Skeletal Rearrangement of 8-Methylenebicyclo[4.2.0]octan-2-ones with Mercury(II) Perchlorate

Kiyomi Kakiuchi,* Tomoyuki Horiguchi, Koichi Minato, Yoshito Tobe,† and Hideo Kurosawa

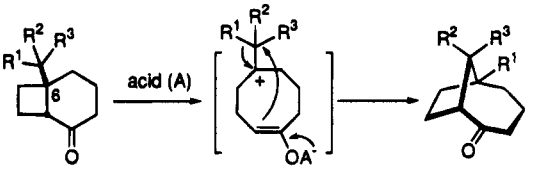
Department of Applied Chemistry, Faculty of Engineering, Osaka University, Suita, Osaka 565, Japan

Received April 13, 1995[⊗]

Skeletal rearrangement of C6-substituted 8-methylenebicyclo[4.2.0]octan-2-ones **1a–d** and **16** with mercury(II) perchlorate was examined, and the remarkable substituent effect on the rearrangement was elucidated. Reactions of the ketones **1a** and **1b** having methyl and ethyl groups with $Hg(ClO_4)_2 \cdot 3H_2O$ gave the bicyclo[2.2.2]octanones **2a,b** and **3a,b** along with a small amount of the bicyclo[3.3.1]nonanones **4a,b**, respectively. The yield of the bicyclo[3.3.1] ketone **4c** increased in the reaction of the isopropyl derivative **1c**. The *tert*-butyl derivative **1d** afforded the bicyclo[3.3.1]-nonanone **4d** as a major product together with a mixture of the bicyclo[2.2.2]octanones **2d** and **3d**. The remarkable substituent effect is explained based on the stability of the conformers **7** and **10** of the postulated intermediate **6**. The intermediacy of **6** was verified by reaction of **6b** prepared independently under similar conditions. Similar treatment of the tricyclic ketone **16** yielded the bicyclo[3.3.1]nonanone **19** as a major product along with a small amount of the bicyclo[2.2.2] ketones **17** and **18**. The structures of products were determined by NMR spectral data including 2D ^{13}C-INADEQUATE spectrum of **19** and the X-ray crystallographic analysis of **4d**. (±)-Desdimethyldihydroclovene (**22**) was easily synthesized from **19** via radical deoxygenation followed by transformation of the tertiary hydroxyl group to the methyl group.

Introduction

Recently we found that the new acid-catalyzed rearrangement of the C6-substituted bicyclo[4.2.0]octan-2-ones proceeds through fission of the central cyclobutane bond to give the bicyclo[4.2.1]nonanones and that the reactivity is influenced by the C6 substituent (eq 1).[1] Thus, reactions of the ketones having *t*-Bu ($R^1 = R^2 = R^3$ = Me) and *i*-Pr (R^1 = H, $R^2 = R^3$ = Me) groups at C6 with $AlCl_3$ gave the corresponding bicyclic ketones in almost quantitative yield, while the rearrangement of the ethyl ($R^1 = R^2$ = H, R^3 = Me) derivative was more sluggish and the methyl ($R^1 = R^2 = R^3$ = H) derivative gave no rearranged product. As an extension of this study, we have recently examined the acid-catalyzed rearrangement of bicyclo[4.2.0]octanones having an exo methylene moiety at C8 such as ketones **1a–d** and **16**[2] and applied the skeletal transformation as a pivotal step to the total synthesis of the diterpenoid, tetramethylmediterraneol B.[3] Fetizon and co-workers reported a different type of cyclobutane ring opening for the ketone **1a** using mercury(II) perchlorate ($Hg(ClO_4)_2$).[4] These results encouraged us to examine skeletal rearrangement of **1b–d** and **16** with $Hg(ClO_4)_2$, and here we disclose the outstanding effect of C6 substituent on the rearrangement. Also reported is the transformation of the rearranged product **19** to (±)-desdimethyldihydroclovene (**22**),[5] which is the nordimethyl and hydrogenated derivative of clovene (**23**).[6]



(1)

Results and Discussion

In order to examine the substituent effect, reactions of bicyclic ketones **1a–d** with 2.5 equiv of $Hg(ClO_4)_2 \cdot 3H_2O$ were carried out under conditions similar to those reported.[4] The results are summarized in Table 1. In the case of the methyl ketone **1a**, a new bicyclo[3.3.1] compound **4a** was isolated in 13% yield, along with the bicyclo[2.2.2]octanones **2a** and **3a** which had been reportedly be obtained in 60% yield (entry 1).[4] Similarly the ethyl derivative **1b** gave three products **2b**, **3b**, and **4b** in a ratio similar to that of **1a** (entry 2). Interestingly, the yield of the new-type product **4c** increased to 35% in the reaction of the isopropyl derivative **1c** (entry 3). In addition, the *tert*-butyl derivative **1d** gave the bicyclo-[3.3.1]nonanone **4d** as a major product (entry 4). Thus, with bulkier of the C6 substituents, yields of the bicyclo-[3.3.1] ketones **4** increased.

The structures of the bicyclo[2.2.2]octanones **2b–d** and **3b–d** were elucidated on the basis of comparison of the NMR spectra with those of **2a** and **3a**.[7] The signals (δ, 1.24) of the C6 methyl protons of **3a–d** appeared at higher field than those (δ, 1.39) of **2a–d** due to the shielding effect of the C2 carbonyl groups. Furthermore,

† Present address: Department of Chemistry, Faculty of Engineering Science, Osaka University, Toyonaka 560, Japan.

⊗ Abstract published in *Advance ACS Abstracts,* September 1, 1995.

(1) Kakiuchi, K.; Fukunaga, K.; Matsuo, F.; Ohnishi, Y.; Tobe, Y. *J. Org. Chem.* **1991**, *56*, 6742.

(2) Kakiuchi, K.; Horiguchi, T.; Minato, K.; Matsuo, F.; Tobe, Y.; Kurosawa, H., manuscripts in preparation.

(3) Kakiuchi, K.; Nakamura, I.; Matsuo, F.; Ogura, M.; Nakata, M.; Tobe, Y.; Kurosawa, H. *J. Org. Chem.* **1995**, *60*, 3318.

(4) Duc, D. K. M.; Fetizon, M.; Hanna, I.; Olesker, A. *Tetrahedron Lett.* **1981**, *22*, 3847.

(5) We term this analog desdimethyldihydroclovene.

