Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2054738 C 2001/08/28

(11)(21) 2 054 738

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1991/03/07
(87) Date publication PCT/PCT Publication Date: 1991/09/19
(45) Date de délivrance/Issue Date: 2001/08/28
(85) Entrée phase nationale/National Entry: 1991/10/29
(86) N° demande PCT/PCT Application No.: JP 91/00305
(87) N° publication PCT/PCT Publication No.: WO 91/13869
(30) Priorité/Priority: 1990/03/08 (57476/1990) JP

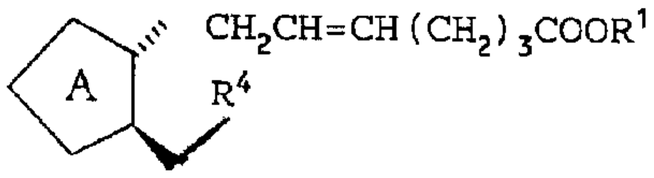
(51) Cl.Int.^{5}/Int.Cl.^{5} C07C 405/00, A61K 31/557

(72) Inventeurs/Inventors:
Goh, Yasumasa, JP;
Kawada, Kenji, JP;
Takahashi, Kimio, JP;
Kishi, Morio, JP

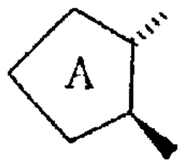
(73) Propriétaire/Owner:
SHIONOGI & CO., LTD., JP

(74) Agent: KIRBY EADES GALE BAKER

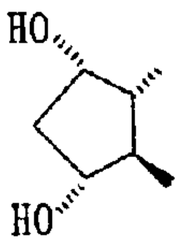
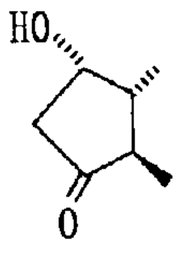
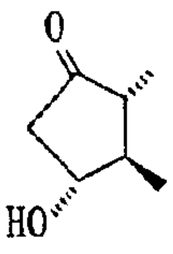
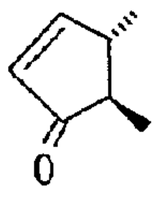
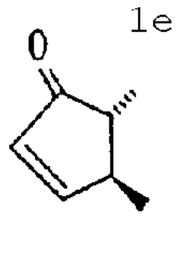
(54) Titre : DERIVES DE LA 15-DESOXYPROSTAGLANDINE
(54) Title: 15-DEOXYPROSTAGLANDIN DERIVATIVES

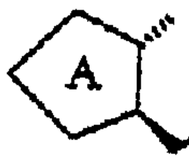


(V)

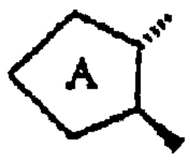
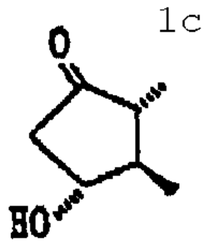
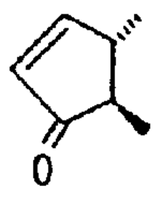


Va

1a  , 1b  , 1c  , 1d  and 1e  ;



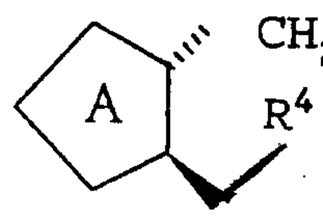
V

Va is  1a or  1c or  1d ,

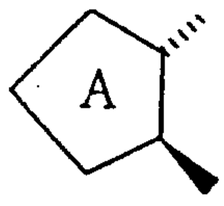
(57) Abrégé/Abstract:
The present invention relates to a 15-deoxyprostaglandin derivative of the formula (V): (see formula V) in which (see formula Va) is a 5-membered ring which is selected from the group consisting of (see formula 1a-1d) and (see formula 1e) R^1 is hydrogen or C_1-C_5 alkyl; R^4 is C_5-C_{11} alkyl, C_5-C_{11} alkenyl or C_5-C_{11} alkadienyl; or pharmaceutically acceptable salts thereof, with the proviso that compounds of the following formulae are excluded: (see formula 1) wherein (see formula Va) is (see formula 1a) or (see formula 1c) or (see formula 1d) and wherein R^4 is C_5-C_{11} alkyl or pharmaceutically acceptable salts thereof. The invention also relates to a pharmaceutical formulation comprising a 15-deoxyprostaglandin derivative as an active ingredient. The derivatives and formulations of the present invention are useful as intraocular pressure reducing agents.

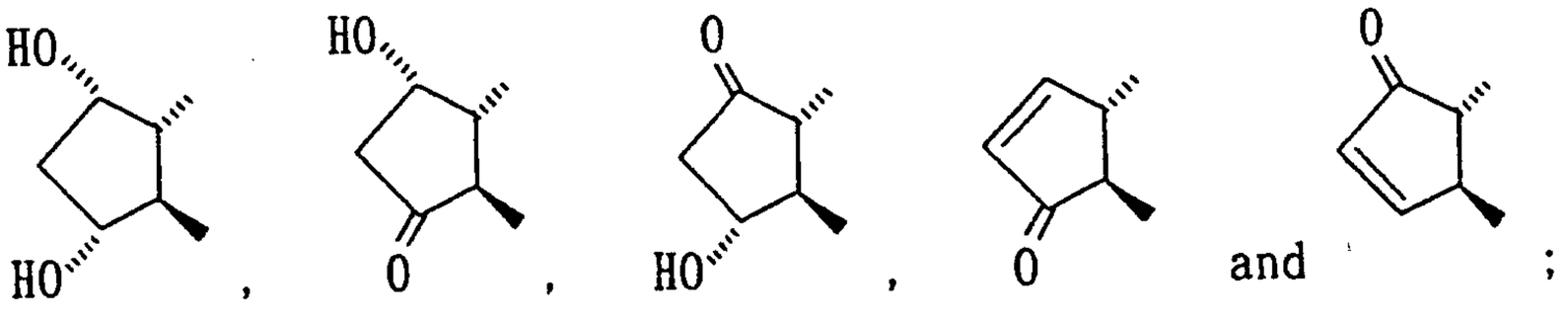
ABSTRACT

The present invention relates to a 15-deoxyprostaglandin derivative of the formula (V):

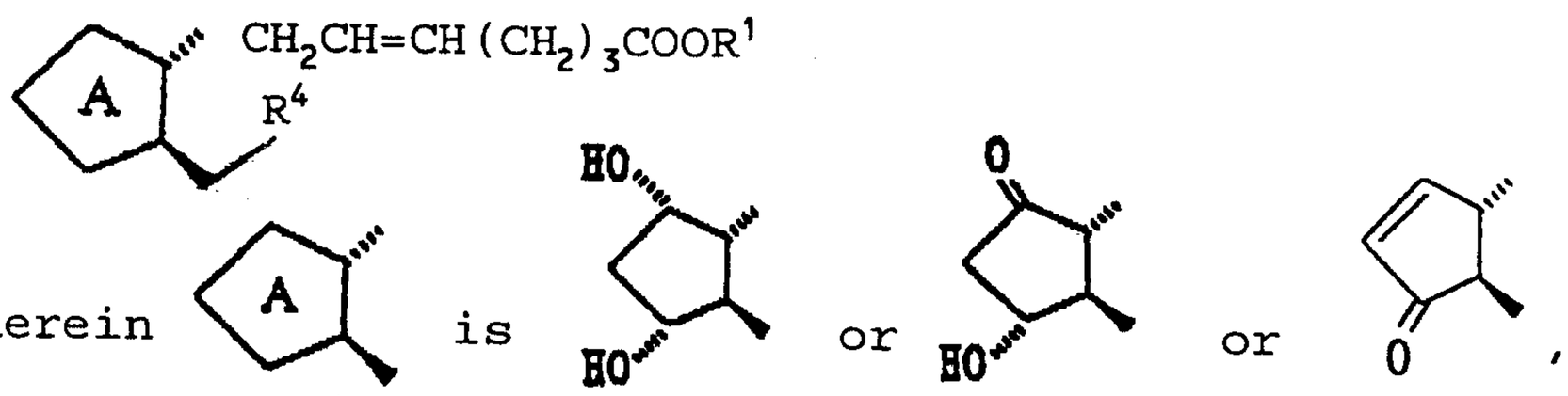


(V)

in which  is a 5-membered ring which is selected from the group consisting of



R^1 is hydrogen or C_1-C_5 alkyl; R^4 is C_5-C_{11} alkyl, C_5-C_{11} alkenyl or C_5-C_{11} alkadienyl; or pharmaceutically acceptable salts thereof, with the proviso that compounds of the following formulae are excluded:



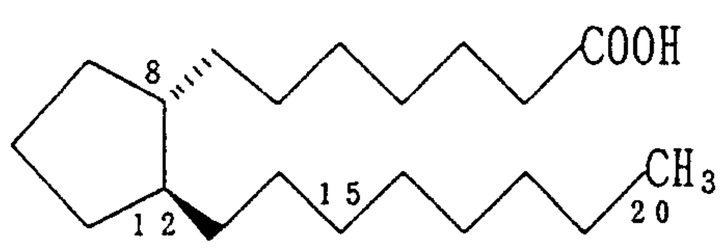
and wherein R^4 is C_5-C_{11} alkyl or pharmaceutically acceptable salts thereof. The invention also relates to a pharmaceutical formulation comprising a 15-deoxyprostaglandin derivative as an active ingredient. The derivatives and formulations of the present invention are useful as intraocular pressure reducing agents.

2054738

15-DEOXYPROSTAGLANDIN DERIVATIVES

The present invention relates to 15-deoxyprostaglandin derivatives and to a pharmaceutical composition containing the same.

Prostaglandins are a class of physiologically active substances which are derived from an eicosa-polyenoic acid, e.g. arachidonic acid, through a biosynthetic pathway in animal tissues and have, as a fundamental chemical structure, prostanoic acid of the formula:



α chain

ω chain

Prostaglandins are produced through biosynthesis in various tissues, and classified into several families. Prostaglandins are categorized into groups A - J depending on the position of the oxygen atom attached to the 5-membered ring moiety and the position of the double bond in the ring moiety. Alternatively, prostaglandins can be categorized into 3 groups depending on the number of double bonds in the side chains. As a result, prostaglandins are designated as PGA_2, PGE_1, $PGF_{2\alpha}$, according to both categorizations.

A'

Prostaglandins possess as a whole diverse bioactivities, which include, for example, vasodilator activity, platelet aggregation-inhibiting activity, uterotonic activity, gastrointestinal motility-promoting activity, etc.

Further, some prostaglandins have intraocular pressure-reducing activity. For example, Japanese Patent Publication (Kokai) No. 1418/1984 describes that $PGF_{2\alpha}$ has high intraocular pressure-reducing activity and that 15-keto-$PGF_{2\alpha}$ has the same activity although it is less potent. However, these natural prostaglandins are chemically and biologically labile, and are easily subject to metabolic degradation because they contain in the chemical structure a labile allyl alcohol moiety comprising a double bond between positions 13 and 14 and a hydroxy group at position 15 in the ω chain.

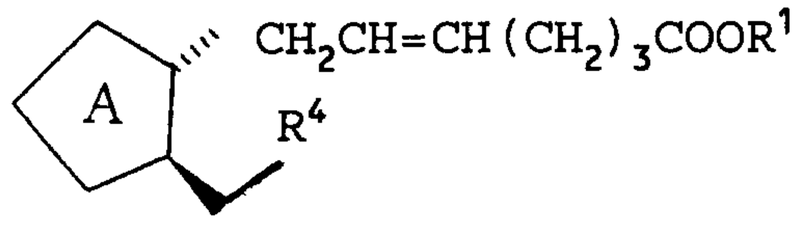
13,14-Dihydro-15-ketoprostaglandin which is a metabolic product of prostaglandins is known to be a compound which does not contain the labile moiety and is known to be a useful compound having intraocular pressure-reducing activity.

The inventors of the present invention have found new useful compounds by screening a large number of

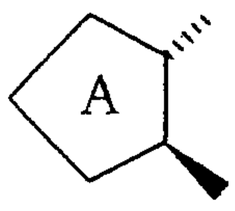
A

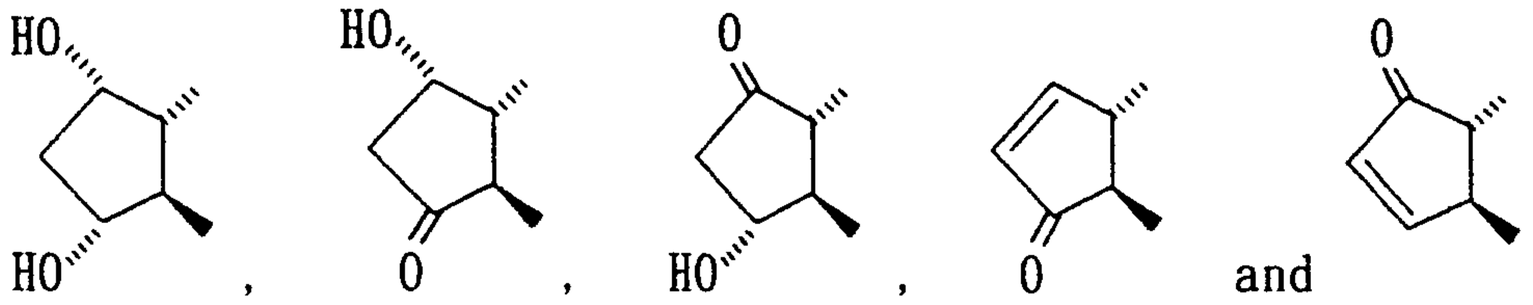
prostaglandin derivatives which are stable and capable of being chemically synthesized.

Thus, the present invention provides 15-deoxyprostaglandin derivatives of the formula (V):

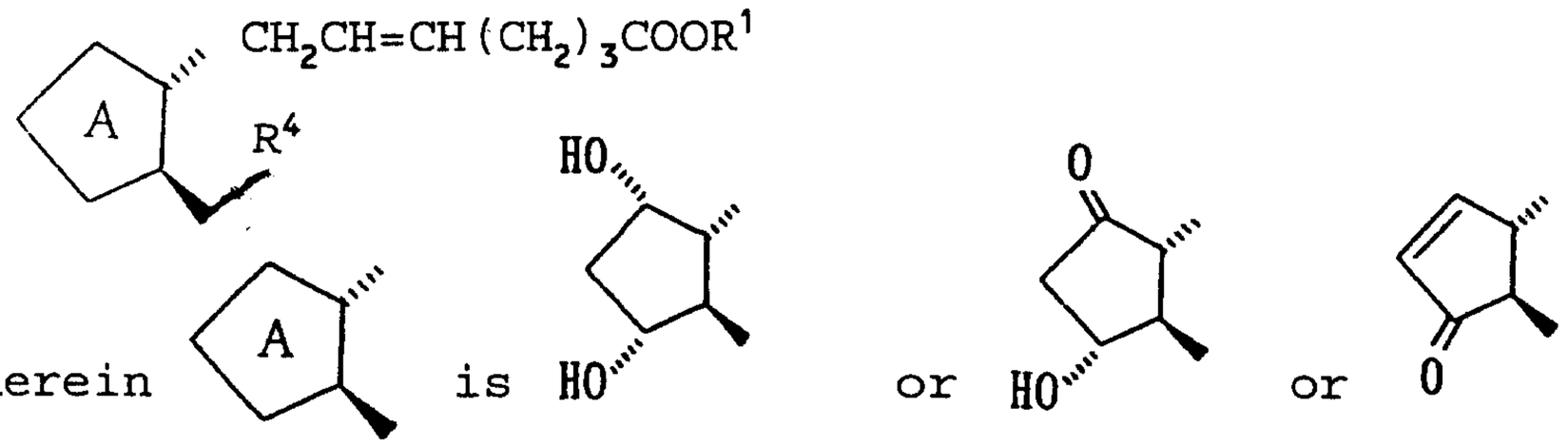


(V)

in which  is a 5-membered ring which is selected from the group consisting of



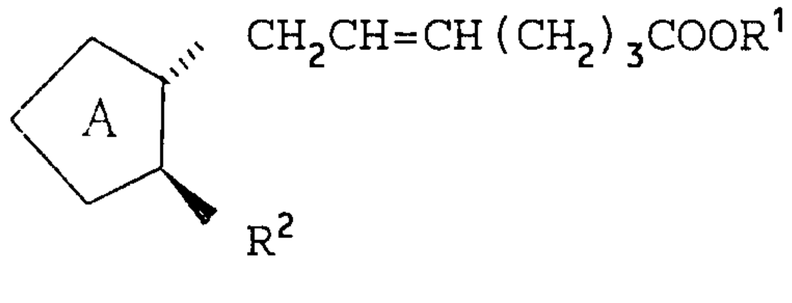
; R^1 is hydrogen or C_1-C_5 alkyl; R^4 is C_5-C_{11} alkyl, C_5-C_{11} alkenyl or C_5-C_{11} alkadienyl; or pharmaceutically acceptable salts thereof, with the proviso that compounds of the following formulae are excluded:



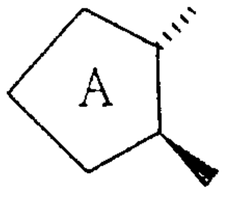
and wherein R^4 is C_5-C_{11} alkyl or pharmaceutically acceptable salts thereof.

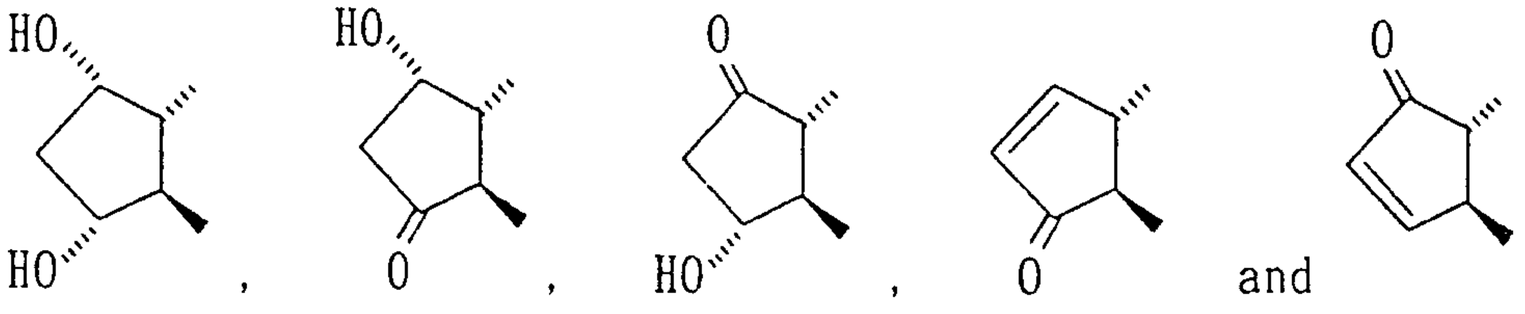
The invention further provides a pharmaceutical formulation comprising a therapeutically effective amount of a 15-deoxyprostaglandin derivative as an active

ingredient, in admixture with a pharmaceutically acceptable carrier or diluent which is useful as an intraocular pressure reducing agent, in which the 15-deoxyprostaglandin derivative of the formula (I):



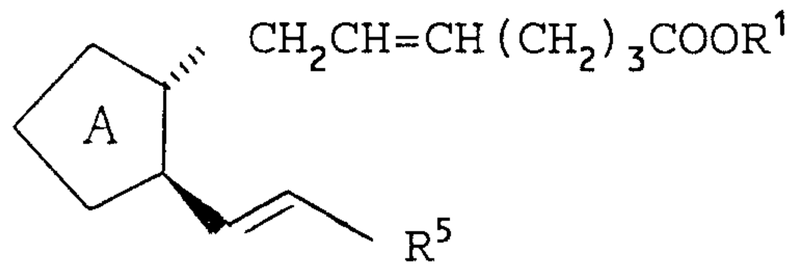
(I)

in which  is a 5-membered ring which is selected from the group consisting of

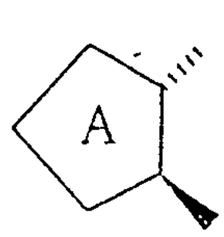


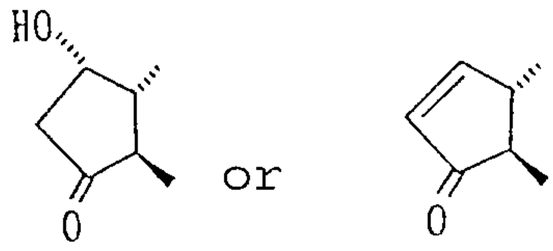
R^1 is hydrogen or C_1-C_5 alkyl; R^2 is C_6-C_{12} alkyl, C_6-C_{12} alkenyl or C_6-C_{12} alkadienyl; or pharmaceutically acceptable salts thereof.

In another embodiment the invention provides a 15-deoxyprostaglandin derivative of the formula (VI):



(VI)

in which  is a 5-membered ring which is



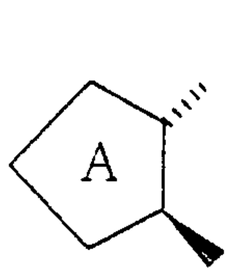
R^1 is hydrogen or C_1-C_5 alkyl;

R^5 is C_4-C_{10} alkyl or C_4-C_{10} alkenyl; or pharmaceutically acceptable salts thereof.

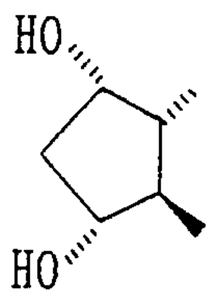
B

The term "C_6-C_{12} alkyl" in the definition of R^2 refers to hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl. R^2 may be an unsaturated hydrocarbon chain containing one or more double bonds, with C_8-C_{10} alkenyl or C_8-C_{10} alkadienyl being preferred. Specific examples of the unsaturated hydrocarbon chain are 1-hexenyl, 2-hexenyl, 1,3-hexadienyl, 1-heptenyl, 2-heptenyl, 1,3-heptadienyl, 1-octenyl, 2-octenyl, 1,3-octadienyl, 1-nonenyl, 2-nonenyl, 1,3-nonadienyl, 1-decenyl, 2-decenyl, 1,3-decadienyl, 1-undecenyl, 2-undecenyl, 1,3-undecadienyl, 1-dodecenyl, 2-dodecenyl, and 1,3-dodecadienyl.

Further, 15-deoxyprostaglandin derivatives of the above foumula in which



is



are also preferred.

15-Deoxyprostaglandin derivatives of the formula (I) include all of the stereoisomers and mixtures thereof.

As another embodiment, the invention provides a new formulation which is useful as an intraocular pressure-reducing agent. The inventors of the present invention have found that derivatives of conventional prostaglandins which are derived from said conventional prostaglandins by

A'

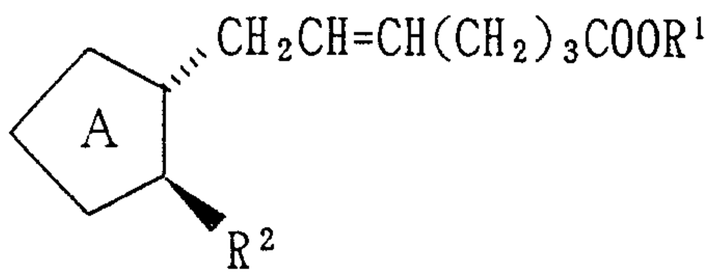
deleting the hydroxy group at position 15 are more stable, particularly in the liquid phase, than the conventional prostaglandins, and that they show the intraocular pressure-reducing activity. Thus, the invention provides a new use for these derivatives. In particular, the compounds of the invention as described above have a significant intraocular pressure-reducing activity, while they do not produce any side effects such as hyperemia of conjunctiva, and an initial increase in intraocular pressure which are often observed in known prostaglandins. Accordingly, the 15-deoxyprostaglandins of the present invention may be a therapeutic agent useful for treating ocular diseases, in particular glaucoma, which is assumed to be caused by increased intraocular pressure.

