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(71) Demandeur/Applicant:
BOEHRINGER INGELHEIM PHARMACEUTICALS,
INC., US

(72) Inventeurs/Inventors:
FRUTOS, ROGELIO P., US;
JOHNSON, MICHAEL DALE, US

(74) Agent: FETHERSTONHAUGH & CO.

(54) Titre : SYNTHÈSE DE (R)-3-(4-BROMOBENZYL)-1-(3,5-DICHLOROPHENYL)-5-iodo--3-METHYL-1-H-
IMIDAZO[1,2-A]IMIDAZOL-2-ONE

(54) Title: SYNTHESIS OF (R)-3-(4-BROMOBENZYL)-1-(3,5-DICHLOROPHENYL)-5-iodo-3-METHYL-1-H-
IMIDAZO[1,2-A]IMIDAZOL-2-ONE

(57) **Abrégé/Abstract:**

A novel process for the preparation of (R)-3-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-5-iodo-3-methyl-1-H-imidazo[1,2-a]imidazol-2-one (1). This compound is useful as an intermediate in the preparation of certain small molecules that are useful in the treatment or prevention of inflammatory and immune cell-mediated diseases. The present invention also relates to certain intermediates used in this novel process.



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- (74) Agents: RAYMOND, Robert, P. et al.; Boehringer Ingelheim Corporation, 900 Ridgebury Road, P.O. Box 368, Ridgefield, CT 06877-0368 (US).
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- (71) Applicant: BOEHRINGER INGELHEIM PHARMACEUTICALS, INC. [US/US]; 900 Ridgebury Road, P.O. Box 368, Ridgefield, CT 06877-0368 (US).
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- (72) Inventors: FRUTOS, Rogelio, P.; 11 Housatonic Drive, Sandy Hook, CT 06482 (US). JOHNSON, Michael, Dale; 1 Beaver Brook Road, Unit 23, Danbury, CT 06810 (US).
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*



WO 02/12243 A3

(54) Title: SYNTHESIS OF (R)-3-(4-BROMOBENZYL)-1-(3,5-DICHLOROPHENYL)-5-iodo-3-methyl-1-H-imidazo[1,2-a]imidazol-2-one

(57) Abstract: A novel process for the preparation of (R)-3-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-5-iodo-3-methyl-1-H-imidazo[1,2-a]imidazol-2-one (1). This compound is useful as an intermediate in the preparation of certain small molecules that are useful in the treatment or prevention of inflammatory and immune cell-mediated diseases. The present invention also relates to certain intermediates used in this novel process.

**SYNTHESIS OF (*R*)-3-(4-BROMOBENZYL)-1-(3,5-DICHLOROPHENYL)-5-
IODO-3-METHYL-1-*H*-IMIDAZO[1,2-*a*]IMIDAZOL-2-ONE**

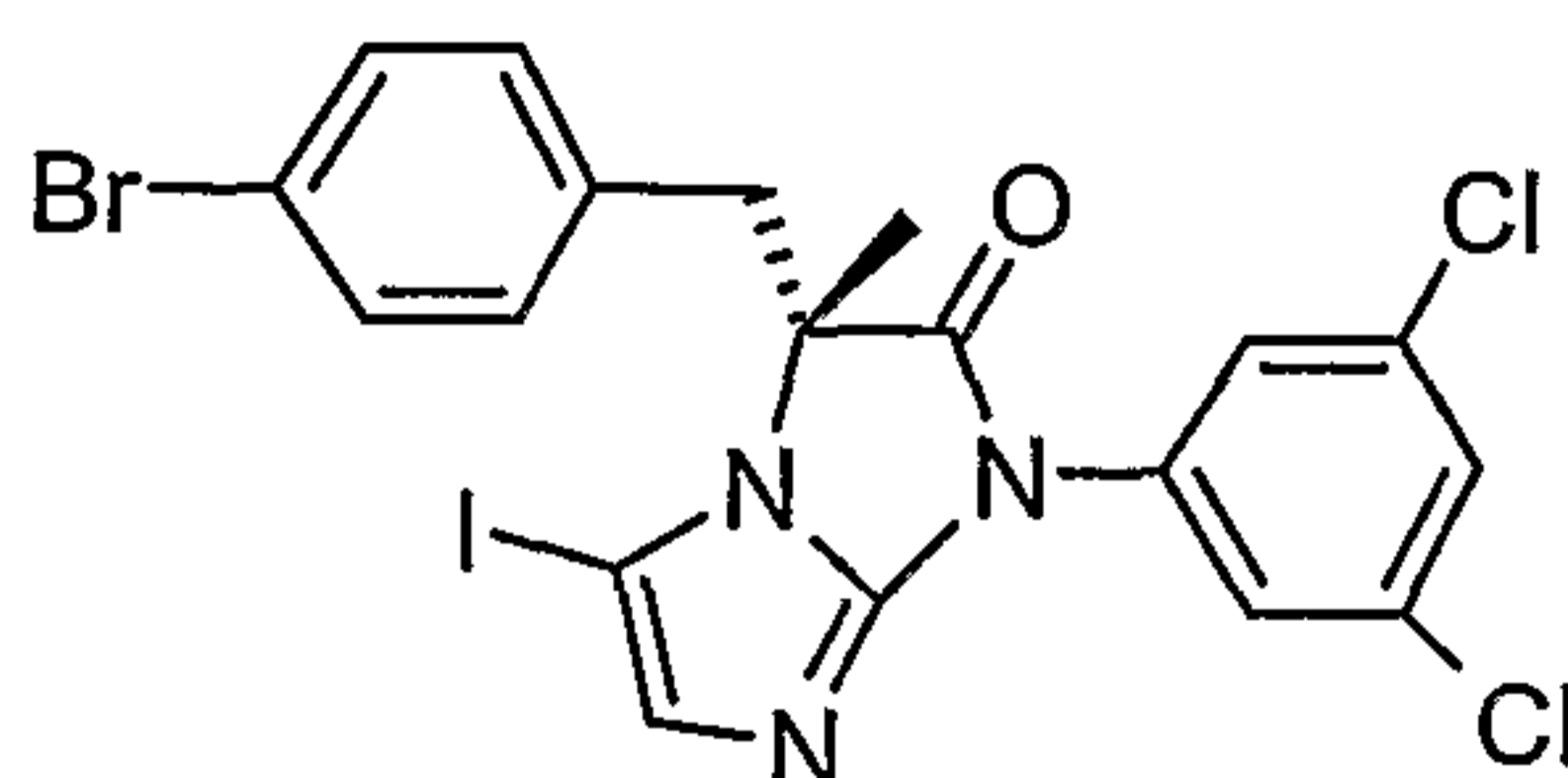
Field of the Invention

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The present invention relates generally to a novel process for the preparation of (*R*)-3-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-5-iodo-3-methyl-1-*H*-imidazo[1,2-*a*]imidazol-2-one. This compound is useful as an intermediate in the preparation of certain small molecules that are useful in the treatment or prevention of inflammatory and immune cell-mediated diseases. The present invention also relates to certain novel intermediates used in this novel process.

Background of the Invention

15 (*R*)-3-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-5-iodo-3-methyl-1-*H*-imidazo[1,2-*a*]-imidazol-2-one (**1**) is an advanced intermediate used in the preparation of certain small molecules that inhibit the interaction of cellular adhesion molecules, specifically by antagonizing the binding of human intercellular adhesion molecules (including ICAM-1, ICAM-2 and ICAM-3) to the Leukointegrins (especially CD18/CD11a or "LFA-1"). As a
20 result, these small molecules are useful in the treatment or prevention of inflammatory and immune cell-mediated diseases. See U.S. Nonprovisional Application No. 09/604,312 (Attorney Docket No. 9/162), Wu et al., filed on June 27, 2000, herein incorporated by



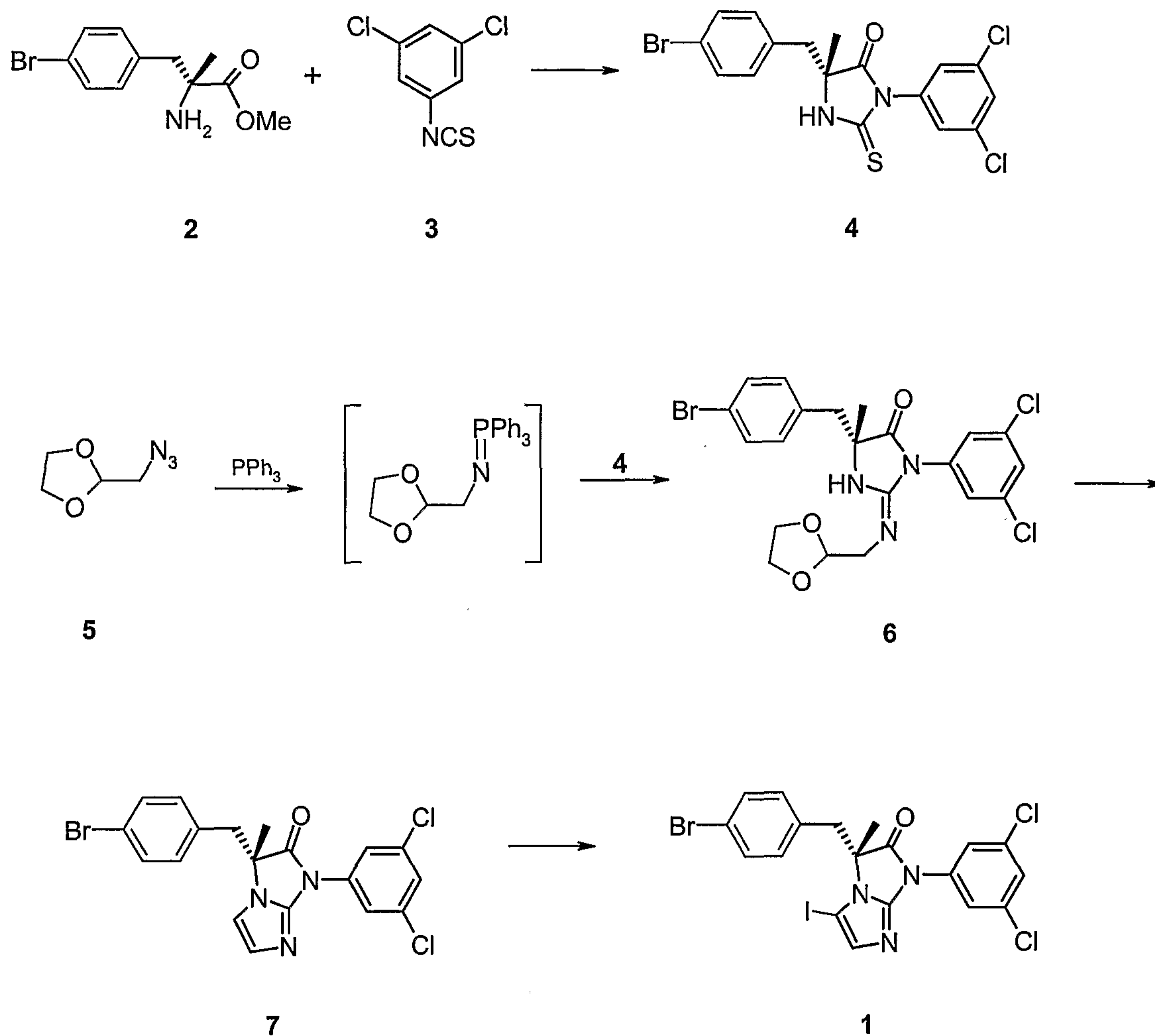
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reference.

25 The method that has been used to prepare compound **1** is illustrated in Scheme 1 below.

Scheme 1

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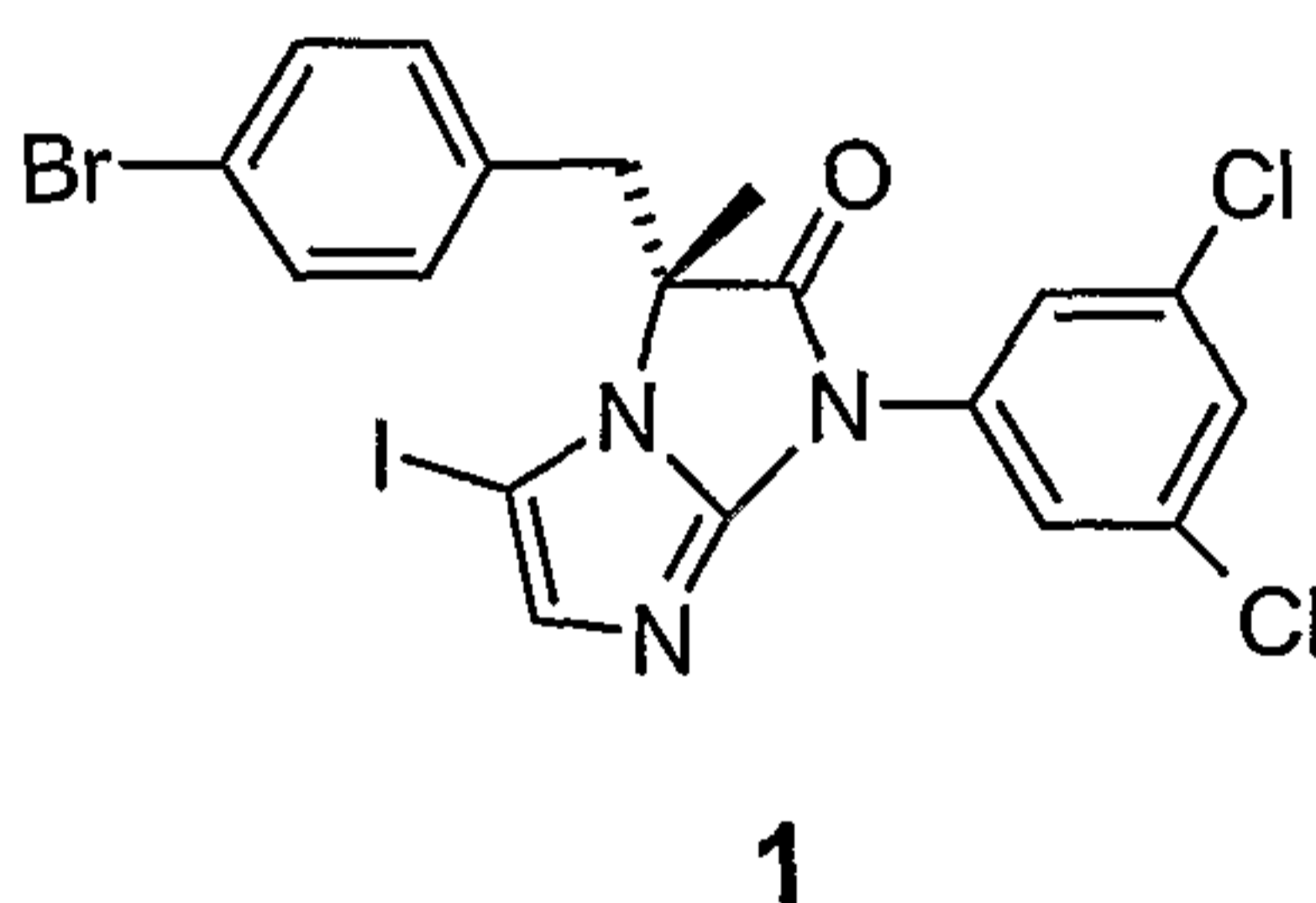


In this procedure, an amino-ester **2** was reacted with 3,5-dichlorophenylisothiocyanate **3** to provide thiohydantoin **4**. To a solution of triphenylphosphine (PPh_3) was added the azide **5**. After stirring at room temperature overnight, thiohydantoin **4** was added to provide **6**. Treatment of **6** with trifluoroacetic acid provided **7**. Iodination was then carried out by reaction of **7** with *N*-iodosuccinimide and pyridinium *p*-toluenesulfonate to provide **1**. Recovered **7** may be recycled to provide additional **1**.

Summary of the Invention

The present invention is directed to a novel process for the preparation of compound **1**.

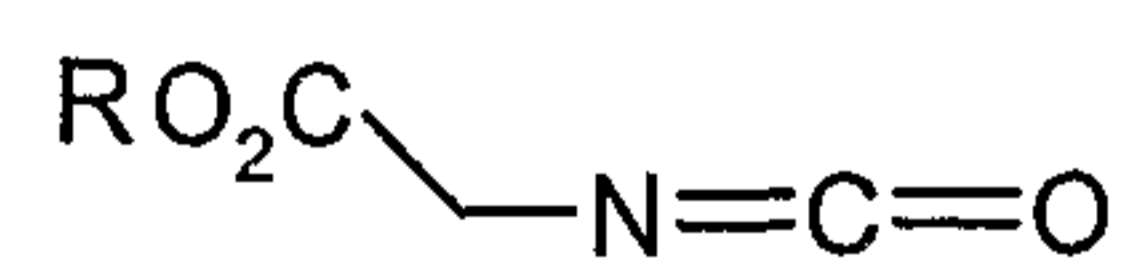
- 5 A first aspect of the invention is directed to a process for preparing a compound of the formula **1**:



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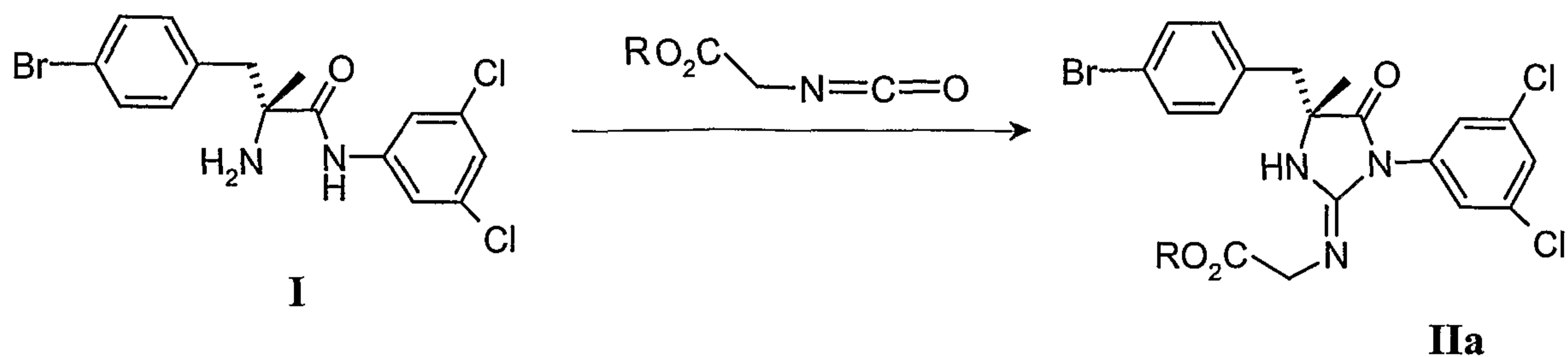
said process comprising the following steps:

