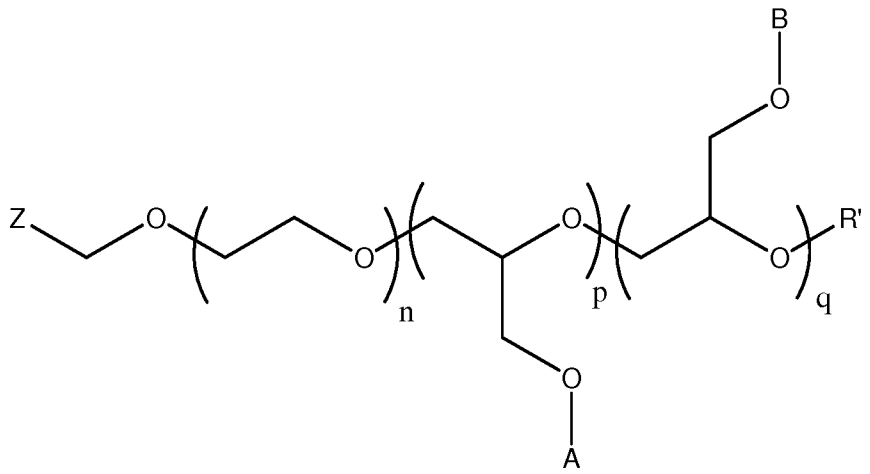
-CH2CNAb2, wherein Ab2 represents an antibiotic with intracellular action,

R' represents a hydrogen atom, -CH2CNAb2 or -CONHAb1 as defined above,
with the proviso that when p is different from 0, then q is 0 and R' represents a hydrogen atom or -CONHAb1, when q is different from 0, then p is 0 and R' represents a hydrogen atom or –CH2CNAb2, when p+q is not zero, at least one of the p or q moieties comprises the formula (II) or (III) respectively, and when p+q is 0, then R' can be -CONHAb1 only,
Z represents a monocyclic or polycyclic alkene to which the polyethyleneglycol-polyglycidol chain is attached, optionally substituted by a group X, wherein X represents an alkyl or alkoxy chain with about 1 to 500 carbon atoms, preferably 40 to 400 carbon atoms, comprising a reactive function of the OH, halogen, NH2, C(O)X1 type, wherein X1 represents a hydrogen atom, a halogen atom, an OR" or NHR" group, in which R" represents a hydrogen atom or an alkyl group, and
G represents the remainder of the R chain as defined above.

In an embodiment, G (or the remainder of the R chain) does not exist as defined above.
In another embodiment, G is an alkyl, alkenyl or alkynyl chain, preferably an alkyl chain, as defined above.
In another embodiment, G comprises at least one chemical group appropriate for linking the monomer unit (deriving from polymerization of a monocyclic or polycyclic alkene) and the polyethyleneglycol-polyglycidol chain of formula (I), as defined above.

The specific or particular embodiments relative to the particles or materials described above are also included (when applicable) for the monocyclic or polycyclic alkene based macromonomers as defined by formula (VI). More specifically, Z of formula (VI) can be Z1 or Z2 or Z3, as defined above.

In an embodiment, the monocyclic or polycyclic alkene based macromonomer of formula (VI) is a monocyclic or polycyclic alkene based macromonomer of formula (IV):



formula (IV) wherein

n represents an integer from about 0 to 300, especially from 10 to 100, p represents an integer from about 0 to 300, q represents an integer from about 0 to 300, with n+p+q is from about 10 to 300,

A represents a hydrogen atom or a group of the following formula (II):
-CONHAb1, where Ab1 represents an antibiotic with extracellular action,

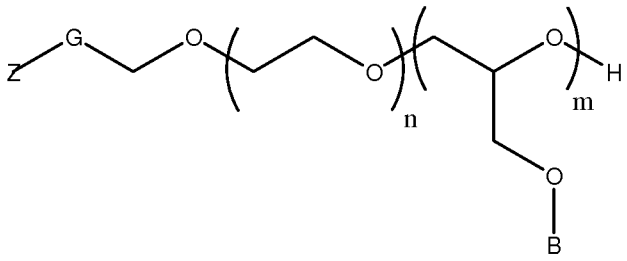
B represents a hydrogen atom or a group of the following formula (III):
-CH2CNAb2, wherein Ab2 represents an antibiotic with intracellular action,

R' represents a hydrogen atom, -CH2CNAb2 or -CONHAb1 as defined above,
with the proviso that when p is different from 0, then q is 0 and R' represents a hydrogen atom or -CONHAb1, when q is different from 0, then p is 0 and R' represents a hydrogen atom or –CH2CNAb2, when p+q is not zero, at least one of the p or q moieties comprises the formula (II) or (III) respectively, and when p+q is 0, then R' can be -CONHAb1 only,

Z represents a monocyclic or polycyclic alkene to which the polyethyleneglycol-polyglycidol chain is attached, optionally substituted by a group X, wherein X represents an alkyl or alkoxy chain with about 1 to 500 carbon atoms, preferably 40 to 400 carbon atoms, comprising a reactive function of the OH, halogen, NH2, C(O)X1 type, wherein X1 represents a hydrogen atom, a halogen atom, an OR" or NHR" group, in which R" represents a hydrogen atom or an alkyl group.

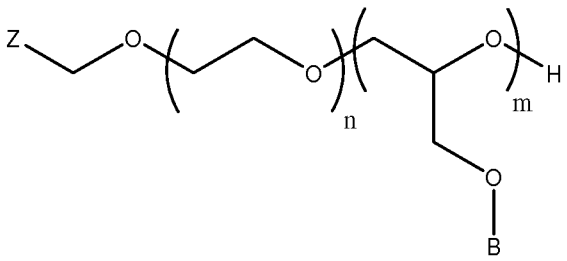
The specific or particular embodiments relative to the particles or materials described above are also included (when applicable) for the monocyclic or polycyclic alkene based macromonomers as defined by formula (IV). More specifically, Z of formula (IV) can be Z1 or Z2, as defined above.

The invention relates more particularly to monocyclic or polycyclic alkenes based macromonomers as defined above, characterized by the following formula (VII):



in which G is as described above, Z is as described above, n is as defined above, more preferably is 0, and m is q as defined above, and B is as defined above (including specific and particular embodiments), wherein at least one of the m moieties comprises the formula (III).

In an embodiment, the monocyclic or polycyclic alkenes based macromonomers of formula (VII) aremonocyclic or polycyclic alkenes based macromonomers characterized by the following formula (V):



in which Z is as described above, n is as defined above, more preferably is 0, and m is q as defined above, and B is as defined above (including specific and particular embodiments), wherein at least one of the m moieties comprises the formula (III).

In a particular embodiment, the cyclic alkenes are selected from norbornene, tetracyclododecadiene, dicyclopentadiene, the dimer of norbornadiene, and cycloocta-

1,5-diene. In a specific embodiment, the cyclic alkene is norbornene, as defined above.

The invention also relates to the use of monocyclic or polycyclic alkenes based macromonomer as defined above for carrying out a method of preparation of particles or biomaterials defined above, especially by the methods described above.

The invention further relates to particles or biomaterials as defined above wherein the monocyclic or polycyclic alkenes based macromonomers are as defined above specifically.

The invention will now be illustrated by the following examples. They are not intended to be limiting. The percentages are expressed by weight, unless otherwise specified.

EXAMPLES

1. Material and methods

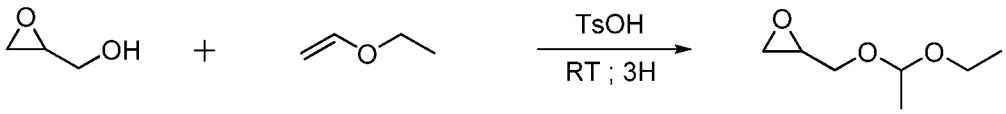
Material: Ethylene oxide (EO; 99.5%; Aldrich) was stirred over sodium at -30°C for 2 hours and subsequently cryodistilled. Tetrahydrofuran (THF; J.T. Baker) was cryodistilled from sodium benzophenone before use. Ethanol (96%; purissimum grade pur; Xilab) and dichloromethane (purissimum grade pur, Xilab) were degassed before use. Diphenyl methyl potassium (DPMK; 0.64 $mol.L^{-1}$ in THF) was synthesized and dosed according to well-established procedures. Sodium hydride (60% in dispersion in mineral oil; Aldrich) was washed with anhydrous heptane before use. Grubbs first generation complex Cl_2-$(PCy_3)_2$Ru=CH-Ph (Aldrich; stored in a glovebox under Argon atmosphere) was used as received. Norbornene (Nb) (99% (GC); Aldrich), 5-norbornene-2-methanol (98%; mixture of endo and exo; Aldrich), bromoacetaldehyde diethyl acetal (97%; Aldrich), 2-bromoethyl acetate (97%; Aldrich), Gentamicin Sulphate (GS; C1, C1a, C2 mixture; Aldrich), were used without further purification. Titanium discs (Ti90Al6V4; Ø=5 mm; h=3 mm; Ra=5-6 µm) were purchased from Good Fellow, France. Anhydrous hexane (99%), anhydrous N-N-dimethylformamide (DMF; 99.8%), dicyclohexylcarbodiimide (DCC; 99%), 3-

aminopropyltriethoxysilane (APTES; ABCR; 97%) was obtained from ABCR, France. N-hydroxysuccinimide (NHS; 98%) was purchased from Alfa Aesar, France. Vancomycin hydrochloride was purchased from Aldrich. 4-Dimethylaminopyridine (DMAP, 99%) and disuccinimidyl carbonate (DSC; 98%) were obtained from Acros, France.

Methods: ROMP (Ring-Opening Metathesis Polymerization) was performed in a glovebox. ^{1}H NMR spectra were obtained using a Bruker spectrometer 400 MHz in $CDCl_3$, D_2O or DMSO-d_6 used as solvent. Size exclusion chromatography analyses were carried out on a Varian apparatus equipped with TOSOHAAS TSK gel columns and a refractive index detector. THF or DMF were used as solvents at a flow rate of 1 mL.min^{-1}. Mass calibration was achieved with narrow polydispersity polystyrene standards. For ROMP in dispersion, conversions of Nb were determined by gas chromatography with a trace of dodecane as internal standard, using a VARIAN GC3900 (GC retention times: t^{GC}_{Nb} = 1.77 min; $t^{GC}_{dodecane}$ = 8.55 min). The PEO-based macromonomer conversions were followed by SEC (SEC retention times: $t^{SEC}_{macromonomers}$ = 18.75 min;.$t^{SEC}_{dodecane}$ = 31.70 min), while the PGLD-based macromonomer conversions were determined by elemental analysis after the particle dispersion purification by ultrafiltration and lyophilisation of the particles and also by gravimetry after ultracentrifugation (Eppendorf centrifuge 5804R ; 8000 rpm ; 5 min ; 10°C) and drying under vacuum. Dynamic light scattering (DLS) measurements were performed using a MALVERN zetasizer Nano ZS equipped with He-Ne laser (4 mW; 633 nm). Before measurements, latexes were diluted about 800 times to minimize multiple scatterings caused by high concentration. The scattering angle used was 173°. TEM pictures were performed with a HITACHI H7650 microscope operating at an accelerating voltage of 80 kV. For the particles size, distribution and morphology observation, samples diluted about 800 times were deposited on a 200 mesh carbon film-coated copper grids surface. The particle grafting density was characterized by SEM observations using a HITACHI S-2500 scanning electron microscope.

2. Synthesis of Gentamicin-functionalized particles with polyglycidol macromonomer

a) Synthesis of glycidol acetal:

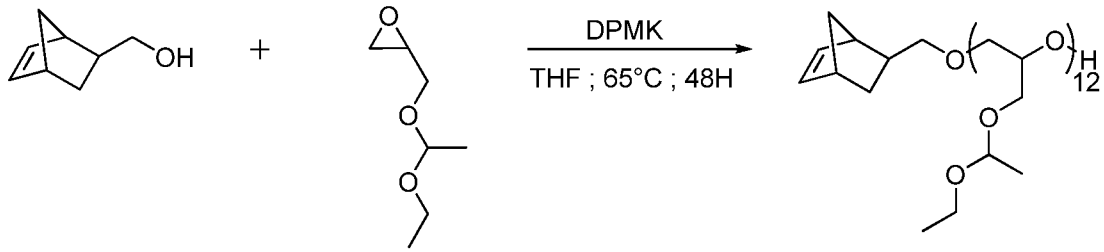


Tosylic acid (TsOH, 1 g) was added portion-wise to a magnetically stirred solution of 40.0 g of 2,3-epoxypropanol (glycidol) in 200 mL of ethyl vinyl ether. The temperature was maintained below 40°C with an ice-water bath. The reaction mixture was stirred for 3 hours. Then, the reaction mixture was washed with 100 mL of $NaHCO_3$ saturated water solution, the organic phase was dried with $MgSO_4$, filtrated, and the solvent (ethyl vinyl ether) was evaporated under reduced pressure. The product was purified by distillation under reduced pressure.