(6) For previous syntheses of clovene, see: (a) Luts, A. W.; Reid, E. B. *J. Chem. Soc.* **1954**, 2265. (b) Doyle, P.; Maclean, I. R.; Parker, W.; Raphael, R. A. *Proc. Chem. Soc.* **1963**, 239. (c) Doyle, P.; Maclean, I. R.; Murray, R. D. H.; Parker, W.; Raphael, R. A. *J. Chem. Soc.* **1965**, 1344. (d) Becker, D.; Loewenthal, H. J. E. *Ibid.* **1965**, 1338. (f) Shultz, A. G.; Dittami, J. P. *J. Org. Chem.* **1983**, *48*, 2318. (g) Ackroyd, J.; Karpf, M.; Dreiding, A. S. *Helv. Chim. Acta* **1984**, *67*, 1963. (h) Funk, R. L.; Novak, P. M.; Abelman, M. M. *Tetrahedron Lett.* **1988**, *29*, 1493.

(7) Although the compound **3a** is known, the spectral data were not reported in the reference 4. Therefore, the data are presented in this paper.

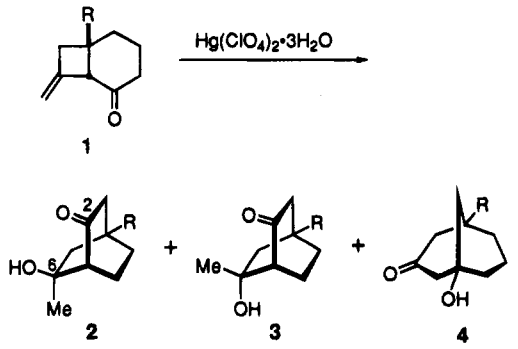
0022-3263/95/1960-6557$09.00/0

Table 1. Skeletal Rearrangement of 1a–d with $Hg(ClO_4)_2 \cdot 3H_2O$[a]

entry	substrate	reaction time (h)	products (yield (%))[b]
1	**1a**	3	**2a** (38),[c] **3a** (15),[c] **4a** (13)
2	**1b**	1	**2b** (50), **3b** (24), **4b** (13)
3	**1c**	2	**2c** (48), **3c** (15), **4c** (35)
4	**1d**	1	**2d** (25), **3d** (10), **4d** (61)

[a] All reactions were carried out using 100 mg of ketone and 2.5 equiv of $Hg(ClO_4)_2 \cdot 3H_2O$ in 4 mL of dry acetone at room temperature. [b] Isolated yield. [c] **2a** and **3a** were obtained in 60% combined yield under similar conditions, see ref 4.

Chart 1



a: R=Me; **b**: R=Et; **c**: R=*i*-Pr; **d**: R=*t*-Bu

the signals (δ, 28.6) of the methyl carbons of **2a–d** were observed at higher field than those (δ, 32.0) of **3a–d** because of the γ-effect. X-ray crystallographic analysis verified the structure of **4d** as 5-*tert*-butyl-1-hydroxybicyclo[3.3.1]nonan-3-one. The structures of the other bicyclo[3.3.1] derivatives **4a–c** were assigned based on the similarity of their spectroscopic data to those of **4d**.

The plausible reaction mechanism leading to these products is shown in Scheme 1, taking into account the pathways proposed by Fetizon.[4] Oxymercuration of the exo methylene double bond forms an intermediate **5** and then the cyclobutane ring opening proceeds with assistance from the C2 carbonyl group to give a diketone **6** which is considered to exist in two stable chair conformers **7** and **10**.[8] From conformer **7** having the R substituent located at the axial position, two possible enolates **8** and **9** are formed and conversions of **8** and **9** to the other conformers **11–13** followed by C–C bond formation lead to the products **2–4**. From conformer **10** where the R group is located at the equatorial position, the enolates **11–13** are produced directly. The remarkable substituent effect of C6 alkyl group on the skeletal rearrangement is reasonably interpreted by difference of the thermodynamic stability between the conformers **7** and **10**. The heats of formation ($\Delta H_f°$) of the individual conformers **7a–d** and **10a–d** calculated by MM2 are shown in Table 2.[9] With *tert*-butyl group at C3, the conformation **10d** (R = *t*-Bu) is more stable than **7d**. The enolate **13d** is kinetically formed from **10d** and the C–C bond formation proceeds to produce the bicyclo[3.3.1] compound **4d** as a major product. On the other hand, in the case of methyl and ethyl groups at C3, the conformations **7a,b** (R = Me, Et) are more stable than **10a,b** and are transformed to the enolates **8a,b** and **9a,b**. However, the conversions of the kinetically preferred enolates **9a,b** to **13a,b** are less likely, since the more bulky substituents in **13a,b** are located at the axial position. Therefore the thermodynamically more stable enolates **8a,b** are produced to give the bicyclo[2.2.2] compounds **2a,b** and **3a,b** through the conformational changes to the half chair forms **11a,b** and **12a,b**. The increasing yield of **4c** from the isopropyl derivative **1c** is explained by increase in existence of the conformer **10c** (R = *i*-Pr), whose heat of formation is almost equal to the other conformer **7c**. The predominant formation of **2** over **3** may be caused by the steric hindrance in the conformer **12** as shown in Scheme 1.

In order to verify the intermediacy of the diketone **6**, we synthesized the ketone **6b** by conjugate addition[10] of allylcopper reagent to 3-ethylcyclohexenone **14**[11] followed by Wacker oxidation. Thus reaction of **14** with allylcopper·$MgBr_2$·SMe_2 and TMSCl at −78 °C gave the ketone **15** although the yield was very low (16%, 45% conversion). Treatment of **15** with $PdCl_2$ and CuCl bubbling a stream of oxygen furnished **6b** in 78% yield. Reaction of **6b** under conditions similar to those used in the reaction of **1b** afforded **2b** (56%), **3b** (23%), and **4b** (10%) whose ratio and yields were almost same as those obtained from **1b** (entry 2 in Table 1). We, therefore, can postulate the diketone **6** as a key intermediate in this skeletal rearrangement.

Similar reaction of the tricyclic ketone **16** gave the trimethylenebicyclo[3.3.1]nonanone **19** in 61% yield along with the bicyclo[2.2.2]octanones **17** and **18** in 11% and 7% yields, respectively. The structure of **19** was determined unambiguously by 2D ^{13}C-INADEQUATE spectrum, and those of **17** and **18** were assigned by comparison of the chemical shifts of the methyl protons and carbons in NMR spectra as described above. In this case, the [3.3.1] ketone **19** was obtained as a major product, although a conformer ($\Delta H_f°$ = −100.02 kcal/mol, calculated by MM2[9]) analogous to **7** is more stable than the other one ($\Delta H_f°$ = −98.80 kcal/mol) analogous to **10**, like the methyl and ethyl derivatives **1a,b**. At present, we do not have any reasonable explanation why **19** was obtained in preference to **17** and **18**. It is noted that the ketone **19** ($\Delta H_f°$ = −105.37 kcal/mol, calculated by MM2[9]) is more stable than **17** ($\Delta H_f°$ = −101.49 kcal/mol) and **18** ($\Delta H_f°$ = −100.73 kcal/mol).[12]

Since the tricyclic compound **19** has the same skeleton as does the sesquiterpene clovene (**23**), transformation of **19** to (±)-desdimethyldihydroclovene (**22**) was undertaken via radical-mediated deoxygenation.[13] Toward this end, reduction of **19** with DIBALH in ether at 0 °C followed by selective esterification of phenyl chlorothionoformate in pyridine gave the monothionocarbonate **20** as the sole product in 85% overall yield. Radical reduction of **20** with Bu_3SnH in the presence of AIBN in toluene at reflux afforded the alcohol **21** quantitatively. Finally heating of **21** with trimethylaluminum (Me_3Al)[14] in hexane–benzene in a sealed tube at ca. 180 °C for 22 h furnished the hydrocarbon **22** in 44% yield (54% conversion).

