(3S,4S,5S)-3-[5-Carboxy-4-(carboxymethyl)-3-pyrrolidinyl]-1,6-dihydro-6-oxo-2-pyridinecarboxylic Acid (Acromelic Acid B, 2). To a solution of pyridone **38** (26 mg, 0.06 mmol) in MeOH (1.1 mL) was added 1 N KOH (0.54 mg, 0.54 mmol, 9 equiv), and the mixture was left at room temperature overnight. The solvent was removed, the residue was dissolved in trifluoroacetic acid (0.5 mL), and the mixture was stirred at room temperature. After 30 min, the mixture was diluted with water and evaporated. The residue was purified with PEP (20 × 46 cm, 10 sheets, +9 cm at pH 4.6, py-AcOH-H_2O, 3:3:996, 600 V, 2 h) to afford acromelic acid B (13 mg, 73%) as amorphous powder: $[\alpha]_D$ 50.1° (*c* 0.45, H_2O); SIMS, *m/z* 311 $(M + H)^+$; UV (pH 7) 239 (5.150) and 311 (3.250), (pH 2) 241 (4.650) and 312 (2.960), (pH 12) 236 (6.320), and 302 (2.920) nm; FT-IR 3165-3045, 1715, 1695, 1620 cm^{-1}; CD (H_2O) 225 (+3.500) nm; ^1H NMR (500 MHz, D_2O) δ 2.22 (2 H, d, *J* = 7.3), 3.15 (1 H, ddt, *J* = 3.4 8.3, 7.3), 3.66 (1 H, t, *J* = 11.7), 3.76 (1 H, dd, *J* = 8.3, 11.7), 4.14 (1 H, d, *J* = 3.4), 4.47 (1 H, dt, *J* = 11.7, 8.3), 6.67 (1 H, d, *J* = 9.3), 7.67 (1 H, d, *J* = 9.3); cellulose TLC R_f 0.16 (*n*-BuOH-AcOH-H_2O, 4:1:5), 0.25 (*n*-BuOH-HCO_2H-H_2O, 6:1:2), 0.07 (*i*-PrOH-H_2O, 3:1), 0.21 (*n*-BuOH-py-AcOH-H_2O, 15:10:3:12); PEP, +7.7 cm (pH 3.5, py-AcOH-H_2O, 1:10:190, 600 V, 2 h), +8.2 (pH 4.6, py-AcOH-H_2O, 3:3:994, 600 V, 2 h), +8.8 (pH 6.5, py-AcOH-H_2O, 100:4:900, 600 V, 2 h), +11.3 (pH 9.2, 0.05 M Borax, 600 V, 2 h).

A New Route to the Prostaglandin Skeleton via Radical Alkylation. Synthesis of 6-Oxoprostaglandin E_1†

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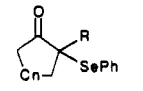
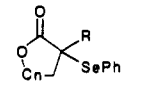
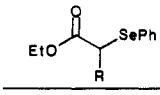
Abstract: A new, mild, and efficient method for the construction of the prostanoid skeleton involving cuprate addition to α-(phenylseleno)cyclopentenones followed by radical-based coupling to the resulting products with allylstannane derivatives is described. The method is applied to the synthesis of 6-oxoprostaglandin E_1, a biologically active and naturally occurring compound.

A large number of strategies toward prostaglandins (PGs) have been reported[1] since the first pioneering syntheses of these molecules were developed by the Corey[2a] and Upjohn groups.[2b] Among these methods, that starting with a protected 4-hydroxy-2-cyclopenten-1-one should be noted as one of the most efficient approaches to the PG skeleton.[3] We have been interested in finding an effective way to PGs via a free-radical chain process, which is attractive due to its characteristic mode of reaction.[4] Heretofore, a few methods involving a radical process have appeared; Stork[5a] and Keck[5b] with their collaborators have reported intramolecular radical cyclization reactions to give PG intermediates. We now report (1) a radical-based allylation of several α-phenylseleno carbonyl compounds, (2) a new synthesis of 6-methyleneprostaglandin E_1 (6-methylene-PGE_1) via a free-radical alkylation of a β-substituted α-(phenylseleno)cyclopentanone, readily obtainable from the cyclopentenone, and (3) the transformation of 6-methylene-PGE_1 methyl ester to 6-oxoprostaglandin E_1 (6-oxo-PGE_1), a biologically and pharmacologically important prostanoid.[6]

