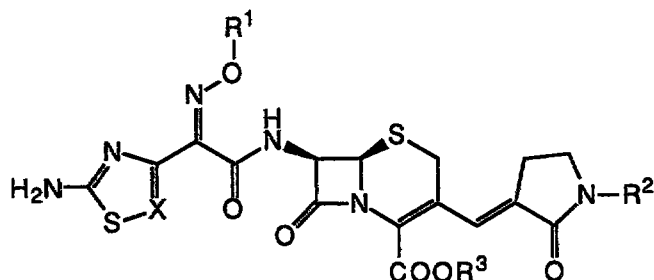


Vinyl-pyrrolidinone Cephalosporins with basic Substituents

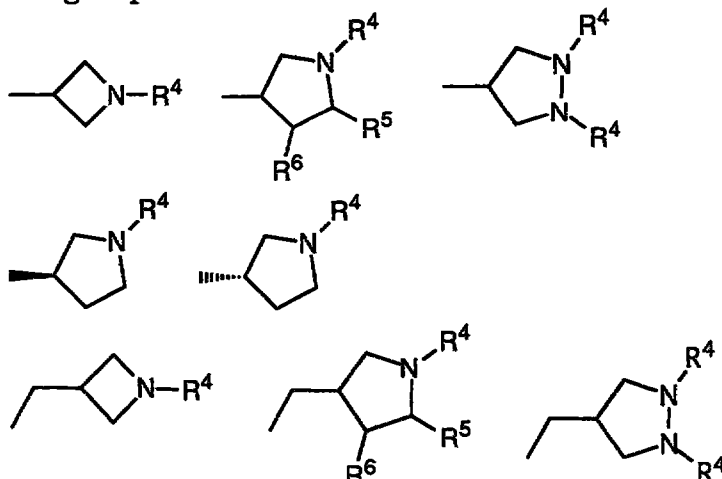
The present invention relates to cephalosporin derivatives of the general formula



I

wherein

- X is CH or N;
R¹ is hydrogen or cyclopentyl;
R² is a group of formula

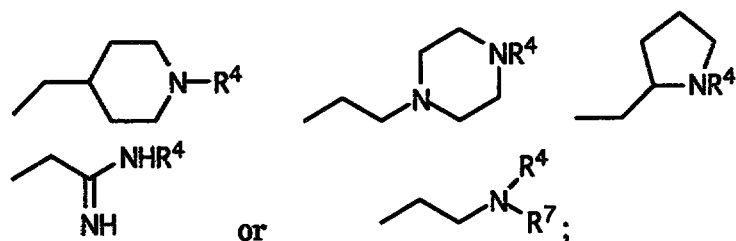


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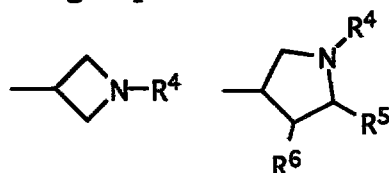


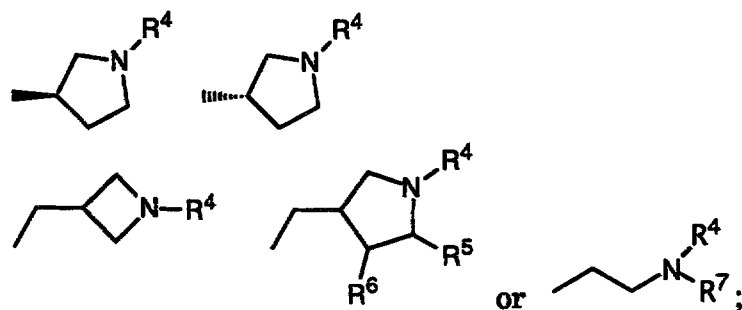
- R³** is hydrogen, an alkalimetal ion or a tertiary ammonium group;
- R⁴** is hydrogen, an amino protecting group, pyrrolidin-2-ylmethyl, azetidin-3-ylmethyl, iminomethyl, 1-carbamimidoyl;
- R⁵** is hydrogen, dialkylcarbamoyl, ω -hydroxyalkyl, ω -aminoalkyl, pyridinium-1-ylmethyl, 1-hydroxy-3-aminomethyl-propyl or (hydroxy)-(pyrrolidin-2-yl)methyl;
- R⁶** is hydrogen, trifluoromethyl or hydroxy; and
- R⁷** is alkyl, ω -hydroxy-alkyl, cycloalkyl, 3-pyrrolidinyl, 3-azetidiny, iminomethyl or 1-carbamimidoyl;
- as well as readily hydrolyzable esters thereof, pharmaceutically acceptable salts of said compounds and hydrates of the compounds of formula I and of their esters and salts.

Furthermore, the invention is concerned with the manufacture of compounds of formula I; with their use as pharmaceutically active substances, particularly for the treatment and prophylaxis of infectious diseases, and with pharmaceutical preparations containing a compound of formula I for the treatment and prophylaxis of infectious diseases, especially infectious diseases caused by methicillin resistant *Staphylococcus aureus* (MRSA).

Preferred compounds of formula I are compounds wherein

- X** is CH or N;
- R¹** is hydrogen;
- R²** is a group of formula

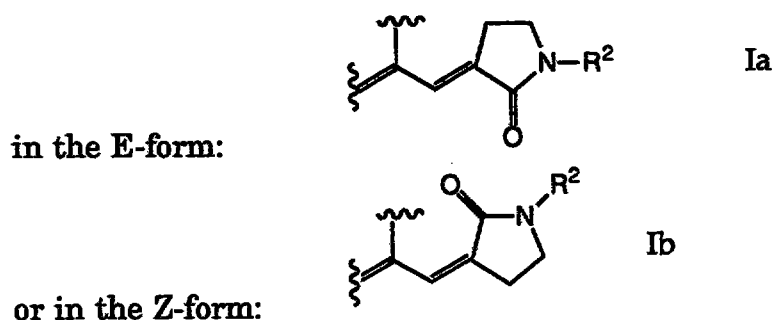




- R^3 is hydrogen, an alkalimetal ion or a tertiary ammonium group;
- 5 R^4 is hydrogen, an amino protecting group, iminomethyl, or 1-carbamimidoyl;
- R^5 is hydrogen, hydroxymethyl;
- R^6 is hydrogen or hydroxy; and
- R^7 methyl or 2-hydroxyethyl;
- 10 as well as readily hydrolyzable esters thereof, pharmaceutically acceptable salts of said compounds and hydrates of the compounds of formula I and of their esters and salts.

The compounds of the present formula I are useful in the treatment of infectious diseases caused by bacterial pathogens in particular methicillin
 15 resistant *Staphylococci aureus* (MRSA) and *Pseudomonas aeruginosa*.

In above compounds of formula I the R^2 substituted pyrrolidinone can be present



20 Compounds of formula Ia, i.e. compounds wherein the pyrrolidinone is in the E-form are generally preferred.

The term "protected amino group" refers to groups such as those employed in peptide chemistry, such as an alkoxycarbonyl group such as
 25 tert-butoxycarbonyl, allyloxy carbonyl and the like; a substituted alkoxy-carbonyl group such as trichloroethoxycarbonyl etc.; an optionally

substituted aralkyloxycarbonyl group, for example, p-nitrobenzyloxycarbonyl or benzyloxycarbonyl; an aralkyl group such as trityl or benzhydryl; an alkanoyl group such as formyl or acetyl; a halogen-alkanoyl group such as chloroacetyl, bromoacetyl, iodoacetyl or trifluoroacetyl; or a silyl protective
5 group such as the trimethylsilyl group.

Preferred amino protecting groups are tert-butoxycarbonyl (t-BOC), allyloxycarbonyl (ALLOC) and trityl.

As used herein, the term "alkyl" refers to both straight and branched chain saturated hydrocarbon groups having 1 to 8 and preferably 1 to 4
10 carbon atoms, for example, methyl, ethyl, n-propyl, isopropyl, tertiary butyl and the like.

As used herein, the term " ω -hydroxy-alkyl" refers to both straight and branched chain saturated hydrocarbon groups as defined above bearing a hydroxy group in the terminal position, e.g. hydroxymethyl, 2-hydroxyethyl,
15 3-hydroxypropyl, and the like.

As used herein, the term " ω -amino-alkyl" refers to both straight and branched chain saturated hydrocarbon groups as defined above bearing an amino group in the terminal position, e.g. aminomethyl, 2-aminoethyl, 3-aminopropyl, and the like.

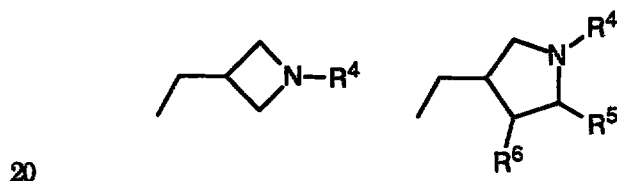
20 As used herein pharmaceutically acceptable salts useful in this invention include salts derived from metals, salts from amino acids and salts of mineral or organic acids. Examples of preferred metal salts are those derived from the alkali metals, for example, lithium (Li^+), sodium (Na^+) and potassium (K^+), from the earth alkali metals, for example
25 magnesium (Mg^{++}). Those salts derived from amino acids such as, for example, salts with arginine or lysine. Examples of salts of mineral acids are for example chlorides, sulphates or phosphates, and examples of salts of organic acids mesylates, napsylates, besylates, maleates, salicylates, tartrates, lactates, citrates, benzoates, succinates, acetates and the like.
30 Especially preferred are chlorides, sulfates, phosphates, lactates or mesylates.

As readily hydrolyzable esters of the compounds of formula I there are to be understood compounds of formula I, wherein the carboxy group in 2-position is present in the form of readily hydrolyzable ester group. Examples
35 of such esters, which can be of the conventional type, are the lower

alkanoyloxy-alkyl esters (e.g., the acetoxymethyl, pivaloyloxymethyl, 1-acetoxyethyl and 1-pivaloyloxyethyl ester), the lower alkoxy-carbonyloxyalkyl esters (e.g., the methoxycarbonyloxymethyl, 1-ethoxycarbonyloxyethyl and 1-isopropoxycarbonyloxyethyl ester), the lactonyl esters (e.g., the phthalidyl
 5 and thiophthalidyl ester), the lower alkoxy-methyl esters (e.g., the methoxymethyl ester) and the lower alkanoylaminomethyl esters (e.g., the acetamidomethyl ester). Other esters (e.g., the benzyl and cyanomethyl esters) can also be used. Other examples of such esters are the following: (2,2-dimethyl-1-oxopropoxy)methyl ester; 2-[(2-methylpropoxy)carbonyl]-2-pentenyl ester; 1-[[[(1-methylethoxy)carbonyl]oxy] ethyl ester; 1-(acetyloxy)
 10 ethyl ester; (5-methyl-2-oxo-1,3-dioxol-4-yl) methyl ester; 1-[[[(cyclohexyloxy)carbonyl]oxy] ethyl ester; and 3,3-dimethyl-2-oxobutyl ester. It will be appreciated by those of ordinary skill in the art that the readily hydrolyzable esters of the compounds of the present invention can be formed
 15 at a free carboxy group of the compound.

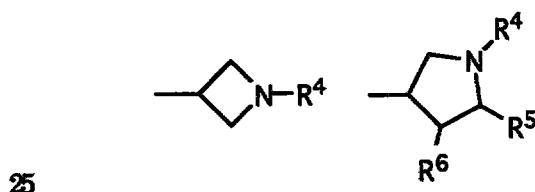
Examples of salts of the compounds of formula I are defined under "pharmaceutically acceptable salts" above.

A preferred embodiment of the invention are compounds of formula I wherein X is CH or N and R² represents a group of the formula



wherein R⁴ is hydrogen, iminomethyl or 1-carbamimidoyl; R⁵ is hydrogen or hydroxymethyl; and R⁶ is hydrogen or hydroxy.

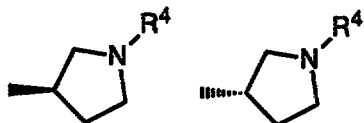
In a further preferred embodiment of the compounds of formula I X is CH or N and R² represents a group of the formula



wherein R⁴, R⁵ and R⁶ are as defined above.

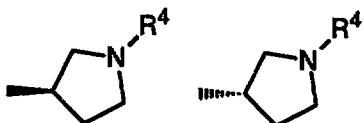
Especially preferred are compounds of formula I wherein R⁵ and R⁶ are hydrogen.

An especially preferred embodiment of the invention are compounds of formula I, wherein X is CH and R² is a group of formula



wherein R⁴ is as defined above.

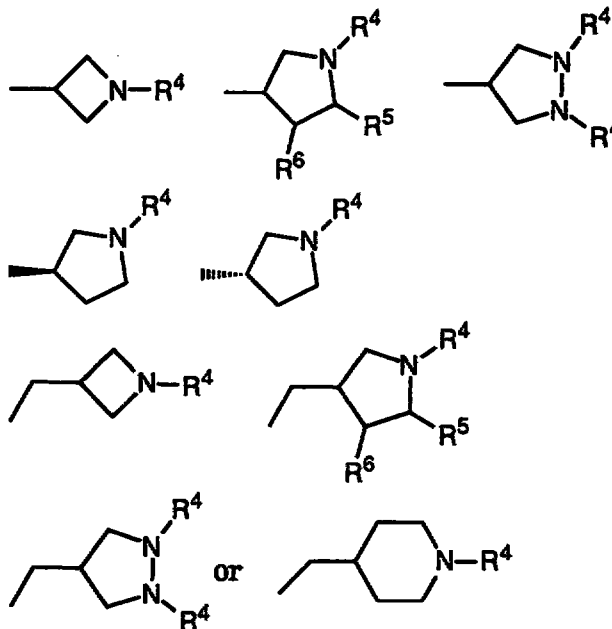
- 5 A further especially preferred group of compounds consists of compounds of formula I wherein X is N and R² is a group of formula



wherein R⁴ is as defined above.

A further preferred embodiment are compounds of formula I, wherein

- 10 X is CH or N
R¹ is hydrogen or cyclopentyl
R² is a group of formula



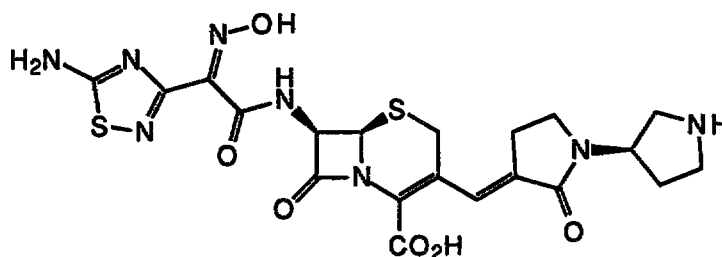
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- R³ is hydrogen, an alkalimetal ion or a tertiary ammonium group,
R⁴ is hydrogen, an amino protecting group;
20 R⁵ is hydrogen, dialkylcarbamoyl, and
R⁶ is hydrogen or trifluoromethyl,

as well as readily hydrolyzable esters thereof, pharmaceutically acceptable salts of said compounds and hydrates of the compounds of formula I and of their esters and salts.

