Functionalization of *trans*-Decalin. IV. A Stereoselective Synthesis of *dl*-β-Costol, *dl*-Arctiol, and the Related Eudesmane Type Sesquiterpenes

Sigeru Torii* and Tsutomu Inokuchi

Department of Industrial Chemistry, School of Engineering, Okayama University, Tsushima, Okayama 700

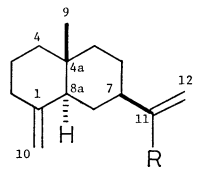
(Received February 15, 1980)

The efficient synthetic procedures to *dl*-β-costol (**1a**), *dl*-arctiol (**2**), and the related eudesmane type sesquiterpenes are described. *trans*-8,8-Ethylenedioxy-4aβ-methyldecalin-2α-ol (**6a**), prepared from *trans*-1,1-ethylenedioxy-4aβ-methyl-$\Delta^{6,7}$-octalin by epoxidation and subsequent reduction of the epoxy ring, was converted into **1a** as follows: (1) deacetalization of **6a** followed with mesylation, giving 2α-methylsulfonyloxy-4aβ-methyldecalin-8-one (**7b**), (2) condensation of **7b** with methyl sodiomalonate and subsequent Wittig reaction with methylenetriphenylphosphorane affording dimethyl (*trans*-4aβ-methyl-1-methylene-7β-decalinyl)malonate (**9**), (3) reduction of sodium salt of **9** with $NaAl(OCH_2CH_2OMe)_2H_2$. Oxidation of **1a** with PCC gave *dl*-β-costal. *dl*-Arctiol (**2**), structurally related to **1a**, was prepared from *trans*-5,5-ethylenedioxy-8aβ-methyldecalin-2-one. Introduction of two equatorial substituents, such as hydroxyl and 1-hydroxy-1-methylethyl groups at the C-2 and C-3 carbons of **2**, was carried out as follows: (1) methoxycarbonylation followed by methylation of the sodium salt of keto ester with MeLi, (2) subsequent reduction with lithium in liquid NH_3, giving *trans*-5,5-ethylenedioxy-3β-(1-hydroxy-1-methylethyl)-8aβ-methyldecalin-2α-ol (**14**), and (3) deacetalization of **14** followed by the reaction with methylenetriphenylphosphorane. *dl*-Eudesma-4(14),7(11)-dien-8-one was also prepared from **2** by oxidation with PCC followed by dehydration and subsequent isomerization of double bond.

In the course of our efforts to study the stereocontrolled synthesis of *dl*-dehydrofukinone[1] and *dl*-isopetasol,[2] we have found an efficient preparative way of *trans*-8,8-ethylenedioxy-4aβ-methyldecalin-2α-ol (**6a**)[1] and *trans*-5,5-ethylenedioxy-8aβ-methyldecalin-2-one (**11**)[2] from methyl 1-oxo-$\Delta^{6,7}$-octalin-4a-carboxylate.[3] The compounds **6a** and **11** are considered to be versatile intermediates[4] for eudesmane class sesquiterpenoid syntheses.[5] Herewith, we report the stereoselective syntheses of *dl*-β-costol (**1a**), *dl*-β-costal (**1b**), a major constituent of costus root oil[6] (*Saussurea lappa* Clark), *dl*-arctiol (**2**), found in the leaves of Gobo[7] (*Arctium lappa* L.), and *trans*-3-isopropylidene-8aβ-methyl-5-methylenedecalin-2-one (*dl*-eudesma-4(14),7(11)-dien-8-one) (**3**),[8] isolated from the essential oil of *Asarum caulescens* Maxim.

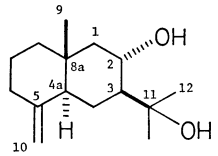
A key intermediate for the preparation of *dl*-β-costol (**1a**) must be 1,1-ethylenedioxy-4aβ-methyl-$\Delta^{6,7}$-octalin (**4**), prepared from methyl 1-oxo-$\Delta^{6,7}$-octalin-4a-carboxylate (65% overall yield).[1] Epoxidation of **4** with *m*-chloroperbenzoic acid at 0—5 °C gave the corresponding 2α,3α-epoxide **5** in 91% yield. Reductive epoxy ring opening at the C-3 position of **5** with lithium metal in liquid ammonia afforded the desired alcohol **6a** in 82% yield, in accordance with the axial ring opening rule.[9] The stereochemistry for the hydroxyl group of **6a** can be assigned by comparison of ^{13}C NMR and ^1H NMR results with those of the steroisomer **6c**, prepared from **6a** by oxidation with pyridinium chlorochromate (PCC)[10] and subsequent reduction with lithium aluminium hydride. The ^{13}C chemical shift values of the C-2 and C-8a carbons of **6a** appeared at 5.3 and 5.1 ppm higher fields than those of **6c**, due to the γ-effects,[11] are consistent with the assigned stereochemistry of the axial hydroxyl group of **6a**. In addition, the significant downfield shift of ^1H NMR signal due to the C-2 equatorial proton (δ 4.15) of **6a** as compared to the C-2 axial proton of **6c** (δ 3.58) is also consistent with the structures **6a** and **6c**.