- a) reacting a compound of the formula **I** with a compound of the formula

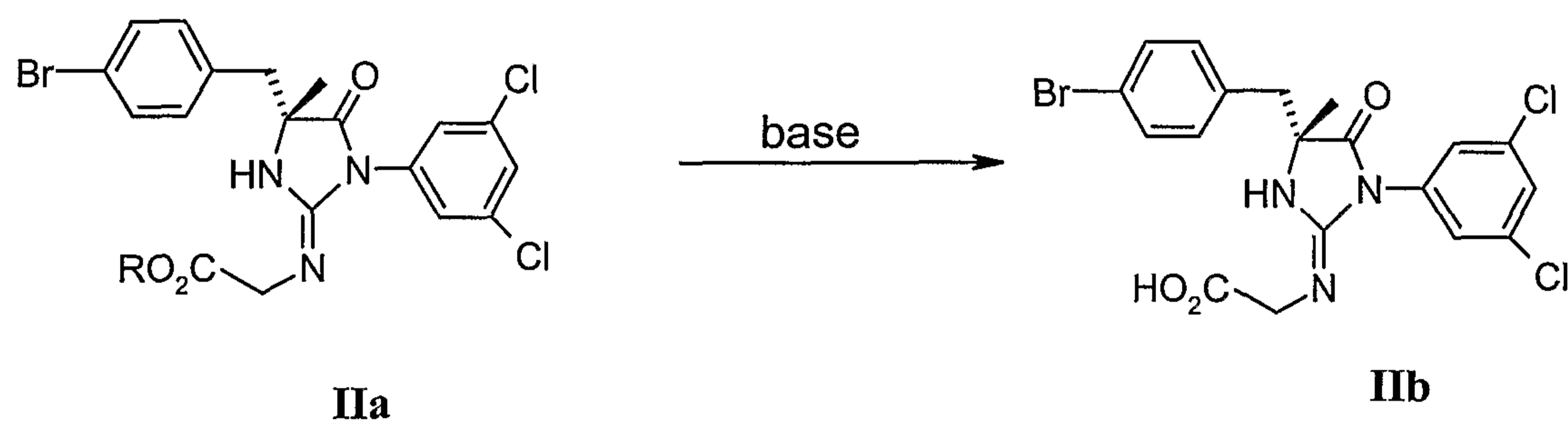


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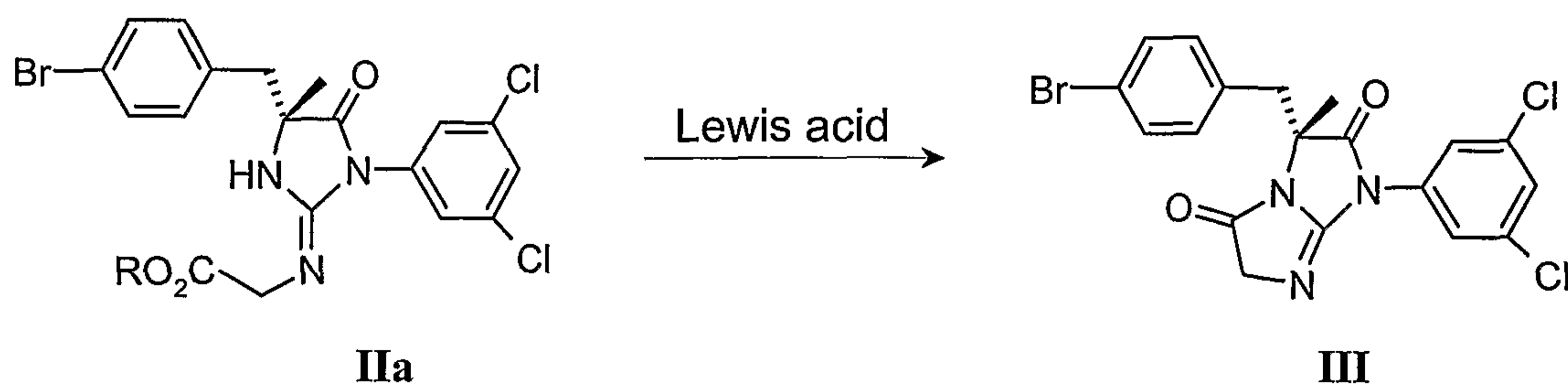
where R is C₁₋₆alkyl, in an aprotic organic solvent, followed by adding a triarylphosphine, a carbon tetrahalide and a tertiary amine, to form a compound of the formula **IIa** where R is C₁₋₆alkyl:



- b) optionally hydrolyzing a compound of the formula **IIa** produced in step a) by reacting the compound of formula **IIa** with a base to form a compound of the formula **IIb**:

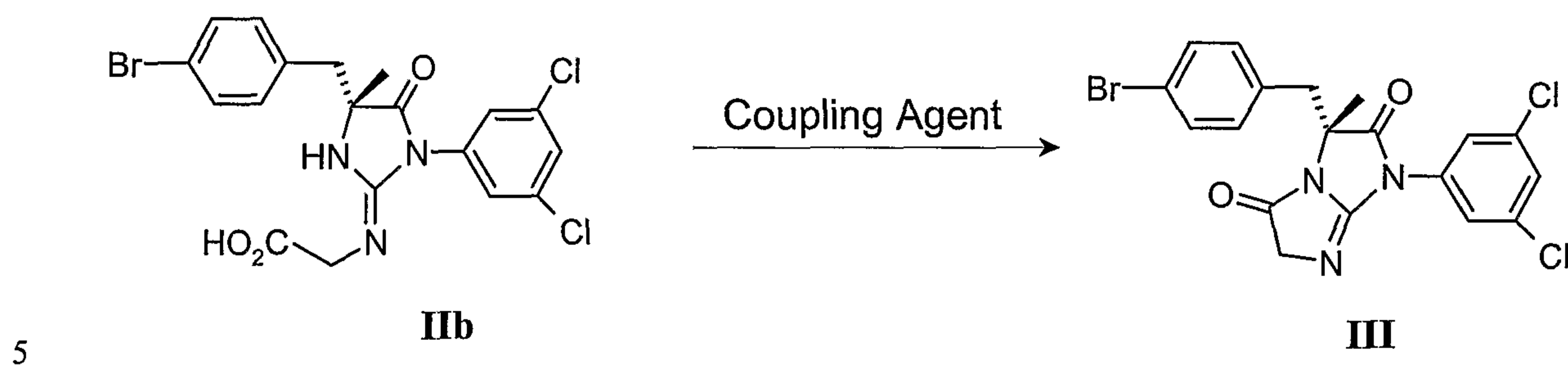


- c) reacting a compound of the formula **IIa** produced in step a) with a Lewis acid and a phosphine oxide compound of the formula $(R_1)_3PO$, wherein R_1 is C_{1-6} alkyl or aryl, in an aprotic organic solvent to form a compound of the formula **III**:



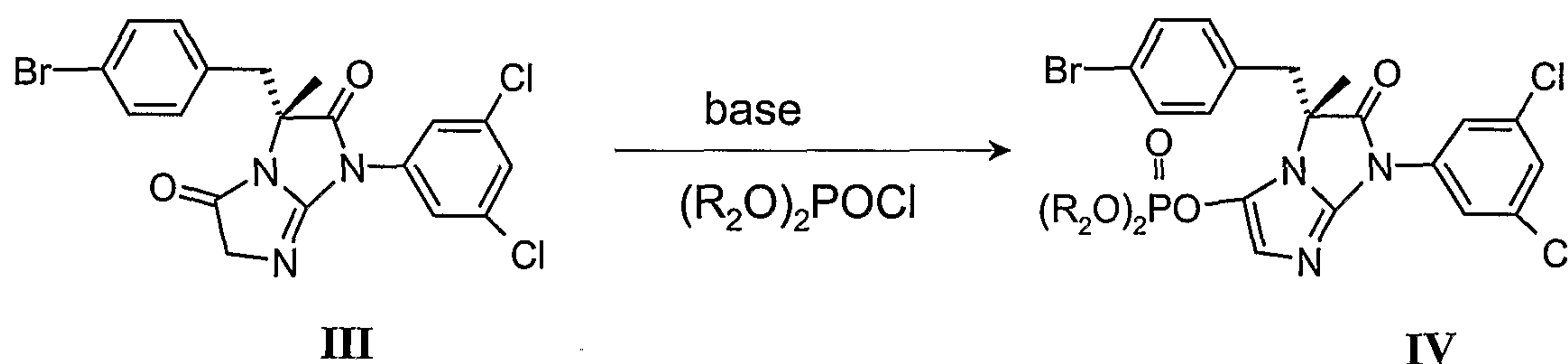
or

when the optional step b) is performed, reacting a compound of the formula **IIb** produced in step b) with a coupling agent in an aprotic organic solvent to form a compound of the formula **III**:



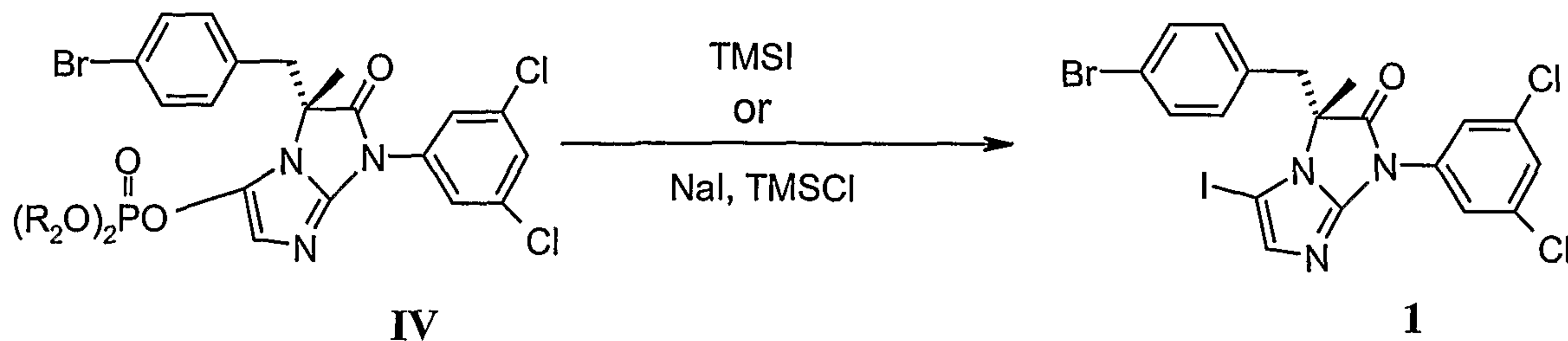
d) reacting a compound of the formula **III** produced in step c) with a strong base and a compound of the formula $(R_2O)_2POCl$, wherein R_2 is C_{1-6} alkyl or aryl, in a polar organic solvent at a temperature of about $-90\text{ }^\circ\text{C}$ to about $0\text{ }^\circ\text{C}$ to form a compound of the formula **IV** where R_2 is C_{1-6} alkyl or aryl:

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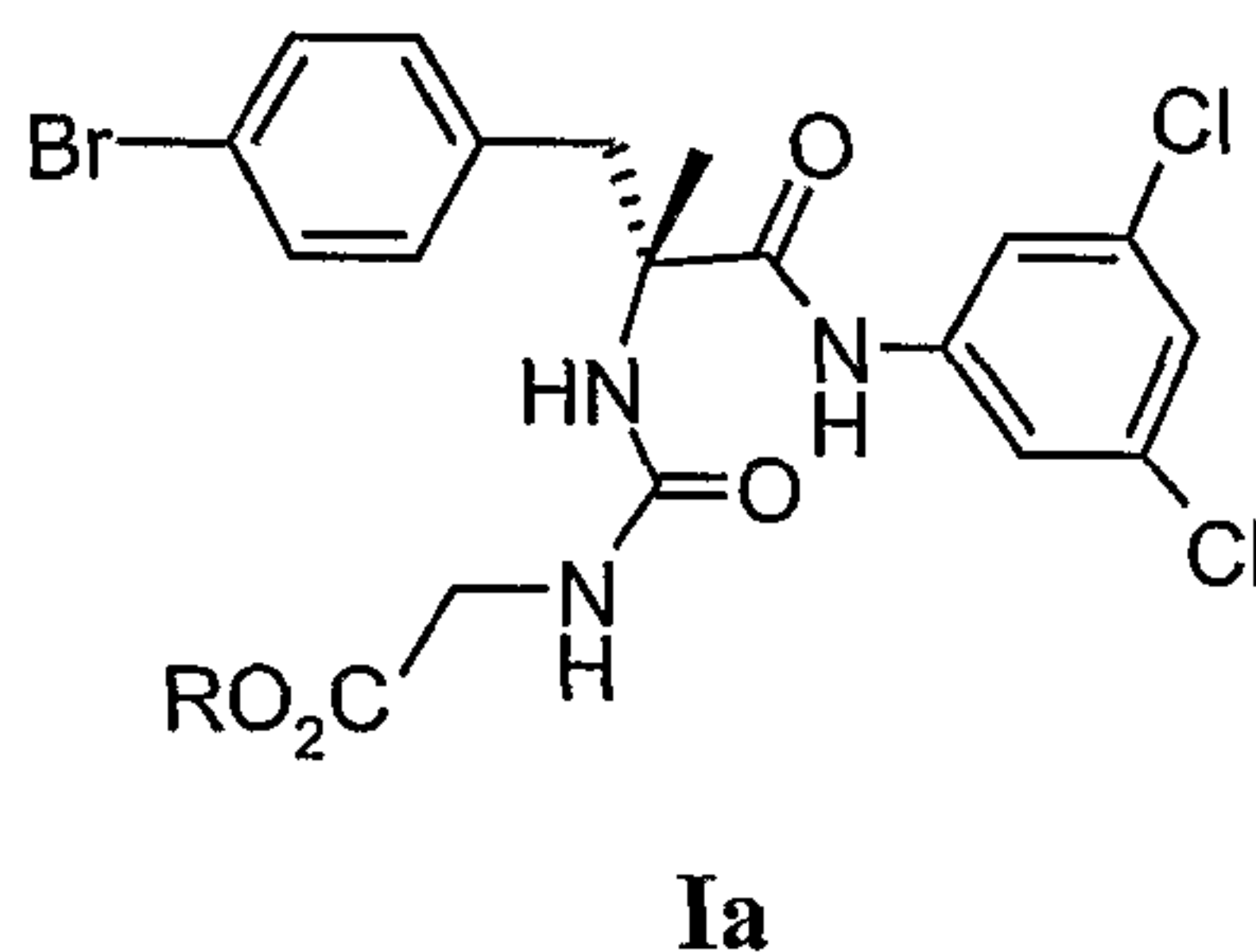
e) reacting a compound of the formula **IV** produced in step d) with trimethylsilyl iodide, or with sodium iodide and trimethylsilyl chloride, in an aprotic organic solvent to form a compound of the formula **1**:

15



A second aspect of the invention is directed to the individual novel steps of the above
 5 inventive process. A third aspect of the invention is directed to the novel intermediates
IIa, **IIb**, **III** and **IV**. A final aspect of the invention is directed to the novel urea
 intermediate of the following formula **Ia** produced in the first step of the inventive process
 and its process of preparation:

10



wherein R is C₁₋₆alkyl.

15

Detailed Description of the Invention

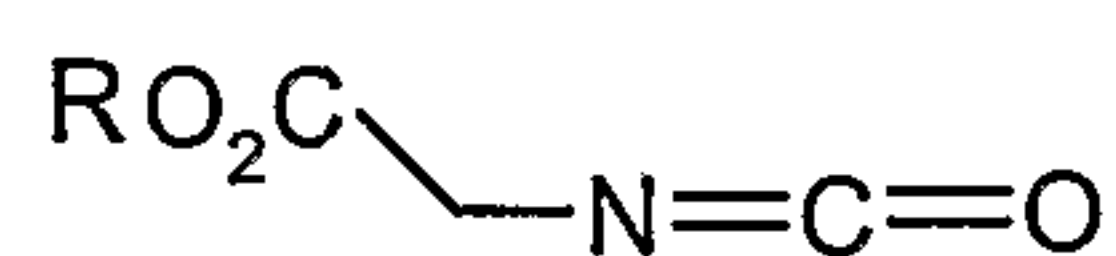
The individual steps of the inventive process are described in detail below, along with
 20 other aspects of the present invention.

All terms as used herein in this specification, unless otherwise stated, shall be understood in their ordinary meaning as known in the art. For example, a "C₁₋₆alkyl" is an alkyl group having from 1 to 6 carbon atoms, which group can be branched or unbranched. The term "aryl", either alone or as part of another group, shall be understood to mean an optionally substituted 6-10 membered aromatic carbocycle; "aryl" includes, for example, phenyl and naphthyl, each of which may be optionally substituted.

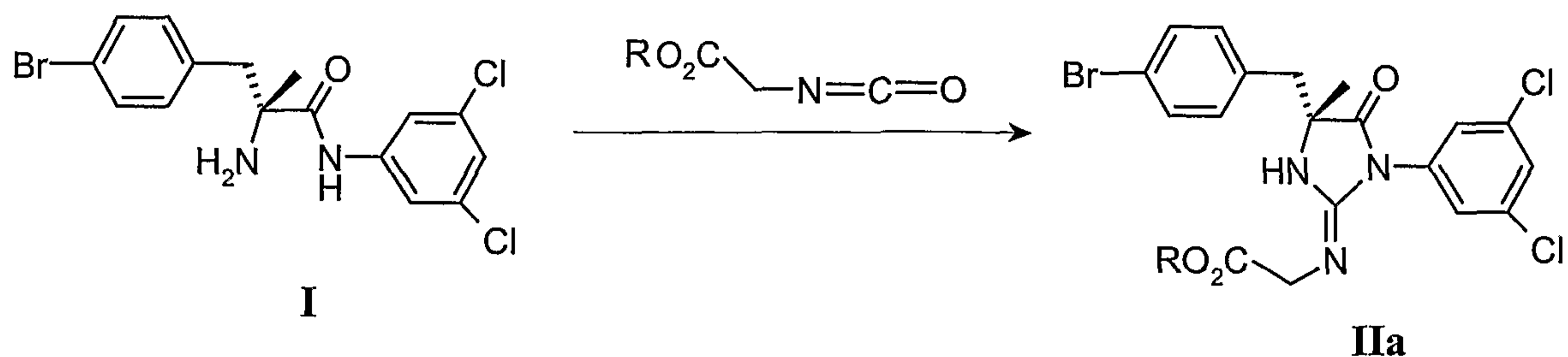
Optimum reaction conditions and reaction times for the individual steps may vary depending on the particular reactants used. Unless otherwise specified, solvents, temperatures, pressures and other reaction conditions may be readily selected by one of ordinary skill in the art. Specific procedures are provided in the Synthetic Examples section. Typically, reaction progress may be monitored by thin layer chromatography (TLC) if desired. Intermediates and products may be purified by chromatography on silica gel and/or recrystallization. Unless otherwise set forth, the starting materials and reagents are either commercially available or may be prepared by one skilled in the art using methods described in the chemical literature.