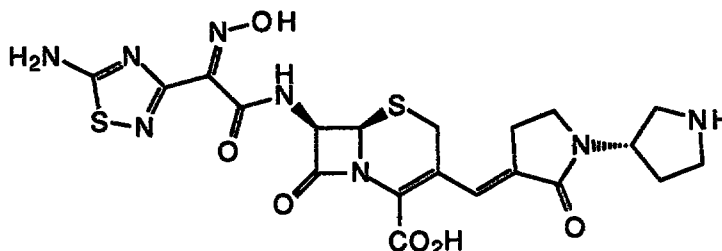
Such especially preferred compounds are for example

- 5 A: (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



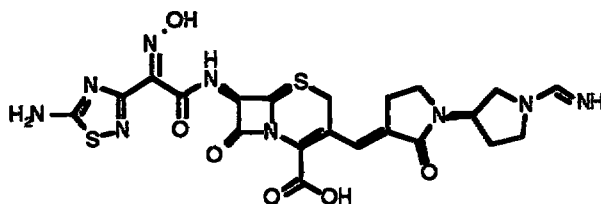
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- B: (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



15

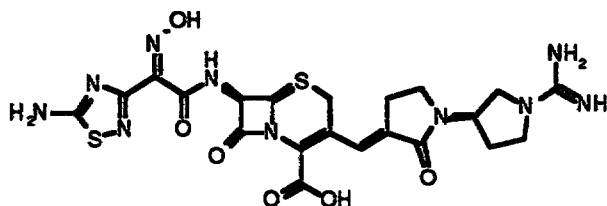
- C: (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-(R)-1'-iminomethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



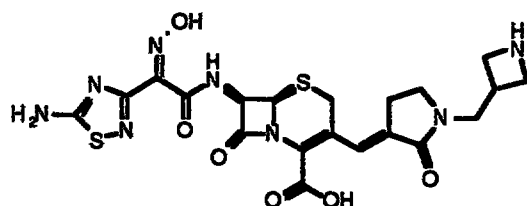
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- D: (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-(R)-1'-carbamimidoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

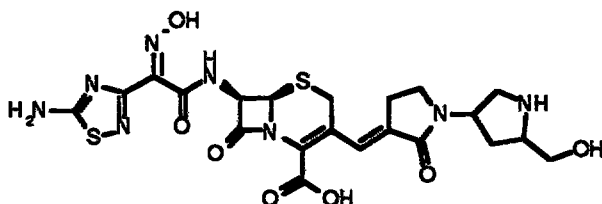
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E: (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-azetidin-3-ylmethyl-2-oxo-pyrrolidin-3-ylidenemethyl]-
5 8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



F: (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-5'-hydroxymethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-
10 oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



15 The compounds of formula I as well as their salts and readily hydrolyzable esters can be hydrated. The hydration can be effected in the course of the manufacturing process or can occur gradually as a result of hygroscopic properties of an initially anhydrous product.

The compounds of the present invention are useful as antibiotics having
20 potent and broad antibacterial activity; especially against methicillin resistant Staphylococci (MRSA) and *Pseudomonas aeruginosa*.

The products in accordance with the invention can be used as medicaments, for example, in the form of pharmaceutical preparations for parenteral administration, and for this purpose are preferably made into
25 preparations as lyophilisates or dry powders for dilution with customary agents, such as water or isotonic common salt or carbohydrate (e.g. glucose) solution.

Depending on the nature of the pharmacologically active compound the pharmaceutical preparations can contain the compound for the prevention and treatment of infectious diseases in mammals, human and non-human. A daily dosage of about 10 mg to about 4000 mg, especially about 50 mg to about 3000 mg, is usual, with those of ordinary skill in the art appreciating that the dosage will depend also upon the age, conditions of the mammals, and the kind of diseases being prevented or treated. The daily dosage can be administered in a single dose or can be divided over several doses. An average single dose of about 50 mg, 100 mg, 250 mg, 500 mg, 1000 mg, and 2000 mg can be contemplated.

Representative compounds (A and B, above) of the present invention were tested. In vitro activity was determined by minimum inhibitory concentration by the agar dilution method in Mueller Hinton agar, inoculum = 10^4 CFU/spot.

15

***In vitro* activity (MIC [μ g/ml])**

	A	B
MIC <i>S.aureus</i> 6538 (MSSA)	0.5	0.25
MIC <i>S. aureus</i> 743 (MRSA)	2	2
MIC <i>S. aureus</i> 270A (MRSA)	2	4
MIC90 (MRSA, n=38)*	4	4
MIC <i>P. aeruginosa</i> ATCC27853	2	4

*Agar dilution method on Mueller-Hinton agar, inoculum: 10^5 CFU/spot

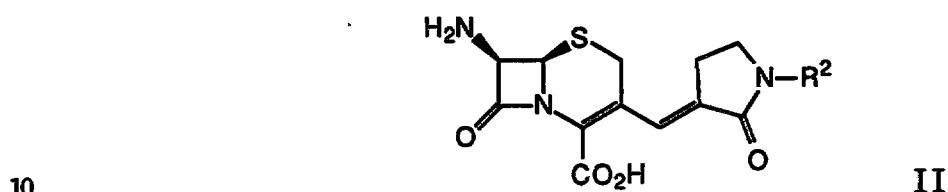
20 *In vivo* efficacy was determined with a sc abscess model in mice, infected with *S. aureus* 270 A (MRSA). The dose (ip) was 10 mg/kg. The median log of colony forming units (CFU) was determined. A more than hundred-fold reduction in the number of CFUs was achieved by compound A as compared to the untreated control. The compound A was more active than vancomycin, the standard drug for clinical infections due to MRSA.

In vivo efficacy

Compound	no. mice	Median log CFU
None	3	6.92
Vancomycin	3	5.28
A	3	4.72

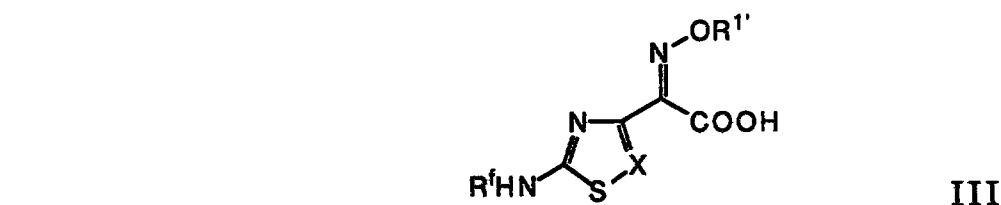
The compounds of the formula I in accordance with the invention as
 5 well as their pharmaceutical acceptable salts, hydrates, or readily hydrolyzable esters can be manufactured in accordance with the invention for example by

(a) treating a compound having the formula II



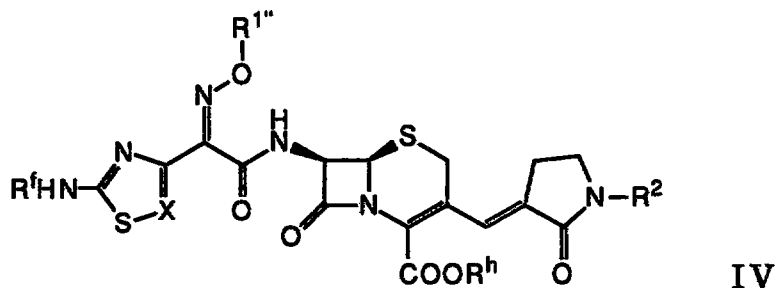
wherein R^2 is defined as above, or an ester or a salt thereof, the amino group and the carboxylic groups present in the compound of formula II may be unprotected or protected,

15 with a carboxylic acid of the general formula III



in which R^f is hydrogen or an amino protecting group, $R^{1'}$ is hydrogen, cyclopentyl or a hydroxy protecting group and X is as defined above, or
 20 with a reactive functional derivative thereof, or

(b) cleaving off the amino, hydroxy and/or carboxy protecting group in a compound having the formula IV



in which R^2 is as defined above, R^f is hydrogen or an amino protecting group, $R^{1''}$ is hydrogen or a hydroxy protecting group, R^h is hydrogen or a carboxy protecting group, provided that at least one of R^f , $R^{1''}$ and R^h is a corresponding protecting group, or a salt thereof.

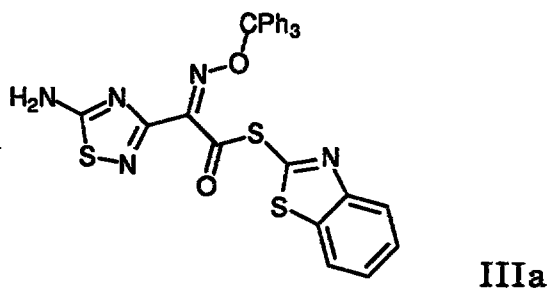
The reaction of compounds of formula II and III or a reactive derivative of formula III according to embodiment (a) can be carried out in a manner known per se. The carboxy group in compounds of formula II can be protected, for example, by esterification to form a readily cleavable ester such as a silyl ester (e.g. the trimethylsilyl ester), a tert-butyl, allyl, p-methoxybenzyl or a benzhydryl ester.

The amino group present in the acylating agent of formula III can be protected. Possible protecting groups R^f are, for example, protecting groups which are cleavable by acid hydrolysis (e.g. the tertbutoxycarbonyl or trityl groups), by basic hydrolysis (e.g. the trifluoroacetyl group), by hydrazinolysis (e.g. the phthalimido group) or by catalytic cleavage in presence of Pd (the allyloxycarbonyl group). Preferred protecting groups are the allyloxy-carbonyl, the tert-butyloxy-carbonyl, the chloroacetyl, bromoacetyl and iodoacetyl groups, especially the chloroacetyl group. These last-mentioned protecting groups can be cleaved off by treatment with thiourea. The 7-amino group in compounds II can be protected, for example, by a silyl protective group such as the trimethylsilyl group.

In reacting a 7-amino compound of formula II with a carboxylic acid of formula III or a reactive functional derivative thereof, for example, a free carboxylic acid can be reacted with an aforementioned ester of a compound of formula II in the presence of a carbodiimide such as dicyclohexylcarbodiimide in an inert solvent such as ethyl acetate, acetonitrile, dioxane, chloroform, methylene chloride, benzene or dimethylformamide, and subsequently the ester group can be cleaved off.

According to another embodiment, a salt of an acid of formula II (e.g. a trialkylammonium salt such as the triethylammonium salt) is reacted with a reactive functional derivative of a carboxylic acid of formula III in an inert solvent (e.g. dimethylformamide or dimethylacetamide).

- 5 According to a further embodiment, preferred acylation, where the amino group present in the acylating agent of formula III need not be protected, involves the use of a reactive functional derivative of the acylation agent of formula III, for example, a mixed anhydride of thiophosphoric acid of the carboxylic acid, a 1-hydroxybenzotriazole ester or a 2-benzothiazolyl thioester. For instance, a mixed anhydride of thiophosphoric acid may be
10 reacted with the compound of formula II preferably in a polar solvent as dimethyl formamide (DMF), dichloromethane, or a mixture of DMF/i-propanol/water in presence of a base as e.g. triethylamine. The 1-hydroxybenzotriazole ester as well as the 2-benzthiazolyl thioester may be reacted
15 with the compound II in an inert organic solvent such as a chlorinated hydrocarbon e.g. methylene chloride, or in dimethylformamide, dimethylacetamide, acetone, ethyl acetate or in a mixture of such solvents with water. Such a reactive 2-benzthiazolyl thioester is for example



- 20 this compound is new and is part of the present invention.

The reaction of a 7-amino compound of formula II with the carboxylic acid of formula III or a reactive derivative thereof can conveniently be carried out at a temperature between about -40°C and +60°C, e.g. at room temperature.

- 25 Embodiment (b) of the process of the present invention involves deprotection (removal) of a protected amino group in the 2-position of the thiazol or the thiadiazol ring and /or the protected pyrrolidin ring (R⁴ as the protecting group), and/or protected hydroxy or carboxylic groups present in a compound of formula IV and can be carried and as follows:

Removal of amino protecting groups

As mentioned above the amino protecting groups may be cleaved off by acid hydrolysis (e.g. the tert-butoxycarbonyl or trityl group), e.g. aqueous formic acid, trifluoroacetic acid or by basic hydrolysis (e.g. the trifluoroacetyl group). Further protecting groups may be cleaved off by hydrazinolysis (e.g. the phthalimido group). The allyloxycarbonyl group may be cleaved off by Pd catalysed transfer to nucleophiles. The chloroacetyl, bromoacetyl and iodoacetyl groups are cleaved off by treatment with thiourea.

Amino-protecting groups which are cleavable by acid hydrolysis are preferably removed with the aid of a lower alkanecarboxylic acid which may be halogenated. In particular, formic acid or trifluoroacetic acid is used. The reaction is carried out in the acid or in the presence of a co-solvent such as a halogenated lower alkane, e.g. methylene chloride. The acid hydrolysis is generally carried out at room temperature, although it can be carried out at a slightly higher or slightly lower temperature (e.g. a temperature in the range of about -30°C to +40°C). Protecting groups which are cleavable under basic conditions are generally hydrolyzed with dilute aqueous caustic alkali at 0°C to 30°C. The chloroacetyl, bromoacetyl and iodoacetyl protecting groups can be cleaved off using thiourea in acidic, neutral or alkaline medium at about 0°C-30°C.

Removal of hydroxy protecting groups

The term "hydroxy protecting group" refers to protecting groups as conventionally used in the art such as trityl (triphenylmethyl), trimethylsilyl, tert.-butyl-dimethylsilyl, dimethylphenylsilyl, triphenylmethyl, lower alkanoyl, acetyl, tetrahydropyranyl, benzyl, p-nitrobenzyl and the like.

Preferred hydroxy protecting groups are such as are commonly known in the art, e.g. for protection of hydroxyimino groups (R^1 = hydrogen in compounds of formula I), usually trityl, lower alkanoyl, especially acetyl, tetrahydropyranyl.