The electrophilic alkylation of α-carbanions of α-phenylseleno carbonyl compounds followed by deselenenylation is a widely used method for the synthesis of naturally occurring compounds.[7] Construction of the PG skeleton along these lines appears unattractive due to the base-labile nature[8] of the β-alkoxycarbonyl moiety of the cyclopentanone framework. A free-radical pathway, however, which can be carried out under neutral conditions may be the method of choice for the direct alkylation to a carbonyl group.

We first studied the photolytic allylation of α-phenylseleno carbonyl compounds with allyltributylstannane.[9] Several representative results are summarized in Table I. Allylated products were obtained in high yields from primary, secondary, or tertiary selenides. On the basis of these results we next applied this radical-based allylation to base-labile and sterically hindered, seleno-substituted β-(silyloxy)cyclopentanones, aiming at a new synthesis of the PG skeleton.

Table I. Photoinitiated Allylation of α-Phenylseleno Carbonyl Compounds with Allyltributylstannane[a]

selenide	R	*n*	reaction time, h	allylated product,[b] %
	H	1	1	80
	H	2	1.5	81
	H	3	1.5	79
	Me	1	4.5	63
	H	1	1	90[c]
	H	2	1	81
	H	3	3	76
	Me	1	2.5	64
	H		1	74
	Me		1	79

[a] Two equivalents of allyltributylstannane/1 equiv of substrate/degassed benzene solution (1 mL/mmol of substrate). [b] Isolated yields. [c] Irradiation (1 h) with 1.3 equiv of allyltributylstannane also afforded the allylated product in high yield (90%).

† This paper is dedicated to Professor E. J. Corey on the occasion of his 60th birthday.

(1) For recent review of PG syntheses, see: (a) Roberts, S. M.; Scheinmann, F. *New Synthetic Routes to Prostaglandins and Thromboxanes*; Academic: New York, 1982. (b) Noyori, R.; Suzuki, M. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 847. (c) Taylor, R. J. K. *Synthesis* **1985**, 364. (d) Pike, J. E.; Morton, D. R. *Chemistry of Prostaglandins and Leukotrienes*; Raven: New York, 1985.

(2) (a) Corey, E. J.; Andersen, N. H.; Carlson, R. M.; Paust, J.; Vedejs, E.; Vlattas, I.; Winter, R. E. K. *J. Am. Chem. Soc.* **1968**, *90*, 3245. (b) Corey, E. J.; Vlattas, I.; Andersen, N. H.; Harding, K. *Ibid.* **1968**, *90*, 3247. (c) Schneider, W. P.; Axen, U.; Lincoln, F. H.; Pike, J. E.; Thompson, J. L. *Ibid.* **1968**, *90*, 5895.

(3) For the synthesis of prostaglandins via the three-component coupling process, see: (a) Suzuki, M.; Yanagisawa, A.; Noyori, R. *J. Am. Chem. Soc.* **1985**, *107*, 3348. (b) Johnson, C. R.; Penning, T. D. *Ibid.* **1986**, *108*, 5655. (c) Corey, E. J.; Niimura, K.; Konishi, Y.; Hashimoto, S.; Hamada, Y. *Tetrahedron Lett.* **1986**, *27*, 2199. See also ref 1 for trapping enolates by acid chlorides, aldehydes, a ketone dithioacetal, or an α-nitro olefin.