The term "15-deoxyprostaglandin derivatives" used in the specification and the claims refer to any derivatives from natural prostaglandins (preferably, PGA_1, PGA_2, PGB_1, PGB_2, PGE_1, PGE_2, PGE_3, $PGF_{1\alpha}$, $PGF_{2\alpha}$, $PGF_{3\alpha}$, PGJ_1 or PGJ_2), which lack the hydroxy group at position 15 in the ω chain. The ω chain may be saturated or unsaturated, and may have one or more double and/or triple bonds. Further, the double bonds may be E form, Z form or a mixture thereof. Preferably, however, the α chain has Z form and the ω chain has E form. Further, the derivatives of the invention include those in which the terminal carbon in the ω chain (20 position) is bound to a lower alkyl or a lower alkenyl.

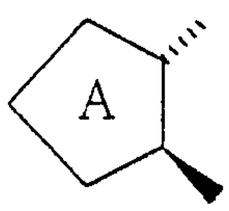
A

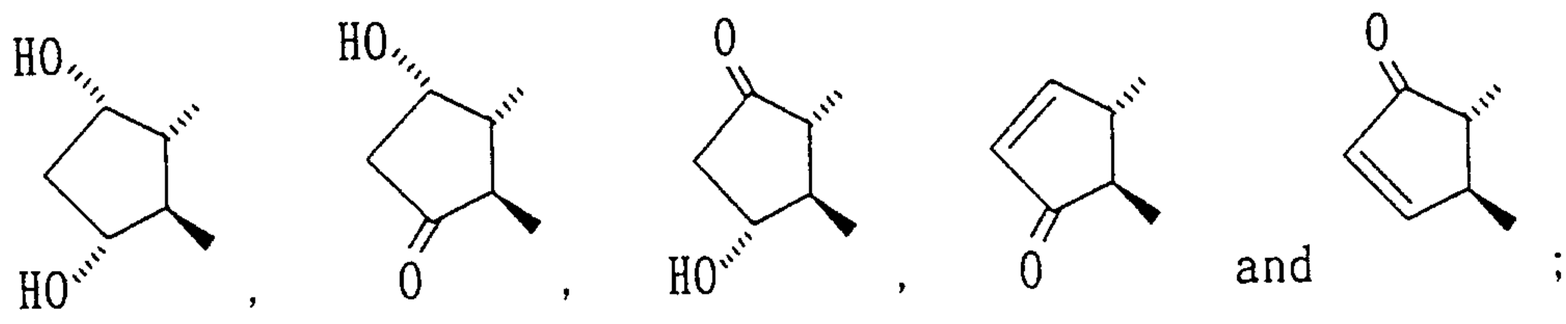
The derivatives may have 2 - 4 asymmetric carbon atoms. The invention includes all of the optical isomers and mixtures thereof.

Among the 15-deoxyprostaglandin derivatives of the invention which are useful as intraocular pressure-reducing agents, preferred derivatives are those having the formula (I):



(I)

in which  is a 5-membered ring selected from

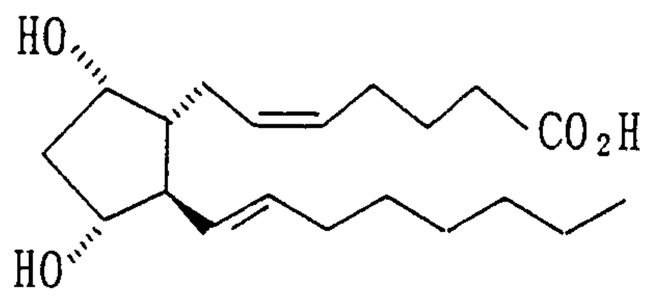


R^1 is hydrogen or lower alkyl;

R^2 is C_6-C_{12} alkyl, C_6-C_{12} alkenyl or C_6-C_{12} alkadienyl;

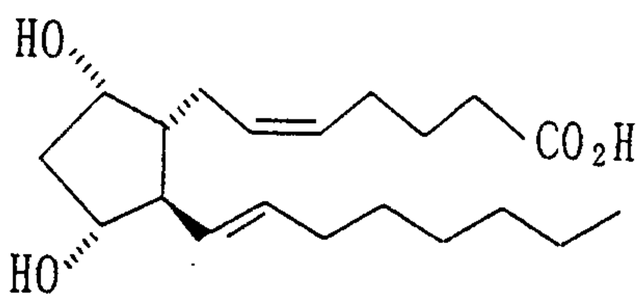
or pharmaceutically acceptable salts thereof.

Most preferred derivatives are (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid of the formula:



or pharmaceutically acceptable salts or esters thereof. Among the above preferred derivatives, a sodium salt of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid is especially preferred in the light of its solubility in water.

It should be noted that (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid of the formula:



and methyl ester thereof have been described in Gorman, Proc., Natl., Acad., Sci., U.S.A. 74 vol.,9,4007-4011. However, Gorman neither describes nor suggests the use of the compounds as an intraocular pressure-reducing agent.

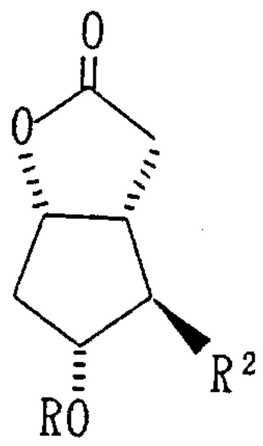
The carboxy moiety in the above-noted preferred compounds may be either a free carboxylic acid or a pharmaceutically acceptable salt or ester thereof. The salt may be, for example, an alkali metal salt, e.g. a lithium salt, a sodium salt, or a potassium salt; an alkaline earth metal salt, e.g. a calcium salt; an ammonium salt; an organic base salt, e.g. triethylamine, 2-aminobutane, tertbutylamine, diisopropylethylamine, n-butylmethylamine, n-butyldimethylamine, tri-n-butylamine, dicyclohexylamine, N-isopropylcyclohexylamine, tromethamine, furfurylamine, benzylamine, methylbenzylamine, dibenzylamine, N,N,-dimethylbenzylamine, 2-chlorobenzylamine,

A

4-methoxybenzylamine, 1-naphthylmethylamine, diphenylbenzylamine, triphenylamine, 1-naphthylamine, 1-aminoanthracene, 2-aminoanthracene, dehydroabietylamine, N-methylmorpholine or pyridine; an amino acid salt, e.g. a lysine or arginine salt. Examples of the ester are a lower alkyl ester, for example, methyl, ethyl, propyl, isopropyl, butyl, isobutyl, tert-butyl or pentyl ester. The lower alkyl ester moiety may be substituted with an optional group.

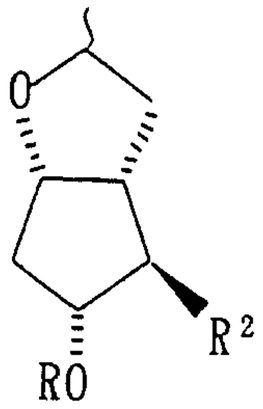
The compounds of the invention can be prepared by the following process:

A lactone of the formula (IV):



(IV)

in which R is a hydroxy-protecting group, and R_2 has the same meaning as defined above is reduced with a metal hydride to form a lactol of the formula (III):

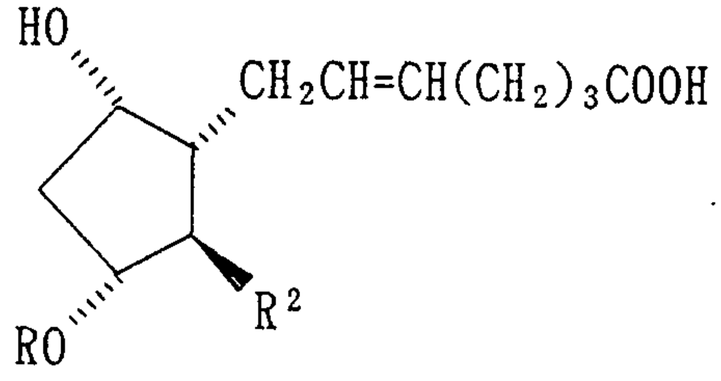


(III)

A

in which R and R_2 have the same meaning as above.

The resultant lactol (III) is then reacted with an ylide under the conditions of a Wittig reaction to yield the compound of the formula (II):



(II)

in which R and R_2 have the same meaning as above.

Following deprotection and optional esterification or salification of the compound, 15-deoxyprostaglandin derivatives of the type of $PGF_{2\alpha}$ can be obtained. The hydroxy protecting group may be selected from various protecting groups which are described in Protective Groups in Organic Synthesis, T.W. Greene, John Wiley & Sons, Inc., New York, p. 10, 1981. Examples of the protecting group are those forming an alkyl ether, e.g. methyl, methoxymethyl, methylthiomethyl, 2-methoxyethoxymethyl, tetrahydropyranyl, 1-ethoxyethyl, benzyl, and p-methoxybenzyl; those forming a silyl ether, e.g. triethylsilyl, t-butyldimethylsilyl, and t-butyldiphenylsilyl; those forming an ester, e.g. acetyl, benzoyl, p-methylbenzoyl, and o-methoxybenzoyl.

The lactone (IV) as a starting material, is prepared from the aldehyde analogue which is obtained by

oxidating commercially available Corey lactone, using the process described below:

(i) Synthesis of compounds (IV) wherein R^2 is 1-alkenyl

The compounds (IV) can be prepared by reacting the above-noted aldehyde and an ylide prepared from an alkyltriphenylphosphonium halide under the conditions of a Wittig reaction. If desired, a cis-trans isomerization reaction may be conducted on the resultant compounds.

(ii) Synthesis of compound (IV) wherein R^2 is alkyl

The compounds (IV) can be prepared by catalytic reduction of the lactone (IV) obtained in process (i) above.

(iii) Synthesis of compounds (IV) wherein R^2 is unsaturated alkyl other than 1-alkenyl.

The above aldehyde is reacted with a formylalkylenetriphenylphosphorane or an ylide obtainable from an alkyltriphenylphosphonium halide having a protected hydroxy under the conditions of a Wittig reaction. If desired, catalytic reduction or a cis-trans isomerization reaction can be conducted.

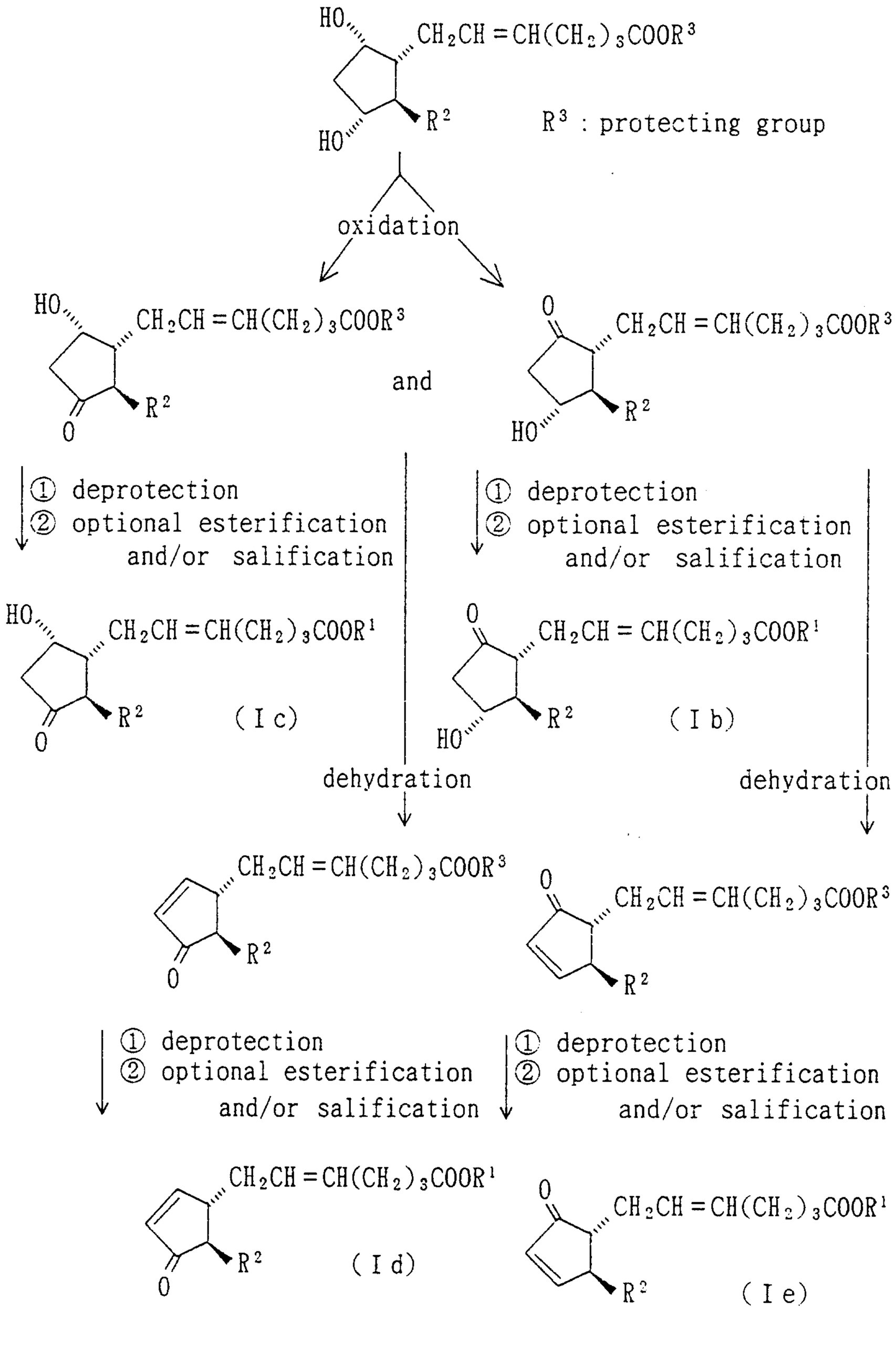
In the case that the ylide having a protected hydroxy is used, deprotection and oxidation are carried out to form formyl compounds. The desired compound (IV) can be prepared by treating the resultant aldehyde thus obtained according to process (i).

A

15-Deoxyprostaglandin derivatives of the type of PGD_2, PGE_2, PGJ_2 or PGA_2 can be prepared using the derivatives of the type of $PGF_{2\alpha}$ as starting materials. The outline of the process is shown in the scheme below. The details are illustrated in the working examples hereinafter described.

A'

COMPOUNDS (II)



The 15-deoxyprostaglandin derivatives of the invention can be administered topically or systemically using known procedures for administration. The derivatives of the invention can be formulated into a dosage form which is suitable for oral, intraarterial, intravenous, intracutaneous, intramuscular, intrarectal, or ophthalmic administration.

Recently, the inventors have found that the compounds in which the carboxy moiety is a lower alkyl ester are preferred in terms of pharmacological activity. However, esterification of the carboxylic acid results in a decrease of water-solubility. Accordingly, in preparing a formulation for use as an eye drop, the compound in the form of an ester is preferably formulated into an oily formulation, or the solubility of the compound may be improved either by addition of any surfactant to the formulation or introduction of any hydrophilic group (for example hydroxy or lower alkoxy, e.g. methoxy) into the ester moiety of the compound.

The dose of the compounds of the invention vary depending on the purpose and desired effect of the treatment, method of administration, or age and body weight of the particular patient. Typically, in the case of oral administration, the dose is about 200 μg/kg/day - about 20 mg/kg/day, preferably about 1 mg/kg/day - about 10 mg/kg/day, but not limited to such doses. In the case of ophthalmic application for

treating glaucoma, the dose is about 0.01 μg - about 1000μg/eye/day, preferably about 0.1 μg - about 200μg/eye/day. This dose may be divided into 1 - 5 portions in application.

The following detailed examples are presented by way of illustration of certain specific embodiments of the invention. The examples are representative only and should not be construed as limiting the invention in any respect.

Example 1

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(1Z)-octenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 2)

Heptyltriphenylphosphonium bromide (3.78 g, 8.58 mmole) was suspended in tetrahydrofuran (23 ml), and potassium tert-butoxide (0.873 g, 7.79 mmole) was added thereto under ice-cooling. The mixture was stirred at the same temperature for 10 minutes. The dark orange mixture thus obtained was cooled to - 78°C and 10 ml of a solution of (1S,6R,7R)-2-oxa-3-oxo-6-formyl-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]-octane (compound 1) (0.99 g, 3.89 mmole) in tetrahydrofuran, which had been prepared from Corey lactone according to E.J.Corey, H. Shirahama, H. Yamamoto, S. Terashima, A. Venkateswarlu and T. K. Schaaf, J. Am. Chem.Soc., 93, 1490 (1971), was added thereto. The ice bath was removed, and the reaction mixture was allowed to warm up

A1

to room temperature over 30 minutes while stirring. After stirred for one additional hour at room temperature, an aqueous solution of ammonium chloride was added. The mixture was concentrated in vacuo, and the residue was extracted with ether - ethyl acetate (2 : 1). The extract was washed with diluted hydrochloric acid, aqueous sodium bicarbonate and brine successively, and then dried over anhydrous magnesium sulfate, and the solvent was evaporated off. The resultant brown semi-solid material (3.1 g) was chromatographed over silica gel (39 g), eluting with 1 : 7 - 1 : 3 of ethyl acetate : n-hexane, to yield 600 mg of a crude product. The product was purified with Lobar column (ethyl acetate : n-hexane = 1 : 3) to yield 484 mg of the title compound 2 as a colourless oil (yield 37%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.1-3.05 (m, 22H), 3.50 (m, 1H), 3.8-4.1 (m, 2H), 4.67 (m, 1H), 5.05 (m, 2H), 5.50 (m, 1H),

IR ($CHCl_3$); 1765cm^{-1}.

Example 2

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(1E)-octenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 3)

The compound 2 obtained in Example 1 (336 mg, 1 mmole) was dissolved in benzene (15 ml), and 5-mercapto-1-methyltetrazole disulfide (115 mg, 0.5 mmole) and α,α'-azobis-isobutyronitrile (16 mg, 0.1 mmole) were added

thereto, and the mixture was refluxed with stirring for 10 hours. The reaction mixture was washed with aqueous sodium carbonate and then with brine, and dried over anhydrous sodium sulfate, and the solvent was evaporated off. The resultant colourless oil (400 mg) was chromatographed over silica gel (10 g), eluting with 1:7 - 1:5 of ethyl acetate:n-hexane, to yield a crude product (260 mg). The product was further purified with Lobar column (ethyl acetate : n-hexane = 1:3) to yield 202 mg of the title compound 3 as a colourless oil (yield 60%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.1-2.8 (m, 22H), 3.50 (m, 1H), 3.7-4.2 (m, 2H), 4.68 (m, 1H), 4.95 (m, 1H), 5.25 (m, 1H), 5.50 (m, 1H),

IR ($CHCl_3$); 1765cm^{-1}.

Example 3

Preparation of (5Z,13E,9S,11R)-9-hydroxy-11-tetrahydropyranyloxy-5,13-prostadienoic acid (compound 5)

The compound 3 obtained above (336 mg, 1 mmole) was dissolved in toluene (12 ml), and 1 M diisobutyl aluminum hydride in toluene (1.1 ml, 1.1 mmole) was added thereto at -78°C. The solution was stirred at the same temperature for one hour, then aqueous ammonium chloride was added thereto, and the temperature was allowed to warm to room temperature. The reaction mixture was extracted with ethyl acetate, and the extract was washed with brine and dried over anhydrous sodium sulfate, and then the

A

solvent was evaporated off. The residue (340 mg) was chromatographed over silica gel (3.4 g), eluting with 1 : 2 of ethyl acetate:n-hexane, to yield lactol 4 (314 mg, 93%) as a colourless oil. IR ($CHCl_3$); 3610, 3390 cm^{-1}.

After 4-carboxybutyltriphenylphosphonium bromide (1.219 g, 2.76 mmole) was suspended in tetrahydrofuran (15 ml), a potassium tert-butoxide (680 mg, 6.07 mmole) was added thereto under ice cooling, and the mixture was stirred at the same temperature for 10 minutes. The resultant red mixture was cooled to -30°C, and 6 ml of a solution of the lactol 4 obtained above (310 mg, 0.92 mmole) in tetrahydrofuran was added thereto. After removing the cooling bath, the reaction mixture was allowed to warm to room temperature with stirring, and stirred for one additional hour. To the resultant yellow mixture was added a solution of ammonium chloride in water, and the mixture was concentrated in vacuo. Ice water was added to the residue, and the mixture was acidified with diluted hydrochloric acid to pH 4-5 under cooling, and extracted with ethyl acetate. The ethyl acetate layer was extracted with aqueous sodium carbonate, and the water phase was acidified again to pH 4-5, and then extracted with a mixture of methylene chloride and ethyl acetate (2:1). After the extract was dried over anhydrous magnesium sulfate, the solvent was evaporated off to yield 790 mg of a semicrystalline product. To the product was added ethyl

ether, and the dissolved portion was filtered and the solvent was evaporated off to yield 288 mg of a crude product. The product was chromatographed over silicic acid (8.6 g), eluting with 1:10 - 1:3 of ethyl acetate : n-hexane, to yield 234 mg of the title compound as a colourless oil (yield 60%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.2-2.5 (m, 30H), 3.45 (m, 1H), 3.85 (m, 1H), 4.07 (m, 2H), 4.69 (m, 1H), 5.2-5.6 (m, 4H).

IR ($CHCl_3$); 3500, 2700-2400 (broad), 1705 cm^{-1}.

Example 4

Preparation of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid (compound 6)

The compound 5 obtained above (205 mg, 0.485 mmole) was dissolved in 4 ml of a mixture of acetic acid, water, and tetrahydrofuran (65:35:10). The mixture was stirred under heating at 40-45°C for one and half hours, and then evaporated to dryness in vacuo. The residue (184 mg) was chromatographed over silicic acid (5.5g), eluting with 1:5 - 1:1 of ethyl acetate : n-hexane, to yield 149 mg of the title compound 6 as a colourless oil (yield 91%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz,3H), 1.2-2.5 (m, 22H), 3.94 (m, 1H), 4.17 (m, 1H), 4.0-4.8 (broad ,3H), 5.2-5.6 (m, 4H).

IR ($CHCl_3$); 3400, 2700-2400(broad), 1705 cm^{-1}.

Example 5

Preparation of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid methyl ester (compound 7)

The compound 6 obtained above (104 mg, 0.307 mmole) was dissolved in acetonitrile (5 ml), and 1,8-diazabicyclo[5.4.0]-7-undecene (70 μl, 0.46 mmole) was added thereto. The mixture was stirred at room temperature for 15 minuites. Then, methyl iodide (0.19 ml, 3 mmole) was added thereto and the mixture was stirred at room temperature for five hours, and then concentrated in vacuo. To the residue was added water, and the mixture was extracted with ethyl acetate. The extract was washed successively with diluted hydrochloric acid, aqueous sodium sulfite, and brine, and then dried over anhydrous magnesium sulfate. After the solvent was evaporated off, 113 mg portion of the residue was purified with Lobar colum (ethyl acetate : n-hexane = 1:1), to yield 103 mg of the title compound 7 as a colourless oil (yield 95%).

NMR ($CDCl_3$); δ 0.88(t, J=7Hz, 3H), 1.2-2.4 (m, 24H), 3.67 (s, 3H), 3.92 (m, 1H), 4.17 (m, 1H), 5.18-5.61 (m, 4H).

IR ($CHCl_3$); 3450, 1720cm^{-1}.

Example 6

Preparation of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid isopropyl ester (compound 8)

The title compound 8 was obtained as a colorless oil (36 mg, 95%), following a procedure similar to that disclosed in Example 5 except that the compound 6 obtained above (33 mg, 0.1 mmole) was dissolved in acetonitrile (1 ml), and 1,8-diazabicyclo [5.4.0]-7-undecene (40 μl, 0.3 mmole) and then isopropyl iodide (0.19 μl, 1 mmole) were added thereto.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.22 (d, J=6Hz, 6H), 1.25-2.35 (m, 24H), 3.92 (m, 1H), 4.17 (m, 1H), 5.00 (sept, J=6Hz, 1H), 5.18-5.60 (m,4H).

IR ($CHCl_3$); 3450, 1720cm^{-1}.