These protecting groups are e.g. removed as follows:

-trityl	in acidic solvents like 90% formic acid at about 0 to 50°C or triethylsilane in trifluoroacetic acid at about -20 to 25°C;
	in organic solutions of hydrochloric acid at about -50 to 25°C;

- acetyl with weak inorganic bases like sodium bicarbonate in methanol or ethanol/water at about 0 to 50°C;
- tetrahydropyranyl with weak organic acids like p-toluenesulfonic acid in an alcohol, e.g. ethanol, at about 0°C to the boiling point of the mixture.
- 5

Removal of protecting groups at the carboxy function

The term "carboxylic acid protecting group" refers to protecting groups conventionally used to replace the acidic proton of a carboxylic acid. As carboxyl protecting groups one may utilize an ester form which can be easily

10 converted into a free carboxyl group under mild conditions, for example, methoxymethyl, methylthiomethyl, 2,2,2-trichloroethyl, 2-haloethyl, 2-(trimethylsilyl)ethyl, tert-butyl, allyl, benzyl, triphenylmethyl (trityl), diphenylmethyl, p-nitrobenzyl, p-methoxybenzyl, trimethylsilyl, triethylsilyl, tert-butyldimethylsilyl, i-propyl-dimethylsilyl. Preferred are benzyhydryl,

15 tert-butyl, p-nitrobenzyl, p-methoxybenzyl and allyl.

These protecting groups may be removed as follows:

- benzhydryl trifluoroacetic acid with anisol, phenol, cresol or triethylsilane at about -40°C to room temperature; hydrogen with Pd/C in an alcohol such as ethanol or in tetrahydrofuran;
- 20 BF₃-etherate in acetic acid at about 0 to 50°C;
- tert-butyl formic acid or trifluoroacetic acid with or without anisol, phenol, cresol or triethylsilane and a solvent such as dichloromethane at about -10°C to room temperature;
- p-nitrobenzyl sodium sulfide in acetone/water at about 0 to room
- 25 temperature; or hydrogen with Pd/C in an alcohol such as ethanol or in tetrahydrofuran;
- p-methoxybenzyl formic acid at about 0 to 50°C; or trifluoroacetic acid and anisol, phenol or triethylsilane at about -40°C to room temperature;
- 30 allyl palladium(O) catalyzed transalkylation reaction in the presence of tri-n-butyltinhydride and acetic acid, see for example F. Guibé et al. in J. Org. Chem. (1987) 52, 4984-4993

Further methods for the manufacture of the compounds according to

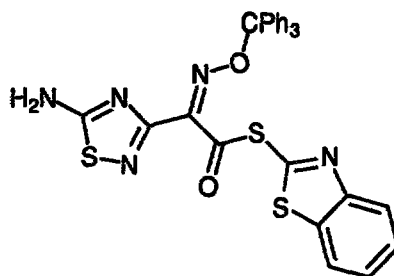
35 the invention are known in the art. Compounds of formula I can for example be manufactured in analogy to the methods described in US pat. no. 5 523400 and according to the examples given below.

Examples

Example 1

Preparation of the acylation agent (Z)-(5-Amino-[1,2,4]thiadiazol-3-yl)-trityl-oxyimino-thioacetic acid S-benzothiazol-2-yl ester

5

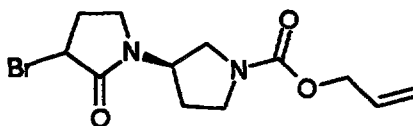


To a suspension of (Z)-(5-amino-[1,2,4]thiadiazol-3-yl)-trityloxyimino-acetate 1-allyl-1-methyl-pyrrolidinium salt (1.89 g, 3.4 mmol) in 25 ml acetonitrile
10 were added at 0°C 2,2'-dithio-bisbenzothiazole (1.36 g, 4.1 mmol). A solution of triethylphosphite (0.7 ml, 5.8 mmol) in 7 ml acetonitrile was added within 40 min and the mixture was stirred at room temperature for 27 h. The precipitate was collected by filtration and washed with acetonitrile and n-hexane.

15 Yield: 1.615 g (82%) beige crystals
IR(KBr) 1704, 1619, 1003 cm⁻¹
MS(ISP) 580.2 (M+H)⁺.

Example 2

2.1. Preparation of a mixture of (1R,3'R)- and (1S,3'R)-3-bromo-2-oxo-
20 [1,3']bipyrrolidiny-1'-carboxylic acid allyl ester



A solution of (R)-3-amino-pyrrolidine-1-carboxylic acid allyl ester trifluoro-
25 acetate (1 : 3.2) (47.84 g, 0.089 mol) in 180 ml dichloromethane was treated with 50% aqueous sodium hydroxide solution (72 ml, 0.894 mol). To the vigorously stirred mixture was added within 18 min at 0°C a solution of 2-bromo-4-chloro-butanoyl chloride (21.62 g, 0.098 mol) in 90 ml dichloromethane. The reaction mixture was stirred at 0°C for 1 h. The phases were separated, the
30 aqueous phase was extracted twice with 100 ml dichloromethane and the combined organic phases were washed twice with 50 ml water. They were

dried over magnesium sulfate and the solvent was removed by evaporation. The residual yellow oil (32 g) was redissolved in 380 ml dichloromethane and 190 ml of a 50% aqueous sodium hydroxide solution and 3.23 g Dowex 2x10 were added with vigorous stirring at room temperature. After 6 h, the phases
5 were separated, the aqueous phase was extracted twice with 150 ml dichloromethane. The combined organic phases were washed once with 100 ml water, once with brine, were dried over magnesium sulfate and concentrated.

Yield: 28.7 g (quant.) of a yellow oil

IR(neat) 1697cm^{-1}

10 MS(ISP) 317.2 (M)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

2.2. Mixture of (1R,3'S) and (1S,3'S)-3-bromo-2-oxo-[1,3']bipyrrolidinyl-1'-carboxylic acid allyl ester

15 IR(neat) 1697cm^{-1}

MS(ISP) 317.1 (M)⁺.

2.3. Mixture of (3RS,3'RS)- and (3RS,3'SR)-3-bromo-2-oxo-[1,3']bipyrrolidinyl-1'-carboxylic acid allyl ester

IR(neat) 1695cm^{-1}

20 MS(EI) 259 (M-OC₃H₅)⁺.

2.4. (RS)-3-(3-Bromo-2-oxo-pyrrolidin-1-yl)-azetidine-1-carboxylic acid allyl ester

IR(neat) 1700cm^{-1}

MS(ISP) 303.2 (M)⁺.

25 2.5. (RS)-4-(3-Bromo-2-oxo-pyrrolidin-1-ylmethyl)-piperidine-1-carboxylic acid allylester

IR(neat) 1699cm^{-1}

MS(ISP) 345.2 (M)⁺.

2.6. (RS)-4-(3-Bromo-2-oxo-pyrrolidin-1-yl)-pyrazolidine-1,2-dicarboxylic acid
30 diallyl ester

IR(KBr) 1704cm^{-1}

MS(ISP) 404 (M+H)⁺.

2.7. 1:1 Mixture of (3S,4R)-3-[(R)- and -(S)-3-bromo-2-oxo-pyrrolidin-1-ylmethyl]-4-trifluoromethyl-pyrrolidine-1-carboxylic acid allyl ester

IR(KBr) 1702 cm^{-1}
MS(ISP) 401.3 (M+H)⁺.

2.8. Mixture of (3R,3'S,5'S)- and (3S,3'S,5'S)-3-bromo-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidiny-1'-carboxylic acid allyl ester

5 IR(KBr) 1699, 1649 cm^{-1}
MS(EI) 388 (M+H)⁺.

2.9. 1:1 Mixture of (3R,3'S,5'R)- and (3S,3'S,5R)-3-bromo-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidiny-1'-carboxylic acid allyl ester

10 IR(KBr) 1698, 1654 cm^{-1}
MS(ISP) 388.1 (M+H)⁺.

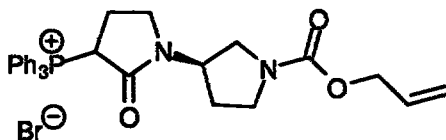
2.10. (RS)-3-(3-Bromo-2-oxo-pyrrolidin-1-ylmethyl)-azetidine-1-carboxylic acid allyl ester

IR(KBr) 1698 cm^{-1}
MS(ISP) 319.2 (M+H)⁺.

15

Example 3

3.1. Mixture of (1R,3'R) and (1S,3'R)-(1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidiny-3-yl)-triphenyl-phosphonium bromide



20

Triphenylphosphine (23.62 g, 0.090 mol) and a mixture of (1R,3'R)- and (1S,3'R)-3-bromo-2-oxo-[1,3']bipyrrolidiny-1'-carboxylic acid allyl ester (28.56 g, 0.090 mol) were dissolved in 80 ml dichloromethane. The solvent was removed *in vacuo* and the residual oil was heated for 2 h at 100°C. The resulting solid was dissolved in 130 ml dichloromethane and added with stirring to 1500 ml n-hexane resulting in the separation of the product. The solvent was decanted and the residue triturated with 1500 ml diethylether. The thereby formed solid was collected by filtration, washed with n-hexane and diethylether and dried *in vacuo*, yielding 45.1 g (78%) of the product as colourless crystals.

30

IR(KBr) 1682 cm^{-1}
MS(ISP) 499.3 (M)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

3.2. Mixture of (3R,3'S) and (3S,3'S)-(1'-allyloxycarbonyl-2-oxo-[1,3']bi-pyrrolidinyl-3-yl)-triphenyl-phosphonium bromide

IR(KBr) 1684 cm⁻¹

MS(ISP) 499.2 (M)⁺.

5 **3.3. Mixture of (3RS,3'RS)- and (3RS,3'SR)-(1'-allyloxycarbonyl-2-oxo-[1,3']bi-pyrrolidinyl-3-yl)-triphenyl-phosphonium bromide**

IR(KBr) 1684 cm⁻¹

MS(ISP) 499.4 (M+H)⁺.

10 **3.4. (RS)-[1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-yl]-triphenyl-phosphonium bromide**

IR(KBr) 1687 cm⁻¹

MS(ISP) 485.4 (M+H)⁺.

3.5. (RS)-[1-(1-Allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-yl]-triphenyl-phosphonium bromide

15 **IR(KBr) 1688 cm⁻¹**

MS(ISP) 527.3 (M)⁺.

3.6. (RS)-[1-(1,2-Bis-allyloxycarbonyl-pyrazolidin-4-yl)-2-oxo-pyrrolidin-3-yl]-triphenyl-phosphonium bromide

IR(KBr) 1688 cm⁻¹

20 **MS(ISP) 585.5 (H)⁺.**

3.7. 1:1 Mixture of [(R)- and [(S)-1-[(S)-1-allyloxycarbonyl-pyrrolidin-2-ylmethyl]-2-oxo-pyrrolidin-3-yl]-triphenyl-phosphonium bromide

IR(KBr) 1682 cm⁻¹

MS(ISP) 513.4 (M)⁺.

25 **3.8. 1:1 Mixture of (3S,4R)-[(R)- and -[(S)-1-(1-allyloxycarbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl)-2-oxo-pyrrolidin-3-yl]-triphenyl-phosphonium bromide**

IR(KBr) 1690 cm⁻¹

MS(ISP) 581.2 (M+H)⁺.

30 **3.9. 1:1 Mixture of (3R,3'S,5'S)- and (3S,3'S,5'S)-(1'-allyloxycarbonyl-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-yl)-triphenyl-phosphonium bromide**

IR(KBr) 1687 cm⁻¹

MS(ISP) 570.3 (M)⁺.

3.10. 1:1 Mixture of (3R,3'S,5'R)- and (3S,3'R,5'S)-3-(1'-allyloxycarbonyl-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-yl)-triphenyl-phosphonium bromide

IR(KBr) 1686 cm^{-1}

5 MS(ISP) 570.3 (M)⁺.

3.11. (RS)-[1-(1-Allyloxycarbonyl-azetidin-3-ylmethyl)-2-oxo-pyrrolidin-3-yl]-triphenyl-phosphonium bromide (1:1)

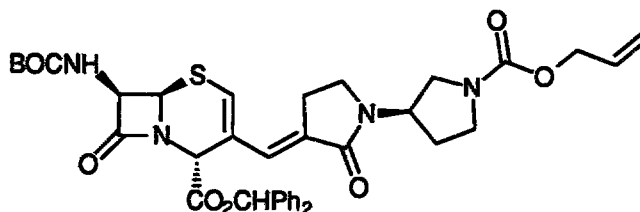
IR(KBr) 1679 cm^{-1}

MS(ISP) 499.2 (M)⁺.

10

Example 4

4.1. (E)-(2R,6R,7R)-3-[(R)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl ester



15

A suspension of the mixture of (1R,3'R) and (1S,3'R)-(1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-yl)-triphenyl-phosphonium bromide (43.5 g, 0.075 mol) and (2R,6R,7R)-tert-butoxycarbonylamino-3-formyl-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl ester (33.74 g, 0.068 mol) in 950 ml butylenoxide was refluxed for 1.5 h. The solvent was removed *in vacuo* and the residue was purified by column chromatography (300 g SiO₂, ethyl acetate : n-hexane = 2:1, 3:1) giving 67.8 g of a 1:1 (molar ratio) mixture containing the product and triphenylphosphine oxide as a yellow foam.

25 Further purification was not necessary to proceed with the next step.

IR(KBr) 1781, 1744 cm^{-1}

MS(ISP) 732.5 (M+NH₄)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

30 **4.2. (E)-(2R,6R,7R)-3-[(S)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl ester**

IR(KBr) 1782, 1744, 1705 cm^{-1}

MS(ISP) 732.4 (M+NH₄)⁺.

4.3. Mixture of (E)-(2R,6R,7R)-3-[(R)- and -[(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl ester

5 IR(KBr) 1780, 1744, 1704 cm⁻¹

MS(ISP) 715.4 (M+H)⁺.

4.4. (E)-(2R,6R,7R)-3-[1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl ester

10 IR(KBr) 1782, 1743, 1713 cm⁻¹

MS(ISP) 718.4 (M+NH₄)⁺.

4.5. (E)-(2R,6R,7R)-3-[1-(1-Allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl ester

15 IR(KBr) 1779, 1743, 1692 cm⁻¹

MS(ISP) 760.5 (M+NH₄)⁺.