Yield: 71%

^1H NMR data in $CDCl_3$: δ (ppm) 0.8-1.2 (m; 6H ; $-CH_3$) ; 2.4-2.7 (m ; 2H CH_2 acetal) ; 3.05 (m ; 1H ; CH glycidol) ; 3.3-3.9 (m ; 4H ; CH_2 glycidol) ; 4.85 (t ; 1H ; CH acetal)

b) Synthesis of α-norbornenyl-poly(glycidol acetal) macromonomer:



For a macromonomer with a number-average polymerization degree (DP_n) of 12, 0.44 mL of the initiator 5-norbornene-2-methanol was added to 200 mL of freshly cryodistilled THF, following by the addition of 4.5 mL of DPMK solution (0.64 $mol.L^{-1}$ in THF). Then, Glycidol acetal, (6.55 mL) was added to the reaction medium. For a full conversion, the reaction was left stirring for approximately 24 hours at 65°C. 5-7 drops of degassed acidified methanol were added to the reaction mixture to desactivate the polymerization. After a 2-3 days dialysis in ethanol, the solution was filtered and the solvent was removed by rotary evaporation and the macromonomer was dried under vacuum.

Yield: 67%

^{1}H NMR data in $CDCl_3$: δ (ppm) (400 MHz): 1.12-1.95 (80H, $-CH_3$); 2.35-2.45 (3H, $-CH-_{cycle}$); 3.49-3.99 (96H, -O-CH-CH_2-O- and CH-CH_2-OAc); 4.71 (13H ; CH) 6.00-6.28 (2H ; $-CH=CH-_{cycle}$)

Characteristics of the α-norbornenyl-poly(glycidol acetal) macromonomers

$DP_{n;Th}$ [1]	$DP_{n;NMR}$ [2]	$M_{n;NMR}$ ($g.mol^{-1}$) [3]	$M_{n;SEC}$ ($g.mol^{-1}$) [4]	PDI[5]
13	12	1910	1630	1.06
27	25	3830	3710	1.06
54	50	7440	7630	1.09

[1] $DP_{n;Th}=n_{mono}/n_{NbOH}$ with n_{mono} the initial amount of monomer and n_{NbOH} the initial amount of norbornene methanol.

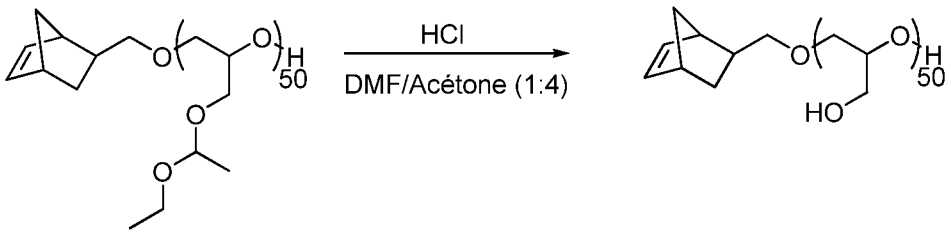
[2] $DP_{n;NMR}=2I_{CH}/I_{Nb}$ with I_{Nb}: integration of the ethylenic protons of the norbornenyl entity, I_{CH}: integration of the CH proton of the acetal entity

[3] $M_{n;NMR}=M_{Nb}+146DP_{n;NMR}$ M_{Nb} molecular weight of the norbornenyl entity, 146: molecular weight of the glycidol acetal unit.

[4] molecular weight measured by Size Exclusion Chromatography

[5] PDI: Polydispersity index

c) Synthesis of α-norbornenyl-polyglycidol macromonomer:



The α-norbornenyl-poly(glycidol acetal) macromonomer (1.65 g ; DP_n=50 ; M_n=7440 g/mol) was dissolved in 75 mL of a mixture of N,N-dimethylformamide (DMF)/acetone (1:4 v/v), and 4.5 mL of concentrated hydrochloric acid (HCl) solution (11.7 $mol.L^{-1}$) were added. The reaction was stirred for 1 hour, and then a saturated Na_2CO_3 aqueous solution was added to neutralize HCl until pH=8 (monitored with pH paper). The solvent was evaporated under reduced pressure and the macromonomer was redissolved in 50 mL of ethanol and filtrated to remove residual salts. Then, ethanol was evaporated, and the macromonomer was redissolved

in 50 mL of water. Purification of the sample was carried out by a 2-3 days dialysis in water, then the macromonomer was lyophilized.

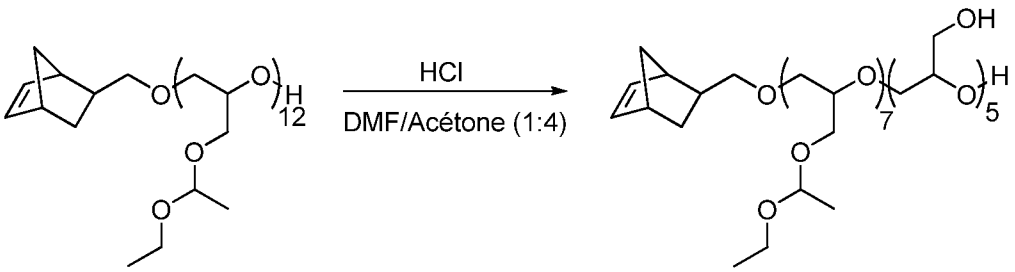
- Yield: 85%

- ^{1}H NMR data in D_2O: δ (ppm) (400 MHz): 1.12-1.95 (m, 4H, -$CH_{2\text{-cycle}}$); 2.35-2.45 (m, 3H, -$CH_{\text{-cycle}}$); 3.49-3.99 (2m, 125H, -O-CH-CH_2-O- and CH-CH_2-OH); 6.00-6.28 (-CH=CH-$_{\text{cycle}}$)

$DP_{n;NMR}$=53; $M_{n:NMR}$=3900 g/mol

- SEC in DMF: M_n=4000 g.mol^{-1}; PDI=1.15

d) Partial deprotection of α-norbornenyl-poly(glycidol acetal) macromonomer

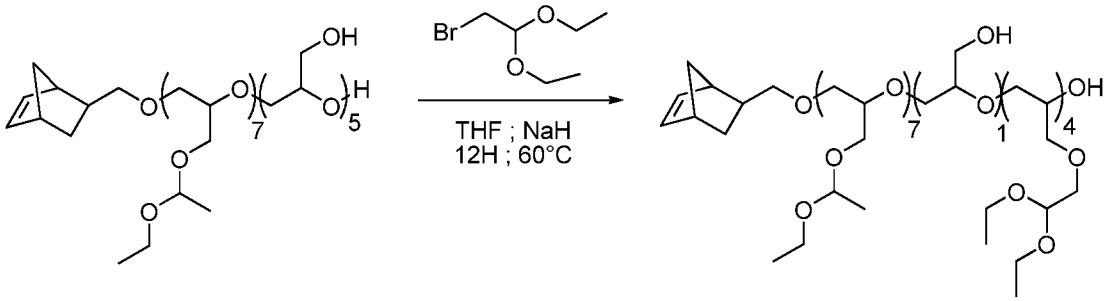


α-norbornene-poly(glycidol acetal) macromonomer (1.65 g) was added to a 75 mL solution of N,N-dimethylformamide (DMF)/acetone (1:4 v/v). Then, 0.64 mL of concentrated hydrochloric acid (HCl) solution (11.7 mol/L) were added. The reaction was stirred for 4 min, then a saturated Na_2CO_3 aqueous solution was added to neutralize the HCl until pH=8 (monitored with pH paper). The solvent was evaporated and the product was dissolved in ethanol. The residual salts were removed by filtration. After a 2-3 days dialysis, the product was lyophilized.

Yield: 72% for DP_n=12 (1); 89% for DP_n=25 (2)

SEC in THF: (1): M_n=1270 g.mol^{-1} ; PDI=1.08. (1): M_n=2570 g.mol^{-1} ; PDI=1.08

e) Acetal functionalization of partially deprotected macromonomers

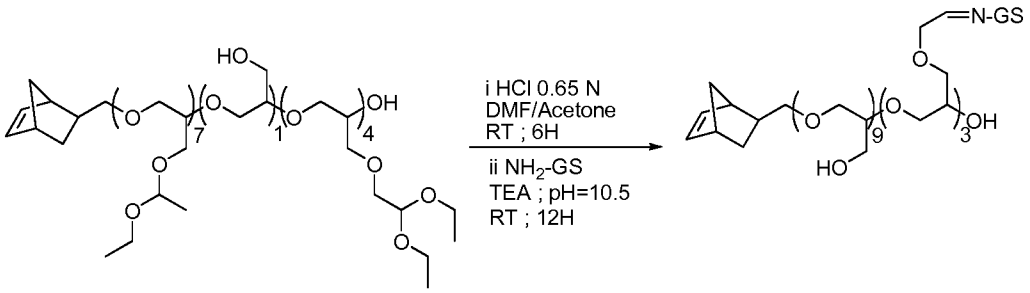


In a typical experiment, 1 g of partially deprotected α-norbornenyl-poly(glycidol acetal) macromonomer was dissolved in 30 mL of freshly cryodistilled THF. 10 equivalents of NaH (M=24 g/mol; dispersed in mineral oil 60% (w/w)), previously washed with heptane to remove the mineral oil, were dispersed in 10 mL of THF. The macromonomer solution was added dropwise to NaH under stirring and under a nitrogen flux. After 30 min, 4.5 equivalents of bromoacetaldehyde diethyl acetal (M=197 $g.mol^{-1}$; d=1.31) were added dropwise. The reaction mixture was stirred for 12 hours at 60°C. NaH was then neutralized with a 1 N HCl solution and the solution mixture was evaporated, redissolved in CH_2Cl_2, dried with $MgSO_4$ and filtrated. Finally, CH_2Cl_2 was evaporated and the product was dried under vacuum.

Yield: 72% for DP_n=12 (1); 89% for DP_n=25 (2)

SEC in THF: (1): M_n=1270 $g.mol^{-1}$; PDI=1.08. (1): M_n=2570 $g.mol^{-1}$; PDI=1.08

f) Synthesis of GS-functionalized α-norbornenyl-polyglycidol macromonomer

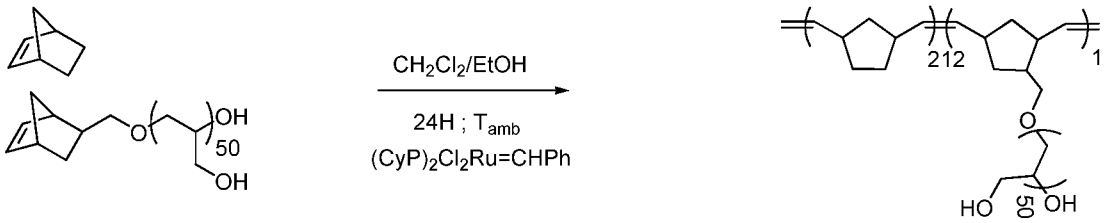


Acetal functionalized polyglycidol macromonomer (0.4 g) was dissolved in 18 mL of DMF/Acetone (1:4 v/v) and 1.1 mL of concentrated HCl (11.7 N) was added dropwise. The mixture was stirring for 6 hours at room temperature. Then the solution was basified by adding dropwise a solution of triethylamine (TEA) (1 M) dissolved in the solvent medium under nitrogen flux (pH=10). Finally, GS (5 eq.) dissolved in 10 mL of buffer solution pH=12 was added dropwise. After 12 hours, the solvent was evaporated and the product was purified by a 3-days dialysis in a TEA solution 10 mM (pH=10.5).

$M_{n;NMR}$=2710 g/mol for DP_n=12 (1) and $M_{n;NMR}$=5890 g/mol for DP_n=25 (2).

- SEC in DMF: (1): M_n=1980 $g.mol^{-1}$; PDI=1.27. (2): M_n=3420 $g.mol^{-1}$; PDI=1.32

g) Synthesis of unfunctionalized polynorbornene-polyglycidol particles



Dispersion polymerizations were carried out at room temperature under inert atmosphere (glovebox) and under stirring. Solvents were degassed according to the freeze-pump-thaw procedure. In a typical experiment, 10 mg ($3.6\ 10^{-5}$ mol) of Grubbs 1st generation complex were dissolved in 3.3 mL of dichloromethane/ethanol mixture (1:1 v/v). Both norbornene (201 mg; $6.18\ 10^{-3}$ mol) and α-norbornenyl-polyglycidol macromonomer (241 mg; $3.24\ 10^{-5}$ mol) were first dissolved in 6 mL of dichlomethane/ethanol solution (35:65 v/v) and added to the catalyst. 206 mg of dodecane is also added as internal standard. The mixture was stirred during 24 hours. The desactivation of the reaction medium was performed by addition of 0.3 mL of ethyl vinyl ether.

- Nb conversion by GC: π_{Nb}>99%.