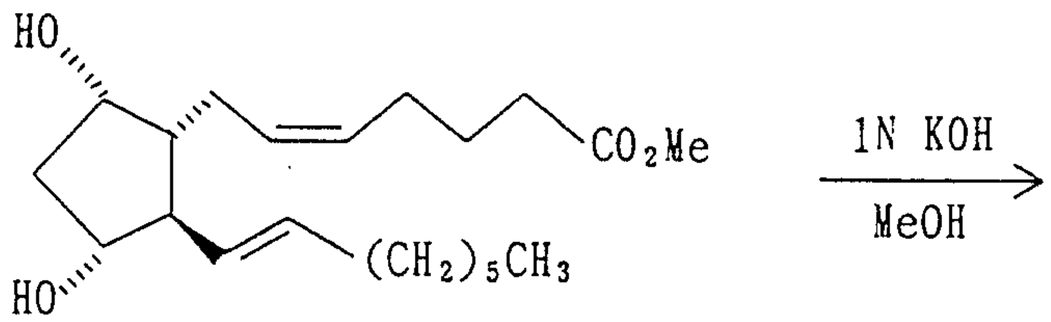
Example 7

Test for demonstrating stability of the compound 6 [The formation of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid (compound 6)]

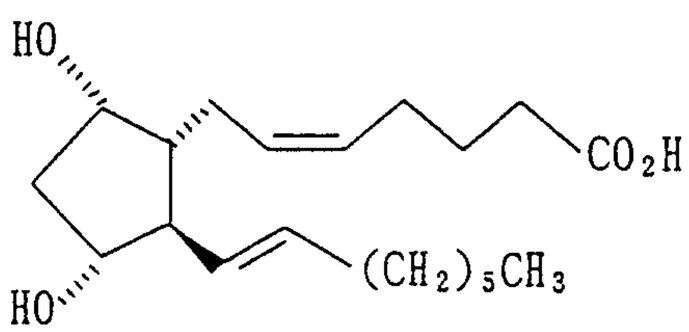
The compound 7 obtained above (73 mg, 0.207 mmole) was dissolved in 2 ml of methanol. One ml of 1 N aqueous potassium hydroxide solution was added thereto, and the mixture was refluxed with stirring for one hour. After concentrating the solution to remove the methanol, the residue was dissolved in water and washed with ethyl acetate. The aqueous solution was acidified with the addition diluted hydrochloric acid under cooling and extracted with ethyl acetate. The extract was washed with brine, and dried over anhydrous magnesium sulfate. Then, the solvent was evaporated off to give 70 mg of a crude product. The

product was chromatographed over silicic acid (2 g), eluting with 1:1 of ethyl acetate : n-hexane, to give the title compound (68 mg, 97 %) as a colourless oil.

The above reaction is illustrated by the following scheme.



7



6

Example 8

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(1Z)-decenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 2')

Nonyltriphenylphosphonium bromide (3.85 g, 8.20 mmole) was suspended in 25 ml of tetrahydrofuran, and 0.836 g (7.46 mmole) of potassium tert-butoxide was added, and the mixture was stirred at the same temperature for 10 minutes. The deep orange mixture thus obtained was cooled to -78°C, and 10 ml of a solution of the compound 1 obtained above (0.95 g, 3.74 mmole) in tetrahydrofuran was added thereto. Then, the reaction mixture was treated following a procedure

A'

similar to that disclosed in Example 1, to yield the title compound 2' (573 mg, 42 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.1-3.05 (m, 26H), 3.50 (m, 1H), 3.8-4.1 (m, 2H), 4.68 (m, 1H), 5.05 (m, 2H), 5.50 (m, 1H).

IR ($CHCl_3$); 1765cm^{-1}.

Example 9

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(1E)-decenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 3')

The compounds 2' obtained above (566 mg, 1.55 mmole) was dissolved in 30 ml of benzene, and 5-mercapto-1-methyltetrazole disulfide (180 mg, 0.78 mmole) and α,α'-azobis-isobutyronitrile (25 mg, 0.15 mmole) were added thereto, and the mixture was refluxed with stirring for 2.5 hours. Then, the reaction mixture was treated following a procedure similar to that of Example 2, to yield the compound 3' (383 mg, 67%) as a colourless oil.

NMR ($CDCl_3$); δ 0.88(t, J=7Hz, 3H), 1.1-2.85 (m, 26H), 3.50 (m, 1H), 3.75-4.15 (m, 2H), 4.68 (m, 1H), 4.97 (m, 1H), 5.25 (m, 1H), 5.50 (m, 1H).

IR ($CHCl_3$); 1765cm^{-1}.

Example 10

Preparation of (5Z,13E,9S,11R)-20-ethyl-9-hydroxy-11-tetrahydropyranyloxy-5,13-prostadienoic acid (compound 5')

The compound 3' obtained above (398 mg, 1.09 mmole) was dissolved in 14 ml of toluene, and 1.2 ml of 1 M solution of diisobutyl aluminum hydride (1.2 mmole) in toluene was added thereto at -78°C. Then, the reaction mixture was treated following a procedure similar to that of Example 3, to yield the compound 4' (395 mg, 98%) as a colourless oil.

IR ($CHCl_3$); 3600, 3390 cm^{-1}.

4-Carboxybutyltriphenylphosphonium bromide (1.409 g, 3.18 mmole) was suspended in tetrahydrofuran (15 ml), and potassium tert-butoxide (780 mg, 6.99 mmole) was added under ice-cooling. The mixture was stirred at the same temperature for 10 minutes. The red mixture thus obtained was cooled to -30°C, and to the mixture was added 10 ml of a solution of the lactol compound 4' obtained above (388 mg, 1.06 mmole) in tetrahydrofuran. Then, the reaction mixture was treated following a procedure similar to that of Example 3, to yield the title compound 5' (304 mg, 64 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88(t, J=7Hz, 3H), 1.1-2.5 (m, 34H), 3.45 (m, 1H), 3.85 (m, 1H), 4.07 (m, 2H), 4.70 (m, 1H), 5.2 -5.6 (m, 4H).

IR ($CHCl_3$); 3512, 2700-2400 (broad), 1708 cm^{-1}.

Example 11

Preparation of (5Z,13E,9S,11R)-20-ethyl-9,11-dihydroxy-5,13-prostadienoic acid (compound 6')

The compound 5' obtained above (297 mg, 0.66 mmole) was dissolved in 6 ml of a mixture of acetic acid, water, and tetrahydrofuran (65:35:10), and the solution was heated with stirring at 40-45°C for two hours. Then, the reaction mixture was treated following a procedure similar to that of Example 4, to yield the title compound 6' (194 mg, 80 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.2-2.4 (m, 26H), 3.93 (m, 1H), 4.18 (m, 1H), 3.4-4.5 (broad, 3H), 5.15-5.60 (m, 4H).

IR ($CHCl_3$); 3400, 2700-2400 (broad), 1705 cm^{-1}.

Example 12

Preparation of (5Z,13E,9S,11R)-20-ethyl-9,11-dihydroxy-5,13-prostadienoic acid isopropyl ester (compound 8')

The compound 6' obtained above (37 mg, 0.1 mmole) was dissolved in acetonitrile (1ml), and 1,8-diazabicyclo[5.4.0]-7-undecene (75 μl, 0.5 mmole) and isopropyl iodide (0.29ml, 3mmole) were successively added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 5, to yield the title compound 8' (35 mg, 85 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.22 (d, J=6Hz, 6H), 1.25-2.40 (m, 28H), 3.92 (m, 1H), 4.18 (m, 1H), 5.01 (sept, J=6Hz, 1H), 5.15-5.60 (m,4H).

IR ($CHCl_3$); 3500, 1715cm^{-1}.

The comprehensive scheme illustrating the reactions described in Examples 1-12 is shown below.

Reaction scheme for preparation of Δ^{13}-PG

(Examples 1-12)

Example 13

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-octyl-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 9)

The compound 2 obtained above (405 mg, 1.20 mmole) was dissolved in methanol (10 ml), and 5% palladium - carbon (80 mg) was added thereto, and the mixture was stirred under hydrogen at one atmospheric pressure for one hour. After the mixture was filtered and the filtrate was evaporated, the residue (405 mg) was chromatographed over silica gel (4 g), eluting with 1:10 - 1:3 of ethyl acetate : n-hexane, to yield the title compound 9 (393 mg, 97 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.1-2.9 (m, 26H), 3.50 (m, 1H), 3.75-4.15 (m, 2H), 4.66 (m, 1H), 5.01 (m, 1H).

IR ($CHCl_3$); 1764 cm^{-1}.

Example 14

Preparation of (5Z,9S,11R)-9-hydroxy-11-tetrahydropyranyloxy-5-prostenoic acid (compound 11)

The compound 9 obtained above (378 mg, 1.12 mmole) was dissolved in toluene (12 ml), and 1 M solution of diisobutyl aluminum hydride in toluene (1.23 ml, 1.23 mmole) was added thereto at -78°C. Then, the reaction mixture was treated following the procedure similar to that of Example 3, to yield lactol 10 (370 mg, 97 %) as a colourless oil.

IR ($CHCl_3$); 3594, 3384 cm^{-1}.

4-Carboxybutyltriphenylphosphonium bromide (1.427 g, 3.21 mmole) was suspended in tetrahydrofuran (15 ml), and potassium tert-butoxide (794 mg, 7.06 mmole) was added thereto under ice cooling. The mixture was stirred at the same temperature for 10 minutes. The red mixture thus obtained was cooled to -30°C, and to the mixture was added 7 ml of a solution of the lactol 10 obtained above (365 mg, 1.07 mmole) in tetrahydrofuran. Then, the reaction mixture was treated following a procedure similar to that of Example 3, to yield the title compound 11 (317 mg, 70 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.1-2.45 (m, 34H), 3.50 (m, 1H), 3.85 (m, 1H), 4.06 (m, 2H), 4.69 (m, 1H), 5.3-5.6 (m, 2H).

IR (CHC_3); 3512, 2700-2400 (broad), 1708 cm^{-1}.

Example 15

Preparation of (5Z,9S,11R)-9,11-dihydroxy-5-prostenoic acid 12

The compound 11 obtained above (220 mg, 0.518 mmole) was dissolved in 4 ml of a mixture of acetic acid-water-tetrahydrofuran (65:35:10) and the solution was heated with stirring at 40-45°C for one and a half hours. Then, the reaction mixture was treated following a procedure similar to that of Example 4, to yield the title compound 12 (156 mg, 88 %) as a colourless oil.

A

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.1-2.45 (m, 26H), 3.96 (m, 1H), 4.18 (m, 1H), 3.6-4.9 (broad, 3H), 5.3-5.6 (m,2H).

IR ($CHCl_3$); 3664, 3432, 2700-2400 (broad), 1707 cm^{-1}.

Example 16

Preparation of (5Z,9S,11R)-9,11-dihydroxy-5-prostenoic acid isopropyl ester (compound 13)

The compound 12 obtained above (80 mg, 0.235 mmole) was dissolved in acetonitrile (3 ml), and 1,8-diazabicyclo[5.4.0]-7-undecene (0.21 ml, 1.4 mmole) and then isopropyl iodide (0.69 ml, 7.0 mmole) were added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 5, to yield the title compound 13 (82 mg, 91 %) as a colourless oil.

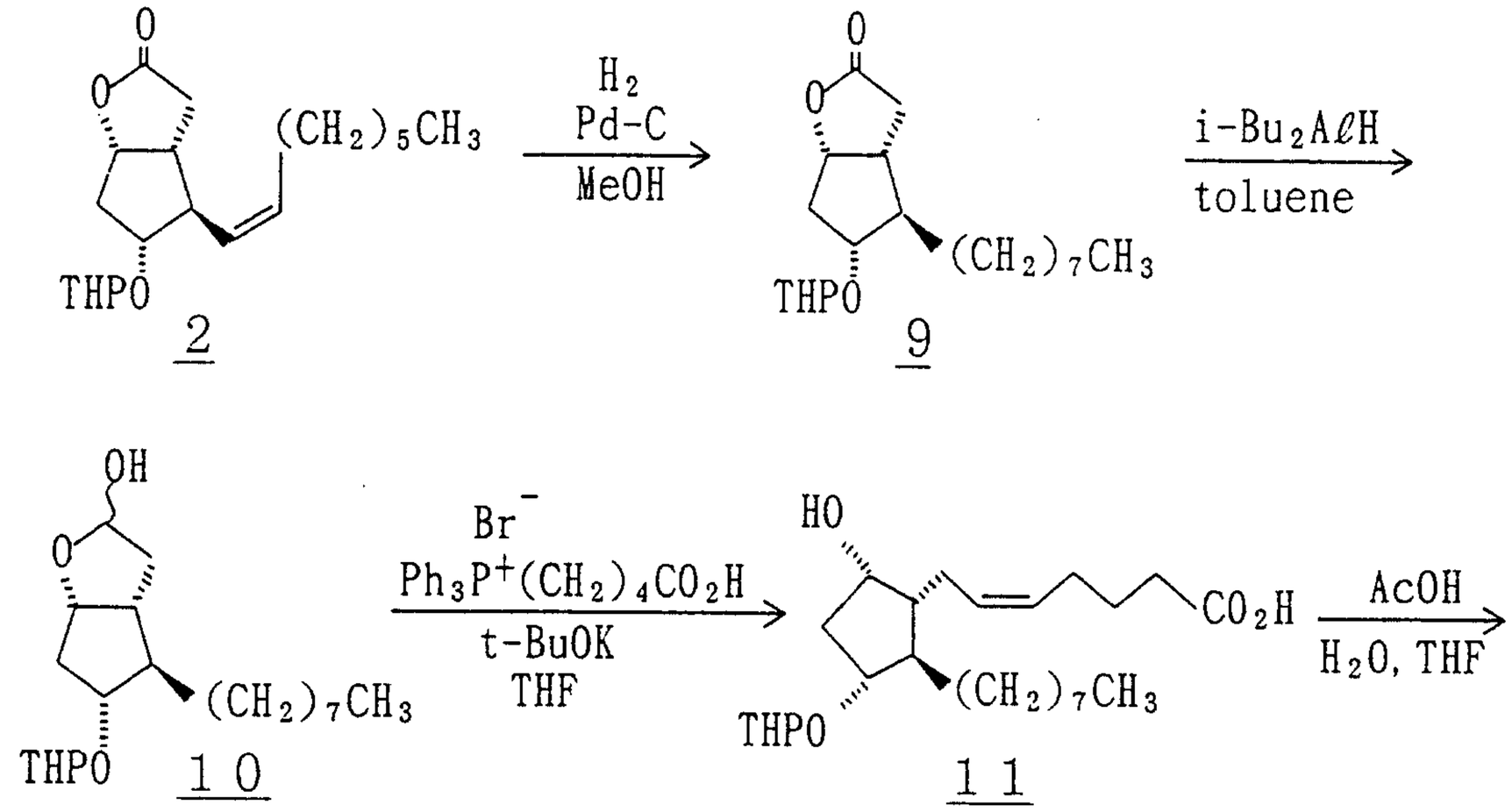
NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.22 (d, J=6Hz, 6H), 1.2-2.45 (m, 28H), 3.95 (m, 1H), 4.18 (m, 1H), 5.01 (sept, J=6Hz, 1H), 5.3-5.6 (m, 2H).

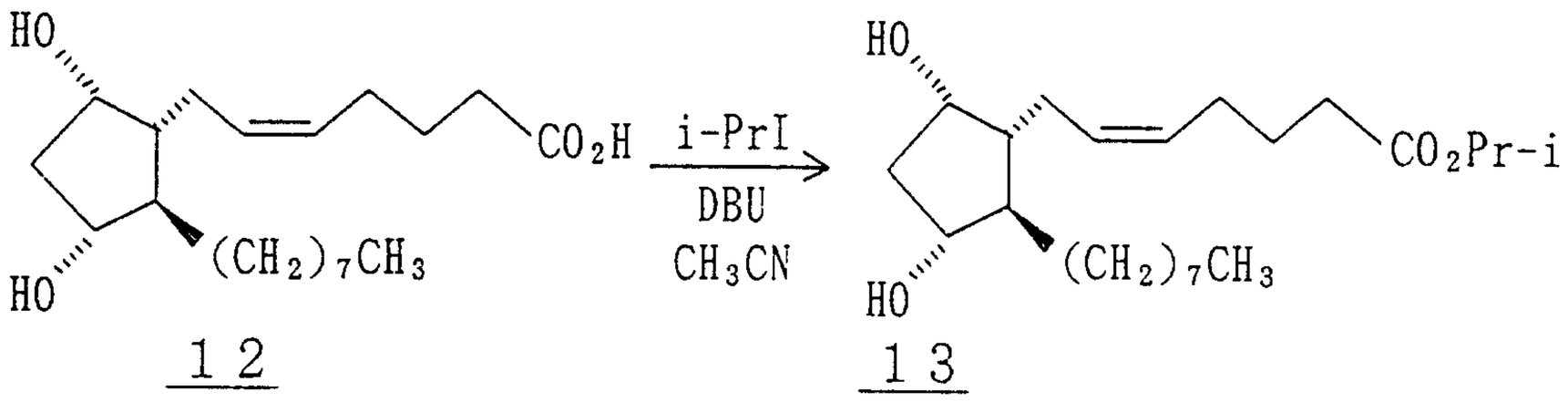
IR ($CHCl_3$); 3512, 1716 cm^{-1}.

The comprehensive scheme illustrating the reactions described in Examples 13-16 is shown below.

Reaction scheme for preparation of saturated PG

(Examples 13-16)





"A"

Example 17

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[7-tert-butyldimethylsilyloxy-(1Z)-heptenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 14)

After (6-tert-butyldimethylsilyloxyhexyl)-triphenylphosphonium bromide (2.56 g, 4.59 mmole) was dissolved in tetrahydrofuran (26 ml), potassium tert-butoxide (467 mg, 4.17 mmole) was added thereto under ice-cooling, and the mixture was stirred at the same temperature for 10 minutes. The deep orange mixture thus obtained was cooled to -78°C, and 6 ml of a solution of the compound 1 obtained above (530mg, 2.08mmole) in tetrahydrofuran was added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 1, to yield the title compound 14 (520 mg, 55 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.05 (s, 6H), 0.89 (s, 9H), 1.2-3.0 (m, 20H), 3.48 (m, 1H), 3.60 (t, J=7Hz, 2H), 3.76-4.07 (m, 2H), 4.68 (m, 1H), 4.9-5.15 (m, 2H), 5.48 (m, 1H).

IR ($CHCl_3$); 1765 cm^{-1}.

Example 18

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-(7-tert-butyldimethylsilyloxyheptyl)-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 15)

The compound 14 obtained above (335 mg, 0.741 mmole) was dissolved in methanol (10 ml), and 5% palladium -

carbon (67 mg) was added thereto, and the mixture was stirred under hydrogen at one atmospheric pressure for one hour. The mixture was filtered, and the filtrate was evaporated to yield the title compound 15 (320 mg, 97 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.05 (s, 6H), 0.89 (s, 9H), 1.2-2.9 (m, 24H), 3.49 (m, 1H), 3.60 (t, J=7Hz, 2H), 3.75-4.15 (m, 2H), 4.65 (m, 1H), 5.01 (m, 1H).

IR ($CHCl_3$); 1764 cm^{-1}.

Example 19

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-(7-hydroxyheptyl)-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 16)

The compound 15 obtained above (320 mg, 0.704 mmole) was dissolved in tetrahydrofuran (4 ml), and 1 M solution of tetrabutylammonium fluoride in tetrahydrofuran (0.845 ml, 0.845 mmole) was added thereto at room temperature, and the mixture was stirred for three hours. After adding acetic acid (40 μl, 0.668 mmole) thereto under cooling, the reaction mixture was evaporated to dryness. The residue was chromatographed over silica gel (7.2 g), eluting with 1:3 - 1:2 of ethyl acetate : n-hexane, to yield the title compound 16 (224 mg, 93 %) as a colourless oil.

NMR ($CDCl_3$); δ 1.1-2.9 (25H), 3.50 (m, 1H), 3.64 (t, J=7Hz, 2H), 3.75-4.15 (m, 2H), 4.65 (m, 1H), 5.01 (m, 1H).

A

IR ($CHCl_3$); 3622, 3468, 1764 cm^{-1}.

Example 20

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-(6-formylhexyl)-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 17)

Thirty five μl (0.4 mmole) of oxalyl chloride was dissolved in methylene chloride (1 ml), and 1 ml of a solution of dimethylsulfoxide (57 μl, 0.8 mmole) in methylene chloride was added thereto at -60°C, and the mixture was stirred at the same temperature for 10 minutes. Two ml of a solution of the compound 16 obtained above (68 mg, 0.2 mmole) in methylene chloride and 0.11 ml of triethylamine (0.8 mmole) were successively added thereto, and then the cooling bath was removed. The reaction was allowed to warm to 0°C, and water was added to the resultant white suspension. The mixture was extracted with methylene chloride. The extract was washed with diluted hydrochloric acid, aqueous sodium bicarbonate and brine successively, and dried over sodium sulfate. Then, the solvent was evaporated off to yield the title compound 17 (68 mg, quantitative) as a colourless oil.

NMR ($CDCl_3$); δ 1.1-2.9 (m, 24H), 3.50 (m, 1H), 3.75-4.15 (m, 2H), 4.64 (m, 1H), 5.01 (m, 1H), 9.77 (t, J=2Hz, 1H).

IR ($CHCl_3$); 2726, 1764, 1720 cm^{-1}.

Example 21

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-(7-octenyl)-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 18)

Methyltriphenylphosphonium bromide (642 mg, 1.79 mmole) was suspended in tetrahydrofuran (4 ml), and 1.6 M n-buthyl lithium-hexane solution (1.0 ml, 1.6 mmole) was added thereto under ice cooling, and the mixture was stirred at the same temperature for 10 minutes. The yellow mixture thus obtained was cooled to -78°C, and to the mixture was added 2 ml of a solution of the compound 17 obtained above (66 mg, 0.195 mmole) in tetrahydrofuran. Then, the reaction mixture was treated following a procedure similar to that of Example 1, to yield the title compound 18 (24 mg, 37 %) as a colourless oil.

NMR ($CDCl_3$); δ 1.1-3.05 (m, 24H), 3.50 (m, 1H), 3.75-4.17 (m, 2H), 4.64 (m, 1H), 4.87-5.10 (m, 3H), 5.80 (m, 1H).

IR ($CHCl_3$); 1761, 1639 cm^{-1}.

Example 22

Preparation of (5Z,9S,11R)-9-hydroxy-11-tetrahydropyranyloxy-5,19-prostadienoic acid (compound 20)

The compound 18 obtained above (62 mg, 0.184 mmole) was dissolved in toluene (2 ml), and 1 M solution of diisobutyl aluminum hydride in toluene (0.20 ml, 0.20 mmole) was added thereto at -78°C. Then, the reaction mixture was

treated following a procedure similar to that of Example 3, to yield lactol 19 (50 mg, 80 %) as a colourless oil.

IR ($CHCl_3$); 3590, 3380, 1640 cm^{-1}.

4-Carboxybutyltriphenylphosphonium bromide (196 mg, 0.442 mmole) was suspended in tetrahydrofuran (2 ml), and potassium tert-butoxide (99 mg, 0.884 mmole) was added thereto under ice cooling. The mixture was stirred for 10 minutes. The deep orange mixture thus obtained was cooled to -30°C, and to the mixture was added one ml of a solution of the lactol 19 obtained above (50 mg, 0.148 mmole) in tetrahydrofuran. Then, the reaction mixture was treated following a procedure similar to that of Example 3, to yield the title compound 20 (34 mg, 55 %) as a colourless oil.

NMR ($CDCl_3$); δ 1.0-2.5 (m, 32H), 3.50 (m, 1H), 3.84 (m, 1H), 4.05 (m, 2H), 4.67 (m, 1H), 4.90-5.10 (m, 2H), 5.30-5.65 (m, 2H), 5.80 (m, 1H).

IR ($CHCl_3$); 3500, 2700-2400 (broad), 1705, 1640 cm^{-1}.

Example 23

Preparation of (5Z,9S,11R)-9,11-dihydroxy-5,19-prostadienoic acid (compound 21)

The compound 20 obtained above (31 mg, 0.073 mmole) was dissolved in one ml of a mixture of acetic acid-water-tetrahydrofuran (65:35:10), and the solution was heated with stirring at 40-45°C for one hour and fifteen

minutes. Then, the reaction mixture was treated following a procedure similar to that of Example 4, to yield the title compound 21 (22 mg, 89 %) as a colourless oil.