4.6. (E)-(2R,6R,7R)-3-[1-[(3S,4R)-1-Allyloxycarbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid

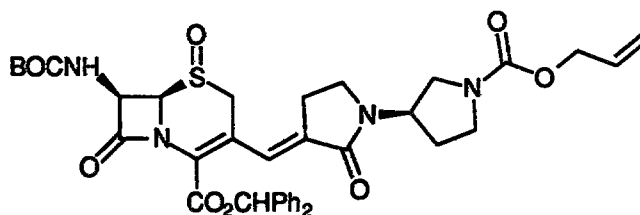
20 benzhydryl ester

IR(KBr) 1782, 1711 cm⁻¹

MS(ISP) 797.0 (M+H)⁺.

Example 5

5.1. 1:1 Mixture of (E)-(5R,6R,7R)- and -(5S,6R,7R)-3-[(R)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-5,8-dioxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester



30 A solution of the mixture described above of (E)-(2R,6R,7R)-3-[(R)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-3-ene-2-carboxylic acid benzhydryl

ester and triphenylphosphine oxide (67.8 g, 0.068 mol) in 400 ml dichloromethane was cooled to -10°C. To this was added dropwise a solution of m-chloroperbenzoic acid (70%, 16.82 g, 0.068 mol) in 250 ml dichloromethane. The resulting solution was stirred for 2.5 h at -5 to 0°C, 150 ml aqueous
5 sodium thiosulfate solution (5%) was added and the mixture was stirred for 15 min. The phases were separated and the aqueous phase was extracted twice with 100 ml dichloromethane. The combined organic phase were washed with each 150 ml of aqueous solutions of sodium thiosulfate (5%), sodium bicarbonate (5%) and finally brine. The solution was dried over
10 magnesium sulfate, concentrated after filtration and purified by column chromatography (1000 g SiO₂, ethyl acetate : n-hexane = 3 : 1, 1 : 0 and ethyl acetate : methanol = 9 : 1).

Yield: 36.3 (73%)

IR(KBr) 1797, 1711 cm⁻¹

15 MS(ISP) 748.5 (M+NH₄)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

5.2. Mixture of (E)-(5R,6R,7R)- and -(5S,6R,7R)-3-[(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-5,8-
20 dioxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1796, 1710 cm⁻¹
MS(ISP) 748.5 (M+NH₄)⁺.

5.3. Mixture of (E)-(5R,6R,7R)- and -(5S,6R,7R)-3-(1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl)-7-tert-butoxycarbonylamino-5,8-dioxo-5-
25 thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester (config.at C3' in bipyrrolidine-moeity R and S)
IR(KBr) 1796, 1716 cm⁻¹
MS(ISP) 748.5 (M+NH₄)⁺.

5.4. Mixture of (E)-(5R,6R,7R)- and -(5S,6R,7R)-3-[1-(1-allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-
30 5,8-dioxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1797, 1718 cm⁻¹
MS(ISP) 734.5 (M+NH₄)⁺.

35 5.5. 1:1 Mixture of (E)-(5R,6R,7R)-and (5S,6R,7R)-3-[1-(1-allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxy-

carbonylamino-5,8-dioxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester

IR(KBr) 1795, 1721, 1692 cm^{-1}

MS(ISP) 776.5 ($\text{M}+\text{NH}_4$)⁺.

- 5 **5.6. Mixture of (E)-(5R,6R,7R)- and -(5S,6R,7R)-3-[1-[(3S,4R)-1-Allyloxy-carbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-5,8-dioxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester**

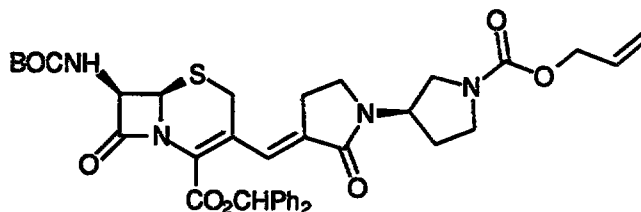
IR(KBr) 1796, 1716 cm^{-1}

- 10 MS(ISP) 813.4 ($\text{M}+\text{H}$)⁺.

Example 6

6.1. (E)-(6R,7R)-3-[(R)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester

15



- To a solution of a mixture of a 1:1 mixture of (E)-(5R,6R,7R)- and -(5S,6R,7R)-3-[(R)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-5,8-dioxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester (36.3 g, 0.050 mol) in 370 ml dichloro-
20 methane, 30 ml DMF and 44 ml N-methylacetamide was added within 20 min at -30°C a solution of phosphorous tribromide (19.1 ml, 0.203 mol) in 56 ml dichloromethane. After stirring for 1.5 h at -30°C, the mixture was
25 allowed to warm up to -5°C and quenched with 800 ml cold water. The phases were separated, the aqueous phase was extracted twice with 300 ml dichloro-methane. The combined organic phases were washed with 500 ml water and brine and dried over magnesium sulfate. After removal of the solvent *in vacuo*, the residue was treated with a 1:1 mixture of ethyl acetate and n-
30 hexane (700 ml). The precipitated product was collected by filtration.
Yield: 32.9 g (91%) orange crystals.
IR(KBr) 1785, 1715 cm^{-1}
MS(ISP) 732.5 ($\text{M}+\text{NH}_4$)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

6.2. (E)-(6R,7R)-3-[(S)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
5 IR(KBr) 1786, 1712 cm^{-1}
MS(ISP) 732.5 ($\text{M}+\text{NH}_4$)⁺.

6.3. Mixture of (E)-(6R,7R)-3-[(R)- and -(S)-1'-allyloxycarbonyl-2-oxo- [1,3']-bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
10 IR(KBr) 1785, 1712 cm^{-1}
MS(ISP) 732.6 ($\text{M}+\text{NH}_4$)⁺.

6.4. (E)-(6R,7R)-3-[1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo-
15 [4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1786, 1717 cm^{-1}
MS(ISP) 718.6 ($\text{M}+\text{NH}_4$)⁺.

6.5. (E)-(6R,7R)-3-[1-(1-Allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
20 IR(KBr) 1784, 1688 cm^{-1}
MS(ISP) 760.6 ($\text{M}+\text{NH}_4$)⁺.

6.6. (E)-(6R,7R)-4-[3-(2-Benzhydryloxycarbonyl-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-en-3-ylmethylene)-2-oxo-pyrrolidin-1-yl]-pyrazolidine-1,2-dicarboxylic acid diallyl ester
25 IR(KBr) 1785 cm^{-1}
MS(ISP) 800.6 ($\text{M}+\text{H}$)⁺.

6.7. (E)-(6R,7R)-3-[1-(S)-1-Allyloxycarbonyl-pyrrolidin-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
30 IR(KBr) 1784 cm^{-1}
MS(ISP) 729.3 ($\text{M}+\text{H}$)⁺.

6.8. (E)-(6R,7R)-3-[1-[(3S,4R)-1-Allyloxycarbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1790, 1713 cm^{-1}

5 MS(ISP) 797.4 (M+H)⁺.

6.9. (E)-(6R,7R)-3-[(3'S,5'S)-1'-Allyloxycarbonyl-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1787, 1713 cm^{-1}

10 MS(ISP) 786.4 (M+H)⁺.

6.10. (E)-(6R,7R)-3-[(3'S,5'R)-1'-Allyloxycarbonyl-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1786, 1712 cm^{-1}

15 MS(ISP) 786.5 (M+H)⁺.

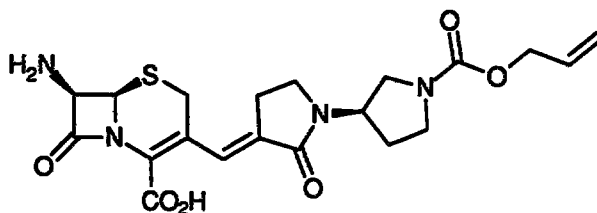
6.11. (E)-(6R,7R)-3-[1-(1-Allyloxycarbonyl-azetidin-3-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester
IR(KBr) 1780, 1700 cm^{-1}

20 MS(ISP) 715.3 (M+H)⁺.

Example 7

7.1. (E)-(6R,7R)-3-[(R)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methy)-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate

25



To a solution of (E)-(6R,7R)-3-[(R)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-tert-butoxycarbonylamino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid benzhydryl ester (32.9 g, 0.046 mol) in 320 ml dichloromethane was added at 0°C 32 ml anisol and 180 ml trifluoroacetic acid. The mixture was stirred for 2.5 h stirring at room temperature,

30

concentrated to a volume of 50 ml and poured on 1000 ml ice-cold diethyl-ether. The precipitated solid was collected by filtration and dried.

Yield: 24.9 g (98%) beige solid

IR(KBr) 1782, 1680 cm^{-1}

5 MS(ISP) 466.4 ($\text{M}+\text{NH}_4$)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

7.2. (E)-(6R,7R)-3-[(S)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10 trifluoroacetate

IR(KBr) 1782, 1679 cm^{-1}

MS(ISP) 466.3 ($\text{M}+\text{NH}_4$)⁺.

7.3. Mixture of (E)-(6R,7R)-3-[(R)- and -(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bi-pyrrolidinyl-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-

15 ene-2-carboxylic acid trifluoroacetate

IR(KBr) 1783, 1678 cm^{-1}

MS(ISP) 449.5 ($\text{M}+\text{H}$)⁺.

7.4. (E)-(6R,7R)-3-[1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic

20 acid trifluoroacetate

IR(KBr) 1783, 1681 cm^{-1}

MS(ISP) 435.5 ($\text{M}+\text{H}$)⁺.

7.5. (E)-(6R,7R)-3-[1-(1-Allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-

25 ene-2-carboxylic acid trifluoroacetate

IR(KBr) 1784, 1681 cm^{-1}

MS(ISN) 492.3 ($\text{M}-\text{H}+\text{NH}_3$)⁻.

7.6. (E)-(6R,7R)-7-Amino-3-[1-(1,2-bis-allyloxycarbonyl-pyrazolidin-4-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-

30 carboxylic acid

m.p. 148-149°C

7.7. (E)-(6R,7R)-3-[1-[(S)-1-Allyloxycarbonyl-pyrrolidin-2-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate (1:0.2)

IR(KBr) 1780, 1690 cm^{-1}

MS(ISP) 463.3 (M+H)⁺.

7.8. (E)-(6R,7R)-3-[1-[(3S,4R)-1-Allyloxycarbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

IR(KBr) 1779, 1686 cm^{-1}

MS(ISP) 531.3 (M+H)⁺.

7.9. (E)-(6R,7R)-3-[(3'S,5'S)-1'-Allyloxycarbonyl-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate (1:0.4)

IR(KBr) 1779, 1681 cm^{-1}

MS(ISP) 520.2 (M+H)⁺.

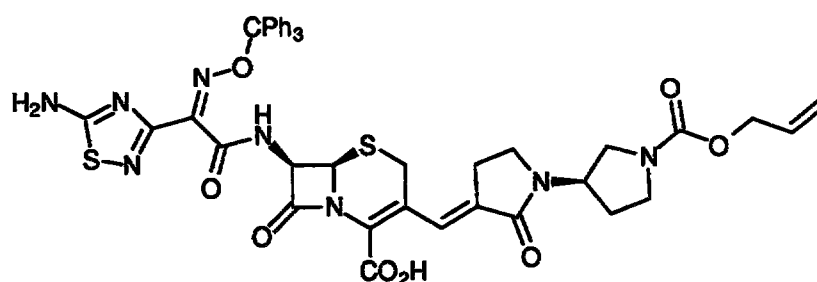
7.10. (E)-(6R,7R)-3-[(3'S,5'R)-1'-Allyloxycarbonyl-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate (1:0.5)

IR(KBr) 1779, 1681 cm^{-1}

MS(ISP) 520.3 (M+H)⁺.

Example 8

8.1. (6R,7R)-3-[(E)-(R)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



A solution of (E)-(6R,7R)-3-[(R)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate (3.90 g, 7.06 mmol) in 75 ml DMF was treated with (Z)-(5-amino-[1,2,4]thiadiazol-3-yl)-trityloxyimino-thioacetic acid S-benzothiazol-2-yl ester (4.5 g, 7.76 mmol) for 48 h at room temperature. The reaction mixture was concentrated *in vacuo* and the residue distributed between 550 ml ethyl acetate and 375 ml water. The solid was discarded, the

phases were separated and the aqueous phase was extracted with 150 ml ethyl acetate. The combined organic phases were concentrated upon which the product separated. It was collected by filtration, washed with ethyl acetate and dried.

- 5 Yield: 4.42 g (68%) beige crystals
IR(KBr) 1785, 1681 cm^{-1}
MS(ISP) 878.6 ($\text{M}+\text{NH}_4$)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

- 10 8.2. (6R,7R)-3-[(E)-(S)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
IR(KBr) 1784, 1680 cm^{-1}
MS(ISP) 878.6 ($\text{M}+\text{NH}_4$)⁺.

- 15 8.3. Mixture of (6R,7R)-3-[(E)-(R)- and -(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
IR(KBr) 1783, 1681 cm^{-1}
20 MS(ISP) 861.5 ($\text{M}+\text{H}$)⁺.

- 8.4. (6R,7R)-3-[(E)-1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
IR(KBr) 1784, 1683 cm^{-1}
25 MS(ISP) 864.3 ($\text{M}+\text{NH}_4$)⁺.

- 8.5. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-3-[(E)-1-(1,2-bis-allyloxycarbonyl-pyrazolidin-4-yl)-3-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
30 m.p. 184-185°C
MS(ISP) 946.1 ($\text{M}+\text{H}$)⁺.

- 8.6. (6R,7R)-3-[(E)-1-[(S)-1-Allyloxycarbonyl-pyrrolidin-2-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
35

IR(KBr) 1790, 1681 cm^{-1}

MS(ISP) 875.4 (M+H)⁺.

8.7. (6R,7R)-3-[(E)-1-[(3S,4R)-1-Allyloxycarbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(5-amino-
5 [1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

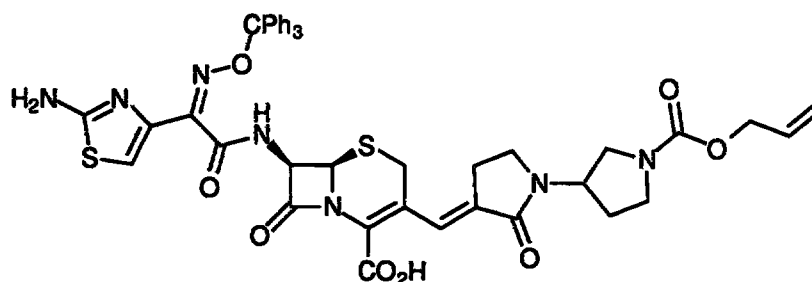
IR(KBr) 1790, 1687 cm^{-1}

MS(ISP) 943.7 (M+H)⁺.

