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Bisannelation with Vinylselenoxide: Synthesis of Tricyclo[3.2.1.0^{2,7}]octane-6-one and its Congeners

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Abstract—Reaction of kinetic enolate of α′-substituted cyclohexenone derivatives with vinylselenoxides provided tricyclo[3.2.1.0^{2,7}]-octane-6-one derivatives via domino Michael–Michael-substitution protocol. © 2000 Elsevier Science Ltd. All rights reserved.

Domino reaction strategies can accomplish several synthetic objectives in a single operation. The rapidity with which they can build-up molecular complexity is a most useful and impressive virtue. Among them, the reactions initiated by carbanion species and especially the domino Michael–Michael-alkylative strategies have contributed largely towards the syntheses of several complex cyclic compounds.[1] Since bicyclo[2.2.2]octane or tricyclo-[3.2.1.0^{2,7}]octane framework has been involved often in several natural products as a basic skeleton, development of synthetic strategies towards these frameworks have been an interesting task. Among these, the representative sesquiterpene natural products namely ishwaranes and cyclomyltaylanes (Fig. 1) still pose as challenging targets to realize these synthetic methodologies.[2]

As a part of our synthetic study towards such natural products, we wish to disclose a new synthetic protocol towards tricyclo[3.2.1.0^{2,7}]octane-6-one derivatives **10**, formed as a result of domino Michael–Michael-substitution reaction involving the kinetically derived enolate **2** of cyclohexenone **1** with vinylselenoxide **3** in a single pot operation (Scheme 1).

In these reactions, two carbon–carbon bond formation by tandem Michael–Michael reaction closes one ring and the subsequent intramolecular substitution closes second ring, thereby forming two rings at a time (bisannelation). When the starting substrate already poses cyclic structures, tricyclic or tetracyclic compound is obtained in one pot operation as a result of bisannelation. For that purpose, vinyltriphenylphosphonium bromide,[3] vinylsulfone,[4] nitroethylene,[5] methyl 2-bromopropenoate[6,7] or methyl chlorocyclopropylidene-acetate[8] have been used as a bisannelating reagent so far. In the former three cases,[3–5] functional group (PPh_3, SO_2Ph or NO_2) of initial Michael acceptor played a dual role of electron withdrawing as well as leaving group. It may be noted that in 1980 Shimizu and Kuwajima reported the reaction of ketone enolate with vinylselenoxide to give cyclopropylketone by Michael-substitution reaction (Scheme 1, path c).[9]

If proton transfer from the anion **4** to **5** is suppressed, we expected that successive intramolecular Michael reaction of carbanion **4** would give bicyclic compound **7** which after isomerization into *exo*-selenoxide **8** will undergo intramolecular substitution reaction to close the second ring to give tricyclo[3.2.1.0^{2,7}]octane-6-one derivatives **10** (Scheme 1, path b). In order to prevent proton transfer from **4** to **5**, a cyclic enone **1** having a substituent at α′-position was employed as a starting material in this protocol. In fact, unsaturated ketone having an extra proton

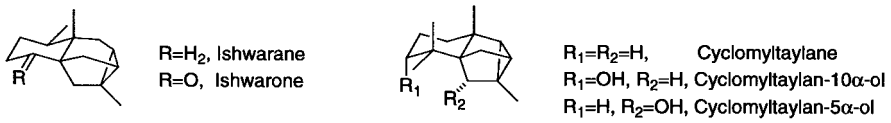

Figure 1.

