FORMATION AND REACTIONS OF TRICHLORO-γ-LACTONES

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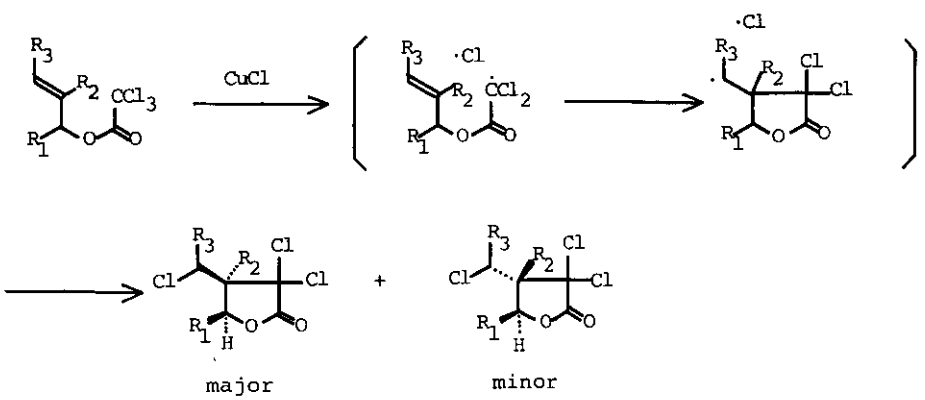
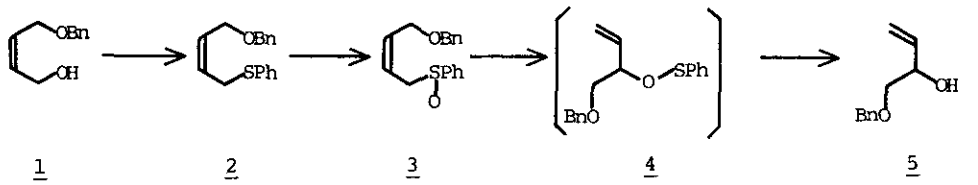
Abstract —— The allyl trichloroacetates, (6) and (7), have been converted into the trichloro-γ-lactones, (8) and (9), by cuprous chloride. On dechlorination using tri-n-butyltin hydride , regioselective reaction has occurred initially at α position to convert the trichlorides, (8) and (9), into the dichlorides, (11) and (12), which in turn have been converted into the monochlorides, (13) and (14), depend on amount of the reducing agent. On dehydrochlorination, both the trichlorides, (8) and (9), have furnished the dihalobutenolides, (16) and (17), via 1,2-elimination with DBU, while the monohalides, (13) and (14), have yielded the cyclopropa[2,3]butyrolactones, (26) and (27), via 1,3-elimination with potassium tert-butoxide.

In relation to our recent synthetic efforts using γ-lactone intermediates[1], we describe here a formation of two trichloro-γ-lactone derivatives and their modifications at the halogen bearing centers. As we have sometimes encountered with difficulties in functionalizing the β position of a γ-lactone substrate, a recent



Scheme 1

developed method, by Nagashima et al., yielding β-halogenoalkyl-γ-lactone via free radical cyclization[2] is of particular attractive to us (Scheme 1). In order to exploit this reaction, we chose two isomeric allyl trichloroacetates, (6) and (7), as the substrates of the present investigation. The secondary allyl alcohol (5) served as the alcohol moiety of the former ester (6) was prepared from the primary alcohol (1) which itself being served as the alcohol moiety of the latter ester (7) via [2,3]-sigmatropic rearrangement of the sulfoxide intermediate (3) as outlined in Scheme 2.



1 2 3 4 5

Scheme 2

Treatment of the primary alcohol (1)[3] with diphenyl disulfide in the presence of tri-n-butylphosphine[4] gave the allyl sulfide (2) in an excellent yield. Oxidation of (2) could be simply carried out using either sodium periodate or m-chloroperbenzoic acid to give the sulfoxide (3). Treatment of (3) with trimethyl phosphite yielded the secondary alcohol (5) via concurrent [2,3]-sigmatropic rearrangement and reductive removal of the sulfur moiety.[5] Acylation of the secondary alcohol (5) with trichloroacetyl chloride gave the trichloroacetate (6) in nearly quantitative yield. By similar acylation, the primary alcohol (1) could also be converted into the trichloroacetate (7) in an excellent yield.