10

Example 9

9.1. Mixture of (6R,7R)-3-[(E)-(R)- and -(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bi-pyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



15

A solution of (E)-(6R,7R)-3-[(R)- and [(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bi-pyrrolidinyl-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate (721 mg, 1.3 mmol) in 25 ml DMF was
20 treated with (Z)-(2-aminothiazol-4-yl)-trityloxyimino-acetic acid 1-benzotriazolyl ester (782 mg, 1.43 mmol) at room temperature for 36 h. The reaction mixture was concentrated *in vacuo* and the residue distributed between 100 ml ethyl acetate and 50 ml water. The insoluble material was removed by filtration, the phases were separated and the organic phase was
25 concentrated upon which the product precipitated. The solid was collected by filtration, washed with ethyl acetate and dried.

Yield: 725 mg (60%)

IR(KBr) 1783, 1681 cm^{-1}

MS(ISP) 860.6 (M+H)⁺.

30 According to the procedure set forth in the preceding example, the following additional compounds were prepared:

9.2. (6R,7R)-3-[(E)-(R)-1'-Allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

IR(KBr) 1783, 1679 cm^{-1}

5 MS(ISP) 860.5 (M+H)⁺.

9.3. (6R,7R)-3-[(E)-1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10 IR(KBr) 1785, 1680 cm^{-1}

MS(ISP) 846.6 (M+H)⁺.

9.4. (6R,7R)-3-[(E)-1-(Allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

15 IR(KBr) 1782, 1673 cm^{-1}

MS(ISP) 888.5 (M)⁺.

9.5. (6R,7R)-3-[(E)-1-(1,2-bis-allyloxycarbonyl-pyrazolidin-4-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

20 IR(KBr) 1756 cm^{-1}

MS(ISP) 536.3 (M+H)⁺.

9.6. (6R,7R)-3-[(E)-1-[(3S,4R)-1-Allyloxycarbonyl-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-

25 carboxylic acid

IR(KBr) 1790, 1686 cm^{-1}

MS(ISP) 942.4 (M+H)⁺.

9.7. (6R,7R)-3-[(E)-1-[(S)-1-Allyloxycarbonyl-pyrrolidin-2-ylmethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

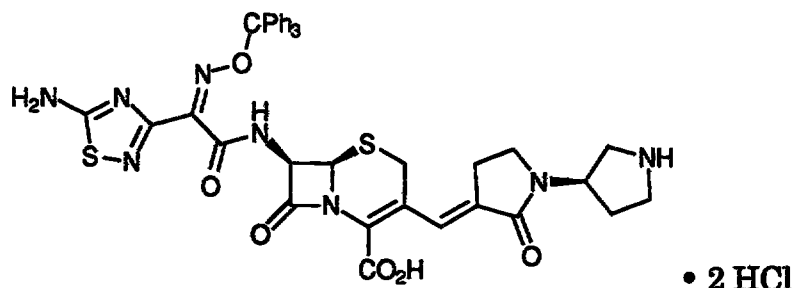
30 IR(KBr) 1783, 1685 cm^{-1}

MS(ISP) 874.5 (M+H)⁺.

Example 10

10.1. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

35



To a suspension of (6R,7R)-3-[(E)-(R)-1'-allyloxycarbonyl-2-oxo-[1,3']bi-
 5 pyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityl-
 oxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic
 acid (4.12 g, 4.79 mmol) in 280 ml dichloromethane was added 1.87 ml (7.66
 mmol) N,O-bis(trimethylsilyl)acetamide whereby an orange solution formed
 which was subsequently treated with 84 mg (0.12 mmol) bis-(triphenyl-
 10 phosphine)-palladium(II)-dichloride, 5.48 ml (95.8 mmol) acetic acid and
 11.7 ml (44.1 mmol) tributyltin hydride and stirred at room temperature for
 40 min. After addition of a few drops of water, the suspension was poured on
 15 1500 ml diethylether containing 12 ml of a solution of 6 M hydrogen chloride
 in diethylether. The suspension was stirred for 2 h and the product was
 collected by filtration.

Yield: 4.04 g (99%) beige solid

IR(KBr) 1781, 1659 cm^{-1}

MS(ISP) 777.4 (M+H)⁺.

According to the procedure set forth in the preceeding example, the
 20 following additional compounds were prepared:

10.2. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-
 amino]-8-oxo-3-[(E)-(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-
 aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

IR(MIR) 1779, 1660 cm^{-1}

25 MS(ISP) 777.4 (M+H)⁺.

10.3. Mixture of (6R,7R)-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-
 trityloxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)- and -(S)-2-oxo-
 [1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-
 carboxylic acid dihydrochloride

30 IR(KBr) 1780, 1660 cm^{-1}

MS(ISP) 777.3 (M+H)⁺.

10.4. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-3-[(E)-1-azetidin-3-yl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

IR(KBr) 1780, 1667 cm^{-1}

5 MS(ISP) 763.3 (M+H)⁺.

10.5. Mixture of (6R,7R)-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)- and -(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

10 IR(KBr) 1780, 1659 cm^{-1}

MS(ISP) 776.4 (M+H)⁺.

10.6. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-3-[(E)-1-azetidin-3-yl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

15 IR(KBr) 1780, 1661 cm^{-1}

MS(ISP) 762.5 (M+H)⁺.

10.7. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-piperidin-4-ylmethyl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

20 IR(KBr) 1778, 1661, 1631 cm^{-1}

MS(ISP) 804.7 (M+H)⁺.

10.8. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-pyrazolidin-4-yl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

25 hydrochloride (1:1)

m.p. 163-164°C

IR(KBr) 1785 cm^{-1}

MS(ISP) 778.4 (M+H)⁺

10.9. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-trityloxyimino-acetyl-amino]-8-oxo-3-[(E)-1-oxo-2-[(3R,4R)-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid hydrochloride (1:2)

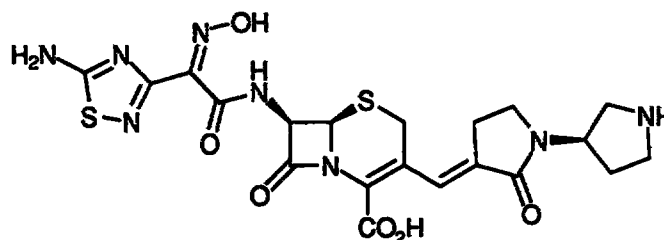
30 IR(KBr) 1790, 1633 cm^{-1}

MS(ISP) 859.4 (M+H)⁺.

Example 11

11.1. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



To a solution of (6R,7R)-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-trityl-oxyimino-acetyl-amino] -8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride
10 (4.04 g, 4.76 mmol) in 26 ml trifluoroacetic acid was added at 0-5°C 1.69 ml triethylsilane and the mixture was stirred for 30 min. The reaction mixture was poured with stirring on 780 ml ice-cold diethylether upon which the product separated as a beige solid. After stirring for 1 h, the solid was
15 collected by filtration and dried. The product was purified by gel chromatography (MCI Gel 75-150μ, using a gradient of water with increasing concentrations of acetonitrile).

Yield: 1.24 g (49%).

IR(MIR) 1764, 1658 cm⁻¹

20 MS(ISP) 535.1 (M+H)⁺.

¹H-NMR(DMSO, 250 MHz): inter alia δ 1.92-2.16 (m, 2H); 3.60 (d, J = 17 Hz, 1H); 3.79 (d, J = 17 Hz, 1H); 4.66, (m, 1H); 5.07 (d, J = 8 Hz, 1H); 5.75 (dd, J = 5 Hz, J = 8 Hz 1H); 7.30 (s, 1H); 8.05 (s, 2H); 9.46 (d, J = 8 Hz, 1H); 10.3 (s br, 1H); 12.0 (s br, 1H) ppm.

25 According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

11.2. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

30 IR(KBr) 1766, 1687 cm⁻¹

MS(ISP) 535.2 (M+H)⁺.

¹H-NMR(DMSO, 250 MHz): inter alia δ 1.92-2.16 (m, 2H); 3.69 (s, 2H); 4.58 (m, 1H), 5.08 (d J = 8 Hz, 1H); 5.75 (dd, J = 5 Hz, J = 8 Hz, 1H); 7.30 (s, 1H); 8.05 (s, 2H); 9.44 (d, J = 8 Hz, 1H); 10 (s br, 1H) ppm.

11.3. Mixture of (6R,7R)-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)- and -(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5 IR(KBr) 1765, 1659 cm^{-1}
MS(ISP) 535.3 (M+H)⁺.

11.4. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-azetidin-3-yl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10 IR(KBr) 1762, 1689, 1668 cm^{-1}
MS(ISP) 521.2 (M+H)⁺.

11.5. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

15 IR(KBr) 1766, 1670 cm^{-1}
MS(ISP) 534.2 (M+H)⁺.

11.6. Mixture of (6R,7R)-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)- and -(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

20 dihydrochloride
IR(KBr) 1775, 1667 cm^{-1}
MS(ISP) 534.3 (M+H)⁺.

11.7. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-azetidin-3-yl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-

25 bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride
IR(KBr) 1776, 1669 cm^{-1}
MS(ISP) 520.2 (M+H)⁺.

11.8. (6R,7R)-7-[(Z)-2(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-piperidin-4-ylmethyl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate

30 IR(KBr) 1774, 1664 cm^{-1}
MS(ISP) 562.4 (M+H)⁺.

11.9. 7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-pyrazolidin-4-yl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

35

IR(KBr) 1756 cm^{-1}

MS(ISP) 536.3 (M+H)⁺.

- 11.10. (6R,7R)-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-1-pyrazolidin-4-yl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

m.p. 239-240°C

IR(KBr) 1764 cm^{-1}

MS(ISP) 535.3 (M+H)⁺.

- 11.11. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-(S)-(2-oxo-1-pyrrolidin-2-ylmethyl-pyrrolidin-3-ylidenemethyl)]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-carboxylic acid

IR(KBr) 1785, 1624 cm^{-1}

MS(ISP) 549.1 (M+H)⁺.

- 11.12. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-(S)-(2-oxo-1-pyrrolidin-2-ylmethyl-pyrrolidin-3-ylidenemethyl)]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-carboxylic acid

IR(KBr) 1767 cm^{-1}

MS(ISP) 548.2 (M+H)⁺.

- 11.13. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-1-[(3R,4R)-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

IR(KBr) 1770, 1665 cm^{-1}

MS(ISP) 616.3 (M+H)⁺.

- 11.14. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-1-[(3R,4R)-4-trifluoromethyl-pyrrolidin-3-ylmethyl]-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

IR(KBr) 1768, 1625 cm^{-1}

- 11.15. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-3-[(E)-(3'S,5'R)-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

IR(KBr) 1768, 1656 cm^{-1}

MS(ISP) 606.1 (M+H)⁺.

11.16. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-3-[(E)-(3'S,5'S)-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid formate (1:1)

5 **IR(KBr) 1768 cm^{-1}**
MS(ISP) 606.1 (M+H)⁺.

11.17. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-[(E)-(3'S,5'R)-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

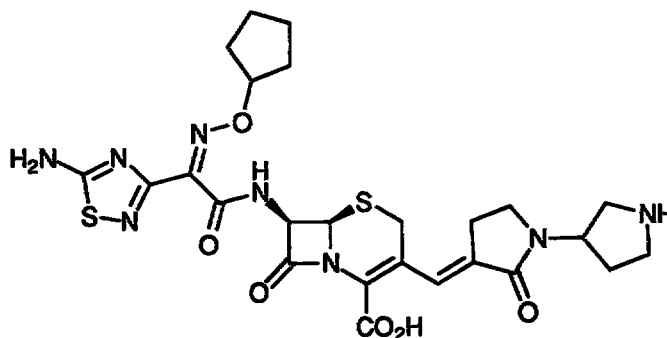
10 **IR(KBr) 1766, 1656 cm^{-1}**
MS(ISP) 605.3 (M+H)⁺.

11.18. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-[(E)-(3'S,5'S)-5'-dimethylcarbamoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

15 **IR(KBr) 1767, 1657 cm^{-1}**
MS(ISP) 605.1 (M+H)⁺.

Example 12

12.1. Mixture of (6R,7R)-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-cyclopentyloxyimino-acetylamino]-8-oxo-3-[(E)-(R)- and -(S)-2-oxo-
 20 **[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid**



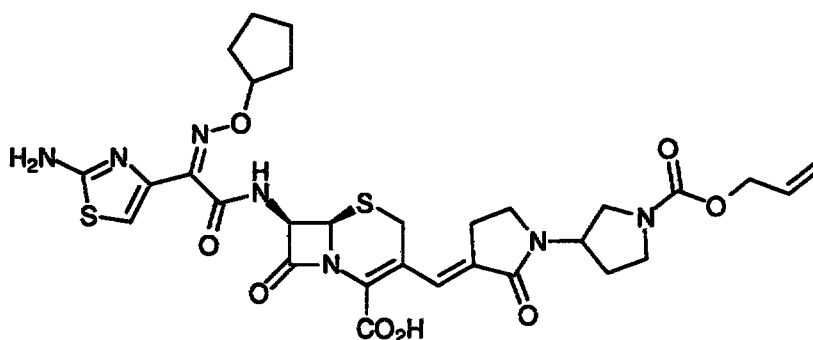
25 To a suspension of 454 mg (1.19 mmol) (Z)-(5-amino-[1,2,4]thiadiazol-3-yl)-cyclopentyloxyimino-acetate 1-allyl-1-methyl-pyrrolidinium salt in 9.5 ml dimethylformamide was added 451 mg (1.19 mmol) O-benzotriazol-1-yl-N,N,N',N'-tetramethyluronium-hexafluorophosphate (HBTU) and the mixture was stirred for 1 h. To the resulting orange solution was added a
 30 mixture of (E)-(6R,7R)-3-[(R)- and -(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl)-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-

ene-2-carboxylic acid trifluoroacetate (600 mg, 1.08 mmol) and the mixture was stirred for 40 h at room temperature. The reaction mixture was concentrated *in vacuo* and the residue distributed between 100 ml ethyl acetate and 70 ml water. The phases were separated and the organic phase was concentrated upon which the product precipitated. The solid was collected by filtration, washed with ethyl acetate and dried, yielding 291 mg (39%) of a beige amorphous powder. Removal of the allyloxycarbonyl-protective group was accomplished according to example 9. The product was purified by gel chromatography (MCI Gel 75-150 μ , using a gradient of water with increasing concentrations of acetonitrile).
Yield: 40 mg (16%) beige solid
IR(KBr) 1771, 1672 cm^{-1}
MS(ISP) 603.3 (M+H)⁺.