Keywords: cyclisation; cage compounds; Michael reactions; selenium and compounds.
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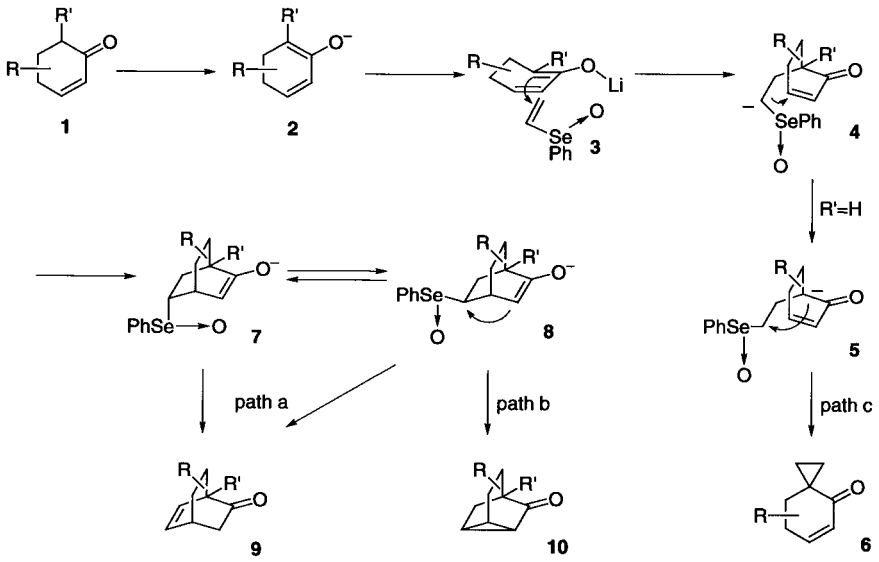
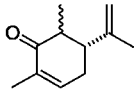
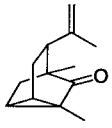
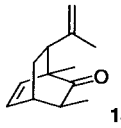
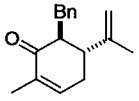
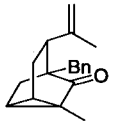
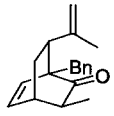
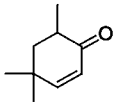
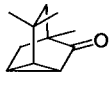
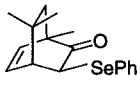
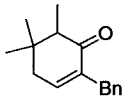
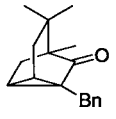
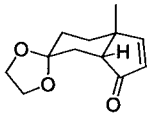
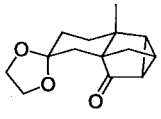
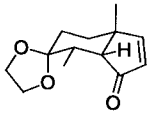
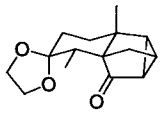
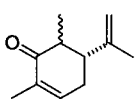
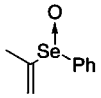
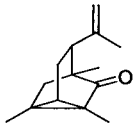


Scheme 1.

Table 1. Bisannelation with vinylselenoxides

Entry	Substrate	Selenoxide	Product	
1	 **11**[a]	 **3**	 **12** 46%	 **13** 23%
2	 **14**		 **15** 12%	 **16** 8%
3	 **17**		 **18** 6%	 **19** 2%
4	 **20**		 **21** 25%	
5	 **22**		 **23** 12%	
6	 **24**		 **25** 12%	
7	 **11**	 **26**	 **27** 40%	

[a] A diastereomeric mixture was used (1:1.5).

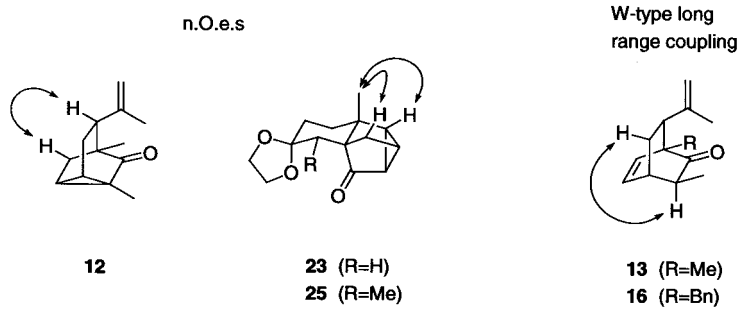


Figure 2.

at α′-position provided cyclopropyl ketone **6** as reported by Shimizu and Kuwajima (Scheme 1, path c).[9] Vinylselenoxides were easily prepared according to the reported procedure[9] and used soon after their preparation. After initial tuning of the reaction conditions, enolates **2** generated by lithium diisopropylamide (LDA) at 0°C gave better yields than those by lithium hexamethyldisilazide (LHMDS). Some of the representative results are summarized in Table 1. Not only tricyclic but also tetracyclic compounds without ester group on cyclopropane ring were obtained, though yields are moderate and almost comparable to those previously reported.[3–8]