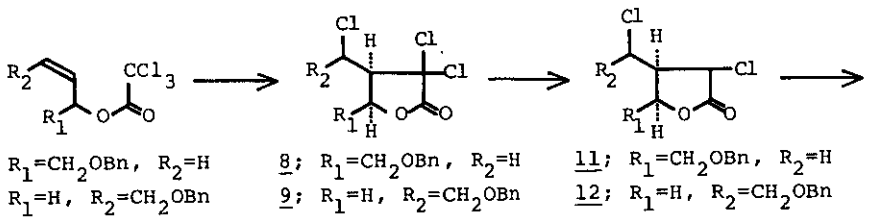
Cyclization was first applied to the secondary ester (6) under the conditions reported by Nagashima et al.[2] Although the yield was far from satisfactory, two separable isomeric trichlorolactones could be isolated in 29 and 4 % yield, respectively, the major one of which was assigned to be cis-isomer (8) based on the coupling constant (9.2 Hz) between the protons at β and γ position.[6]

On the other hand, the same treatment on the primary ester (7) also afforded the trichlorolactone (9) in 27 % yield as a single product. In this conversion no trace of elimination product from the β-alkoxy radical intermediate could be detected.

Under the cyclization conditions neither the dichloroacetate nor the monochloroacetate derivatives of the both esters, (6) and (7), yielded the cyclization products. Moreover, when tri-n-butyltin hydride was used as an initiator[7] in place of cuprous chloride, cyclization did not occur but dechlorination occurred instead.

Having obtained the cyclization products, (8) and (9), though in unsatisfactory yields, we next examined dechlorination using tri-n-butyltin hydride as reducing agent since selective removal of the particular halogen atom is indispensable for the versatile use of these halo-γ-lactones as synthetic units. We first

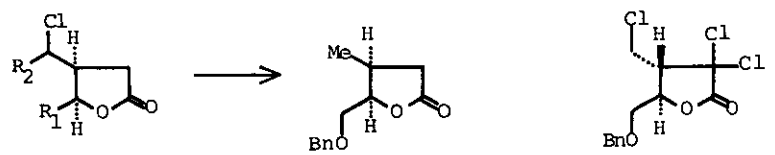
applied one molar equivalent of the reducing agent to (8) in refluxing benzene in the presence of a catalytic amount of AIBN. The reaction completed within 3 h to give a separable mixture (1 : 1) of the dichloro-(11) and the monochloro-(13) lactones, in 73 % yield, both leaving the chlorine atom on the β substituent intact. When the reaction temperature was reduced to 40 °C, though the reaction was greatly retarded, the dichloride (11) was formed much predominant over the monochloride (13) (ca. 4 : 1). On the other hand, the isomeric trichlorolactone (9) furnished the dichlorolactone (12) exclusively in 72 % yield with one molar equivalent of the hydride under refluxing conditions. Interestingly, both the dichlorides obtained were revealed to be single epimers though their correct stereochemistry could not be determined. With two molar equivalents of the hydride, the former (8) gave the monohalolactone (13) exclusively in 76 % yield, while the latter (9) afforded the isomeric monohalolactone (14) in 77 % yield both as single epimers. Upon treatment with an excess amount of the reducing agent (3 mol. equiv.), the former lactone (8) yielded fully dehalogenated lactone (15) quantitatively, while the latter (9) yielded the monochlorolactone (14) which itself was also found to be intact under the same conditions.



