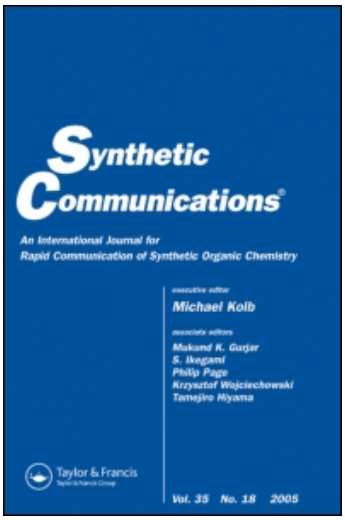


Synthetic Communications
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597304

SYNTHESIS OF XANTHENES, INDANES, AND TETRAHYDRONAPHTHALENES VIA INTRAMOLECULAR PHENYL-CARBONYL COUPLING REACTIONS

Chih-Wei Kuo [a]; Jim-Min Fang [a]
[a] Department of Chemistry, National Taiwan University, Taipei, Taiwan, Republic of China

Online Publication Date: 13 January 2001

To cite this Article Kuo, Chih-Wei and Fang, Jim-Min(2001)'SYNTHESIS OF XANTHENES, INDANES, AND TETRAHYDRONAPHTHALENES VIA INTRAMOLECULAR PHENYL-CARBONYL COUPLING REACTIONS',Synthetic Communications,31:6,877 — 892

To link to this Article: DOI: 10.1081/SCC-100103323

URL: http://dx.doi.org/10.1081/SCC-100103323

SYNTHETIC COMMUNICATIONS, 31(6), 877–892 (2001)

SYNTHESIS OF XANTHENES, INDANES, AND TETRAHYDRONAPHTHALENES VIA INTRAMOLECULAR PHENYL–CARBONYL COUPLING REACTIONS

Chih-Wei Kuo and Jim-Min Fang*

Department of Chemistry, National Taiwan University,
Taipei, Taiwan, 106, Republic of China

ABSTRACT

Benzaldehydes and acetophenones bearing tethered carbonyl chains underwent the intramolecular phenyl–carbonyl coupling reactions, by mediation of samarium diiodide and hexamethylphosphoramide, to afford the xanthenes and fused benzocarbocyclic compounds containing carbonyl and hydroxyl substituents.

INTRODUCTION

SmI_2 is a one-electron-transfer reducing agent[1–6] that can be utilized in the reductive couplings of carbonyl compounds to form pinacols.[7–9] When α,β-unsaturated esters, ketones, and amides are treated with SmI_2, reductions by saturation of the double bonds[10–14] or reductive couplings at β-carbons[16–21] may occur, depending on the reaction conditions. Besides the well-documented pinacolic couplings of aromatic carbonyl compounds,[7–9]

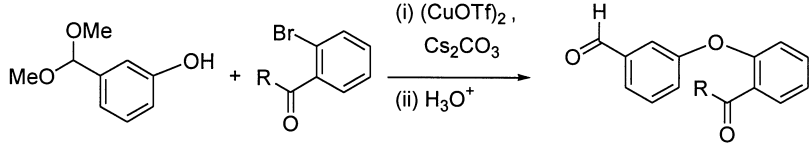
* Corresponding author.

we found that various benzaldehydes and acetophenones can undergo the phenyl–carbonyl coupling reactions on treatment with SmI_2 and HMPA.[21,22] In such reactions, benzaldehydes and acetophenones may be considered as extended vinylogous conjugated carbonyls.[23–25] We have also demonstrated in four examples[21,22] that beazaldehydes and acetophenones bearing appropriate carbonyl tethers can proceed via the intramolecular phenyl–carbonyl coupling reactions to give some benzene-fused oxacyclic compounds. We thus studied further such SmI_2/HMPA-promoted reactions as a route to construct xanthenes and benzene-fused carbocyclic compounds.

RESULTS AND DISCUSSION

Preparation of Xanthenes

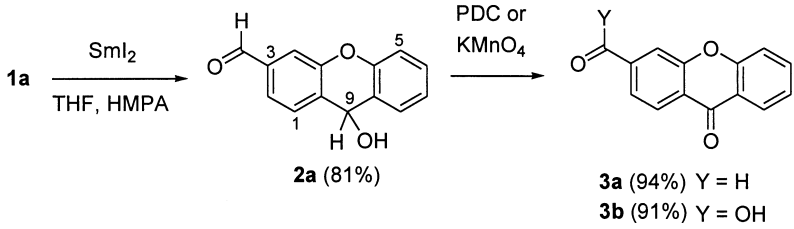
The diphenyl ethers **1a** and **1b** containing appropriate formyl and acetyl substituents were prepared according to Equation 1. By the mediation of $(CuOTf)_2$ C_6H_6 and Cs_2CO_3, 3-(dimethoxymethyl)phenol underwent a coupling reaction[26] with 2-bromobenzaldehyde to give **1a** in 72% yield, after hydrolysis of the moiety of dimethyl acetal. Coupling of 3-(dimethoxymethyl)phenol with 2-bromoacetophenone, followed by hydrolysis, also afforded compound **1b** in 83% yield.



R = H or Me

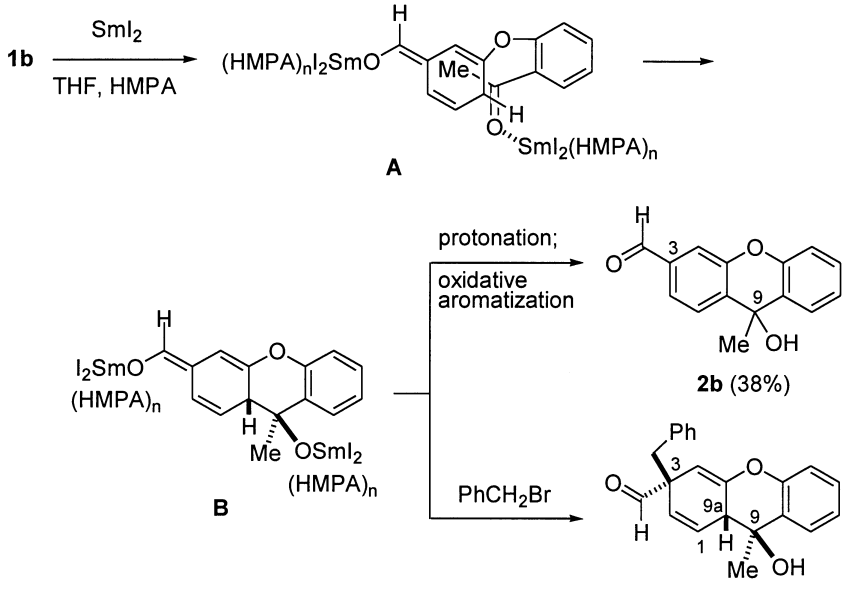
1a (72%) R = H
1b (83%) R = Me (1)