12.2. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-cyclopentyloxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
IR(KBr) 1777, 1670 cm^{-1}
MS(ISP) 603.2 (M+H)⁺.

Example 13

13.1. Mixture of (6R,7R)-3-[(E)-(R)- and -(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-cyclopentyl-oxyimino-acetyl-amino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



25

A suspension of (E)-(6R,7R)-3-[(R)- and [(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-amino-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid trifluoroacetate (555 mg, 1.0 mmol) in 20 ml DMF was treated for 12 h at room temperature with (Z)-(2-aminothiazol-4-yl)-cyclopentyloxyimino-thioacetic acid S-benzothiazol-2-yl ester (445 mg, 1.1 mmol).

The reaction mixture was concentrated *in vacuo* and the residue triturated in a mixture of 70 ml ethyl acetate and 50 ml water. The solid was collected by filtration, washed with water, ethyl acetate and dried.

Yield: 484 mg (71%).

5 IR(KBr) 1778, 1677, 1629 cm^{-1}

MS(ISP) 686.4 (M+H)⁺.

According to the procedure set forth in the preceeding example, the following additional compounds were prepared:

13.2 (6R,7R)-3-[(E)-1-(1-Allyloxycarbonyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-cyclopentyloxyimino-acetylamino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10 IR(KBr) 1774, 1673 cm^{-1}

MS(ISP) 672.4 (M+H)⁺.

13.3. (6R,7R)-3-[(E)-1-(Allyloxycarbonyl-piperidin-4-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-cyclopentyloxyimino-acetylamino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

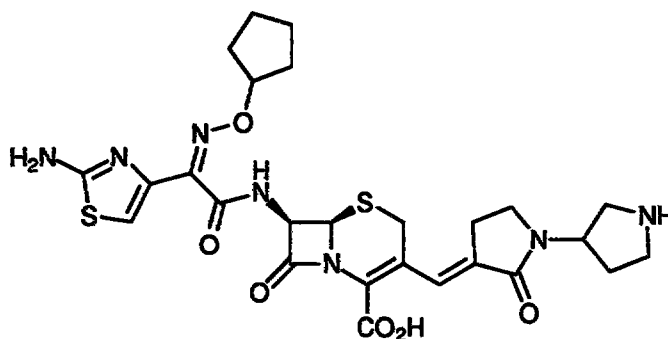
15 IR(KBr) 1779, 1676, 1630 cm^{-1}

MS(ISP) 714.5 (M+H)⁺.

20

Example 14

14.1. Mixture of (6R,7R)-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-cyclopentyloxyimino-acetylamino]-8-oxo-3-[(E)-(R)- and -(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



25

Removal of the allyloxycarbonyl-protective group in the mixture of (6R,7R)-3-[(E)-(R)- and -(S)-1'-allyloxycarbonyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidene-methyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-cyclopentyloxyimino-acetylamino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acids was accomplished

30

using the procedure described in example 9. The crude product (328 mg) was purified by gel chromatography (MCI Gel 75-150 μ , using a gradient of water with increasing concentrations of acetonitrile). The pure product crystallized from the chromatographic fractions and was collected by
5 filtration.

Yield: 102 mg (28%) yellow crystals

IR(KBr) 1770, 1666, 1625 cm^{-1}

MS(ISP) 602.4 (M+H)⁺.

According to the procedure set forth in the preceding example, the
10 following additional compounds were prepared:

14.2. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-cyclopentyloxyimino-acetyl-amino]-3-(E)-1-azetidin-3-yl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid dihydrochloride

IR(KBr) 1780, 1661 cm^{-1}

15 MS(ISP) 588.3 (M+H)⁺.

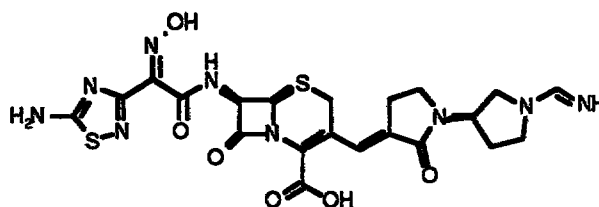
14.3. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-cyclopentyloxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-piperidin-4-ylmethyl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid hydrochloride

20 IR(KBr) 1771, 1665, 1627 cm^{-1}

MS(ISP) 630.6 (M+H)⁺.

Example 15

(6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-(R)-1'-iminomethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid
25



To a suspension of 66 mg sodium hydride (65% in mineral oil) in 2 ml DMSO
30 was added 200 mg of ethylformimidate hydrochloride and 100 mg (0.2 mmol) (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid. The reaction mixture was

stirred for 30 min at room temperature before it was hydrolysed with some drops of water. It was purified by reversed-phase chromatography on MCI gel by elution with water: acetonitrile = 9:1.

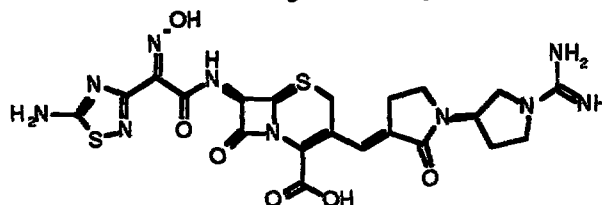
Yield: 30 mg

5 IR(KBr) 1767 cm^{-1}

MS(ISP) 562. 2 (M+H)⁺.

Example 16

(6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetylamino]-3-[(E)-(R)-1'-carbamimidoyl-2-oxo-[1,3']bipyrrolidinyl-3-
10 ylidenemethyl)]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



To a solution of 150 mg [1,2,4]triazole-1-carboxamidine hydrochloride in 1 ml DMSO were added 13 μl tetramethylguanidine and 53 mg (6R,7R)-7-[(Z)-2-(5-
15 amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl)]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid. After 1 h stirring at room temperature, the reaction mixture was purified by reversed-phase chromatography on MCI gel by elution with water: acetonitrile = 9:1.

20 Yield: 30 mg

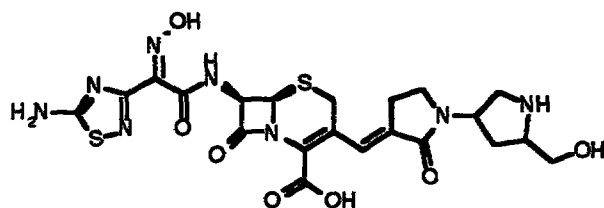
IR(KBr) 1769 cm^{-1}

MS(ISP) 577.0 (M+H)⁺.

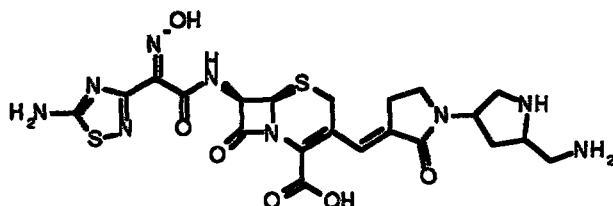
Example 17

Following the procedures set forth in the above Examples the following
25 compounds can be prepared:

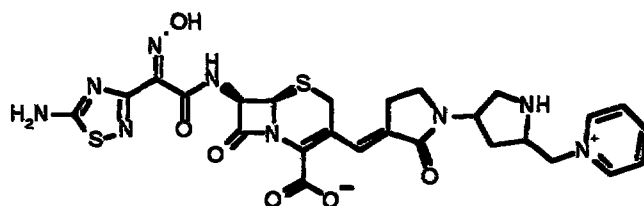
17.1. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetylamino]-3-[(E)-5'-hydroxymethyl-2-oxo-[1,3']bipyrrolidinyl-3-
ylidenemethyl)]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



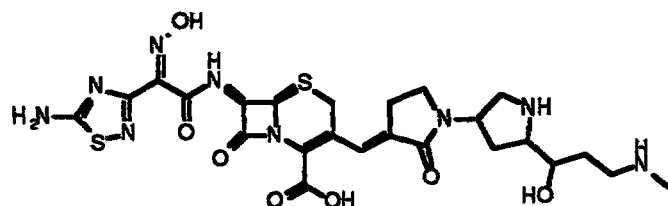
- 17.2. (6R,7R)-3-[(E)-5'-Aminomethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(5-amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



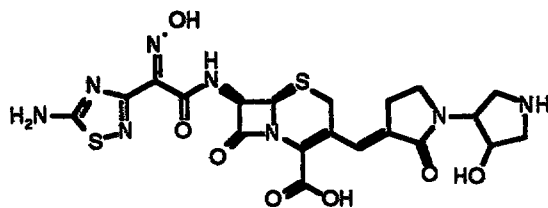
- 17.3. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-5'-pyridin-1-ium-1-ylmethyl-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylate



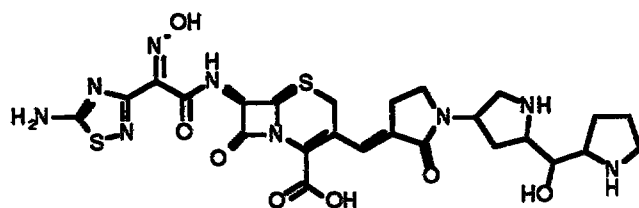
- 17.4. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-3-[(E)-5'-(1-hydroxy-3-methylamino-propyl)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



- 17.5. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-3-[(E)-4'-hydroxy-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



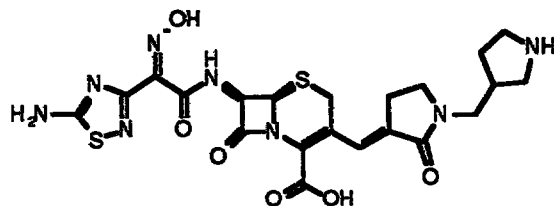
- 17.6. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
5 acetylamin]-3-[(E)-5'-(hydroxy-pyrrolidin-2-yl-methyl)-2-oxo-
[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-
ene-2-carboxylic acid



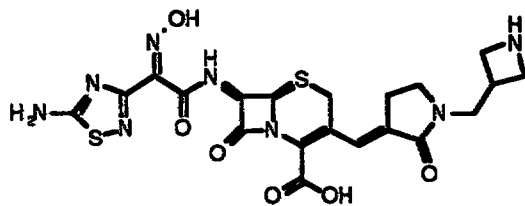
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- 17.7. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetylamin]-8-oxo-3-[(E)-2-oxo-1-pyrrolidin-3-ylmethyl-pyrrolidin-3-
ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

15



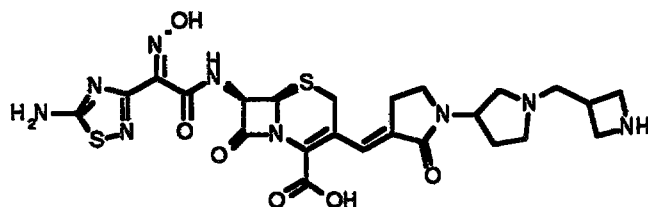
- 17.8. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
20 acetylamin]-3-[(E)-1-azetidin-3-ylmethyl-2-oxo-pyrrolidin-3-ylidenemethyl]-
8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



25

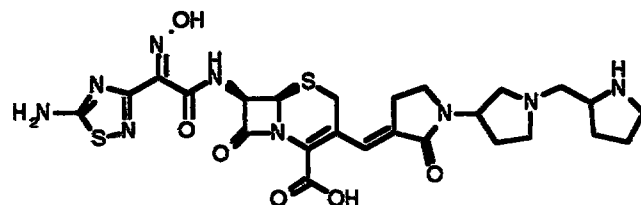
17.9. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1'-azetidin-3-ylmethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



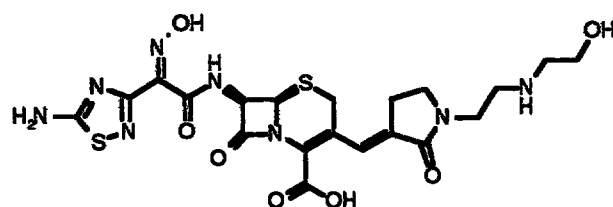
17.10. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1'-pyrrolidin-2-ylmethyl-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10



17.11. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-[2-(2-hydroxy-ethylamino)-ethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

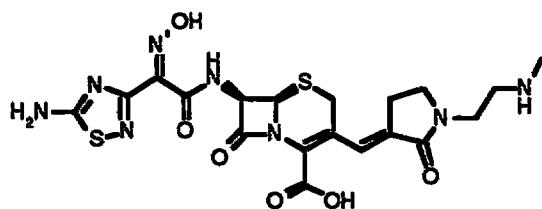
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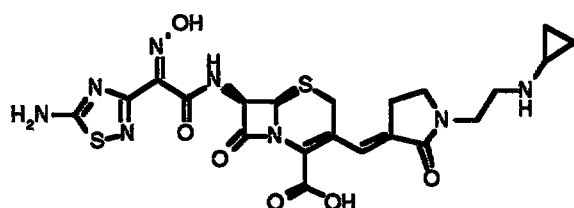
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17.12. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-(2-methylamino-ethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

25

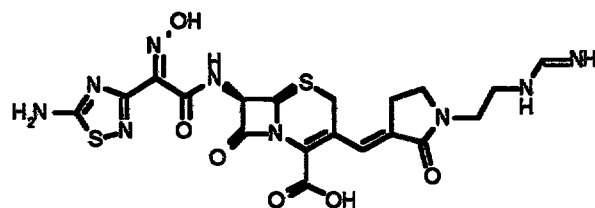


- 17.13. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
5 acetyl-amino]-3-[(E)-1-(2-cyclopropylamino-ethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



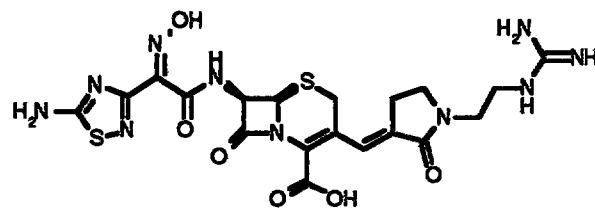
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- 17.14. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetyl-amino]-3-[(E)-1-[2-(iminomethylamino)-ethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



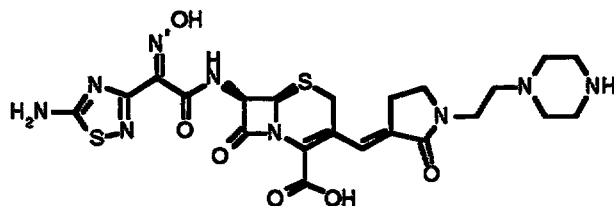
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- 17.15. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetyl-amino]-3-[(E)-1-(2-guanidino-ethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-
20 8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