Step (a)

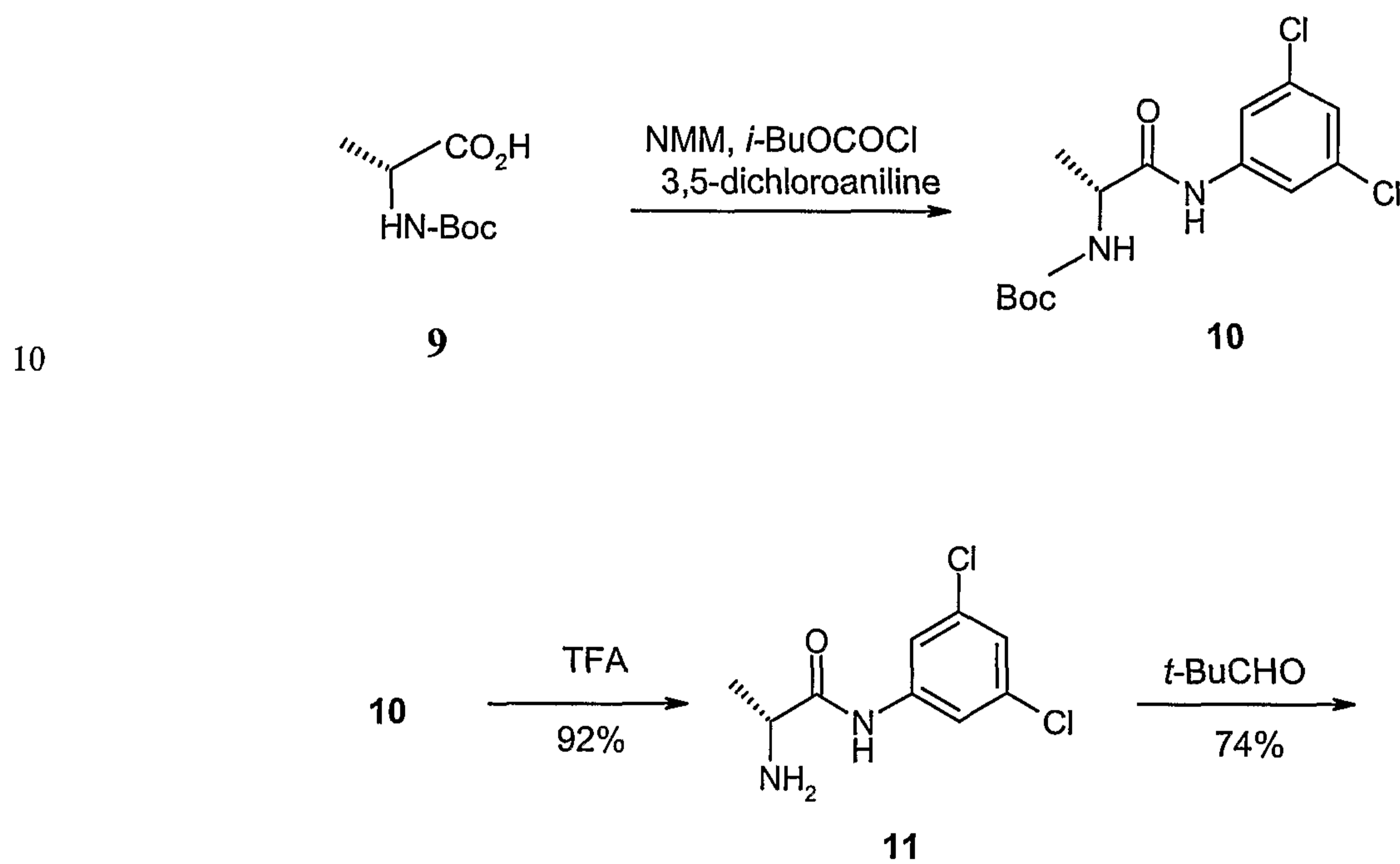
Step a) of the inventive process comprises reacting a compound of the formula I with a compound of the formula

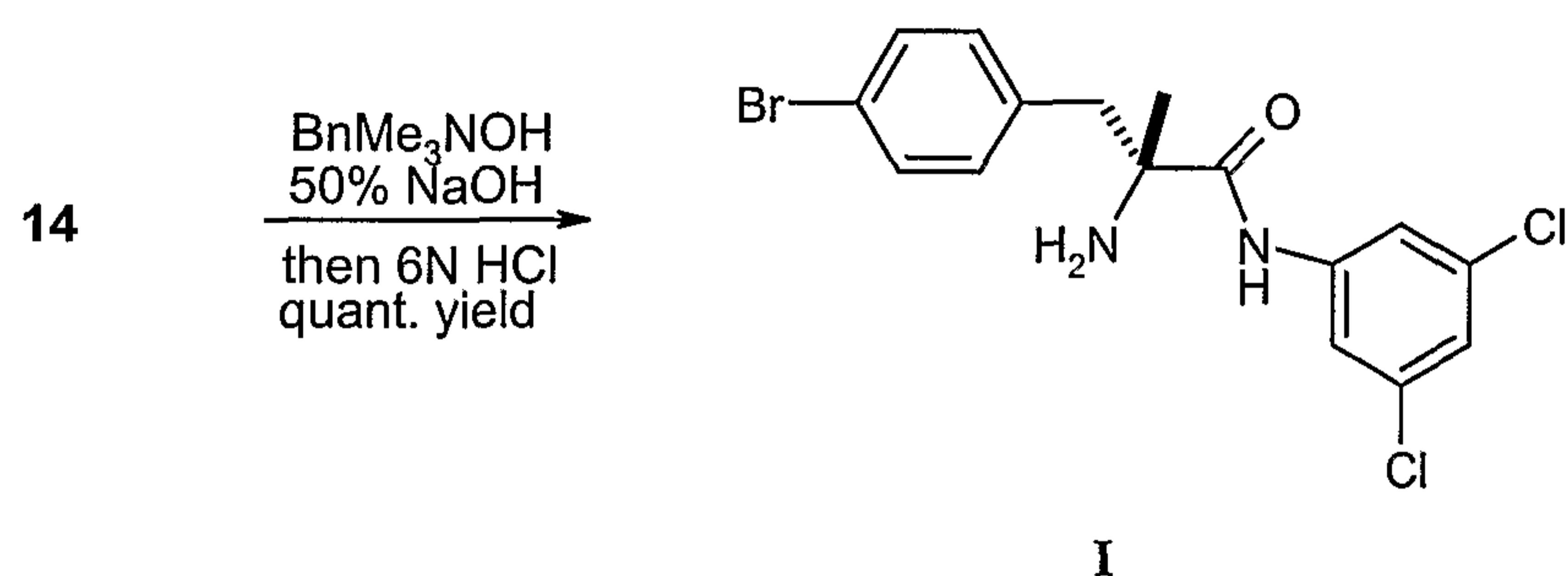
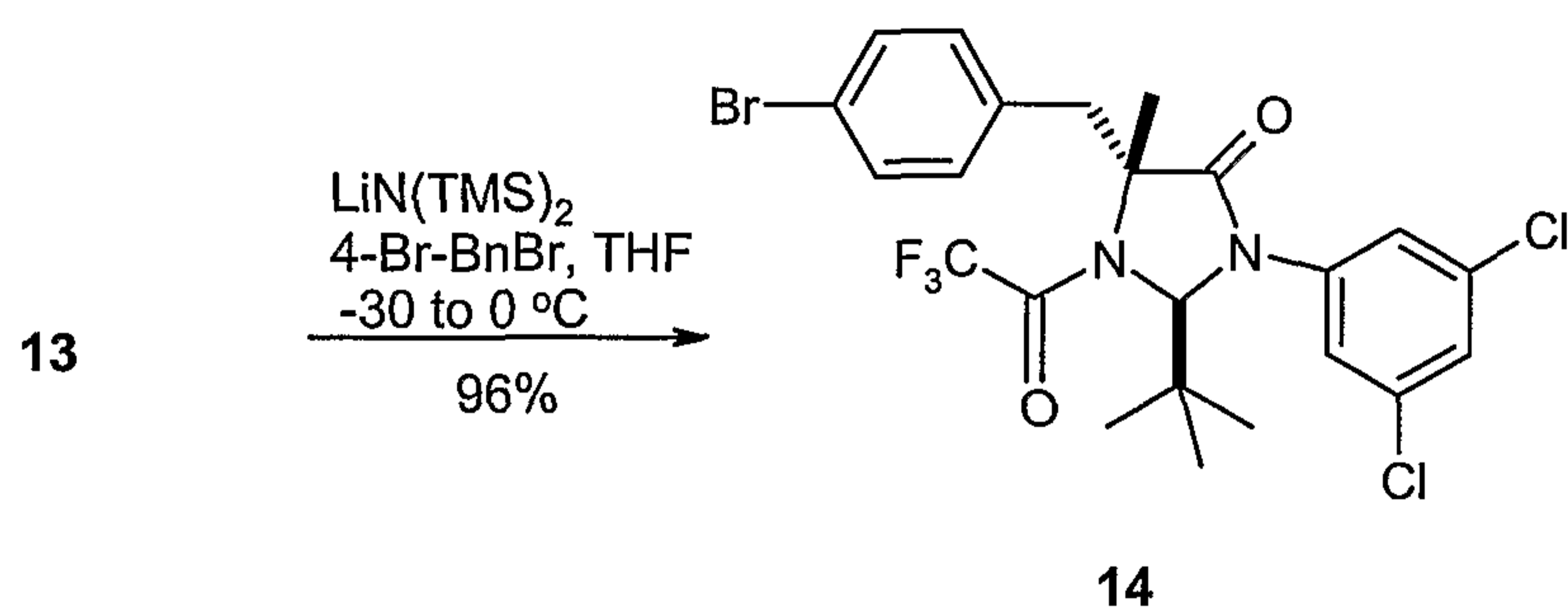
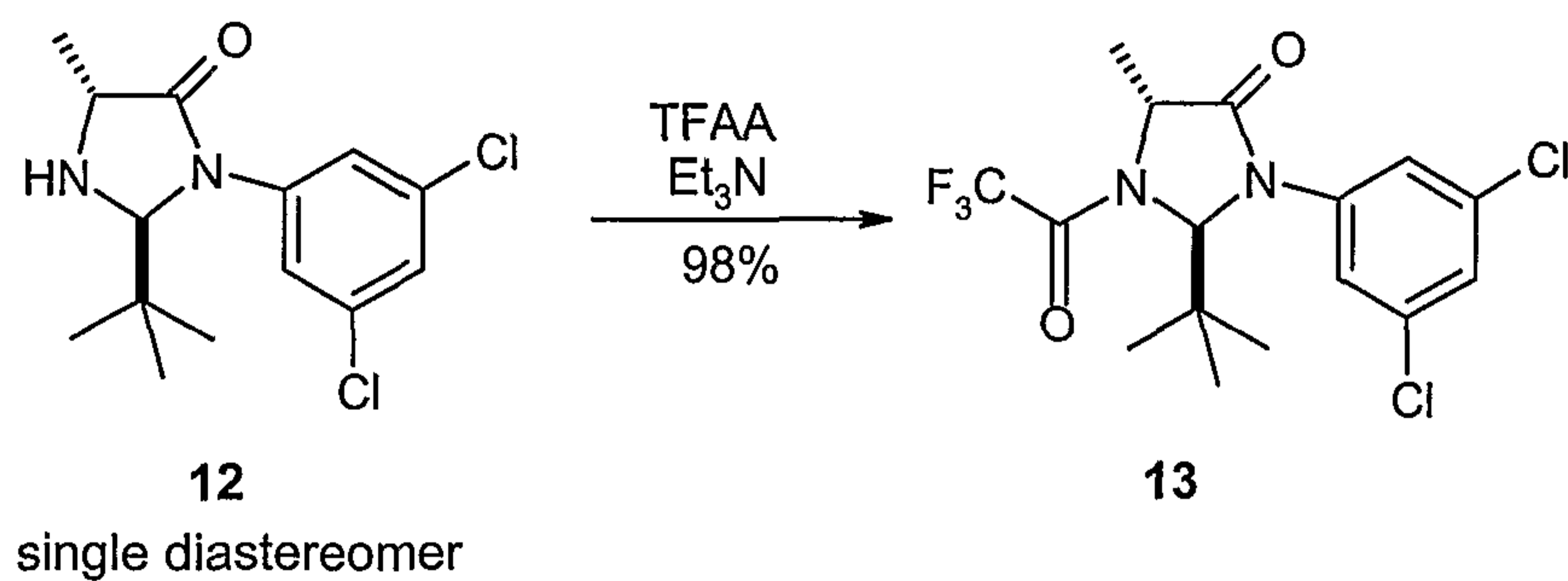


where R is C₁₋₆alkyl, in an aprotic organic solvent, followed by adding a triarylphosphine, a carbon tetrahalide and a tertiary amine, to form a compound of the formula IIa where R is C₁₋₆alkyl:



The starting material of formula **I** is prepared as described in Yee, N., "Self-Regeneration of Stereocenters: A Practical Enantiospecific Synthesis of LFA-1 Antagonist BIRT-377" (submitted and accepted for publication in *Organic Letters*), which is herein incorporated by reference in its entirety. This process is set forth in detail below:





5

The commercially available (D)-N-Boc-alanine **9** is reacted with 3,5-dichloroaniline via a mixed anhydride intermediate (*i*-BuOCOCl, N-methylmorpholine, -10 °C to rt, THF) to give amide **10**. Deprotection of the crude amide **10** by TFA in dichloromethane afforded amino N-aryl amide **11** in 92% yield over two steps.

The amino amide **11** is treated with pivalaldehyde in refluxing pentane. A crystalline solid is directly formed from the reaction mixture and identified as the desired *trans* imidazolidinone **12** as a single diastereomer in 74% yield. After protection of **12** (TFAA,

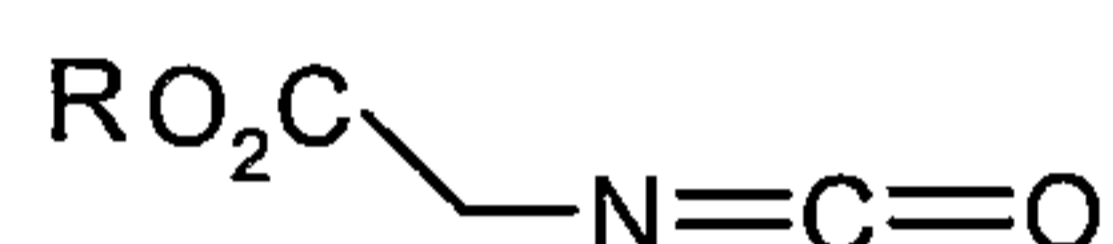
Et₃N, 0 °C to rt, CH₂Cl₂, 98% yield) to obtain **13**, the crude **13** in THF is deprotonated with LiN(TMS)₂ at -30 to -20 °C and then the resulting enolate is alkylated at -30 °C to 0 °C with 4-bromobenzyl bromide from the opposite face of the *t*-butyl group to give the 5,5-disubstituted **14** as a single diastereomer in 96% yield.

5

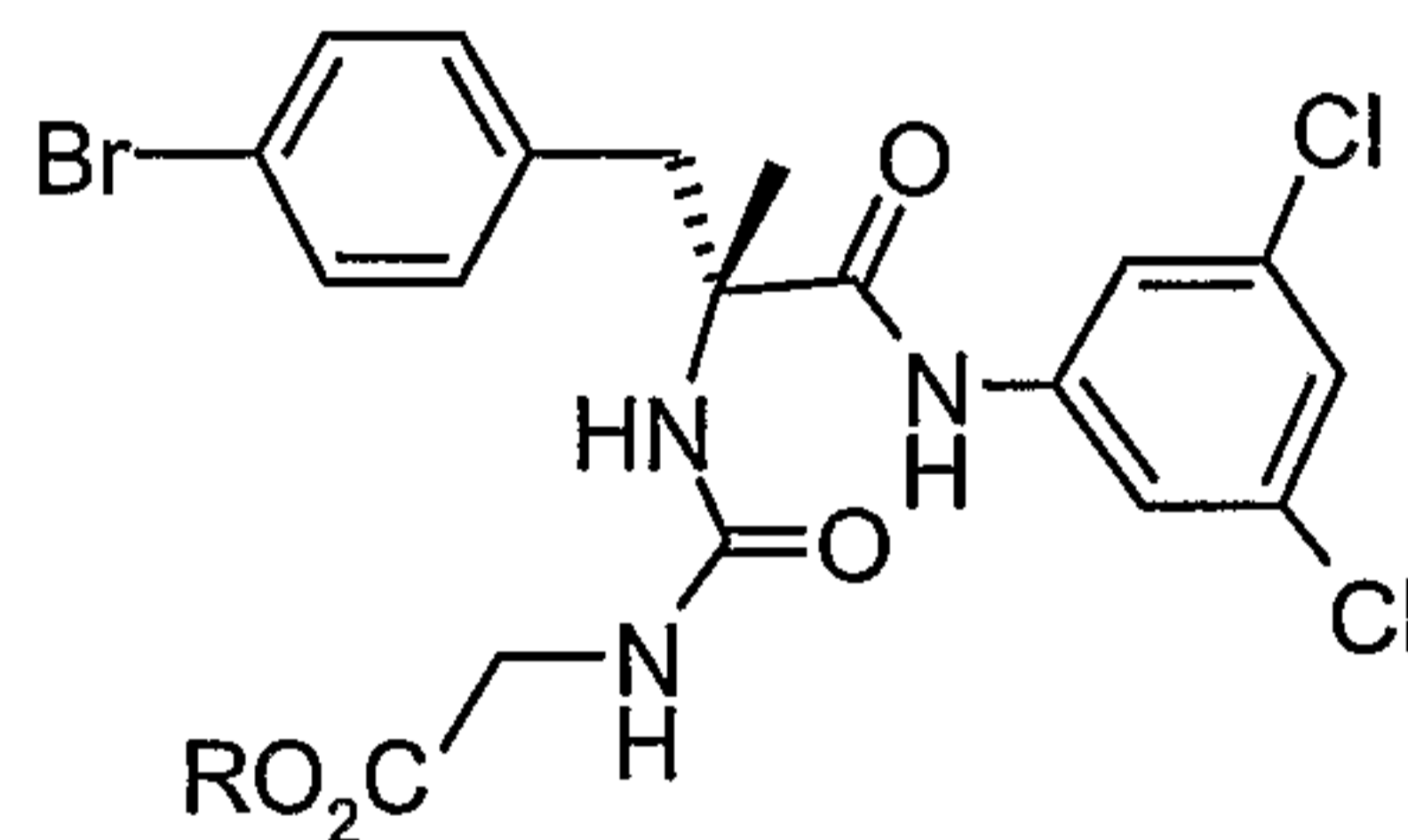
The trifluoroacetamide group of **14** is first hydrolyzed (1.5 eq. BnMe₃NOH, 2.0 eq. 50% NaOH, rt to 40 °C, dioxane) to give a mixture of the corresponding partially hydrolyzed N-unsubstituted acetal of **14**, Schiff base of **I**, and **I** itself. Subsequent direct addition of 6N HCl to the above mixture resulted in complete hydrolysis to afford amino amide **I** in quantitative yield.