The intramolecular phenyl–carbonyl coupling reaction was achieved by slow addition of a THF solution of **1a** to the deep purple solution of SmI_2/HMPA in THF at 0°C (Eq. 2). After stirring at room temperature for 2 h, the reaction mixture was treated with NH_4Cl solution and exposed to the air to furnish the final oxidative step to regenerate the aromaticity, giving the xanthenecarbaldehyde **2a** in 81% yield. Compound **2a** decomposed gradually on standing (even in the refrigerator); it was thus converted to the stable xanthones[27–30] **3a** and **3b** by oxidation with pyridinium dichromate (PDC) or $KMnO_4$. The xanthonecarboxylic acid **3b** is known to bind to human serum albumin and lower the level of oxygen in blood.[27–30]



(2)

Under similar reaction conditions, the cyclization of **1b** was less effective (Eq. 3), giving a 38% yield of xanthenecarbaldehyde **2b**, along with 12% recovery of **1b**. The presumed Sm(III)-enolate intermediate **B** was trapped by alkylation with benzyl bromide to give **4** in a stereoselective manner.[21,22] The relative (3*S**,9*S**,9a*S**) configuration of **4** was established by the NOESY analysis. Thus, the methyl group (at δ 1.23) showed an obvious NOE correlation with the aldehyde proton (at δ 9.45). H-9a (at δ 2.92) also showed a strong NOE correlation with the benzyl protons (at δ 3.00), but not with the methyl group. The intramolecular coupling reaction might proceed via transition state **A**, followed by alkylation of the intermediate **B** via the less hindered face, to give **4** with the (3*S**,9*S**,9a*S**) configuration.



(3)

Preparation of Benzene-Fused Carbocyclic Compounds

Coupling of 3-bromobenzaldehyde dimethyl acetal with 3-butenylmagnesium bromide in the presence of $PdCl_2$(pddf),[31] followed by acid-catalyzed hydrolysis, gave 3-(3-butenyl)benzaldehyde **5a** in 83% yield (Eq. 4). Ozonolysis of **5a** afforded the aldehyde **6a** (91%), whereas Wacker oxidation[32] yielded the methyl ketone **6d** (64%). Oxidation of **5a** with MnO_2 in MeOH by the mediation of NaCN produced methyl 3-(3-butenyl)benzoate **5b**, which was subjected to ozonolysis to give **6b** in 76% overall yield. Compound **6c** was similarly prepared in a three-step sequence: (a) coupling of 3-bromoacetophenone dimethyl acetal with 3-butenylmagnesium bromide; (b) acid-catalyzed hydrolysis of the acetal; and (c) ozonolysis of the double bond. Starting with the coupling reactions of 4-pentenylmagnesium bromide with 3-bromobenzaldehyde dimethyl acetal or 3-bromoacetophenone dimethyl acetal, compounds **6e–h** were obtained in 59–73% yields by similar methods.

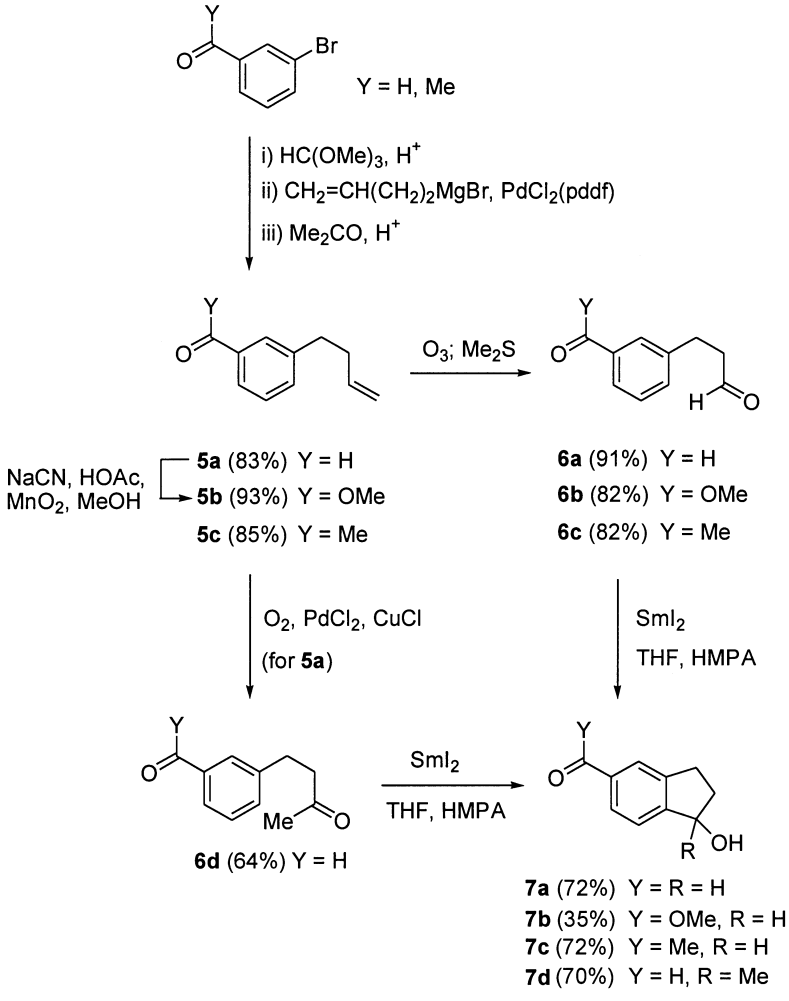
The SmI_2/HMPA promoted intramolecular cyclizations of **6a–h** were carried out to produce the benzocyclic compounds **7a–h**, including the indane and naphthalene derivatives (Eqs. 4 and 5). An aromatic carbonyl was generally more reactive than an aliphatic carbonyl on treatment with SmI_2. The intramolecular coupling reaction was considered to proceed via a nucleophilic addition of the cyclohexadienyl Sm(III) intermediate to the aliphatic carbonyl, similar to that operated in the transition state **A**. The bulky HMPA molecules might coordinate with the samarium species[21,22,33–36] to disfavor any coupling at the ketyl or *ortho* positions of the aromatic carbonyls.