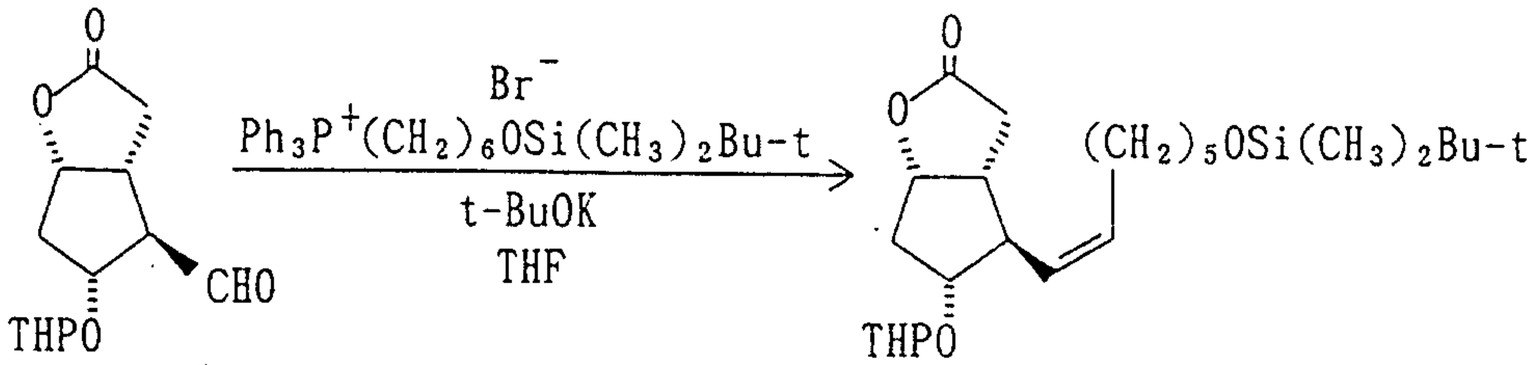
NMR ($CDCl_3$); δ 1.0-2.5 (m, 24H), 3.96 (m, 1H), 4.17 (m, 1H), 3.6-3.8 (broad, 3H), 4.90-5.10 (m, 2H), 5.30-5.60 (m, 2H), 5.80 (m, 1H).

IR ($CHCl_3$); 3450, 2700-2400 (broad), 1708, 1640 cm^{-1}.

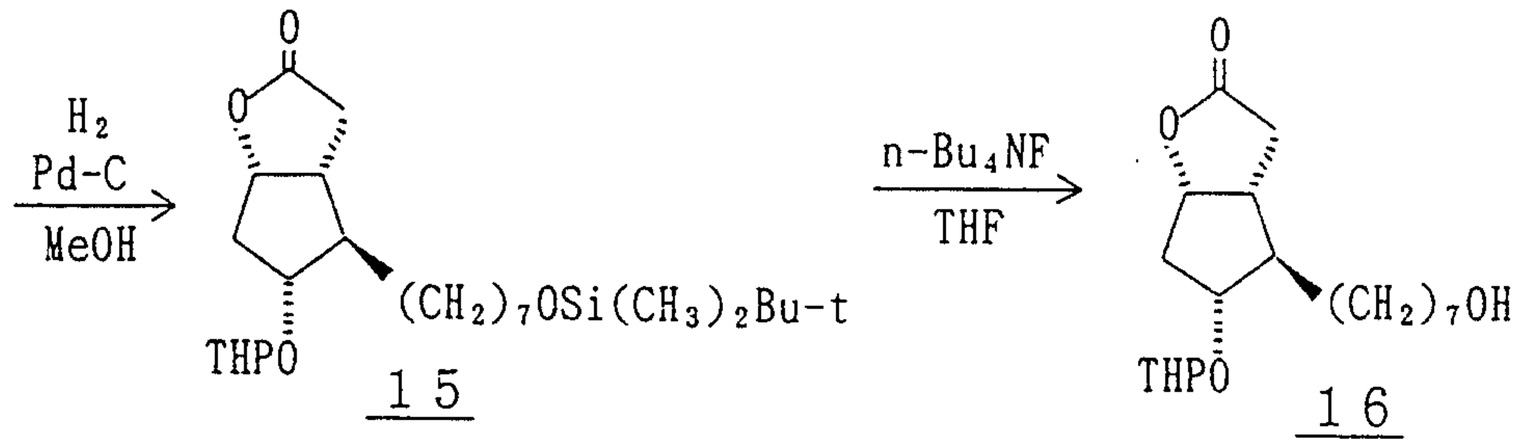
The comprehensive scheme illustrating the reactions described in Examples 17-23 is shown below.

Reaction scheme for preparation of Δ^{19}-PG

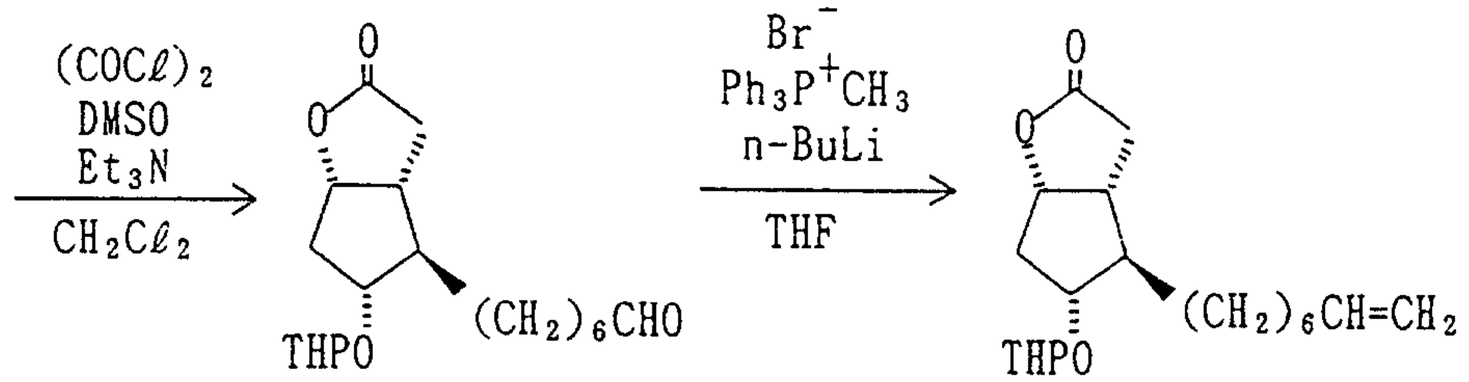
(Example 17-23)



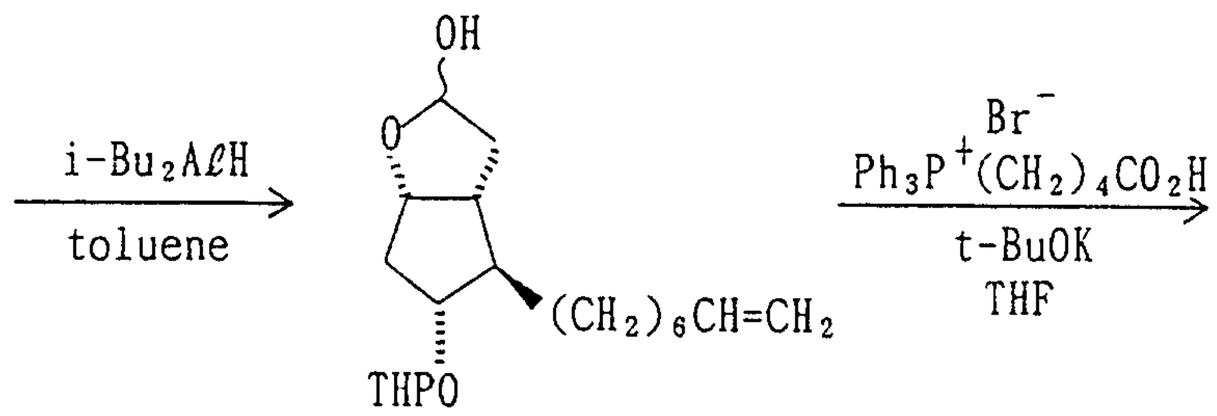
1 14



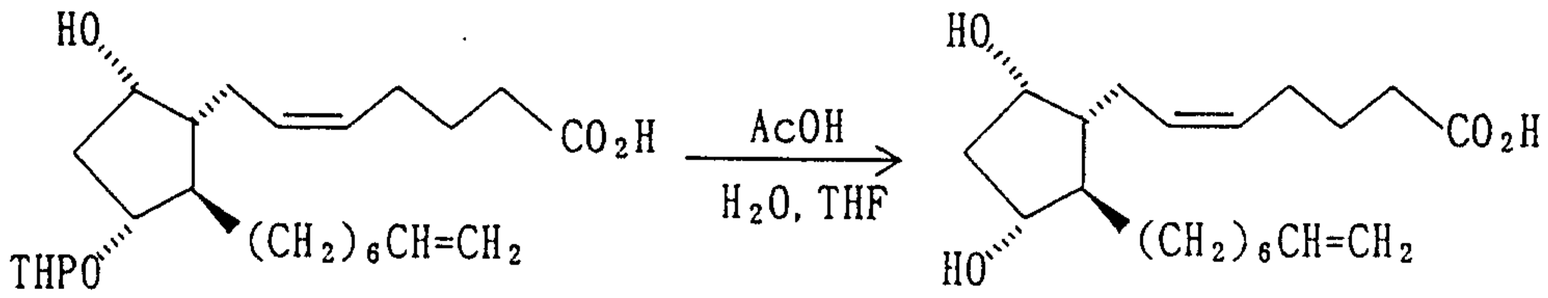
15 16



17 18



19



20 21

Example 24

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[2-formyl-(1E)-ethenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 22)

The compound 1 obtained above (4.0 g, 15.73 mmole) and triphenylphosphoranylidene acetaldehyde (5.75 g, 18.88 mmole) were dissolved in benzene (50 ml), and the mixture was refluxed with stirring for one and a half hours. The solvent was evaporated off. The residue was purified with Lobar column (ethyl acetate:n-hexane = 7:3), to yield the title compound 22 (3.29 g, 59 %) as a pale yellow oil.

NMR ($CDCl_3$); δ 1.40-1.80 (m, 6H), 2.25-3.00 (m, 6H), 3.35-3.60 (m, 1H), 3.70-3.95 (m, 1H), 4.00-4.30 (m, 1H), 4.66 (m, 1H), 5.02 (m, 1H), 6.18, 6.70 (each dd, J=8Hz, 16Hz, each 1H), 9.54 (d, J=8Hz, 1H).

Example 25

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-(2-formylethyl)-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 23)

The compound 22 obtained above (3.0 g, 10.70 mmole) was dissolved in ethyl acetate (60 ml), and 10% palladium - carbon (0.3 g) was added thereto. The mixture was stirred under hydrogen at one atmospheric pressure for 30 minutes. The mixture was filtered and the filtrate was evaporated to yield the title compound 23 (3.0 g, 99 %).

NMR ($CDCl_3$); δ 1.40-1.80 (m, 6H), 2.20-2.90 (m, 10H), 3.40-3.60 (m, 1H), 3.70-4.10 (m, 2H), 4.64 (m, 1H), 4.98 (m, 1H), 9.80 (s, 1H).

Example 26

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(3Z)-octenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 24)

Pentyltriphenylphosphonium bromide (8.27 g, 20 mmole) was suspended in tetrahydrofuran (50 ml), and potassium tert-butoxide (2.69 g, 24 mmole) was added thereto under ice cooling. The mixture was stirred at the same temperature for half an hour. The deep orange mixture thus obtained was cooled to -78°C, and 10 ml of a solution of the compound 23 obtained above (2.82 g, 10 mmole) in tetrahydrofuran was added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 1, to yield the title compound 24 (2.0 g, 60 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.90 (t, J=7Hz, 3H), 1.20-2.90 (m, 22H), 3.52 (m, 1H), 3.75-4.12 (m, 2H), 4.66 (m, 1H), 5.02 (m, 1H), 5.35 (m, 2H).

Example 27

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(3E)-octenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 25)

A

The compound 24 obtained above (1.30 g, 3.86 mmole) was dissolved in benzene (20 ml), and 5-mercapto-1-methyltetrazole disulfide (0.44 g, 1.93 mmole) and α,α'-azobis-isobutyronitrile (63 mg, 0.386 mmol) were added thereto, and the mixture was refluxed with stirring for two hours. Then, the reaction mixture was treated following a procedure similar to that of Example 2, to yield the title compound 25 (1.05 g, 80 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.20-2.90 (m, 22H), 3.52 (m, 1H), 3.75-4.12 (m, 2H), 4.66 (m, 1H), 5.02 (m, 1H), 5.39 (m,2H).

Example 28

Preparation of (5Z,15E,9S,11R)-9-hydroxy-11-tetrahydropyranyloxy-5,15-prostadienoic acid (compound 27)

The compound 25 obtained above (336 mg, 1.0 mmole) was dissolved in toluene (12 ml), and 1 M diisobutyl aluminum hydride in toluene (1.1 ml, 1.1 mmole) was added thereto at -78°C. Then, the mixture was treated following a procedure similar to that of Example 3, to yield lactol 26 (285 mg, 84 %).

IR ($CHCl_3$); 3600, 3400 cm^{-1}.

After 4-carboxybutyltriphenylphosphonium bromide (1.12 g, 2.53 mmole) was suspended in tetrahydrofuran (15 ml), potassium tert-butoxide (623 mg, 5.56 mmole) was added thereto under ice cooling, and the mixture was stirred at the same temperature for 30 minutes. The resultant red

mixture was cooled to -30°C, and 6 ml of a solution of the lactol 26 obtained above (285 mg, 0.843 mmole) in tetrahydrofuran was added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 3, to yield 210 mg of the title compound as a colourless oil (yield 59%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.20-2.40 (m, 30H), 3.55 (m, 1H), 3.87 (m, 1H), 4.00-4.28 (m, 2H), 4.70 (m, 1H), 5.42 (m, 4H).

Example 29

Preparation of (5Z,15E,9S,11R)-9,11-dihydroxy-5,15-prostadienoic acid (compound 28)

The compound 27 obtained above (200 mg, 0.474 mmole) was dissolved in 3 ml of a mixture of acetic acid, water, and tetrahydrofuran (65:35:10). The mixture was heated at 40-45°C with stirring for one and a half hours. Then, the reaction mixture was treated following a procedure similar to that of Example 4, to yield 128 mg of the title compound 28 as a colourless oil (yield 80%).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.20-2.30 (m, 20H), 2.32 (t, J=6Hz, 2H), 3.95 (broad s, 1H), 4.14 (broad s, 1H), 4.4-6.1 (broad, 3H), 5.43 (m, 4H).

IR ($CHCl_3$); 3490, 2700-2400 (broad), 1708 cm^{-1}.

Example 30

Prepraration of (5Z,15E,9S,11R)-9,11-dihydroxy-

5,15-prostadienoic acid isopropyl ester (compound 29)

The compound 28 obtained above (237 mg, 0.70 mmole) was dissolved in acetonitrile (3 ml), and 1,8-diazabicyclo[5.4.0]-7-undecene (0.178 ml, 1.2 mmole) and isopropyl iodide (0.12 ml, 1.2 mmole) were added thereto and the mixture was stirred at room temperature for 15 hours. Then, the reaction mixture was treated following a procedure similar to that of Example 5, to yield 266 mg of the title compound 29 as a colourless oil (quantitative).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.23 (d, J=6Hz, 6H), 1.20-2.25 (m, 22H), 2.30 (t, J=6Hz, 2H), 3.97 (broad s, 1H), 4.18 (broad s, 1H), 5.01 (sept, J=6Hz, 1H), 5.43 (m, 4H).

IR ($CHCl_3$); 3496, 1714 cm^{-1}.

Example 31

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(3Z)-decenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 24')

Heptyltriphenylphosphonium bromide (10.94 g, 24.8 mmole) was suspended in tetrahydrofuran (50 ml), and potassium tert-butoxide (3.33 g, 29.76 mmole) was added thereto under ice cooling, and the mixture was stirred at the same temperature for 30 minutes. The deep orange mixture thus obtained was cooled to -78°C, and 10 ml of a solution of the compound 23 obtained above (3.5 g, 12.4 mmole) in tetrahydrofuran was added thereto. Then, the reaction

mixture was treated following a procedure similar to that of Example 1, to yield the title compound 24' (2.09 g, 46 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.20-2.80 (m, 26H), 3.40-3.60 (m, 1H), 3.60-4.18 (m, 2H), 4.66 (m, 1H), 5.02 (m, 1H), 5.36 (m, 2H).

Example 32

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(3E)-decenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 25')

The compound 24' obtained above (1.0 g, 2.74 mmole) was dissolved in benzene (20 ml), and 5-mercapto-1-methyltetrazole disulfide (316 mg, 1.37 mmole) and α,α'-azobis-isobutyronitrile (45 mg, 0.274 mmol) were added thereto, and the mixture was refluxed with stirring for two hours. Then, the reaction mixture was treated following a procedure similar to that of Example 2, to yield the title compound 25' (320 mg, 32 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.20-2.85 (m, 26H), 3.40-3.55 (m, 1H), 3.75-3.96 (m, 1H), 4.16-4.20 (m, 1H), 4.66 (m, 1H), 5.02 (m, 1H), 5.40 (m, 2H).

Example 33

Preparation of (5Z,15E,9S,11R)-20-ethyl-9-hydroxy-11-tetrahydropyranyloxy-5,15-prostadienoic acid (compound 27')

A

The compound 25' obtained above (550 mg, 1.51 mmole) was dissolved in toluene (20 ml), and 1 M diisobutyl aluminum hydride in toluene (1.66 ml, 1.66 mmole) was added thereto at -78°C. Then, the mixture was treated following a procedure similar to that of Example 3, to yield lactol 26' (550 mg, 99 %).

IR ($CHCl_3$); 3600, 3400 cm^{-1}.

After 4-carboxybutyltriphenylphosphonium bromide (1.33 g, 3.0 mmole) was suspended in tetrahydrofuran (15 ml), potassium tert-butoxide (672 mg, 6.0 mmole) was added thereto under ice cooling, and the mixture was stirred at the same temperature for 30 minutes. The resultant red mixture was cooled to -30, and 15 ml of a solution of the lactol 26' obtained above (550 mg, 1.50 mmole) in tetrahydrofuran was added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 3, to yield 484 mg of the title compound 27' as a colourless oil (yield 72 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.20-2.42 (m, 34H), 3.55 (m, 1H), 3.88 (m, 1H), 4.00-4.30 (m, 2H), 4.71 (m, 1H), 5.42 (m, 4H).

Example 34

Preparation of (5Z,15E,9S,11R)-20-ethyl-9,11-dihydroxy-5,15-prostadienoic acid (compound 28')

The compound 27' obtained above (242 mg, 0.537 mmole) was dissolved in 3 ml of a mixture of acetic acid,

water, and tetrahydrofuran (65:35:10). The mixture was heated at 40-45°C with stirring for one and a half hours. Then, the reaction mixture was treated following a procedure similar to that of Example 4, to yield 87 mg of the title compound 28' as a colourless oil (yield 44 %).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.20-2.30 (m, 24H), 2.36 (t, J=7Hz, 2H), 3.98 (broad s, 1H), 4.17 (broad s, 1H), 4.1-5.3 (broad, 3H), 5.42 (m, 4H).

IR ($CHCl_3$); 3498, 2700-2400 (broad), 1708 cm^{-1}.

Example 35

Preparation of (5Z,15E,9S,11R)-20-ethyl-9,11-dihydroxy-5,15-prostadienoic acid isopropyl ester (compound 29')

The compound 28' obtained above (87 mg, 0.237 mmole) was dissolved in acetonitrile (2 ml), and 1,8-diazabicyclo[5.4.0]-7-undecene (0.716 ml, 4.8 mmole) and isopropyl iodide (0.24 ml, 2.4 mmole) were added thereto and the mixture was stirred at room temperature for 16 hours. Then, the reaction mixture was treated following a procedure similar to that of Example 5, to yield 62 mg of the title compound 29' as a colourless oil (yield 64 %).

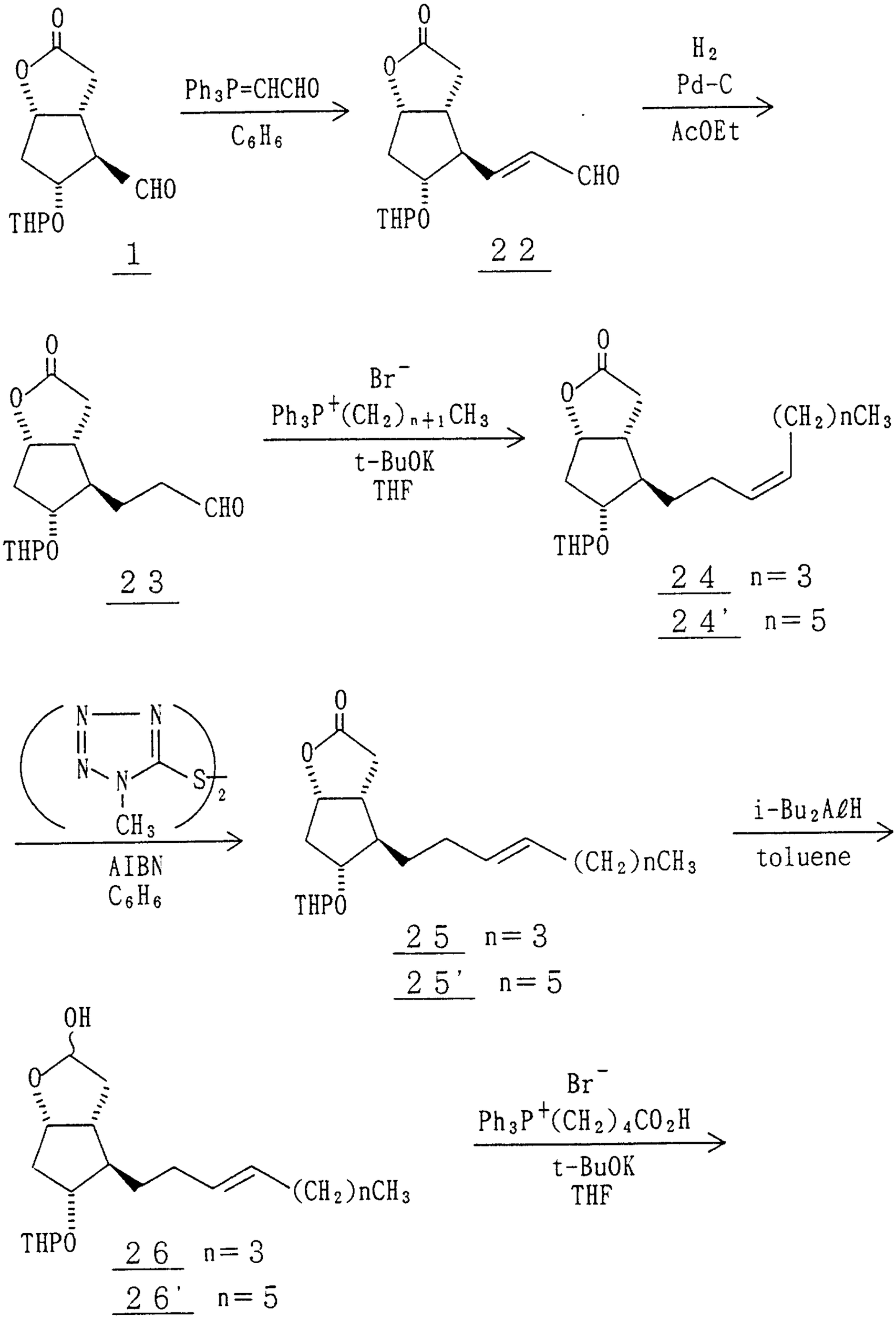
NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.22 (d, J=6Hz, 6H), 1.20-2.30 (m, 26H), 2.29 (t, J=7Hz, 2H), 3.96 (broad s, 1H), 4.17 (broad s, 1H), 5.01 (sept, J=6Hz, 1H), 5.43 (m, 4H).