- Macromonomer conversion by gravimetric analysis: first 5 mL of dispersion was ultra-centrifuged (8000 rpm; 10°C; for 5 min), then the solid phase (m^f_{sol}=198.9 mg; PNb-PGLD) and the liquid phase (m^f_{liq}=144.4mg; dodecane, desactivated Grubbs I catalyst and unreacted PGLD) were dried under vacuum. These weights were compared with the theoretical weights determined by considering the introduced products before the reaction (norbornene and PGLD; m^{th}_{sol}=229 mg; m^{th}_{liq}=112 mg). The macromonomer conversion can be calculated with the following equation:

$$\pi_{PGLD} = \frac{m^f_{sol} - m^i_{Nb}}{m^{th}_{sol} - m^i_{Nb}} = 1 - \frac{m^f_{liq} - m^{th}_{liq}}{m^i_{PGLD}} = 75\%$$

π_{PGLD} : macromonomer conversion

m^i_{Nb} : initial weight of the Nb monomer

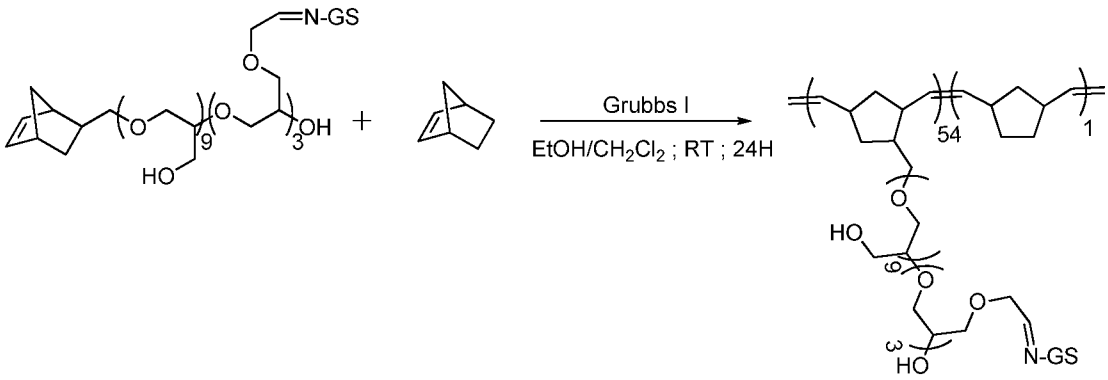
m^i_{PGLD} : initial weight of the PGLD macromonomer

- Macromonomer conversion by elemental analysis: first, the particles were transferred in water and purify by ultrafiltration, then the dispersion was lyophilized. Elemental analysis: Measured: (mol%) C: 33.19; H: 58.03; O: 8.78. Theoretical values for a total conversion: (mol. %) C: 34.18; H: 56.57; O: 9.25.

The macromonomer conversion can be calculated by considering the elemental analysis and the polymer formula $(C_7H_{10})_n$-$(C_8H_{12}O(C_3H_6O_2)_{DPn})_m$, the initial proportions and a total conversion of Nb: π_{PGLD}=94%.

- particle size measurement by DLS are presented on Figure 1:

h) Synthesis of GS-functionalized polynorbornene-polyglycidol particles



10 mg (3.6 10^{-5} mol) of Grubbs 1st generation complex were dissolved in 3.3 mL of dichloromethane/ethanol mixture (1:1 v/v). Both norbornene (201 mg; 2.14 10^{-3} mol) and GS-functionalized α-norbornenyl polyglycidol macromonomer (241 mg; M_n=3420 g/mol; 7.05 10^{-5} g/mol) were first dissolved in 6 mL of dichlomethane/ethanol solution (35:65 v/v) and added to the catalyst. 206 mg of dodecane is also added as internal standard. The mixture was stirred during 24 hours. The desactivation of the reaction medium was performed by addition of 0.3 mL of ethyl vinyl ether.

- Nb conversion by GC: π_{Nb}=80%

- Macromonomer conversion by gravimetric analysis: Macromonomer conversion π_{PGLD} was determined thanks to a gravimetric analysis. After ultracentrifugation the solid phase (m^f_{sol}=197.7 mg; PNb-PGLD was dried under vacuum. This weight was compared with the theoretical weight determined by considering the introduced products before the reaction (Nb; macromonomer) and a Nb conversion of 80% (m^{th}_{sol}=324.8 mg). The calculated macromonomer conversion is 45%.

$$\pi_{PGLD} = \frac{m^f_{sol} - 0.8m^i_{Nb}}{m^{th}_{sol} - 0.8m^i_{Nb}} = 45\%$$

- Macromonomer conversion by elemental analysis: first, the particles were transferred in water and purify by ultrafiltration, then the dispersion was lyophilized.

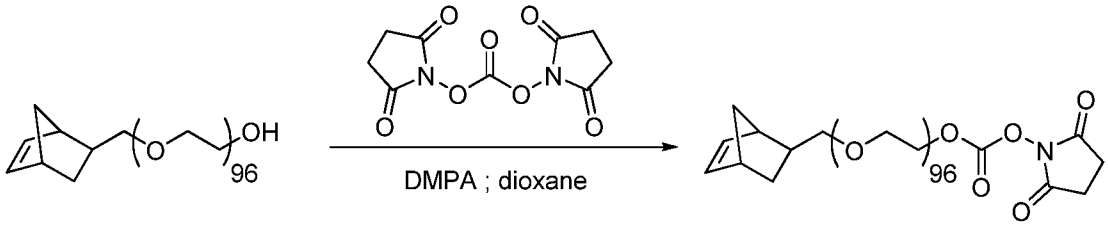
Elemental analysis: Measured: (mol%): C: 30.51 ; H: 63.68 ; N: 0.63 ; O: 5.18. Theoretical values for a total conversion (mol%): C: 34.06 ; H: 57.22 ; N: 2.28; O: 6.44.

Elemental analysis measured values were compared with the theoretical ones calculated from the initial state and considering a conversion of 80% for Nb and a total conversion for the macromonomer. A macromonomer conversion of 41% was determined, close to the macromonomer conversion calculated by gravimetric analysis.

- SEC in THF: M_n=97300 g/mol (styrene eq) PDI=1.59
- Size measurement: The DLS analysis of the dispersion showed the presence of big objects with diameters of about 5-6 µm in the ethanol/dichloromethane solvent mixture and with diameters of 2-3 µm in water after their transfer and an ultrafiltration purification step. The GS loading is about 20 10^6 molecules per particle versus 3 10^6 molecules per particle with the PEO based particles.

3. Grafting of vancomycin-functionalized poly(ethylene oxide)-polynorbornene particles onto titanium surface

a) Synthesis of α-norbornenyl-ω-Succinimidyl poly(ethylene oxide)



In a typical experiment, 5g of a-norbornenyl-poly(ethylene oxide) macromonomer (M_n=4300 g/mol; 1.16 mmol) was dissolved in 25 mL of dry dioxane and then DSC (9 mmol in 20 mL of dry acetone) was added. DMAP (9 mmol in 15 mL of dry acetone) was added slowly under magnetic stirring and the reaction was carried out at room temperature for 6 h. Nb-PEO-SC was directly precipitated from the reaction mixture by diethyl ether and then several cycles of redissolving of the product in acetone and precipitation in diethyl ether were carried out in order to remove excess DSC and DMAP. The activated product was stored dry in a glovebox.

Yield: 75%

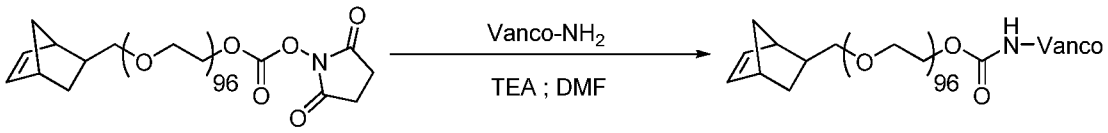
^{1}H NMR ($CDCl_3$, 400 MHz): δ (ppm) Norbornenyl moiety, 5.85-6.04, 3.30, 3.11, 3.00, 2.84, 2.68-2.72, 2.25, 1.74, 1.62, 1.04-1.40, 0.41; EO moiety, 4.40, 3.40-3.80; Succinimidyl moiety, 2.77

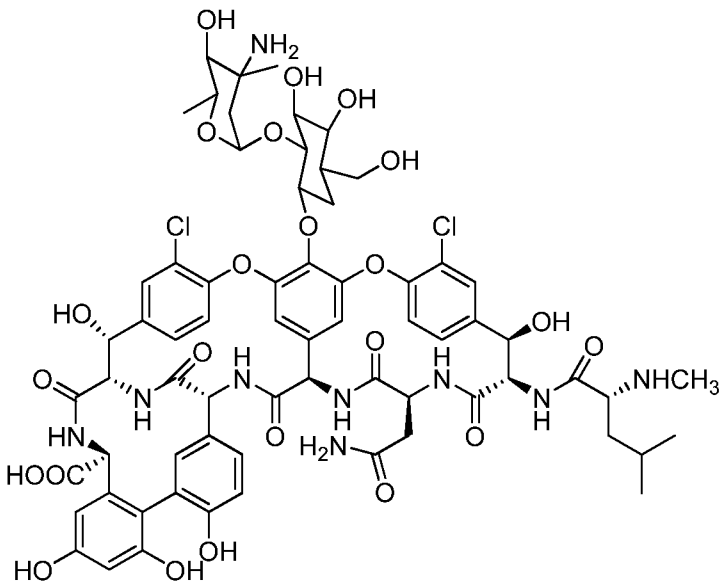
$M_{n;NMR}$=4300 g/mol

functionalization: F>99%

- SEC in THF: $M_{n;SEC}$=3900 g/mol (styrene eq) PDI=1.08

b) Synthesis of α-norbornenyl-ω-vancomycin poly(ethylene oxide)





Structure of Vancomycin

To a solution of vancomycin (0.2235 g, 0.15 mmol) and triethylamine (TEA, 0.4 mL, 3.0 mmol) in anhydrous dimethylformamide (DMF, 10 mL) was added a solution of Nb-PEO-SC (0.3 g, 0.075 mmol) in anhydrous DMF (10 mL) and 2.235 g molecular sieves (4 Å). The reaction mixture was stirred at 30 °C for 12 hrs, filtered through celite, and the solid product was obtained by precipitation with diethyl ether, filtered, and dried. The product was purified by ultrafiltration using deionized H_2O as the solvent and a regenerated cellulose membrane (5 K Daltons) to separate the product from unreacted vancomycin. The retained fraction was frozen with liquid nitrogen and lyophilized for 48 hrs.

- Yield: 88%

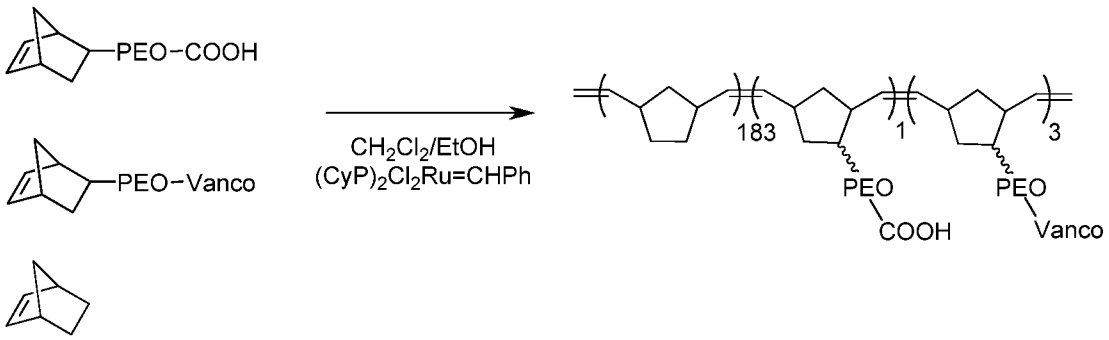
^{1}H NMR (DMSO-d_6, 400 MHz): δ (ppm) Norbornenyl moiety, 5.85-6.04, 3.30, 3.11, 3.00, 2.84, 2.68-2.72, 2.25, 1.74, 1.62, 1.04-1.40, 0.41; EO moiety, 3.40-3.80; Vancomycin moiety, 6.44-7.66, 5.29-5.49, 4.06-4.47, 3.41-3.75 (overlapped by EO moiety peak), 2.73, 1.11-2.02, 0.84.

$M_{n;NMR}$=5100 g/mol

functionalization: F>99%

- SEC in DMF: M_n=8000 g/mol (styrene eq.) PDI=1.13

c) Synthesis of vancomycin-carboxylic acid particles



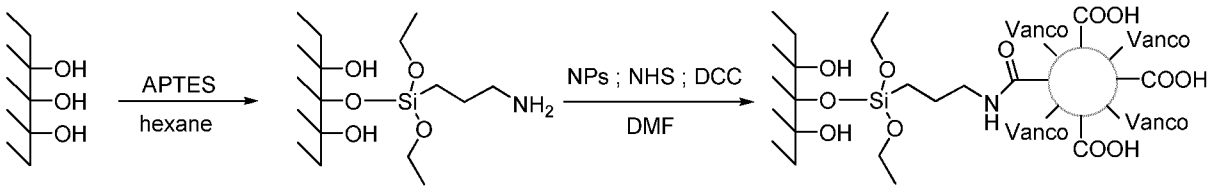
Functionalized particles were formed by ROMP in dispersion. Dispersion polymerizations were carried out at room temperature under inert atmosphere (glovebox) and stirring. Solvents were degassed according to the freeze-pump-thaw procedure. In a typical synthesis, 30 mg (3.6 10^{-5} mol) of Grubbs 1st generation complex were dissolved in 10 mL of dichloromethane/ethanol mixture (50/50% vs volume). Norbornene (6.1 10^{-3} mol), α-norbornenyl-ω-carboxylic acid-poly(ethylene oxide) macromonomer (3.7 10^{-5} mol) and α-norbornenyl-ω-vancomycin-poly(ethylene oxide) macromonomer (1.1 10^{-4} mol) were first dissolved in 18 mL of dichlomethane/ethanol solution (35/65% V/V) and added to the Grubbs 1 solution. The mixture was stirred during 24 hours. At the end of polymerization Ruthenium end-capped chains were deactivated by addition of 0.3 mL of ethyl vinyl ether. Then, the particles were transferred to DMF to carry out the grafting step onto titanium surfaces: first DMF was added drop wise, then dichloromethane and ethanol were evaporated under reduced pressure.