SUMMARY

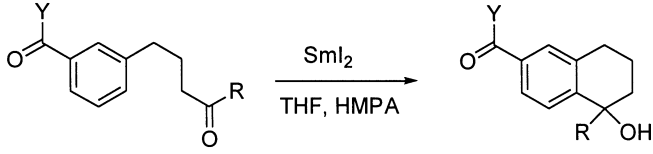
This study shows the limitation and scope of the SmI_2/HMPA promoted cyclizations of aromatic carbonyl compounds. This method afforded some carbonyl- and hydroxyl-substituted derivatives of xanthenes, indanes, and naphthalenes, which were not readily accessible by other methods. Provided with suitably designed substrates and optimized reaction conditions, this method may also be useful in the synthesis of other heterocyclic aromatic compounds.[37–39]

EXPERIMENTAL

Melting points are uncorrected. Chemical shifts are reported relative to $CHCl_3$ (δ_H 7.26) and $CDCl_3$ [δ_C (central line of t) 77.0]. All reactions



(4)



6e (59%)	Y = R = H	**7e** (58%)
6f (73%)	Y = Me, R = H	**7f** (71%)
6g (71%)	Y = H, R = Me	**7g** (62%)
6h (70%)	Y = R = Me	**7h** (47%)

(5)

requiring anhydrous conditions were conducted in a flame-dried apparatus under an atmosphere of nitrogen. Syringes and needles for the transfer of reagents were dried at 120°C and allowed to cool in a desiccator over P_2O_5 before use. Ethers were distilled from sodium benzophenone ketyl, and (chlorinated) hydrocarbons from CaH_2. Column chromatography was carried out on Kieselgel 60 (40–63 μm). Merck silica gel 60F sheets were used for analytical thin-layer chromatography. The acronym dppf represents 1,1′-bis(diphenylphosphino)ferrocene.

Caution: HMPA should be handled with caution, as it is considered as a potential carcinogen.

2-(3-Formylphenoxy)benzaldehyde (1a)

Under an atmosphere of argon, a mixture of $(CuOTf)_2$ C_6H_6 (90% purity, 70 mg, 0.25 mmol), Cs_2CO_3 (3.26 g, 10 mmol) and toluene (30 mL) was placed in a two-necked flask. A solution of 3-(dimethoxymethyl)phenol (1.68 g, 10 mmol), 2-bromobenzaldehyde (925 mg, 5 mmol), and EtOAc (22 mg, 0.25 mmol) in toluene (15 mL) was added dropwise. After refluxing at 110°C for 12 h, the mixture was cooled, treated with Et_2O (20 mL), and washed with aqueous NaOH (1 N solution). The organic phase was concentrated by rotary evaporation to give a crude product (the dimethyl acetal of **1a**), which was dissolved in THF (20 mL) and treated with a small amount of aqueous HCl (1 N solution) at room temperature for 3 h. The mixture was extracted with EtOAc, dried (Na_2SO_4), concentrated, and chromatographed on a silica gel column by elution with EtOAc/hexane (1:9) to give **1a** (817 mg, 3.62 mmol, 72% overall yield).

1a: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.25$; IR (neat) 1701 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) δ 6.95 (1H, d, $J = 8.2$ Hz), 7.27–7.39 (2H, m) 7.52–7.62 (3H, m), 7.67–7.72 (1H, m), 7.97 (1H, dd, $J = 7.7$, 1.7 Hz), 9.99 (1H, s), 10.46 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 118.3, 119.1, 124.3, 124.9, 125.9, 127.2, 128.9, 130.8, 135.9, 138.2, 157.5, 158.7, 188.8, 191.1; MS m/z (rel intensity) 226 (100, M^+); HRMS calcd. for $C_{14}H_{10}O_3$ 226.0630. Found 226.0625.

3-(2-Acetylphenoxy)benzaldehyde (1b)

According to the procedure similar to that for **1a**, coupling of 3-(dimethoxymethyl)phenol (1.01 g, 6 mmol) with 2-bromoacetophenone (597 mg, 3 mmol) using $(CuOTf)_2C_6H_6$ (42 mg, 0.15 mmol), Cs_2CO_3 (2.15 g, 6.6 mmol), and EtOAc (13 mg, 0.15 mmol) in toluene solution, followed by an acid-catalyzed hydrolysis, gave compound **1b** (597 mg, 83%).

1b: Solid; m.p. 58°–59°C; TLC (EtOAc/hexane (1:19)) $R_f = 0.09$; IR (KBr) 1682, 1698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.61 (3H, s), 6.96 (1H, d, $J = 8.3$ Hz), 7.22–7.32 (2H, m), 7.49 (1H, s), 7.46–7.53 (1H, m), 7.57 (1H, d, $J = 8.0$ Hz), 7.66 (1H, d, $J = 7.4$ Hz), 7.87 (1H, dd, $J = 7.7$, 1.7 Hz), 9.98 (1H, s); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 31.2, 117.7, 119.9, 124.4, 125.4, 130.7, 130.9, 133.8, 138.2, 155.0, 157.5, 191.2, 198.3; MS m/z (rel intensity) 240 (98, M^+), 197 (100); HRMS calcd. for $C_{15}H_{12}O_3$ 240.0786. Found 240.0784.