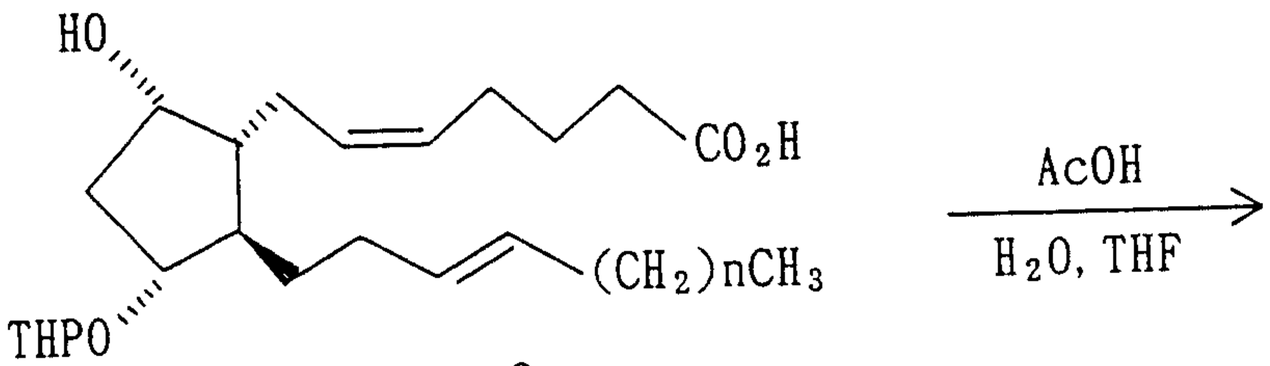
IR ($CHCl_3$); 3504, 1714 cm^{-1}.

A

The comprehensive scheme illustrating the reactions described in Examples 24-35 is shown below.

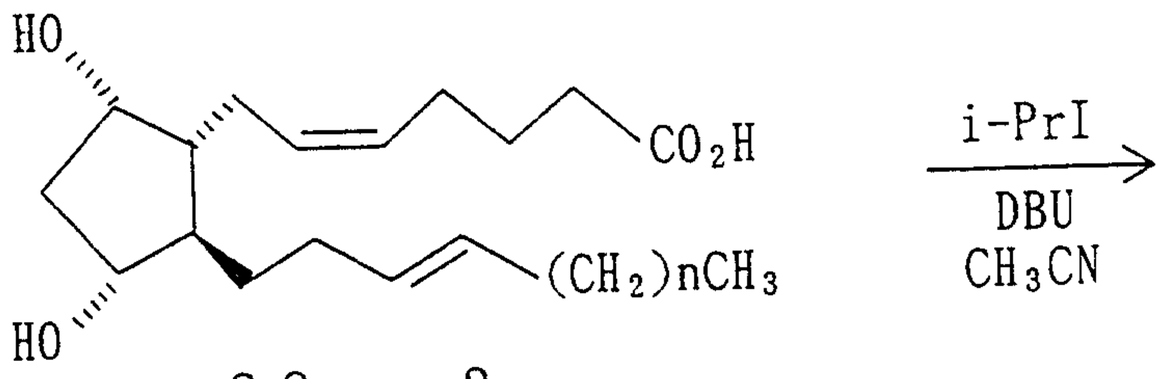
Reaction scheme for preparation of Δ^{15}-PG





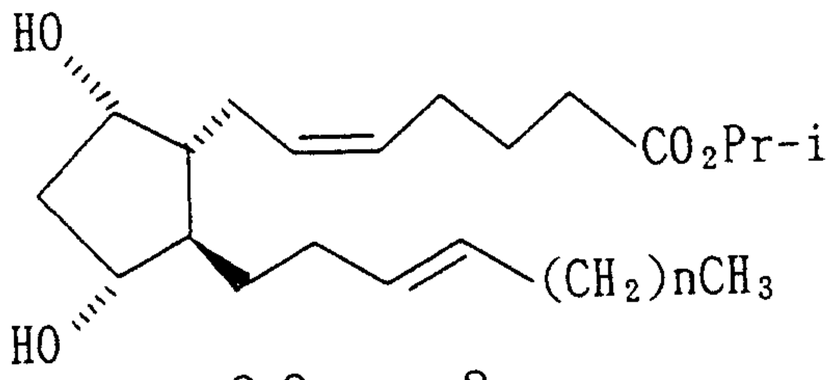
27 n=3

27' n=5



28 n=3

28' n=5



29 n=3

29' n=5

Example 36

Preparation of a sodium salt of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid

The compound 6, (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid obtained above (169 mg, 0.5 mmole) was dissolved in 1 N aqueous sodium hydroxide solution (0.475 ml, 0.475 mmole), and the solution was diluted with distilled water (4 ml). The solution was diluted with filtered. The filtrate was lyophilized over eight hours to yield a colourless crystal (194 mg). The material was triturated with diisopropyl ether and filtered. The resultant filter cake was washed with diisopropyl ether to yield 153 mg of the title compound (yield 85 %) as a colourless crystal.

M.p.; 40-43°C.

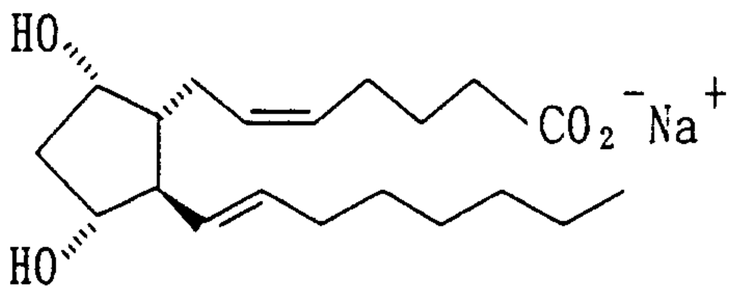
NMR (CD_3OD); δ 0.89 (t, J=7Hz, 3H), 1.2-2.4 (m, 22H), 3.77 (m, 1H), 4.07 (m, 1H), 5.19-5.60 (m, 4H).

IR (Nujol); 3350, 1565, 1550, 1425 cm^{-1}.

Elemental analysis (for $C_{20}H_{33}O_4Na \cdot 1.5H_2O$)

Theory: C,61.83; H,9.34; Na,5.90%

Found : C,62.14; H,9.44; Na,5.94%.



Example 37

Preparation of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid p-methoxybenzyl ammonium

After (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid (compound 6) (208 mg, 0.615 mmole) was dissolved in dried diethyl ether (3 ml), p-methoxybenzylamine (85 μl, 0.645 mmole) was added thereto. The resultant crystal was removed by filtration, and washed with diethyl ether to yield a colourless crystal (278 mg). The product was recrystallized from dichloromethane-diethyl ether to yield 245 mg of the title compound (yield 84 %) as a colourless crystal.

M.p.: 101-104°C.

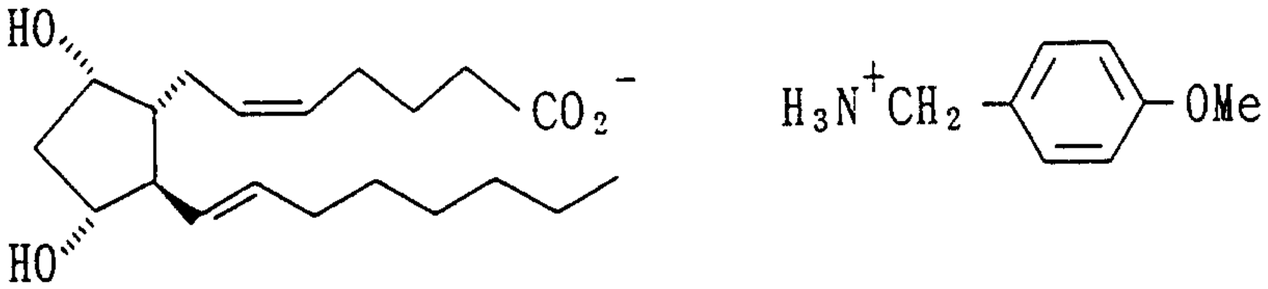
NMR (D_2O); δ 0.85 (t, J=7Hz, 3H), 1.1-2.4 (m, 22H), 3.79 (s, 3H), 3.82 (m, 1H), 4.05 (m, 1H), 4.09 (s, 2H), 5.15-5.60 (m, 4H), 7.00, 7.40 (each d, J=8Hz, each 2H).

IR (Nujol); 3375, 1610, 1560, 1515, 1410 cm^{-1}.

Elemental analysis (for $C_{28}H_{45}O_5N$)

Theory; C,70.70; H,9.54; N,2.95%

Found : C,70.31; H,9.40; N,2.93%.



Example 38

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-(2-methoxyvinyl)-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 103)

Methoxymethyltriphenylphosphonium chloride (13.2 g, 38.4 mmole) was suspended in tetrahydrofuran (132 ml), and potassium tert-butoxide (4.32 g, 38.4 mmole) was added thereto under ice cooling. The mixture was stirred at the same temperature for 10 minutes. The red mixture thus obtained was cooled to -35°C, and 50 ml of a solution of the compound 1 obtained above (4.9 g, 19.2 mmole) in tetrahydrofuran was added thereto. The reaction mixture was allowed to warm to room temperature over one hour, and an aqueous solution of ammonium chloride was added thereto. The mixture was evaporated in vacuo to remove most of the tetrahydrofuran. The residue was extracted with ether, and the extract was washed with diluted hydrochloric acid, aqueous sodium bicarbonate and brine, successively. Then, the extract was dried over anhydrous magnesium sulfate, and the solvent was evaporated off. The resultant brown solid material (13.6 g) was chromatographed over silica gel (139 g), eluting with 1 : 1 of ethyl acetate : n-hexane, to yield 6.7 g of a yellow oil. The product was purified with Lobar column (ethyl acetate : n-hexane = 2 : 1) to yield 3.47 g of the title compound 103 as a colourless oil (yield 64 %) which

A

is a mixture of geometrical isomers in terms of the vinyl group.

NMR ($CDCl_3$); δ 1.40-2.85 (m, 12H), 3.45 (m, 1H), 3.52, 3.53, 3.60, 3.61 (each s, 3H total), 3.75-4.17 (m, 2H), 4.45-4.60 (m, 1H), 4.65-4.75 (m, 1H), 4.85-5.05 (m, 1H), 5.89-5.98, 6.33-6.45 (each m,1H total).

IR ($CHCl_3$); 1763, 1654, 1112, 1033 cm^{-1}.

Example 39

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-formylmethyl-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 104)

The compound 103 obtained above (3.94 g, 13.97 mmole) was dissolved in tetrahydrofuran-water (10:1, 66 ml), and to the solution was added mercuric acetate (5.34 g, 16.77 mmole), and the mixture was stirred at room temperature for 30 minutes. Then, potassium iodide (11.6 g, 69.85 mmol)-water (20 ml) was added thereto. The mixture was stirred for 30 minutes, and concentrated in vacuo. The residue was extracted with chloroform. The extract was washed with aqueous potassium iodide and water, and dried over anhydrous sodium sulfate, and then the solvent was evaporated off, to yield 3.52 g of the title compound 104 (yield 94 %).

NMR ($CDCl_3$); δ 1.40-1.92 (m, 8H), 2.08-2.96 (m, 6H), 3.40-4.10 (m, 3H), 4.62-4.74 (m, 1H), 4.94-5.02 (m, 1H), 9.88 (t, J=1Hz, 1H).

Example 40

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(2Z)-octenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 105)

After n-hexyltriphenylphosphonium bromide (11.47 g, 26.84 mmole) was suspended in tetrahydrofuran (110 ml) and potassium tert-butoxide (3.01 g, 26.84 mmole) was added thereto under ice cooling. The mixture was stirred at room temperature for 30 minutes. The mixture was cooled to 0°C, and 36 ml of a solution of the compound 104 obtained above (3.60 g, 13.42 mmole) in tetrahydrofuran was added thereto, and the mixture was stirred for 30 minutes. An aqueous solution of ammonium chloride was added thereto, and the mixture was concentrated in vacuo. The residue was extracted with ethyl acetate, and the extract was washed with brine. Then, the washed extract was dried over anhydrous magnesium sulfate, and the solvent was evaporated off. The resultant residue was chromatographed over silica gel (20 g), eluting with 600 ml of 1 : 4 ethyl acetate:n-hexane, to yield 4.24 g of the title compound 105 (-yield 94 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.18-1.84 (m, 14H), 1.88-2.32 (m, 6H), 2.48-2.86 (m, 2H), 3.44-4.12 (m, 3H), 4.62-4.68 (m, 1H), 4.94-5.08 (m, 1H), 5.24-5.56 (m, 2H).

Example 41

Preparation of (1S,6R,7R)-2-oxa-3-oxo-6-[(2E)-octenyl]-7-tetrahydropyranyloxy-cis-bicyclo[3.3.0]octane (compound 107)

The compound 105 obtained above (4.20 g, 12.48 mmole) was dissolved in benzene (125 ml), and 5-mercapto-1-methyltetrazole disulfide (1.44 g, 6.42 mmole) and α,α'-azobis-isobutyronitrile (0.205 g, 1.25 mmole) were added thereto, and the mixture was refluxed for 3 hours. The mixture was allowed to cool to room temperature, and washed with aqueous sodium carbonate and water, and then dried over anhydrous sodium sulfate. The solvent was evaporated off in vacuo. The resultant residue was chromatographed over silica gel (100 g) eluting with 100 ml of 1:4 ethyl acetate:n-hexane, to yield the title compound 107 (3.624 g, 86 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.18-2.28 (m, 20H), 2.46-2.86 (m, 2H), 3.42-4.12 (m, 3H), 4.62-4.68 (m, 1H), 4.92-5.06 (m, 1H), 5.24-5.56 (m, 2H).

Example 42

Preparation of (5Z,14E,9S,11R)-9-hydroxy-11-tetrahydropyranyloxy-5,14-prostadienoic acid (compound 109)

The compound 107 obtained above (3.60 g, 10.7 mmole) was dissolved in tetrahydrofuran (72 ml), and 1 M diisobutyl aluminum hydride in toluene (10.7 ml) was added thereto at -78°C. The reaction was stirred at the same

temperature for one hour, and then ethyl acetate (2 ml) was added thereto, and the temperature was allowed to warm to 0°C. At the same temperature, aqueous ammonium chloride (5 ml), aqueous potassium sodium tartrate (40 ml) and ethyl acetate (80 ml) were added thereto successively. The mixture was stirred for one hour, and the organic layer was isolated. The layer was dried over anhydrous sodium sulfate, and then the solvent was evaporated off, to yield lactol 108 (3.39 g, 93%).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 1H), 1.18-1.40 (m, 8H), 1.42-1.84 (m, 6H), 1.84-2.08 (m, 6H), 2.16-2.52 (m, 2H), 3.40-4.14 (m, 3H), 4.56-4.78 (m, 2H), 5.02-5.64 (m, 3H).

After (4-carboxybutyl)triphenylphosphonium bromide (8.86 g, 20 mmole) was suspended in tetrahydrofuran (100 ml), a potassium tert-butoxide (4.48 g, 40 mmole) was added thereto under ice cooling, and the mixture was stirred at room temperature for one hour. The resultant mixture was cooled to -78°C, and 50 ml of a solution of the lactol 108 obtained above (3.39 mg, 10 mmole) in tetrahydrofuran was added thereto. The mixture was allowed to warm to room temperature over one hour. To the mixture was added a solution of ammonium chloride in water under ice cooling, and then the mixture was concentrated in vacuo to remove most of the tetrahydrofuran. To the residue, cooled and diluted hydrochloric acid was added, and the mixture was

extracted with ethyl acetate. The extract was dried over anhydrous sodium sulfate, and the solvent was evaporated off. To the residue was added ether, and insoluble materials were filtered off. The filtrate was concentrated, and the residue was purified with Lobar column (ethyl acetate:n-hexane:acetic acid = 50:50:1), to yield the title compound 109 (3.42 g, 77 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.18-2.30 (m, 26H), 2.34 (t, J=7Hz, 2H), 3.42-3.56 (m, 1H), 3.78-3.96 (m, 1H), 3.98-4.18 (m, 2H), 4.58-4.76 (m, 1H), 5.38-5.58 (m, 4H).

Example 43

Preparation of (5Z,14E,9S,11R)-9,11-dihydroxy-5,14-prostadienoic acid methyl ester (compound 111)

The compound 109 obtained above (3.42 g, 7.73 mmole) was dissolved in a mixture of acetic acid (27 ml), tetrahydrofuran (9 ml) and water (9 ml). The solution was stirred at 65°C for three hours, and then the solvent was evaporated off. The residue was dissolved in ethyl acetate, and the solution was washed with brine, dried over anhydrous sodium sulfate, and evaporated. The residue was chromatographed over Lobar column (ethyl acetate:n-hexane:acetic acid = 50:50:1), to yield 2.31 g of the crude dihydroxycarboxylate (compound 110) (yield 88 %).

The compound 110 (1.85 g, 5.46 mmole) was dissolved in acetonitrile (18 ml), and 1,8-diazabicyclo[5.4.0]-7-undecene

A

(2.50 g, 16.40 mmole) and then methyl iodide (3.88 g, 27.33 mmole) were added thereto, and the mixture was stirred at room temperature for three hours. The mixture was concentrated in vacuo, and the residue was dissolved in ethyl acetate, and the solution was washed successively with diluted hydrochloric acid and brine, and dried over anhydrous magnesium sulfate. The solvent was evaporated off, and the residue was purified with Lobar colum (methylene chloride:methanol = 97:3), to yield the title compound 111 (1.59 g, 83 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.18-1.55 (m, 6H), 1.60-2.30 (m, 15H), 2.34 (t, J=7Hz, 2H), 3.67 (s, 3H), 3.94-4.02 (m, 1H), 4.16-4.22 (m, 1H), 5.30-5.58 (m, 4H).

Example 44

Preparation of (5Z,14E,9S,11R)-9,11-dihydroxy-5,14-prostadienoic acid (compound 110)

The compound 111 obtained above (720 mg, 2.04 mmole) was dissolved in methanol (4 ml), and 1 N sodium hydroxide solution was added thereto. The mixture was stirred at room temperature for two hours. The methanol was evaporated off in vacuo, and then the residue was acidified by adding diluted hydrochloric acid under ice cooling. The acidified mixture was extracted with ethyl acetate. The extract was washed with brine, and dried over anhydrous sodium sulfate, and the solvent was evaporated off. The residue was chromatographed over silicic acid (7 g), eluting

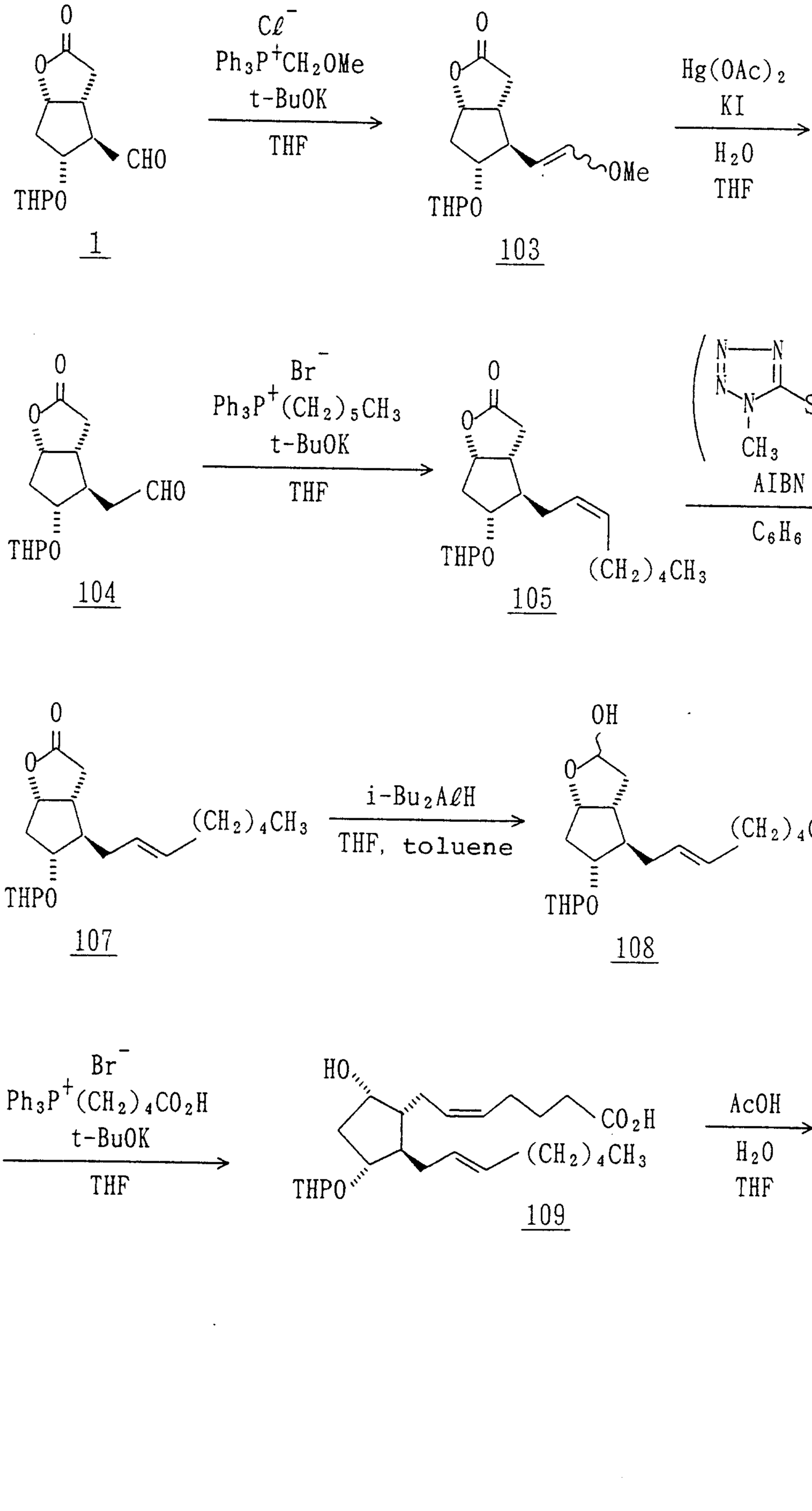
with 100 ml of 1:1 of ethyl acetate:n-hexane, to yield the title compound 110 (681 mg, 99 %).

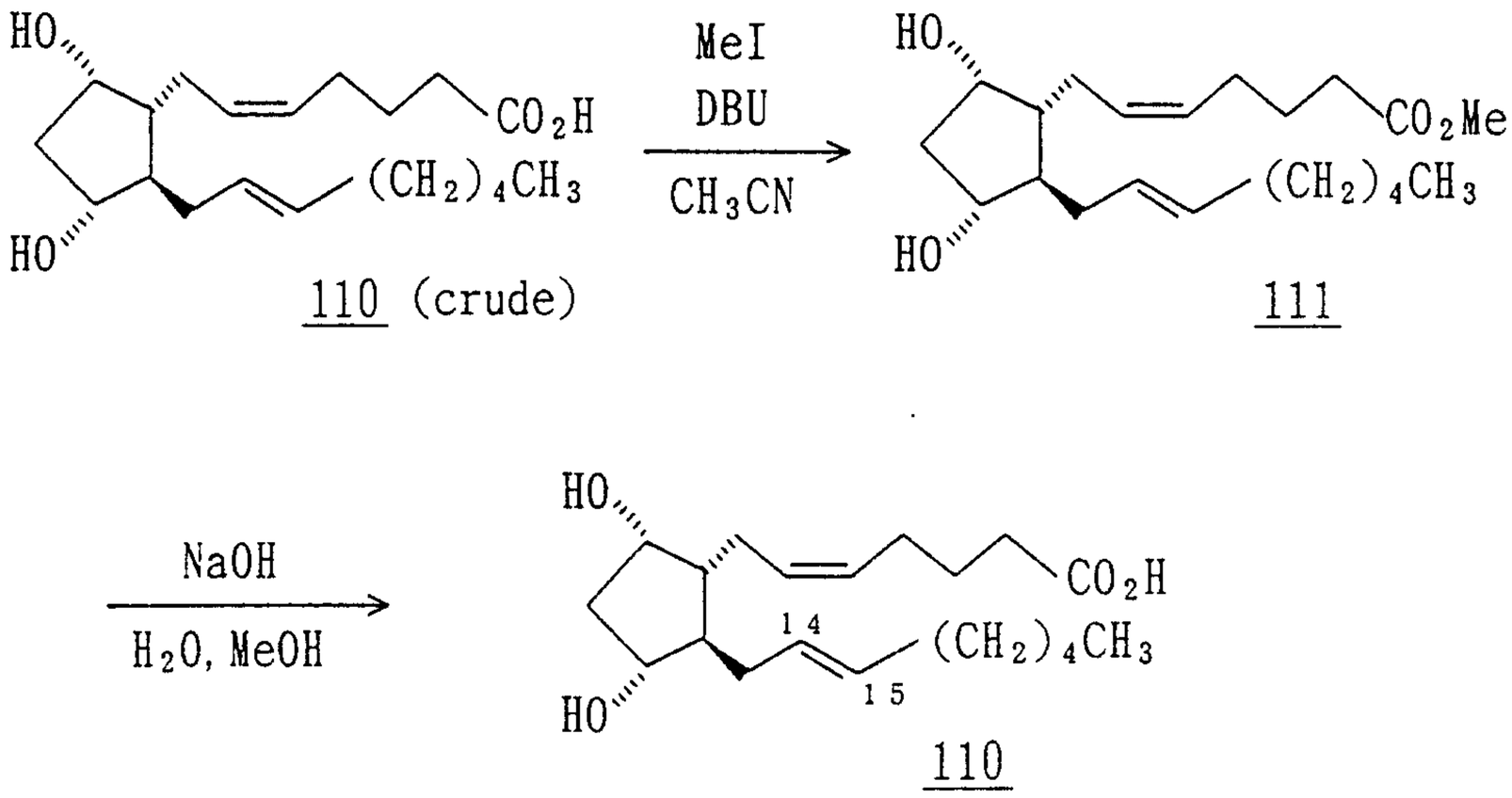
NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.18-1.56 (m, 6H), 1.60-2.30 (m, 14H), 2.36 (t, J=7Hz, 2H), 3.92-4.02 (m, 1H), 4.16-4.20 (m, 1H), 4.60 (broad, 3H), 5.30-5.58 (m, 4H).