Addition of hexamethylphosphoric triamide did not affect the yield in case of entry 1. Entries 1–3 were accompanied by bicyclo[2.2.2]octene derivatives, **13**, **16** and **19**. In entries 1, 2, 5, 6 and 7, single stereoisomers were obtained thereby indicating that the present bisannelation was sensitive to steric factors existing in the substrates. The other side products obtained were α-vinylic compounds. The reaction with phenyl vinylselenone resulted in the formation of complex mixture. On the other hand, the reaction with vinylselenide resulted in the recovery of starting enone **1** under the present reaction conditions even in the presence of Lewis acid catalysts starting from trimethylsilylenol ether of the enone **1**.

Relative stereochemistries of the tri- and bicyclic compounds **12**, **13**, **16**, **23** and **25** were established as represented in Fig. 2 by a combination of COSY, DEPT, HMBC, HMQC and NOESY experiments. The relative stereochemistries of the tricyclic compounds **15** and **27** were determined by comparison with NMR spectra of compound **12**, especially on the basis of the chemical shift values and spectral patterns of the protons on a carbon bearing isopropenyl group. These stereochemical aspects indicated that the vinylselenoxides approached stereoselectively from less hindered side of the enolates.

Since bisannelated compounds **10** were isolated as a major product of the reaction in spite of having the two substrates **7** and **8**, an alternative pathway to form the tricyclic compound **10** is anticipated by intramolecular addition of carbene generated after falling off phenylselenoxy anion from the anion **4** (Scheme 1). However, addition of excess methylcyclohexene in entry 1, Table 1, did not provide any cyclopropane derivatives derived from methylcyclohexene.

In conclusion, we have shown that vinylselenoxides **3** and **26** function as a new bisannelating reagent leading to tricyclic compound such as tricyclo[3.2.1.$0^{2,7}$]octane-6-one derivatives **10** and their congeners. Synthetic study of polycyclic natural products along this line is now underway.[10]

Experimental

Meltings points were determined with a Yanaco MP hot-stage apparatus and are uncorrected. IR spectra were recorded on a Shimadzu FT/IR-4200 spectrophotometer for solutions in chloroform unless otherwise indicated. ^{1}H NMR spectra were obtained for solutions in deuteriochloroform with Varian Gemini 200H (200 MHz) and Unity 500 plus (500 MHz) instruments with tetramethylsilane as internal standard. ^{13}C NMR spectra were measured with Varian Gemini 200H (50 MHz) or Unity 500 plus (125 MHz) instruments. Mass spectral data were run on a JOEL SX-102A or a JEOL GCmate spectrometer. Medium-pressure liquid chromatography (MPLC) were carried out on a GL Sciences PU 612 instrument with a silica gel packed column. Microanalyses were carried out in the microanalytical laboratory of the Instrumental Analysis Center for Chemistry, Tohoku University.

Typical experimental procedure for preparation of vinyl selenoxide

Phenyl vinylselenoxide 3. To a stirred solution of vinylmagnesium bromide (18 ml, 18 mmol, 1.0 M solution in THF) was dropwisely added a solution of diphenyl diselenide (2.8 g, 9.0 mmol) in THF (35 ml) at 0°C for 30 min under nitrogen atmosphere. After being warmed to ambient temperature, the reaction mixture was stirred overnight. The reaction was quenched by addition of 1 M HCl solution and washed with 1 M NaOH solution, water and brine. After air oxidation of the combined aqueous solution, which was extracted with ethyl acetate five times. The combined organic layers were dried over anhydrous Na_2SO_4. After removal of the solvent in vacuo, purification by flash silica gel column chromatography gave diphenyl diselenide (1.22 g, 44%) and phenyl vinylselenide (1.50 g, 91%) as colorless oil which had: ν_{max}/cm^{-1} (neat) 3073, 3059, 2999, 1580, 1478, 1439, 1072, 1022, 957, 887, 737 and 690; ^{1}H NMR (200 MHz) δ (ppm) 5.54 (d, 1H, J=16.9 Hz), 5.78 (d, 1H, J=9.5 Hz), 6.84 (dd, 1H, J=16.9, 9.5 Hz), 7.31 (m, 3H) and 7.53 (m, 2H); m/z 184 (M^+, 100%), 183 (74), 182 (53), 157 (17), 155 (9), 104 (59), 103 (32), 78 (52), 77 (52), 51 (38) and 50 (18).