Representative Procedure for the SmI_2/HMPA Promoted Reactions

A deep blue SmI_2 solution (0.1 M, 1.5 mmol) was prepared by treatment of Sm (240 mg, 1.6 mmol) with 1,2-diiodoethane (423 mg, 1.5 mmol) in anhydrous THF (15 mL) for 1.5 h at room temperature. HMPA (1.05 mL, 6 mmol) was added, and the resulting deep purple solution was cooled to 0°C. A solution of **1a** (113 mg, 0.5 mmol) in THF (7 mL) was added dropwise over a period of 45 m via a syringe pump. The mixture was stirred at 0°C for 30 m, warmed to room temperature, and stirred at room temperature for 2 h. The serum cap was removed, and saturated NH_4Cl aqueous solution (0.5 mL) was added. After addition of Et_2O (20 mL), the resulting precipitates were removed by passing them through a pad of silica gel, and the crude product was obtained by elution with EtOAc. Further purification by silica gel column (EtOAc/hexane (1:4)) afforded a sample of **2a** (92 mg, 81%), which decomposed gradually on standing.

9-Hydroxy-9*H*-xanthene-3-carbaldehyde (2a)

TLC (EtOAc/hexane (1:4)) $R_f = 0.28$; IR (KBr) 1698, 3209 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 3.10 (1H, br s, OH), 5.71 (1H, s), 7.08–7.18 (2H, m), 7.27–7.36 (1H, m), 7.48–7.57 (3H, m), 7.64 (1H, d, $J = 7.8$ Hz), 9.86 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 63.0, 116.6, 117.9, 121.9, 123.8, 123.9, 128.8, 129.4, 129.8, 130.4, 137.1, 150.2, 150.9, 191.5; MS (FAB) m/z (rel intensity) 225 (20, $M^+ - 1$), 154 (100).

9-Hydroxy-9-methyl-9*H*-xanthene-3-carbaldehyde (2b)

Treatment of **1b** (120 mg, 0.5 mmol) with SmI_2 (2 mmol)/HMPA (1.4 mL) in THF solution (20 mL), according to the representative procedure, gave the title compound **2b** (45 mg, 38% yield), along with a 12% recovery of **1b** (15 mg).

2b: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.13$; IR (neat) 1701, 3389 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) δ 1.69 (3H, s), 2.75 (1H, br, s), 7.11–7.37 (3H, m), 7.56 (1H, d, $J = 1.5$ Hz), 7.64 (1H, dd, $J = 8.0$, 1.5 Hz), 7.72 (1H, dd, $J = 7.6$, 1.5 Hz), 7.88 (1H, d, $J = 8.0$ Hz), 9.96 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 34.5, 66.6, 116.3, 117.6, 124.0, 124.1, 126.3, 127.5, 129.1, 134.6, 136.8, 149.1, 149.9, 153.6, 191.4; MS m/z (rel intensity) 240 (2, M^+), 209 (100); HRMS calcd. for $C_{14}H_8O_3$ ($M^+ - CH_4$) 224.0474. Found 224.0475.

9-Oxo-9*H*-xanthene-3-carbaldehyde (3a)[30]

Compound **2a** (113 mg, 0.5 mmol) was treated with pyridinium dichromate (376 mg, 1 mmol) and Celite (200 mg) in CH_2Cl_2 (20 mL) for 2 h at room temperature. The reaction mixture was filtered through a pad of silica gel and rinsed with EtOAc. The filtrate was concentrated, and chromatographed on a silica gel column by elution with EtOAc/hexane (1:9) to give **3a** (106 mg, 94%).

3a: Solid; m.p. 125°–127°C; ^1H NMR ($CDCl_3$, 200 MHz) δ 7.37 (1H, t, $J = 7.9$ Hz), 7.47 (1H, d, $J = 8.5$ Hz), 7.68–7.82 (2H, m), 7.92 (1H, d, $J = 1.0$ Hz), 8.27 (1H, dd, $J = 8.0$, 1.0 Hz), 8.41 (1H, d, $J = 8.0$ Hz), 10.11 (1H, s).

9-Oxo-9*H*-xanthene-3-carboxylic Acid (3b)[27]

A mixture of **2a** (23 mg, 0.1 mmol) and $KMnO_4$ (24 mg, 0.15 mmol) in water (10 mL) was heated at 60°C for 20 m. The mixture was cooled, and extracted with CH_2Cl_2. The organic phase was dried (Na_2SO_4), filtered, and concentrated to give **3b** (21 mg, 91%).

3b: Solid; m.p. > 300°C; ^1H NMR (CD_3COCD_3, 300 MHz) δ 7.49 (1H, t $J = 7.6$ Hz), 7.64 (1H, d, $J = 8.5$ Hz), 7.86–7.94. (2H, m), 8.10 (1H, d, $J = 1.4$ Hz), 8.24 (1H, dd, $J = 8.1$, 1.4 Hz), 8.39 (1H, d, $J = 8.1$ Hz), 10.23 (1H, s).

3-Benzyl-9-hydroxy-9-methyl-9,9a-dihydro-3*H*-xanthene-3-carbaldehyde (4)

According to the representative procedure, the intermediate resulting from the intramolecular coupling reaction of **1b** (120 mg, 0.5 mmol) was

trapped by alkylation with benzyl bromide (4 equiv) at room temperature for 2 days to give **4** (35 mg, 21%) after silica gel chromatography.

4: Oil; TLC (EtOAc/hexane (1:4)) $R_f = 0.3$; IR (neat) 1720, 3423 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.23 (3H, s), 1.94 (1H, br s), 2.91 (1H, m), 3.00 (2H, s), 5.22 (1H, t, $J = 1.8$ Hz), 5.77 (1H, dt, $J = 10.1$, 1.8 Hz), 6.11 (1H, dd, $J = 10.1$, 3.0 Hz), 6.88 (1H, d, $J = 8.1$ Hz), 6.98 (1H, t, $J = 7.4$ Hz), 7.10–7.26 (6H, m), 7.46 (1H, dd, $J = 7.7$, 1.5 Hz), 9.45 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 25.8, 41.4, 43.7, 56.4, 70.4, 101.3, 115.9, 121.1, 124.5, 126.0, 126.4, 127.0, 127.9, 129.0, 130.4, 131.5, 136.0, 150.1, 151.0, 199.1; HRMS calcd. for ($C_{22}H_{20}O_3 - CH_2O$) 302.1306. Found 302.1310.