IR ($CHCl_3$); 3396, 2660(broad), 1707 cm^{-1}.

The comprehensive scheme illustrating the reactions described in Examples 38-44 is shown below.

Reaction scheme for preparation of Δ^{14}-PG
(Examples 38-44)





110 (crude) 111

110

Example 45

Preparation of (5Z,13Z,9S,11R)-9-hydroxy-11-tetrahydropyranyloxy-5,13-prostadienoic acid methyl ester (compound 114)

The compound 2 obtained above (12.66 g, 37.6 mmole) was dissolved in toluene (240 ml), and the solution was cooled to -78°C, and 60 ml of 0.94 M solution of diisobutyl aluminum hydride in hexane was added thereto. Then, the mixture was treated following a procedure similar to that of Example 5 to yield lactol 112. After (4-carboxybutyl)triphenylphosphonium bromide (50.0 g, 112.8 mmole) was suspended in tetrahydrofuran (270 ml), potassium tert-butoxide (23.6 g, 210.6 mmole) was added thereto under ice cooling, and the mixture was stirred for 40 minutes. The resultant mixture was cooled to -15°C, and 100 ml of a solution of the lactol 12 obtained above in tetrahydrofuran

was added thereto. Then, the reaction mixture was treated following a procedure similar to that of Example 42, to yield carboxy compound 113. The compound was dissolved in 240 ml of tetrahydrofuran-methanol mixture (5:1), and a slight excess amount of diazomethane-ether solution was added thereto. The solution was evaporated and the residue was chromatographed over silica gel (750 g) eluting with ethyl acetate-n-hexane (1:4), to yield 14.78 g of the title compound 114 (yield 90 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7.5Hz, 3H), 1.19-2.38 (m, 25H), 2.33 (t, J=7.5Hz, 2H), 2.68-2.93 (m, 1H), 3.39-4.18 (m, 4H), 3.67 (s, 3H), 4.63-4.72 (m, 1H), 5.11-5.58 (m, 4H).

IR ($CHCl_3$); 3600, 3500, 1726 cm^{-1}.

Example 46

Preparation of (5Z,13Z,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid methyl ester (compound 115)

The compound 114 (14.78 g, 33.9 mmole) was dissolved in a mixture of acetic acid (90 ml), tetrahydrofuran (30 ml) and water (30 ml), and the solution was stirred at 55°C for five hours. After diluting with water, the solution was extracted with ethyl acetate, and the extract was washed with aqueous sodium bicarbonate and brine. The extract was dried over anhydrous sodium sulfate and evaporated. Then, the residue was chromatographed over silica gel (300 g) eluting with ethyl acetate-n-hexane

(1:2), to yield 10.35 g of the title compound 115 (yield 87 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7.5Hz, 3H), 1.20-2.40 (m, 19H), 2.36 (t, J=7.5Hz, 2H), 2.63-2.77 (m, 1H), 3.68 (s, 3H), 3.85-3.95 (m, 1H), 4.16-4.24 (m, 1H), 5.09-5.62 (m, 4H).

IR ($CHCl_3$); 3600, 3500, 1726 cm^{-1}.

Example 47

Preparation of (5Z,13Z,9S,11R)-9,11-bis(tert-butyldimethylsilyloxy)-5,13-prostadienoic acid methyl ester (compound 116)

The compound 115 (10.35 g, 29.4 mmole) was dissolved in dimethylformamide (64 ml), and imidazole (9.01 g, 132 mmole) and tert-butyl dimethylsilyl chloride (17.73 g, 118 mmole) were added to the solution under ice cooling, and the mixture was stirred at room temperature for five hours. After diluting with ethyl acetate, the mixture was washed with brine, and dried over anhydrous sodium sulfate, and evaporated. Then, the residue was chromatographed over silica gel (750 g) eluting with ethyl acetate-n-hexane (1:50), to yield 16.34 g of the title compound 116 (yield 96 %).

NMR ($CDCl_3$); δ -0.04, -0.02, 0.02, 0.05 (each s, each 3H), 0.85, 0.90 (each s, each 9H), 0.88 (t, J=7.5Hz, 3H), 1.18-2.26 (m, 19H), 2.29 (t, J=7.5Hz, 2H), 2.66-2.83

(m, 1H), 3.66 (s, 3H), 3.68-3.81 (m, 1H), 4.04-4.13 (m, 1H), 4.99-5.57 (m, 4H).

IR ($CHCl_3$); 1727 cm^{-1}.

Example 48

Preparation of (5E,13E,9S,11R)-9,11-bis(tert-butyldimethylsilyloxy)-5,13-prostadienoic acid methyl ester (compound 117)

The compound 116 obtained above (7.27 g, 12.5 mmole) was dissolved in benzene (40 ml), and 5-mercapto-1-methyltetrazole disulfide (2.88 g, 12.5 mmole) and α,α'-azobis-isobutyronitrile (205 mg, 1.25 mmole) were added thereto, and the mixture was refluxed with stirring for 19 hours. Then, the reaction mixture was treated following a procedure similar to that of Example 41, to yield a residue. The residue was chromatographed over silica gel (330 g), eluting with ethyl acetate:n-hexane (1:50), to yield 5.34 g of a mixture of geometrical isomers with respect to the double bond. The material was further chromatographed over 10 % silver nitrate - silica gel (500 g), eluting with ether-n-hexane (1:50), to yield 3.64 g of the title compound 117 (yield 50%).

NMR ($CDCl_3$); δ -0.02, -0.01, 0.01, 0.04 (each s, each 3H), 0.85, 0.89 (each s, each 9H), 0.89 (t, J=7.5Hz, 3H), 1.18-2.26 (m, 20H), 2.29 (t, J=7.5Hz, 2H), 3.66 (s, 3H), 3.70-3.83 (m, 1H), 4.02-4.11 (m, 1H), 5.03-5.53 (m, 4H).

IR ($CHCl_3$); 1727 cm^{-1}.

Example 49

Preparation of (5E,13E,9S,11R)-9,11-dihydroxy-5,13prostadienoic acid methyl ester (compound 118)

The compound 117 obtained above (4.81 g, 8.28 mmole) was dissolved in 1.0 M solution (41.4 ml) of tetra(n-butyl)ammonium fluoride in tetrahydrofuran solution (41.4 ml), and the solution was stirred at room temperature for 14 hours. After diluting with water, the mixture was extracted with ethyl acetate and washed with brine. The extract was dried over anhydrous sodium sulfate, and evaporated. Then, the residue was chromatographed over silica gel (330 g), eluting with ethyl acetate-n-hexane (1:1), to yield 2.81 g of the title compound 118 (yield 96 %).

NMR ($CDCl_3$); 0.89 (t, J=7.5Hz, 3H), 1.20-2.32 (m, 20H), 2.31 (t, J=7.5Hz, 2H), 3.68 (s, 3H), 3.85-3.98 (m, 1H), 4.16-4.25 (m, 1H), 5.13-5.60 (m, 4H).

IR ($CHCl_3$); 3580, 3500, 1727 cm^{-1}.

Example 50

Preparation of (5E,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid (compound 119)

The compound 118 obtained above (2.81 g, 7.97 mmole) was dissolved in methanol (28 ml), and 1.0 M aqueous potassium hydroxide (28 ml). The mixture was stirred at 65°C for two hours. The methanol was removed from the mixture in vacuo, and the residue was diluted with water.

The aqueous solution was washed with ether. The aqueous phase was acidified with sodium bisulfate, and then the solution was extracted with ethyl acetate, and the extract was washed with brine. The washed extract was dried over anhydrous sodium sulfate, and evaporated. Then, the residue was chromatographed over silicic acid (13.5 g), eluting with ethyl acetate-n-hexane (1:2), to yield 2.70 g of the title compound 119 (almost quantitative).

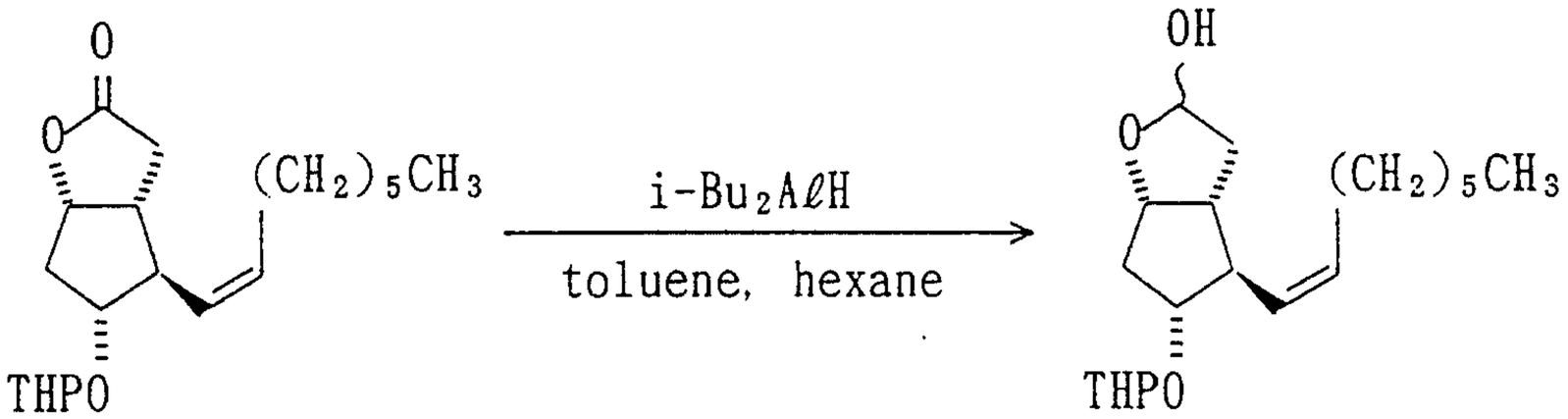
NMR ($CDCl_3$); δ 0.88 (t, J=7.5Hz, 3H), 1.17-2.40 (m, 20H), 2.34 (t, J=7.5Hz, 2H), 3.80-4.06 (m, 1H), 4.06-4.33 (m, 1H), 5.13-5.60 (m, 4H).

IR ($CHCl_3$); 3400, 2660 (broad), 1705 cm^{-1}.

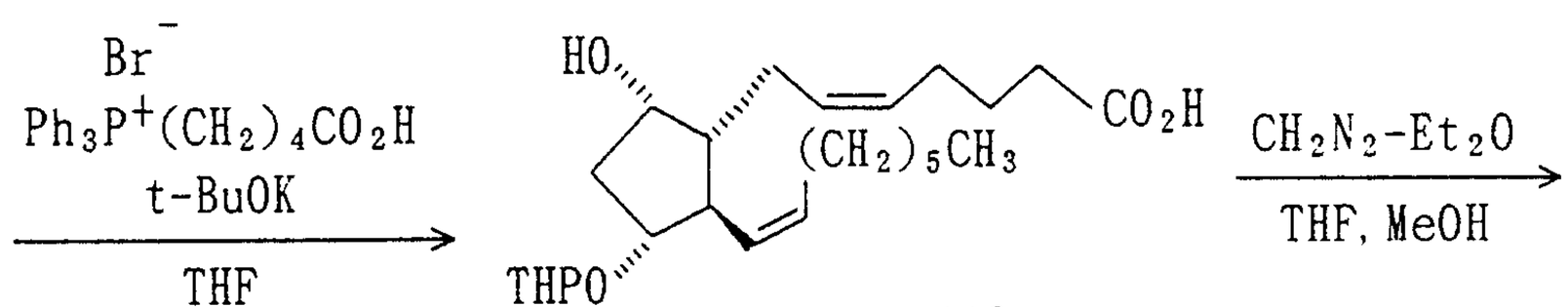
The comprehensive scheme illustrating the reactions described in Examples 45-50 is shown below.

A

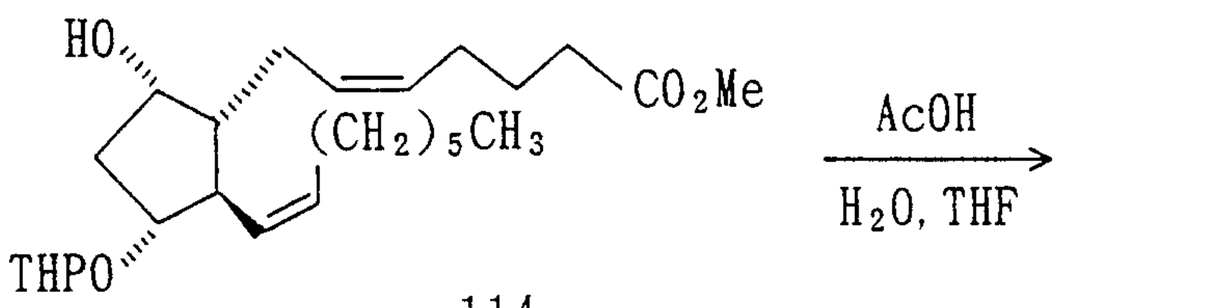
Reaction scheme of preparation of Δ^5 trans (E)-PG
(Examples 45-50)



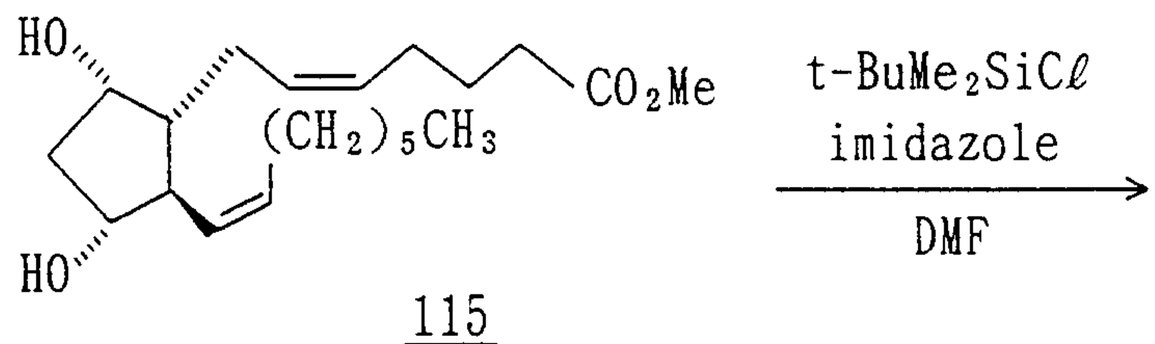
2 112



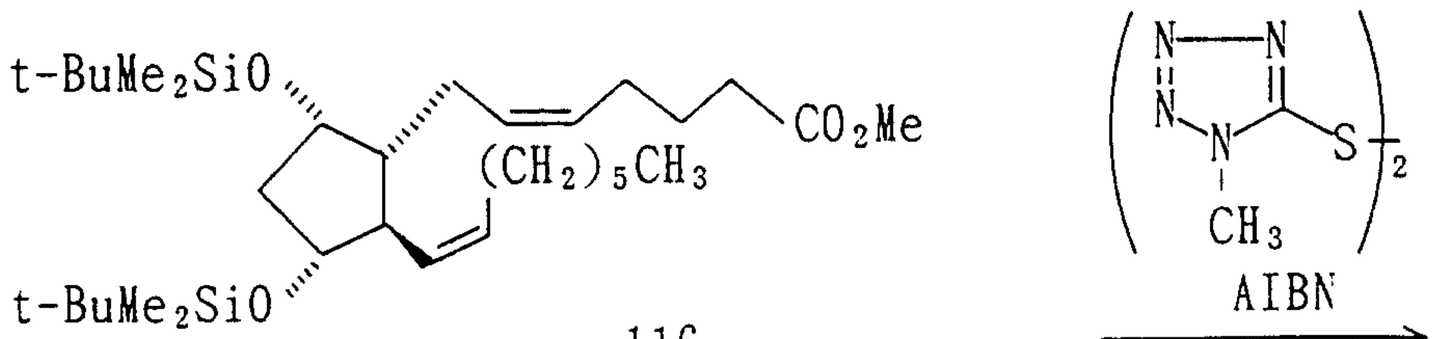
113



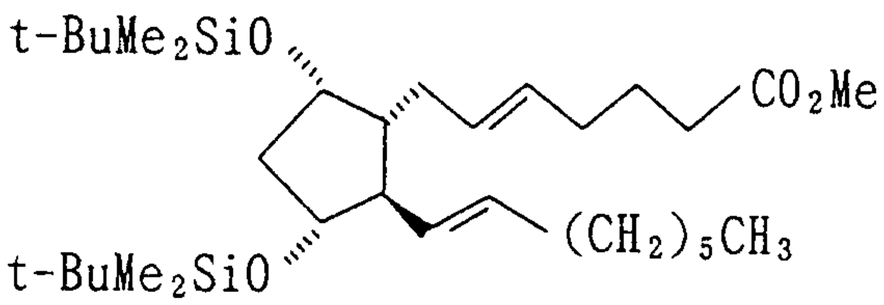
114



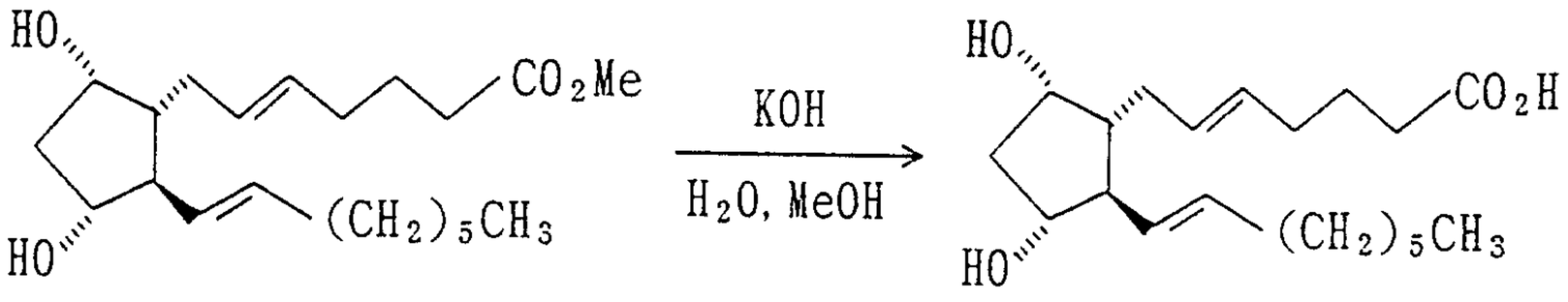
115



116



117



118 119

Example 51

Preparation of (5Z,13E,15E,9S,11R)-9,11-diacetoxy-5,13,15-prostatrienoic acid (compound 121)

After a mixture comprising prostaglandin $F_{2\alpha}$ (3.545 g, 10 mmole), pyridine (10 ml), and acetic anhydride (10 ml) was stirred at room temperature for two hours, the solvent was evaporated off in vacuo. The residue was dissolved in ethyl acetate, and the solution was washed with diluted hydrochloric acid and brine. The washed solution was dried over anhydrous sodium sulfate, and evaporated. Then, the residue was chromatographed over silica gel (30 g), eluting with ethyl acetate-n-hexane (1:1, 300 ml), to yield 4.50 g of prostaglandin $F_{2\alpha}$ 9,11,15-O-triacetate 120 (yield 94%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.20-1.42 (m, 6H), 1.48-1.78 (m, 6H), 2.02, 2.06, 2.07 (each s, each 3H),

A

1.90-2.22 (m, 4H), 2.34 (t, J=7Hz, 2H), 2.42-2.62 (m, 2H), 4.82-4.92 (m, 1H), 5.06-5.14 (m, 1H), 5.20-5.30 (m, 1H), 5.35-5.40 (m, 2H), 5.50-5.60 (m, 2H).

The compound 120 obtained above (4.50 g, 9.36 mmole) was dissolved in tetrahydrofuran (45 ml), and tetrakis(triphenylphosphine)palladium (1.082 g, 0.936 mmole) and triethylamine (1.89 g, 18.72 mmole) were added thereto. The mixture was stirred at 65°C in an atmosphere of nitrogen for two hours. The solvent was evaporated off, and the residue was chromatographed over silica gel (40 g), eluting with ethyl acetate-n-hexane (1:1, 200 ml), to yield 3.90 g of the title compound 121 (yield 99%).

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.18-1.42 (m, 4H), 1.48-1.76 (m, 4H), 2.02, 2.07 (each s, each 3H), 1.96-2.22 (m, 6H), 2.34 (t, J=7Hz, 2H), 2.45-2.65 (m, 2H), 4.82-4.94 (m, 1H), 5.04-5.15 (m, 1H), 5.30-5.50 (m, 3H), 5.58-5.72 (m, 1H), 5.82-6.18 (m, 2H).

Example 52

Preparation of (5Z,13E,15E,9S,11R)-9,11-dihydroxy-5,13,15-prostatrienoic acid (compound 122)

The compound 121 obtained above (3.90 g, 9.27 mmole) was dissolved in methanol (40 ml), and 10% aqueous sodium hydroxide was added to the solution, and the mixture was stirred at room temperature for one hour. Then, the mixture was treated following a procedure similar to that of Example 44 to yield a residue (2.84 g). The residue was

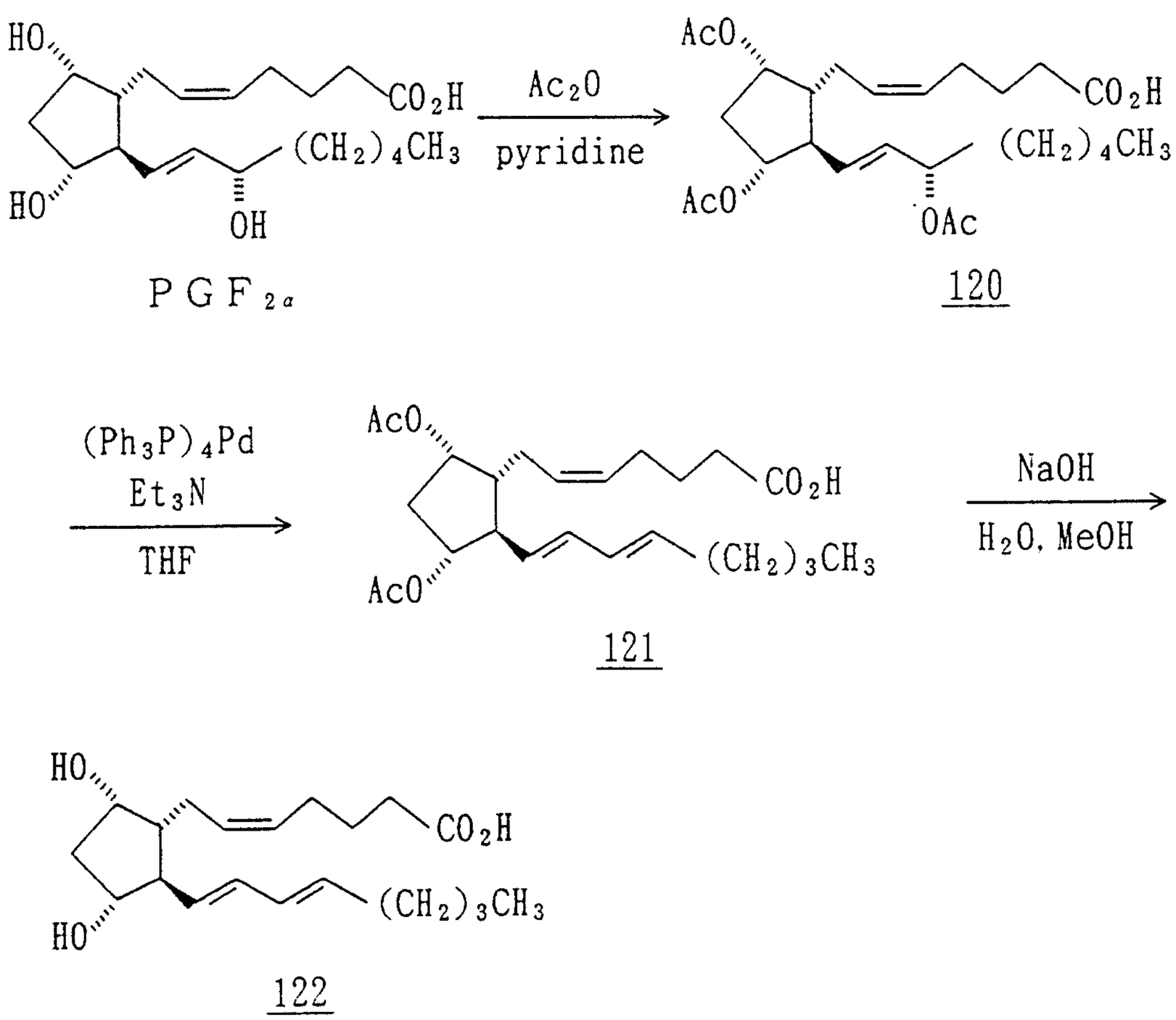
purified with Lobar column (ethyl acetate:n-hexane:acetic acid = 50:50:1), to yield the title compound 122 (2.67 g, 84 %).

