Practical Synthesis of Myrcene Derivatives Possessing Oxidized Methyl Groups

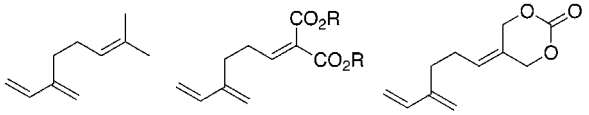
Makoto Naito, Akihiro Ezoe, Masanari Kimura, and Yoshinao Tamaru*

Department of Applied Chemistry, Faculty of Engineering, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan

tamaru@net.nagasaki-u.ac.jp

Received February 20, 2001

Myrcene (**1**) is a member of the monoterpene family and is abundantly found in the oil of bay, verbena, hop, and others. It has long been utilized as an intermediate in organic synthesis. Here, we report a practical synthesis of myrcene oxidation derivatives **2** and **3** that possess structural and functional features desirable for natural and unnatural product synthesis.

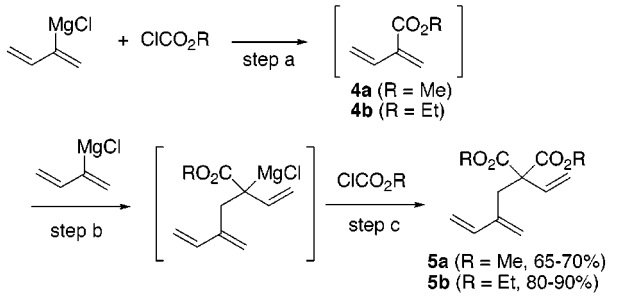


1 **2** **3**

We found a synthetic route to **2** and **3** quite by chance as follows. In one of our ongoing projects on cycloaddition reaction of allenes and alkenes,[1] we needed 1,3-butadienes possessing electron-withdrawing groups at the 2-position; hence, we tried to prepare 2-methylene-3-butenoic acid ester (**4**) by the coupling reaction of 2-(1,3-butadienyl)magnesium chloride[2] and ethyl chloroformate[3] (3 equiv) (Scheme 1). To our surprise, however, the expected **4b** was not produced even in trace amounts; instead, distillation of the reaction mixture, after usual workup, gave rise to 2-(2-methylene-3-butenyl)-2-vinylmalonic acid diethyl ester (**5b**) in 80−90% isolated yield.

The essentially quantitative formation of **5b** may be rationalized as follows: (i) the coupling reaction of the Grignard reagent and ethyl chloroformate takes place as expected and provides **4b** (step a, Scheme 1); (ii) **4b** serves as a Michael acceptor for the nucleophilic addition of a second equivalent of the Grignard reagent (step b); (iii) step b proceeds much faster than step a even in the presence of ethyl chloroformate in much higher concentration than **4b**; and (iv) the magnesium enolate of ethyl 4-methylene-2-vinyl-5-hexenoate, thus formed, reacts further with ethyl chloroformate to finally provide **5b** (step c). Thus, overall, 2 mol of chloroprene and 2 mol of ethyl chloroformate combine to give 1 mol of **5b**.

Scheme 1



It should be noted that a Russian group has reported that 1-trimethylsilylvinylmagnesium bromide undergoes a similar cascade reaction with methyl chloroformate to furnish 2-trimethylsilyl-2-propenylmalonic acid dimethyl ester in 50% yield.[4] These results together with our observations suggest that the trimethylsilyl and vinyl groups of the primary coupling products serve as an electron pool and facilitate the Michael addition of a second equivalent of the vinyl Grignard reagents.

Several attempts to selectively prepare **4b** by specifically facilitating step a, e.g., with the aid of transition metal catalysts,[3a,c,d] turned out to be unsuccessful. For example, the reaction of 2-(1,3-butadienyl)magnesium chloride and ethyl chloroformate (3 equiv) in the presence of 5 mol % of tetrakis(triphenylphosphine)palladium(0) provided a complex mixture of products, from which **5b** was isolated in 17−32% yield by column chromatography over silica gel. GLC of the reaction mixture showed no peaks ascribable to **4b**.