The compound **6a** is nicely functionalized for the straightforward introduction of *exo*-methylene group as well as isopropenyl function at the C-8 and C-2 carbons. In particular, in the formation of the equatorial oriented substituent at C-7 carbon of **1**, the axial hydroxyl group of **6a** is expected to be easily replaced by a nucleophile, such as sodiomalonate. Thus, hydrolysis

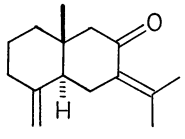


1a: R = $^{13}CH_2OH$

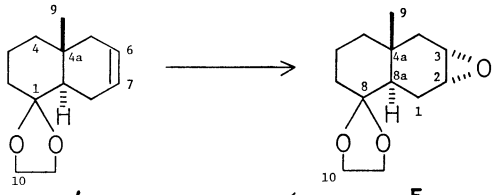
1b: R = CHO



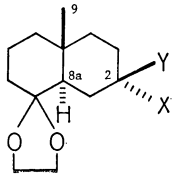
2



3



4 **5**



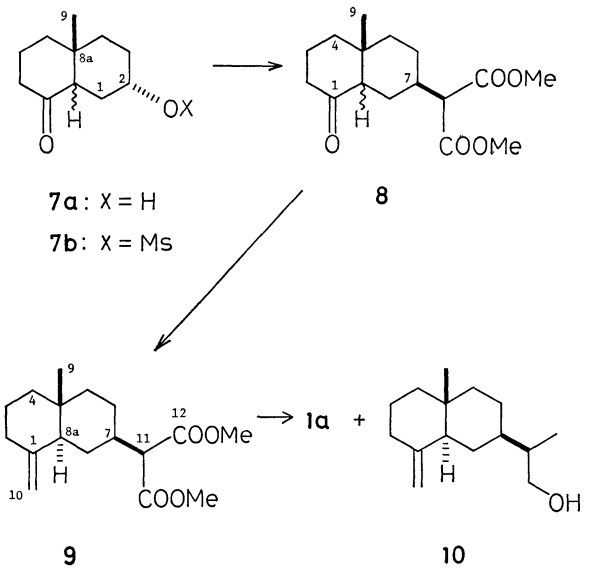
6a: X = OH, Y = H

6b: X = Y = O

6c: X = H, Y = OH

of **6a** with perchloric acid and subsequent treatment of **7a** with methanesulfonyl chloride in pyridine afforded the mesylate **7b** in 92% yield (from **6a**). The reaction of **7b** with methyl sodiomalonate in 1,2-dimethoxyethane (DME) provided the diester **8** in 82% yield. The Wittig reaction of **8** with a salt free solution of methylenetriphenylphosphorane[12] in benzene gave the *trans*-1-methylenedecalin **9** in 78% yield, accompanying with epimerization of the concomitant *cis*-fused decalin to its trans system.[13]

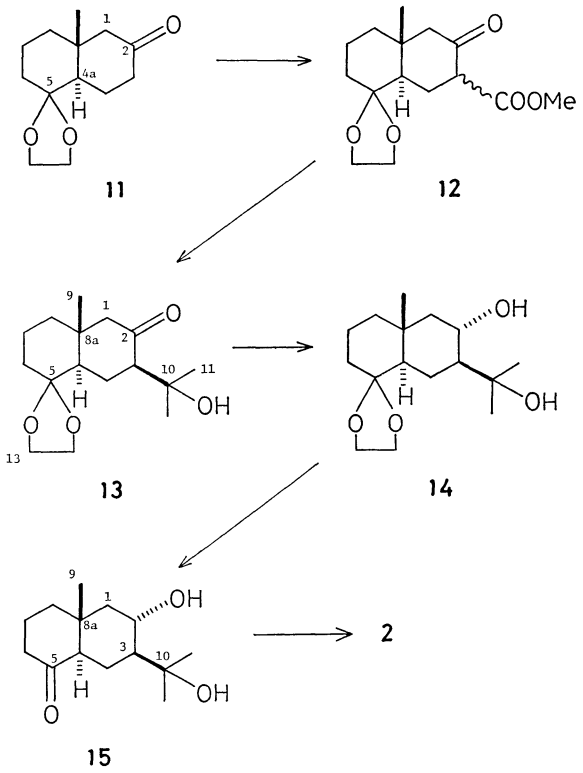
According to the slightly modified Marshall's procedure,[14] so called the malonic enolate reduction-elimination method, reduction of **9** with sodium bis(2-methoxyethoxy)aluminium hydride[15] and sodium hydride led to *dl*-β-costol (**1a**) in 74% yield along with the hydrogenated **10** (13%).[16] *dl*-β-Costal (**1b**) could be obtained in 84% yield by oxidation of *dl*-**1a** with PCC (Scheme 1).[6c,17]



Scheme 1.

We tried to prepare another eudesmane sesquiterpenes **2** and **3**, structurally related to **1**, from the masked diketone **11**.[2] One of the structural features of *dl*-arctiol (**2**) must be the C-2 and C-3 equatorial substituents. In connection with the synthesis of *dl*-isopetasol,[2] we have experienced that the reduction of the *trans*-decalin-2-one derivative with lithium metal in liquid ammonia provides the thermodynamically more stable *trans*-decalin-2α-ol, exclusively. The analogous reaction would be expected to proceed in the case of the ketone **13**, giving the 2α-alcohol **14**, a key precursor for the target **2**.

As shown in Scheme 2, the compound **11** is considered to be a suitable precursor for the preparation of the desired **13**. Methoxycarbonylation at the C-3 position of **11** with sodium hydride in dimethyl carbonate gave the keto ester **12** (84% yield) and subsequent methylation of **12** with methyllithium afforded **13**, smoothly. The stereochemistry of the C-3 substituent of **13** is considered to be a thermodynamically stable equatorial isomer.[18] The chemical shift value of the C-4a carbon (δ 50.4) of **13** is close to the C-4a

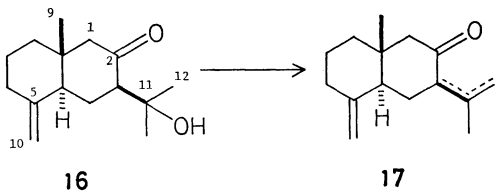


Scheme 2.

carbon (δ 50.1) of **11**, suggesting absence of the γ-effect between the C-3 substituent and the C-4a carbon of **13**.