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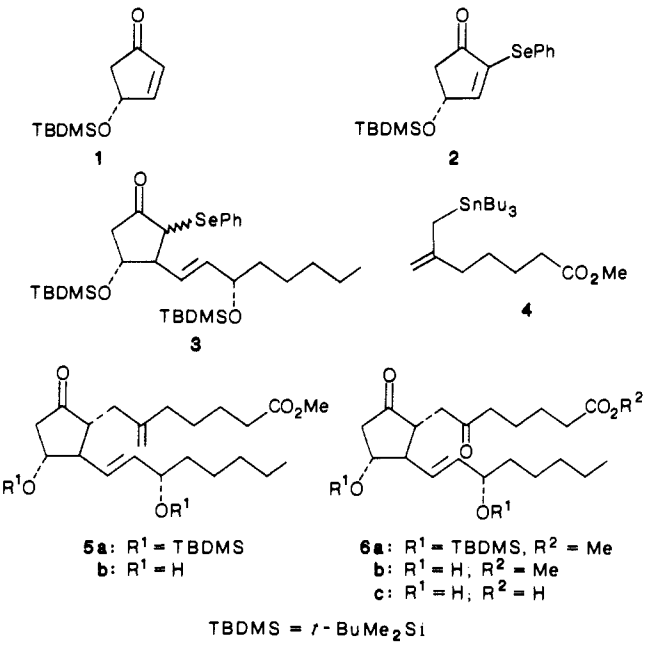
The key intermediate (4*R*)-4-[(*tert*-butyldimethylsilyl)oxy]-2-(phenylseleno)-2-cyclopenten-1-one (**2**) ($[\alpha]^{25}_D$ −19.6°, *c* 1.99, CCl_4) was prepared in 91% yield from (4*R*)-4-[(*tert*-butyldimethylsilyl)oxy]-2-cyclopenten-1-one[10] (**1**) by the action of benzeneselenenyl chloride in the presence of pyridine.[11] Conjugate addition of dialkyl cuprate[12] prepared from cuprous halide and (3*S*)-(*E*)-3-[(*tert*-butyldimethylsilyl)oxy]-1-lithio-1-octene[13] to selenocyclopentenone **2** gave selenocyclopentanone **3**[14] in 79% yield. Irradiation of a benzene solution of selenocyclopentanone **3** containing 1.5 equiv of methyl 6-[(tributylstannyl)methyl]-6-heptenoate[15] (**4**) for 2 h afforded protected 6-methylene-PGE_1 methyl ester[16] (**5a**) in 76% yield. Interestingly, no formation of the 8-iso isomer[17] of **5a** was observed in this reaction.[18] Desilylation of **5a** with hydrogen fluoride–pyridine in acetonitrile yielded 6-methylene-PGE_1 methyl ester[16] (**5b**) in 86% yield.



The transformation of the 6-methylene-PGE_1 derivative **5a** to 6-oxo-PGE_1[19] (**6c**) was accomplished as follows. Thus, selective ozonolysis of **5a** gave **6a** in 50% yield. Desilylation of **6a** led to 6-oxo-PGE_1 methyl ester (**6b**) in 90% yield. Hydrolysis of the ester function by porcine liver esterase[19b] completes the synthesis of 6-oxo-PGE_1 (**6c**).

The present method realized an extremely efficient intermolecular radical alkylation of a cyclopentanone with only a slight excess of a long-chain allylstannane derivative (**4**). The success of this reaction may be due to the formation of the stannyl radical as a chain transfer reagent via intramolecular β-elimination[20] as well as the high reactivity of the electron-deficient α-carbon radical of the carbonyl system toward the terminal carbon of **4**.

In summary, we have demonstrated a short and highly efficient construction of the prostanoid skeleton on the basis of radical alkylation of a cyclopentanoid system with an allylstannane derivative of the α-chain. As an application of the present method, the synthesis of 6-oxo-PGE_1 was carried out. Further application in the construction of other natural products is currently in progress in our laboratories.