10

In step (a) of the present inventive process, the compound of formula **I** is first reacted with an isocyanatoacetate of the formula



15 where R is C₁₋₆alkyl to form a urea of the following formula **Ia** *in situ*:

**Ia**

where R is C₁₋₆alkyl. It is not necessary to isolate the novel urea **Ia**, although it has been isolated and characterized. The urea of formula **Ia** is dehydrated *in situ* by adding a triarylphosphine, a carbon tetrahalide and a tertiary amine to the reaction mixture. The resulting carbodiimide undergoes a spontaneous cyclization to provide the ester of formula **Ia** in good yield.

20

The formation of ureas from isocyanates in general is documented in the scientific literature (See, e.g., *Chem. Rev.* **1981**, 589, and references cited therein). In the process of the present invention, however, it is not necessary to isolate the urea, which can be dehydrated *in situ* to afford a carbodiimide that further undergoes a spontaneous
5 cyclization.

The dehydration of a urea to afford an intermediate carbodiimide is also documented in the literature (Appel, R., Kleinstuck, R., Ziehn, K. *Chem. Ber.* **1971**, 104, 1335). However, the process of the present invention goes beyond the dehydration of the urea intermediate,
10 since the carbodiimide is not isolated and undergoes a spontaneous cyclization to give **IIa**.

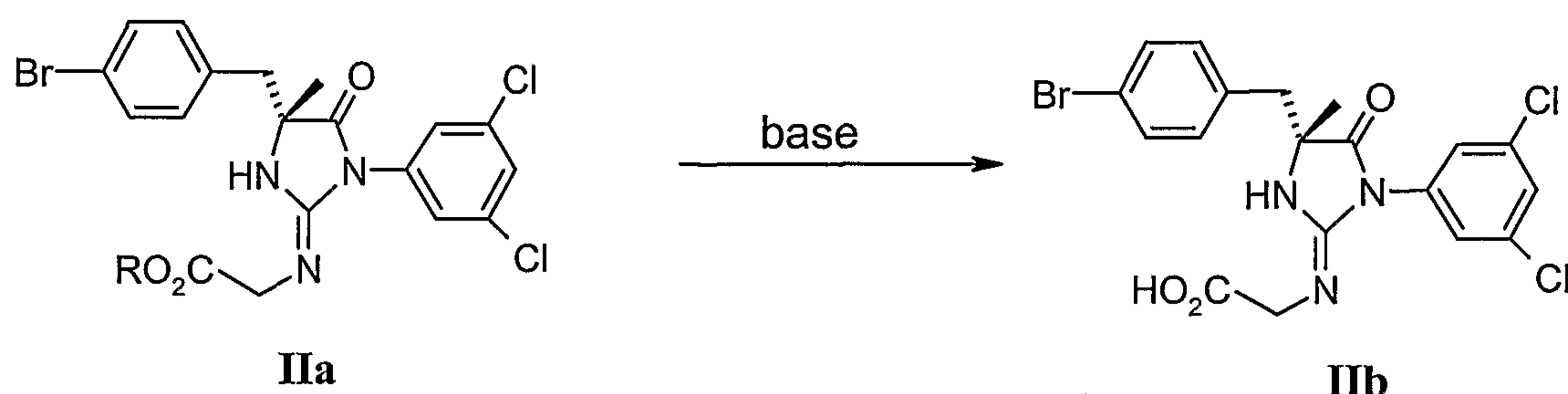
Moreover, the novel compound of formula **IIa** is another aspect of the present invention and is not disclosed in the above cited references.

15 Suitable C₁₋₆alkyl R groups for the isocyanatoacetate and formula **IIa** in step a) include, for example, methyl and ethyl.

Step a) is performed in an aprotic organic solvent. Suitable aprotic organic solvents for this step include, for example, tetrahydrofuran, toluene, dichloromethane, dichloroethane
20 and chloroform. Suitable triarylphosphines in step a) include, for example, triphenylphosphine, wherein the phenyl groups are optionally substituted, for example, with one or more methoxy or amino groups. Suitable carbon tetrahalides in step a) include, for example, CCl₄ and CBr₄. Suitable tertiary amines in step a) include, for example, trialkylamine, 1-methylpyrrolidine or 1-methylmorpholine. A preferred tertiary
25 amine for use in step a) is triethylamine.

Step (b)

Step (b) of the inventive process is an optional hydrolysis step and comprises hydrolyzing
30 the ester compound of the formula **IIa** produced in step a) by reacting the compound of formula **IIa** with a base to form the corresponding acid compound of the formula **IIb**:



Suitable bases for this step include, for example, alkali metal hydroxides such as lithium hydroxide, sodium hydroxide or potassium hydroxide. The novel compound of formula **IIb** produced in this step is another aspect of the present invention.

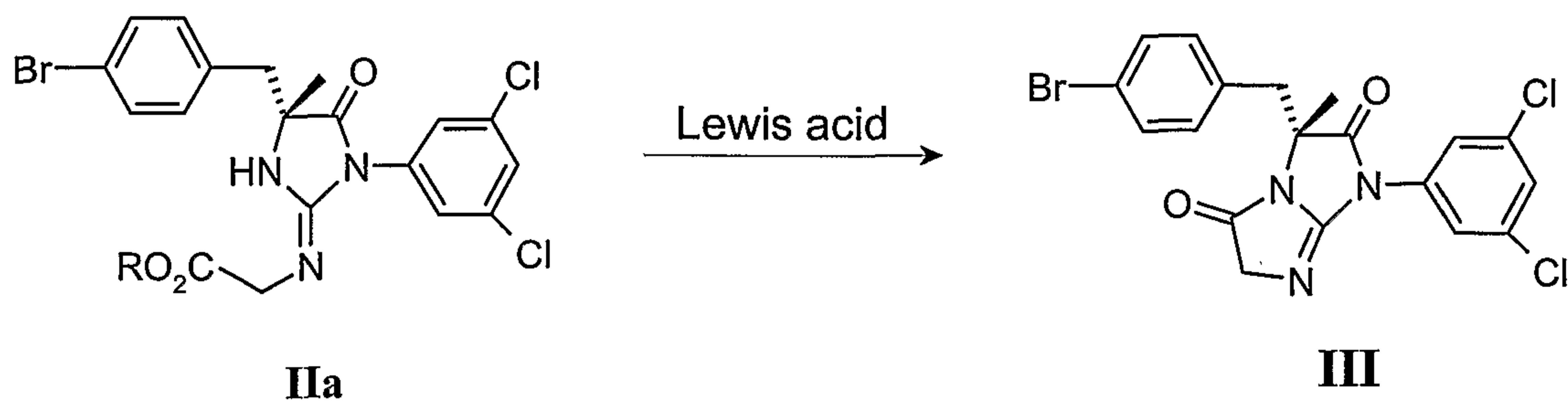
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In one embodiment of the inventive process, this optional hydrolysis step b) is not performed and the ester of formula **IIa** produced in step a) is used directly in the next step of the process, step c).

Step (c)

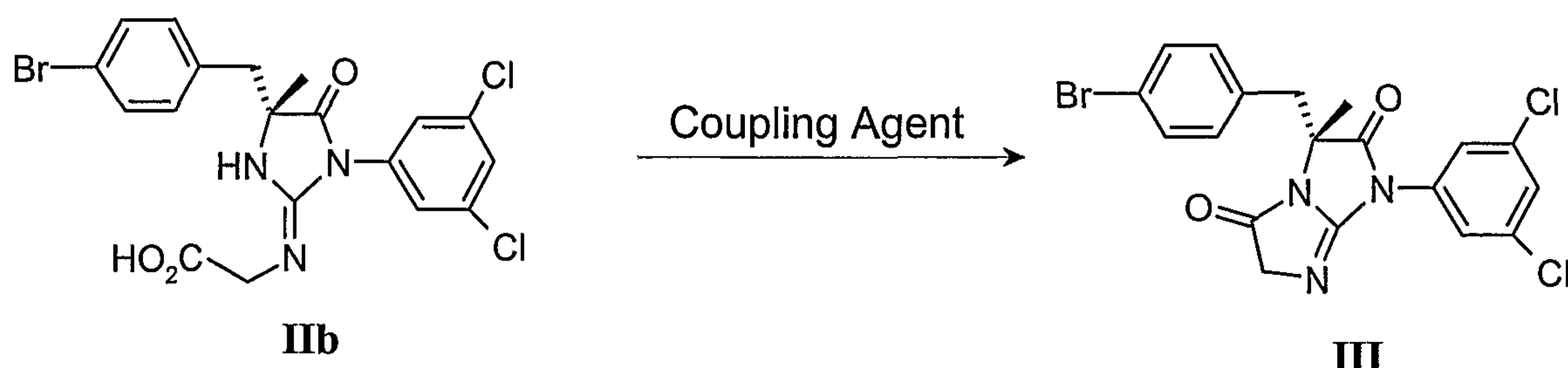
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Step (c) of the inventive process comprises reacting a compound of the formula **IIa** produced in step a) with a Lewis acid and a phosphine oxide compound of the formula $(R_1)_3PO$, wherein R_1 is C_{1-6} alkyl or aryl, in an aprotic organic solvent to form a compound of the formula **III**:



15 or

when the optional step b) is performed, step c) comprises reacting a compound of the formula **IIb** produced in step b) with a coupling agent in an aprotic organic solvent to form a compound of the formula **III**:



When the ester compound of formula **IIa** is employed in step (c), the ester **IIa** is cyclized
 5 in the presence of a Lewis acid and a phosphine oxide compound to provide the imidazo-
 imidazole-3,5-dione of formula **III** in good yield. This is similar to a known procedure for
 the synthesis of lactams (Takahata, H., Banba, Y., Momose, T. *Tetrahedron*, **1991**, *47*,
 7635). It was observed, however, that following the reaction conditions described in the
 literature failed to afford the desired product **III** in significant yield. It was discovered
 10 that the addition of a phosphine oxide compound of the formula $(R_1)_3PO$, wherein R_1 is
 C_{1-6} alkyl or aryl, was necessary for the reaction to proceed efficiently.

Step c) is performed in an aprotic organic solvent. Suitable aprotic organic solvents for
 this step include, for example, tetrahydrofuran, toluene, dichloromethane, dichloroethane
 15 or chloroform. Suitable Lewis acids for use in this step include, for example, $AlCl_3$, $TiCl_4$
 and trialkylaluminums of the formula $(C_{1-6}alkyl)_3Al$, such as Me_3Al . Suitable phosphine
 oxides for this step include, for example, triarylphosphine oxides such as
 triphenylphosphine oxide, wherein the phenyl groups are optionally substituted with one or
 more methoxy or amino groups.

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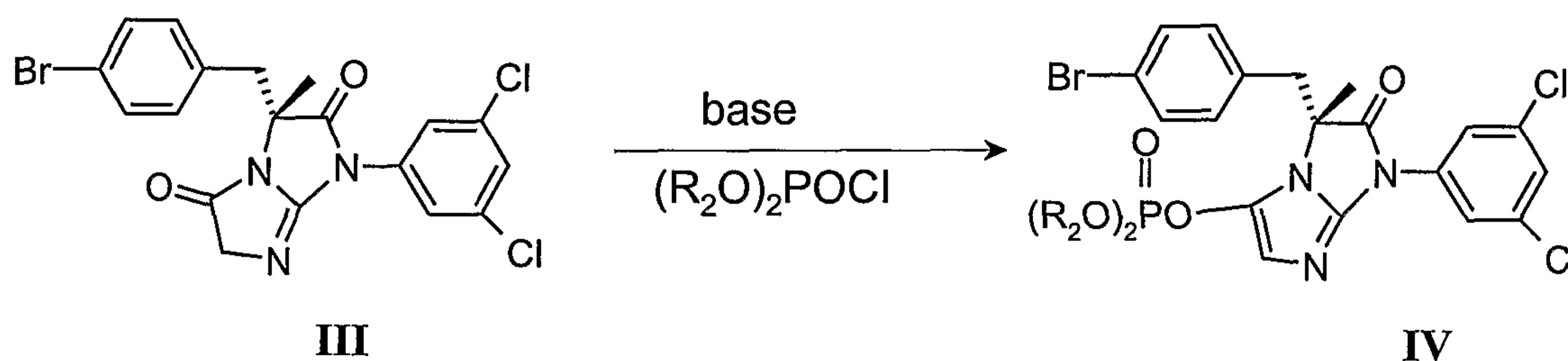
When the acid compound of formula **IIb** is employed in step (c), a coupling agent is used
 to cause cyclization via an intramolecular coupling between the carboxylic acid group and
 the amine group (i.e., a peptide-type coupling reaction). Suitable coupling agents for this
 purpose include conventional peptide coupling agents, for example, acetic anhydride,
 25 acetyl chloride, thionyl chloride and oxalyl chloride. Suitable aprotic organic solvents for
 this step are the same as described above.

The novel imidazo-imidazole-3,5-dione compound of formula **III** produced in step c) is another aspect of the present invention.

5 Step (d)

Step (d) of the inventive process comprises reacting a compound of the formula **III** produced in step c) with a strong base and a compound of the formula $(R_2O)_2POCl$, wherein R_2 is C_{1-6} alkyl or aryl, in a polar organic solvent at a temperature of about $-90\text{ }^\circ\text{C}$ to about $0\text{ }^\circ\text{C}$ to form a compound of the formula **IV** where R_2 is C_{1-6} alkyl or aryl:

10



15

The synthesis of the vinyl phosphate compound **IV** is similar to a known procedure for the preparation of ketene aminal phosphates from lactams (Nicolau, K. C., Shi, G., Kenji, N., Bernal, F. *Chem. Commun.* **1998**, 1757).

The novel vinyl phosphate compound of formula **IV** produced in step d) is another aspect of the present invention and is not disclosed by the above cited reference.

20

Step d) is conducted in the presence of a strong base. In the context of this invention, a strong base is a base having a pK_a of greater than 20. Suitable strong bases for use in this step include, for example, alkali metal amides, such as potassium bis(trimethylsilyl)amide, lithium bis(trimethylsilyl)amide, sodium bis(trimethylsilyl)amide and lithium diisopropylamide.

25

In one embodiment, the R_2 group in the chlorophosphate compound $(R_2O)_2POCl$ and in the compound of formula **IV** is a C_{1-6} alkyl group, preferably methyl or ethyl.

Step d) is conducted in a polar organic solvent. Suitable polar organic solvents include, for example, diethyl ether, dipropyl ether, diisopropyl ether, dibutyl ether, methyl tert-butyl ether (MTBE), dipentyl ether, diisopentyl ether, ethylene glycol dimethyl ether, diethylene glycol dimethyl ether, dioxane, tetrahydrofuran, N,N-dimethylformamide, N,N-dimethylacetamide, DMSO or N-methyl-2-pyrrolidone.

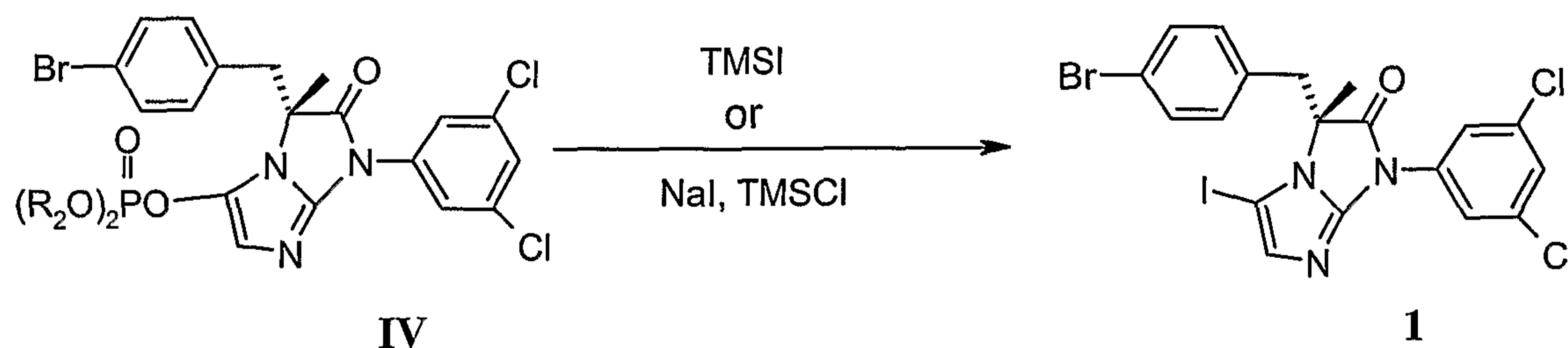
Step d) is conducted at a temperature of about -90 °C to about 0 °C, preferably about -50 °C to about -5 °C, more preferably about -30 °C to about -10 °C. In one embodiment, step d) is conducted at a temperature of about -20 °C. The term "about" in this context means a temperature between 10% above and 10% below the recited value, inclusive. For example, "about -20 °C" means a temperature falling in the range -18 °C to -22 °C.

Step (e)

15

Step (e) of the inventive process is an iodination that comprises reacting a compound of the formula IV produced in step d) with trimethylsilyl iodide (TMSI), or with sodium iodide (NaI) and trimethylsilyl chloride (TMSCl), in an aprotic organic solvent to form a compound of the formula 1:

20



25 The synthesis of the compound of formula 1 from the vinyl phosphate compound of formula IV is related to a known procedure for the preparation of vinyl iodides from ketone-derived enol phosphates (Lee, K., Wiemer, D. F. *Tetrahedron Lett.* **1993**, 34, 2433).

However, the enol phosphates in the literature procedure are ketone-derived vinyl phosphates and not lactam-derived ketene aminal phosphates like formula IV.

The iodination in step e) is conducted by reacting the vinyl phosphate compound of formula IV with trimethylsilyl iodide, or with sodium iodide and trimethylsilyl chloride. When sodium iodide and trimethylsilyl chloride are used, these two compounds react *in situ* to form trimethylsilyl iodide, which then reacts with formula IV to form the iodinated compound of formula 1.

Step e) is conducted in an aprotic organic solvent. Suitable aprotic organic solvents for this step include, for example, tetrahydrofuran, toluene, dichloromethane, dichloroethane, chloroform and acetonitrile.

