[3,3]Sigmatropic Ring Expansion of Cyclic Thionocarbonates. VII.1) On the Formation of 8-Membered Thionocarbonates as the Intermediates

Shinya HARUSAWA, Sachiko TOMII, Chiaki TAKEHISA, Hirofumi OHISHI, Ryuji YONEDA, and Takushi KURIHARA*

Osaka University of Pharmaceutical Sciences, 2-10-65 Kawanohata, Matsubara, Osaka 580, Japan. Received February 19, 1992

In order to clarify the reaction mechanism of [3,3]sigmatropic ring expansion of cyclic thionocarbonates, the 8-membered thionocarbonates (6 and 7) were synthesized by treatment of the corresponding diol monothionocarbonates (5 and 13) with lithium bis(trimethylsilyl)amide. However, reaction of 7 with meta-chloroperbenzoic acid afforded an 8-membered carbonate (14) in a quantitative yield.

Keywords [3,3]sigmatropic ring expansion; 8-membered thionocarbonate; diol monothionocarbonate; lithium bis(trimethylsilyl)amide; meta-chloroperbenzoic acid; 8-membered carbonate

The exclusive (E)-selectivity of the double bond created by [3,3]sigmatropic rearrangement has been extensively used in organic synthesis. However, few studies on the opposite (Z)-selective [3,3]sigmatropic rearrangement have so far been reported. We have recently reported that treatment of a diol monothionocarbonate (1a) with base in tetrahydrofuran (THF) instantly gives a 10-membered thiolcarbonate (3a) containing a (Z)-double bond via [3,3]sigmatropic rearrangement of the 8-membered thionocarbonate (2a) formed in situ (Chart 1).4a,4b In order to demonstrate the synthetic utility of the present method, the sexual phenome of yellow scale insect, (±)-(E)-6-isopropyl-3,9-dimethyl-5,8-decadienyl acetate, was stereo-selectively synthesized.4c On the other hand, we recently reported that the highly stereoselective synthesis of a (Z)- or (E)-double bond in 10-membered thiolcarbonates (3) could be achieved by controlling the chair–boat-like transition state in the [3,3]sigmatropic rearrangement of 8-membered thionocarbonates (2) (Chart 2).4b Reaction of (E)-1b having an (E)-double bond gave a (Z)-10-membered thiolcarbonate (3b) in 88% yield and the same treatment of (Z)-1c having a (Z)-double bond correspondingly provided (E)-3c in 78% yield. The geometry of (Z)-3c can be explained by the chairlike transition state (T_C), whereas that of (E)-3c is due to the boatlike transition state (T_B).4b Further, the proposed transition states (T_C and T_B) were quantitatively evaluated by a combination of molecular mechanics and orbital computations.4b The 8-membered ring of the calculated T_C and T_B adopt a boat–chair conformation existing predominantly in cyclooctane and its simple derivatives. However, since the reactions go to completion instantly,
the 8-membered thionocarbonates intermediates (2) have not been isolated. Thus, we have studied the formation of 8-membered thionocarbonates (2) to clarify the above reaction mechanism.

First, we examined whether a diol monothionocarbonate (5), which contains an ethyl group instead of the ethenyl group of 1a, can form an 8-membered thiolcarbonates (6) on treatment with base. Compound 5 was easily synthesized from 5-hydroxypentanal (4) (Chart 3). Reaction of 4 with ethylmagnesium chloride followed by treatment with phenyl chlorothionoformate (1 eq) in the presence of pyridine (1 eq) and 4-dimethylaminopyridine (4-DMAP) (0.1 eq) in acetonitrile gave the monothionocarbonate (5). Although sodium bis(trimethylsilyl)amide [(TMS)₂NaN] has been used as a base for the present reaction, we have newly found that its lithium salt [(TMS)₂NLi] is more effective through our study of the yellow scale pheromone synthesis. A hexane solution of (TMS)₂NLi (1 eq) was injected rapidly into a dry THF solution of 5 at room temperature under N₂. The reaction went to completion immediately and the desired 8-membered heterocyclic thionocarbonate (6) could be isolated by chromatography even in the presence of the counter ion (PhO⁻) generated in situ. The structure of 6 was indicated to be 4-ethyl-1,3-dioxoan-2-thione by the proton nuclear magnetic resonance (¹H-NMR) and carbon 13 nuclear magnetic resonance (¹³C-NMR) spectra. Each proton at C₁ was separately observed at δ 4.21 (1H, dt, J = 11.6, 5.0 Hz) and δ 4.80 (1H, dt, J = 11.6, 5.0 Hz), suggesting that this 8-membered ring is conformationally fixed at room temperature. Although Copeland et al. reported that the chemical shift of carbon [OC(S)O] in a variety of thionocarbonates was centered at about 193 ppm, it was observed that the carbon resonance [OC(S)O: 200.5 ppm] of 6 showed a downfield shift by about 7 ppm.