Experimental Section

General Procedures. ^{1}H NMR spectra were recorded on either JEOL JNM-PMX60Si (60 MHz) or Varian XL-200 (200 MHz) spectrometers and are reported in δ from Me_4Si. IR spectra were recorded on a JASCO A-102 spectrometer, and the IR figures reported are ν_{max} in cm^{-1}. Mass spectra were recorded on a ESCO EMD-05**B** spectrometer.

All reactions were performed under argon. All reactions were monitored by thin-layer chromatography carried out on 0.25-mm E. Merck silica gel plates (60F-254) with UV light and 7% phosphomolybdic acid in ethanol–heat as developing agent. Flash chromatography was carried out with a Michael Miler column packed with Fuji Davison silica gel BW-200, equipped with FMI LAB Pump RPG150 and a FMI Pulse Damper PD-60LF, normally at a pressure of 1–2 kg cm^{-2}.

All irradiations were with a 400-W high-pressure Toshiba mercury lamp. A glass tube containing a benzene solution of a substrate and an allylstannane compound was externally irradiated under argon at a distance of 15 cm from the mercury lamp.

General Procedure for the Allylation of α-Seleno Carbonyl Compounds.[21,22] **2-Allylcyclopentanone.**[23] A solution of 2-(phenylseleno)-

(4) For review of radical reactions, see: (a) Beckwith, A. L. J. *Tetrahedron* **1981**, *37*, 3073. (b) Tedder, J. M. *Ibid.* **1982**, *38*, 313. (c) Tedder, J. M. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 401. (d) Giese, B. *Ibid.* **1983**, *22*, 753. (e) Hart, D. J. *Science (Washington, D.C.)* **1984**, *223*, 883. (f) Giese, B. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 553. (g) Giese, B. *Radicals in Organic Synthesis: Formation of Carbon–Carbon Bonds*; Pergamon: New York, 1986. (h) Viehe, H. G.; Janousek, Z.; Merenyi, R. *Substituent Effects in Radical Chemistry*; Reidel: Dordrecht, 1986. See also a recent Symposium-in-Print on radical reactions: (i) *Tetrahedron Symp.* **1985**, *41*, No. 19.

(5) (a) Stork, G.; Sher, P. M.; Chen, H. *J. Am. Chem. Soc.* **1986**, *108*, 6384. (b) Keck, G. E.; Burnett, D. E. *J. Org. Chem.* **1987**, *52*, 2960.

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(7) For a recent survey of selenium chemistry, see: (a) Nicolaou, K. C.; Petasis, N. A. *Selenium in Natural Products Synthesis*; CIS: Philadelphia, 1984. (b) Paulmier, C. *Selenium Reagents and Intermediates in Organic Synthesis*; Pergamon: Oxford, 1986. (c) Liotta, D. *Organoselenium Chemistry*; Wiley: New York, 1987.

(8) Davis, R.; Untch, K. G. *J. Org. Chem.* **1979**, *44*, 3755.

(9) Coupling reactions of alkyl radicals with allylstannanes have been reported; however, such reactions using α-seleno carbonyl compounds as radical precursors is without precedent, see: (a) Kosugi, M.; Kurino, K.; Takayama, K.; Migita, T. *J. Organomet. Chem.* **1973**, *56*, C11. (b) Grignon, J.; Pereyre, M. *Ibid.* **1973**, *61*, C33. (c) Grignon, J.; Servens, C.; Pereyre, M. *Ibid.* **1975**, *96*, 225. (d) Kosugi, M.; Arai, H.; Yoshino, A.; Migita, T. *Chem. Lett.* **1978**, 795. (e) Keck, G. E.; Yates, J. B. *J. Am. Chem. Soc.* **1982**, *104*, 5829. (f) Keck, G. E.; Yates, J. B. *J. Org. Chem.* **1982**, *47*, 3591. (g) Keck, G. E.; Yates, J. B. *J. Organomet. Chem.* **1983**, *248*, C21. (h) Webb, R. R. II; Danishefsky, S. *Tetrahedron Lett.* **1983**, *24*, 1357. (i) Keck, G. E.; Enholm, E. J.; Kachensky, D. F. *Ibid.* **1984**, *25*, 1867. (j) Ono, N.; Zinsmeister, K.; Kaji, A. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 1069. (k) Moriya, O.; Kakihata, M.; Urata, Y.; Sugizaki, T.; Kageyama, T.; Ueno, Y.; Endo, T. *J. Chem. Soc., Chem. Commun.* **1985**, 1401. See also ref 4.