3-(3-Oxopropyl)benzaldehyde (6a)

Under an atmosphere of argon, 3-butenylmagnesium bromide (20 mmol, 20 mL of 1 M solution in Et_2O) was added dropwise to a mixture of 3-bromobenzaldehyde dimethyl acetal (1.99 g, 10 mmol) and $PdCl_2$(dppf) (73 mg, 0.1 mmol) in anhydrous Et_2O (10 mL) at $-78°C$. The mixture was stirred for 24 h at room temperature, and quenched by addition of aqueous NH_4Cl (0.5 N solution). The aqueous layer was separated and extracted with Et_2O. The organic phase was combined, dried (Na_2SO_4), filtered, and concentrated. The crude acetal product was dissolved in Me_2CO (30 mL) and stirred with a small amount of *p*-TsOH at room temperature for 4 h. The mixture was partitioned with water and EtOAc. The aqueous layer was separated and extracted three times with EtOAc. The combined organic phase was dried (Na_2SO_4), filtered, concentrated, and chromatographed on a silica gel column by elution with EtOAc/hexane (1:99) to give 3-(3-butenyl)benzaldehyde (**5a**, 1.33 g, 83%).

Ozone was passed through a CH_2Cl_2 solution (50 mL) of **5a** (1.20 g, 7.5 mmol) at $-78°C$ until the light blue color of ozone persisted. Me_2S (5 mL) was added. The mixture was warmed to room temperature and stirred for 16 h. The mixture was concentrated, and chromatographed on a silica gel column by elution with EtOAc/hexane (l:19) to give **6a** (1.11 g, 91%).

6a: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.12$; IR (neat) 1698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.71–2.80 (2H, m), 2.95 (2H, td, $J = 7.7$, 1.4 Hz), 7.36–7.43 (2H, m), 7.58–7.65 (2H, m), 9.73 (1H, t, $J = 1.1$ Hz), 9.89 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 27.4, 44.6, 127.9, 128.9, 129.0, 134.4, 136.5, 141.4, 192.1, 200.7; MS m/z (rel intensity) 162 (100, M^+); HRMS calcd. for $C_{10}H_{10}O_2$ 162.0681. Found 162.0696.

Methyl 3-(3-Oxopropyl)benzoate (6b)

A MeOH solution (20 mL) of 3-(3-butenyl)benzaldehyde (480 mg, 3 mmol) was treated with MnO_2 (85% content, 1.84 g, 18 mmol), NaCN (232 mg, 4.5 mmol), and HOAc (0.26 mL, 4.5 mmol) at room temperature for 12 h. The mixture was filtered and rinsed with EtOAc. The filtrate was concentrated and chromatographed on a silica gel column by elution with EtOAc/hexane (1:99) to give methyl 3-(3-butenyl)benzoate (**5b**, 530 mg, 93%). According to the procedure similar to that for **6a**, ester **5b** (475 mg, 2.5 mmol) was subjected to ozonolysis to give **6b** (395 mg, 82%).

6b: Solid; m.p. 71°–72°C; TLC (EtOAc/hexane (1:9)) $R_f = 0.24$; IR (KBr) 1720 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.76 (2H, td, $J = 7.1$, 1.1 Hz), 2.95 (2H, t, $J = 7.1$ Hz), 3.86 (3H, s), 7.31–7.35 (2H, m), 7.82–7.85 (2H, m), 9.77 (1H, t, $J = 1.1$ Hz); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 27.7, 44.9, 52.0, 127.5, 128.5, 129.2, 130.3, 132.9, 140.6, 166.9, 200.9; MS m/z (rel intensity) 192 (78, M^+), 160 (100); HRMS calcd. for $C_{11}H_{12}O_3$ 192.0787. Found 192.0789.

3-(3-Acetylphenyl)propanal (6c)

According to the procedure similar to that for **6a**, coupling of 3-bromoacetophenone dimethyl acetal (1.17 g, 4.78 mmol) with 3-butenylmagnesium bromide afforded 3-(3-butenyl)acetophenone dimethyl acetal, which was subjected to hydrolysis and ozonolysis to give **6c** (589 mg, 70%).

6c: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.15$; IR (neat) 1683, 1712 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.54 (3H, s), 2.77 (2H, td, $J = 7.3$, 1.2 Hz), 2.96 (2H, t, $J = 7.3$ Hz), 7.33–7.36 (2H, m), 7.73–7.75 (2H, m), 9.77 (1H, t, $J = 1.2$ Hz); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 26.5, 27.7, 44.9, 126.4, 127.8, 128.7, 133.1, 140.9, 198.1, 200.9; MS m/z (rel intensity) 176 (58, M^+), 161 (100); HRMS calcd. for $C_{11}H_{12}O_2$ 176.0837. Found 176.0831.

3-(3-Oxobutyl)benzaldehyde (6d)

Under an atmosphere of O_2, a DMF solution (5 mL) of 3-(3-butenyl)-benzaldehyde (**5a**, 320 mg, 2 mmol) was added to a mixture of $PdCl_2$ (47 mg, 0.4 mmol), CuCl (218 mg, 2.2 mmol), and water (0.1 mL). The mixture was stirred for 24 h, and extracted with CH_2Cl_2 after addition of aqueous NH_4Cl solution (0.5 N solution). The organic phase was dried (Na_2SO_4), filtered, concentrated, and chromatographed on a silica gel column by elution with

EtOAc/hexane (1:9) to give **6d** (225 mg, 64%), along with an 11% recovery of the starting material.

6d: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.13$; IR (neat) 1716 cm^{-1}; ^{1}H NMR($CDCl_3$, 200 MHz) δ 2.09 (3H, s), 2.75 (2H, t, $J = 6.3$ Hz), 2.91 (2H, t, $J = 6.3$ Hz), 7.37–7.41 (2H, m), 7.62–7.66 (2H, m), 9.92 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 29.0, 29.9, 44.4, 127.8, 129.0 (2C), 134.6, 136.5, 142.0, 192.3, 207.3; MS m/z (rel intensity) 176 (70, M^+), 133 (100); HRMS calcd. for $C_{11}H_{12}O_2$ 176.0837. Found 176.0839.