We next considered that oxidation of the 8-membered thionocarbonate (7) having a phenylselenoethyl group might lead to 3a via the spontaneous [3,3]sigmatropic ring expansion of the intermediate (2a) which would be formed by an elimination reaction of the resulting selenoxide (8) (Chart 4). Thus, the selenide (7) was prepared from acrolein via the sequence outlined in Chart 5. Conjugate addition of sodium benzeneselenolate to acrolein according to Yoshikoshi’s procedure gave the aldehyde (9). Reaction of 9 with the lithium salt (11) derived from 1,4-butanediol gave an alcohol (12) in 66% yield. Deprotection
of 12 with tetrabutylammonium fluoride followed by treatment with phenyl chlorothoniforate gave a diol monothionocarbonate (13) in 65% yield. Reaction of 13 with (TMS)₃NLi by the procedure described above smoothly afforded the 8-membered thionocarbonate (7) in 91% yield. The C₂ proton signals [-CH₂·H₂O:] δ: 4,23 (dt, J = 11,2, 5,3 Hz), 4.78 (dt, J = 11,2, 5,3 Hz)] and the thiocarbonyl carbon signal (δ 200.0) of 7 were similar to those of 6. The oxidation of 7 thus obtained with meta-chloroperbenzoic acid (m-CPBA) at 0 °C in dichloromethane (CH₂Cl₂) was completed immediately to give unexpectedly a cyclic carbonate (14) containing an O atom instead of the S atom of 7. Although the 1H-NMR spectrum of 14 closely resembled that of 7, the infrared (IR) (1750 cm⁻¹, C = O) and mass spectra (MS) (M⁺ 314) indicated the structure of 14. Yamamoto et al.¹⁰ reported that thionolactones are easily oxidized to the corresponding lactones in high yield with m-CPBA in CH₂Cl₂ at room temperature. Metzner et al.¹¹ also showed that reaction of thiokeetones¹¹⁰ or thionoesters¹¹⁰ with m-CPBA easily affords the sulfones,¹² which are converted into the corresponding ketones or esters with loss of sulfur. By analogy with these recent reports, our observation can be explained by the formation of an oxathiriane (16) arising from thermally allowed electrocyclization of the sulfine (15) followed by sulfur extrusion.

In conclusion, although the formation of 3a via [3,3]-sigmatropic ring expansion from the selenoxide (8) as outlined in Chart 4 has not been accomplished, easy production of the 8-membered thionocarbonates (6 and 7) supports the hypothesis that the reaction of diol monothionocarbonates (1) having a double bond with base proceeds via the [3,3]sigmatropic ring expansion of the postulated 8-membered thionocarbonates (2) to give the 10-membered thiocolonates (3).

### Experimental
IR spectra were recorded on a Shimadzu IR-435 spectrophotometer. ¹H- and ¹³C-NMR spectra were taken with tetramethylsilane as an internal standard on a Varian Gemini-200 spectrometer in CDC₁₂. Low-resolution and high-resolution mass spectra (HRMS) were obtained on a Hitachi M-80 instrument. All reactions were carried out under a nitrogen atmosphere. For column chromatography, SiO₂ (Merk 9385) was used.

---

**Figures and Tables**

**Chart 6**

1. the organic layer was washed with brine and dried over anhydrous Na₂SO₄. Evaporation of the solvent left 1,5-heptanediol (1.45 g, 55%) [¹H-NMR δ: 0.90 (3H, t, J = 7.5 Hz, CH₃), 1.30–1.65 (8H, br, CH₂) × 2, 3.44–3.67 (6H, br, CH₃OH, CH₂OH)] as a pale yellow oil. This oil was subjected to the following reaction without further purification. A solution of phenyl chlorothoniforate (1.8 mol, 12.72 mm) in acetonitrile (10 ml) was added dropwise to a solution of 1,5-heptanediol (1.4 g, 10.6 mm) in acetonitrile (20 ml) in the presence of pyridine (1.0 g, 12.72 mm) and 4-DMAP (129 mg, 1.06 mm) over 2.5 h at 0 °C. After the reaction temperature had risen to room temperature, the solvent was evaporated off under reduced pressure. The residue was dissolved in EtOAc–hexane (1:1). The organic layer was washed with H₂O and brine, dried over anhydrous Na₂SO₄, and then evaporated off under reduced pressure. The residue was purified by column chromatography (10% EtOAc in hexane) to give 5 (1.52 g, 54%). IR (film) cm⁻¹: 3380–3390 (OH). ¹H-NMR δ: 0.93 (3H, t, J = 7.5 Hz, CH₃), 1.35–1.68 (6H, br, CH₂ × 3), 1.75–1.92 (2H, br, CH₂CH₃), 3.45–3.60 (1H, br, CH₃OH), 4.51 (2H, t, J = 6.5 Hz, OCH₂), 7.05–7.46 (5H, m, ArH). This compound did not give the expected MS peaks due to thermal instability.