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.22-1.40 (m, 4H), 1.42-1.82 (m, 4H), 2.00-2.30 (m, 8H), 2.36 (t, J=7Hz, 2H), 3.92-4.02 (m, 1H), 4.16-4.22 (m, 1H), 5.20 (broad, 3H), 5.30-5.50 (m, 3H), 5.56-5.70 (m, 1H), 5.94-6.18 (m, 2H).

IR (Neat); 3376, 2620 (broad), 1706 cm^{-1}.

The comprehensive scheme illustrating the reactions described in Examples 51-52 is shown below.

Scheme for preparation of $\Delta^{13,15}$diene-PG (Examples 51-52)



PGF$_{2\alpha}$

120

121

122

Example 53

Preparation of (5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid diphenylmethyl ester (compound 123)

The compound 6 obtained above (820 mg, 2.42 mmole) and diphenyldiazomethane (565 mg, 2.88 mmole) were dissolved in methylene chloride (14 ml), and the solution was refluxed for two hours. The reaction was concentrated in vacuo, and the residue was chromatographed over silica gel (14 g), eluting with ethyl acetate-n-hexane (1:10-2:1), to yield the title compound 123 (1.16 g, 95 %) as a colorless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.20-2.30 (m, 22H), 2.44 (t, J=7Hz, 2H), 3.91 (m, 1H), 4.13 (m, 1H), 5.15-5.60 (m, 4H), 6.89 (s, 1H), 7.32 (m, 10H).

IR ($CHCl_3$); 3590, 3510, 1726, 1599 cm^{-1}.

Example 54

Preparation of (5Z,13E,9S)-9-hydroxy-11-oxo-5,13-prostadienoic acid diphenylmethyl ester (compound 124) and (5Z,13E,11R)-9-oxo-11-hydroxy-5,13-prostadienoic acid diphenylmethyl ester (compound 125)

The compound 123 obtained above (1.13 g, 2.24 mmole) was dissolved in acetone (20 ml), and the solution was cooled to -20°C, and Jones reagent (1.3 ml) was added dropwise thereto. After stirring at the same temperature for one hour, isopropanol (0.5 ml) was added to the mixture, and the mixture was allowed to warm to 0°C. The warmed mixture was diluted with ethyl acetate - n-hexane (1:2, 80 ml), the

supernatant was passed through silica gel (10 g). The solution was evaporated to yield an yellow oil (0.97 g), and the oil was purified with Lobar column (ethyl acetate - n-hexane = 1:3). There were obtained the oily title compound 124 (405 mg, 36 %), mixture (105 mg, 9 %) of the compound 124 and the title compound 125, and the compound 125 as a crystal (240 mg, 21 %) in the order of elution.

124: NMR ($CDCl_3$); δ 0.87 (t, J=7Hz, 3H), 1.15-2.50 (m, 22H), 2.75 (dd, J=12.5, 7.5Hz, 1H), 4.47 (m, W1/2=7Hz, 1H), 5.19 (dd, J=15, 7.5Hz, 1H), 5.42 (m, 2H), 5.56 (dt, J=15, 6Hz, 1H), 6.89 (s, 1H), 7.32 (m, 10H).

IR ($CHCl_3$); 3600, 3520, 1735, 1600 cm^{-1}.

125: NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.15-2.50 (m, 22H), 2.72 (dd, J=17.5, 7.5Hz, 1H), 4.03 (q, J=8Hz, 1H), 5.20-5.47 (m, 3H), 5.61 (dt, J=15, 6Hz, 1H), 6.88 (s, 1H), 7.32 (m, 10H).

IR ($CHCl_3$); 3590, 1735, 1600 cm^{-1}.

Example 55

Preparation of (5Z,13E,9S)-9-hydroxy-11-oxo-5,13-prostadienoic acid (compound 126)

The compound 124 obtained above (47 mg, 0.094 mmole) and anisole (50 μl, 0.46 mmole) were dissolved in methylene chloride (2.5 ml), and the solution was cooled to -40°C, and a solution of aluminum chloride (32 mg, 0.23 mmole) in nitromethane (1 ml) was added thereto. The

mixture was allowed to warm to -10°C over 30 minutes, and saturated brine was added thereto. To the mixture was added ether to form two separate phases, and the aqueous phase was extracted with ethyl acetate. The extract was combined with the above organic phase, and the combined extract was washed with saturated brine, and dried over anhydrous magnesium sulfate. The dried extract was evaporated to yield a yellow oil (56 mg). The oil was chromatographed over silicic acid (1.1 g), eluting ethyl acetate - n-hexane (1:20 - 1:1), to yield the title compound 126 (24 mg, 77 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.15-2.55 (m, 23H), 2.78 (dd, J=12.5, 7.5Hz, 1H), 4.47 (m, W1/2=7Hz, 1H), 5.21 (dd, J=15, 7.5Hz, 1H), 5.38-5.70 (m, 3H).

IR ($CHCl_3$); 3500, 3454, 2660 (broad), 1735, 1707 cm^{-1}.

Example 56

Preparation of (5Z,13E,11R)-9-oxo-11-hydroxy-5,13-prostadienoic acid (compound 127)

The compound 125 obtained above (40 mg, 0.08 mmole) and anisole (43 μl, 0.4 mmole) were dissolved in methylene chloride (2 ml), and the solution was cooled to -40°C, and a solution of aluminum chloride (27 mg, 0.2 mmole) in nitromethane (1 ml) was added thereto. Then, the mixture was treated following a procedure similar to that

of Example 55 to yield the title compound 127 (25 mg, 92 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.89 (t, J=7Hz, 3H), 1.15-2.50 (m, 23H), 2.75 (dd, J=17.5, 7.5Hz, 1H), 4.07 (q, J=8Hz, 1H), 5.25-5.55 (m, 3H), 5.66 (dt, J=15, 6Hz, 1H).

IR ($CHCl_3$); 3586, 3500, 3400, 2660 (broad), 1737, 1707 cm^{-1}.

Example 57

Preparation of (5Z,13E)-11-oxo-5,9,13-prostatrienoic acid diphenylmethyl ester (compound 128)

The compound 124 obtained above (150 mg, 0.3 mmole) was dissolved in methylene chloride (3 ml), and to the solution, triethylamine (0.125 ml, 0.9 mmole) and methanesulfonyl chloride (35 μl, 0.45 mmole) were added under ice cooling. After the solution was stirred under ice cooling for 30 minutes, the reaction was chromatographed over silica gel (1.5 g), eluting with ethyl acetate - n-hexane (1:4), to yield the title compound 128 (136 mg, 94 %) as a pale yellow oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.15-2.50 (m, 18H), 2.55 (dd, J=7.5, 2Hz, 1H), 2.73 (m, 1H), 5.20-5.70 (m, 4H), 6.12 (dd, J=6, 2Hz, 1H), 6.89 (s, 1H), 7.32 (m, 10H), 7.51 (dd, J=6, 2Hz, 1H).

IR ($CHCl_3$); 1726, 1701, 1586 cm^{-1}.

Example 58

Preparation of (5Z,13E)-11-oxo-5,9,13-

prostatrienoic acid (compound 129)

The compound 128 obtained above (123 mg, 0.25 mmole) and anisole (0.136 ml, 1.25 mmole) were dissolved in methylene chloride (5 ml), and the solution was cooled to -40°C, and a solution of aluminum chloride (84 mg, 0.625 mmole) in nitromethane (2.5 ml) was added thereto. Then, the mixture was treated following a procedure similar to that of Example 55 to yield the title compound 129 (60 mg, 75 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.15-2.45 (m, 19H), 2.58 (dd, J=7.5, 2Hz, 1H), 2.78 (m, 1H), 5.25-5.70 (m, 4H), 6.16 (dd, J=6, 2Hz, 1H), 7.57 (dd, J=6, 2Hz, 1H).

IR ($CHCl_3$); 2670 (broad), 1703, 1586 cm^{-1}.

Example 59

Preparation of (5Z,13E)-9-oxo-5,10,13-prostatrienoic acid diphenylmethyl ester (compound 130)

The compound 125 obtained above (150 mg, 0.3 mmole) was dissolved in methylene chloride (3 ml), and to the solution, triethylamine (0.125 ml, 0.9mmole) and methanesulfonyl chloride (35 μl, 0.45 mmole) were added under ice cooling. Then, the mixture was treated following a procedure similar to that of Example 57 to yield the title compound 130 (135 mg, 93 %) as a colourless oil.

NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.15-2.55 (m, 19H), 3.13 (m, 1H), 5.20-5.60 (m, 4H), 6.13 (dd, J=6, 2Hz, 1H), 6.88 (s, 1H), 7.32 (m, 10H), 7.45 (dd, J=6, 2Hz, 1H).

IR ($CHCl_3$); 1725, 1698, 1584 cm^{-1}.

Example 60

Preparation of (5Z,13E)-9-oxo-5,10,13-prostatrienoic acid (compound 131)

The compound 130 obtained above (123 mg, 0.25 mmole) and anisole (0.136 ml, 1.25 mmole) were dissolved in methylene chloride (5 ml), and the solution was cooled to -40°C, and a solution of aluminum chloride (84 mg, 0.625 mmole) in nitromethane (2.5 ml) was added thereto. Then, the mixture was treated following a procedure similar to that of Example 55 to yield the title compound 131 (66 mg, 83 %) as a colourless oil.

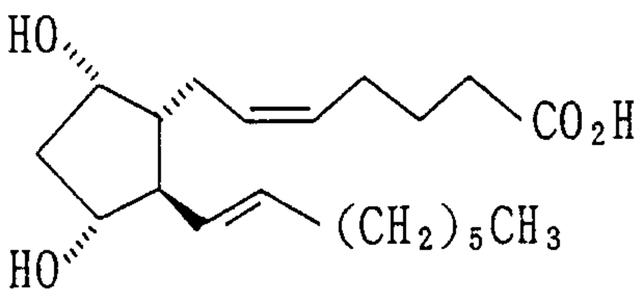
NMR ($CDCl_3$); δ 0.88 (t, J=7Hz, 3H), 1.15-2.60 (m, 20H), 3.17 (m, 1H), 5.25-5.60 (m, 4H), 6.14 (dd, J=6, 2Hz, 1H), 7.49 (dd, J=6, 2Hz, 1H).

IR ($CHCl_3$); 2670 (broad), 1701, 1583 cm^{-1}.

The comprehensive scheme illustrating the reactions described in Examples 53-63 is shown below.

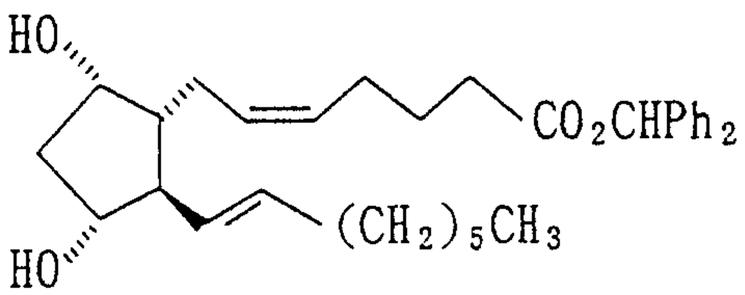
Reaction scheme for preparation of 15-deoxy PGD_2, 15-deoxy PGE_2, 15-deoxy PGJ_2, 15-deoxy PGA_2,

(Example 53-60)

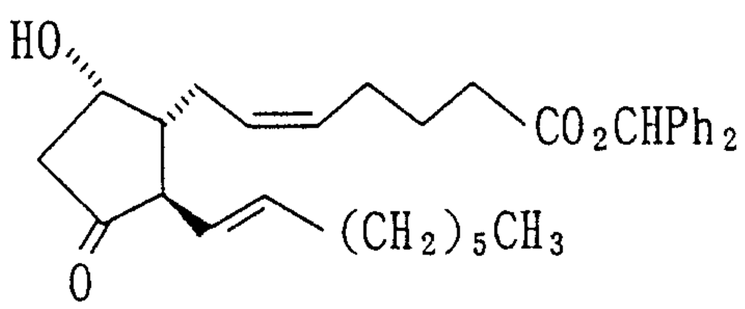


15-deoxy $PGF_{2\alpha}$

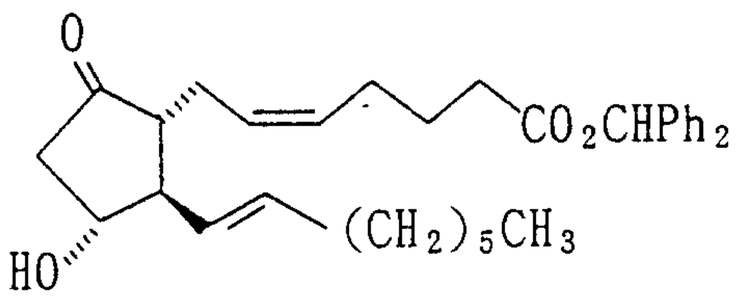
6



123

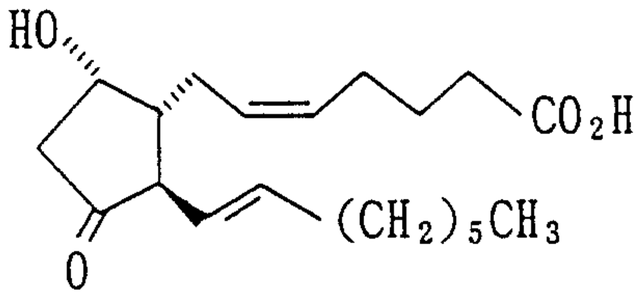


124

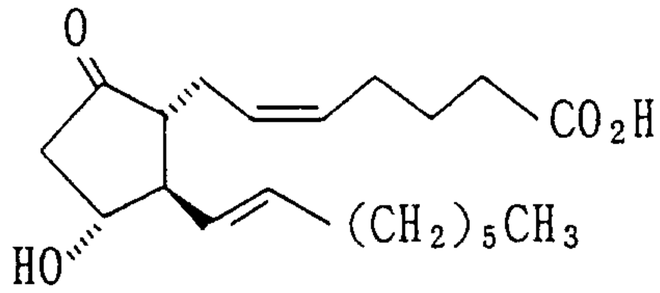


125

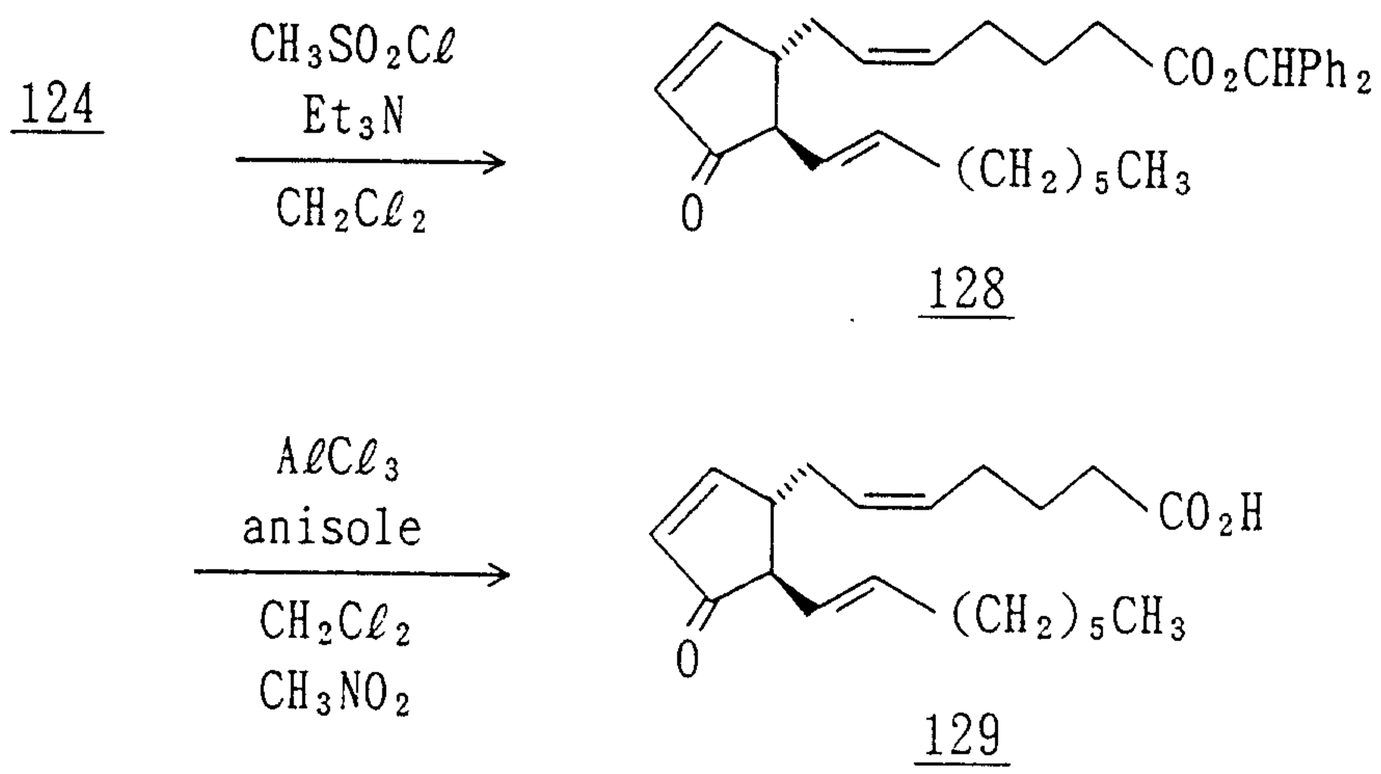
$AlCl_3$ / anisole | CH_2Cl_2 / CH_3NO_2



126



127


124
$CH_3SO_2C\ell$
Et_3N
$CH_2C\ell_2$
CO_2CHPh_2
$(CH_2)_5CH_3$
O
128
$A\ell C\ell_3$
anisole
$CH_2C\ell_2$
CH_3NO_2
CO_2H
$(CH_2)_5CH_3$
O
129
125
$CH_3SO_2C\ell$
Et_3N
$CH_2C\ell_2$
O
CO_2CHPh_2
$(CH_2)_5CH_3$
130
$A\ell C\ell_3$
anisole
$CH_2C\ell_2$
CH_3NO_2
O
CO_2H
$(CH_2)_5CH_3$
131

Pharmacological Test

The compounds of the invention were tested for their pharmacological activities. The results of the tests are provided below.

Test 1

Cats (3.0-6.5 kg) were anesthetized with ketamine (10 mg/kg, i.m), and 0.4% oxybuprocaine was applied to the animals' eyes in the form of an eye drop. The intraocular pressure was measured using applanation pneumatonometer (Japan Alcan Inc.).

The test compounds were suspended in physiological saline. Each 25 μl portion of the suspensions was applied to either one of the eyes of the animals, and the contralateral eye received 25 μl of physiological saline. The intraocular pressure was measured at 0.5, 1, 2, 3 hours after administration. One group comprised 3-6 animals.

The results are shown in Table 1. The numerical values in the table are the mean of the differences between intraocular pressure values for the treated eye and the control eye.

Table 1

Compound No.	dose (μg)	difference(mmHg)
6	50	4.4
6	10	2.0
6'	50	1.1
7	50	6.2
7	10	1.3
8	50	3.7
8	10	2.1
8'	50	3.4
12	50	1.1
13	50	0.7
21	50	5.1
28	50	3.0
28'	50	2.0
29	50	3.8
29'	50	1.3
110	100	1.2
119	100	2.2
122	100	2.4
126	100	0.3
127	100	2.2
129	100	0.2
131	100	1.0
A	50	5.0
B	50	2.8
C	50	5.8
D	50	4.5
E	50	2.4

A: PGE2

B: $PGF_{2\alpha}$

C: $PGF_{2\alpha}$ isopropyl ester

D: 13,14-dihydro-15-keto $PGF_{2\alpha}$

E: 20-ethyl-13,14-dihydro-15-keto $PGF_{2\alpha}$ isopropylester

The above results apparently demonstrate that 15-deoxy PG derivatives have significant intraocular pressure-reducing activity.

Test 2

Test compounds were administered topically to the eye of a Rhesus monkey (female, 4.2-6.1 kg), and the intraocular pressure was measured over four hours. The intraocular pressure was measured using applanation pneumatonometer (Japan Alcan Inc.) after surface anesthesia treatment with 0.4 % oxybuprocaine. The test compounds were suspended in physiological saline. Each 25 μl portion of the suspension was applied to either one of the eyes of the animals, and the contralateral eye received 25 μl of only physiological saline as a control. One group comprised 3-7 animals. The results are shown in Table 2. The numerical values in the table are the mean of the differences between the intraocular pressure values of the treated eye and the control eye.

As shown in Table 2, each of 15-deoxy PG derivatives is an effective intraocular pressure-reducing agent in the monkey. Additionally, Table 2 also demonstrates that the 15-deoxy PG derivatives are equivalent to or more than timolol maleate in their activities, which is currently used most frequently in clinical fields.

A'

Table 2

Compound No.	dose(μg)	difference(mmHg)
6	20	3.0
6	50	3.4
7	50	2.8
8	10	1.0
8	50	2.7
timolol maleate	100	3.2

Test 3

Possible side effects which may be produced by the test compounds of the invention were examined using rabbits (male, 2.2-2.5 kg) fixed to a rabbit retainer. The test compounds were suspended in physiological saline. Each 25 μl portion of the suspension was administered to either one of the eyes of the animals, and the contralateral eye received 25 μl of physiological saline as a control. According to the criteria described in Y. Goh, M. Nakajima, I. Azuma and O. Hayaishi, Jpn. J. Ophthalmol., 32, 4-71(1988), the side effects such as conjunctival hyperemia, iris hyperemia, and irritation (which was judged from lid closing response) were observed over four hours after the ophthalmic administration. One group comprised 3-5 animals.

A

The results are shown in Table 3. The data in Table 3 illustrates typical values.

The evaluations were carried out using the following symbols; -: non-reaction, ±: weak reaction, +: apparent reaction, and ++: strong reaction.

The results in Table 3 apparently demonstrate that all of the 15-deoxy PG derivatives exhibit much lower side effects. Particularly, the 15-deoxy PG derivatives exhibit significantly lower side effects than $PGF_{2\alpha}$ and $PGF_{2\alpha}$ isopropyl ester which are recommended in Japanese Patent Publication No. 1418/1984, and the known 13,14-dihydro-15-keto PG derivatives.