(8) While we could not isolate any diketones **6**, such diketones were obtained in some cases, see reference 4.

(9) Allinger, N. L. *QCPE No. MM2 (85).*

(10) Lipshutz, B. H.; Hackmann, C. *J. Org. Chem.* **1994**, *59*, 7437.

(11) Dauben, W. G.; Shaffer, G. W.; Vietmeyer, N. D. *J. Org. Chem.* **1968**, *33*, 4060.

(12) Reaction of a small amount of the tricyclic ketone **17** under conditions similar to those used in the reaction of **16** gave a mixture of **17** and **18** for 4 h; formation of the ketone **19** was observed by GC-MS analysis after 3 days. Similar treatments of **2c,d** for 3 days, however, gave only mixtures of **2c,d** and **3c,d**, respectively.

(13) Robins, M. J.; Wilson, J. S. *J. Am. Chem. Soc.* **1981**, *103*, 932. Robinson, M. J.; Wilson, J. S. Hansske, F. *J. Am. Chem. Soc.* **1983**, *105*, 4059.

(14) Meisters, A.; Mole, T. *J. Chem. Soc., Chem. Commun.* **1972**, 595. Harney, D. W.; Meisters, A.; Mole, T. *Aust. J. Chem.* **1974**, *27*, 1639.

Scheme 1

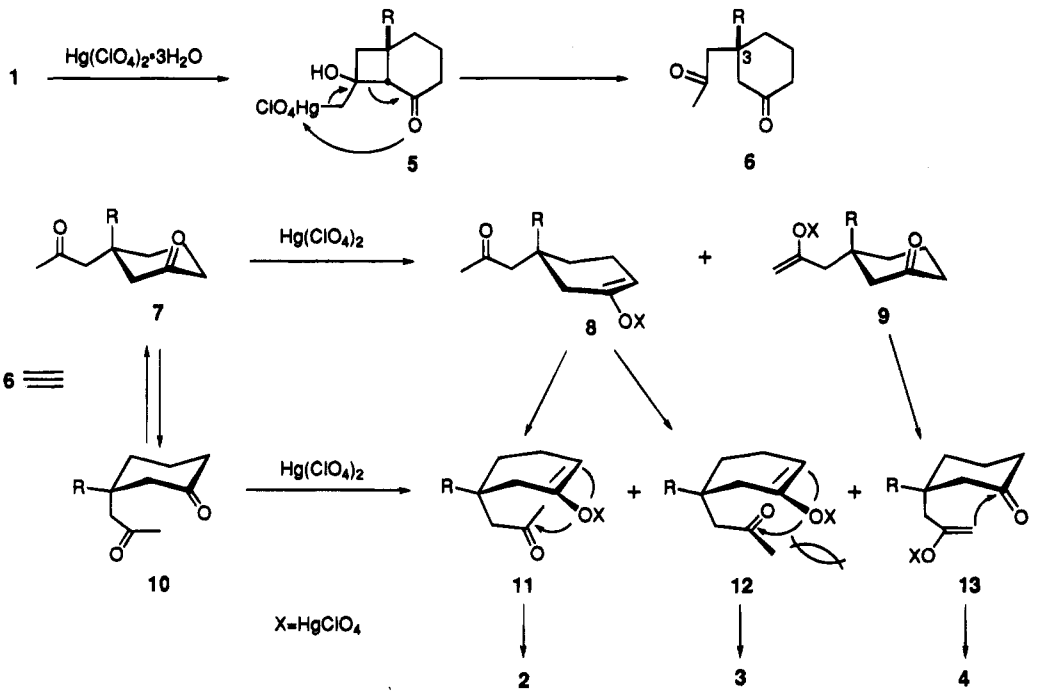


Table 2. Heats of Formation of 7a–d and 10a–d[a]

conformer	$\Delta H_f°$ (kcal/mol)	conformer	$\Delta H_f°$ (kcal/mol)
7a	−105.57	**10a**	−104.57
7b	−109.36	**10b**	−108.24
7c	−112.44	**10c**	−112.23
7d	−113.48	**10d**	−116.71

[a] Calculated by MM2.

Chart 2

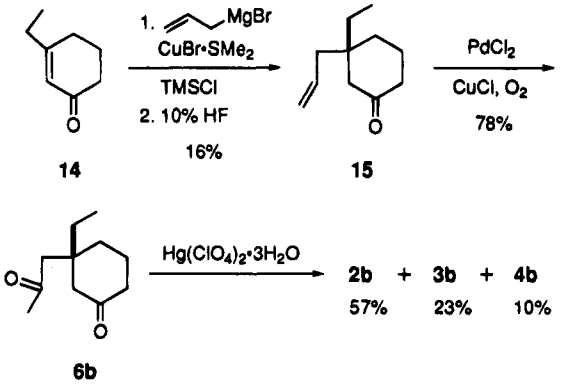
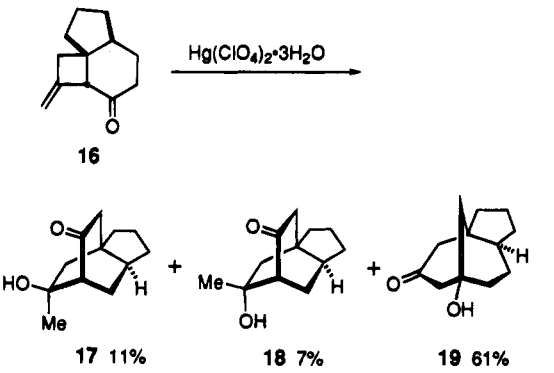


Chart 3



In summary, we have found the outstanding substituent effect of the C6 alkyl groups on skeletal rearrangement of 8-methylenebicyclo[4.2.0]octanones **1a–d** using $Hg(ClO_4)_2$. Furthermore, the convenient synthesis of desdimethyldihydroclovene (**22**) was achieved from the major rearrangement product of the tricyclic ketone **16**.