As expected from the partial 1,5-hexadiene structure, **5** underwent the Cope rearrangement with great ease[5] and provided **2**, a derivative of myrcene with both its methyl groups fully oxidized, in good yield;[6] heating at 120 °C for 9 h in *o*-dichlorobenzene was sufficient to complete the conversion (Scheme 2).

2-Alkylidene-1,3-propanediol and its derivatives have been utilized in many ways[7] as a building block of a unique structural motif. Accordingly, we examined hydride reduction of **2b** into the corresponding diol. However, none of $LiAlH_4$, DIBAL, and $AlH_3-N(Et)(Me)_2$[8] was capable of reducing the carbonyl groups; instead, they

* To whom correspondence should be addressed. Fax: +95-847-9008.

(1) (a) Horino, Y.; Kimura, M.; Naito, M.; Tanaka, S.; Tamaru, Y. *Tetrahedron Lett.* **2000**, *41*, 3627. (b) Horino, Y.; Kimura, M.; Wakamiya, Y.; Okajima, T.; Tamaru, Y. *Angew. Chem., Int. Ed. Engl.* **1999**, *38*, 121. (c) Kimura, M.; Horino, Y.; Wakamiya, Y.; Okajima, T.; Tamaru, Y. *J. Am. Chem. Soc.* **1997**, *119*, 10869.

(2) Reaction of 2-(1,3-butadienyl)magnesium chloride with electrophiles: (a) Nunomoto, S.; Yamashita, Y. *J. Org. Chem.* **1979**, *44*, 4788. (b) Kondo, K.; Dobashi, S.; Matsumoto, M. *Chem. Lett.* **1976**, 1077.

(3) Reaction of alkyl chloroformate with vinylic oraganometallics: (a) Rossi, R.; Carpita, A.; Bellina, F.; De Santis, M. *Gazz. Chim. Ital.* **1991**, *121*, 261. (b) Verkruijsse, H. D.; Brandsma, L. *Recl. Trav. Chim. Pays-Bas* **1986**, *105*, 66. (c) Jabri, N.; Alexakis, A.; Normant, J. F. *Tetrahedron* **1986**, *42*, 1369. (d) Negishi, E.; Bagheri, V.; Chatterjee, S.; Luo, F.-T.; Miller, J. A.; Stoll, A. T. *Tetrahedron Lett.* **1983**, *24*, 5181. (e) Cahiez, G.; Normant, J. F. *Bull. Soc. Chim. Fr.* **1977**, 570. (f) Zweifel, G.; Lynd, R. A. *Synthesis* **1976**, 625.

(4) Mironov, V. F.; Feoktistov, A. E.; Kozyukov, V. P. *J. Gen. Chem. USSR*, **1985**, *55*, 1212.

(5) Hill, R. K. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Paquette, L. A., Eds.; Pergamon: Oxford, 1991; Vol. 5, p 785.

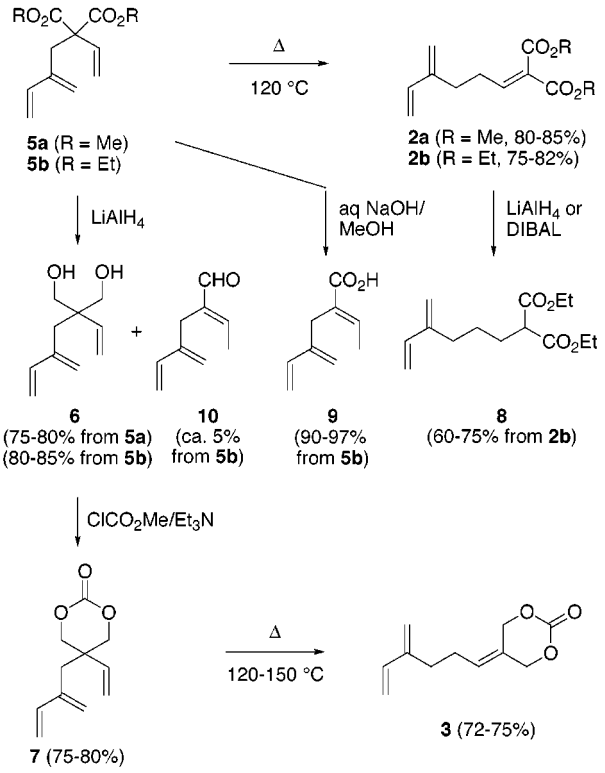
(6) Compound **2** may be prepared from 4-methylene-5-hexenal by the Knoevenagel condensation with dialkyl malonate. The aldehyde is available by the ozonolysis of myrcene: Bertele, E.; Schudel, P. *Helv. Chim. Acta* **1967**, *50*, 2445.