(10) We are indebted to the Teijin Co. for a generous gift of homochiral 4-[(*tert*-butyldimethylsilyl)oxy]-2-cyclopenten-1-one (**1**).

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(13) Kluge, A. F.; Untch, K. G.; Fried, J. H. *J. Am. Chem. Soc.* **1972**, *94*, 7827.

(14) A 30:70 mixture of cis and trans isomers was used for the radical reaction. Compound **3** with different protecting groups has been reported, see: Schwartz, J.; Hayasi, Y. *Tetrahedron Lett.* **1980**, *21*, 1497.

(15) For the preparation of 1,3-bis(tributylstannyl)-2-methylenepropane, see: (a) Chandrasekhar, S.; Latour, S.; Wuest, J. D.; Zacharie, B. *J. Org. Chem.* **1983**, *48*, 3810. (b) Sano, H.; Okawara, M.; Ueno, Y. *Synthesis* **1984**, 933.

(16) Tanaka, T.; Okamura, N.; Bannai, K.; Hazato, A.; Sugiura, S.; Tomimori, K.; Manabe, K.; Kurozumi, S. *Tetrahedron* **1986**, *42*, 6747.

(17) (a) Danniels, E. G.; Krueger, W. C.; Kupiecki, F. P.; Pike, J. E.; Schneider, W. P. *J. Am. Chem. Soc.* **1968**, *90*, 5894. (b) Pike, J. E.; Lincoln, F. H.; Schneider, W. P. *J. Org. Chem.* **1969**, *34*, 3552.

(18) Irradiation (1 h) of 3-butyl-4-[(*tert*-butyldimethylsilyl)oxy]-2-(phenylseleno)cyclopentanone and 1.5 equiv of allylstannane **4** afforded a ca. 3:1 mixture of stereoisomers of a 2-allylated product (84%), the stereochemistry of which has not been determined.

(19) For syntheses of 6-oxoprostaglandin E_1, see: (a) Nicolaou, K. C.; Barnette, W. E.; Magolda, R. L. *Ibid.* **1979**, *101*, 766. (b) Tanaka, T.; Hazato, A.; Bannai, K.; Okamura, N.; Sugiura, S.; Manabe, K.; Kurozumi, S.; Suzuki, M.; Noyori, R. *Tetrahedron Lett.* **1984**, *25*, 4947. (c) The dissertation of Toshio Tanaka, Nagoya University, 1987. (d) Nokami, J.; Ono, T.; Hiraga, J.; Wakabayashi, S. *Chem. Lett.* **1985**, 557.

(20) Generally, sterically hindered olefins result in lower rates of alkylation of the radical species, since the chain transfer of the radical is largely influenced by steric factors (see ref 4).

cyclopentanone (53 mg, 0.22 mmol) and allyltributylstannane (147 mg, 0.44 mmol) in degassed benzene (0.2 mL) was irradiated for 1 h. The reaction mixture was then subjected to flash column chromatography (silica gel, 10% ether in pentane) to afford 2-allylcyclopentanone (26 mg, 80%).