Experimental Section

All melting points were uncorrected. Instruments for the measurement of spectra and the technique of chromatography techniques were the same as those used in previous work.[1,3] Ketones **1a** was prepared according to the literature.[4] Ketones **1d**[3] and **16**[15] were prepared as described previously. *Mercury(II) perchlorate trihydrate is highly toxic and should be handled carefully.*

(1*R,6*S**)-6-Ethyl-8-methylenebicyclo[4.2.0]octan-2-one (1b) and (1*R**,6*R**)-6-Ethyl-7-methylenebicyclo[4.2.0]-octan-2-one (24).** A solution of **14**[11] (4.00 g, 30.2 mmol) and allene (ca. 40 mL) in dry CH_2Cl_2 (170 mL) was irradiated at −78 °C for 3.5 h in a Pyrex vessel with a 500-W high-pressure mercury lamp. Excess allene and the solvent were evaporated *in vacuo*, and the residue was chromatographed on SiO_2 (elution with ether/hexane, 3:97) to give **1b** (2.46 g) and two fractions of a mixture of **1b** and the head to tail adduct **24** (2.07 g and 0.23 g, which contain **1b** as a major and a minor component, respectively) in 86% combined yield. The stereochemistry of **1b** and the other adduct was determined as described previously.[3] **1b**: colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.90 (dd, J = 5.4, 2.7 Hz, 1H), 4.89 (dd, J = 5.0, 2.4 Hz, 1H), 3.21 (d, J = 2.6 Hz, 1H), 2.57–2.46 (m, 3H), 2.13 (m, 1H), 2.01 (m, 1H), 1.83 (m, 1H), 1.70 (m, 1H), 1.58 (q, J = 7.3 Hz, 2H), 1.53 (m 1H), 0.87 (t, J = 7.4 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 209.9 (s), 141.6 (s), 108.6 (t), 59.8 (d), 40.0 (t), 39.4 (s), 38.9 (t), 34.2 (t), 31.9 (t), 19.2 (t), 8.3 (q); IR (film) 1700, 1660 cm^{-1}; MS m/e (rel intensity) 164 (M^+, 14), 135 (44), 125 (100); HRMS calcd for $C_{11}H_{16}O$ 164.1202, found 164.1178. **24**: colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.87 (m, 1H), 4.83 (m, 1H), 3.01 (m, 1H), 2.67–2.49 (m, 3H), 2.17 (m, 1H), 2.05-1.76 (m, 3H), 1.63–1.58 (m, 2H), 1.46 (m, 1H), 0.92 (t, J = 7.4 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 214.6 (s), 152.7 (s), 105.5 (t), 53.2 (s), 46.7 (d), 39.4 (t), 32.7 (t), 32.6 (t), 31.7

(15) Kakiuchi, K.; Ue, M.; Tsukahara, H.; Shimizu, T.; Miyao, T.; Tobe, Y.; Odaira, Y.; Yasuda, M.; Shima, K. *J. Am. Chem. Soc.* **1989**, *111*, 3707.

Chart 4

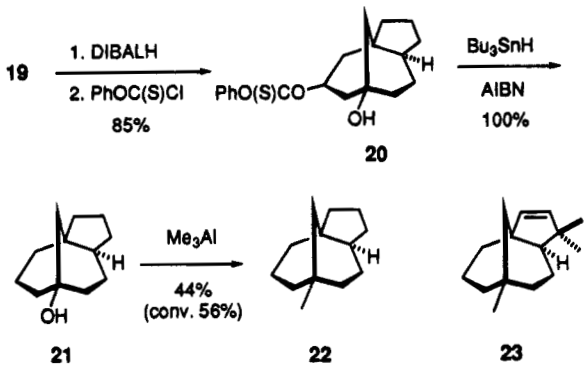
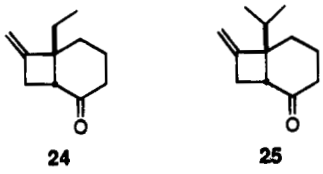


Chart 5



(t), 20.0 (t), 8.4 (q); IR (film) 1700, 1660 cm^{-1}; MS *m/e* (rel intensity) 164 (M^+, 50), 149 (41), 135 (100); HRMS calcd for $C_{11}H_{16}O$ 164.1202, found 164.1229.

(1*R,6*S**)-6-Isopropyl-8-methylenebicyclo[4.2.0]octan-2-one (1c) and (1*R**,6*S**)-6-Isopropyl-7-methylenebicyclo-[4.2.0]octan-2-one (25).** Irradiation of 3-isopropylcyclohex-2-en-1-one[16] (7.30 g, 52.8 mmol) and allene (ca. 40 mL) in dry CH_2Cl_2 (170 mL) at −78 °C for 5 h as described above gave **1c** (5.05 g) and two fractions of a mixture of **1c** and the head to tail adduct **25** (3.49 g and 0.64 g which contain **1c** as a major and a minor component, respectively) in 89% combined yield after column chromatography on SiO_2 (elution with ether/hexane, 3:97). **1c**: colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 4.89−4.86 (m, 2H), 3.25 (m, 1H), 2.63−2.51 (m, 3H), 2.09−2.01 (m, 2H), 1.84 (m, 1H), 1.74 (m, 1H), 1.61 (m, 1H), 1.50 (m, 1H), 0.86 (d, *J* = 6.8 Hz, 3H), 0.82 (d, *J* = 6.8 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 209.7 (s), 141.2 (s), 108.4 (t), 59.4 (d), 42.5 (s), 40.3 (t), 38.8 (t), 37.7 (d), 27.5 (t), 18.8 (t), 16.5 (q), 16.2 (q); IR (film) 1700, 1660 cm^{-1}; MS *m/e* (rel intensity) 178 (M^+, 45), 163 (83), 135 (100), 107 (96); HRMS calcd for $C_{12}H_{18}O$ 178.1358, found 178.1374. **25**: colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 4.91−4.86 (m, 2H), 2.99 (m, 1H), 2.70 (dd, *J* = 11.3, 5.3 Hz 1H), 2.58−2.50 (m, 2H), 2.12 (m, 1H), 2.01−1.86 (m, 2H), 1.84−1.67 (m, 2H), 1.49 (td, *J* = 13.2, 3.9 Hz, 1H), 0.95 (d, *J* = 6.8 Hz, 3H), 0.93 (d, *J* = 6.8 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 214.8 (s), 152.4 (s), 106.5 (t), 56.5 (s), 45.7 (d), 39.4 (t), 34.9 (d), 32.7 (t), 28.0 (t), 19.7 (t), 17.2 (q), 17.0 (q); IR (film) 1700, 1660 cm^{-1}; MS *m/e* (rel intensity) 178 (M^+, 22), 163 (59), 135 (100), 107 (53); HRMS calcd for $C_{12}H_{18}O$ 178.1358, found 178.1341.