3-(4-Oxobutyl)benzaldehyde (6e)

According to the procedure similar to that for **6a**, 3-(4-pentenyl)-benzaldehyde (**5e**, 522 mg, 3 mmol) was subjected to ozonolysis to give **6e** (311 mg, 59%).

6e: Oil; TLC (EtOAc/hexane (1:4)) $R_f = 0.36$; IR (neat) 1698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.93 (2H, quin, $J = 7.2$ Hz), 2.43 (2H, t, $J = 7.2$ Hz), 2.68 (2H, t, $J = 7.2$ Hz), 7.39–7.41 (2H, m), 7.64–7.67 (2H, m), 9.71 (1H, s), 9.93 (1H, s); ^{13}C NMR ($CDCl_3$, 50MHz) δ 23.2, 34.5, 42.8, 127.8, 129.0, 129.1, 134.5, 136.5, 142.3, 192.3, 201.7; MS m/z (rel intensity) 176 (24, M^+), 132 (100); HRMS calcd. for $C_{11}H_{12}O_2$ 176.0837. Found 176.0842.

4-(3-Acetylphenyl)butanal (6f)

According to the procedure similar to that for **6a**, 3-(4-pentenyl)-acetophenone (**5f**, 552 mg, 3 mmol) was subjected to ozonolysis to give **6f** (418 mg, 73%).

6f: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.14$; IR (neat) 1683, 1709 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.98 (2H, quin, $J = 7.4$ Hz), 2.48 (2H, t, $J = 7.4$ Hz), 2.60 (3H, s), 2.72 (2H, t, $J = 7.4$ Hz), 7.38–7.40 (2H, m),7.78–7.79 (2H, m), 9.76 (1H, s); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 23.3, 26.5, 34.7, 42.8, 126.2, 127.9, 128.5, 133.1, 137.2, 141.7, 198.1, 201.8; MS m/z (rel intensity) 190 (11, M^+), 131 (100); HRMS calcd. for $C_{12}H_{14}O_2$ 190.0994. Found 190.0994.

3-(4-Oxopentyl)benzaldehyde (6g)

Wacker oxidation of 3-(4-pentenyl)benzaldehyde (**5e**, 261 mg, 1.5 mmol), according to the procedure similar to that for **6d**, gave **6g** (203 mg, 71%), along with a 12% recovery of the starting material.

6g: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.17$; IR (neat) 1713 cm^{-1}; ^1H NMR($CDCl_3$, 200 MHz) δ 1.91 (2H, quin, $J = 7.4$ Hz), 2.11 (3H, s), 2.44 (2H, t, $J = 7.4$ Hz), 2.68 (2H, t, $J = 7.4$ Hz), 7.42–7.44 (2H, m), 7.67–7.72 (2H, m), 9.97 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 24.9, 30.0, 34.7, 42.6, 127.9, 129.1, 129.3, 134.7, 136.6, 142.7, 192.5, 208.3; MS m/z (rel intensity) 190 (84, M^+), 133 (100), 119 (16); HRMS calcd. for $C_{12}H_{14}O_2$ 190.0994. Found 190.0992.

5-(3-Acetylphenyl)-2-pentanone (6h)

According to the procedure similar to that for **6d**, coupling of 3-bromoacetophenone dimethyl acetal with 4-pentenylmagnesium bromide, followed by hydrolysis, afforded 3-(4-pentenyl)acetophenone (**5f**), which was subjected to Wacker oxidation to give **6h** (427 mg, 70%).

6h: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.13$; ^1H NMR ($CDCl_3$, 200 MHz) δ 1.92 (2H, quin, $J = 7.5$ Hz), 2.13 (3H, s), 2.46 (2H, t, $J = 7.5$ Hz), 2.60 (3H, s), 2.68 (2H, t, $J = 7.5$ Hz), 7.38–7.40 (2H, m), 7.77–7.82 (2H, m); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 24.9, 26.5, 29.8, 34.7, 42.5, 126.0, 127.9, 128.5, 133.1, 137.0, 142.0, 198.2, 208.4; MS m/z (rel intensity) 204 (23, M^+), 147 (100); HRMS calcd. for $C_{13}H_{16}O_2$ 204.1150. Found 204.1152.

1-Hydroxyindane-5-carbaldehyde (7a)

By a procedure similar to that for **2a**, treatment of **6a** (81 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7a** (59 mg, 72%).

7a: Solid; m.p. 58°–59°C; TLC (EtOAc/hexane (3:7)) $R_f = 0.24$; IR (KBr) 1686, 3378 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) δ 1.85–2.04 (1H, m), 2.44–2.60 (1H, m), 2.78–2.90 (1H, m), 2.98–3.15 (1H, m), 5.24 (1H, t, $J = 6.6$ Hz), 7.51 (1H, d, $J = 8.1$ Hz), 7.69 (1H, s), 7.70 (1H, d, $J = 8.1$ Hz), 9.93 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 29.3, 35.9, 75.8, 124.6, 125.8, 129.2, 136.6, 144.1, 151.9, 192.3; MS m/z (rel intensity) 162 (95, M^+), 133 (100); HRMS calcd. for $C_{10}H_{10}O_2$ 162.0681. Found 162.0680.

Methyl 1-Hydroxyindane-5-carboxylate (7b)

By a procedure similar to that for **2a**, treatment of **6b** (96 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7b** (34 mg, 35%).