(7) (a) Hirashima, S.; Aoyagi, S.; Kibayashi, C. *J. Am. Chem. Soc.* **1999**, *121*, 9873. (b) Fürstner, A.; Weintritt, H. *J. Am. Chem. Soc.* **1997**, *119*, 2944. (c) Kang, K.-T.; Kim, E. H.; Kim, W. J.; Song, N. S.; Shin, J. K.; Cho, B. Y. *Synlett* **1998**, 921. (d) Oriyama, T.; Ishiwata, A.; Sano, T.; Matsuda, T.; Takahashi, M.; Koga, G. *Tetrahedron Lett.* **1995**, *36*, 5581. (e) Paquette, L. A.; Sauer, D. R.; Cleary, D. G.; Kinsella, M. A.; Blackwell, C. K.; Anderson, L. G. *J. Am. Chem. Soc.* **1992**, *114*, 7375. (f) Trost, B. M. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 1.

(8) (a) Loh, T.-P.; Cao, G.-Q.; Yin, Z. *Tetrahedron Lett.* **1999**, *40*, 2649. (b) Cha, J. S.; Brown, H. C. *J. Org. Chem.* **1993**, *58*, 3974.

10.1021/jo010193o CCC: $20.00 © 2001 American Chemical Society
Published on Web 05/19/2001

Scheme 2



selectively reduced the C−C double bond and provided 4-methylene-5-hexenylmalonic acid diethyl ester (**8**) in 60−75% yield.

2-Alkylidene-1,3-propanediol carbonate **3** could be obtained via reduction of **5** with $LiAlH_4$, cyclic carbonation of the thus-obtained diol **6** with methyl chloroformate in the presence of triethylamine,[9] followed by the Cope rearrangement of the thus-obtained cyclic carbonate **7**. These transformations could all be accomplished in reasonable yield. Reduction of **5b** with $LiAlH_4$ (1.6 equiv) provided (*E*)-2-ethylidene-4-methylene-5-hexenal (**10**) as a minor product (ca. 5%) along with the diol **6** (80−85%).

Interestingly, an alkaline hydrolysis of **5b**, followed by an acidic workup, caused spontaneous decarboxylation and olefin isomerization and provided (*E*)-2-ethylidene-4-methylene-5-hexenoic acid (**9**) in quantitative yield and with high stereoselectivity. The structures of **9** and **10** were elucidated by means of NOE experiments.

In summary, a divergent, efficient synthesis of myrcene derivatives **2** and **3** and related compounds **5**−**9** has been developed. We believe that the characteristic structural and functional features associated with all these products will find wide application to natural and unnatural product synthesis. The utility may be augmented by the use of cheap, industry products as the starting materials (chloroprene and alkyl chloroformate) as well as by the ease with which the reactions can be performed.