- Norbornene conversion: >99%

- Global macromonomer conversion: 90%

- Distribution profiles of the particle size functionalized with carboxylic acid groups and Vancomycin: measurement by DLS given in Figure 2

d) Particle grafting onto titanium surfaces

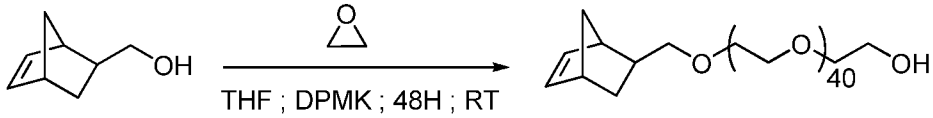


The particle grafting step was a two-step process: first, titanium surfaces were functionalized with anime groups using APTES through a well-established protocol: Briefly, titanium samples were first outgassed at 150°C under vacuum (10^{-5} Torr) for 20 h. Silanization of the surface was performed by immersing the substrate in a solution of APTES (10^{-2} M) in anhydrous hexane under inert atmosphere (glovebox) during 2 h. Samples were washed in glovebox by two rinsings under stirring and sonication for 30 min (both steps have been performed using anhydrous hexane). Finally, samples were outgassed at 100°C under vacuum (10^{-5} Torr) for 4 h. Next, the particles were covalently linked onto the titanium surface through the formation of an amide bond between the carboxylic acid groups of the particles and the amine groups present onto the surfaces (activated by NHS and DCC). In inert atmosphere (glovebox), DCC (237 mg, 82 eq.; 1.1 10^{-3} mol) and NHS (100 mg, 62 eq.; 8.7 10^{-4} mol) were diluted in 2 mL of particle dispersed in DMF (n_{-COOH}=1.5 10^{-5} mol). Finally, the mixture was deposited on titanium materials and stirred for 72 h at room temperature. The samples were then washed in three successive ethanol baths, dried and stored under inert atmosphere. The grafting step was carried out three times. Between two successive steps, the materials were rinsed in ethanol baths.

SEM observation of the titanium surface after grafting of particles functionalized with carboxylic acid groups and Vancomycin is presented on Figure 3.

4. Synthesis of α-norbornenyl poly(ethylene oxide)-*bloc*-polyglycidol

a) Synthesis of α-norbornenyl poly(ethylene oxide):

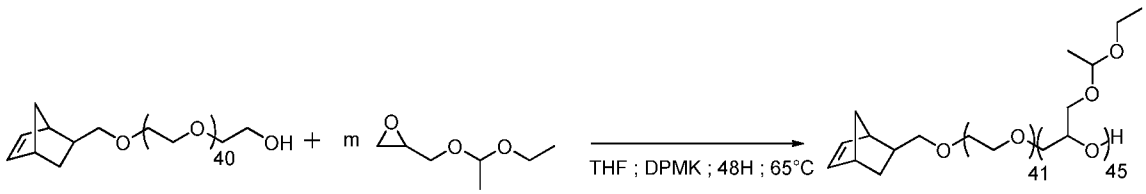


α-norbornenyl poly(ethylene oxide) was prepared by anionic ring-opening polymerization of ethylene oxide. 1.1 mL of norbornene methanol (1 eq.; 9.35 10^{-3} mol) were dissolved in 200 mL of THF previously cryodistilled. 11.7 mL of DPMK (0.8 eq.; 0.64 mol.L^{-1}) are added. Then 21 mL (45 eq.; 0.421 mol) of ethylene oxide stirred over sodium and cryodistilled were promptly added. The mixture was stirred during 48 hours under vacuum at room temperature, and the anionic active centres were neutralized with 5 mL of acidic methanol. The polymer was precipitated in anhydrous diethyl ether, filtered, dissolved in dichloromethane, dried with $MgSO_4$, filtered on celite, concentrated, precipitated in diethyl ether, filtered and dried under vacuum.

- 50% yield
- ^{1}H NMR data in $CDCl_3$: δ (ppm) = 1.08-1.79 (m, 4H, -$CH_{2\text{-cycle}}$); 2.72-3.45 (m, 3H, -$CH_{\text{-cycle}}$); 3.63 (m, 164H, -CH_2-O-); 5.91-6.09 (m, 2H, -CH=$CH_{\text{-cycle}}$)

$DP_{n;NMR}$=41 ; $M_{n;NMR}$=1930 g/mol
- SEC in THF: $M_{n;SEC}$=2240 g/mol (styrene eq) PDI=1.09

b) Synthesis of α-norbornenyl poly(ethylene oxide)-*bloc*-poly(glycidol actetal):



8 g of α-norbornenyl poly(ethylene oxide) (1 eq; M_n=1930 g/mol; 4.14 10^{-3} mol) were dissolved in 200 mL of freshly cryodistilled THF. Then, 5.2 mL of DPMK (0.8 eq; 0.64 mol/L) were added. Finally, 18 mL (30 eq.; 0.124 mol) of glycidol acetal are promptly added. The mixture was stirred during 48 hours under vacuum at 65°C, and the anionic active centres were neutralized with 5 mL of acidic methanol. The solvent was evaporated, the polymer was dissolved in dichloromethane, dried with $MgSO_4$, filtered on celite. The dichloromethane was evaporated. The polymer was dried under vacuum and lyophilized overnight in dioxane.

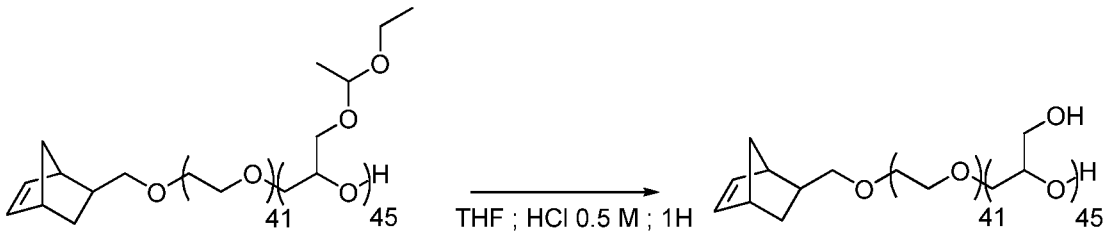
- 99% yield

- ^{1}H NMR data in $CDCl_3$: δ (ppm) = 1.1-1.5 (d, 278H, $-CH_3$); 2.72-3.45 (m, 3H, $-CH-_{cycle}$); 3.5-3.7 (m, 586H, $-CH_2-O-$, -CH-O-); 4.75 (s, 45H, -CH-); 5.91-6.09 (m, 2H, $-CH=CH-_{cycle}$)

$DP_{n;PEO}$= 41; $DP_{n;PGLDAc}$= 45; $M_{n;NMR}$=8500g/mol

- SEC in THF: M_n=5930 g/mol (styrene eq) PDI=1.07

c) Deprotection of α-norbornenyl poly(ethylene oxide)-*bloc*-poly(glycidol actetal):



5 g of a-norbornenyl poly(ethylene oxide)-*bloc*-poly(glycidol actetal) were dissolved in 150 mL of THF. Then, 6.4 mL of HCl 37% were added. The reaction mixture was stirred during 1H at room temperature. Then, the solution was neutralized by adding $NaHCO_3$ saturated water solution. The solvent was evaporated; the polymer was dissolved in water, purified by ultrafiltration (MWCO 1000) and lyophilized overnight.

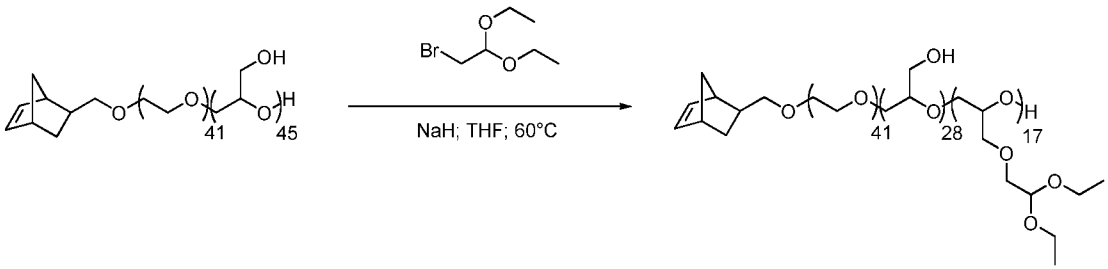
- 90% yield

- ^{1}H NMR data in DMSO-d_6: δ (ppm) = 2.72-3.45 (m, 3H, $-CH-_{cycle}$); 3.2-3.8 (m, 432H, $-CH_2-O-$, -CH-O-); 4.49 (s, 39H, -OH); 5.9-6.2 (m, 2H, $-CH=CH-_{cycle}$)

$M_{n;NMR}$=5260 g/mol

- SEC in THF: M_n=2030 g/mol (styrene eq) PDI=1.03

d) Acetal functionalization of α-norbornenyl poly(ethylene oxide)-*bloc*-polyglycidol

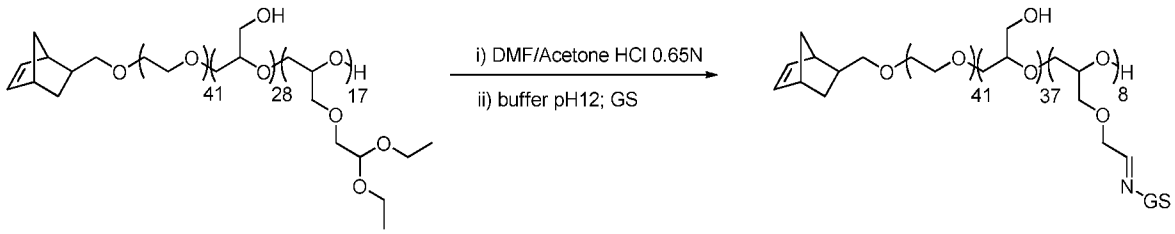


2.8 g (M_n=5260 g/mol; $DP_{n;PGLD}$=45; n_{OH}=2.4 10^{-2} mol) of α-norbornenyl poly(ethylene oxide)-*bloc*-polyglycidol macromonomer was dissolved in 20 mL of freshly cryodistilled THF. 5 equivalents of NaH (M=24 g/mol; dispersed in mineral oil 60% (w/w)), previously washed with heptane to remove the mineral oil, were dispersed in 20 mL of THF. The macromonomer solution was added dropwise to NaH under stirring and under a nitrogen flux. After 30 min, 4.5 equivalents of bromoacetaldehyde diethyl acetal (M=197 g.mol^{-1}; d=1.31) were added dropwise. The reaction mixture was stirred for 12 hours at 60°C. NaH was then neutralized with a 3 N HCl solution and the solution mixture was evaporated, redissolved in CH_2Cl_2, dried with $MgSO_4$ and filtrated. Finally, CH_2Cl_2 was evaporated and the product was dried under vacuum and lyophilized overnight in dioxane.

- 87% yield
- ^{1}H NMR data in D_2O: δ (ppm) = 1.12-1.48 (m, 103H,-CH_3); 2.72-3.45 (m, 3H, -CH-$_{cycle}$); 3.3-4.0 (m, 532H, -CH_2-O-, -CH-O-); 5.9-6.2 (m, 2H, -CH=CH-$_{cycle}$)

- $DP_{n;PEO}$=41; $DP_{n;PGLD}$=28; $DP_{n;PGLDAc}$=17
- Functionalization: 38%
- $M_{n;NMR}$=7210 g/mol
- SEC in THF: M_n=3150 g/mol; PDI=1.3

e) Synthesis of GS-functionalized α-norbornenyl-poly(ethylene oxide)-*bloc*-polyglycidol macromonomer



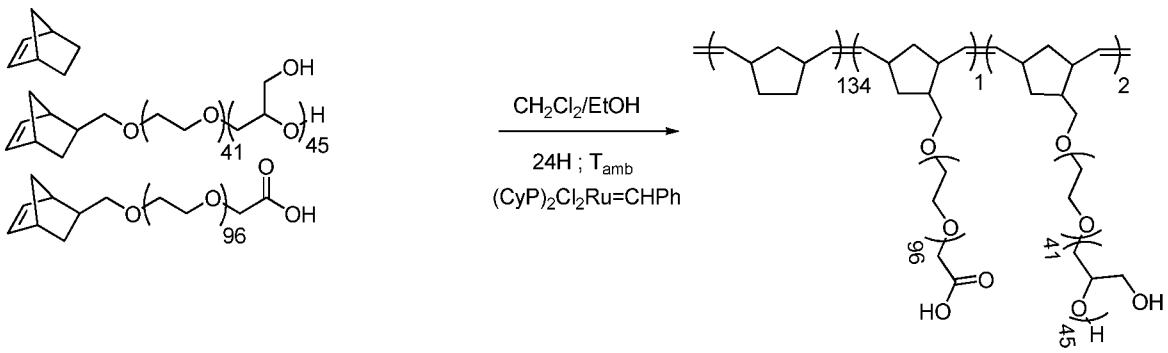
Acetal functionalized α-norbornenyl-poly(ethylene oxide)-*bloc*-polyglycidol macromonomer (2.36 g; M_n=7210 g/mol; n_{Ac}=5.56 10^{-3} mol) was dissolved in 40 mL of 3M HCl solution. The mixture was stirring for 6 hours at room temperature. Then 280 mL of buffer solution pH 12 and NaOH pellets were added to basified the solution and finally, GS (5 eq.; M=477 g/mol; 13.20 g), dissolved in 70 mL of buffer solution pH 12, was added dropwise. The mixture was stirred during 12 hours at room temperature. After this time, the solvent was evaporated, the reminder taken up in a

10 mM solution of triethylamine in deionized H_2O and purified by a 3 days dialysis using a 10 mM solution of triethylamine in deionized H_2O as the solvent and a regenerated cellulose membrane (1 K Daltons) to separate the product from unreacted GS. The retained fraction was frozen with liquid nitrogen and lyophilized for 48 hours.