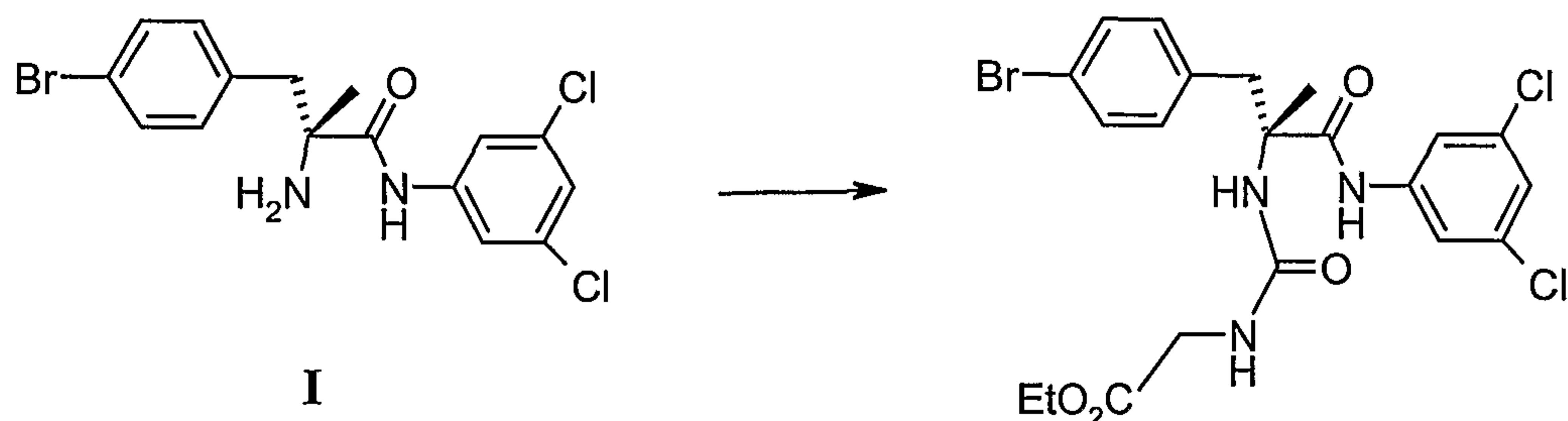
Step (e) is optionally conducted in the presence of water. It has been found that water accelerates the formation of the iodide compound of formula 1. This step has been run with up to 6 equivalents of water, although higher amounts of water can be used. In one embodiment, the amount of water present is from about 0.5 to 1.5 equivalents, preferably about 0.8 to 1.2 equivalents.

Synthetic Examples

The invention is further illustrated by the following non-limiting examples of the inventive process.

Example 1

(R){3-[2-(4-Bromophenyl)-1-(3,5-dichlorophenylcarbamoyl)-1-methyl-ethyl]-ureido}-acetic acid ethyl ester

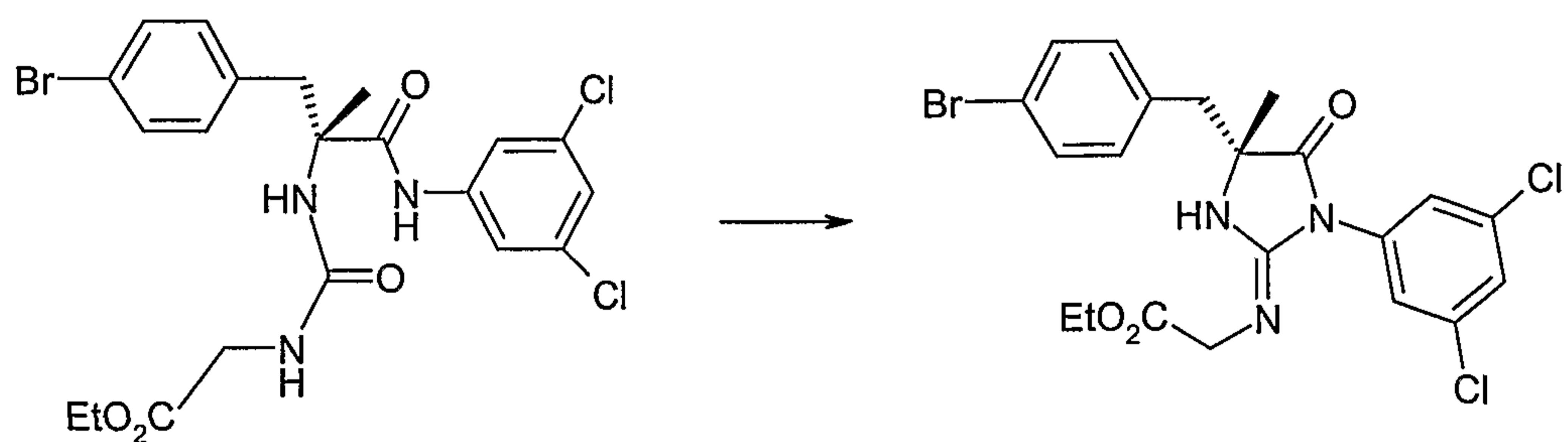


Ethyl isocyanatoacetate (80.7 mL, 719 mmol) was added dropwise to a stirred solution of **I** (281 g, 698 mmol) and THF (2 L) at ambient temperature. The mixture was stirred at room temperature for 12 h and hexane (600 mL) was added. The resulting solid was collected by filtration. The filtrate was concentrated under reduced pressure and the resulting precipitate was again collected by filtration. The solid material was combined to afford a total of 325 g of product as a white solid: ^1H NMR (400 MHz, $(\text{D}_3\text{C})_2\text{SO}$) δ 1.17 (t, $J = 7.1$ Hz, 3H), 1.23 (s, 3H), 3.05 (d, $J = 13.3$ Hz, 1H), 3.29 (d, $J = 13.3$ Hz, 1H), 3.75 (dd, $J = 6.0$ Hz, $J = 17.7$ Hz, 1H), 3.84 (dd, $J = 6.0$, $J = 17.7$ Hz, 1H), 4.10 (q, $J = 7.1$ Hz, 2H), 6.35 (s, 1H), 6.40 (t, $J = 6.0$ Hz, 1H), 7.10 (d, $J = 8.2$ Hz, 2H), 7.23 (t, $J = 1.8$ Hz, 1H), 7.44 (d, $J = 8.2$ Hz, 2H), 7.74 (d, $J = 1.8$ Hz, 2H), 9.83 (s, 1H).

Example 2

(*R*)-[4-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-4-methyl-5-oxo-imidazolidin-2-ylideneamino]-acetic acid ethyl ester

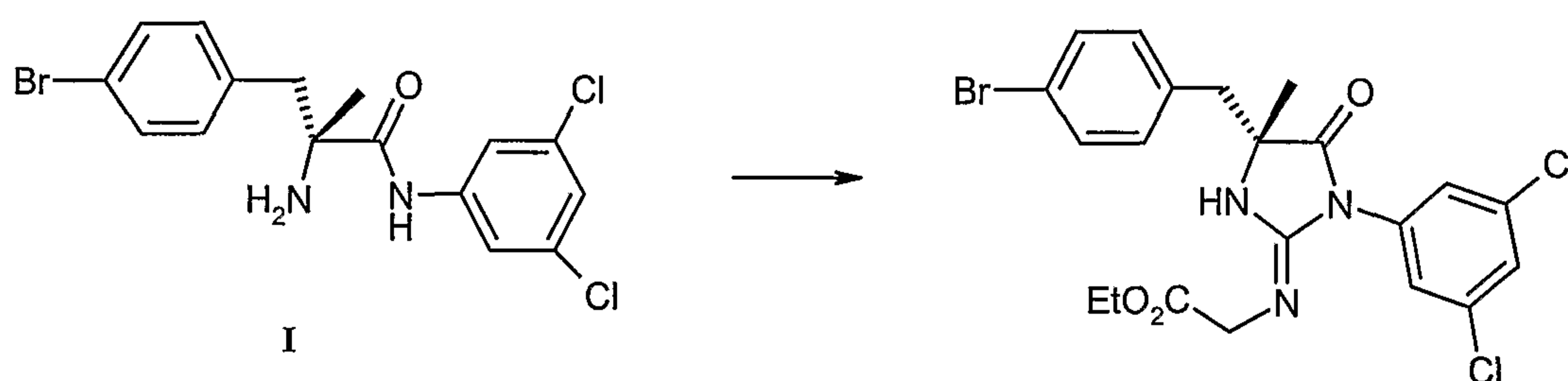
Method A:



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Carbon tetrachloride (43.6 mL, 452 mmol) was added dropwise to a stirred solution of the product of Example 1 (120 g, 226 mmol), triethylamine (63.0 mL, 452 mmol), triphenylphosphine (119 g, 452 mmol) and dichloromethane (1.8 L) at room temperature. The mixture was stirred at ambient temperature for 12 h and concentrated under reduced pressure. Ethyl acetate (1.2 L) was added and the mixture was stirred for 5-10 min. The solids were removed by filtration and the organic layer was washed sequentially with 0.5 N HCl (450 mL) and saturated aqueous NaHCO₃ (450 mL). The mixture was concentrated under reduced pressure to afford an orange oil. Ethyl acetate (240 mL) was added to the mixture at 50 °C followed by MTBE (720 mL) and the mixture was stirred at 60 °C for a few min. The mixture was allowed to reach ambient temperature and was stirred for 12 h. The precipitate (triphenylphosphine oxide) was then removed by filtration and the filtrate was concentrated under reduced pressure to afford 134 g of an orange solid. ¹H NMR analysis of the crude material indicated it contained about 38% ^{w/w} triphenylphosphine oxide. A small sample was purified by chromatography for analytical purposes and the bulk of the material was used for the next step without further purification.

Method B:



20

Ethyl isocyanatoacetate (0.287 mL, 2.56 mmol) was added dropwise to a stirred solution of I (1.0 g, 2.49 mmol) and dichloromethane (5 mL) at room temperature. The mixture was stirred for 10 min at room temperature and the urea (product of Example 1) forms as a white precipitate. Stirring was continued for about 2 h thereafter to ensure complete conversion to the urea, and then triphenylphosphine (1.31 g, 4.98 mmol), triethylamine (0.69 mL, 4.98 mmol), and carbon tetrachloride (0.48 mL, 4.98 mmol) were added to the stirred suspension. The mixture was then stirred at ambient temperature for 12 h.

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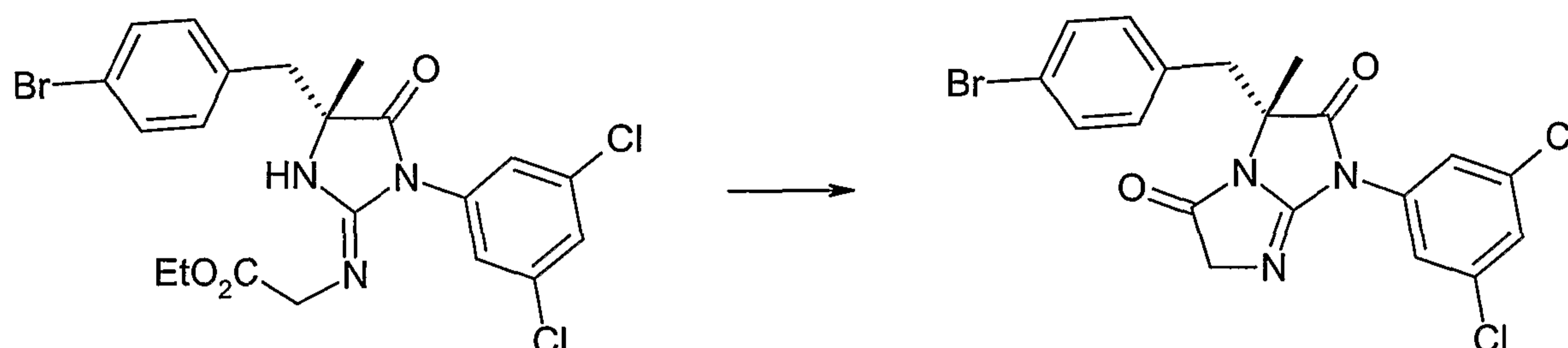
Aqueous workup (1 N HCl, dichloromethane, MgSO₄) afforded a yellow oil. Flash chromatography (silica gel, 4:1 hexane/ethyl acetate ^{v/v}) afforded 906 mg (71%) of product as a white solid: mp 103-105 °C; ¹H NMR (400 MHz, CDCl₃) δ1.31 (t, *J* = 7.1 Hz, 3H), 1.52 (s, 3H), 2.95 (d, *J* = 12.9 Hz, 1H), 2.98 (d, *J* = 12.9 Hz, 1H), 4.05-4.13 (m, 3H), 4.23 (m, 2H), 6.57 (d, *J* = 1.6 Hz, 2H), 7.04 (d, *J* = 8.2 Hz, 2H), 7.37 (m, 3H); ¹³C NMR (CDCl₃, 100 MHz) δ14.1, 23.7, 42.9, 44.2, 61.7, 70.4, 120.9, 125.6, 129.4, 130.8, 131.9, 133.2, 134.8, 136.1, 151.1, 169.6, 181.5; Anal. calcd for C₂₁H₂₀BrCl₂N₃O₃: C, 49.15; H, 3.93; N, 8.19. Found C, 49.46; H, 3.92; N, 7.96.

10

Example 3

(*R*)-3-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-3-methyl-1,6-dihydroimidazo[1,2-*a*]imidazole-2,5-dione.

15



Toluene (450 mL) was added to 76.9 g of a mixture of the product of Example 2 (47.1 g, 91.7 mmol) and triphenylphosphine oxide (29.2 g, 105 mmol), and the resulting solution was cooled down to -10 °C. Trimethylaluminum (46 mL of a 2 M solution in toluene, 92 mmol) was added dropwise keeping the temperature at or below 0 °C and the mixture was then allowed to reach ambient temperature. The mixture was stirred at ambient temperature for two h and more trimethylaluminum (27.6 mL of a 2 M solution in toluene, 55.2 mmol) was added in two portions at two h intervals. The mixture was placed over an ice bath and slowly quenched with 1 N HCl (360 mL). The organic portion was separated and the aqueous portion was extracted with toluene (200 mL). The combined organic

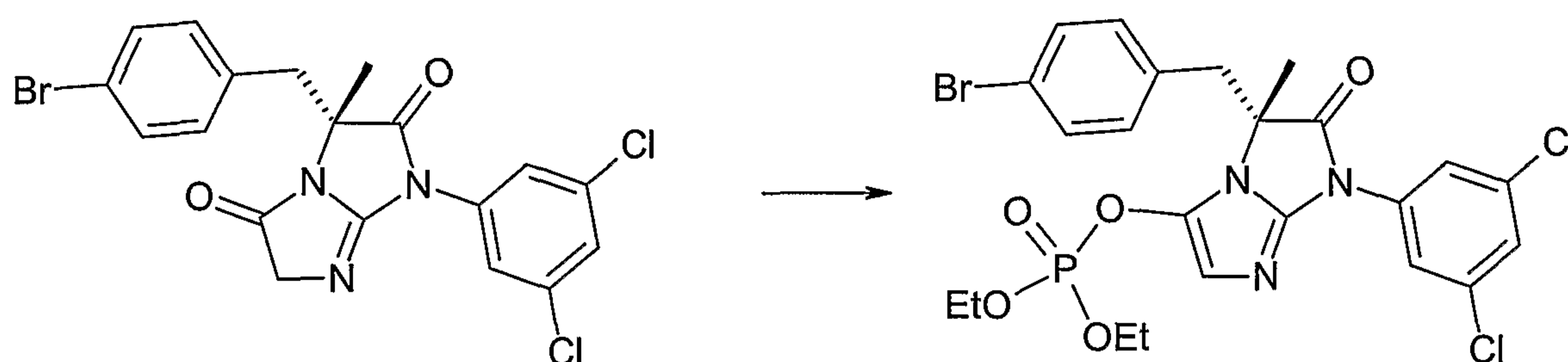
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portions were washed with water and concentrated under reduced pressure to afford an orange oil. Flash chromatography (silica gel, hexane/ethyl acetate 4:1 v/v) afforded 38.1 g (89%) of product as an oil that solidified upon standing: mp 52-54 °C; ^1H NMR (400 MHz, CDCl_3) δ 1.84 (s, 3H), 3.24 (d, $J = 13.8$ Hz, 1H), 3.43 (d, $J = 13.8$ Hz, 1H), 4.18 (d, $J = 21.9$ Hz, 1H), 4.30 (d, $J = 21.9$ Hz, 1H), 6.95 (d, $J = 8.3$ Hz, 2 H), 7.29 (d, $J = 1.8$ Hz, 2H), 7.33 (t, $J = 1.8$ Hz, 1H), 7.38 (d, $J = 8.3$ Hz, 2H); ^{13}C NMR (100 MHz, CDCl_3) δ 21.5, 40.8, 61.3, 65.1, 122.3, 122.6, 128.5, 131.0, 132.0, 132.5, 132.7, 135.5, 154.6, 174.3, 174.9; Anal. calcd for $\text{C}_{19}\text{H}_{14}\text{BrCl}_2\text{N}_3\text{O}_2$: C, 48.85; H, 3.02; N, 9.00. Found C, 48.89; H, 3.02; N, 8.81.

10

Example 4

Phosphoric acid (*R*)-5-(4-bromobenzyl)-7-(3,5-dichlorophenyl)-5-methyl-6-oxo-6,7-dihydro-5*H*-imidazo[1,2-*a*]imidazol-3-yl ester diethyl ester



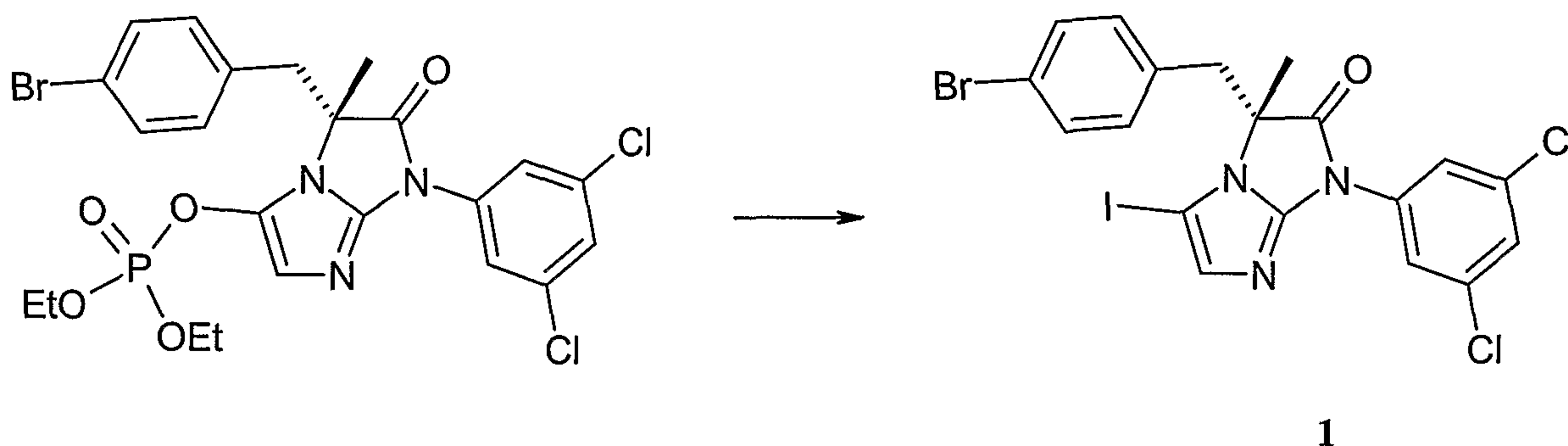
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Potassium bis(trimethylsilyl)amide (265 mL of a 0.5 M solution in toluene, 133 mmol) was added dropwise to a stirred solution of the product of Example 3 (51.5 g, 110.3 mmol), diethyl chlorophosphate (23.9 mL, 165 mmol) and THF (700 ml) at -20 °C. The mixture was stirred at -20 °C for one h. Aqueous workup (aqueous NH_4Cl , ethyl acetate, MgSO_4) afforded an oil. Flash chromatography (silica gel, hexane/ethyl acetate 2:1 v/v) afforded 61.2 g (92%) of product as a yellow oil: ^1H NMR (400 MHz, CDCl_3) δ 1.44 (t, $J = 7.1$ Hz, 6H), 1.86 (s, 3H), 3.26 (d, $J = 13.9$ Hz), 3.34 (d, $J = 13.9$ Hz, 1H), 4.33 (m, 4 H), 6.50 (s, 1H), 6.84 (d, $J = 8.2$ Hz, 2H), 7.24-7.28 (m, 3H), 7.58 (d, $J = 1.6$ Hz, 2H).