Reduction of **13** with lithium metal in liquid ammonia provided the diol **14** in 84% yield. The tentative assignment of the equatorial hydroxyl group at C-2 of **14** is based on the comparison of ^{1}H NMR signals of the C-8a methyl group with those of **13**. In the *dl*-isopetasol synthesis,[2] we have encountered a significant 1,3-downfield shift[19] of signals due to the C-8a methyl protons of *trans*-decalin-2β-ol system in the value of 0.28 ppm compared to that of *trans*-decalin-2-one, in contrast to 0.06 ppm of the corresponding *trans*-decalin-2α-ol system. In the conversion of **13** into **14**, no remarkable shift on C-8a methyl protons was observed and the result would reveal absence of the shielding effect of C-2 axial hydroxyl group for the C-8a angular methyl protons of **14**. Hydrolysis of the ethylene acetal of **14** with perchloric acid and subsequent treatment of the ketone **15** with methylenetriphenylphosphorane afforded the desired **2** in 74% yield (from **14**), whose spectral data was identical with those of authentic specimen.[20]

dl-Eudesma-4(14),7(11)-dien-8-one (**3**), possessing a medical interest for a potential antiinflammatory activity,[21] was prepared from *dl*-arctiol (**2**) by oxi-



dation with PCC and subsequent dehydration of the ketol **16** on treatment with thionyl chloride in pyridine. Isomerization of the resulting *exo* and *endo* double bond isomers **17** by passing through an activated alumina column gave **3** in 41% yield (from **2**).[8a,17]

Experimental

Melting points and boiling points are uncorrected. IR spectra were determined with a JASCO IRA-I grating spectrometer. ^{1}H NMR (100 MHz) and ^{13}C NMR (25.05 MHz) spectra were measured with a JEOL Fourier transform spectrometer, Model FX-100. Samples were dissolved in $CDCl_3$ and signals are reported in parts per million (δ) downfield from the internal Me_4Si. Elemental analyses were performed in our laboratory.

trans-*2α,3α-Epoxy-8,8-ethylenedioxy-4aβ-methyldecalin (**5**).* To a solution of *m*-CPBA (199 mg, 1.15 mmol) in CH_2Cl_2 (5 ml) was added a solution of **4** (150 mg, 0.72 mmol) in CH_2Cl_2 (1 ml) at 0 °C. After being stirred at 0 °C for 1 h and 5 °C for 20 h, the mixture was quenched with water and taken up in CH_2Cl_2. The extract was washed with aqueous 10% $Na_2S_2O_3$ (3 ml), aqueous 5% NaOH, and brine, dried (Na_2SO_4), and concentrated. The residue was chromatographed (SiO_2, hexane–AcOEt 4:1) to give 147 mg (91%) of **5**: bp 75.0—77.0 °C/0.003 Torr (Kugelrohr); IR (neat) 1284, 1213, 1194, 1143, 1078, 1030, 901, 810, 797 cm^{-1}; ^{1}H NMR δ 0.86—2.24 (m, 11, CH_2, CH), 0.93 (s, 3, CH_3), 2.97—3.06 (m, 1, CH–O), 3.14—3.20 (m, 1, CH–O), 3.60—3.96 (m, 4, CH_2O); ^{13}C NMR δ 19.1 (t, C-6), 19.7 (q, C-9), 20.2 (t, C-1), 32.5 (s, C-4a), 35.4 (t, C-7), 40.5 (t, C-5), 41.9 (t, C-4), 42.9 (d, C-8a), 50.5 (t, C-2), 53.1 (d, C-3), 64.0 (t, C-10), 65.4 (t, C-11), 110.0 (s, C-8). Found: C, 69.72; H, 8.98%. Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99%.

trans-*8,8-Ethylenedioxy-4aβ-methyldecalin-2α-ol (**6a**).* To a blue solution of lithium (35 mg, 5 mmol) in liquid NH_3 (35 ml) was added a solution of **5** (245 mg, 1.09 mmol) in DME (5 ml) at −78 °C. After being stirred for 1 h at −78 °C and for 1.5 h at −33 °C, the mixture was quenched with NH_4Cl (500 mg) at −78 °C, allowed to stand at room temperature until most of liquid NH_3 has removed. The residue was worked up in the usual manner. The crude product was chromatographed (SiO_2, hexane–AcOEt 2:1) to give 202 mg (82%) of **6a**: bp 104.0—106.5 °C/0.005 Torr (Kugelroher); IR (neat) 3400 (OH), 1095, 1063, 1030, 1000, 945, 914, 878 cm^{-1}; ^{1}H NMR δ 0.90—2.04 (m, 13, CH_2, CH), 0.98 (s, 3, CH_3), 1.90 (s, 1, OH), 3.64—4.01 (m, 4, CH_2O), 4.15 (m, 1, CH–O); ^{13}C NMR δ 17.0 (q, C-9), 19.5 (t, C-6), 27.3 (t), 28.1 (t), 35.2 (s, C-4a), 35.8 (t, C-7), 36.6 (t, C-4), 40.8 (t, C-5), 44.1 (d, C-8a), 64.0 (t, C-10), 65.3 (t, C-11), 66.5 (d, C-2), 110.3 (s, C-8). Found: C, 69.02; H, 9.97%. Calcd for $C_{13}H_{22}O_3$: C, 68.99; H, 9.80%.

trans-*8,8-Ethylenedioxy-4aβ-methyldecalin-2-one (**6b**).* To a suspension of $Py\cdot CrO_3\cdot HCl$ (449 mg, 1.68 mmol) and anhydrous AcONa (275 mg, 3.35 mmol) in CH_2Cl_2 (5 ml) was added a solution of **6a** (127 mg, 0.56 mmol) in CH_2Cl_2 (4 ml) at 0—5 °C. After being stirred for 30 min at 0—5 °C and for 3 h at room temperature, the mixture was diluted with ether (5 ml) and passed through a short silica gel column eluting with ether–AcOEt. The eluate was concentrated and the residue was chromatographed (SiO_2, hexane–AcOEt 3:1) to give 118 mg (94%) of **6b** as white solids: mp 65.5—66.6 °C: IR (Nujol) 1710 cm^{-1} (C=O); ^{1}H NMR δ 0.96—2.04 (m, 9, CH_2, CH), 1.16 (s, 3, CH_3), 2.12—2.32 (m, 4, $COCH_2$), 3.68—4.04 (m, 4, CH_2O); ^{13}C NMR δ 17.1 (q, C-9), 19.4 (t, C-6), 34.6 (s, C-4a), 35.0 (t), 36.8 (t), 37.9 (t), 39.8 (t, C-4), 41.4 (t, C-5), 49.8 (d, C-8a), 64.2 (t, C-10), 65.6 (t, C-11), 109.3 (s, C-8), 212.2 (s, C-2). Found: C, 69.74; H, 9.25%. Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99%.