The structure was confirmed by ^1H NMR in D_2O

- 8 GS molecules per macromonomer
- Functionalization: 47%
- $M_{n;NMR}$=7640 g/mol

f) Synthesis of polynorbornene-poly(ethylene oxide)-poly(ethylene oxide)-*bloc*-polyglycidol particles



The Dispersion polymerization was carried out at room temperature under inert atmosphere (glovebox) and under stirring. Solvents were degassed according to the freeze-pump-thaw procedure. In a typical experiment, 30 mg ($3.6\ 10^{-5}$ mol) of Grubbs 1st generation complex was dissolved in 10 mL of dichloromethane/ethanol mixture (1:1 v/v). Norbornene (580 mg; $6.18\ 10^{-3}$ mol), α-norbornenyl-ω-carboxylic acid-poly(ethylene oxide) macromonomer (153 mg; $5.1\ 10^{-5}$ mol) and α-norbornenyl-poly(ethylene oxide)-*bloc*-polyglycidol macromonomer (582 mg; $1.1\ 10^{-4}$ mol) were first dissolved in 18 mL of dichlomethane/ethanol solution (35:65 v/v) and added to the catalyst. 0.2 mL of dodecane is also added as internal standard. The mixture was stirred during 24 hours. The desactivation of the reaction medium was performed by addition of 0.3 mL of ethyl vinyl ether. Then, the particles were transferred to DMF to carry out the grafting step onto titanium surfaces: first DMF was added dropwise, then dichloromethane and ethanol were evaporated under reduced pressure.

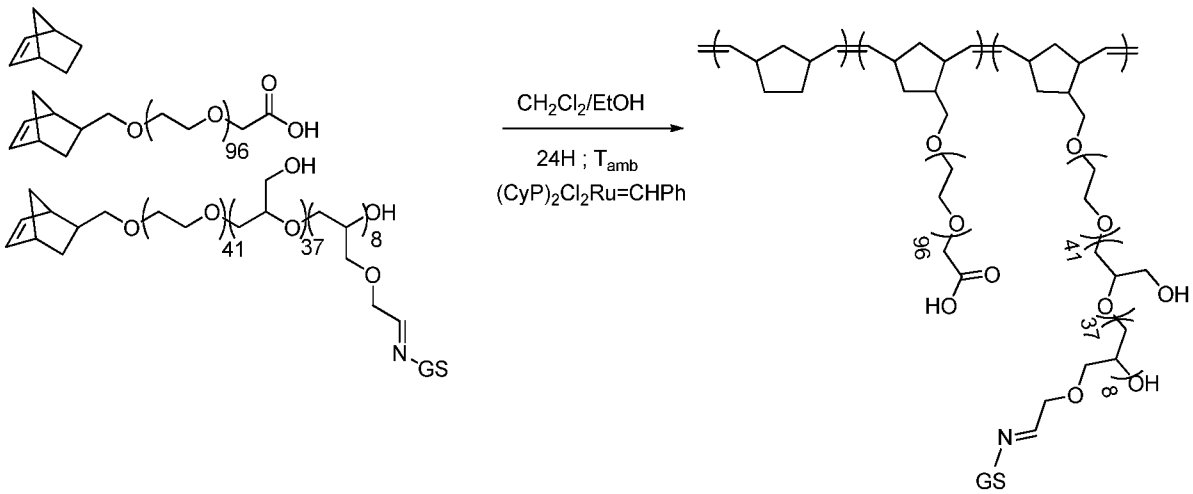
- Norbornene conversion: >99%

- Global macromonomer conversion: 92%

- Size distribution of the particles by DLS in the reaction medium ($EtOH/CH_2Cl_2$), in water and in DMF is given on Figure 4. In $EtOH/CH_2Cl_2$: D=245 nm (0.122). In H_2O: D=365 nm (0.358) (aggregation of the Particles). In DMF: D=230 nm (0.069).

- TEM observations of the particles are presented on Figure 5.

g) Synthesis of polynorbornene-poly(ethylene oxide)-poly(ethylene oxide)-*bloc*-polyglycidol particles functionalized with GS



7 mg ($7.6\ 10^{-6}$ mol) of Grubbs 1st generation complex were dissolved in 2 mL of dichloromethane/ethanol mixture (1:1 v/v). Norbornene (121 mg; $1.3\ 10^{-3}$ mol), α-norbornenyl-ω-carboxylic acid-poly(ethylene oxide) macromonomer (32mg; $1.05\ 10^{-5}$ mol) and α-norbornenyl-poly(ethylene oxide)-*bloc*-polyglycidol macromonomer (182 mg; $2.4\ 10^{-4}$ mol) were first dissolved in 6 mL of dichlomethane/ethanol solution (35:65 v/v) and added to the catalyst. 0.2 mL of dodecane is also added as internal standard. The mixture was stirred during 24 hours. The desactivation of the reaction medium was performed by addition of 0.2 mL of ethyl vinyl ether. Then, the particles were transferred to DMF to carry out the grafting step onto titanium surfaces:

- Norbornene conversion: >99%

- Size distribution of the particles by DLS in the reaction medium ($EtOH/CH_2Cl_2$), in water and in DMF is given on Figure 6. In $EtOH/CH_2Cl_2$: D=620 nm (0.30). In H_2O: D=565 nm (0.32). In DMF: D=520 nm (0.27)

4. MIC activities of the compounds of the invention

From a 24h bacterial culture, MRSA BCB8 were suspended in Mueller-Hinton broth to obtain a 0.5 McF suspension, which was diluted to a final concentration of 1.10^6 CFU.ml^{-1}.

Then twofold serial dilutions of chemicals were prepared (from 256 µg.ml^{-1} to 0.06 µg.ml^{-1}) and 100 µl of MRSA BCB8 suspension were incubated with 200 µl of chemical containing solutions for 24h at 37 °C.

After this time, suspension absorbances were measured at 600 nm. MICs were determined as the minimal concentration for which the lowest absorbance is observed.

The MICs were as follows:

MIC Vancomycin (Vanco.): 0.6 µg.ml^{-1}

MIC Macromonomer Vancomycin (Nb-PEO-Vanco; macro Vanco, as obtained by example 3.b)): 1.3 µg.ml^{-1}

MIC particles grafted with Vancomycin as obtained by example 3 c) (Vanco particles): 10.6 µg.ml^{-1}

The MICs are gathered in Figure 7 including also MICs measurements of Nb-PEO-OH (macro OH, equivalent to macro Vanco without Vancomycin), and Nb-PEO-OH particles (OH particles, equivalent to Vanco particles without Vancomycin).

5. In vivo results of the compounds of the invention

Prosthetic joint infection is a major complication of hip or knee arthroplasty and may lead to prosthesis removal or loss of function. *Staphylococcus aureus* is the most causative bacteria and methicillin resistance is increasing. The options for treatment of bone infections due to methicillin-resistant *S. aureus* (MRSA) are limited by pharmacokinetic factors (such as penetration into bone tissues) and susceptibility pattern of the causal bacteria. Nanoparticles loaded with gentamicin and/or vancomycin, fixed onto titanium devices, could prevent health-care associated infections.

Materials and methods

Strain studied: an MRSA strain obtained from blood cultures (gentamicin MIC < 0.5 µg/mL). Assessment of the animal model was realized with 10^3 CFU/mL inoculum.

Titanium devices: 4 mm diameter, 20 mm length.

These devices were:

a. Coated with gentamicin-nanoparticles (as described below) and sterilized by γ irradiation (25kGy).
b. Coated with vancomycin and gentamicin-nanoparticles (as described below) and sterilized by γ irradiation (25kGy).
c. Nude for the control group

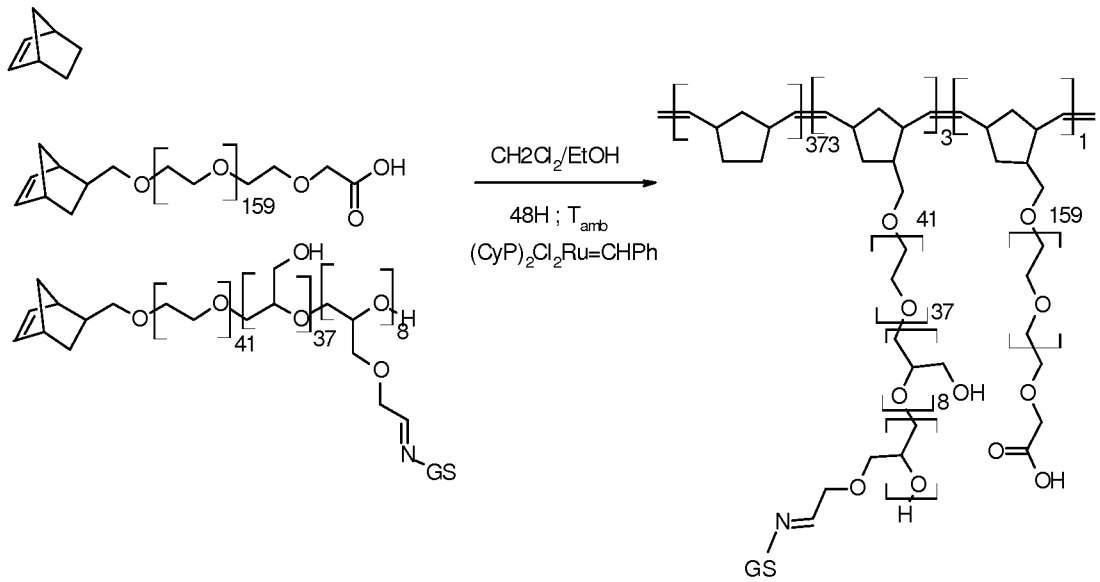
MRSA infection induction and titanium implantation at day 0

Bacterial counts on Chapman plates were realized 4 days after induction and titanium implantation for the control group (10^3 CFU/mL) and the treatment groups

Arterial catheter was placed for the *in vivo* study by HPLC of the gentamicin blood release.

Synthesis of particles used for the *in vivo* experiments:

Synthesis of Gentamicin functionalized particles with high density:

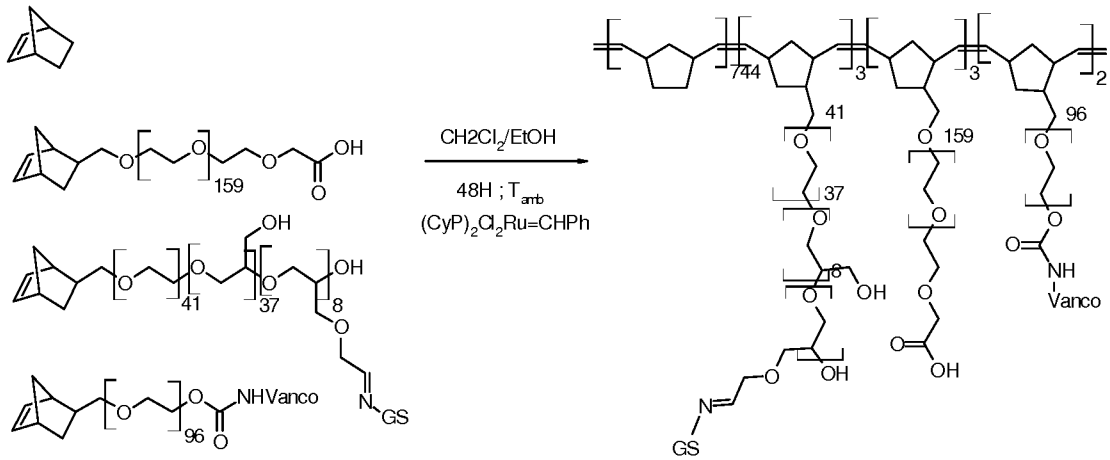


30 mg (823 g/mol; 3.65 10^{-5} mol) of Grubbs 1st generation complex were dissolved in 10 mL of dichloromethane/ethanol mixture (1:1 v/v). Norbornene (580 mg; 94 g/mol; 6.2 10^{-3} mol), α-norbornenyl-ω-carboxylic acid-poly(ethylene oxide) macromonomer (128.5 mg; 7000 g/mol; 1.84 10^{-5} mol) and gentamicin sulfate (GS) functionalized α-norbornenyl-poly(ethylene oxide)-*bloc*-polyglycidol macromonomer (451.5 mg; 8200 g/mol; 5.5 10^{-5} mol) were first dissolved in 18 mL of dichlomethane/ethanol solution (35:65 v/v) and added to the catalyst. 1 mL of the macromonomer solution was

sampled for analysis. 0.2 mL of dodecane was also added as internal standard. The mixture was stirred during 24 hours. The desactivation of the reaction medium was performed by addition of 0.2 mL of ethyl vinyl ether. Then, the particles were transferred to DMF to carry out the grafting step onto titanium surfaces:

- Norbornene conversion: >99% (gas chromatography)
- Global macromonomer conversion: 75% (gravimetric analysis)
- Size distribution of the particles by DLS in the reaction medium ($EtOH/CH_2Cl_2$), in water and in DMF: In $EtOH/CH_2Cl_2$: D=645 nm (0.16). In H_2O: D=680 nm (0.22). In DMF: D=655 nm (0.27)
- Calculation of the drug density (amount of GS molecules per particle): $N_{GS/part}$=32 10^6.