To a solution of phenyl vinylselenide (161 mg, 0.88 mmol) in dichloromethane (4 ml) was added *m*-CPBA (229 mg, 1.06 mmol, 80%) at 0°C. After being stirred for 15 min, the reaction mixture was diluted with dichloromethane followed by washing with 10% NaOH solution, brine and dried over anhydrous Na_2SO_4 twice. Evaporation of the solvent in vacuo afforded phenyl vinylselenoxide **3** (163 mg, 93%) spectroscopically pure as white oil which had: ^{1}H NMR (200 MHz) δ (ppm) 6.14 (dd, 1H, J=9.2, 1.1 Hz), 6.37 (dd, 1H, J=16.6, 1.1 Hz), 6.88 (dd, 1H, J=16.6, 9.2 Hz), 7.52 (m, 3H) and 7.71 (m, 2H).

Isopropenyl phenylselenoxide 26. Isopropenyl phenylselenide had 78%, colorless oil; ν_{max}/cm^{-1} (neat) 3071, 3059, 2961, 1615, 1580, 1478, 1437, 1177, 1022, 903, 868, 739 and 692; ^{1}H NMR (200 MHz) δ (ppm) 2.07 (s, 3H), 5.10 (s, 1H), 5.46 (d, 1H, J=1.4 Hz), 7.31 (m, 3H) and 7.56 (m, 2H); *m*/*z* 198 (M$^+$, 99%), 196 (50), 183 (34), 181 (18),158 (57), 156 (29), 117 (29), 115 (10), 78 (100), 77 (46), 51 (35) and 41 (30).

Isopropenyl phenylselenoxide **26** had 94–100%, white oil; ^{1}H NMR (200 MHz) δ (ppm) 1.90 (br s, 3H), 5.73 (m, 1H), 5.99 (m, 1H), 7.51 (m, 3H) and 7.70 (m, 2H).

Typical experimental procedure of bisannelation

4*S*-Isopropenyl-5,7-dimethyltricyclo[3.2.1.0^{2,7}]octane-6-one 12 and 7*S*-isopropenyl-1,3*S*-dimethyl-2-oxobicyclo[2.2.2]oct-5-ene 13. To a stirred solution of diisopropylamine (128 μl, 0.974 mmol) in THF (1.5 ml) was added a solution of *n*-BuLi (567 μl, 0.913 mmol, 1.61 M solution in *n*-hexane) at 0°C under nitrogen atmosphere. After being stirred for 15 min, a solution of 6-methylcarvone **11** (105 mg, 0.64 mmol) in THF (1.5 ml) was added and the resulting solution was stirred for 15 min. Subsequently, a solution of phenyl vinylselenoxide **3** (212 mg, 1.06 mmol) in THF (1.5 ml) was added and stirring was continued for 30 min. The reaction was quenched by addition of aq. NH_4Cl and diluted with ethyl acetate. The organic layer was washed with water and brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent in vacuo followed by MPLC separation afforded bicyclic compound **13** (28 mg, 23%) and tricyclic compound **12**[3b] (55 mg, 46%) in the order of elution.