trans-*8,8-Ethylenedioxy-4aβ-methyldecalin-2β-ol (**6c**).* To a suspension of $LiAlH_4$ (15 mg, 0.40 mmol) in ether (0.5 ml) was added a solution of **6b** (17 mg, 0.076 mmol) in ether (0.5 ml) at 0—5 °C. After being stirred for 1 h at 5 °C and for 2 h at room temperature, the mixture was quenched with AcOEt and aqueous 5% $NaHCO_3$. The usual work-up gave 14 mg (82%) of **6c**: bp 106.0—107.5 °C/0.005 Torr (Kugelrohr); IR (neat) 3360 (OH), 1060, 1020, 958, 944, 887, 872, 852 cm^{-1}; ^{1}H NMR δ 0.99 (s, 3, CH_3), 1.08—2.02 (m, 13, CH_2, CH), 1.63 (br s, 1, OH), 3.58 (m, 1, CH–O), 3.72—4.01 (m, 4, CH_2O); ^{13}C NMR δ 17.8 (q, C-9), 19.5 (t, C-6), 29.3 (t), 31.1 (t), 34.6 (s, C-4a), 35.6 (t, C-7), 40.4 (t, C-4), 40.9 (t, C-5), 49.2 (d, C-8a), 64.2 (t, C-10), 65.4 (t, C-11), 71.8 (d, C-2), 109.8 (s, C-8). Found: C, 68.89; H, 9.77%. Calcd for $C_{13}H_{22}O_3$: C, 68.99; H, 9.80%.

*2α-Hydroxy-4aβ-methyldecalin-8-one (**7a**).* A solution of **6a** (175 mg, 0.77 mmol) and 70% $HClO_4$ (50 mg) in THF (5 ml) and H_2O (2.5 ml) was stirred for 12 h at 5 °C. The mixture was taken up in ether–benzene (1:1) and the extract was worked up in the usual manner to give 134 mg (95%) of **7a**: bp 114.5—115.5 °C/0.01 Torr (Kugelrohr); IR (neat) 3400 (OH), 1702 cm^{-1} (C=O); ^{1}H NMR δ 0.79, 0.98 (s, 3, CH_3), 1.08—2.48 (m, 13, CH_2, CH, OH), 2.72 (d, d, 1, J=11, 5 Hz, COCH), 4.15 (m, 1, CH–O). Found: C, 72.31; H, 10.09%. Calcd for $C_{11}H_{18}O_2$: 72.49; H, 9.95%.

*2α-Methylsulfonyloxy-4aβ-methyldecalin-8-one (**7b**).* To a solution of **7a** (154 mg, 0.85 mmol) in pyridine (3 ml) was added $MeSO_2Cl$ (200 mg, 1.74 mmol) at 0—5 °C. After being stirred for 20 h at 5 °C, the mixture was quenched with cold water and taken up in ether–benzene (1:1). The extract was worked up in the usual manner to give 214 mg (97%) of **7b** as white solids after chromatography (SiO_2, hexane–AcOEt 4:1): mp 91.5—93.5 °C; IR (Nujol) 1700 (C=O), 1354, 1170 cm^{-1}; ^{1}H NMR δ 0.80, 1.18 (s, 3, CH_3), 1.10—2.16 (m, 11, CH_2, CH), 2.32 (d, 2, J=7 Hz, $COCH_2$), 2.66 (d, d, 1, J=12, 2 Hz, COCH), 2.99 (s, 3, SO_2CH_3), 5.05 (br s, 1, CH–O); ^{13}C NMR (major peaks) δ 16.3 (q, C-9), 22.4 (t, C-6), 26.3 (t), 26.5 (t), 34.2 (t) 38.5 (q, SO_2CH_3), 39.0 (s, C-4a), 40.0 (t, C-4), 41.1 (t, C-5), 50.8 (d, C-8a), 79.0 (d, C-2), 211.3 (s, C-8). Found: C, 55.26; H, 7.88%. Calcd for $C_{12}H_{20}O_4S$: C, 55.37; H, 7.74%.

*Dimethyl (4aβ-Methyl-1-oxo-7β-decalinyl) malonate (**8**).* To a solution of dimethyl sodiomalonate prepared from dimethyl malonate (330 mg, 2.5 mmol) and NaH (55 mg, 2.3 mmol) in DME (3 ml) was added a solution of **7b** (105 mg, 0.40 mmol) in DME (1 ml). After being heated at reflux for 36 h, the mixture was quenched with 5% HCl at 0—5 °C and taken up in ether–benzene (1:1). The extract was washed with brine, dried (Na_2SO_4), and concentrated to give 97 mg (82%) of **8** as white solids after chromatography (SiO_2, hexane–AcOEt 3:1): mp 97.5—98.5 °C; IR (Nujol) 1750 (ester C=O), 1698 cm^{-1} (C=O); ^{1}H NMR δ 0.77, 1.13 (s, 3, CH_3), 1.10—2.40 (m, 14, CH_2 CH), 3.25 (d, 1, J=9 Hz, CHCOO), 3.72 (s, 6, OCH_3); ^{13}C NMR (major peaks) δ 16.8 (q, C-9), 22.5 (t, C-3), 24.7 (t), 25.0 (t), 37.5 (d, C-7), 39.2 (s, C-4a), 40.2 (t, C-2, C-4), 41.1 (t, C-5), 52.4 (q, OCH_3), 56.8 (d, C-8a), 57.7 (d, malonic ester CH), 168.7 (s, COO), 168.9 (s, COO), 211.7 (s, C-1). Found: C, 64.80; H, 8.29%. Calcd for $C_{16}H_{24}O_5$: C, 64.84; H, 8.16%.