Synthesis of particles functionalized with Gentamicin (high density) and Vancomycin:



30 mg (823 g/mol; 3.65 10^{-5} mol) of Grubbs 1st generation complex were dissolved in 10 mL of dichloromethane/ethanol mixture (1:1 v/v). Norbornene (580 mg; 94 g/mol; 6.2 10^{-3} mol), α-norbornenyl-ω-carboxylic acid-poly(ethylene oxide) macromonomer (128.5 mg; 7000 g/mol; 1.84 10^{-5} mol), GS functionalized α-norbornenyl-poly(ethylene oxide)-*bloc*-polyglycidol macromonomer (225.5 mg; 8200 g/mol; 2.75 10^{-5} mol) and α-norbornenyl-ω-Vancomycin-poly(ethylene oxide) macromonomer (130.6 mg; 4750 g/mol; 2.75 10^{-5} mol) were first dissolved in 18 mL of dichlomethane/ethanol solution (35:65 v/v) and added to the catalyst. 1 mL of the macromonomer solution was sampled for analysis. 0.2 mL of dodecane is also added

as internal standard. The mixture was stirred during 24 hours. The desactivation of the reaction medium was performed by addition of 0.2 mL of ethyl vinyl ether. Then, the particles were transferred to DMF to carry out the grafting step onto titanium surfaces:

- Norbornene conversion: >99% (gas chromatography)
- Global macromonomer conversion: 75% (gravimetric analysis)
- Size distribution of the particles by DLS in the reaction medium ($EtOH/CH_2Cl_2$) and in DMF: In $EtOH/CH_2Cl_2$: D=370 nm (0.24). In DMF: D=280 nm (0.22)
- Calculation of the drug density (amount of GS and Vancomycin molecules per particle): $N_{GS/part}=26\ 10^6$; $N_{Vanco/part}=3.2\ 10^6$.

Determination of the global macromonomer conversions and calculation of the drug densities:

Macromonomer conversion measurement:

Macromonomer conversions were measured by gravimetric analyses. 1 mL of dispersion was first filtrated with a 0.1 µm PTFE filter, then the filtrate volume was measured (V_f), and finally this filtrate was evaporated under vacuum overnight in order to keep only the unreacted macromonomers. This residual macromonomers were weighed (m^f_{macro}) and compared to the initial mass. The macromonomer conversion can be calculated with the following equation:

$$\pi_{macro} = 1 - \frac{m^f_{macro}/V_f}{m^i_{macro}/V_i}$$

With,

- m^i_{macro} the initial weight of macromonomers introduced of the reaction
- V_i the initial volume

For this calculation, we approximated that the weight of the residual Grubbs catalyst is negligible.

Determination of the drug amounts per particle:

Determination of the GS concentration in the latex:

The GS concentration in the latex can be calculated with the following equation:

$$C_{GS} = \frac{\pi \times 8 \times n_{Macro-GS} \times M_{GS}}{m_{Nb} + \pi \sum m_{Macro}}$$

With:

- 8 is the amount of GS molecule linked on a macromonomer
- $n_{Macro-GS}$ the initial amount of macromonomer functionalized with GS
- M_{GS} the molecular weight of Gentamicin
- m_i the initial weight of compound i
- π the conversion of the macromonomers

For this calculation, we assumed that the macromonomers are consumed at the same time regardless the functionalization.

For Gentamicin functionalized particles with high density: C_{GS} = 182 mg/g

For particles functionalized with Gentamicin (high density) and Vancomycin C_{GS} = 83 mg/g

Determination of the Vancomycin concentration in the latex:

The Vancomycin concentration in the latex can be calculated with the following equation:

$$C_{Vanco} = \frac{\pi \times n_{Macro-Vanco} \times M_{Vanco}}{m_{Nb} + \pi \sum m_{Macro}}$$

With:

- $n_{Macro-Vanco}$ the initial amount of macromonomer functionalized with Vancomycin
- M_{Vanco} the molecular weight of Vancomycin
- m_i the initial weight of compound i
- π the conversion of the macromonomers

For this calculation, we assumed that the macromonomers are consumed at the same time regardless the functionalization.

For particles functionalized with Gentamicin (high density) and Vancomycin C_{Vanco} = 3.2 mg/g

Determination of the drug amounts per particle:

Knowing the GS and Vancomycin concentrations in the latexes and the volume of one particle we can approximate the GS and the Vancomycin amounts per particle:

$$N_{GS/part} = \frac{C_{GS} \times \rho_{part} \times V_{part} \times N_A}{M_{GS}}$$

$$N_{Vanco/part} = \frac{C_{GS} \times \rho_{part} \times V_{part} \times N_A}{M_{Vanco}}$$

with:

- C_{GS}: Gentamicin concentration in the latex (in mg/g)
- C_{Vanco}: Vancomycin concentration in the latex (in mg/g)
- ρ_{part}: latex density approximated to equal to 1 g/mL
- V_{part}: volume of a particle ($V_{part}= D^3/6$)
- N_A: Avogadro number
- M_{GS}: molecular weight of Gentamicin
- M_{Vanco}: molecular weight of Vancomycin

For Gentamicin functionalized particles with high density: $N_{GS/part} = 32\ 10^6$.
For particles functionalized with Gentamicin (high density) and Vancomycin: $N_{GS/part} = 26\ 10^6$ and $N_{Vanco/part} = 3.2\ 10^6$.

Statistical analyses will be performed with GraphPad Prism® v4.0 (GraphPad Software, San Diego, CA). Bacterial counts in bone marrow and spongy bone for per-operative model were compared by a Kruskal-Wallis test. A $P \leq 0.05$ was considered significant.

Results

Bacterial counts

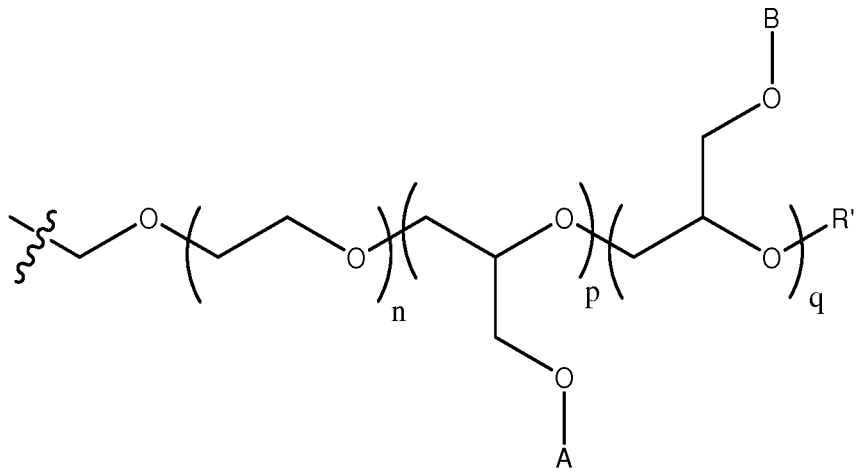
		% or sterile tissue	
	Number of rabbits	**Bone Marrow**	**Spongy bone**
Control	10	0	0
Vanco + Genta	12	16.7	41.67
Genta	12	16.7	41.67

Conclusion

Titanium devices coated with covalent vancomycin plus pH sensitive gentamicin or with higher load of pH sensitive gentamicin seem to be able to limit MRSA infection in spongy bone and bone marrow in 4 days, for nosocomial infection assessment.

CLAIMS

1. Polymer particles, the said particles being formed by polymer chains containing about 30 to 10000 monomer units, identical or different, derived from polymerization of monocyclic or polycyclic alkenes, wherein at least one of the said monomer units is substituted by a chain R comprising a polyethyleneglycol-polyglycidol chain of formula (I), wherein formula (I) is as follows:



(I),

formula (I) wherein:

n represents an integer from about 0 to 300, especially from 10 to 100, p represents an integer from about 0 to 300, q represents an integer from about 0 to 300, with n+p+q is from about 10 to 300,

A represents a hydrogen atom or a group of the following formula (II):
-CONHAb1, where Ab1 represents an antibiotic with extracellular action,

B represents a hydrogen atom or a group of the following formula (III):
-CH2CNAb2, wherein Ab2 represents an antibiotic with intracellular action,

R' represents a hydrogen atom, -CH2CNAb2 or -CONHAb1 as defined above,
with the proviso that when p is different from 0, then q is 0 and R' represents a hydrogen atom or -CONHAb1 as defined above, when q is different from 0, then p is 0 and R' represents a hydrogen atom or -CH2CNAb2, when p+q is not zero, at least one of the p or q moieties comprises the formula (II) or (III) respectively, and when

said particles are formed by polymer chains with p+q is 0 exclusively, then at least one of said polymer chains presents a R chain comprising a polyethyleneglycol-polyglycidol chain of formula (I) where R' is -CONHAb1 as defined above,

 represents a covalent bond by which the polyethyleneglycol-polyglycidol chain is attached to the remainder of the R chain,

and wherein at least one of said monomer units, identical or different from the monomer units substituted by R chain, is substituted by a group X, wherein X represents an alkyl or alkoxy chain with about 0 to 500 carbon atoms, preferably 1 to 500 carbon atoms, more preferably 40 to 400 carbon atoms, comprising a reactive function of the C=CH2, C≡CH, OH, OR''', wherein R''' represents an alkyl group, halogen, NH2, C(O)X1 type, wherein X1 represents a hydrogen atom, an alkyl group, a halogen atom, an OR" or NHR" group, in which R" represents a hydrogen atom or an alkyl group..

2. The polymer particles according to claim 1, wherein the monocyclic or polycyclic alkenes from which the monomer units are derived are selected from the group consisting of norbornene (bicyclo[2.2.1]hept-2-ene), tetracyclododecadiene, dicyclopentadiene, the dimer of norbornadiene, and cycloocta-1,5-diene.

3. The polymer particles according to claim 1 or 2, wherein the chain or chains R substituting the monomers are represented by the formula (I), more specifically wherein at least one, or all, of the following specific embodiments are fulfilled:

n+p+q is from 10 to 100; and/or

n is from 35 to 70, more specifically n is from 40 to 60 (e.g. n=45); and/or

either p or q is from 1 to 300.

4. The polymer particles according to anyone of claim 1-3, wherein the chain of formula (I) is of the following formula:

,

wherein R' -CONHAb1 and n is as defined in claim 1, and preferably n is from 1 to 300, more preferably from 10 to 100, or Ab1 is preferably vancomycin or a salt thereof.

5. The polymer particles according to anyone of claim 1-3, wherein R' in formula (I) is an hydrogen atom.

6. The polymer particles according to anyone of claim 1-5, wherein Ab1 represents a cephalosporin, including those from first to the fifth generations, such as cefalexin, cefuroxim, ceftriaxone, cefepime, ceftobiprole; a carbacephem, such as Loracarbef; a carbapenem, such as imipenem; a glycopeptide, such as vancomycin, teicoplanin or ramoplanin; a lipopeptide, such as daptomycin; a monobactam, such as aztreonam; a penicillin, such as amoxicillin; or a polymyxin, such as polymyxin B; preferably Ab1 is vancomycin and any salt thereof.

7. The polymer particles according to anyone of claim 1-6, wherein Ab2 represents an aminoglycoside, including gentamicin, neomycin, and streptomycin; an anzamycin, such as rifaximin; a lincosamide, such as clindamycin; a macrolide, such as azithromycin; a nitrofurane, such as furazolidone; an oxazolidinone, such as linezolid; a quinolone or a fluoroquinolone, such as nalidixic acid, ofloxacin, ciprofloxacin, or levofloxacin; a sulfonamide, such as sulfacetamide, furosemide; a tetracycline, such as doxycycline; preferably Ab2 is an aminoglycoside, preferably gentamicin or any salt thereof.