6; R_1=CH_2OBn, R_2=H
7; R_1=H, R_2=CH_2OBn

8; R_1=CH_2OBn, R_2=H
9; R_1=H, R_2=CH_2OBn

11; R_1=CH_2OBn, R_2=H
12; R_1=H, R_2=CH_2OBn



13; R_1=CH_2OBn, R_2=H
14; R_1=H, R_2=CH_2OBn

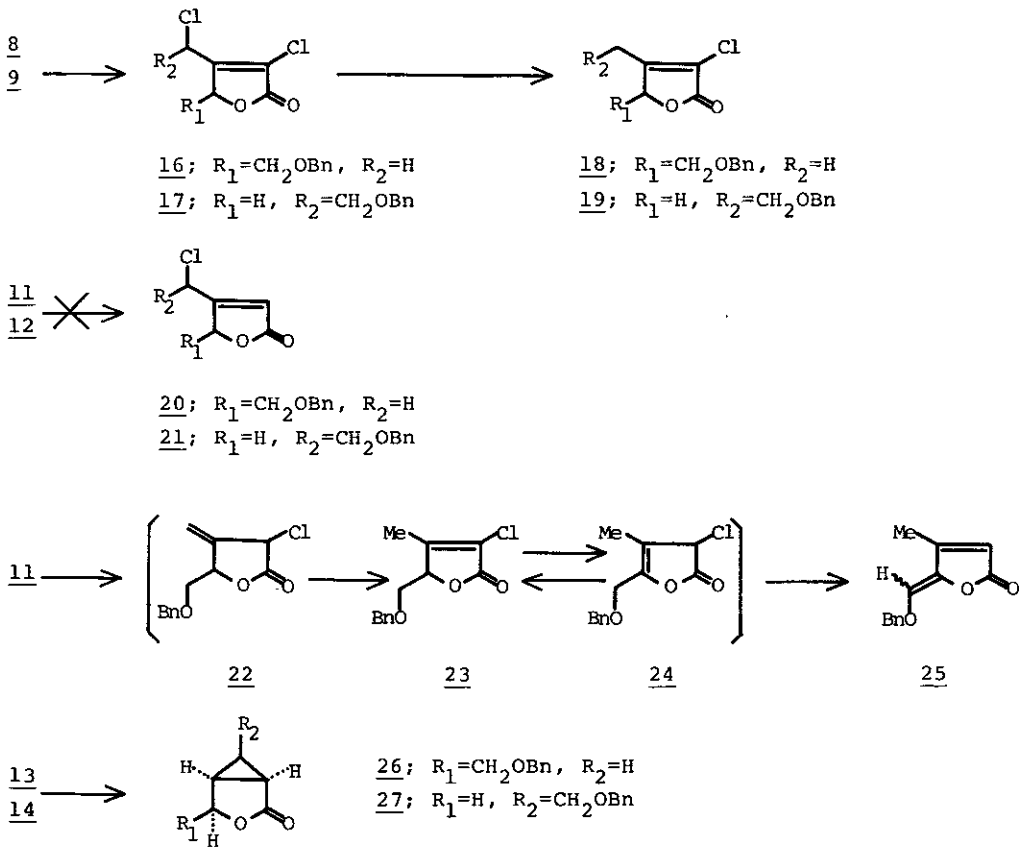
15

10

Scheme 3

We next examined dehydrochlorination of the chlorolactones. On treatment with DBU in boiling benzene, both of the isomeric trichlorolactones, (8) and (9), were smoothly converted into the corresponding dichlorobutenolides, (16) and (17), respectively, in good yields. Of two chlorine atoms left in the both

butenolides, the allylic one could be selectively replaced by hydrogen under the conditions using tri-n-butyltin hydride, while the vinylic one could not be removed even by using an excess of the hydride. Thus, the former (16) gave the α-chlorobutenolide (18) in 59 % and the latter (17) gave (19) in 56 % yields, respectively. Very curiously, the dihalolactone (11) did not furnish the expected monohalobutenolide (20) under the same conditions, but the dienelactone (25) was obtained in 45 %-yield as an only isolable compound presumably by double elimination via an initial formation of the exo-methylene intermediate (22) and the following isomerization to (23) and (24). The isomeric dihalolactone (12), on the same treatment, did not yield any isolable product.



Scheme 4

On the other hand, dehydrochlorination of the both monochlorolactones, (13) and (14), with potassium tert-butoxide was found to occur in 1,3-manner to give the corresponding cyclopropalactones, (26) and (27), respectively in excellent yields. In the latter reaction, exclusive formation of one epimer was observed though its stereochemistry remained to be uncertain.

In conclusion, although further improvement in the free radical formation of the β-alkylated lactones should be necessitated, regio-selective dehalogenation as well as regio-selective dehydrohalogenation of these lactone derivatives described here will be useful in our future synthesis. We are now exploring application of the present findings to the synthesis of some natural products using chiral substrates.