*Dimethyl (trans-4aβ-Methyl-1-methylene-7β-decalinyl) malonate (**9**).* A salt free solution of methylenetriphenylphosphorane prepared from methyltriphenylphosphonium bromide (217 mg, 0.61 mmol) and $LiNH_2$ (95 mg, 2.43 mmol) in benzene (5 ml) was added dropwise to a solution of **8** (45 mg, 0.15 mmol) in benzene (1 ml). After being stirred for 20 h at room temperature, the mixture was quenched with aqueous 5% HCl and taken up in ether–benzene (1:1). The extracts were washed with brine, dried (Na_2SO_4), and concentrated. The residue was chromatographed (SiO_2, hexane–AcOEt 5:1) to give 38 mg (86%) of **9**: bp 101.0—102.5 °C/0.02 Torr (Kugelrohr); IR (neat) 3065, 1760 (ester C=O), 1738 (ester C=O), 1645 cm^{-1} (C=C); ^1H NMR δ 0.70 (s, 3, CH_3), 0.84—2.36 (m, 14, CH_2, CH), 3.25 (d, 1, J=9 Hz, CHCOO), 3.73 (s, 6, OCH_3), 4.35, 4.66 (br s, 2, H_2C=C); ^{13}C NMR δ 16.2 (q, C-9), 23.4 (t, C-3), 25.7 (t, C-6), 28.3 (t, C-8), 35.8 (s, C-4a), 36.7 (t, C-2), 38.4 (d, C-7), 40.5 (t, C-4), 41.7 (t, C-5), 49.3 (d, C-8a), 52.2 (q, OCH_3), 58.0 (d, C-11), 105.6 (t, C-10), 150.2 (s, C-1), 169.0 (s, C-12, C-13). Found: C, 69.35; H, 8.98%. Calcd for $C_{17}H_{26}O_4$: C, 69.36; H, 8.90%.

*dl-β-Costol (**1a**)* and *trans-7β-(2-Hydroxy-1-methylethyl)-4aβ-methyl-1-methylenedecalin (**10**).* A mixture of **9** (40 mg, 0.135 mmol) and NaH (25 mg, 1.04 mmol) in DME (3 ml) was heated at reflux for 24 h and to this solution was added a solution of 70% $NaAl(OCH_2CH_2OCH_3)_2H_2$ (540 mg, 1.87 mmol) in benzene. The mixture was heated at reflux for 1 h, quenched with MeOH at 0—5 °C, acidified with aqueous 5% HCl, and taken up in benzene–AcOEt (1:1). The extract was washed with brine, dried (Na_2SO_4), and concentrated. The residue was chromatographed (SiO_2, hexane–AcOEt 4:1) to give 22 mg (74%) of **1a** (R_f 0.82, hexane–ether 2:1) and 4 mg (13%) of **10** (R_f 0.69). **1a**: bp 79.5—81.0 °C/0.015 Torr (Kugelrohr) (lit,[6a] 150 °C/0.5 Torr, lit,[6d] 130 °C/0.3 Torr); IR (neat) 3300 (OH), 3060 (HC=C), 1645 (C=C), 1438, 1407, 1380, 1175, 1150, 1055, 1043, 1030, 1022, 885 cm^{-1}; ^1H NMR δ 0.74 (s, 3, CH_3), 0.84—2.41 (m, 15, CH_2, CH, OH), 4.13 (br s, 2, CH_2O), 4.41, 4.69 (br s, 2, H_2C=C), 4.93, 5.03 (br s, 2, H_2C=C); ^{13}C NMR δ 16.4 (q, C-9), 23.5 (t, C-3), 27.3 (t, C-6), 30.0 (t, C-8), 36.0 (s, C-4a), 36.8 (t, C-2), 41.2 (d, C-7), 41.7 (t, C-4), 41.9 (t, C-5), 50.0 (d, C-8a), 65.3 (t, C-13), 105.4 (t, C-10), 107.8 (t, C-12), 150.7 (s, C-1), 154.1 (s, C-11).

10: [6d] Bp 81.5—83.0 °C/0.01 Torr (Kugelrohr); IR (neat) 3300 (OH), 3060, 1644 (C=C), 1440, 1378, 1057, 1039, 884 cm^{-1}; ^1H NMR δ 0.71 (s, 3, CH_3), 0.85—2.40 (m, 19, CH_3, CH_2, CH, OH), 3.35—3.76 (m, 2, CH_2O), 4.39, 4.68 (br s, 2, H_2C=C).

*dl-β-Costal (**1b**).* To a suspension of $Py\cdot CrO_3\cdot HCl$ (60 mg, 0.28 mmol) and AcONa (37 mg, 0.45 mmol) in CH_2Cl_2 (1 ml) was added a solution of **1a** (22 mg, 0.1 mmol) in CH_2Cl_2 (1 ml) at 0—5 °C. After being stirred for 0.5 h at 0—5 °C and for 3 h at room temperature, the mixture was diluted with ether. The usual work-up gave 16 mg (73%) of **1b** after chromatography (SiO_2, hexane–AcOEt 3:1): bp 53—57 °C/0.02 Torr (Kugelrohr) (lit,[6d] 110 °C/0.3 Torr); IR (neat) 3070, 2700, 1698 (C=O), 1646 (C=C), 1628 (C=C), 1440, 1380, 1208, 1150, 922, 918, 888 cm^{-1}; ^1H NMR δ 0.75 (s, 3, CH_3), 1.10—2.70 (m, 14, CH_2, CH), 4.36, 4.69 (br s, 2, H_2C=C), 5.98, 6.28 (s, 2, H_2C=C), 9.54 (s, 1, CHO); ^{13}C NMR δ 16.4 (q, C-9), 23.5 (t, C-3), 27.0 (t, C-6), 29.5 (t, C-8), 35.9 (s, C-4a), 36.5 (t, C-2), 36.9 (d, C-7), 41.0 (t, C-4), 41.9 (t, C-5), 49.8 (d, C-8a), 105.6 (t, C-10), 133.0 (t, C-12), 150.8 (s, C-1), 155.5 (s, C-11), 194.9 (s, C-13).