**4-Ethyl-1,3-dioxan-2-thione (6)** A 1 mol solution of (TMS)₃NLi in THF (0.5 ml, 0.5 mm) was added rapidly to a solution of 5 (134 mg, 0.5 mm) in THF (50 ml) at room temperature, and the mixture was stirred for 5 min. The reaction was quenched by the addition of H₂O and the solvent was evaporated off under reduced pressure. The residue was extracted with EtOAc–hexane (1:1) and the extract was washed with brine, dried over anhydrous Na₂SO₄, and then evaporated off under reduced pressure. The residual oil was purified by column chromatography (4% EtOAc in hexane) to give 6 (66 mg, 76%) as an oil. IR (film) cm⁻¹: 2940, 1440, 1350, 1180, 1070, 1030, 930, 910. ¹H-NMR δ: 0.98 (3H, t, J = 8.0 Hz, CH₃), 1.50–2.00 (2H, br, CH₂CH₃), 2.16 (1H, d, J = 11.6, 5.0 Hz, CH₂H₂OCSi), 4.80 (1H, d, J = 11.6, 5.0 Hz, CH₂H₂OCSi), 4.72–4.92 (1H, br, CHO). ¹³C-NMR δ: 10.5, 23.8, 27.5, 31.5, 35.5, 75.0, 90.4, 200.5. MS m/z: 174 (M⁺). HRMS Calcd for C₃H₇O₂S: 174.0714. Found: 174.0716.

**3-Phenylethene propanol (9)** This compound was quantitatively prepared from acrolein on a 2 mm scale according to Yonokoshi's procedure. IR (film) cm⁻¹: 1715 (CO). ¹H-NMR δ: 2.83 (2H, t, J = 7.5 Hz, CH₂Se), 3.08 (2H, t, J = 7.5 Hz, CH₂CHO), 7.20–7.65 (5H, br, ArH), 9.75 (1H, s, CHO). MS m/z: 214 (M⁺). HRMS Calcd for C₁₃H₁₂O₃Se: 213.8986. Found: 213.8984.

**4-isocyanato tert-Butyldimethylsilyl Ether (10)** A solution of tert-butyldimethylsilyl chloride (TBDMSI) (6.8 g, 45 mm) in dimethylformamide (DMF) (20 ml) was added dropwise to a mixture of 1,4-butanediol (4.06 g, 45 mm) and imidazole (7.65 g, 112 mm) in DMF (20 ml) over 4 h at 0 °C. After additional stirring for 40 min at 0 °C, the mixture was dissolved in EtOAc–hexane (3:1) (100 ml). The organic layer was washed with H₂O (x 3) and brine, dried over anhydrous Na₂SO₄, and then evaporated under reduced pressure. The oily residue was purified by column chromatography (10% EtOAc in hexane) to give 4-tert-butyldimethylsilyloxibutanol (6.83 g, 74%) as an oil. IR (film) cm⁻¹: 3700–3500 (OH), 1200–1200, 1140–920. ¹H-NMR δ: 0.05 (6H, s, (CH₃)₂Si), 0.87 (9H, s, (CH₃)₂CSi), 1.57–1.67 (4H, m, CH₂), 2.63 (1H, br, OH), 3.65 (4H, br, J = 5.5 Hz, CH₂OH, CH₂OSi). Imidazole (544 mg, 8 mm), triphenylphosphine (1.42 g, 5 mm) and iodine (1.63 g, 6.4 mm) were added in turn to a solution of 4-tert-butyldimethylsilyloxybutanol (653 mg, 3.2 mm) in benzene (30 ml). After being stirred at room temperature for 0.5 h, the reaction mixture was washed with saturated sodium sulphite solution and brine and then dried over anhydrous MgSO₄. The solvent was evaporated off in vacuo to give an oily residue, which was purified by column chromatography (5% EtOAc in hexane) to give 10 (940 mg, 94%) as a colorless liquid. IR (film) cm⁻¹: 1280–1190, 1140–1040. ¹H-NMR δ: 0.02 (6H, s, (CH₃)₂Si), 0.87 (9H, s, (CH₃)₂CSi), 1.58 (2H, dt, J = 14.3, 6.0 Hz, CH₂), 1.88 (2H, t, J = 14.3, 7.0 Hz, CH₂), 3.20 (2H, t, J = 7.0 Hz, CH₂), 3.60 (2H, t, J = 7.0 Hz, CH₂). MS m/z: 313 (M⁺, 1), 299 (M⁺–CH₃). HRMS Calcd for C₁₃H₂₂O₃Si (M⁺–CH₃): 299.0328. Found: 299.0327.