7b: Solid; m.p. 68°–69°C; TLC (EtOAc/hexane (1:4)) $R_f = 0.17$; IR (KBr) 1718, 3418 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) δ 1.67 (1H, br s), 1.86–2.04 (1H, m), 2.48–2.60 (1H, m), 2.78–2.90 (1H, m), 2.98–3.12 (1H, m), 3.88 (3H, s), 5.24 (1H, t, $J = 6.4$ Hz), 7.44 (1H, d, $J = 8.4$ Hz), 7.88 (1H, s), 7.90 (1H, d, $J = 8.4$ Hz); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 29.5, 36.0, 52.1, 75.9, 124.0, 126.1, 128.4, 130.1, 143.4, 150.0, 167.2; MS m/z (rel intensity) 192 (47, M^+), 133 (100); HRMS calcd. for $C_{11}H_{12}O_3$ 192.0787. Found 192.0791.

5-Acetyl-1-indanol (7c)

By a procedure similar to that for **2a**, treatment of **6c** (88 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7c** (63 mg, 72%).

7c: Solid; m.p. 45°–46°C; TLC (EtOAc/hexane (1:4)) $R_f = 0.13$; IR (KBr) 1678, 3388 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) δ 1.88–2.02 (1H, m), 2.44–2.57 (1H, m), 2.55 (3H, s), 2.72–2.88 (1H, m), 2.96–3.02 (1H, m), 5.22 (1H, t, $J = 6.5$ Hz), 7.43 (1H, d, $J = 8.3$ Hz), 7.77 (1H, s), 7.78 (1H, d, $J = 8.3$ Hz); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 26.8, 29.5, 35.9, 75.8, 124.1, 124.7, 127.3, 137.2, 143.6, 150.3, 198.4; MS m/z (rel intensity) 176 (43, M^+), 161 (100); HRMS calcd. for $C_{11}H_{12}O_2$ 176.0838. Found 176.0847.

1-Hydroxy-1-methylindane-5-carbaldehyde (7d)

By a procedure similar to that for **2a**, treatment of **6d** (88 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7d** (62 mg, 70%).

7d: Oil; TLC (EtOAc/hexane (1:4)) $R_f = 0.17$; IR (neat) 1686, 3396 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.55 (3H, s), 1.72–1.68 (1H, m), 2.10 (1H, br s), 2.14–2.30 (1H, m), 2.81–2.91 (1H, m), 2.99–3.09 (1H, m), 7.47 (1H, d, $J = 8.2$ Hz), 7.70 (1H, s), 7.73 (1H, d, $J = 8.2$ Hz), 9.95 (1H, s); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 27.3, 29.1, 42.4, 80.9, 122.9, 126.0, 129.0, 129.5, 136.6, 143.4, 192.2; MS m/z (rel intensity) 176 (58, M^+), 161 (100); HRMS calcd. for $C_{11}H_{12}O_2$ 176.0837. Found 176.0843.

1-Hydroxy-1,2,3,4-tetrahydro-6-naphthaldehyde (7e)

By a procedure similar to that for **2a**, treatment of **6e** (88 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7e** (51 mg, 58%), along with a 14% recovery of **6e**.

7e: Oil; TLC (EtOAc/hexane (1:4)) $R_f = 0.18$; IR (neat) 1698, 3387 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.77–2.07 (4H, m), 2.18 (1H, br s), 2.82 (2H, m), 4.77 (1H, t, $J = 5.1$ Hz), 7.57–7.68 (3H, m), 9.91 (1H, s); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 18.9, 29.0, 32.1, 68.1, 127.2, 129.0, 130.4, 135.4, 137.9, 145.6, 192.3; MS m/z (rel intensity) 176 (59, M^+), 147 (100); HRMS calcd. for $C_{11}H_{12}O_2$ 176.0837. Found 176.0840.

6-Acetyl-1,2,3,4-tetrahydro-1-naphthol (7f)

By a procedure similar to that for **2a**, treatment of **6f** (95 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7f** (68 mg, 71%), along with an 8% recovery of **6f**.

7f: Oil; TLC (EtOAc/hexane (1:9)) $R_f = 0.05$; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.76–2.05 (4H, m), 2.40 (1H, br s), 2.53 (3H, s), 2.70–2.86 (2H, m), 4.75 (1H, br s), 7.50 (1H, d, $J = 8.0$ Hz), 7.64 (1H, s), 7.71 (1H, d, $J = 8.0$ Hz); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 18.9, 26.6, 29.2, 32.1, 67.9, 125.9, 128.6, 128.9, 136.0, 137.4, 144.2, 198.3; MS m/z (rel intensity) 190 (75, M^+), 147 (100); HRMS calcd. for $C_{12}H_{14}O_2$ 190.0994. Found 190.0999.

1-Hydroxy-1-methyl-1,2,3,4-tetrahydro-6-naphthaldehyde (7g)

By a procedure similar to that for **2a**, treatment of **6g** (95 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7g** (59 mg, 62%), along with a 17% recovery of **6g**.

7g: Oil; TLC (EtOAc/hexane (1:4)) $R_f = 0.23$; IR (neat) 1698, 3424 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.57 (3H, s), 1.86–2.04 (5H, m), 2.85–2.89 (2H, m), 7.58 (1H, s), 7.70 (1H, d, $J = 8.0$ Hz), 7.77 (1H, d, $J = 8.0$ Hz), 9.95 (1H, s); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 20.3, 29.6, 30.8, 38.4, 70.8, 127.2, 127.4, 130.5, 135.2, 137.1, 149.7, 192.2; MS m/z (rel intensity) 190 (1, M^+), 175 (100); HRMS calcd. for $C_{12}H_{14}O_2$ 190.0994. Found 190.0995.

6-Acetyl-1-methyl-1,2,3,4-tetrahydro-1-naphthol (7h)

By a procedure similar to that for **2a**, treatment of **6h** (102 mg, 0.5 mmol) with SmI_2/HMPA in THF gave **7h** (48 mg, 47%), along with a 19% recovery of **6h**.

7h: Oil; TLC (EtOAc/hexane (1:4)) $R_f = 0.17$; IR (neat) 1681, 3433 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.51 (3H, s), 1.88–1.93 (4H, m),

2.13 (1H, br s), 2.52 (3H, s), 2.79 (2H, t, $J = 5.6$ Hz), 7.61–7.70 (3H, m); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 20.3, 26.6, 29.7, 30.7, 39.4, 70.5, 126.1, 126.6, 128.8, 135.6, 136.4, 148.2, 198.2; MS m/z (rel intensity) 204 (7, M^+), 189 (100); HRMS calcd. for $C_{13}H_{16}O_2$ 204.1150. Found 204.1152.