*Methyl trans-5,5-Ethylenedioxy-8aβ-methyl-2-oxodecalin-3-carboxylate (**12**).* A mixture of **11**[2] (210 mg, 0.94 mmol), dimethyl carbonate (270 mg, 3.0 mmol), and NaH (37 mg, 1.54 mmol) was heated at 60—65 °C for 3 h and quenched with aqueous 50% MeOH at 0—5 °C. The mixture was extracted with benzene–AcOEt (1:1) and the extract was washed with aqueous $NaHCO_3$, dried (Na_2SO_4), and concentrated. The residue was chromatographed (SiO_2, hexane–AcOEt 2:1) to give 223 mg (84%) of **12**: bp 137.0—139.0 °C/0.03 Torr (Kugelrohr); IR (neat) 1742 (ester C=O), 1710 (C=O), 1655, 1618 cm^{-1}; ^1H NMR δ 0.89—1.96 (m, 7, CH_2, CH), 0.99 (s, 3, CH_3), 2.04—2.50 (m, 4, CH_2), 3.76 (s, 3, OCH_3), 3.90—4.04 (m, CH_2O, COCH), 12.06 (s, OH). Found: C, 63.95; H, 8.03%. Calcd for $C_{15}H_{22}O_5$: C, 63.81; H, 7.85%.

*trans-5,5-Ethylenedioxy-3β-(1-hydroxy-1-methylethyl)-8aβ-methyldecalin-2-one (**13**).* To a suspension of NaH (50 mg, 2.1 mmol) in THF (5 ml) was added a solution of **12** (200 mg, 0.71 mmol) in THF (5 ml) at 0 °C. When H_2 evolution was complete, an ethereal solution of 1.4 M MeLi (3.1 ml, 4.3 mmol) was added at 5 °C. After being stirred at reflux for 12 h, the mixture was quenched with aqueous 10% NH_4Cl at 0—5 °C and taken up in AcOEt. The extract was washed with aqueous $NaHCO_3$, dried (Na_2SO_4), and concentrated. The residue was chromatographed (SiO_2, hexane–AcOEt 1:1) to give 27 mg of **11** and 146 mg (73%) of **13** as white solids: mp 87.0—88.5 °C; IR (Nujol) 3480 (OH), 1688 (C=O), 1290, 1228, 1172, 1098, 1074, 1051, 1032, 952, 855 cm^{-1}: ^1H NMR δ 0.93 (s, 3, CH_3), 1.10—2.48 (m, 12, CH_2, CH), 1.22, 1.26 (s, 6, CH_3), 3.68—4.02 (m, 4, CH_2O), 4.10 (br, 1, OH); ^{13}C NMR δ 18.6 (q, C-9), 19.5 (t, C-7), 23.7 (s, C-8a), 25.5 (q, C-11), 28.6 (q, C-12), 35.6 (t, C-4), 39.7 (s, C-8a), 40.4 (t, C-8), 50.4 (d, C-4a), 58.8 (t, C-1), 59.1 (d, C-3), 64.4 (t, C-13), 65.6 (t, C-14), 71.8 (s, C-10), 109.8 (s, C-5), 214.7 (s, C-2). Found: C, 68.19; H, 9.41%. Calcd for $C_{16}H_{26}O_4$: C, 68.06; H, 9.28%.

*trans-5,5-Ethylenedioxy-3β-(1-hydroxy-1-methylethyl)-8aβ-methyldecalin-2α-ol (**14**).* To a blue solution of lithium (19 mg, 2.71 mmol) in liquid NH_3 (20 ml) was added a solution of **13** (115 mg, 0.41 mmol) in ether (3 ml), EtOH (36 μl), and dioxane (0.5 ml) at −78 °C. After being stirred for 30 min at −78 °C and for 1 h at −33 °C, the mixture was quenched with NH_4Cl (200 mg) at −78 °C and allowed to stand at room temperature until the most of liquid NH_3 had evaporated. The residue was taken up in AcOEt–benzene and worked up in the usual manner to give 101 mg (87%) of **14** as while crystals after chromatography (SiO_2, hexane–AcOEt 1:1): mp 143.5—145.0 °C; IR (Nujol) 3330 (OH), 1380, 1174, 1088, 1037, 907 cm^{-1}; ^1H NMR δ 0.97 (s, 3, CH_3), 1.04—1.90 (m, 12, CH_2, CH), 1.26, 1.28 (s, 6, CH_3), 2.39 (br, 2, OH), 3.60—3.94 (m, 4, CH_2O), 4.02 (d, d, d, 1, J=10, 5, 5 Hz, CH–O); ^{13}C NMR δ 18.9 (q, C-9), 19.2 (t, C-7), 21.3 (t, C-4), 23.9 (q, C-10), 30.2 (q, C-12), 35.5 (t, C-6), 36.1 (s, C-8a), 40.4 (t, C-8), 50.8 (d, C-4a), 51.5 (t, C-1), 54.1 (d, C-3), 64.1 (t, C-13), 65.2 (t, C-14), 68.9 (d, C-2), 75.2 (s, C-10), 109.9 (s, C-5). Found: C, 67.55; H, 10.08%. Calcd for $C_{16}H_{28}O_4$: 67.57; H, 9.92%.