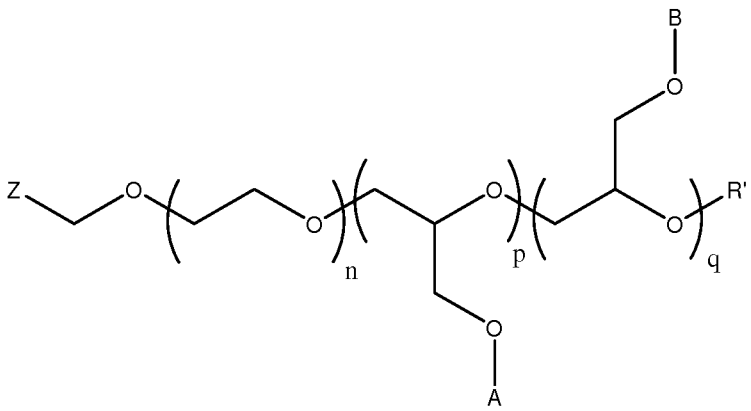
8. The polymer particles according to anyone of claim 1-7, wherein they comprise: between about 0.5% and 99.5% of monomer units substituted by a chain R as defined in anyone of the preceding claims, the said chain R being identical for these monomers, and between about 0.5% and 99.5% of monomer units substituted by a chain R as defined in anyone of the preceding claims, the said chain R of these monomers being different from the chain R of the preceding monomers, more preferably said chain R comprises groups of formula (II) and the said other different chain R comprises groups of formula (III), and between 0.0% and about 99% of unsubstituted monomer units, optionally at least one of the monomer units substituted by a chain R is also substituted by a group X,

and/or between about 0.5% and 99.5% of monomer units substituted by a chain R as defined in anyone of the preceding claims, the said chain R being identical or different for these monomers, and between about 0.5% and 99.5% of unsubstituted monomer units, optionally at least one of the monomer units substituted by a chain R is also substituted by a group X,

and/or between about 0.5% and 99.5% of monomer units directly substituted by a group X as defined in anyone of the preceding claims, and between about 0.5% and 99.5% of monomer units substituted by a chain R as defined in anyone of the preceding claims, the said chain R being identical or different for these monomers, and between 0.0% and about 99.0% of unsubstituted monomer units,

the total of the percentages of the monomers mentioned above being 100%.

9. A monocyclic or polycyclic alkene based macromonomer of formula (IV) as follows:



formula (IV) wherein

n represents an integer from about 0 to 300, especially from 10 to 100, p represents an integer from about 0 to 300, q represents an integer from about 0 to 300, with n+p+q is from about 10 to 300,

A represents a hydrogen atom or a group of the following formula (II):

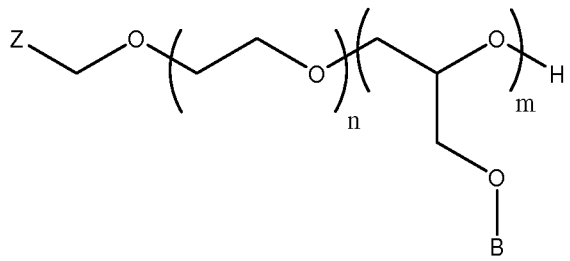
-CONHAb1, where Ab1 represents an antibiotic with extracellular action,

B represents a hydrogen atom or a group of the following formula (III):

-CH2CNAb2, wherein Ab2 represents an antibiotic with intracellular action,

R' represents a hydrogen atom, -CH2CNAb2 or -CONHAb1 as defined above,
with the proviso that when p is different from 0, then q is 0 and R' represents a hydrogen atom or -CONHAb1, when q is different from 0, then p is 0 and R' represents a hydrogen atom or –CH2CNAb2, when p+q is not zero, at least one of the p or q moieties comprises the formula (II) or (III) respectively, and when p+q is 0, then R' can be -CONHAb1 only,
Z represents a monocyclic or polycyclic alkene to which the polyethyleneglycol-polyglycidol chain is attached, optionally substituted by a group X, wherein X represents an alkyl or alkoxy chain with about 1 to 500 carbon atoms, preferably 40 to 400 carbon atoms, comprising a reactive function of the OH, halogen, NH2, C(O)X1 type, wherein X1 represents a hydrogen atom, a halogen atom, an OR" or NHR"group, in which R" represents a hydrogen atom or an alkyl group.

10. The macromonomer according to claim 9, wherein it is of the following formula (V):



in which Z is as defined in claim 9, n is as defined in anyone of the preceding claims, more preferably is 0, and m is q as defined in anyone of the previous claims, and B is as defined in anyone of the previous claims, wherein at least one of the m moieties comprises the formula (III).

11. The macromonomer according to anyone of claim 9-10, wherein the cyclic alkene is selected from norbornene, tetracyclododecadiene, dicyclopentadiene, the dimer of norbornadiene, and cycloocta-1,5-diene, more particularly it is norbornene.

12. A biomaterial comprising a support material having on its support surface covalently bonded polymer particles as defined in anyone of claims 1-8.

13. The biomaterial according to claim 12, wherein the support material is chosen from:

- metals or metal oxides thereof, preferably titanium or TiO2,
- metal alloys, in particular alloys with or without shape memory such as Ni-Ti alloys,
- polymers, such as polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE), polyvinylidine fluoride (PVDF), polyether etherketone (PEEK), polycarbonate-urethane (PCU), polyhydroxyethylmethacrylate (PHEMA), polymethylmethacrylate (PMMA), poluethylmethacrylate (PEMA), poly(4-hydroxystyrene),
- copolymers, such as the copolymer ethylene vinyl acetate (EVA), the copolymer vinylidene fluoride-hexafluoropropylene P(VDF-HFP), poly(lactic acid)-co-poly(glycolic acid) (PLA-PGA), copolymers of polymethylmethacrylate (PMMA) and poluethylmethacrylate (PEMA),
- ceramics, such as hydroxyapatites, or compounds of hydroxyapatites and tricalcium phosphate.

14. A medical device, including implants, prostheses, stents, lenses or cements as well as any pharmaceutical composition, comprising a biomaterial as defined in anyone of claim 12 and 13.

15. The medical device of claim 14, wherein the medical device is an implant, prostheses, stents, lenses, cements, or any pharmaceutical composition.

16. Polymer particles of anyone of claims 1-8, a biomaterial of anyone of claims 12-13, or a medical device according to anyone of claim 14-15, as a medicine, more particularly for a use in the treatment of bacterial infections.