General Procedure of Skeletal Rearrangement of Ketones 1a−d and 16 with $Hg(ClO_4)_2$. To a stirred solution of ketone (100 mg) in dry acetone (2 mL) was added a solution of $Hg(ClO_4)_2 \cdot 3H_2O$ (2.5 equiv) in dry acetone (2 mL) at rt under argon. The progress of the reaction was monitored by GLC. Saturated $NaHCO_3$ solution was added, and the mixture was extracted with ether. The combined extracts were dried over $MgSO_4$ and concentrated *in vacuo*. The products were isolated by flash chromatography on SiO_2 (elution with ether/hexane, 40:60−80:20). The results for bicyclic ketones are summarized in Table 1.

(1*R,4*S**,6*S**)-4-Ethyl-6-hydroxy-6-methylbicyclo[2.2.2]-octan-2-one (2b):** white solid; mp 93−95 °C; ^1H NMR (600 MHz, $CDCl_3$) δ 2.51 (bs, 1H), 2.21−2.18 (m, 2H), 1.93 (dd, *J* = 18.7, 2.7 Hz, 1H), 1.81−1.69 (m, 2H), 1.64 (d, *J* = 14.0 Hz, 1H), 1.48 (dd, *J* = 14.0, 2.6 Hz, 1H), 1.39 (s, 3H), 1.35−1.28 (m, 4H), 0.83 (t, *J* = 7.4 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 216.2 (s), 72.0 (s), 55.7 (d), 46.7 (t), 46.2 (t), 36.6 (s), 32.2 (t), 29.0 (t), 28.6 (q), 20.2 (t), 7.9 (q); IR (film) 3360, 1700 cm^{-1}; MS *m/e* (rel intensity) 182 (M^+, 24), 153 (100), 124 (85), 107 (43), 93 (90); HRMS calcd for $C_{11}H_{18}O_2$ 182.1307, found 182.1300.

(1*R,4*R**,6*S**)-4-Isopropyl-6-hydroxy-6-methylbicyclo-[2.2.2]octan-2-one (2c):** white solid; mp 106−107 °C; ^1H NMR (600 MHz, $CDCl_3$) δ 2.50 (bs, 1H), 2.23−2.19 (m, 2H), 1.97 (dd, *J* = 18.5, 2.9 Hz, 1H), 1.78−1.69 (m, 2H), 1.66 (dd, *J* = 14.0, 3.0 Hz, 1H), 1.51−1.32 (m, 7H, containing s at 1.39), 0.85 (dd, *J* = 6.9, 1.4 Hz, 6H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 216.4 (s), 71.9 (s), 55.5 (d), 44.3 (t), 44.2 (t), 39.3 (s), 34.5 (d), 28.6 (q), 26.6 (t), 20.2 (t), 17.3 (q), 17.1 (q); IR (film) 3360, 1700 cm^{-1}; MS *m/e* (rel intensity) 196 (M^+, 6), 153 (100), 138 (52), 93 (60); HRMS calcd for $C_{12}H_{20}O_2$ 196.1464, found 196.1459.

(1*R,4*R**,6*S**)-4-*tert*-Butyl-6-hydroxy-6-methylbicyclo-[2.2.2]octan-2-one (2d):** white solid; mp 152−153 °C; ^1H NMR (600 MHz, $CDCl_3$) δ 2.30 (dd, *J* = 18.2, 3.4 Hz, 1H), 2.20 (t, *J* = 3.0 Hz, 1H), 2.13 (bs, 1H), 2.08 (dd, *J* = 18.2, 3.0 Hz, 1H), 1.75−1.71 (m, 3H), 1.57 (dd, *J* = 14.0, 2.9 Hz, 1H), 1.52 (m, 1H), 1.42−1.36 (m, 4H, containing s at 1.39), 0.86 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 216.3 (s), 72.0 (s), 55.0 (d), 42.8 (t), 41.8 (t), 41.6 (s), 33.8 (s), 28.7 (q), 25.3 (q, 3C), 24.3 (t), 20.5 (t); IR (film) 3370, 1700 cm^{-1}; MS *m/e* (rel intensity) 210 (M^+, 8), 153 (100), 135 (38), 107 (32), 93 (39); HRMS calcd for $C_{13}H_{22}O_2$ 210.1620, found 210.1600.

(1*R,4*S**,6*R**)-4,6-Dimethyl-6-hydroxybicyclo[2.2.2]-octan-2-one (3a):**[4,7] colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 2.32 (m, 1H), 2.23 (t, *J* = 2.6 Hz, 1H), 2.04 (dd, *J* = 18.9, 3.3 Hz, 1H), 1.93 (dd, *J* = 19.0, 2.7 Hz, 1H), 1.71−1.53 (m, 5H), 1.43 (m, 1H), 1.25 (s, 3H), 0.99 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 215.2 (s), 70.5 (s), 56.3 (d), 50.6 (t), 48.8 (t), 33.0 (s), 32.0 (q), 30.5 (t), 26.6 (q), 18.5 (t); IR (film) 3400, 1710 cm^{-1}; MS *m/e* (rel intensity) 168 (M^+, 16), 110 (100), 95 (35); HRMS calcd for $C_{10}H_{16}O_2$ 168.1151, found 168.1150.

(1*R,4*S**,6*R**)-4-Ethyl-6-hydroxy-6-methylbicyclo[2.2.2]-octan-2-one (3b):** colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 2.31 (m, 1H), 2.23 (m, 1H), 2.01 (dd, *J* = 18.9, 3.3 Hz, 1H), 1.90 (dd, *J* = 18.9, 2.6 Hz, 1H), 1.63−1.50 (m, 5H), 1.41 (m, 1H), 1.31 (q, *J* = 7.5 Hz, 2H), 1.24 (s, 3H), 0.83 (t, *J* = 7.6 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 215.6 (s), 70.4 (s), 56.5 (d), 48.1 (t), 46.4 (t), 36.1 (s), 32.3 (t), 32.0 (q), 27.8 (t), 18.3 (t), 7.8 (q); IR (film) 3400, 1710 cm^{-1}; MS *m/e* (rel intensity) 182 (M^+, 26), 153 (61), 124 (100), 95 (54); HRMS calcd for $C_{11}H_{18}O_2$ 182.1307, found 182.1295.

(1*R,4*R**,6*R**)-4-Isopropyl-6-hydroxy-6-methylbicyclo-[2.2.2]octan-2-one (3c):** colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 2.31 (m, 1H), 2.23 (t, *J* = 2.7 Hz, 1H), 2.02 (dd, *J* = 18.8, 3.4 Hz, 1H), 1.94 (dd, *J* = 18.8, 2.8 Hz, 1H), 1.67 (dd, *J* = 14.1, 3.4 Hz, 1H), 1.65−1.40 (m, 6H), 1.25 (s, 3H), 0.85 (d, *J* = 6.9 Hz, 6H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 215.7 (s), 70.4 (s), 56.2 (d), 45.6 (t), 44.6 (t), 38.7 (s), 34.6 (d), 32.0 (q), 25.1 (t), 18.3 (t), 17.2 (q), 17.1 (q); IR (film) 3400, 1710 cm^{-1}; MS *m/e* (rel intensity) 196 (M^+, 3), 153 (100), 138 (92), 95 (52); HRMS calcd for $C_{12}H_{20}O_2$ 196.1464, found 196.1441.