*trans-2α-Hydroxy-3β-(1-hydroxy-1-methylethyl)-8aβ-methyldecalin-5-one (**15**).* A mixture of **14** (53 mg, 0.19 mmol) and 70% $HClO_4$ (20 mg) in THF (3 ml) and H_2O (1.5 ml) was stirred for 12 h at 5—10 °C and taken up in CH_2Cl_2. The extract was worked up in the usual manner to give 38 mg (85%) of **15** as while crystals after chromatography (SiO_2, hexane–AcOEt 1:1): mp 164.5—165.5 °C (benzene); IR (Nujol) 3250 (OH), 1710 cm^{-1} (C=O); ^1H NMR δ 0.80 (s, 3, CH_3), 1.06—2.00 (m, 10, CH_2, CH), 1.28 (s, 6, CH_3), 2.22—2.40 (m, 3, CH_2CO, CHCO), 2.80 (br s, 2, OH), 3.97 (d, d, d, 1, J=10, 5, 5 Hz, CH–O); ^{13}C NMR δ 17.9 (q, C-9), 22.2 (t, C-4, C-7), 23.8 (q, C-11), 30.4 (q, C-12),

40.0 (t, C-6), 40.5 (s, C-8a), 41.1 (t, C-8), 49.5 (t, C-1), 53.2 (d, C-3), 56.9 (d, C-4a), 68.5 (d, C-2), 75.5 (s, C-10), 212.5 (s, C-5). Found: C, 70.08; H, 9.99%. Calcd for $C_{14}H_{24}O_3$: C, 69.96: H, 10.07%.

dl-*Arctiol (2)*. To a solution of **15** (46 mg, 0.19 mmol) in benzene (1 ml) was added a solution of salt-free methylenetriphenylphosphorane (555 mg, 2.01 mmol) in benzene (10 ml). After being stirred for 24 h at room temperature, the mixture was quenched with aqueous 5% HCl at 0—5 °C and taken up in AcOEt. The organic layer was washed with brine, dried (Na_2SO_4), and concentrated to give 35 mg (77%) of **2** as white crystals after chromatography (SiO_2, hexane–AcOEt 2:1): mp 135.5—136.5 °C (hexane) (lit,[7] 157.5—159.0 °C); IR (Nujol) 3250 (OH), 3060, 1642 (C=C), 1147, 1037, 1012, 913, 883 cm^{-1}; ^1H NMR δ 0.74 (s, 3, CH_3), 0.85—2.37 (m, 12, CH_2, CH), 1.28, 1.30 (s, 6, CH_3), 2.81 (br, 2, OH), 4.00 (d, d, d, 1, J=10, 5, 5 Hz, CH-O), 4.40, 4.71 (br s, 2, H_2C=C); ^{13}C NMR δ 17.3 (q, C-9), 22.9 (t, C-7), 24.0 (q, C-12), 26.0 (t, C-4), 30.3 (q, C-13), 36.6 (t, C-6), 37.7 (s, C-8a), 41.4 (t, C-8), 49.4 (d, C-4a), 50.2 (t, C-1), 54.3 (d, C-3), 69.2 (d, C-2), 75.2 (s, C-11), 105.5 (t, C-10), 150.0 (s, C-5). Found: C, 75.49; H, 11.02%. Calcd for $C_{15}H_{26}O_2$: C, 75.58; H, 10.99%.

trans-*3β-(1-Hydroxy-1-methylethyl)-8aβ-methyl-5-methylenedecalin-2-one (16)*. To a suspension of $Py \cdot CrO_3 \cdot HCl$ (73 mg, 0.34 mmol) and AcONa (37 mg, 0.45 mmol) in CH_2Cl_2 (3 ml) was added a solution of **2** (31 mg, 0.13 mmol) in CH_2Cl_2 (1 ml) at 5 °C. After being stirred for 1 h at 5 °C and for 2 h at room temperature, the mixture was worked up in the usual manner to give 27 mg (88%) of **16**: bp 55.0—57.0 °C/0.002 Torr (Kugelrohr); IR (neat) 3540 (OH), 3075, 1691 (C=O), 1642 (C=C), 1437 1378, 1210, 1145, 1052, 880 cm^{-1}; ^1H NMR δ 0.70 (s, 3, CH_3), 1.26 (s, 6, CH_3), 1.40—2.56 (m, 12, CH_2, CH), 3.40 (br, 1, OH), 4.51, 4.82 (br s, 2, H_2C=C); ^{13}C NMR δ 17.1 (q, C-9), 23.0 (t, C-7), 25.6 (q, C-12), 28.2 (t, C-4), 28.6 (q, C-13), 36.6 (t, C-6), 40.9 (s, C-8a), 41.3 (t, C-8), 48.4 (d, C-4a), 57.1 (t, C-1), 59.0 (d, C-3), 71.5 (s, C-11), 107.3 (t, C-10), 148.4 (s, C-5), 214.4 (s, C-2). Found: C, 76.13; H, 10.43%. Calcd for $C_{15}H_{24}O_2$: C, 76.23; H, 10.24%.

dl-*Eudesma-4(14),7(11)-dien-8-one (3)*. To a solution of **16** (12 mg, 0.05 mmol) in pyridine (3 ml) was added $SOCl_2$ (81 mg, 0.68 mmol) at 0 °C. After being stirred for 1.5 h at 0—5 °C, the mixture was quenched with aqueous 5% $NaHCO_3$ and taken up in ether. The extract was worked up in the usual manner to give 7 mg (65%) of **17** after chromatography (SiO_2, hexane–AcOEt 5:1): IR (neat) 3080, 1710 (C=O), 1680 (shoulder), 1645 (C=C), 890 cm^{-1}; ^1H NMR δ 4.50—4.70 (m, H_2C=C). Without further purification, **17** was passed through an activated Al_2O_3 300 (Nakarai Chemicals) column (hexane–AcOEt 5:1) to give 5 mg (71%) of **3**: bp 116—118 °C/11 Torr (lit,[8a] 92.5—95.4 °C/4.5 Torr); IR (neat) 3090, 1680, 1645, 1595, 1210, 890 cm^{-1}; ^1H NMR δ 0.78 (s, 3, CH_3), 1.00—2.80 (m, 1, CH_2, CH), 1.82, 1.98 (s, 6, CH_3), 5.60, 5.84 (br s, 2, H_2C=C).