Table 3

Compound No.	Dose (μg)	Side effect C.H.[1)]	I.H.[2)]	IR[3)]
6	100	-	-	-
6	50	-	-	-
6′	100	±	-	-
6′	50	-	-	-
7	50	-	-	-
7	10	-	-	-
8	50	-	-	-
8	10	-	-	-
8′	50	±	-	-
12	50	-	-	-
13	50	-	-	-
21	50	±	-	-
28	50	-	-	-
28′	50	±	-	-
29	50	±	-	-
29′	50	-	-	-
110	100	+	±	-
119	100	-	-	-
122	100	-	-	-
126	100	±	±	-
127	100	+	+	+
129	100	+	±	±
131	100	±	±	±
A	50	++	++	++
B	50	++	++	++
C	50	++	++	++
D	50	±	++	-
E	50	++	++	++
F	50	++	+	-
G	50	+	++	-
H	50	++	++	-

A: PGE_2

B: $PGF_{2\alpha}$

C: $PGF_{2\alpha}$ isopropyl ester

D: 13,14-dihydro-15-keto $PGF_{2\alpha}$

E: 20-ethyl-13,14-dihydro-15-keto $PGF_{2\alpha}$ isopropyl ester

F: 15-keto $PGF_{2\alpha}$

G: 9β- $PGF_{2\alpha}$

H: 15-(R) $PGF_{2\alpha}$

1) conjunctival hyperemia

2) iris hyperemia

3) Irritation

Test 4

The test compounds were applied to the eyes of rabbits (male, 2.2-2.5 kg) fixed to a rabbit retainer, and the intraocular pressure was measured at 0, 0.5, 1, 2, 3 hours after administration. After conducting surface anesthesia treatment with 0.4 % oxybuprocaine, the intraocular pressure was measured using an applanation pneumatonometer (Japan Alcan Inc.). The test compounds were suspended in physiological saline, and each 25 μl portion of the suspension was administered to either one of the eyes of the animals and the contralateral eye received 25 μl of physiological saline as a control. One group comprised 3-4 animals. The results are shown in Table 4. The numerical values in the table are the mean ($\pm$ SEM) of the results of each of the animals.

As shown in Table 4, 15-deoxy PG derivatives exhibit no initial increase in intraocular pressure, which would be produced by $PGF_{2\alpha}$ or $PGF_{2\alpha}$ isopropyl ester.

Table 4

Compound	Dose (μg)		Time (hr) 0	0.5	1.0	2.0	3.0
6	200	TE	17.4±0.3	18.6±0.5	17.5±0.5	16.5±0.8	15.10.8
		CE	17.4±0.5	18.5±1.4	18.8±0.5	18.1±1.4	19.1±1.2
8	200	TE	16.8±0.3	14.2±0.9	13.5±0.8	15.0±1.2	15.3±1.1
		CE	16.8±0.8	16.5±0.5	16.3±1.2	17.7±1.4	18.0±0.9
B	50	TE	17.1±0.6	22.3±0.3	19.0±1.2	16.5±1.3	12.3±1.1
		CE	17.5±0.9	17.8±0.9	17.6±0.5	18.1±1.2	18.4±0.8
C	50	TE	21.0±1.2	23.2±0.9	20.8±0.3	13.0±0.5	12.5±0.3
		CE	20.8±1.4	18.8±0.9	19.0±1.2	17.5±0.3	21.0±1.3

TE: treated eye, CE: control eye

B : $PGF_{2\alpha}$

C : $PGF_{2\alpha}$ isopropyl ester

Stability Test

The following description shows procedures and results of stability tests of the compounds of the invention.

Test 5

Crystals (10.65 mg) of 15-deoxyprostaglandin $F_{2\alpha}$·Na (Example 36) were dissolved in 10 ml of 0.05 M phosphate buffer (pH 6.5). The solution was filtered through the membrane (Millipore*, MILLEX-HV*) to yield a 0.1% solution (pH 6.5). The stability test was carried out on the resultant solution to give the data as shown in Tables 5 and 6 which are described hereinafter.

*Trade mark

Test 6

Crystals (10.84 mg) of 15-deoxyprostaglandin $F_{2\alpha}$·Na were dissolved in 10 ml of 0.05 M phosphate buffer (pH 7.0). The solution was filtered through the membrane (Millipore*, MILLEX-HV*) to yield a 0.1% solution (pH 7.0). The stability test was carried out on the resultant solution to give the data as shown in Tables 5 and 6 which are described hereinafter.

Test 7

Crystals (10.35 mg) of 15-deoxyprostaglandin $F_{2\alpha}$·Na were dissolved in 10 ml of 0.05 M phosphate buffer (pH 7.5). The solution was filtered through the membrane (Millipore*, MILLEX-HV*) to yield a 0.1% solution (pH 7.4). The stability test was carried out on the resultant solution to give the data as shown in Tables 5 and 6 which are described hereinafter.

Test 8

Crystals (1.10 mg) of 15-deoxyprostaglandin $F_{2\alpha}$·Na were dissolved in 10 ml of 0.05 M phosphate buffer (pH 7.5). The solution was filtered through the membrane (Millipore*, MILLEX-HV*) to yield a 0.01% solution (pH 7.4). The stability test was carried out on the resultant solution to give the data as shown in Table 5 which is described hereinafter.

*Trade mark

Table 5

Results of stability test of 15-deoxy $PGF_{2\alpha}$·Na solutions in boiling water bath (remaining %)

Time (hours)	2	4	6	8
Test 5 (0.1%,pH6.5)	102.9%	101.9%	101.9%	101.7%
Test 6 (0.1%,pH7.0)	100.9%	100.0%	101.1%	99.8%
Test 7 (0.1%,pH7.4)	101.2%	98.9%	99.6%	102.9%
Test 8 (0.01%,pH7.4)	100.9%	101.4%	103.5%	102.4%

Table 6

Results of accelerated stability test of 15-deoxy $PGF_{2\alpha}$·Na solutions (remaining %)

	60°C		50°C		40°C
Time (months)	0.5	1	0.5	1	1
Test 5	101.1%	98.4%	98.6%	98.4%	102.8%
Test 6	101.6%	101.2%	101.8%	100.4%	100.3%
Test 7	97.3%	98.1%	99.8%	99.1%	97.6%

A

Test 9

Crystals (10.29 mg) of 15-deoxyprostaglandin $F_{2\alpha}$·Na were dissolved in 10 ml of 0.05 M phosphate buffer (pH 7.5) to which 0.05 % methylparaben, 0.02 % propylparaben, and 0.6 % sodium chloride had been added. The solution was filtered through the membrane (Millipore*, MILLEX-GV*) to yield a 0.1% solution (pH 7.2) which is useful as an eye drop. The stability test was carried out on the resultant solution to give the data as shown in Tables 7 and 8 which are described hereinafter.

Test 10

Crystals (1.06 mg) of 15-deoxyprostaglandin $F_{2\alpha}$·Na were dissolved in 10 ml of 0.05 M phosphate buffer (pH 7.5) to which 0.05 % methylparaben, 0.02 % propylparaben, and 0.6 % sodium chloride had been added. The solution was filtered through the membrane (Millipore*, MILLEX-GV*) to yield a 0.01% solution (pH 7.2) which is useful as an eye drop. The stability test was carried out on the resultant solution to give the data as shown in Tables 7 and 8 which are described hereinafter.

*Trade mark

Table 7

Results of stability test of 15-deoxy $PGF_{2\alpha}$·Na solutions in boiling water bath (remaining %)

Time (hours)	2	4	6	9
Test 9 (0.1%)	100.6%	99.6%	99.4%	100.4%
Test 10 (0.01%)	99.2%	99.7%	98.9%	99.6%

Test 8

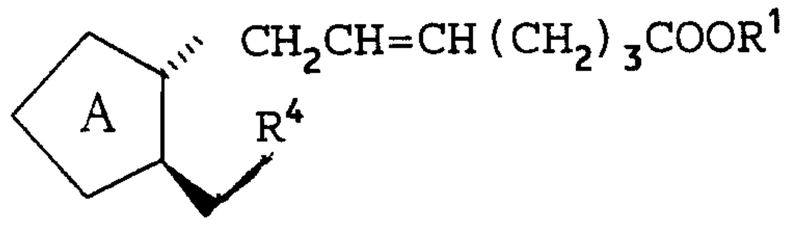
Results of accelerated stability test of 15-deoxy $PGF_{2\alpha}$·Na solutions (remaining %)

	60°C		50°C		40°C
Time (months)	0.5	1	0.5	1	1
Test 9	100.5%	101.3%	98.8%	98.6%	98.4%
Test 10	98.4%	97.4%	98.0%	98.7%	99.2%

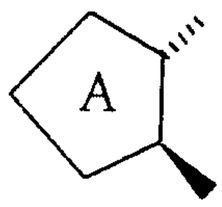
The above data demonstrates that the formulations of the invention are very stable. This results show that the formulations are useful for pharmaceutical use.

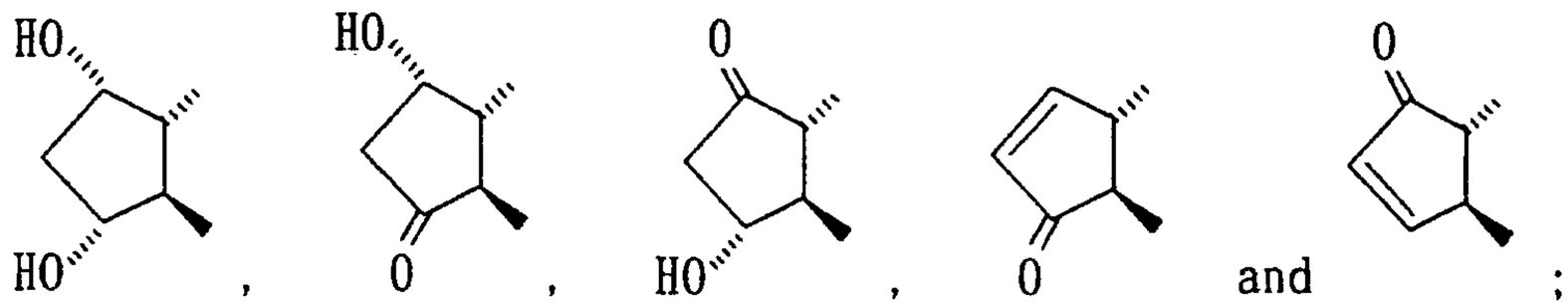
Claims:

1. A 15-deoxyprostaglandin derivative of the formula (V):



(V)

in which  is a 5-membered ring which is selected from the group consisting of



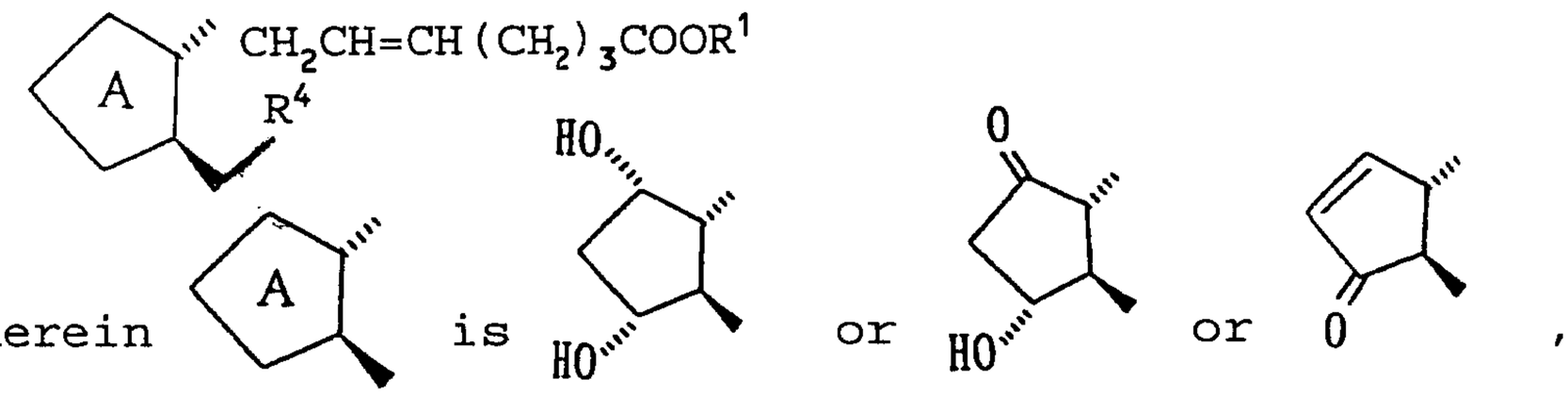
;

R^1 is hydrogen or C_1-C_5 alkyl;

R^4 is a C_5-C_{11} alkyl, C_5-C_{11} alkenyl or C_5-C_{11} alkadienyl;

or pharmaceutically acceptable salts thereof;

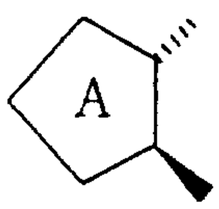
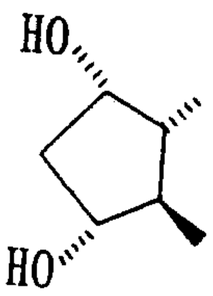
with the proviso that compounds of the following formulae are excluded:



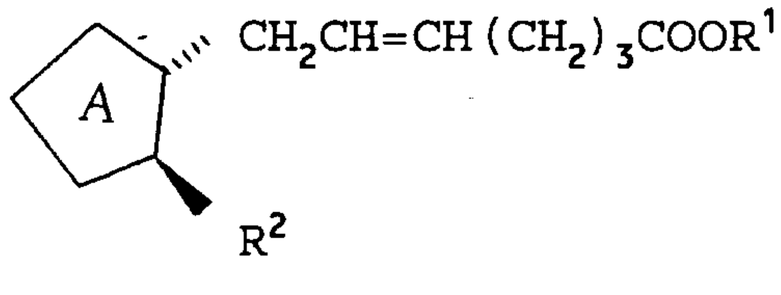
and wherein R^4 is C_5-C_{11} alkyl or pharmaceutically acceptable salts thereof.

2. The 15-deoxyprostaglandin derivative of claim 1 in which R^4 is C_7-C_9 alkyl or C_7-C_9 alkenyl.

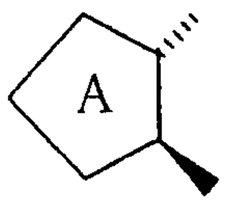
3. The 15-deoxyprostaglandin derivative of claim 1 or 2

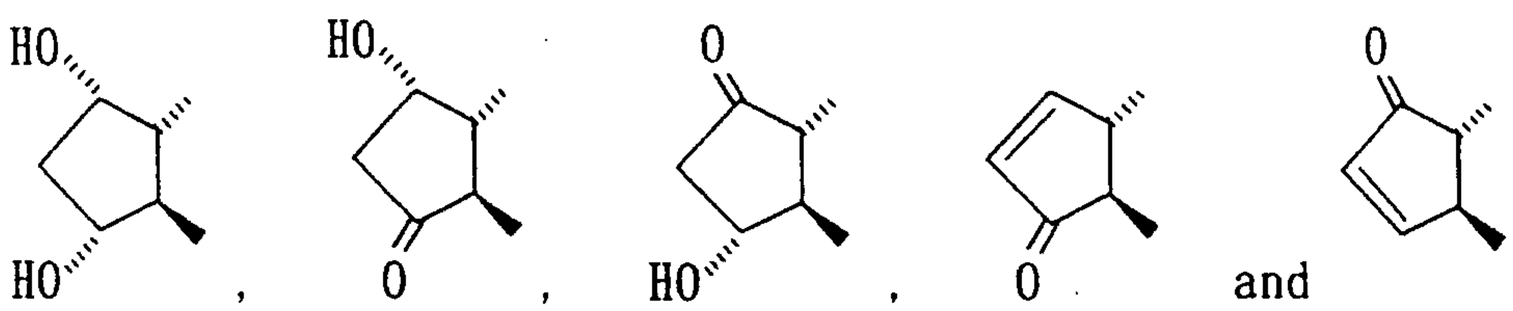
in which  is  .

4. A pharmaceutical formulation comprising a therapeutically effective amount of a 15-deoxyprostaglandin derivative as the active ingredient, in admixture with a pharmaceutically acceptable carrier or diluent which is useful as an intraocular pressure reducing agent, in which the 15-deoxyprostaglandin derivative of the formula (I):



(I)

in which  is a 5-membered ring which is selected from the group consisting of



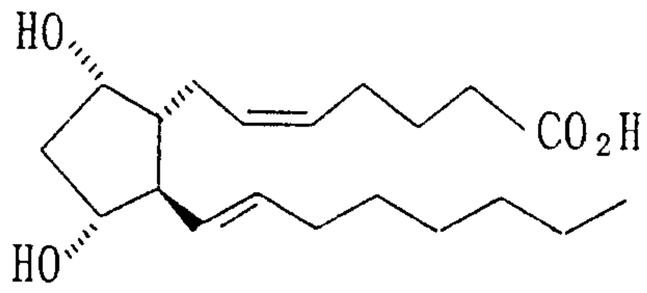
R^1 is hydrogen or C_1-C_5 alkyl;

R^2 is C_6-C_{12} alkyl, C_6-C_{12} alkenyl or C_6-C_{12} alkadienyl; or pharmaceutically acceptable salts thereof.

5. The pharmaceutical formulation of claim 4 in which the 15-deoxyprostaglandin derivative is

C

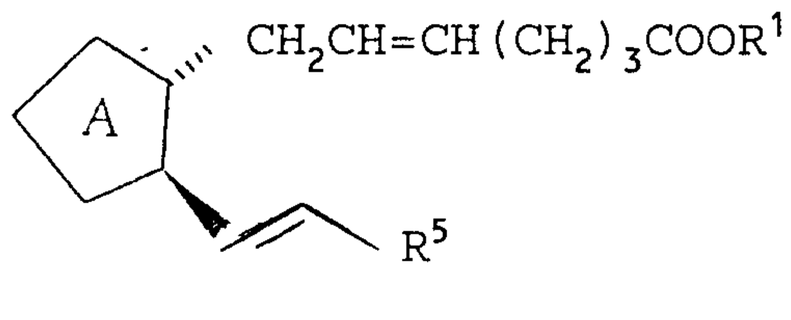
(5Z,13E,9S,11R)-9,11-dihydroxy-5,13-prostadienoic acid of the formula:



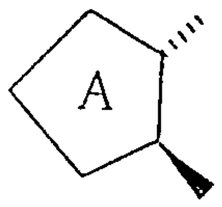
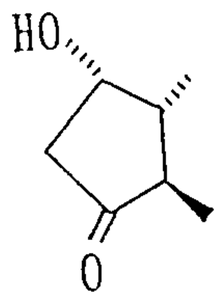
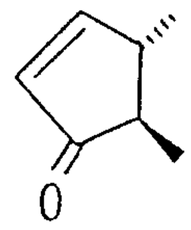
or pharmaceutically acceptable salts thereof.

6. The pharmaceutical formulation of claim 4 or 5 which comprises a sodium salt of a 15-deoxyprostaglandin derivative.

7. A 15-deoxyprostaglandin derivative of the formula (VI):



(VI)

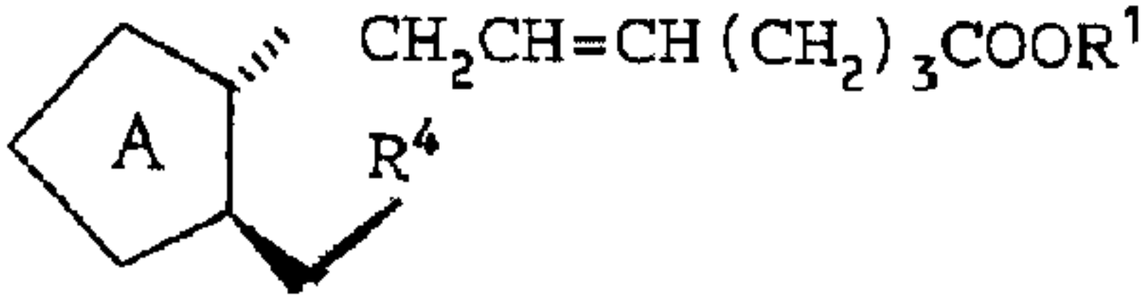
in which  is a 5-membered ring which is  or  ;

R^1 is hydrogen or C_1-C_5 alkyl;

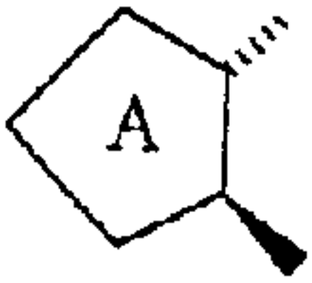
R^5 is C_4-C_{10} alkyl or C_4-C_{10} alkenyl; or

pharmaceutically acceptable salts thereof.

B

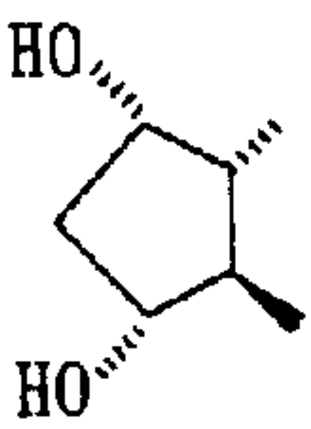
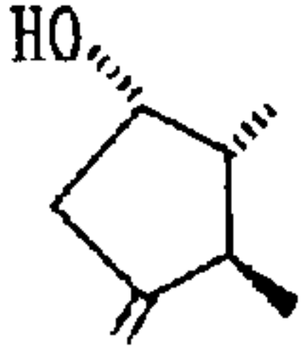
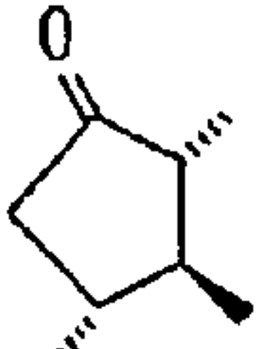
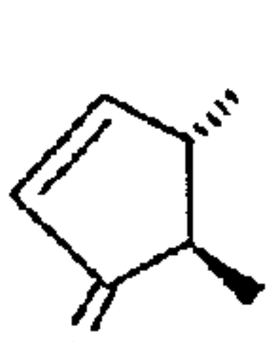
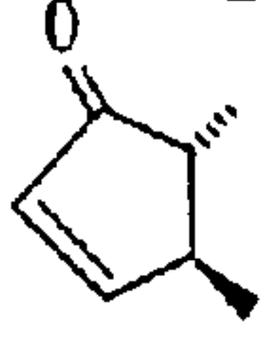


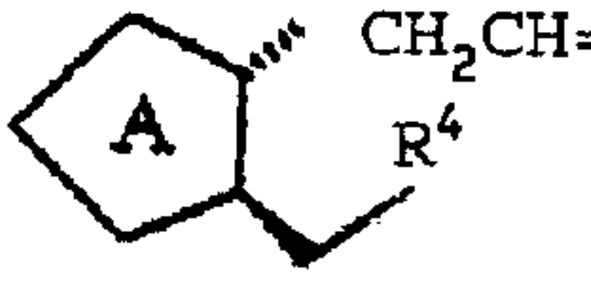
(V)



Va

1a 1b 1c 1d 1e


, 
, 
, 
and 
;

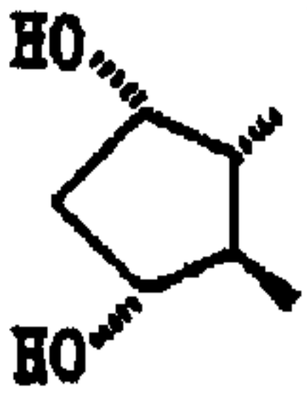


V

Va

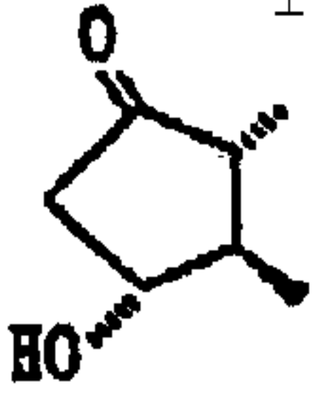
is

1a



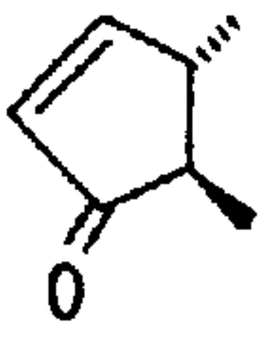
or

1c



or

1d


,