(1*R,4*R**,6*R**)-4-*tert*-Butyl-6-hydroxy-6-methylbicyclo-[2.2.2]octan-2-one (3d):** colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 2.29 (m, 1H), 2.23 (m, 1H), 2.11 (dd, *J* = 18.5, 3.5 Hz, 1H), 2.03 (dd, *J* = 18.6, 3.0 Hz, 1H), 1.77−1.65 (m, 2H), 1.62−1.35 (m, 4H), 1.25 (s, 3H), 0.86 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 215.9 (s), 70.6 (s), 55.7 (d), 43.4 (t), 42.5 (t), 40.9 (s), 33.8 (s), 32.0 (q), 25.2 (q, 3C), 23.0 (t), 18.6 (t); IR (film) 3450, 1710 cm^{-1}; MS *m/e* (rel intensity) 210 (M^+, 2), 153 (100), 135 (26), 111 (41), 43 (33); HRMS calcd for $C_{13}H_{22}O_2$ 210.1620, found 210.1637.

(1*R,5*R**)-5-Methyl-1-hydroxybicyclo[3.3.1]octan-3-one (4a):** colorless oil; ^1H NMR (600 MHz, $CDCl_3$) δ 2.55 (dt, *J* = 16.0, 2.3 Hz, 1H), 2.41 (d, *J* = 15.8 Hz, 1H), 2.21 (dt, *J* = 16.6, 2.1 Hz, 1H), 2.09 (d, *J* = 16.6 Hz, 1H), 1.84−1.75 (m, 3H), 1.68 (m, 1H), 1.60 (dt, *J* = 12.3, 2.7 Hz, 1H), 1.52−1.45 (m, 2H), 1.35−1.20 (m, 2H), 1.06 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 210.5 (s), 71.6 (s), 54.1 (t), 52.5 (t), 48.8 (t), 40.0 (t), 38.1 (t), 35.1 (s), 30.7 (q), 20.9 (t); IR (film) 3400, 1700 cm^{-1}; MS *m/e* (rel intensity) 168 (M^+, 6), 125 (34), 111 (100); HRMS calcd for $C_{10}H_{16}O_2$ 168.1151, found 168.1149.

(16) Sharma, M.; Ghatak, U. R.; Dutta, P. C. *Tetrahedron* **1963**, *19*, 985.

(1*R,5*R**)-5-Ethyl-1-hydroxybicyclo[3.3.1]octan-3-one (4b):** colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.56 (d, J = 16.0 Hz, 1H), 2.42 (d, J = 16.0 Hz, 1H), 2.19 (d, J = 16.6 Hz, 1H), 2.09 (d, J = 16.6 Hz, 1H), 1.84 (bs, 1H), 1.78 (d, J = 12.3 Hz, 2H), 1.69 (m, 1H), 1.56−1.47 (m, 3H), 1.42−1.25 (m, 3H), 1.20 (dt, J = 13.3, 4.7 Hz, 1H), 0.87 (t, J = 7.6 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 210.9 (s), 71.6 (s), 54.5 (t), 50.1 (t), 46.6 (t), 40.3 (t), 37.9 (s), 36.0 (t), 35.6 (t), 20.7 (t), 7.4 (q); IR (film) 3400, 1700 cm^{-1}; MS m/e (rel intensity) 182 (M^+, 47), 153 (23), 139 (21), 125 (100); HRMS calcd for $C_{11}H_{18}O_2$ 182.1307, found 182.1301.

(1*R,5*S**)-5-Isopropyl-1-hydroxybicyclo[3.3.1]octan-3-one (4c):** colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.56 (dt, J = 16.0, 2.3 Hz, 1H), 2.41 (d, J = 15.8 Hz, 1H), 2.23 (dt, J = 16.6, 2.2 Hz, 1H), 2.07 (d, J = 16.6 Hz, 1H), 1.94 (bs, 1H), 1.81−1.76 (m, 2H), 1.70 (m, 1H), 1.59−1.45 (m, 4H), 1.27 (m, 1H), 1.19 (m, 1H), 0.89 (d, J = 3.9 Hz, 3H), 0.88 (d, J = 4.0 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 211.3 (s), 71.7 (s), 54.5 (t), 47.6 (t), 45.0 (t), 40.3 (s), 40.2 (t), 37.9 (d), 32.6 (t), 20.5 (t), 16.9 (q), 16.7 (q); IR (film) 3390, 1700 cm^{-1}; MS m/e (rel intensity) 196 (M^+, 3), 153 (79), 139 (100), 111 (57), 93 (51); HRMS calcd for $C_{12}H_{20}O_2$ 196.1464, found 196.1470.

(1*R,5*S**)-5-*tert*-Butyl-1-hydroxybicyclo[3.3.1]octan-3-one (4d):** white solid; mp 107−108 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.52 (dt, J = 15.9, 2.1 Hz, 1H), 2.37 (d, J = 15.9 Hz, 1H), 2.32 (s, 1H), 2.25 (d, J = 16.8 Hz, 1H), 2.19 (dt, J = 16.7, 1.7 Hz, 1H), 1.81 (dt, J = 12.3, 2.5 Hz, 1H), 1.74 (dd, J = 12.3, 2.2 Hz, 1H), 1.68 (m, 1H), 1.63 (dt, J = 12.3, 2.5 Hz, 1H), 1.50 (dd, J = 13.2, 2.1 Hz, 1H), 1.47−1.35 (m, 2H), 1.22 (m, 1H), 0.88 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 211.9 (s), 71.7 (s), 54.3 (t), 46.1 (t), 42.5 (s), 40.9 (t), 40.0 (t), 35.4 (s), 30.3 (t), 25.1 (q, 3C), 20.6 (t), the signals were also assigned by 2D ^{13}C-INADEQUATE spectrum, see supporting information; IR (film) 3350, 1700 cm^{-1}; MS m/e (rel intensity) 210 (M^+, 47), 153 (91), 111 (100), 97 (55), 93 (88); HRMS calcd for $C_{13}H_{22}O_2$ 210.1620, found 210.1600.