EXPERIMENTAL SECTION

All the reactions were carried out under argon. Melting points are not corrected. IR spectra were measured with a JASCO A-102 spectrophotometer, NMR spectra with JEOL PMX-60 and JEOL JNM-FX 100 spectometers (in deuteriochloroform solution using tetramethylsilane as internal reference), MS spectra with a JEOL JMS-OISG 2 spectrometer.

(Z)-4-Benzyloxybut-2-enyl Phenyl Sulfide (2) A mixture of Z-4-benzyloxybut-2-en-1-ol (1, 8.91 g ((50.0 mmol)), diphenyl disulfide (13.10 g (60.0 mmol)), and tri-n-butylphosphine (14.9 ml (60.0 mmol)) in pyridine (50 ml) was stirred at room temperature for 1 h. After evaporation of the volatiles under reduced pressure, the residue was taken into ether and the solution was washed with water, 10 % hydrochloric acid, 5 % sodium hydrogen carbonate, brine, and dried with magnesium sulfate. After removal of the solvent, the residue was distilled under reduced pressure to give the sulfide (2, 10.88 g (80.5 %)), bp 136-140 °C (0.07 torr); NMR δ: 7.24 (10H, s), 5.73-5.57 (2H, m), 4.39 (2H, s), 3.90 (2H, d, J=4.0 Hz), 3.55-3.35 (2H, m); MS m/e: 270 (M^+), 91 (100 %); Anal. Calcd. for $C_{17}H_{18}OS$: m/e 270.1078. Found: m/e 270.1079.

(Z)-4-Benzyloxybut-2-enyl Phenyl Sulfoxide (3) (a) To the above sulfide (2, 10.88 g (40.2 mmol)) in a mixture of acetonitrile (100 ml) and water (150 ml) was added sodium periodate (10.33 g (48.3 mmol) and the mixture was stirred for 6 h at 50 °C. After separation of insoluble material by filtration, the filtrate was extracted with methylene chloride. The extract was dried with magnesium sulfate and was evaporated to give practically pure sulfoxide (3, 12.58 g (108.5 %)) which was used without purification, NMR δ: 7.40 (5H, s), 7.26 (5H, s), 6.23-5.16 (2H, m), 4.40 (2H, s), 3.96-3.76 (2H, m), 3.60 (2H, d, J=7.6 Hz); MS m/e: 287 (M^+ + 1), 91 (100 %); Anal. Calcd. for $C_{17}H_{19}O_2S$: m/e 287.1104. Found: m/e 287.1103.

(b) The sulfide (2, 1.25 g (4.6 mmol)) in methylene chloride was treated with m-chloroperbenzoic acid (85 % 0.95 g (4.7 mmol)) in the presense of sodium hydrogen carbonate (0.39 g, 4.6 mmol) at -10 °C with stirring. After stirring for 1 h at the same temperature, the reaction mixture was washed with water, 2 % sodium hydrosulfite, 5 % sodium hydrogen carbonate, brine, and dried with magnesium sulfate, and evaporated under reduced pressure to give the sulfoxide (3, 1.24 g (93.7 %)).

1-Benzyloxy-but-3-en-2-ol (5) A mixture of the crude sulfoxide (3, 12.58 g (43.9 mmol) and trimethyl phosphite (13.0 ml, 109.8 mmol) in methanol (55 ml) was refluxed for 24 h. After evaporation of the

solvent, the residue was taken into ether and the solution was washed with brine, 15 % sodium hydroxide, brine, and dried with magnesium sulfate. After removal of the solvent, the residue was chromatographed on silica gel (290 g) using a mixture of ether and n-hexane (1 : 5) as an eluent to give the pure allyl alcohol (5, 4.55 g (58.4 %)); IR ν_{max}^{neat} cm^{-1}: 3425; NMR δ: 7.29 (5H, s), 6.13-5.39 (2H, m), 5.28-5.02 (1H, m), 4.54 (2H, s), 4.52-4.09 (1H, m), 3.67-3.20 (2H, m), 2.66-2.60 (1H, m); MS m/e: 178 (M^+), 91 (100 %); Anal. Calcd. for $C_{11}H_{14}O_2$: 178.0993. Found: m/e 178.1003.