Experimental Section

Glassware and syringes were dried overnight in an oven and flushed with N_2 immediately prior to use. Transfers of liquids were performed either with syringes equipped with stainless steel needles or with a cannula. Reactions were carried out under positive pressure of N_2. THF and ether were freshly distilled from Na/benzophenone ketyl under N_2. CH_2Cl_2, Et_3N (from CaH_2), chloroprene (bp 60 °C, in the presence of 4-*tert*-butylcatechol; offered from Tosoh Corp.), ethyl chloroformate (95 °C, Tokyo Kasei), and methyl chloroformate (72 °C, Tokyo Kasei) were distilled prior to use under N_2. *o*-Dichlorobenzene, 1,2-dibromoethane (Tokyo Kasei), $ZnCl_2$ (Wako), Mg tunings (Nakarai), $LiAlH_4$ (Aldrich), DIBAL (Kanto Chemical), and AlH_3−$N(Et)(Me)_2$ (Aldrich) were used as supplied.

R_f values were determined on a silica gel plate (Merck silica gel $60F_{254}$). The procedures for the preparation of **2a** and **5a** were omitted; they were prepared in a manner similar to that for **2b** and **5b**, respectively.

2-(2-Methylene-3-butenyl)-2-vinylmalonic Acid Diethyl Ester (5b). 1,2-Dibromoethane (1 mL, 11.6 mmol) and then THF (2 mL) were added over Mg (3.65 g, 150 mmol). After addition of $ZnCl_2$ (0.62 g, 4.5 mmol, dried at 150 °C for 6 h under vacuum) dissolved in THF (50 mL), a solution of chloroprene (9.2 mL, 100 mmol) and 1,2-dibromoethane (2 mL, 23.2 mmol) in THF (30 mL) was added over 40 min, during which time the reaction temperature was kept between 25 and 35 °C. The mixture was heated at reflux for 1 h.[2a] The thus-prepared THF solution of 2-(1,3-butadienyl)magnesium chloride was added into a solution of ethyl chloroformate (28.6 mL, 300 mmol) in ether (150 mL) at −20 °C over 40 min. After completion of the addition, the mixture was stirred for 2 h at −10 °C. Into this mixture was added saturated aqueous NH_4Cl, and the mixture was extracted with ethyl acetate. The organic extract was washed with brine and dried ($MgSO_4$), and the solvent was evaporated *in vacuo*. Kugelrohl distillation (100 °C/0.1 mmHg) of the residue provided **5b** (10.1 g, 80%): bp 100 °C (0.1 mmHg); IR (neat) 1730 (s) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.25 (t, J = 7.1 Hz, 3H), 1.26 (t, J = 7.1 Hz, 3H), 3.03 (s, 1H), 3.04 (s, 1H), 4.17 (q, J = 7.1 Hz, 2H), 4.20 (q, J = 7.1 Hz, 2H), 4.97 (brs, 1H), 5.04 (d, J = 10.6 Hz, 1H), 5.13 (brs, 1H), 5.14 (d, J = 17.9 Hz, 1H), 5.26 (d, J = 10.9 Hz, 1H), 5.28 (d, J = 17.1 Hz, 1H), 6.30 (dd, J = 17.1, 10.6 Hz, 1H), 6.37 (dd, J = 17.9, 10.9 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 36.0, 59.8, 61.3, 61.5, 113.8, 116.3, 118.7, 135.2, 139.3, 140.8, 170.1; HRMS calcd for $C_{14}H_{20}O_4$ 252.1362, found *m*/*z* (relative intensity) 252.1391 (M^+, 5), 179 (32), 106 (100). Anal. Calcd for $C_{14}H_{20}O_4$: C, 66.65; H, 7.99. Found: C, 66.96; H, 7.96.