ACKNOWLEDGMENTS

We thank the National Science Council for financial support.

REFERENCES AND NOTES

1. Natale, N.R. Org. Prep. Proc. Int. **1983**, *15*, 387.
2. Kagan, H.B.; Namy, J.L. Tetrahedron **1986**, *42*, 6573.
3. Inanaga, J. Rev. Heteroatom Chem. **1990**, *3*, 75.
4. Molander, G.A. In *Comprehensive Organic Synthesis*; Trost, B.M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 1, 251.
5. Soderquist, J.A. Aldrichimia Acta **1991**, *24*, 15.
6. Molander, G.A. Chem. Rev. **1992**, *92*, 29.
7. Namy, J.L.; Souppe, J.; Kagan, H.B. Tetrahedron Lett. **1983**, *24*, 765.
8. Taniguchi, N.; Kaneta, N.; Uemura, M. J. Org. Chem. **1996**, *61*, 6088.
9. Lu, L.; Fang, J.-M.; Lee, G.-H.; Wang, Y. J. Chin. Chem. Soc. **1997**, *44*, 279.
10. Girard, P.; Namy, J.L.; Kagan, H.B. J. Am. Chem. Soc. **1980**, *102*, 2693.
11. Inanaga, J.; Sakai, S.; Handa, Y.; Yamaguchi, M.; Yokoyama, Y. Chem. Lett. **1991**, 2117.
12. Cabrera, A.; Alper, H. Tetrahedron Lett. **1992**, *33*, 5007.
13. Olson, S.H.; Danishefsky, S.J. Tetrahedron Lett. **1994**, *35*, 7901.
14. Yanada, R.; Bessho, K.; Yanada, K. Synlett **1995**, 443.
15. Fujita, Y.; Fukuzumi, S.; Otera, J. Tetrahedron Lett. **1997**, *38*, 2121.
16. Inanaga, J.; Handa, Y.; Tabuchi, T.; Otsubo, K. Tetrahedron Lett. **1991**, *32*, 6557.
17. Kanemasa, S.; Yamamoto, H.; Kobayashi, S. Tetrahedron Lett. **1996**, *37*, 8505.
18. Cabrera, A.; Rosas, N.; Sharma, P.; Le Lagadec, R.; Velasco, L.; Salmon, M.; Arias, J.L. Synth. Commun. **1998**, *28*, 1103.
19. Cabrera, A.; Le Lagadec, R.; Sharma, P.; Arias, J.L.; Toscano, R.A.; Velasco, L.; Gavino, R.; Alvarez, C.; Salmon, M. J. Chem. Soc., Perkin Trans. 1 **1998**, 3609.
20. Kim, Y.H.; Park, H.S.; Kwon, D.W. Synth. Commun. **1998**, *28*, 4517.

21. Shiue, J.-S.; Lin, C.-C.; Fang, J.-M. Tetrahedron Lett. **1993**, *34*, 335.
22. Shiue, J.-S.; Lin, M.-H.; Fang, J.-M. J. Org. Chem. **1997**, *62*, 4643.
23. Angle, S.R.; Ranier, J.D. J. Org. Chem. **1992**, *57*, 6883.
24. Arseniyadis, S.; Yashunsky, D.V.; Dorado, M.M.; Alves, R.B.; Toromanoff, E.; Toupet, L.; Portier, P. Tetrahedron Lett. **1993**, *34*, 4927.
25. Dinesh, C.U.; Reissig, H.-U. Angew. Chem. Int. Ed. **1999**, *38*, 789.
26. Marcoux, J.-F.; Doye, S.; Buchwald, S.L. J. Am. Chem. Soc. **1997**, *119*, 10539.
27. Goldberg, A.A.; Wragg, A.H. J. Chem. Soc. **1958**, 4227.
28. Valenti, P.; Chiarini, A.; Gasperi, F.; Brudriesi, R. Arzneim. Forsch. **1990**, *40*, 122.
29. Hersey, A.; Hyde, R.M.; Livingstone, D.J.; Rahr, E. J. Pharm. Sci. **1991**, *80*, 333.
30. Montanari, P.; Chiarini, A.; Budruesi, R.; Valenti, P. J. Heterocycl. Chem. **1992**, *29*, 259.
31. Hayashi, T.; Konishi, M.; Kobori, Y.; Kumuda, M.; Higuchi, T.; Hirotsu, K. J. Am. Chem. Soc. **1984**, *106*, 158.
32. Tsuji, J. Synthesis **1984**, 396.
33. The reaction of benzophenone with SmI_2/HMPA in THF, followed by protonation with (2,6-di-*tert*-butyl)-4-methylphenol, gives a HMPA ligated samarium(III) enolate of 2,5-cyclohexadienyl phenyl ketone. Hou, Z.; Yoshimura, T.; Wakatsuki, Y. J. Am. Chem. Soc. **1994**, *116*, 11169.
34. Other indications of HMPA-bound samarium species; Donoghue, J.T.; Fernandez, E.; McMillan, J.A.; Peter, D.A. J. Inorg. Nucl. Chem. **1969**, *31*, 1431.
35. Ujikawa, O.; Inanaga, J.; Yamaguchi, M. Tetrahedron Lett. **1989**, *30*, 2837.
36. Cabrera, A.; Rosas, N.; Alvarez, C.; Sharma, P.; Toscano, A.; Salmon, M.; Aris, J.L. Polyhedron **1996**, *15*, 2971.
37. SmI_2-promoted intramolecular indole-carbonyl and thiophene-carbonyl coupling reactions: Shiue, J.-S.; Fang, J.-M. J. Chem. Soc., Chem. Commun. **1993**, 1277.
38. Lin, S.-C.; Yang, F.-D.; Shiue, J.-S.; Fang, J.-M. J. Org. Chem. **1998**, *63*, 2909.
39. Yang, S.-M.; Fang, J.-M. J. Org. Chem. **1999**, *64*, 394.

Received in Japan April 13, 2000