The bicyclic compound **13** had: ν_{max} cm^{-1} 3040, 2974, 1713, 1640, 1452, 1379, and 901; ^{1}H NMR (200 MHz) δ (ppm) 1.14 (s, 3H), 1.17 (d, 3H, J=7.4 Hz), 1.56 (br s, 3H), 1.65–1.92 (m, 2H), 2.19 (qdd, 1H, J=7.4, 2.0, 2.0 Hz), 2.34 (dd, 1H, J=10.5, 8.2 Hz), 2.73 (m, 1H), 4.65 (br s, 1H), 4.75 (m, 1H), 5.92 (dd, 1H, J=8.0, 1.7 Hz) and 6.52 (dd, 3H, J=8.0, 6.5 Hz); ^{13}C NMR (50 MHz) δ (ppm) 13.2 (q), 16.0 (q), 20.9 (q), 25.8 (t), 37.7 (d), 44.7 (d), 52.2 (s), 53.5 (d), 113.9 (t), 137.1 (d), 137.5 (d), 145.3 (s) and 217.2 (s); *m*/*z* 190 (M$^+$, 25%), 134 (35), 122 (100), 119 (38), 94 (33), 91 (27), 79 (39) and 41 (22); HRMS $C_{13}H_{18}O$ requires 190.1358, found for 190.1364.The tricyclic compound **12** had: ν_{max}/cm^{-1} 3042, 2932, 1709, 1642, 1454, 1379, 1001 and 901; ^{1}H NMR (500 MHz) δ (ppm) 0.88 (s, 3H), 1.24 (s, 3H), 1.52 (br s, 3H), 1.68 (ddd, 1H, J=7.3, 2.6, 2.6 Hz), 1.83 (d, 1H, J=11.5 Hz), 1.90–1.98 (m, 3H), 2.31 (ddd, 1H, J=14.9, 10.6, 2.6 Hz), 2.59 (dd, 1H, J=10.6, 5.5 Hz), 4.60 (m, 1H) and 4.67 (br s, 1H); ^{13}C NMR (125 MHz) δ (ppm) 12.9 (q), 17.1 (q), 19.0 (q), 24.0 (t), 30.8 (d), 34.0 (d), 34.4 (s), 37.7 (t), 44.8 (s), 57.0 (d), 113.5 (t), 146.6 (s) and 216.1 (s); *m*/*z* 190 (M$^+$, 82%), 175 (25), 136 (100), 122 (27), 107 (31), 105 (32), 95 (47), 79 (41) and 67 (43); (Found: C, 81.61; H, 9.46; $C_{13}H_{18}O$ requires C, 82.06; H, 9.54%).

5-Benzyl-4*S*-isopropenyl-7-methyltricyclo[3.2.1.0^{2,7}]-octane-6-one 15. 12%, pale yellow oil; ν_{max} cm^{-1} 3092, 3060, 2932, 1713, 1642, 1454, 1381, and 902; ^{1}H NMR (200 MHz) δ (ppm) 1.22 (s, 3H), 1.61 (br s, 3H), 1.75–2.05 (m, 5H), 2.31 (ddd, 1H, J=14.6, 10.4, 2.4 Hz), 2.57 (d, 1H, J=14.3 Hz), 2.67 (dd, 1H, J=10.4, 5.6 Hz), 2.90 (d, 1H, J=14.3 Hz), 4.72 (br s, 1H), 4.79 (br s, 1H) and 7.12–7.26 (m, 5H); ^{13}C NMR (50 MHz) δ (ppm) 12.9 (q), 19.6 (q), 24.7 (t), 30.9 (d), 33.8 (t), 34.3 (d), 34.7 (s), 36.3 (t), 49.3 (s), 55.6 (d), 114.3 (t), 125.9 (d), 127.8 (d) ×2, 130.7 (d) ×2, 138.6 (s), 146.6 (s) and 215.2 (s); *m*/*z* 266 (M$^+$, 100%), 251 (34), 198 (55), 197 (15), 185 (17), 183 (18), 149 (41), 115 (14), 91 (66) and 41 (14); (Found: C, 85.90; H, 8.37; $C_{19}H_{22}O$ requires C, 85.67; H, 8.32%).