**7-tert-Butyldimethylsilyloxy-1-phenylselenoheptan-3-ol** (12) The dry flask was charged with 10 (597 mg, 1.9 mm) and dry n-pentane-diethyl ether (3·2 by volume, 19 ml). The solution was cooled to −78 °C and...
1.7 M tert-BuLi in n-pentane (2.3 ml) was then added. Stirring was continued at −78°C for 5 min, then at room temperature for 1 h. The mixture was again cooled to −78°C, the aldehyde (9) was added and the resulting mixture was stirred for 2 h. The reaction was quenched with the addition of H₂O₂ and then the mixture was dissolved in EtOAc–hexane (1:1). The organic layer was washed with H₂O (x 2) and brine, dried over anhydrous Na₂SO₄, and then evaporated under reduced pressure. The residue was purified by column chromatography (5% EtOAc in hexane, then 10% EtOAc in hexane) to give 12 (764 mg, 66%) as an oil. IR (film) cm⁻¹: 3642–3000 (OH), 1520, 1150–390. 1H-NMR δ: 0.02 (6H, s, (CH₂)₃S), 0.87 (9H, s, (CH₂)₃C), 1.30–1.55 (4H, brm, CH₂ × 2), 1.59–1.67 (2H, br, CH₂), 1.72–1.88 (2H, m, CH₂), 3.0 (2H, m, CH₂), 3.57 (2H, t, J = 6.0 Hz, CH₂O), 3.64–3.73 (1H, br, CH₂O), 7.18–7.31 (3H, m, ArH), 7.42–7.53 (2H, m, ArH). MS m/z: 402 (M⁺). HRMS Calcd for C₁₄H₁₅O₂S₃: 402.0491. Found: 402.1494.

A 1M solution of tetrabutylammonium fluoride (43) (4.1 ml, 4.1 mmol) in THF was added to a solution of 12 (1.37 g, 3.43 mmol) in THF (50 ml) and the mixture was stirred for 4h. The reaction was quenched by the addition of H₂O and the solvent was evaporated off under reduced pressure. The residue was dissolved in EtOAc–hexane (1:1) and the organic layer was washed with H₂O, brine, dried over anhydrous Na₂SO₄, and then evaporated under reduced pressure. The residue was purified by column chromatography (80% EtOAc in hexane) to give 7-phenylethene-1,5-heptanediol (876 mg, 88%). IR (film) cm⁻¹: 3700–3000 (OH), 1220–940. 1H-NMR δ: 1.28 (8H, m, CH₂ × 4), 1.72–1.88 (2H, m, CH₂), 3.56–3.70 (2H, m, CH₂), 7.19–7.31 (3H, m, ArH), 7.41–7.55 (2H, m, ArH). MS m/z: 288 (M⁺). HRMS Calcd for C₁₃H₁₄O₂Se: 288.0627. Found: 288.0625. A solution of phenyl chloroformate (48 mg, 0.28 mmol) in acetonitrile (5 ml) was added dropwise to a solution of 7-phenylethene-1,5-pentanediol (79 mg, 0.28 mmol) in acetonitrile (6 ml) in the presence of pyridine (22 mg, 0.28 mmol) and 4-DMP (3.4 mg, 0.028 mmol) over 60°C at 6°C. The mixture was evaporated under reduced pressure and the oil residue was dissolved in EtOAc–hexane (1:1). The organic layer was washed with H₂O and brine, dried over anhydrous Na₂SO₄, and then evaporated under reduced pressure. The residue was purified by column chromatography (15% EtOAc in hexane) to give 13 (87 mg, 74%) as an oil. IR (film) cm⁻¹: 3400, 2920, 1722, 1585. 1H-NMR δ: 1.35–1.63 (4H, m, CH₂ × 2), 1.68–1.90 (4H, m, CH₂ × 2), 2.88–3.09 (2H, m, CH₂), 3.63–3.83 (1H, br, CH₂O), 4.50 (2H, t, J = 6.5 Hz, CH₂O), 6.90–7.53 (10H, m, ArH). MS m/z: 424 (M⁺). HRMS Calcd for C₂₁H₂₃NO₂S: 424.0610. Found: 424.0617.

Acknowledgement The authors thank Mrs. M. Fujitake for measurements of mass spectra.

References and Notes

13) These are available from Aldrich Chemical Company.