4-Methylene-5-hexenylidenemalonic Acid Diethyl Ester (2b). A solution of **5b** (7.57 g, 30.0 mmol) in *o*-dichlorobenzene (150 mL), containing a small amount of hydroquinone was heated at 120 °C for 9 h (bath temperature). The reaction was monitored by TLC (R_f = 0.55 for **5b**, 0.45 for **2b**, hexane/ethyl acetate 4:1). *o*-Dichlorobenzene was distilled off (50 °C/100 mmHg). Flash chromatography of the residue over silica gel (hexane/ethyl acetate 32:1) provided **2b** (6.2 g, 82%): IR (neat) 1710 (s) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.29 (t, J = 7.1 Hz, 3H), 1.32 (t, J = 7.1 Hz, 3H), 2.39 (brt, J = 7.7 Hz, 2H), 2.51 (t, J = 7.7 Hz, 1H), 2.52 (t, J = 7.7 Hz, 1H), 4.24 (q, J = 7.1 Hz, 2H), 4.30 (q, J = 7.1 Hz, 2H), 5.02 (brs, 1H), 5.07 (brs, 1H), 5.09 (d, J = 11.2 Hz, 1H), 5.22 (d, J = 17.6 Hz, 1H), 6.37 (dd, J = 17.6, 11.2 Hz, 1H), 7.01 (t, J = 7.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 14.2, 28.3, 29.9, 61.2, 113.6, 116.6, 129.0, 138.4, 144.6, 148.4, 163.9, 165.4; HRMS calcd for $C_{14}H_{20}O_4$ 252.1362, found *m*/*z* (relative intensity) 252.1348 (M^+, 38), 207 (100). Anal. Calcd for $C_{14}H_{20}O_4$: C, 66.65; H, 7.99. Found: C, 66.99; H, 7.90.

2-(2-Methylene-3-butenyl)-2-vinylpropane-1,3-diol (6) and (*E*)-2-Ethylidene-4-methylene-5-hexenal (10). A solution of **5b** (1.01 g, 4 mmol) in ether (5 mL) was added to a suspension of $LiAlH_4$ (0.24 g, 6.4 mmol) in ether (15 mL) at 0 °C. After being stirred for 1 h at 0 °C, the mixture was quenched by addition of a mixture of THF/H_2O (2:1, 0.5 mL) and then 2 N HCl (10 mL). The mixture was extracted twice with ethyl acetate, and the combined extracts were washed with brine and dried ($MgSO_4$). The solvent was removed in vacuo, and the residue was purified by flash chromatography over silica gel (hexane/ethyl acetate 32:1) to give **6** in 81% yield (556 mg, R_f = 0.17, hexane/ethyl acetate 2:1) and **10** in 5% yield (20.5 mg, R_f = 0.67, hexane/ethyl acetate 2:1). **6**: IR (neat) 3380 (s), 1600 (m), 910 (s) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.15 (brs, 2H), 2.38 (s, 2H), 3.67 (d, J = 11.2 Hz, 2H), 3.71 (dd, J = 11.2 Hz, 2H), 5.06 (brs, 1H), 5.07 (brd, J = 11.3 Hz, 1H), 5.08 (dd, J = 17.8, 0.9 Hz, 1H), 5.22 (brs, 1H), 5.23 (dd, J = 0.9, 9.2 Hz, 1H), 5.33 (brd, J = 17.9 Hz, 1H), 5.72 (dd, J = 11.3, 17.9 Hz, 1H), 6.41 (ddd, J = 17.8, 9.2,

(9) Bando, T.; Tanaka, S.; Fugami, K.; Yoshida, Z.; Tamaru, Y. *Bull. Chem. Soc. Jpn.* **1992**, *65*, 97.

0.9 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 33.8, 46.6, 66.8, 113.9, 115.7, 119.6, 140.3, 140.7, 142.1; HRMS calcd for $C_{10}H_{16}O_2$ 168.1150, found *m*/*z* (relative intensity) 137.1022 ($M^+ - CH_2OH$, 26), 120 (100). **10**: IR (neat) 1687 (s), 1645 (s), 1596 (s), 1182 (s), 904 (s) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.95 (d, J = 7.0 Hz, 3H), 3.17 (s, 2H), 4.71 (brs, 1H), 5.02 (brs, 1H), 5.11 (d, J = 11.0 Hz, 1H), 5.32 (d, J = 17.6 Hz, 1 H), 6.45 (dd, J = 11.0, 17.6 Hz, 1H), 6.81 (q, J = 7.0 Hz, 1H), 9.46 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.1, 25.1, 113.6, 115.5, 138.8, 141.9, 142.1, 151.8, 194.2; HRMS calcd for $C_9H_{12}O$ 136.0888, found *m*/*z* (relative intensity) 136.0905 (M^+, 100), 121 (45), 107 (46).