The following allylated products obtained as above showed reasonable spectral data: **2-Allylcyclohexanone**,[24] **2-allylcycloheptanone**,[23] **2-allyl-2-methylcyclopentanone**,[25] **2-allyl-4-butanolide**,[26] **2-allyl-5-pentanolide**,[26] **2-allyl-6-hexanolide**,[27] **2-allyl-2-methyl-4-butanolide**, **ethyl 4-pentenoate**,[28] and **ethyl 2-methyl-4-pentenoate**.[29]

4(*R*)-[(*tert*-Butyldimethylsilyl)oxy]-2-(phenylseleno)-2-cyclopenten-1-one (2). To a magnetically stirred solution of benzeneselenenyl chloride (516 mg, 97% purity, 2.61 mmol) in CH_2Cl_2 (5 mL) under argon was added pyridine (0.22 mL, 2.75 mmol) at room temperature. After 15 min, the mixture was added in one portion to a stirred solution of optically pure cyclopentenone **1** (370 mg, 1.74 mmol) in CH_2Cl_2 (2 mL). The reaction mixture was stirred at room temperature for 3 h. The resulting yellow solution was washed with 5% HCl (3 mL) and brine (3 mL) and dried ($MgSO_4$). Removal of the solvent followed by flash column chromatography (silica gel, 20% CH_2Cl_2 in hexane and then 20% ethyl acetate in hexane) afforded **2** (580 mg, 91%): $[\alpha]^{25}_D$ −19.6° (*c* 1.99, CCl_4); ^1H NMR (200 MHz, CCl_4) δ 0.06 (s, 6 H), 0.82 (s, 9 H), 2.21 (dd, J = 2.4, 18.0 Hz, 1 H), 2.75 (dd, J = 5.9, 18.0 Hz, 1 H), 4.77 (ddd, J = 2.4, 2.5, 5.9 Hz, 1 H), 6.50 (d, J = 2.5 Hz, 1 H), 7.17–7.73 (m, 5 H); IR (thin film) 1710 cm^{-1}; MS, *m/e* (relative intensity) 368 (M^+, Se^{80}, 50), 331 (30), 237 (25), 231 (83), 157 (46), 154 (100). Anal. Calcd for $C_{17}H_{24}O_2SeSi$: C, 55.57; H, 6.58. Found: C, 55.40; H, 6.64.

(3*R*,4*R*)-4-[(*tert*-Butyldimethylsilyl)oxy]-3-[(3*S*)-(*E*)-3-[(*tert*-butyldimethylsilyl)oxy]-1-octenyl]-2-(phenylseleno)cyclopentanone (3). To a magnetically stirred, cold (−78 °C) solution of (3*S*)-(*E*)-3-[(*tert*-butyldimethylsilyl)oxy]-1-iodo-1-octene (481 mg, 131 mmol) in dry ether (5 mL) was added dropwise a 2.20 M solution of *tert*-butyllithium (1.19 mL, 2.61 mmol). The mixture was stirred at −78 °C for 2 h and then treated with a $(MeO)_3P$–CuBr complex (175 mg, 0.65 mmol). The resulting mixture was stirred for 1 h before selenocyclopentenone **2** (160 mg, 0.44 mmol) in dry ether (1 mL) was added. After 10 min, the reaction mixture was poured into saturated NH_4Cl solution (20 mL). The aqueous phase was extracted with ether (2 × 20 mL). The combined organic phases were washed with brine (10 mL) prior to drying ($MgSO_4$) and solvent evaporation. Flash column chromatography (silica gel, 1% ethyl acetate in hexane) yielded **3** (207 mg, 79%) as a 70:30 trans–cis mixture of isomers: ^1H NMR (200 MHz, $CDCl_3$) δ 0.04 (s, 6 H), 0.06 (s, 6 H), 0.84 (s, 18 H), 1.10–1.70 (m, 8 H), 2.22 (dd, J = 5.0, 16.0 Hz, 1 H), several small signals at around 2.4, 2.59 (dd, J = 7.0, 16.0 Hz, 1 H), 2.68–2.90 (m, 1 H), 3.32 (d, J = 7.0 Hz, 0.7 H), 3.89 (d, J = 12.0 Hz, 0.3 H), 4.02–4.24 (m, 2 H); IR (thin film) 1730 cm^{-1}; MS, *m/e* (relative intensity) 610 (M^+, Se^{80}, 16), 553 (56), 453 (18), 396 (50), 369 (15), 322 (55), 294 (100), 157 (22). Anal. Calcd for $C_{31}H_{54}O_3SeSi_2$: C, 61.05; H, 8.92. Found: C, 61.04; H, 9.11.