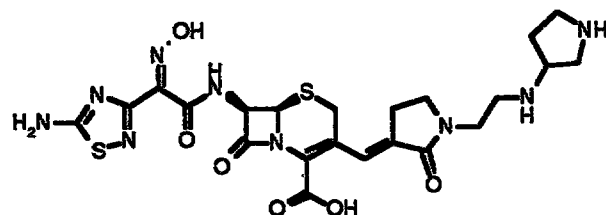
17.16. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-(2-piperazin-1-yl-ethyl)-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



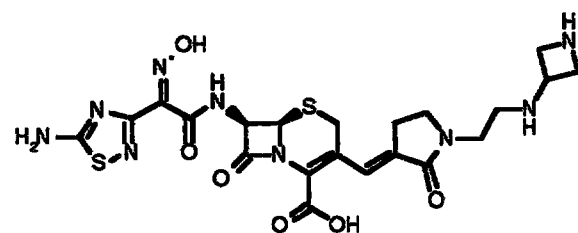
17.17. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-[2-(pyrrolidin-3-ylamino)-ethyl]-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10



17.18. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-[2-(azetidin-3-ylamino)-ethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

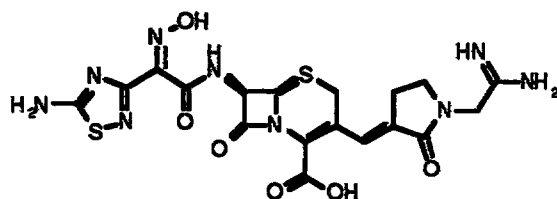
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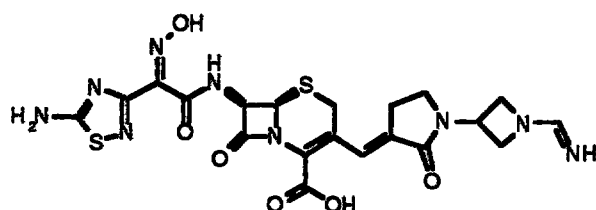
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17.19. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-carbamimidoylmethyl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

25

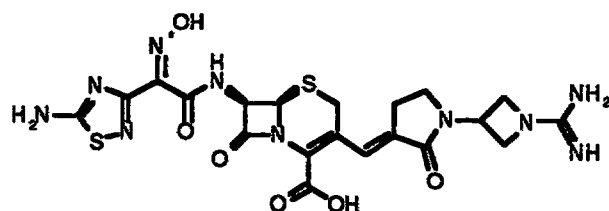


17.20. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
5 acetylamino]-3-[(E)-1-(1-iminomethyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-
ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



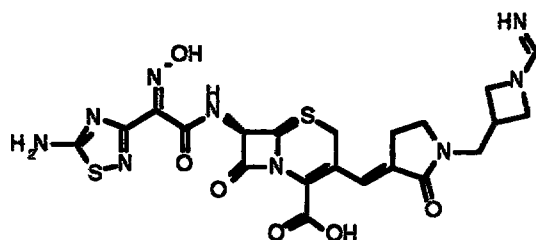
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17.21. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetylamino]-3-[(E)-1-(1-carbamimidoyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-
ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



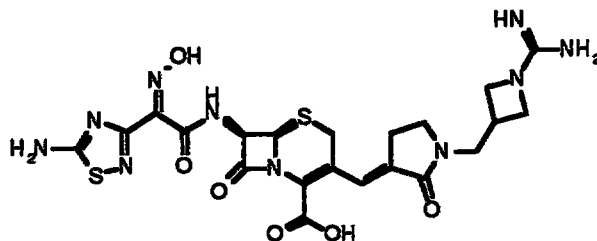
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17.22. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-
acetylamino]-3-[(E)-1-(1-iminomethyl-azetidin-3-ylmethyl)-2-oxo-pyrrolidin-3-
20 ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



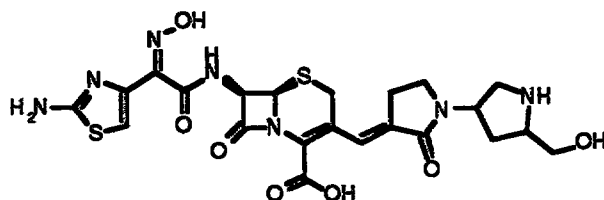
17.23. (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetylamino]-3-[(E)-1-(1-carbamimidoyl-azetidin-3-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



17.24. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-[(E)-5'-hydroxymethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

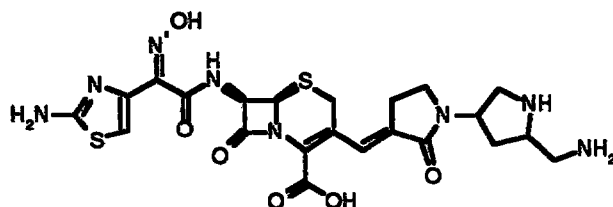
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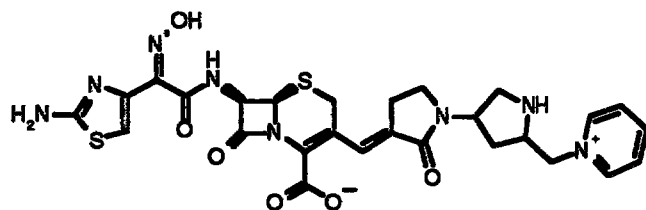
17.25. (6R,7R)-3-[(E)-5'-Aminomethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-7-[(Z)-2-(2-amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

20

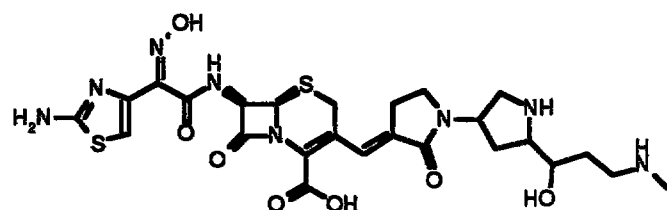


17.26. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-5'-pyridin-1-ium-1-ylmethyl-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylate

25

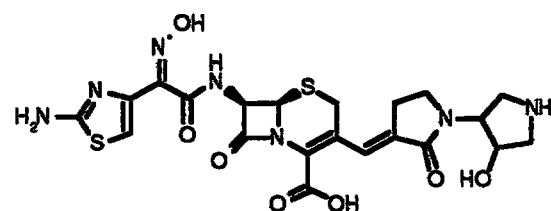


- 17.27. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-
5 [(E)-5'-(1-hydroxy-3-methylamino-propyl)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



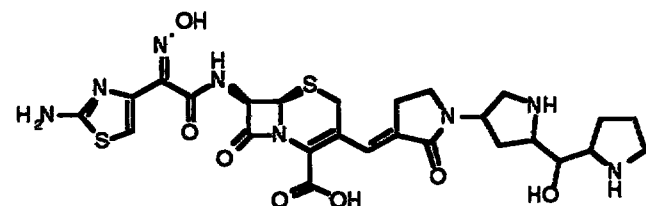
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- 17.28. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-
[(E)-4'-hydroxy-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-
bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



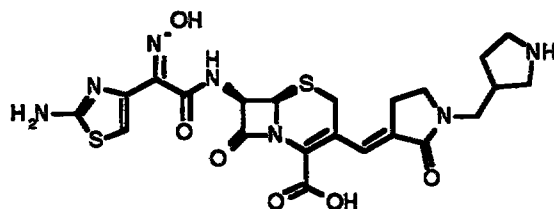
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- 17.29. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-
[(E)-5'-(hydroxy-pyrrolidin-2-yl-methyl)-2-oxo-[1,3']bipyrrolidinyl-3-
20 ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



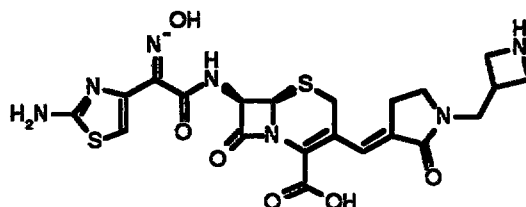
17.30. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-1-pyrrolidin-3-ylmethyl-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



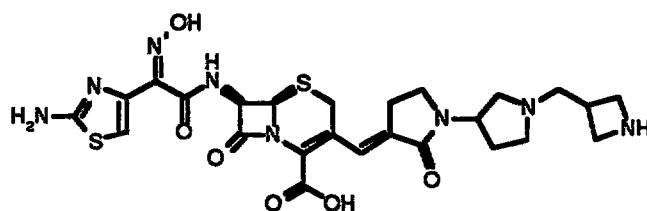
17.31. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-[(E)-1-azetidin-3-ylmethyl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10



17.32. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-3-[(E)-1'-azetidin-3-ylmethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

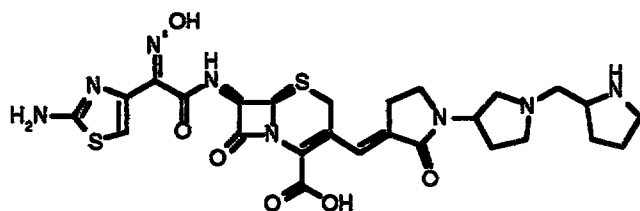
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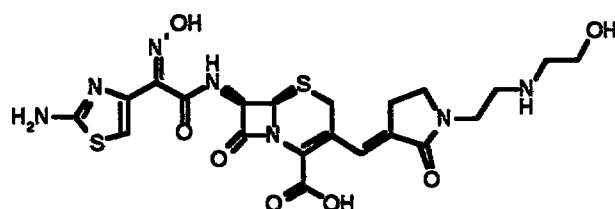
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17.33. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetylamino]-8-oxo-3-[(E)-2-oxo-1'-pyrrolidin-2-ylmethyl-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

25

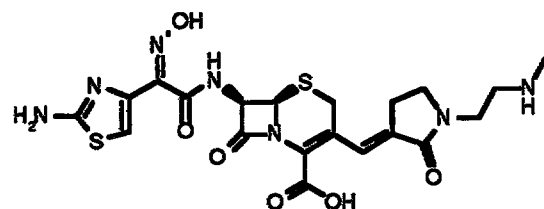


- 17.34. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-
5 [(E)-1-[2-(2-hydroxy-ethylamino)-ethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



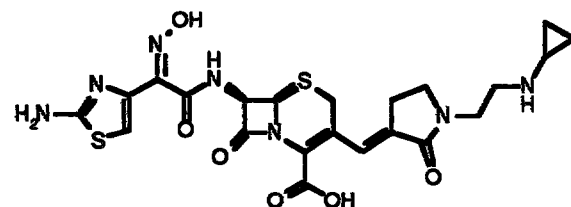
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- 17.35. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-
[(E)- 1-(2-methylamino-ethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-
1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



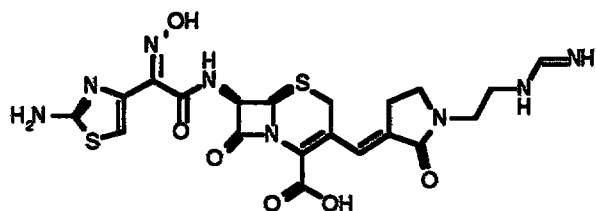
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- 17.36. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-
[(E)- 1-(2-cyclopropylamino-ethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-
20 thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



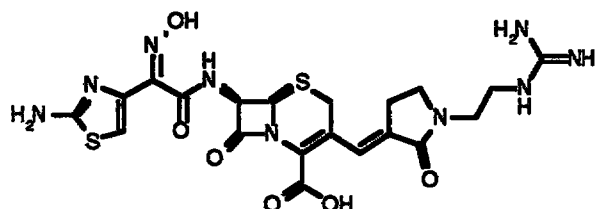
17.37. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-[2-(iminomethyl-amino)-ethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



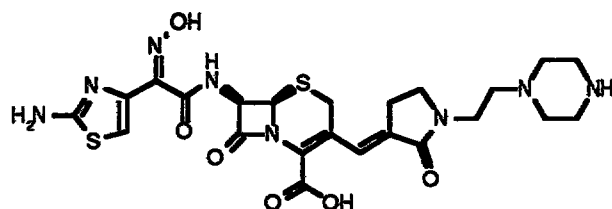
17.38. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-(2-guanidino-ethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10



17.39. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-(2-piperazin-1-yl-ethyl)-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

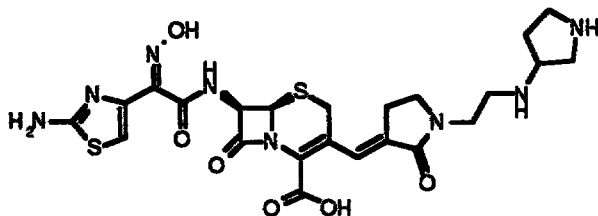
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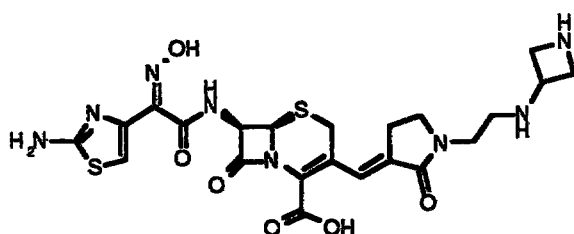
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17.40. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-2-oxo-1-[2-(pyrrolidin-3-yl-amino)-ethyl]-pyrrolidin-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

25

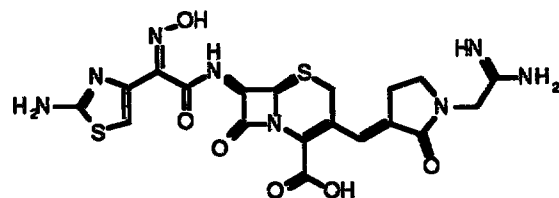


- 17.41. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-
5 [(E)-1-[2-(azetidin-3-ylamino)-ethyl]-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-
5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



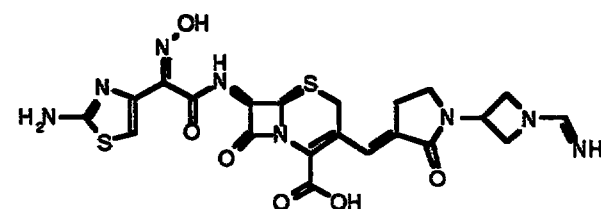
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- 17.42. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-
[(E)-1-carbamimidoylmethyl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-
1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