References

1) S. Torii, T. Inokuchi, and T. Yamafuji, *Bull. Chem. Soc. Jpn.*, **52**, 2640 (1979).

2) S. Torii, T. Inokuchi, and K. Kawai, *Bull. Chem. Soc. Jpn.*, **52**, 861 (1979).

3) S. Torii, T. Kunitomi, and T. Okamoto, *Bull. Chem. Soc. Jpn.*, **47**, 2349 (1974).

4) a) J. W. Huffman and M. L. Mole, *J. Org. Chem.*, **37**, 13 (1972); b) R. G. Carlson and E. G. Zey, *ibid.*, **37**, 2468 (1972); c) R. B. Miller and R. D. Nash, *ibid.*, **38**, 4424 (1973); d) G. H. Posner and G. L. Loomis, *ibid.*, **38**, 4459 (1973); e) J. L. Cooper and K. E. Harding, *Tetrahedron Lett.*, **1977**, 3321; f) E. Huq, M. Meller, E. G. Scovell, and J. K. Sutherland, *J. Chem. Soc., Chem. Commun.*, **1978**, 526.

5) For a review of synthetic approaches to eudesmane type sesquiterpenes, see a) C. H. Heathcock, "The Total Synthesis of Natural Products," ed by J. W. ApSimon, John Wiley & Sons, Inc., New York, N. Y. (1973), Vol. 2, pp. 282—330. Recent reports on the synthesis of eudesmanes; b) G. H. Posner, G. L. Loomis, and H. S. Sawaya, *Tetrahedron Lett.*, **1975**, 1373; c) O. P. Vig, M. L. Sharma, R. Anand, and S. D. Sharma, *J. Ind. Chem. Soc.*, **53**, 81 (1976); d) W. C. Still and M. J. Schneider, *J. Am. Chem. Soc.*, **99**, 948 (1977); e) J. A. Marshall and P. G. M. Wuts, *J. Org. Chem.*, **43**, 1086 (1978); f) S. R. Wilson and D. T. Mao, *J. Am. Chem. Soc.*, **100**, 6289 (1978); g) B. D. MacKenzie, M. M. Angelo, and J. Wolinsky, *J. Org. Chem.*, **44**, 4042 (1979).

6) Isolation: a) A. S. Bawdekar and G. R. Kelkar, *Tetrahedron*, **21**, 1521 (1965); b) S. Ito, K. Endo, H. Honma, and K. Ota, *Tetrahedron Lett.*, **1965**, 3777; c) B. Maurer and A. Grieder, *Helv. Chim. Acta*, **60**, 2177 (1977); Synthesis; d) J. A. Marshall, M. T. Pika, and R. D. Carroll, *J. Org. Chem.*, **31**, 2933 (1966).

7) K. Naya, K. Tsuji, and U. Haku, *Chem. Lett.*, **1972**, 235.

8) a) J. Endo and M. Nagasawa, *Yakugaku Zasshi*, **94**, 1574 (1974); b) Y. Nishikawa, I. Yasuda, Y. Watanabe, and T. Seto, *Shoyakugaku Zasshi*, **30**, 132 (1976); c) F. Bohlmann and A. Suwita, *Phytochemistry*, **17**, 567 (1978).

9) A. S. Hallsworth and H. B. Henbest, *J. Chem. Soc.*, **1957**, 4604.

10) E. J. Corey and J. W. Suggs, *Tetrahedron Lett.*, **1975**, 2647.

11) D. K. Dalling and D. M. Grant, *J. Am. Chem. Soc.*, **94**, 5318 (1972).

12) a) H. J. Bestmann and B. Arnason, *Chem. Ber.*, **95**, 1513 (1962); b) A. Maercker, *Org. React.*, **14**, 270 (1967).

13) a) C. H. Heathcock and R. Ratcliffe, *J. Am. Chem. Soc.*, **93**, 1746 (1971); b) F. E. Ziegler and J. A. Kloek, *Tetrahedron*, **33**, 373 (1977).

14) J. A. Marshall and N. Cohen, *J. Org. Chem.*, **30**, 3475 (1965).

15) L. F. Fieser and M. Fieser, "Reagents for Organic Synthesis," John Wiley & Sons, Inc., New York, N. Y. (1972), Vol. 3, p. 260.

16) The use of $NaAl(OCH_2CH_2OMe)_2H_2$ for reduction-elimination of **9** seems to be pertinent to minimize the undesired **10** in contrast to the results obtained by the reaction of the similar functional group as a malonic ester with $LiAlH_4$[6d,14] leading to a mixture involving more than 20% of a hydrogenated product.

17) The spectra of the synthetic materials were identical with spectra of the corresponding natural products.

18) a) R. M. Coates and J. E. Shaw, *J. Am. Chem. Soc.*, **92**, 5657 (1970); b) D. J. Goldsmith and I. Sakano, *J. Org. Chem.*, **41**, 2095 (1976); c) K. Yamakawa, I. Izuta, H. Oka, R. Sakaguchi, M. Kobayashi, and T. Satoh, *Chem. Pharm. Bull.*, **27**, 331 (1979).

19) R. B. Miller and E. S. Behare, *J. Am. Chem. Soc.*, **96**, 8102 (1974).

20) We are gratefull to Proffessor K. Naya, Kwansei Gakuin University, for providing ^1H NMR and IR spectra of natural arctiol (**2**).

21) K. Endo and H. Hikino, *Bull. Chem. Soc. Jpn.*, **52**, 2439 (1979).