(1*S,5*S**,7*R**,11*S**)-11-Hydroxy-11-methyltricyclo-[5.2.2.0^{1,5}]undecan-8-one (17):** white solid; mp 113−114 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.30 (dd, J = 19.1, 3.3 Hz, 1H), 2.16−2.09 (m, 2H), 1.99−1.89 (m, 3H), 1.83−1.64 (m, 4H), 1.60 (dd, J = 13.5, 3.3 Hz, 1H), 1.50 (m, 1H), 1.46−1.41 (m, 4H, containing s at 1.43), 1.36 (m, 1H), 1.26 (m, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 215.2 (s), 73.0 (s), 57.0 (d), 50.6 (t), 45.1 (s), 42.6 (t), 39.8 (d), 34.3 (t), 30.4 (t), 29.5 (q), 26.0 (t), 22.6 (t); IR (film) 3350, 1700 cm^{-1}; MS m/e (rel intensity) 194 (M^+, 25), 136 (100), 108 (24), 94 (33), 43 (32); HRMS calcd for $C_{12}H_{18}O_2$ 194.1307, found 194.1296.

(1*S,5*S**,7*R**,11*R**)-11-Hydroxy-11-methyltricyclo-[5.2.2.0^{1,5}]undecan-8-one (18):** colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.46 (m, 1H), 2.29 (dd, J = 19.0, 3.7 Hz, 1H), 2.25 (m, 1H), 2.07−1.94 (m, 2H), 1.80 (d, J = 13.9 Hz, 1H), 1.76−1.70 (m, 2H), 1.62 (dd, J = 13.9, 3.7 Hz, 1H), 1.58−1.30 (m, 6H), 1.26 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 215.7 (s), 71.4 (s), 57.2 (d), 51.1 (t), 44.1 (s), 43.1 (t), 39.2 (d), 34.6 (t), 31.6 (q), 30.5 (t), 25.6 (t), 22.4 (t); IR (film) 3400, 1710 cm^{-1}; MS m/e (rel intensity) 194 (M^+, 23), 136 (100), 107 (25); HRMS calcd for $C_{12}H_{18}O_2$ 194.1307, found 194.1300.

(1*R,5*S**,8*R**)-8-Hydroxytricyclo[6.3.1.0^{1,5}]dodecan-10-one (19):** white solid; mp 98−100 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.52 (dt, J = 15.9, 2.2 Hz, 1H), 2.42 (m, 3H containing t, J = 16.5 Hz), 2.08 (dt, J = 15.8, 2.1 Hz, 1H), 1.77 (dt, J = 12.4, 2.5 Hz, 1H), 1.74−1.41 (m, 12H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 210.7 (s), 71.9 (s), 54.5 (t), 52.2 (t), 44.3 (s), 43.1 (d), 42.2 (t), 39.0 (t), 35.2 (t), 28.0 (t), 22.3 (t), 20.1 (t); IR (film) 3400, 1700 cm^{-1}; MS m/e (rel intensity) 194 (M^+, 4), 137 (100), 124 (20); HRMS calcd for $C_{12}H_{18}O_2$ 194.1307, found 194.1330.

(3*S)-3-Ally-3-ethylcyclohexan-1-one (15).** Conjugate addition of allylic copper reagent was carried out according to the literature.[10] To a mixture of $CuBr{\cdot}SMe_2$ (1.64g, 8.0 mmol) and dry LiCl (339 mg, 8.0 mmol) was added dry THF (12 mL) at rt under argon. The mixture was stirred for 10 min at rt to yield a yellow homogeneous solution which was then cooled at −78 °C. To the solution was added a solution of allyl magnesium bromide in ether (1 M, 7.80 mL, 7.80 mmol) dropwise via syringe. The black mixture was stirred for another 10 min at −78 °C. To the mixture was added TMSCl (1.02 mL, 8.0 mmol) followed immediately by the neat addition of **14** (248 mg, 2.00 mmol). The mixture was stirred for 2 h at −78 °C before being quenched at −78 °C with a saturated aqueous NH_4OH/NH_4Cl solution (2:8). The mixture was extracted with ether, and the combined extracts were dried ($MgSO_4$). Evaporation of the solvent *in vacuo* gave the residue which was dissolved in THF (10 mL). To the solution was added 10% aqueous HF solution (2.5 mL) at rt. The mixture was stirred for 30 min, and a saturated $NaHCO_3$ solution was added. The mixture was extracted with ether, and the combined extracts were dried ($MgSO_4$). Evaporation of the solvent *in vacuo* followed by flash chromatography on SiO_2 gave **15** (52 mg, 16%, elution with ether/hexane, 5:95) and the recovered **14** (136 mg, 45% conversion, elution with ether/hexane, 15:85). **15**: colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 5.74 (m, 1H), 5.10−5.02 (m, 2H), 2.28 (t, J = 6.9 Hz, 2H), 2.15 (ABq, J = 13.6 Hz, $\Delta\nu_{AB}$ = 29.4 Hz, 2H), 2.06−1.98 (m, 2H), 1.91−1.80 (m, 2H), 1.63−1.58 (m, 2H), 1.31 (q, J = 7.4 Hz, 2H), 0.83 (t, J = 7.4 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 212.4 (s), 133.5 (d), 118.1 (t), 51.4 (t), 41.21 (s), 41.19 (t), 41.0 (t), 32.9 (t), 29.6 (t), 21.5 (t), 7.3 (q); IR (film) 3060, 1710, 1640, 910 cm^{-1}; MS m/e (rel intensity) 166 (M^+, 6), 125 (100), 55 (84); HRMS calcd for $C_{11}H_{18}O$ 166.1358, found 166.1366.

(3*S)-3-Ethyl-3-(2-oxopropyl)cyclohexan-1-one (6b).** A stream of oxygen was bubbled into a vigorously stirred mixture of **15** (31 mg, 0.19 mmol), $PdCl_2$ (33 mg, 0.19 mmol), CuCl (74 mg, 0.75 mmol), water (0.2 mL), and DMF (1.5 mL) at rt for 24 h. 5% HCl was added, and the mixture was extracted with ether. The combined extracts were washed with $NaHCO_3$ solution and brine and dried ($MgSO_4$). Evaporation of the solvent *in vacuo* followed by flash chromatography on SiO_2 (elution with ether/hexane, 30:70) gave **6b** (27 mg, 78%): colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.39 (ABq, J = 16.3 Hz, $\Delta\nu_{AB}$ = 61.7 Hz, 2H), 2.32 (ABq, J = 13.6 Hz, $\Delta\nu_{AB}$ = 124.3 Hz, 2H), 2.30 (t, J = 6.8 Hz, 2H), 2.14 (s, 3H), 1.92−1.82 (m, 3H), 1.67 (m, 1H), 1.53−1.43 (m, 2H), 0.83 (t, J = 7.5 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 211.8 (s), 207.6 (s), 51.2 (t), 48.5 (t), 41.3 (s), 40.9 (t), 32.7 (t), 32.4 (q), 30.0 (t), 21.6 (t), 7.6 (q); IR (film) 1720, 1710 cm^{-1}; MS m/e (rel intensity) 182 (M^+, 8), 153 (82), 125 (100), 124 (62), 111 (50), 55 (40), 43 (87); HRMS calcd for $C_{11}H_{18}O_2$ 182.1307, found 182.1302.