Methyl 6-[(Tributylstannyl)methyl]-6-heptenoate (4). A solution of 1,3-bis(tributylstannyl)-2-methylenepropane[15] (266 mg, 0.42 mmol) and methyl 4-iodobutyrate (48 mg, 0.21 mmol) in degassed benzene (2.1 mL) was irradiated. After 30 min, an additional 133 mg (0.21 mmol) of the stannane compound was added, and irradiation was continued for an additional 30 min. Then another additional 67 mg (0.11 mmol) of the stannane compound was added. The mixture was irradiated for 1 h further. At this point, the iodobutyrate was completely consumed (TLC monitoring). Removal of the solvent followed by flash column chromatography (silica gel, 3% ether in hexane containing 0.1% ethyldimethylamine) yielded **4** (42 mg, 45%): ^1H NMR (60 MHz, CCl_4) δ 0.64–2.41 (m, 37 H), 3.59 (s, 3 H), 4.21–4.71 (m, 2 H); IR (thin film) 1745, 1625 cm^{-1}; MS, *m/e* (relative intensity) 446 (M^+, S^{120}, 11), 389 (30), 291 (79), 234 (62), 177 (100), 120 (40). Anal. Calcd for $C_{21}H_{42}O_2Sn$: C, 56.65; H, 9.51. Found: C, 56.61; H, 9.55.

6-Methyleneprostaglandin E_1 Methyl Ester (5b). A solution of selenocyclopentanone **3** (151 mg, 0.25 mmol) and the allylstannane compound **4** (169 mg, 0.38 mmol) in degassed benzene (2.5 mL) was irradiated for 2 h. Evaporation of the solvent followed by flash column chromatography (silica gel, 5% and then 10% ethyl acetate in hexane) afforded **5a** (115 mg, 76%): $[\alpha]^{25}_D$ −36.3° (*c* 0.24, MeOH) [lit.[16] $[\alpha]^{21}_D$ −36° (*c* 0.42, MeOH)].

Deprotection of **5a** (90 mg, 0.15 mmol) with hydrogen fluoride–pyridine in acetonitrile according to the procedure described in the literature[16] gave 6-methylene-PGE_1 methyl ester (**5b**) (48 mg, 86%); $[\alpha]^{22}_D$ −55.0° (*c* 0.48, MeOH) [lit.[16] $[\alpha]^{20}_D$ −55° (*c* 1.10, MeOH)]. These 6-methylene-PGE_1 derivatives **5a** and **5b** exhibited identical spectral data with those reported.[16]

6-Oxoprostaglandin E_1 Methyl Ester (6b). A stream of O_3/O_2 gas (Nippon Ozon Type 0-3-2) was bubbled at a rate of 0.5 mL/s through a cooled (−78 °C) solution of 6-methylene-PGE_1 derivative **5a** (34 mg, 0.056 mmol) in a 1:1 mixture of MeOH and CH_2Cl_2 (2.2 mL). After 4 min, argon gas instead of O_3/O_2 gas was passed through the reaction mixture for 5 min. Then, dimethyl sulfide (0.25 mL) was added in one portion at −78 °C. The reaction mixture was slowly brought to room temperature and stirred at that temperature for 18 h. Removal of the solvent followed by flash column chromatography (silica gel, 5% and then 10% ethyl acetate in hexane) yielded protected 6-oxo-PGE_1 methyl ester **6a** (17 mg, 50%): $[\alpha]^{21}_D$ −39.5° (*c* 0.40, MeOH) [lit.[19d] $[\alpha]^{22}_D$ −39.3° (*c* 1.04, MeOH)]; ^1H NMR (60 MHz, $CDCl_3$) δ 0.04 (s, 12 H), 0.87 (s, 21 H), 1.06–1.77 (m, 12 H), 2.13–2.75 (m, 10 H), 3.65 (s, 3 H), 3.83–4.23 (m, 2 H), 5.40–5.60 (m, 2 H); IR (thin film) 1745, 1715 cm^{-1}.