5-(2-Methylene-3-butenyl)-5-vinyl-1,3-dioxan-2-one (7). Into a solution of **6** (280 mg, 1.6 mmol) and triethylamine (2.2 mL, 16 mmol) in CH_2Cl_2 (15 mL) was added ethyl chloroformate (1.0 mL, 12.8 mmol) at 0 °C.[9] After the mixture was stirred for 41 h at room temperature, 2 N HCl was added and the mixture was extracted twice with ethyl acetate. The organic extracts were washed with brine and dried ($MgSO_4$), and the solvent was removed in vacuo. Flash chromatography (silica gel, hexane/ethyl acetate 4:1) provided **7** (250 mg, 77%, R_f = 0.59 for **7** and 0.38 for **6**, hexane/ethyl acetate 1:1): IR (neat) 1720 (s) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (s, 2H), 4.29 (brd, J = 11.7 Hz, 2H), 4.32 (brd, J = 11.7 Hz, 2H), 5.01 (brs, 1H), 5.14 (brd, J = 10.6 Hz, 1H), 5.21 (brd, J = 17.6 Hz, 1H), 5.24 (d, J = 17.6 Hz, 1H), 5.29 (brs, 1H), 5.35 (d, J = 10.9 Hz, 1H), 5.72 (dd, J = 10.9, 17.6 Hz, 1H), 6.38 (dd, J = 10.6, 17.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 29.7, 34.8, 73.7, 114.9, 117.6, 120.9, 136.4, 139.8, 147.8; HRMS calcd for $C_{11}H_{14}O_3$ 194.0943, found *m*/*z* (relative intensity) 194.0899 (M^+, 3), 127 (4), 106 (21), 67 (100).

5-(4-Methylene-5-hexenylidene)-1,3-dioxan-2-one (3). A solution of **7** (851 mg, 4.4 mmol) in *o*-dichlorobenzene (50 mL), containing a small amount of hydroquinone, was heated at 120 °C for 20 h and then at 150 °C for 4 h (bath temperature). The reaction was monitored by TLC (R_f = 0.37 for **7**, 0.47 for **3**, benzene/ethyl acetate 6:1). *o*-Dichlorobenzene was distilled off (50 °C/100 mmHg). Flash chromatography of the residue over silica gel (hexane/ethyl acetate 4:1) provided **3** (640.4 mg, 75%): IR (neat) 1750 (s) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.28 (brdt, J = 7.4, 6.6 Hz, 2H), 2.33 (brt, J = 6.6 Hz, 2H), 4.74 (brs, 2H), 4.90 (brs, 2H), 4.97 (brs, 1H), 5.07 (brs, 1H), 5.11 (d, J = 10.7 Hz, 1H), 5.21 (d, J = 17.8 Hz, 1H), 5.70 (tt, J = 1.5, 7.4 Hz, 1H), 6.37 (dd, J = 10.7, 17.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.2, 30.6, 67.4, 74.1, 113.6, 116.7, 124.2, 129.9, 138.3, 144.5, 149.8; HRMS calcd for $C_{11}H_{14}O_3$ 194.0943, found *m*/*z* (relative intensity) 194.0993 (M^+, 3), 150 (22), 81 (21), 67 (100). Anal. Calcd for $C_{11}H_{14}O_3$: C; 68.32, H; 7.27. Found: C; 68.02, H; 7.27.