1-Benzyl-7*S*-isopropenyl-3*S*-methyl-2-oxobicyclo[2.2.2]-oct-5-ene 16. 8%, pale yellow oil; ν_{max}/cm^{-1} 3112, 3056, 2953, 1711, 1603, 1452, 1377 and 901; ^{1}H NMR (200 MHz) δ (ppm) 1.18 (d, 3H, J=7.4 Hz), 1.65 (br s, 3H), 1.70–1.90 (m, 2H), 2.20 (m, 1H), 2.32 (dd, 1H, J=10.8, 7.5 Hz), 2.69 (m, 1H), 2.85 (d, 1H, J=14.3 Hz), 3.25 (d, 1H, J=14.3 Hz), 4.76 (br s, 1H), 4.86 (br s, 1H), 6.07 (dd, 1H, J=8.2, 1.6 Hz), 6.47 (dd, 1H, J=8.2, 6.6 Hz) and 7.10–7.32 (m, 5H); *m*/*z* 266 (M$^+$, 13%), 210 (22), 198 (100), 183 (62), 120 (41), 119 (35), 91 (89), 77 (15) and 65 (12); HRMS $C_{19}H_{22}O$ requires 266.16706, found for 266.16624.

3,3,5-Trimethyltricyclo[3.2.1.0^{2,7}]octane-6-one 18. 6%, pale yellow oil which decomposed soon after NMR measurement; ^{1}H NMR (200 MHz) δ (ppm) 0.88 (s, 3H), 1.06 (s, 3H), 1.11 (m, 1H), 1.21 (s, 3H), 1.63 (m, 2H), 1.82 (dd, 1H, J=8.3, 5.3 Hz), 1.95 (br s, 2H) and 2.22 (m, 1H).

1,8,8-Trimethyl-3*R-phenylseleno-2-oxobicyclo[2.2.2]-oct-5-ene 19.** 2%, pale yellow oil; ν_{max}/cm^{-1} 3064, 2963, 1713, 1580, 1478, 1454, 1367, 1078 and 1034; ^{1}H NMR (200 MHz) δ (ppm) 0.99 (s, 3H), 1.08 (s, 3H), 1.22 (s, 3H), 1.33 (d, 1H, J=13.2 Hz), 1.50 (d, 1H, J=13.2 Hz), 2.72 (m, 1H), 3.81 (d, 1H, J=2.6 Hz), 5.93 (d, 1H, J=8.0 Hz), 6.56 (dd, 1H, J=8.0, 6.3 Hz), 7.28 (m, 3H) and 7.66 (m, 2H); *m*/*z* 320 (M$^+$, 24%), 319 (14), 318 (12), 163 (26), 135 (28), 122 (100), 107 (93), 91 (26), 77 (35), 55 (19) and 41 (20); HRMS $C_{17}H_{20}OSe$ requires 320.0679, found for 320.0680.

7-Benzyl-4,4,5-trimethyltricyclo[3.2.1.0^{2,7}]octane-6-one 21. 25%, pale yellow oil; ν_{max}/cm^{-1} 3088, 3030, 2971, 1723, 1680, 1454, 999 and 914; ^{1}H NMR (500 MHz) δ (ppm) 0.73 (s, 3H), 0.83 (s, 3H), 0.92 (s, 3H), 1.54 (dd, 1H, J=7.5, 3.5 Hz), 1.62 (dd, 1H, J=12.2, 3.8 Hz), 1.65 (dd, 1H, J=14.0, 3.5 Hz), 1.83–1.86 (m, 2H), 2.07 (d, 1H, J=12.2 Hz), 2.85 (d, 1H, J=14.8 Hz), 3.12 (d, 1H, J=14.8 Hz), 7.18 (m, 3H) and 7.25 (m, 2H); ^{13}C NMR (50 MHz) δ (ppm) 13.1 (q), 25.5 (q), 26.4 (q), 28.8 (d), 29.9 (d), 30.4 (t), 32.7 (t), 34.1 (t), 38.1 (s), 40.9 (s), 48.8

(s), 125.9 (d), 128.1 (d) ×2, 129.1 (d) ×2, 139.6 (s) and 215.4 (s); *m*/*z* 254 (M^+, 71%), 239 (38), 198 (100), 183 (30), 128 (15), 120 (22), 91 (49) and 41 (15); HRMS $C_{18}H_{22}O$ requires 254.1671, found for 254.1662.