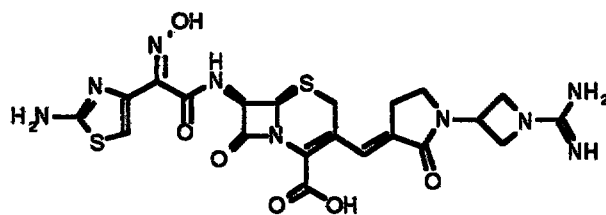
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- 17.43. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-
[(E)-1-(1-iminomethyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-
20 5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid



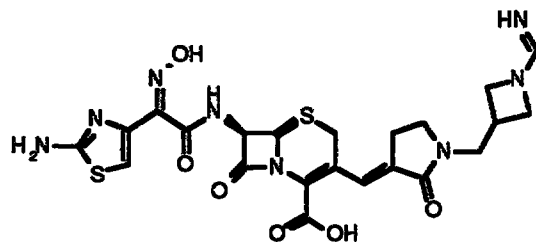
17.44. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-(1-carbamimidoyl-azetidin-3-yl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

5



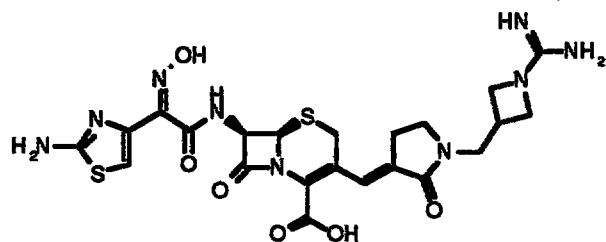
17.45. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-(1-iminomethyl-azetidin-3-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

10



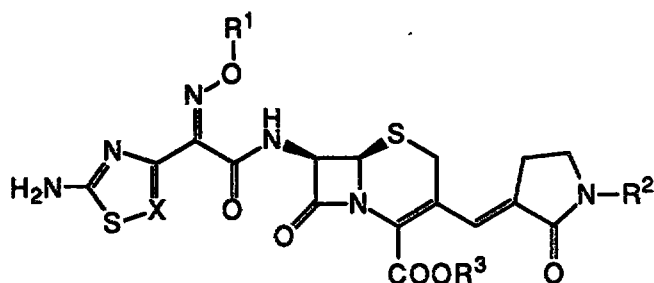
17.46. (6R,7R)-7-[(Z)-2-(2-Amino-thiazol-4-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-1-(1-carbamimidoyl-azetidin-3-ylmethyl)-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid

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Claims

1. Cephalosporin derivatives of the general formula



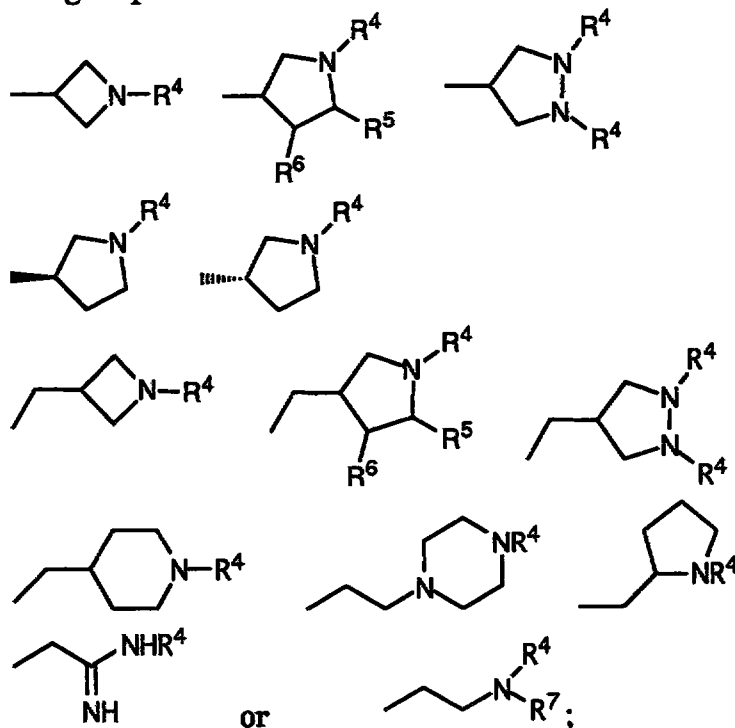
I

5 wherein

X is CH or N;

R¹ is hydrogen or cyclopentyl;

R² is a group of formula



R³ is hydrogen, an alkalimetal ion or a tertiary ammonium group;

R⁴ is hydrogen, an amino protecting group, pyrrolidin-2-ylmethyl, azetidin-3-ylmethyl, iminomethyl, 1-carbamimidoyl;

R⁵ is hydrogen, dialkylcarbamoyl, ω-hydroxyalkyl, ω-aminoalkyl, pyridinium-1-ylmethyl, 1-hydroxy-3-

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aminomethyl-propyl or (hydroxy)-(pyrrolidin-2-yl)methyl;

R^6 is hydrogen, trifluoromethyl or hydroxy; and

R^7 is alkyl, ω -hydroxy-alkyl, cycloalkyl, 3-pyrrolidinyl, 3-azetidiny, iminomethyl or 1-carbamimidoyl;

5

as well as readily hydrolyzable esters thereof, pharmaceutically acceptable salts of said compounds and hydrates of the compounds of formula I and of their esters and salts.

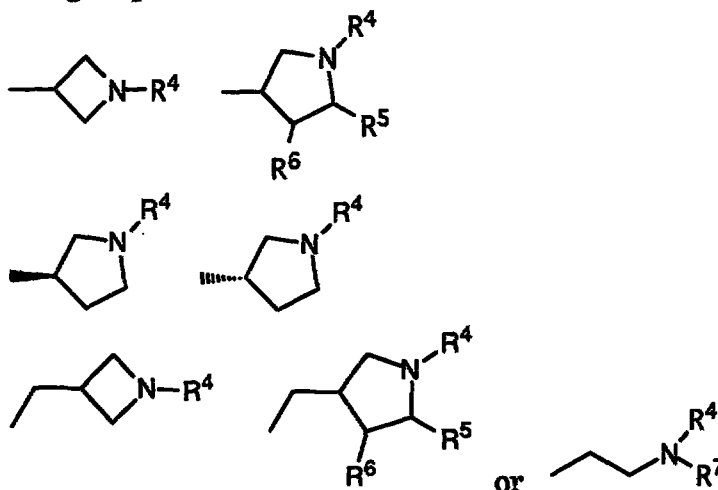
2. Compounds of formula I according to claim 1, wherein

10

X is CH or N;

R^1 is hydrogen;

R^2 is a group of formula



15

R^3 is hydrogen, an alkalimetal ion or a tertiary ammonium group;

R^4 is hydrogen, an amino protecting group, iminomethyl, or 1-carbamimidoyl;

20

R^5 is hydrogen, hydroxymethyl;

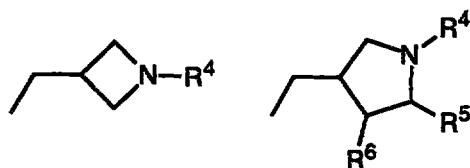
R^6 is hydrogen or hydroxy; and

R^7 methyl or 2-hydroxyethyl;

as well as readily hydrolyzable esters thereof, pharmaceutically acceptable salts of said compounds and hydrates of the compounds of formula I and of
25 their esters and salts.

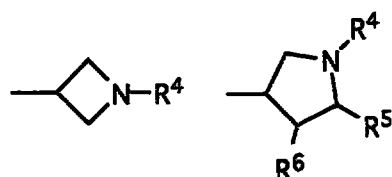
3. Compounds of formula I according to claim 1 or 2, wherein X is CH or N; and R^2 represents a group of the formula





wherein R^4 is hydrogen, iminomethyl or 1-carbamimidoyl; R^5 is hydrogen or hydroxymethyl; and R^6 is hydrogen or hydroxy.

4. Compounds of formula I according to claim 1 or 2, wherein X is CH
5 or N and R^2 represents a group of the formula

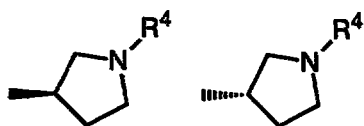


wherein R^4 is hydrogen, iminomethyl or 1-carbamimidoyl; R^5 is hydrogen or hydroxymethyl; and R^6 is hydrogen or hydroxy.

5. Compounds of formula I according to anyone of claims 1 to 4,
10 wherein R^5 and R^6 are hydrogen.

6. Compounds of formula I according to anyone of claims 1 to 5,
wherein the pyrrolidinone is in the E-form.

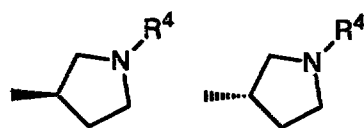
7. Compounds of formula I according to claim 2, wherein X is CH and
 R^2 is a group of formula



15

wherein R^4 is as defined in claim 2.

8. Compounds of formula I according to claim 2, wherein X is N and R^2
is a group of formula



20

wherein R^4 is as defined in claim 2.

9. Compounds of formula I according to claim 1, wherein

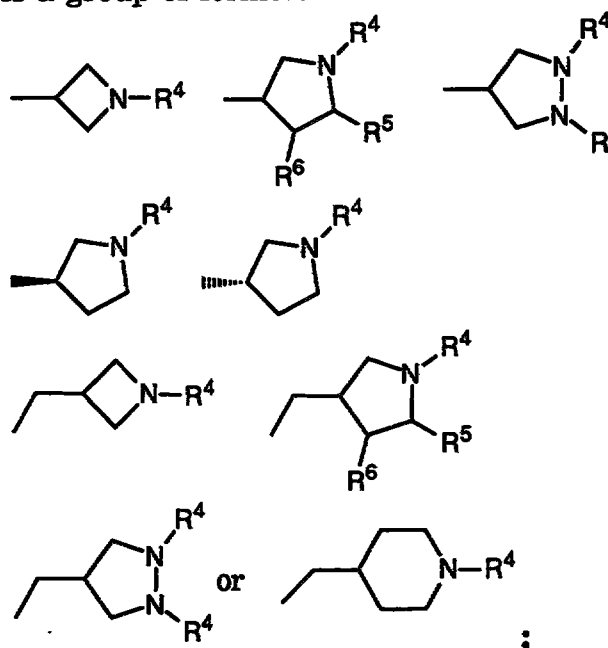


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X is CH or N;
 R¹ is hydrogen or cyclopentyl;
 R² is a group of formula

5



R³ is hydrogen, an alkalimetal ion or a tertiary ammonium group;
 10 R⁴ is hydrogen, an amino protecting group;
 R⁵ is hydrogen, dialkylcarbamoyl; and
 R⁶ is hydrogen or trifluoromethyl;

as well as readily hydrolyzable esters thereof, pharmaceutically acceptable salts of said compounds and hydrates of the compounds of formula I and of
 15 their esters and salts.

10. The compounds

- (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(R)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid,
 20 (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-8-oxo-3-[(E)-(S)-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid,
 (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-(R)-1'-iminomethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-
 25 8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid,



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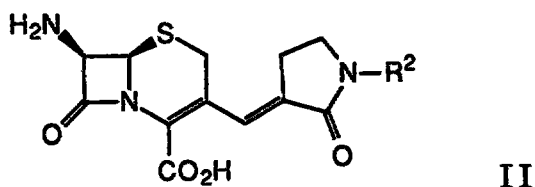


- (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-amino]-3-[(E)-(R)-1'-carbamiimidoyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl)]-8-oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid,
 (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-
 5 amino]-3-[(E)-1-azetidin-3-ylmethyl-2-oxo-pyrrolidin-3-ylidenemethyl]-8-oxo-
 5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid,
 (6R,7R)-7-[(Z)-2-(5-Amino-[1,2,4]thiadiazol-3-yl)-2-hydroxyimino-acetyl-
 amino]-3-[(E)-5'-hydroxymethyl-2-oxo-[1,3']bipyrrolidinyl-3-ylidenemethyl]-8-
 oxo-5-thia-1-aza-bicyclo[4.2.0]oct-2-ene-2-carboxylic acid.

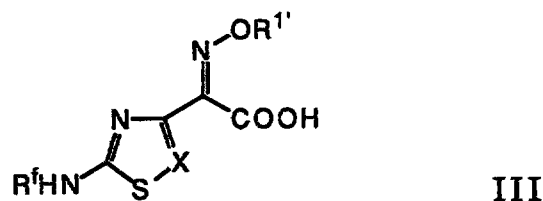
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11. Compounds as in any one of claims 1 to 10 for use as pharmaceutically active substances, particularly for the treatment and prophylaxis of infectious diseases.

12. Process for the manufacture of compounds of formula I, which
 15 process comprises treating a compound having the formula II



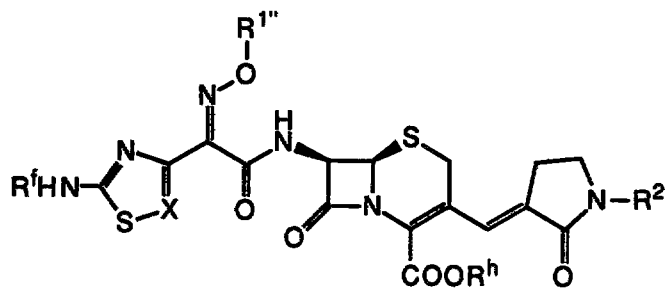
- in which R^2 is defined as in claim 1, or an ester or a salt thereof, the amino group and the carboxylic groups present the compound of formula II may be unprotected or protected,
 20 with a carboxylic acid of the general formula III



- in which R^f is hydrogen or an amino protecting group, $R^{1'}$ is hydrogen, cyclopentyl or a hydroxy protecting group and X is as defined above, or a
 25 reactive functional derivative thereof, or

- (b) cleaving off the amino, hydroxy and/or carboxy protecting group in a compound having the formula IV





IV

in which R^2 is as defined above, R^f is hydrogen or an amino protecting group, $R^{1''}$ is hydrogen or a hydroxy protecting group, R^h is hydrogen or a carboxy protecting group, provided that at least one of R^f , $R^{1''}$ and R^h is a corresponding protecting group, or a salt thereof.

13. The compound of formula IIIa (Z)-(5-Amino-[1,2,4]thiadiazol-3-yl)-trityloxyimino-thioacetic acid S-benzothiazol-2-yl ester.

14. A pharmaceutical preparation containing a compound according to any one of claims 1 to 10 and a therapeutically inert carrier, particularly for the treatment and prophylaxis of infectious diseases.

15. The use of the compounds according to any one of claims 1 to 10 in the treatment and prophylaxis of infectious diseases or for the manufacture of medicaments for the treatment and prophylaxis of infectious diseases.

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