4-Methylene-5-hexenylmalonic Acid Diethyl Ester (8). Reduction with $LiAlH_4$. Into a heterogeneous solution of $LiAlH_4$ (0.24 g, 6.4 mmol) in ether (15 mL) was added a solution of **2b** (1.01 g, 4.0 mmol) in ether (5 mL) at 0 °C, and the mixture was stirred at the same temperature for 1 h. After addition of a small amount of THF−H_2O (2:1) and 2 N HCl (10 mL), the mixture was extracted twice with ethyl acetate. The combined organic extracts were washed with brine and dried ($MgSO_4$). The solvent was removed *in vacuo*. Flash chromatography of the residue over silica gel (hexane/ethyl acetate 64:1) provided **8**: 636.2 mg (65%). R_f (**2b**) = 0.45; R_f (**8**) = 0.55 (hexane/ethyl acetate 4:1).

Reduction with DIBAL. Into a solution of **2b** (1.01 g, 4.0 mmol) in ether (10 mL) was added DIBAL (1 M hexane solution, 4 mmol) at −78 °C. After being stirred at the same temperature for 30 min, the mixture was allowed to warm to room temperature. Into this mixture was added MeOH−H_2O (150−400 μL), and the mixture was filtered through a Celite pad, which was washed with ether. The solvent was removed *in vacuo*. Flash chromatography of the residue over silica gel (hexane/ethyl acetate 64:1) provided **8** (606.6 mg, 59%): IR (neat) 1735 (s) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (t, J = 7.2 Hz, 6H), 1.53 (ddt, J = 5.1, 10.4, 7.6 Hz, 2H), 1.93 (brq, J = 7.6 Hz, 2H), 2.24 (brt, J = 7.6 Hz, 2H), 3.34 (t, J = 7.6 Hz, 1H), 4.19 (q, J = 7.2 Hz, 2H), 4.20 (q, J = 7.2 Hz, 2H), 4.99 (brs, 1H), 5.02 (brs, 1H), 5.05 (d, J = 10.8 Hz, 1H), 5.20 (d, J = 17.8 Hz, 1H), 6.36 (dd, J = 10.8, 17.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 25.8, 28.6, 31.0, 52.0, 61.3, 61.4, 113.3, 116.0, 138.8, 145.6, 169.5; HRMS calcd for $C_{14}H_{22}O_4$ 254.1518, found *m*/*z* (relative intensity) 254.1547 (M^+, 43), 181 (6), 173 (100). Anal. Calcd for $C_{11}H_{14}O_3$: C; 66.12, H; 8.72. Found: C; 66.52, H; 8.72.

(*E*)-2-Ethylidene-4-methylene-5-hexenoic Acid (9). A solution of **5b** (5.65 g, 20 mmol) in 7.5 N NaOH (20 mL)−methanol (100 mL) was stirred at room temperature for 26 h. The mixture was diluted with water and extracted with ether. The water layer was acidified with 2 N HCl and extracted twice with ethyl acetate. The organic extracts were washed with brine and dried ($MgSO_4$). The solvent was removed *in vacuo*. Recrystallization of the residue from CH_2Cl_2 provided **9** as a colorless solid (2.96 g, 97%): mp 66.0−67.0 °C (CH_2Cl_2); IR (KBr) 1670 (s) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.79 (d, J = 7.3 Hz, 3H), 3.21 (brs, 2H), 4.82 (brs, 1H), 5.03 (brs, 1H), 5.11 (d, J = 11.0 Hz, 1H), 5.22 (d, J = 17.4 Hz, 1H), 6.49 (dd, J = 11.0, 17.4 Hz, 1H), 7.22 (q, J = 7.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.7, 27.4, 113.3, 115.1, 129.7, 139.1, 142.3, 142.5, 171.7; HRMS calcd for $C_9H_{12}O_2$ 152.0837, found *m*/*z* (relative intensity) 152.0840 (M^+, 45), 137 (39), 107 (100).

Acknowledgment. We thank Tosoh Corp. for the generous gift of chloroprene. Financial support from the Ministry of Education, Science, Sports and Culture, Japanese Government, Grant-in-Aid for Scientific Research B, is acknowledged.

Supporting Information Available: ^{1}H and ^{13}C NMR spectra of **6**, **7**, **9**, and **10** and NOE data of **9** and **10**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO010193O