6,6-Ethylenedioxy-3*R-methyltetracyclo[6.2.1.0^{2,1}.0^{3,8}]-dodecane-9-one 23.** 12%, pale yellow needles; mp 89–90°C; ν_{max}/cm^{-1} 2918, 1761, 1456, 1364, 1269 and 1089; ^{1}H NMR (500 MHz, C_6D_6, C_6H_6) δ (ppm) 0.71 (s, 3H), 1.18 (m, 1H), 1.19 (br d, 1H, *J*=10.5 Hz), 1.25 (d, 1H, *J*=10.5 Hz), 1.26 (dd, 1H, *J*=5.0, 5.0 Hz), 1.32 (ddd, 1H, *J*=13.5, 3.7, 3.7 Hz), 1.35 (d, 1H, *J*=14.2 Hz), 1.42 (dd, 1H, *J*=5.0, 5.0 Hz), 1.53 (ddd, 1H, *J*=13.5, 13.5, 4.0 Hz), 1.69 (m, 1H), 1.75 (ddd, 1H, *J*=13.5, 13.5, 3.7 Hz), 2.18 (br d, 1H, *J*=14.2 Hz), 3.47 (m, 1H), 3.56 (m, 1H), 3.64 (m, 1H) and 3.88 (m, 1H); ^{13}C NMR (125 MHz) δ (ppm) 18.0 (q), 19.5 (d), 20.5 (d), 28.8 (t), 30.96 (t), 30.99 (d), 31.01 (t), 33.1 (t), 43.4 (s), 49.7 (s), 63.8 (t), 64.3 (t), 108.6 (s) and 212.1 (s); ^{13}C NMR (125 MHz, C_6D_6, C_6H_6) δ (ppm) 18.1 (q), 18.8 (d), 20.4 (d), 28.6 (t), 30.5 (d), 31.3 (t), 32.2 (t), 33.0 (t), 43.2 (s), 49.7 (s), 64.0 (t), 64.3 (t), 108.7 (s) and 208.9 (s); *m*/*z* 234 (M^+, 19%), 206 (7), 178 (4), 139 (5), 105 (9), 99 (100), 91 (10), 86 (30), 77 (6) and 55 (8); HRMS $C_{14}H_{18}O_3$ requires 234.1256, found for 234.1262.

6,6-Ethylenedioxy-3*R,7*S**-dimethyltetracyclo-[6.2.1.0^{2,1}.0^{3,8}]dodecane-9-one 25.** 12%, pale yellow needles; mp 115–116°C; ν_{max}/cm^{-1} 2967, 1748, 1462, 1273, 1113 and 1053; ^{1}H NMR (500 MHz) δ (ppm) 1.06 (s, 3H), 1.07 (d, 3H, *J*=7.0 Hz), 1.38 (ddd, 1H, *J*=14.2, 14.2, 3.7 Hz), 1.44 (dd, 1H, *J*=5.1, 5.1 Hz), 1.53–1.61 (m, 2H), 1.63 (dd, 1H, *J*=11.0, 1.8 Hz), 1.75 (ddd, 1H, *J*=14.2, 3.6, 3.6 Hz), 1.89 (q, 1H, *J*=7.0 Hz), 1.90 (br d, 1H, *J*=11.0 Hz), 1.94 (m, 1H), 2.00 (dd, 1H, *J*=5.1, 5.1 Hz), 3.85 (m, 1H), 3.91 (m, 1H), 3.96 (m, 1H) and 4.13 (m, 1H); ^{13}C NMR (125 MHz) δ (ppm) 8.6 (q), 18.0 (q), 19.2 (d), 20.7 (d), 30.9 (t), 31.3 (t), 31.4 (d), 32.0 (t), 35.7 (t), 44.4 (s), 52.5 (s), 64.6 (t), 65.7 (t), 110.6 (s) and 211.9 (s); *m*/*z* 248 (M^+, 23%), 220 (7), 139 (9), 119 (8), 105 (9), 99 (100), 91 (11), 87 (11), 86 (30) and 55 (9); HRMS $C_{15}H_{20}O_3$ requires 248.1413, found for 248.1404.