25

Example 5

(*R*)-3-(4-Bromobenzyl)-1-(3,5-dichlorophenyl)-5-iodo-3-methyl-1*H*-imidazo[1,2-*a*]imidazol-2-one



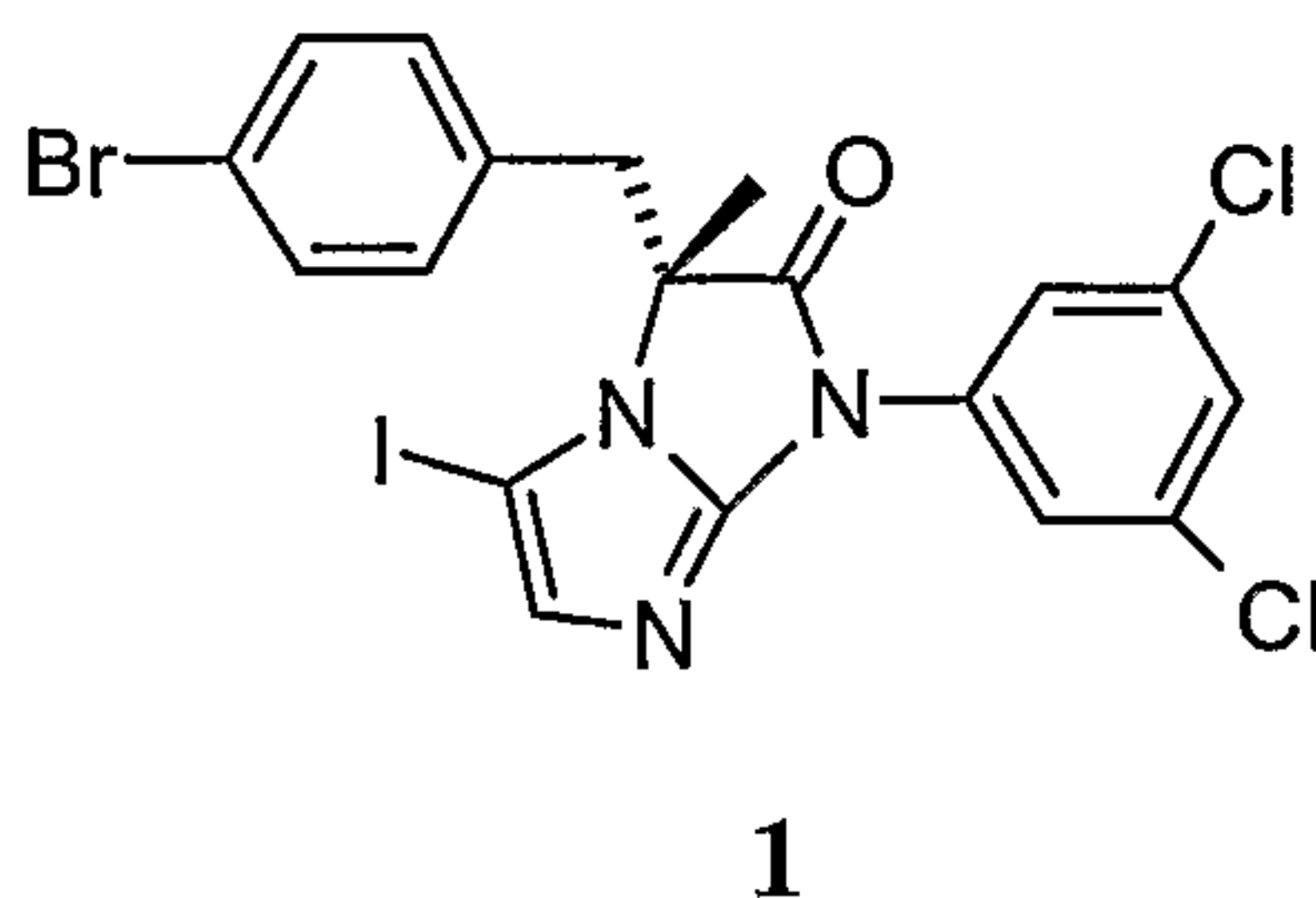
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Trimethylsilyl chloride (42.8 mL, 338 mmol) was added dropwise to a stirred suspension of NaI (49.5 g, 330 mmol), the product of Example 4 (66.3 g, 110 mmol) and dichloromethane (1.1 L) at -10°C . The mixture was allowed to reach ambient temperature and stirred for 90 min. The mixture was placed over an ice bath and quenched with a mixture of saturated aqueous NaHCO_3 solution (360 mL) and 10% aqueous sodium thiosulfate (360 mL). The organic layer was set aside and the aqueous layer was extracted with dichloromethane (500 mL). The combined organic portions were dried (MgSO_4) and concentrated to afford 100 g of a light brown oil. Flash chromatography (silica gel, 6:1 hexane/ethyl acetate v/v) afforded 44.1 g (69%) of product as a colorless solid: ^1H NMR (400 MHz, CDCl_3) δ 1.92 (s, 3H), 3.24 (d, $J = 14$ Hz, 1H), 3.54 (d, $J = 14$ Hz, 1H), 6.78 (d, $J = 8.3$ Hz, 2H), 6.95 (s, 1H), 7.27 (m, 3H), 7.53 (d, $J = 1.8$ Hz, 2H).

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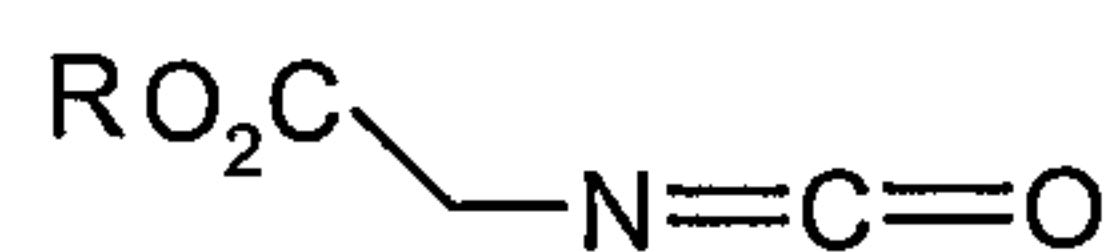
What is Claimed is:

1. A process for preparing a compound of the following formula 1:

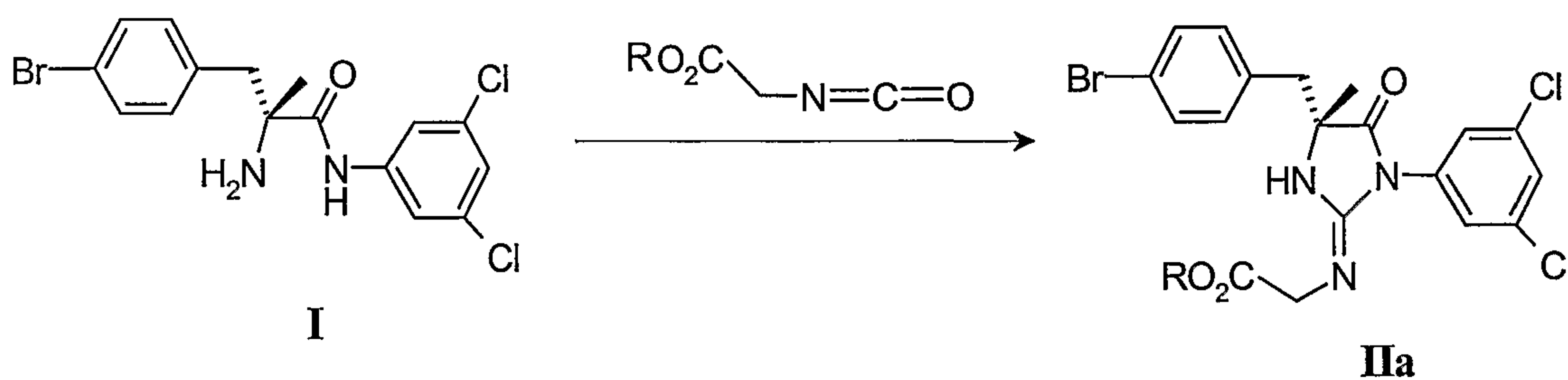


- 5 said process comprising the following steps:

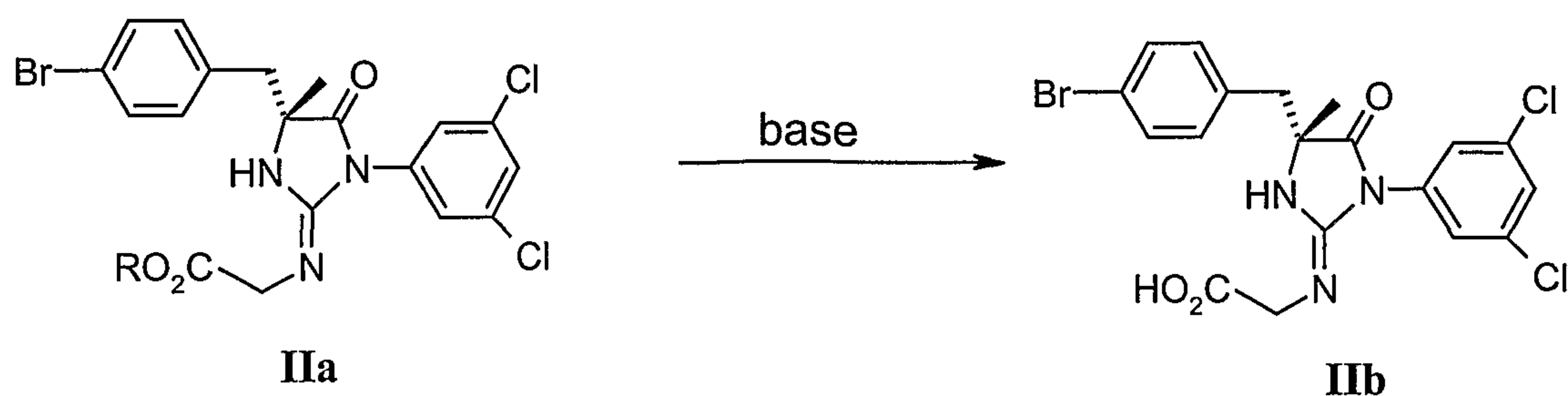
- a) reacting a compound of the formula **I** with a compound of the formula



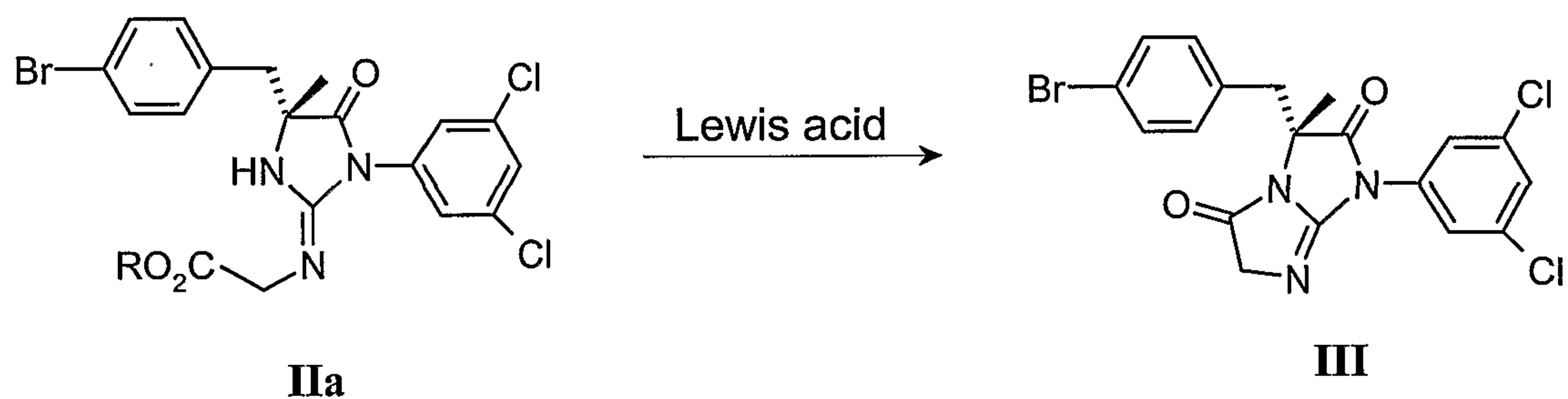
- 10 where R is C₁₋₆alkyl, in an aprotic organic solvent, followed by adding a triarylphosphine, a carbon tetrahalide and a tertiary amine, to form a compound of the formula **IIa** where R is C₁₋₆alkyl:



- 15 b) optionally hydrolyzing a compound of the formula **IIa** produced in step a) by reacting the compound of formula **IIa** with a base to form a compound of the formula **IIb**:

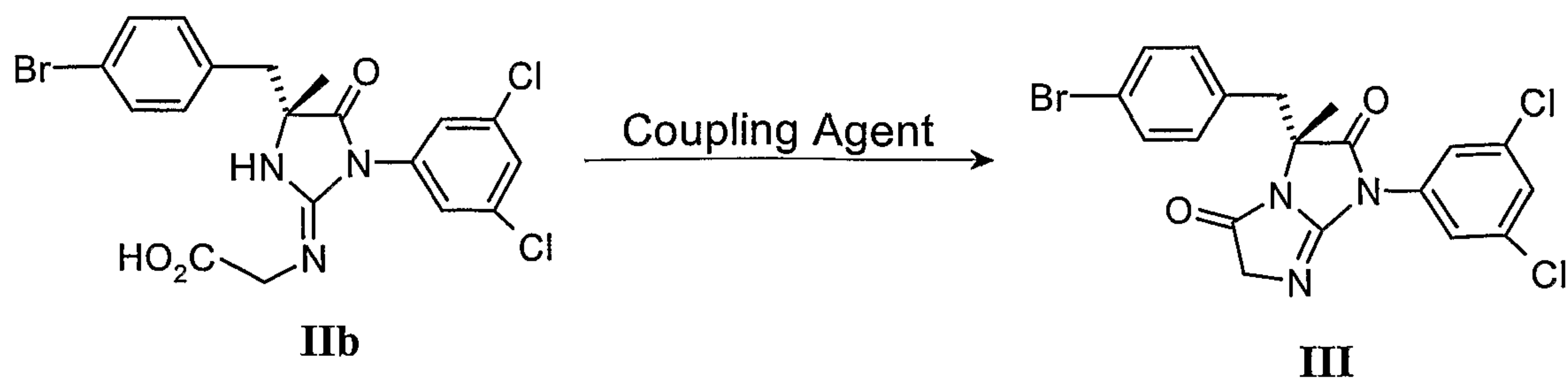


- c) reacting a compound of the formula **IIa** produced in step a) with a Lewis acid and a phosphine oxide compound of the formula $(R_1)_3PO$, wherein R_1 is C_{1-6} alkyl or aryl, in an aprotic organic solvent to form a compound of the formula **III**:



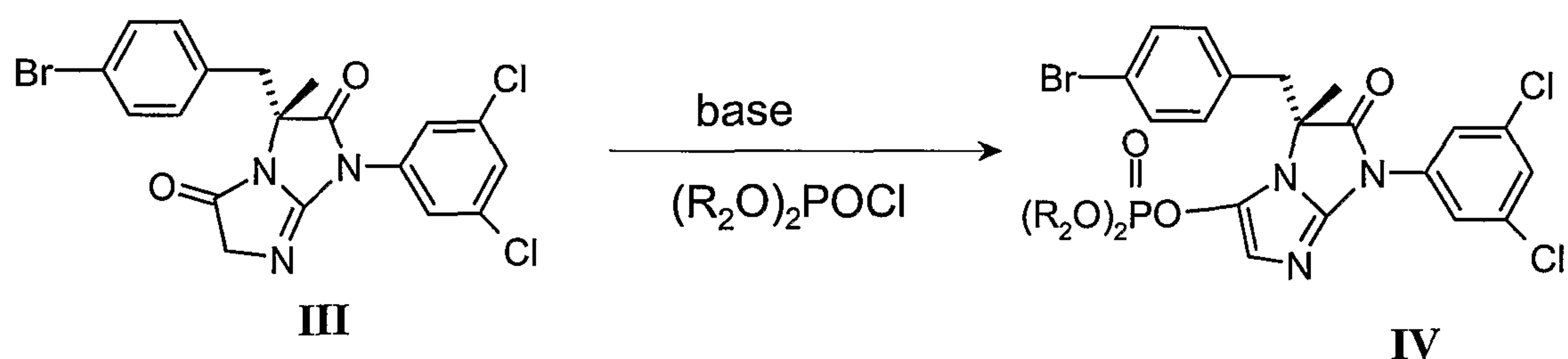
or

- when the optional step b) is performed, reacting a compound of the formula **IIb** produced in step b) with a coupling agent in an aprotic organic solvent to form a compound of the formula **III**:



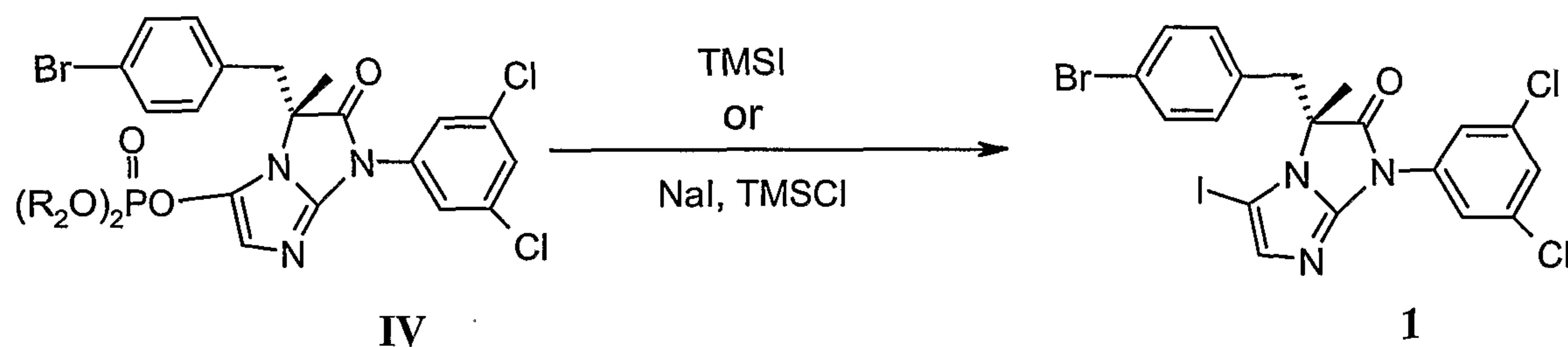
- d) reacting a compound of the formula **III** produced in step c) with a strong base and a compound of the formula $(R_2O)_2POCl$, wherein R_2 is C_{1-6} alkyl or aryl, in a polar organic solvent at a temperature of about $-90\text{ }^\circ\text{C}$ to about $0\text{ }^\circ\text{C}$ to form a compound of the formula **IV** where R_2 is C_{1-6} alkyl or aryl:

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- e) reacting a compound of the formula **IV** produced in step d) with trimethylsilyl iodide, or with sodium iodide and trimethylsilyl chloride, in an aprotic organic solvent to form a compound of the formula **1**:



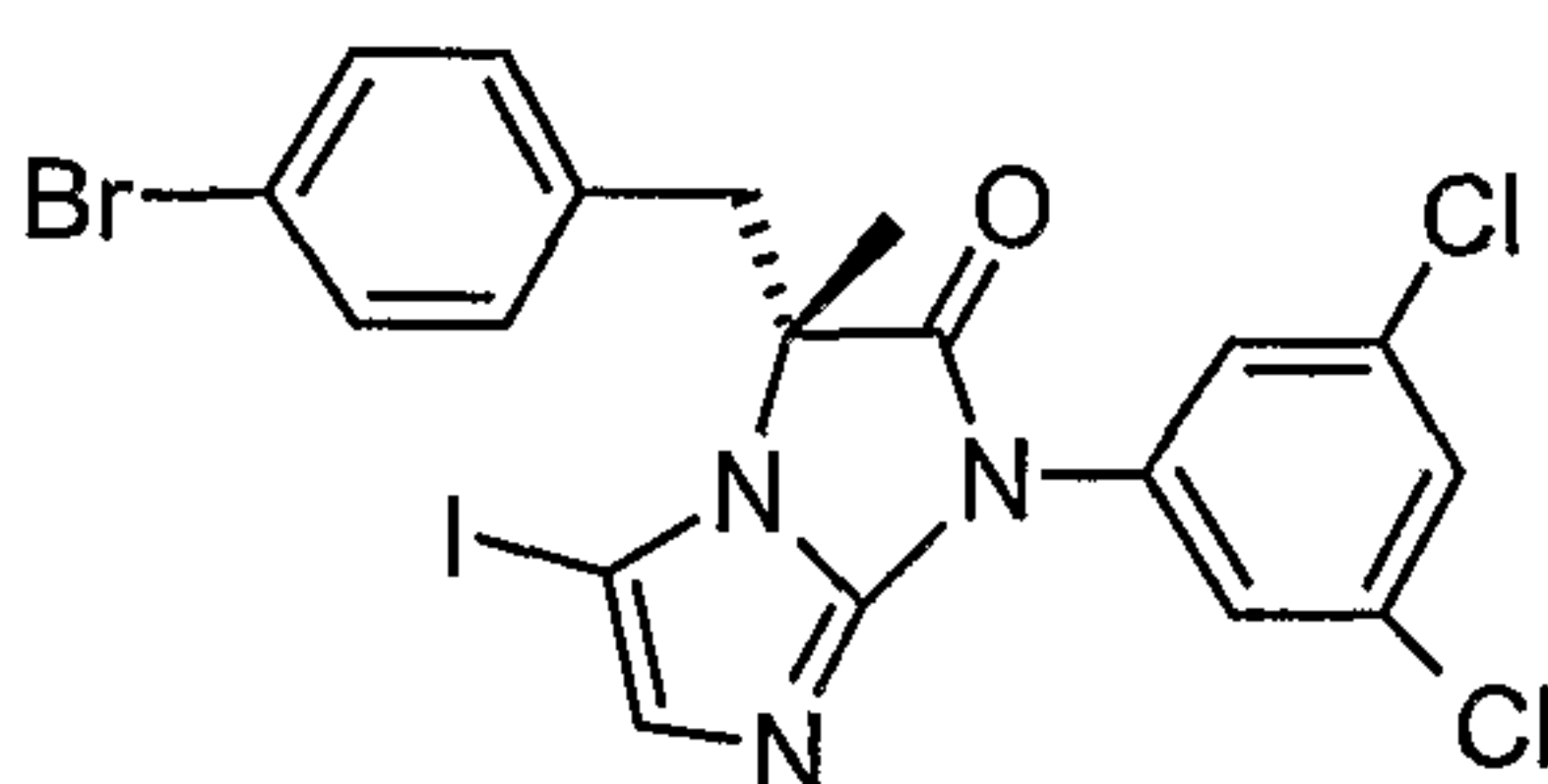
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2. A process according to claim 1, wherein optional step b) is not performed.
3. A process according to claim 1 or 2, wherein R in step a) methyl or ethyl.
4. A process according to claim 1 or 2, wherein the aprotic organic solvent in step a) is tetrahydrofuran, toluene, dichloromethane, dichloroethane or chloroform.

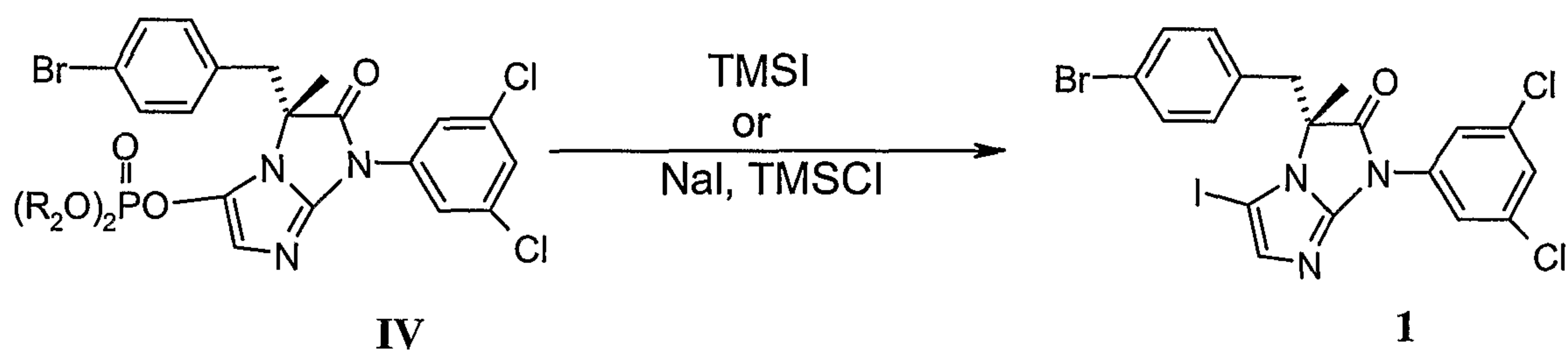
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5. A process according to claim 1 or 2, wherein the triarylphosphine in step a) is triphenylphosphine, wherein the phenyl groups are optionally substituted with one or more methoxy or amino groups.
- 5 6. A process according to claim 1 or 2, wherein the carbon tetrahalide in step a) is CCl_4 or CBr_4 .
7. A process according to claim 1 or 2, wherein the tertiary amine in step a) is trialkylamine, 1-methylpyrrolidine or 1-methylmorpholine.
- 10 8. A process according to claim 7, wherein the tertiary amine in step a) is triethylamine.
9. A process according to claim 1, wherein the base in step b) is an alkali metal
15 hydroxide.
10. A process according to claim 1 or 2, wherein the Lewis acid in step c) is selected from the group consisting of AlCl_3 , TiCl_4 and trialkylaluminums of the formula $(\text{C}_{1-6}\text{alkyl})_3\text{Al}$.
- 20 11. A process according to claim 1 or 2, wherein the phosphine oxide compound in step c) is a triarylphosphine oxide.
12. A process according to claim 11, wherein the phosphine oxide compound in step c)
25 is a triphenylphosphine oxide, wherein the phenyl groups are optionally substituted with one or more methoxy or amino groups.
13. A process according to claim 1, wherein the coupling agent in step c) is selected from the group consisting of acetic anhydride, acetyl chloride, thionyl chloride and
30 oxalyl chloride.

14. A process according to claim 1 or 2, wherein the strong base in step d) is an alkali metal amide.
15. A process according to claim 14, wherein the strong base in step d) is potassium bis(trimethylsilyl)amide, lithium bis(trimethylsilyl)amide, sodium bis(trimethylsilyl)amide or lithium diisopropylamide.
16. A process according to claim 1 or 2, wherein R₂ in step d) is C₁₋₆alkyl.
17. A process according to claim 1 or 2, wherein step d) is conducted at a temperature of about -50 °C to about -5 °C.
18. A process according to claim 17, wherein step d) is conducted at a temperature of about -30 °C to about -10 °C.
19. A process according to claim 18, wherein step d) is conducted at a temperature of about -20 °C.
20. A process according to claim 1 or 2, wherein step e) is conducted in the presence of water.
21. A process for preparing a compound of the following formula 1:

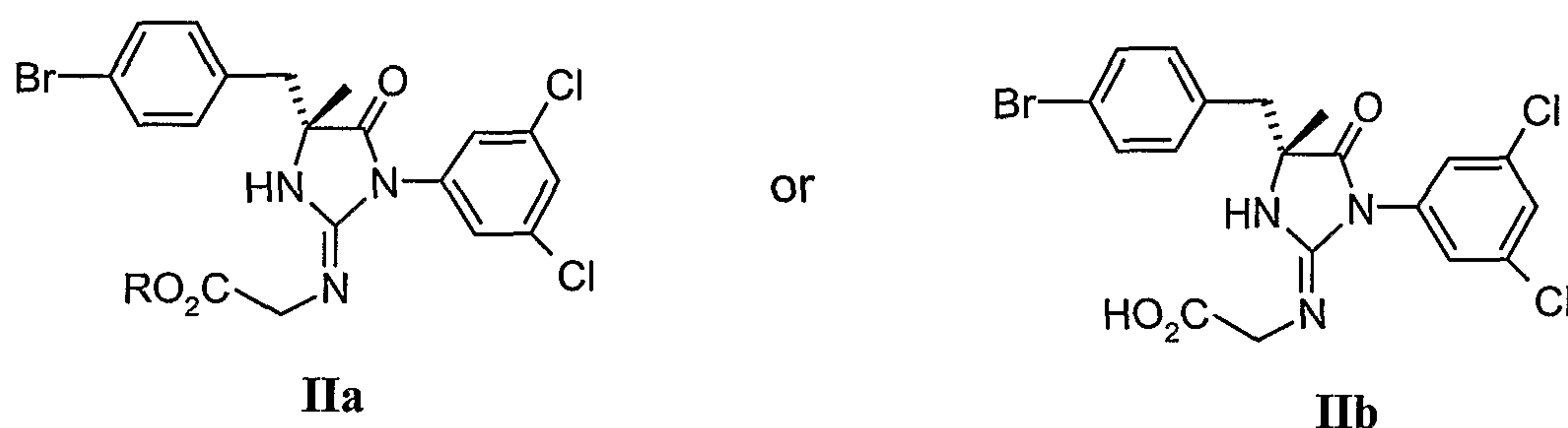
**1**

said process comprising reacting a compound of the formula **IV** wherein R₂ is C₁₋₆alkyl or aryl with trimethylsilyl iodide, or with sodium iodide and trimethylsilyl chloride, in an aprotic organic solvent to form a compound of the formula **1**:



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22. A compound having the following formula **IIa** or **IIb**:



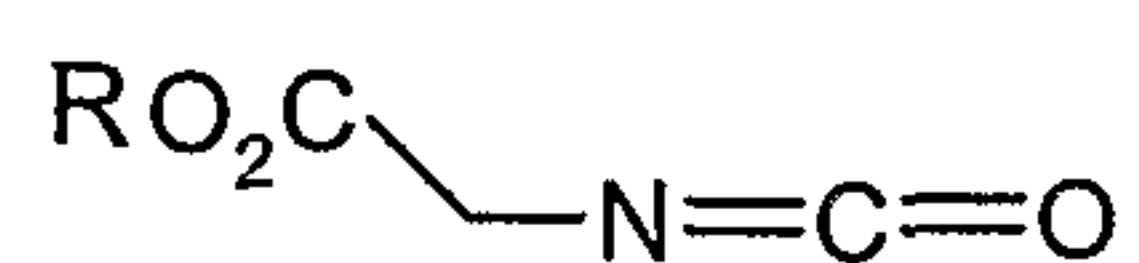
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wherein R is C₁₋₆alkyl.

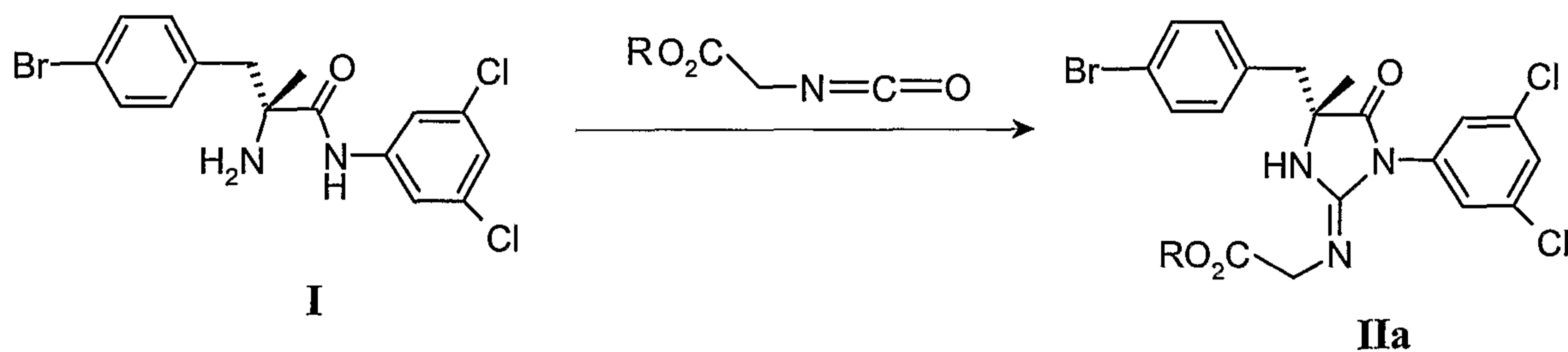
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23. A process for preparing a compound of claim 22 having the formula **IIa** or **IIb**, said process comprising:

a) reacting a compound of the formula **I** with a compound of the formula



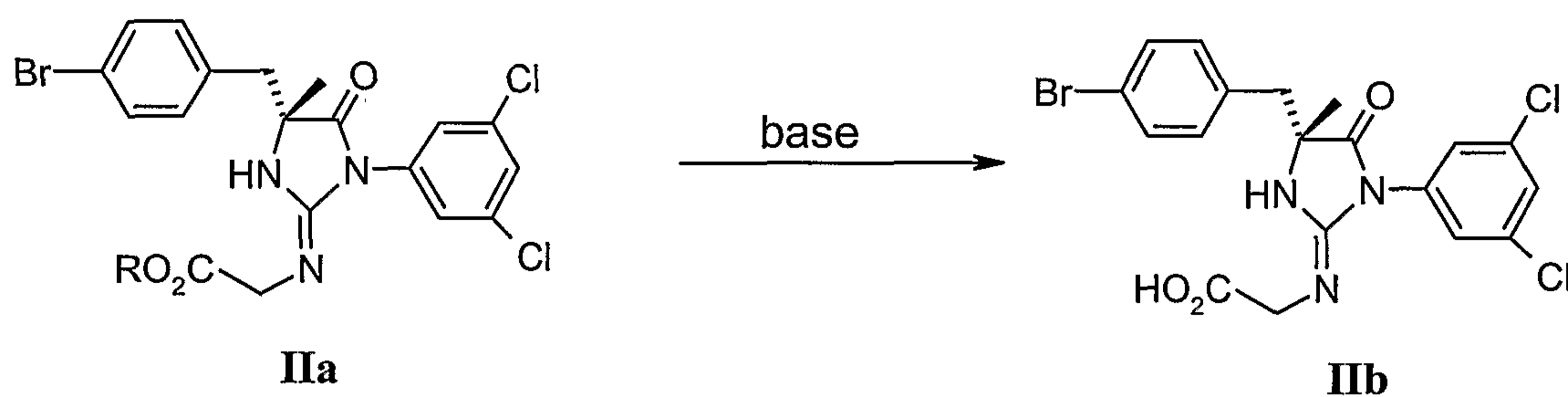
where R is C₁₋₆alkyl, in an aprotic organic solvent, followed by adding a triarylphosphine, a carbon tetrahalide and a tertiary amine, to form a compound of the formula **IIa** where R is C₁₋₆alkyl:



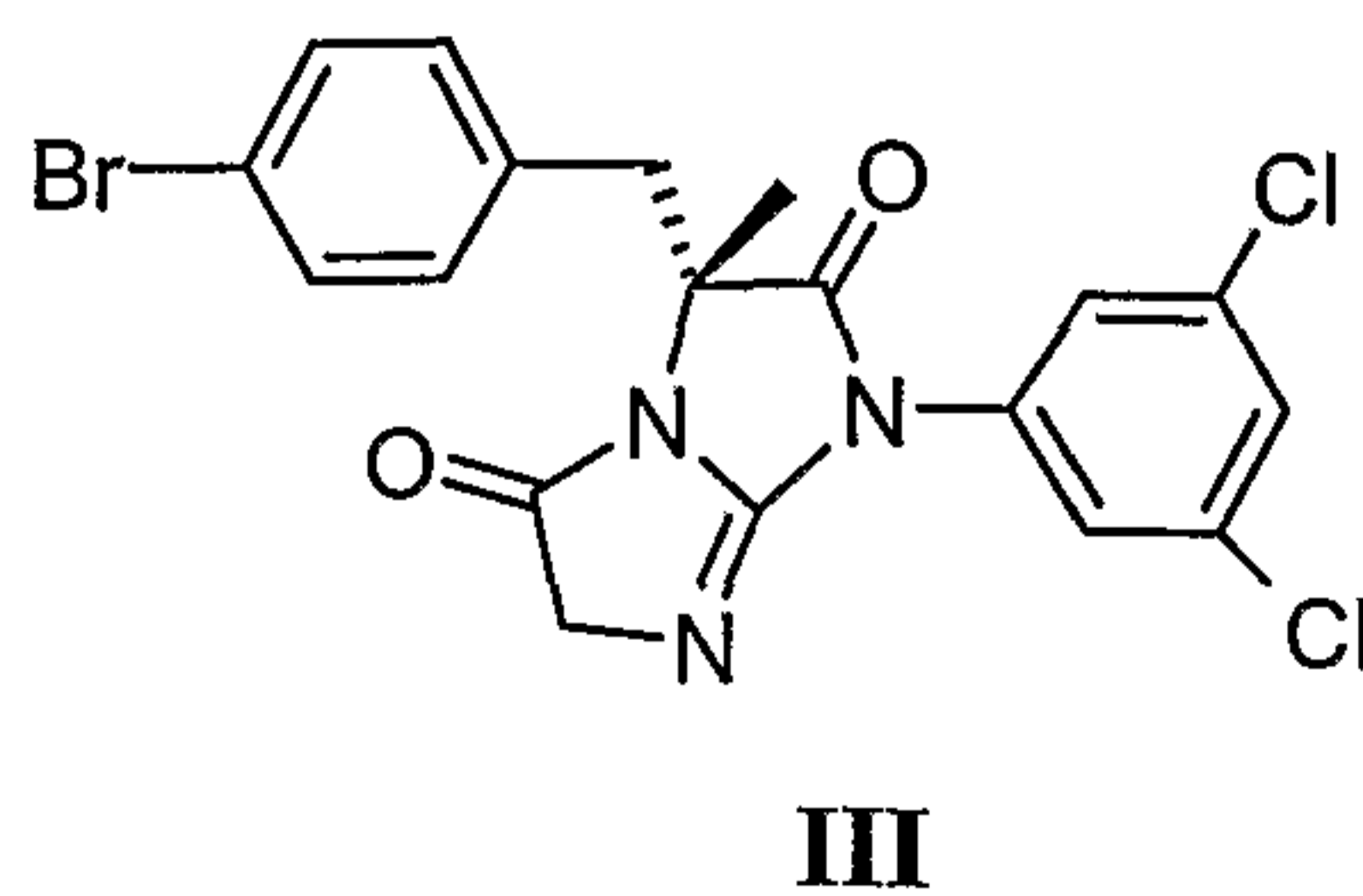
and

b) optionally hydrolyzing a compound of the formula **IIa** produced in step a) by reacting the compound of formula **IIa** with a base to form a compound of the formula **IIb**:

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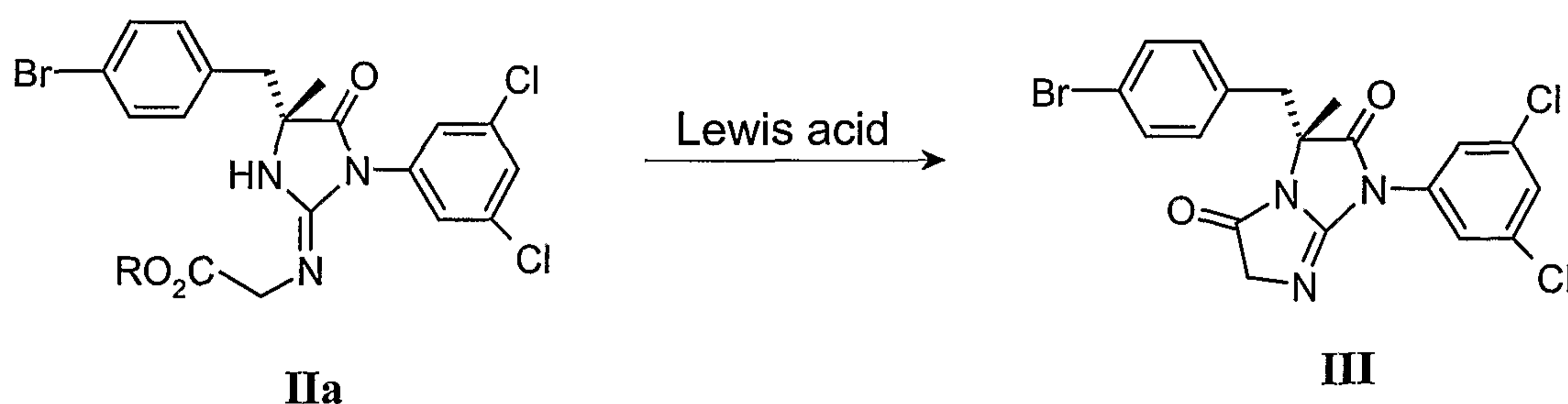


24. A compound having the following formula **III**:

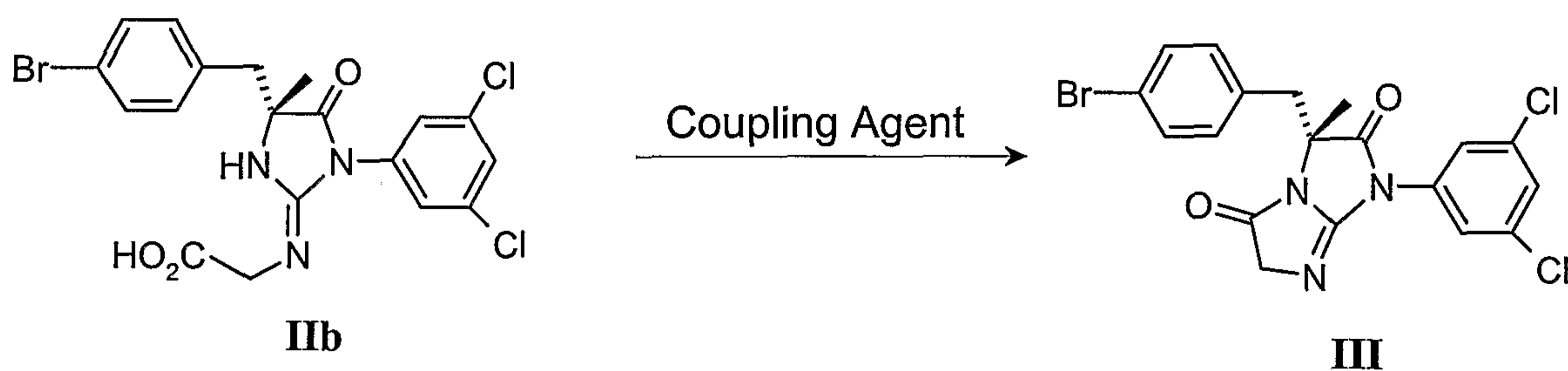


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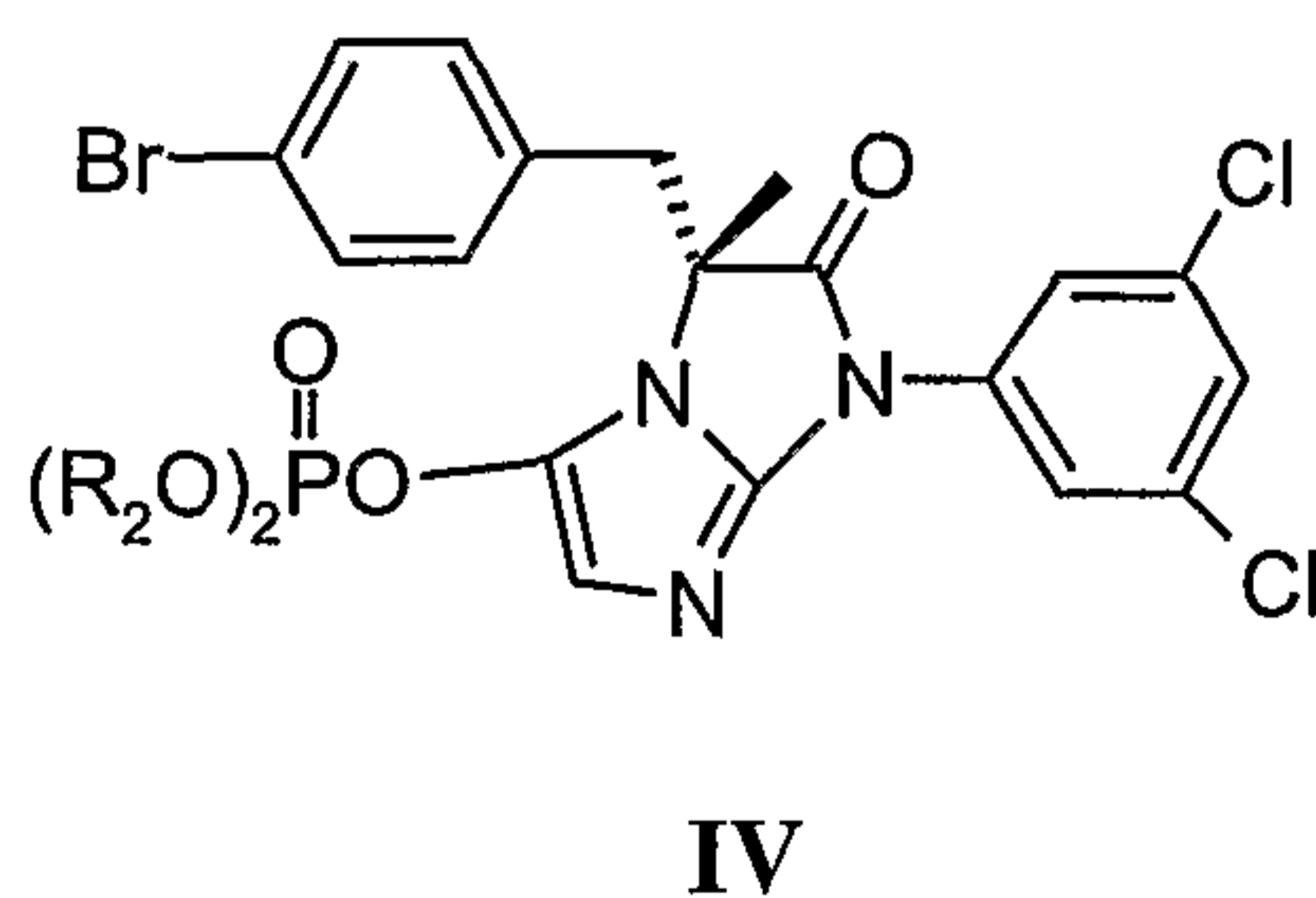
25. A process for preparing a compound of claim 24 having the formula **III**, said process comprising reacting a compound of the formula **IIa** with a Lewis acid and a phosphine oxide compound of the formula $(R_1)_3PO$, wherein R_1 is C_{1-6} alkyl or aryl, in an aprotic organic solvent to form a compound of the formula **III**:



26. A process for preparing a compound of claim 24 having the formula **III**, said process comprising reacting a compound of the formula **IIb** with a coupling agent in an aprotic organic solvent to form a compound of the formula **III**:

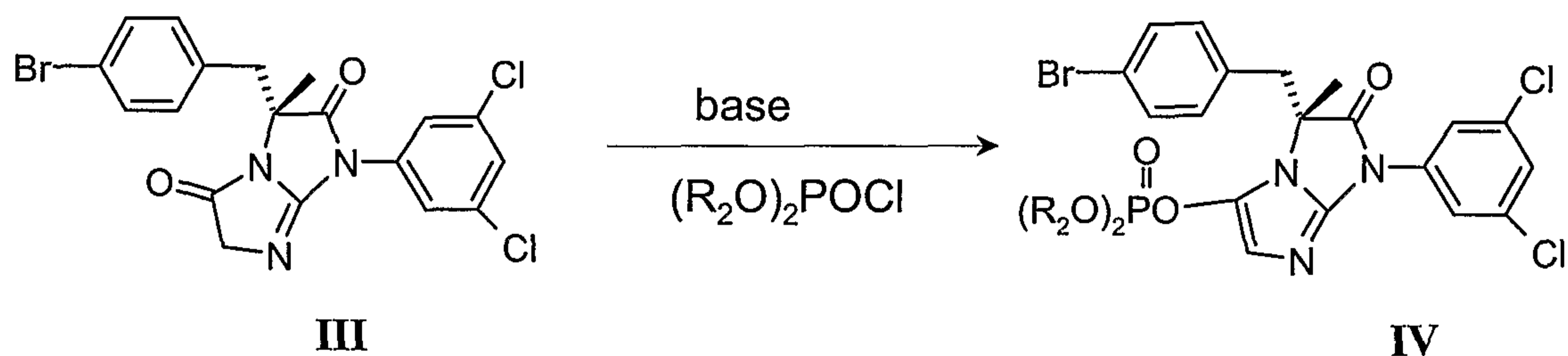


27. A compound having the following formula **IV**:

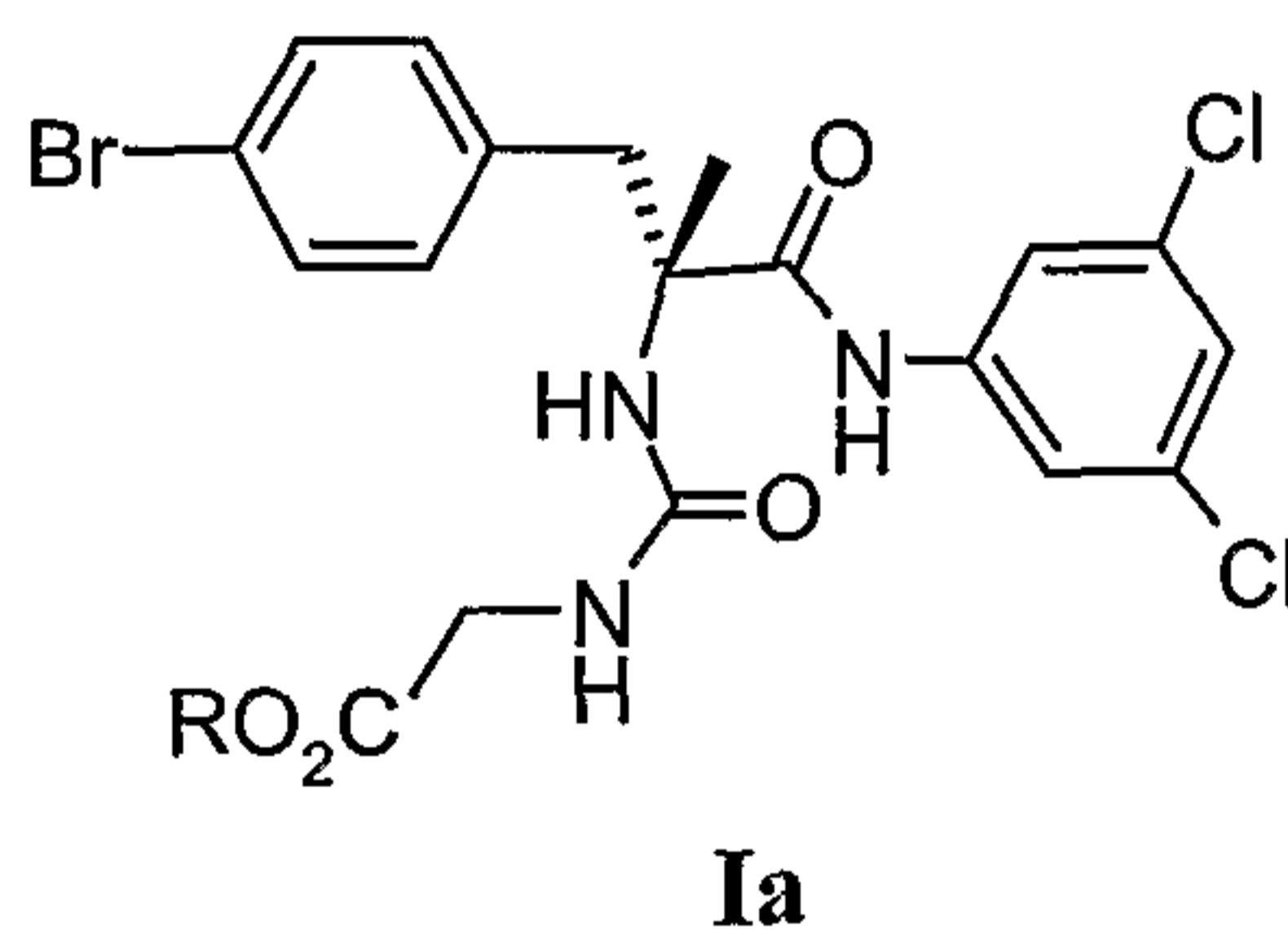


- 15 wherein R_2 is C_{1-6} alkyl or aryl.

28. A process for preparing a compound of claim 27 having the formula **IV**, said process comprising reacting a compound of the formula **III** with a strong base, a compound of the formula $(R_2O)_2POCl$, wherein R_2 is C_{1-6} alkyl or aryl, in a polar organic solvent at a temperature of about $-90\text{ }^\circ\text{C}$ to about $0\text{ }^\circ\text{C}$ to form a compound of the formula **IV** where R_2 is C_{1-6} alkyl or aryl:

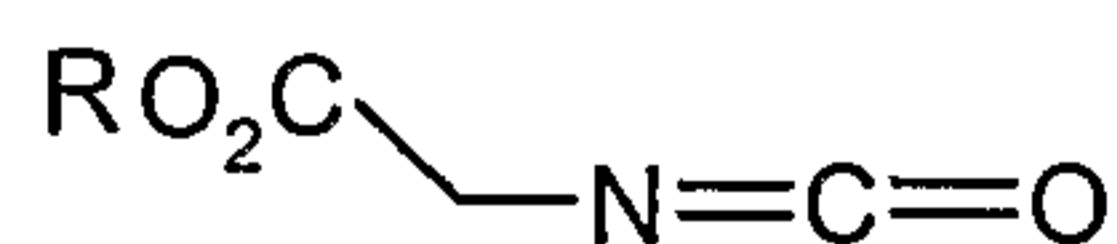


29. A compound having the following formula **Ia**:

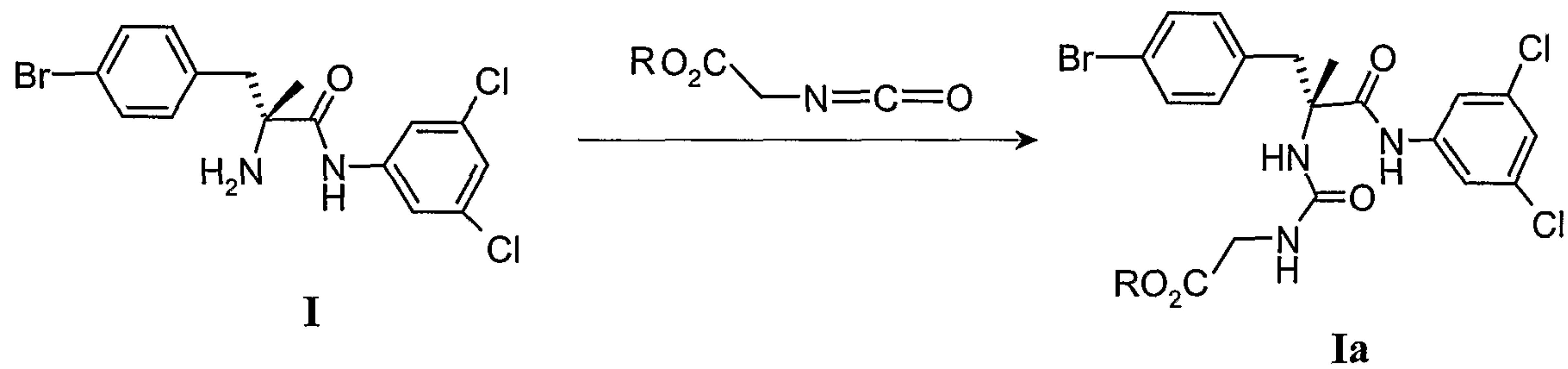


wherein R is C_{1-6} alkyl.

30. A process for preparing a compound of claim 29 having the formula **Ia**, said process comprising reacting a compound of the formula **I** with a compound of the formula



where R is C₁₋₆alkyl, in an aprotic organic solvent, to form a compound of the formula **Ia** where R is C₁₋₆alkyl:



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