Reaction of 6b with $Hg(ClO_4)_2$. Reaction of **6b** (21 mg, 0.12 mmol) with $Hg(ClO_4)_2{\cdot}3H_2O$ as described above for 1 h gave **2b** (12 mg, 57%), **3b** (5 mg, 23%), and **4b** (2 mg, 10%).

(1*S,5*S**,8*R**)-8-Hydroxytricyclo[6.3.1.0^{1,5}]dodecan-10-yl Phenyl Thionocarbonate (20).** To a solution of **19** (77 mg, 0.39 mmol) in dry ether (2 mL) was added DIBALH (1.3 M in toluene, 1.60 mL, 2.3 mmol) at 0 °C under argon. After stirring for 2 h at rt, ice−water and cold NH_4Cl solution was added. The white precipitate was filtered off, and the filtrate was extracted with ether. The combined extracts were dried ($MgSO_4$) and concentrated *in vacuo* to give the crude alcohol (77 mg), which was used in the next reaction without purification.

To a stirred solution of the above product and DMAP (7.8 mg, 0.064 mmol) in pyridine (5 mL) was added phenyl chlorothionoformate (1.8 mL, 1.37 mmol) dropwise via syringe at 0 °C under argon. The mixture was stirred at 0 °C for 1 h and then at rt overnight. Water was added, and the mixture was extracted with ether. The combined extracts were dried ($MgSO_4$) and concentrated *in vacuo*. The residue was chromatographed on SiO_2 (elution with ether/hexane 20:80) gave **20** (90 mg, 85%) as a single isomer whose stereochemistry was not determined. **20**: yellow oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 (m, 2H), 7.28 (t, J = 7.5 Hz, 1H), 7.10 (d, J = 7.7 Hz, 2H), 5.65 (m, 1H), 2.18 (dd, J = 15.2, 1.6 Hz, 1H), 2.01 (m, 1H), 1.90−1.38 (m, 15H), 1.11 (d, J = 12.0 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.7 (s), 153.2 (s), 129.5 (d, 2C), 126.5 (d), 121.9 (d, 2C), 81.2 (d), 70.3 (s), 43.18 (s), 43.16(t), 43.0 (t), 41.9 (t), 41.2 (d), 40.7 (t), 35.6 (t), 32.3 (t), 23.7 (t), 21.4 (t); IR (film) 3400, 1580, 1290, 1180, 760, 680 cm^{-1}; MS m/e (rel intensity) 332 (M^+, trace), 179 (100), 161 (81); HRMS calcd for $C_{19}H_{24}O_3S$ 332.1447, found 332.1442.

(1*S,5*S**,8*R**)-Tricyclo[6.3.1.0^{1,5}]dodecan-8-ol (21).** To a solution of **20** (85 mg, 0.26 mmol) and AIBN (10.5 mg, 0.064 mmol) in toluene (10 mL) was added Bu_3SnH (0.38 mL, 1.45

mmol) dropwise at rt under argon. The mixture was heated at reflux for 2 h under argon and cooled. Evaporation of the solvent followed by column chromatography on SiO_2 (elution with ether/hexane, 20:80) to give **21** (46 mg, 100%) as a colorless oil: ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.84 (m, 1H), 1.78–1.31 (m, 18H), 1.05 (d, J = 11.7 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 71.3 (s), 44.5 (t), 44.3 (s), 41.5 (d), 41.7 (t), 40.3 (t), 37.7 (t), 35.7 (t), 32.8 (t), 26.3 (t), 22.3 (t), 21.6 (t); IR (film) 3350 cm^{-1}; MS m/e (rel intensity) 180 (M^+, 1), 137 (100), 123 (43), 110 (42); HRMS calcd for $C_{12}H_{20}O$ 180.1515, found 180.1510.

(1S*,5S*,8S*)-Tricyclo[6.3.1.0^{1,5}]dodecane (Desdimethyldihydroclovene) (22). A solution of **20** (43 mg, 0.24 mmol) in dry benzene (1 mL) was placed in a Pyrex tube (1 cm diameter). To the solution was added Me_3Al (19% in hexane, 455 mg) slowly at 0 °C under argon. After evolution of methane gas ceased, the tube was sealed and then heated at ca. 180 °C (oil bath temperature) for 22 h. The tube was cooled and the content was poured into ice cold 1 M aqueous HCl. The mixture was extracted with ether, and the combined extract was dried ($MgSO_4$). Evaporation of the solvent *in vacuo* at 0 °C followed by column chromatography gave **22** (22 mg, 44%, elution with pentane) and the recovered **21** (19 mg, conversion 56%, elution with ether/pentane, 40:60). **22**: colorless oil; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.79–1.71 (m, 3H), 1.61–1.23 (m, 14H), 1.08 (dt, J = 13.2, 5.5 Hz, 1H), 0.86 (s, 3H), 0.77 (d, J = 12.4 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 43.7 (t), 42.4 (t), 42.1 (d), 41.3 (s), 39.6 (t), 38.7 (t), 33.9 (t), 33.3 (t), 33.2 (q), 30.7 (s), 26.5 (t), 22.4 (t), 21.3 (t); MS m/e (rel intensity) 178 (M^+, 23), 163 (75), 135 (100); HRMS calcd for $C_{13}H_{22}$ 178.1722, found 178.1721.

X-ray Analysis of 4d. Recrystallized from ether–hexane. Crystal data: $C_{13}H_{22}O_2$, orthorhombic *Cbca*, a = 25.042(4) Å, b = 11.051 (5) Å, c = 8.944(5) Å, V = 2475(2) Å^3, Z = 8. Data were collected at 23 °C on a Rigaku AFC5R diffractometer with graphite monochromated Mo Kα radiation giving 3272 unique reflections. The structure was solved by a direct method (MITHRIL90) to yield R = 0.084, Rw = 0.054 for 1916 independent reflections with $I > 3.00\sigma(I)$.[17]

Acknowledgment. Thanks are due to the Instrumental Analysis Center, Faculty of Engineering, Osaka University, for assistance in obtaining NMR and mass spectra on JEOL JNM-GTX-400 and Bruker AM-600, and JEOL JMS-DX303 spectrometers, respectively.

Supporting Information Available: ^{1}H and ^{13}C NMR spectra of **1b,c**, **2b–d**, **3a–d**, **4a–d**, **6b**, **15**, **17–22**, **24**, and **25**, 2D ^{13}C-INADEQUATE spectra of **4d** and **19**, and an ORTEP drawing of **4d** (49 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO950707H

(17) The authors have deposited atomic coordinates for structure **4d** with the Cambridge Crystallographic Data Center. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Center, 12 Union Road, Cambridge, CB2 1EZ, UK.