Desilylation of **6a** (32 mg, 0.052 mmol) with hydrogen fluoride–pyridine in acetonitrile according to the procedure described in the literature[19b] afforded 6-oxo-PGE_1 methyl ester (**6b**) (18 mg, 90%): mp 43–44 °C (lit.[19b] mp 44–44.5 °C); $[\alpha]^{20}_D$ −48.1° (*c* 0.18, MeOH) [lit.[19b] $[\alpha]^{21}_D$ −48.5° (*c* 0.71, MeOH)]; ^1H NMR (60 MHz, $CDCl_3$) δ 0.87 (s, 3 H), 1.05–1.80 (m, 12 H), 2.05–2.85 (m, 12 H), 3.66 (s, 3 H), 3.82–4.26 (m, 2 H), 5.40–5.60 (m, 2 H); IR ($CHCl_3$) 1740, 1720 cm^{-1}. 6-Oxo-PGE_1 derivatives **6a** and **6b** exhibited identical spectral data with those reported.[19c]

Supplementary Material Available: Spectral data of allylated compounds listed in Table I, **5a**, and **5b** and combustion analysis of 2-allyl-2-methyl-4-butanolide and HRMS of **5a**, **5b**, **6a**, and **6b** (6 pages). Ordering information is given on any current masthead page.

(21) α-Seleno carbonyl compounds were prepared according to the procedure described in the following literature: (a) Reich, H. J.; Reich, I. L.; Renga, J. M. *J. Am. Chem. Soc.* **1973**, *95*, 5813. (b) Sharpless, K. B.; Lauer, R. F.; Teranishi, A. Y. *Ibid.* **1973**, *95*, 6137. (c) Grieco, P. A.; Miyashita, M. *J. Org. Chem.* **1974**, *39*, 120. All the α-seleno compounds listed in Table I are known [2-(phenylseleno)cyclopentanone and 2-(phenylseleno)cyclohexanone]. (d) Clive, D. L. J. *J. Chem. Soc., Chem. Commun.* **1973**, 695 [2-(phenylseleno)cycloheptanone and 2-(phenylseleno)-6-hexanolide]. (e) Reich, H. J.; Renga, J. M.; Reich, I. L. *J. Am. Chem. Soc.* **1975**, *97*, 5434 [2-methyl-2-(phenylseleno)cyclopentanone]. (f) Liotta, D.; Saindane, M.; Monahan, R. III; Brothers, D.; Fivush, A. *Synth. Commun.* **1986**, *16*, 1461 [2-(phenylseleno)-4-butanolide and 2-methyl-2-(phenylseleno)-4-butanolide]. (g) Detty, M. R.; Wood, G. P. *J. Org. Chem.* **1980**, *45*, 80 [2-(phenylseleno)-5-pentanolide]. (h) Lucchetti, J.; Krief, A. *Tetrahedron Lett.* **1978**, 2693 [ethyl 2-(phenylseleno)acetate]. (i) Brocksom, T. J.; Petragnani, N.; Rodrigues, R. *J. Org. Chem.* **1974**, *39*, 2114 [ethyl 2-(phenylseleno)-propionate], see ref 21b.

(22) The contribution of T. Okumura and S. Kusuda is highly appreciated.

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