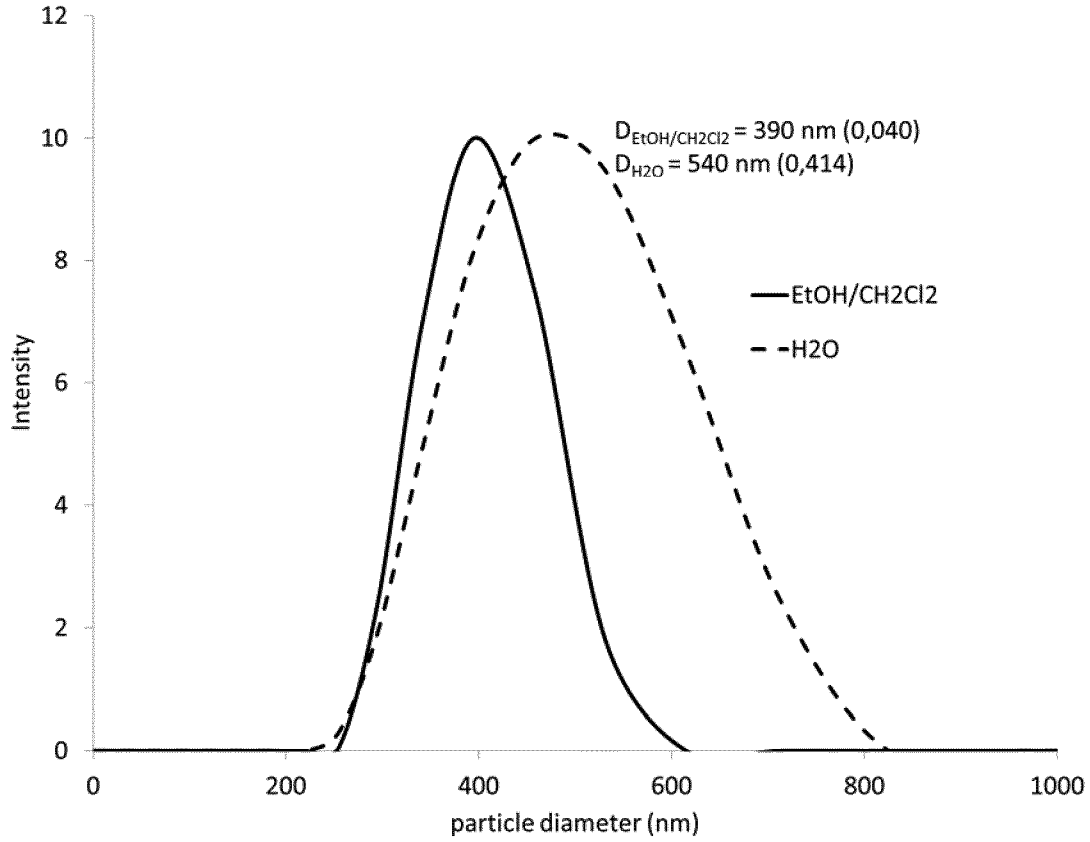


Figure 1

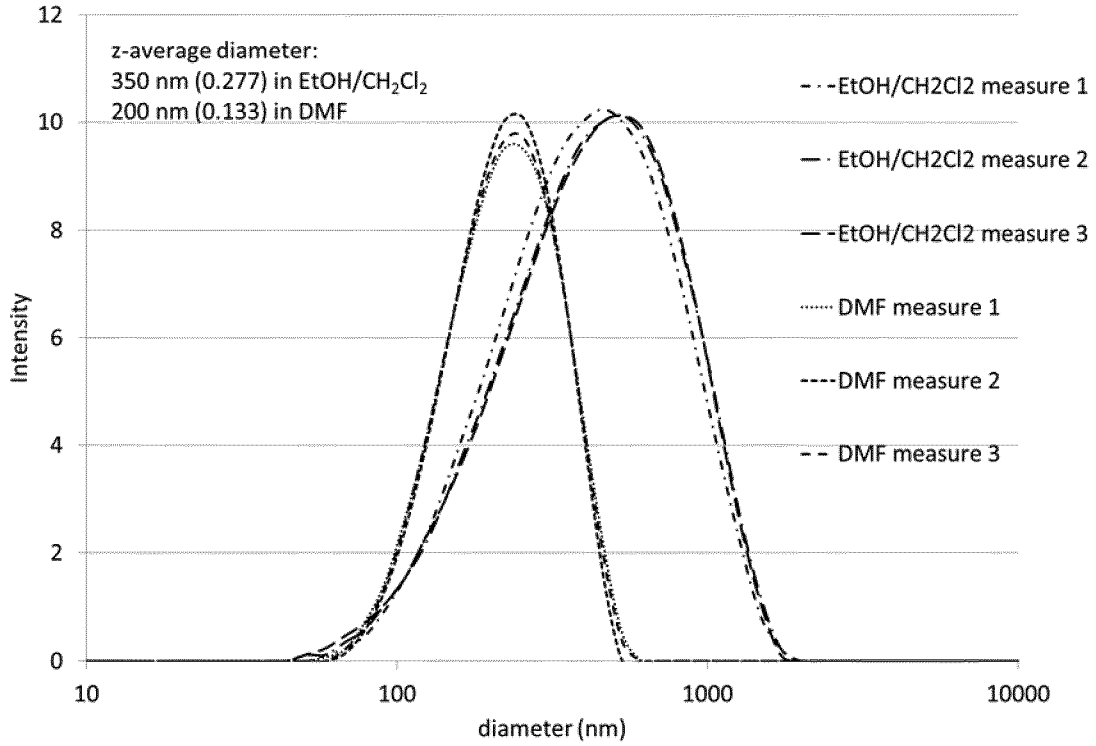


Figure 2

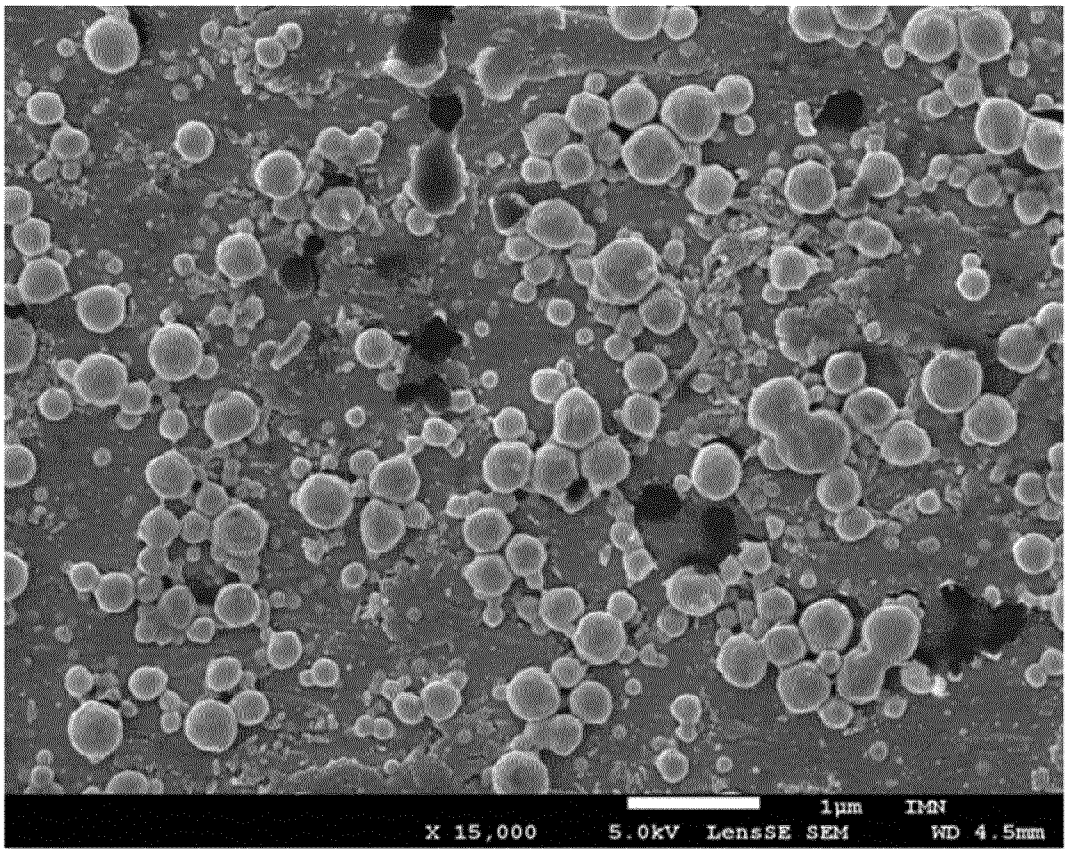


Figure 3

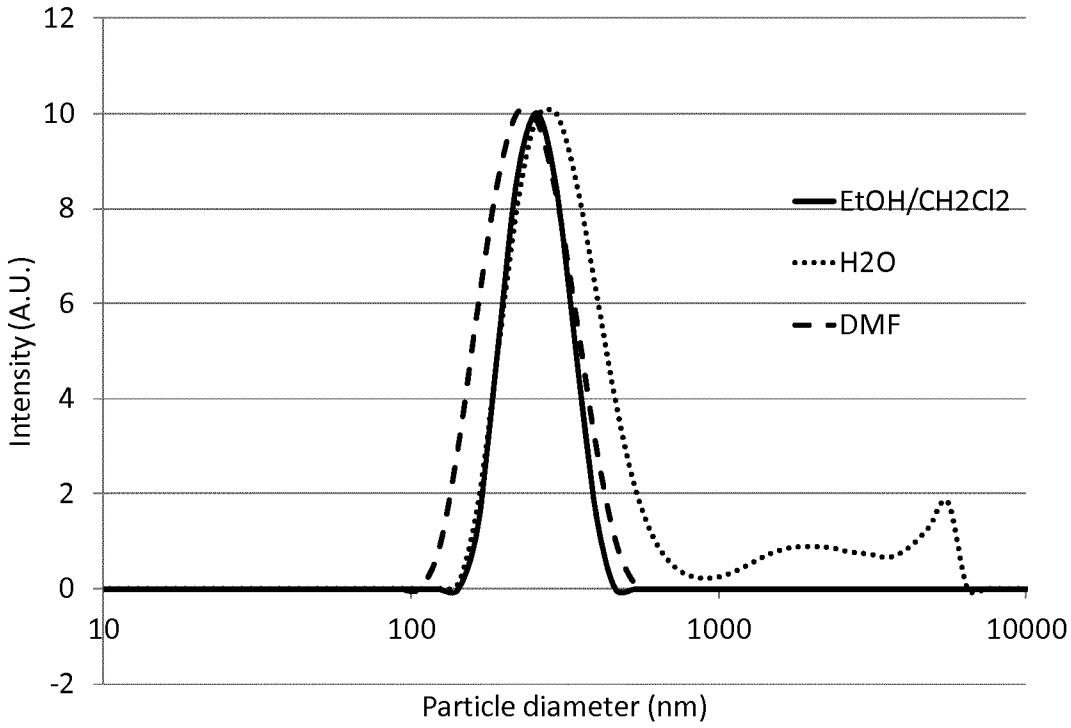


Figure 4

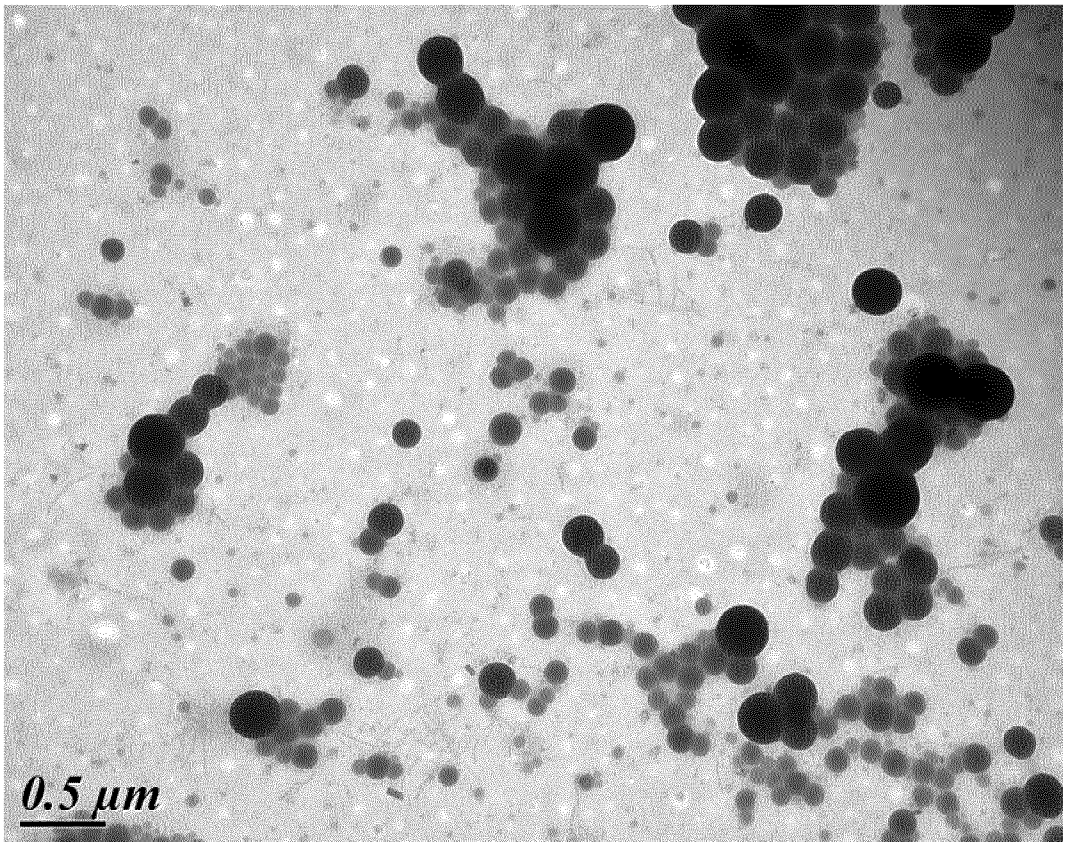


Figure 5

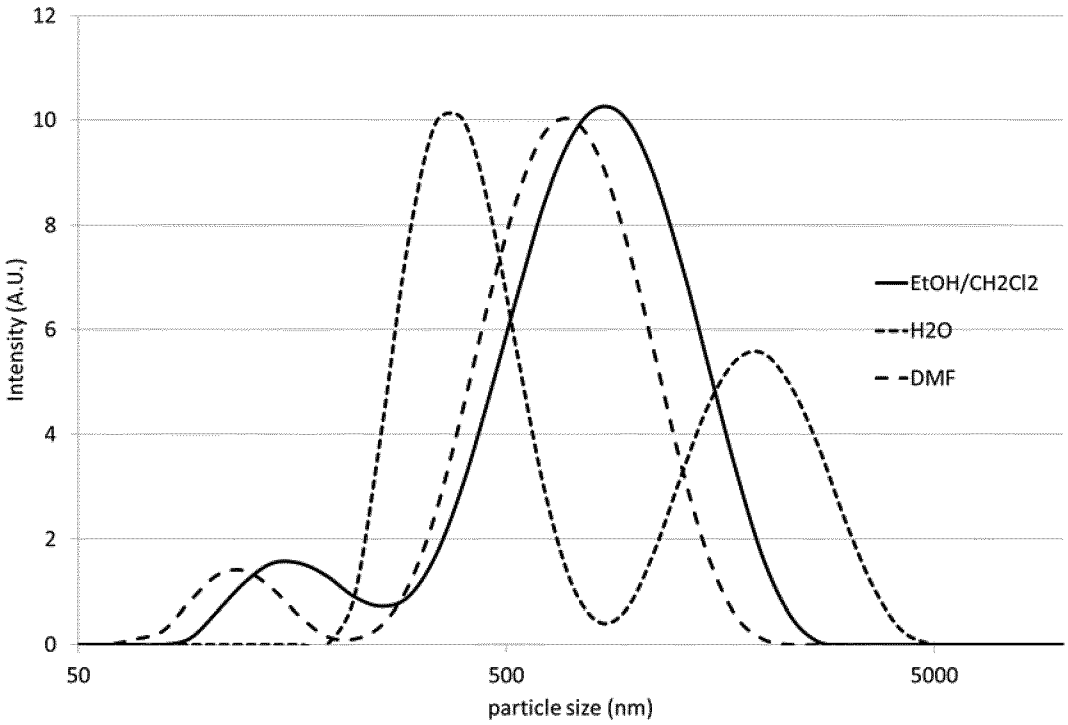


Figure 6

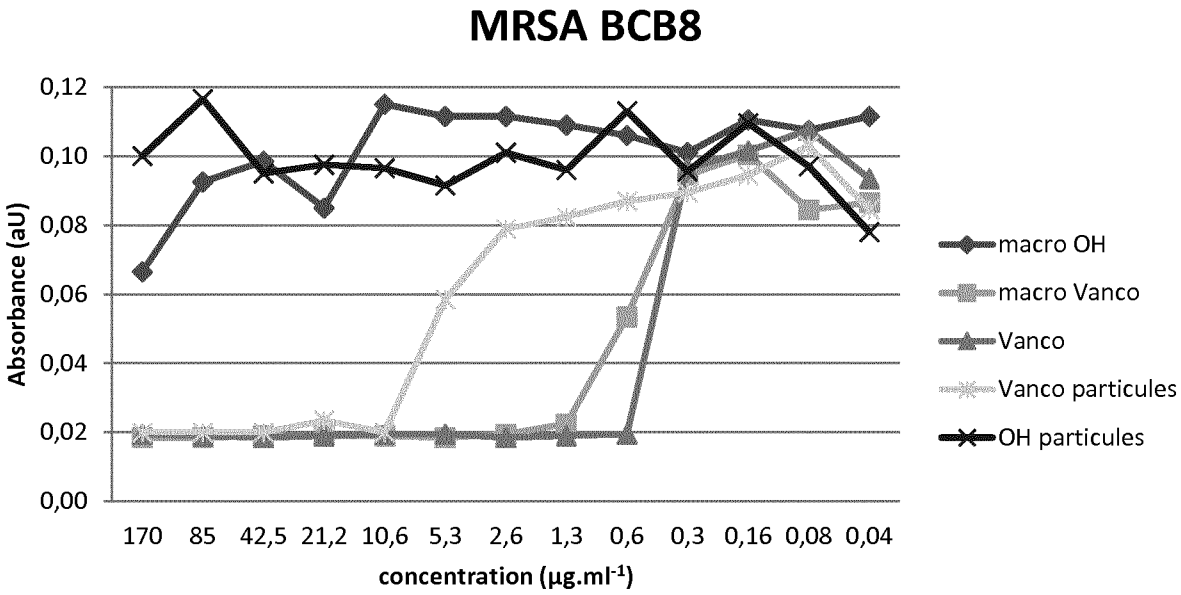

MRSA BCB8
0,12
0,10
0,08
0,06
0,04
0,02
0,00
Absorbance (aU)
170 85 42,5 21,2 10,6 5,3 2,6 1,3 0,6 0,3 0,16 0,08 0,04
concentration (µg.ml-1)
macro OH
macro Vanco
Vanco
Vanco particules
OH particules

Figure 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/080622

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08G65/22 A61K47/48 C08F32/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08G A61K C08F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 758 621 B1 (CENTRE NAT RECH SCIENT [FR]; INST NAT SANTE RECH MED [FR]; UNIV BORDEA) 11 August 2010 (2010-08-11) cited in the application	1-4,6-9, 11-16
A	examples a-c page 19, paragraph [0066] page 16, paragraph [0052] Schéma 2; page 22 Schéma de synthèse; page 19 page 2, paragraph [0002] - paragraph [0006] claims 1-18	5,10

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 February 2016	09/03/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Popescu, Teodora

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/080622

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