4*S*-Isopropenyl-1,5,7-trimethyltricyclo[3.2.1.0^{2,7}]octane-6-one 27. 40%, pale yellow oil; ν_{max}/cm^{-1} 3081, 2971, 1709, 1642, 1452, 1379, 1007 and 901; ^{1}H NMR (200 MHz) δ (ppm) 0.89 (s, 3H), 1.16 (s, 3H), 1.23 (s, 3H), 1.51 (br s, 3H), 1.70–1.93 (m, 3H), 2.28 (ddd, 1H, *J*=14.7, 10.3, 2.5 Hz), 2.57 (dd, 1H, *J*=10.3, 5.9 Hz), 4.60 (m, 1H) and 4.68 (br s, 1H); *m*/*z* 204 (M^+, 35%), 136 (83), 121 (65), 109 (43), 108 (96), 95 (100), 93 (68), 91 (47) and 41 (53); HRMS $C_{14}H_{20}O$ requires 204.15141, found for 204.14973.

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References

1. (a) Hagiwara, H. *J. Synth. Org. Chem., Jpn.* **1992**, *50*, 713. (b) Ho, T.-L. In *Tandem Organic Reactions*, John Wiley & Sons: New York, 1992. (c) Tietze, L. F.; Beifuss, U. *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 131. (d) Ihara, M.; Fukumoto, K. *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 1010. (e) Posner, G.H. *Chem. Rev.* **1986**, *86*, 831. (f) Ihara, M.; Fukumoto, K. *J. Synth. Org. Chem., Jpn.* **1986**, *44*, 96.

2. (a) Takaoka, D.; Tani, H.; Matsuo, A. *J. Chem. Research (S)* **1988**, 130. (b) Asakawa, Y.; Toyota, M.; Ueda, A.; Tori, M.; Fukazawa, Y. *Phytochemistry* **1991**, *30*, 3037. (c) Wu, C.-L.; Chang, S.-J. *Phytochemistry* **1992**, *31*, 2150. (d) Wei, H.-C.; Ma, S.-J.; Wu, C.-L. *Phytochemistry* **1995**, *39*, 91.

3. (a) Cory, R. M.; Chan, D. M. T.; Naguib, Y. M. A.; Rastall, M. H.; Renneboog, R. M. *J. Org. Chem.* **1980**, *45*, 1582. (b) Cory, R. M.; Bailey, M. D.; Tse, D. W. C. *Tetrahedron Lett.* **1990**, *31*, 6839.

4. Cory, R. M.; Renneboog, R. M. *J. Chem. Soc., Chem. Commun.* **1980**, 1081.

5. Cory, R. M.; Anderson, P. C.; McLaren, F. R.; Yamamoto, B. R. *J. Chem. Soc., Chem. Commun.* **1981**, 73.

6. Hagiwara, H.; Kodama, M.; Uda, H. *J. Chem. Soc., Perkin Trans. 1* **1980**, 963.

7. Hagiwara, H.; Abe, F.; Uda, H. *J. Chem. Soc., Perkin Trans. 1* **1993**, 2651.

8. Spitzner, D.; Braun, N. A. *Tetrahedron Lett.* **1996**, *37*, 9187 and earlier references cited therein.

9. Shimizu, M.; Kuwajima, I. *J. Org. Chem.* **1980**, *45*, 2921 and references cited therein.

10. Our recent efforts in this area since Ref 1a: (a) Hagiwara, H.; Akama, T.; Okano, A.; Uda, H. *J. Chem. Soc., Perkin Trans. 1* **1993**, 2173. (b) Hagiwara, H.; Kon-no, M.; Nakano, T.; Uda, H. *J. Chem. Soc., Perkin Trans. 1* **1995**, 777. (c) Hagiwara, H.; Okamoto, T.; Harada, N.; Uda, H. *Tetrahedron* **1995**, *51*, 9891. (d) Hagiwara, H.; Sato, K.; Suzuki, T.; Ando, M. *Tetrahedron Lett.* **1997**, *38*, 2103. (e) Hagiwara, H.; Yamada, Y.; Sakai, H.; Suzuki, T.; Ando, M. *Tetrahedron* **1998**, *54*, 10999.