1-Benzyloxy-2-trichloroacetoxybut-3-ene (6) To a solution of the alcohol (5, 1.64 g (9.2 mmol)) and pyridine (1.12 ml, (13.8 mmol)) in methylene chloride (50 ml) was added dropwise trichloroacetyl chloride (1.13 ml (10.1 mmol)) at 0 °C with stirring. After 1 h, the reaction mixture was washed with 5 % hydrochloric acid, 5 % sodium hydrogen carbonate, brine, and dried with magnesium sulfate. After removal of the solvent, the residue was chromatographed on silica gel (60 g) using a mixture of ether and n-hexane (1 : 6) as an eluent to give the pure ester (6, 2.98 g (100.0 %)); IR ν_{max}^{neat} cm^{-1}: 1762; NMR δ : 7.27 (5H, s), 6.20-5.20 (4H, m), 4.56 (2H, s), 3.68 (2H, d, J=5.4 Hz); MS m/e: 322 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{13}O_3Cl_3$: m/e 321.9929. Found: m/e 321.9912.

4-Benzyloxy-1-trichloroacetoxybut-2-ene (7) To a solution of the alcohol (1, 3.57 g (20.0 mmol)) and pyridine (2.42 ml (30.0 mmol)) in methylene chloride (100 ml) was added dropwise trichloroacetyl chloride (2.45 ml (22.0 mmol)) at 0 °C. After stirring for 1 h, the reaction mixture was treated as for the isomer (5). After removal of the solvent, the residue was chromatographed on silica gel (200 g) using a mixture of ether and n-hexane (1 : 6) as an eluent to give the pure ester (7, 6.49 g (100.0 %)); IR ν_{max}^{neat} cm^{-1}: 1760; NMR δ: 7.27 (5H, s), 6.14-5.48 (2H, m), 5.04-4.81 (2H, m), 4.50 (2H, s), 4.31-4.08 (2H, m); MS m/e: 322 (M^+), 91 (100 %): Anal. Calcd. for $C_{13}H_{13}O_3Cl_3$: m/e 321.9931. Found: 321.9941.

cis- and trans-4-Benzyloxy-3-chloromethyl-2,2-dichloro-4-hydroxyvaleric Acid Lactones, (8) and (10) The trichloroacetate (6, 3.72 g (11.5 mmol) was heated with cuprous chloride (678 mg, 6.9 mmol) in acetonitrile (50 ml) at 140 °C for 3.5 h using a sealed bottle. After removal of the solvent, the residue was chromatographed on silica gel (140 g) to give the cis-lactone (8, 1.09 g (29.3 %) and the trans-lactone (10, 140 mg, 3.8 %). cis-Lactone (8); IR ν_{max}^{neat} cm^{-1}: 1800; NMR δ: 7.29 (5H, s), 4.57 (2H, s), 4.57-4.24 (1H, m), 4.17-3.22 (5H, m); MS m/e: 322 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{13}O_3Cl_3$: m/e 321.9930. Found: m/e 321.9945. trans-Lactone (10); IR ν_{max}^{neat} 1804; NMR δ: 7.29 (5H, s), 4.6 (2H, s), 4.56-4.24 (1H, m), 4.17-3.24 (5H, m); MS m/e: 322 (M^+), 91 (100 %): Anal. Calcd. for $C_{13}H_{13}O_3Cl_3$: m/e 321.9931. Found: m/e 321.9968.

3-(2-Benzyloxy-1-chloroethyl)-2,2-dichloro-4-hydroxybutyric Acid Lactone (9) The trichloroacetate (7, 5.77 g (17.8 mmol)) was heated with cuprous chloride (1.05 g (10.7 mmol)) in acetonitrile (50 ml) at 140 °C for 18 h using a sealed bottle and the reaction mixture was treated as for the isomer (6). Purification of the crude product by silica gel column chromatography (180 g) using a mixture of ether and n-hexane (1 : 4) as an eluent to give the pure lactone (9, 1.56 g (27.0 %)); IR ν_{max}^{neat} cm^{-1}: 1800;

NMR δ: 7.31 (5H, s), 4.62 (2H, s), 4.73-3.20 (6H, m); MS m/e: 322 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{13}O_3Cl_3$: m/e 321.9930. Found: m/e 321.9977.

4-Benzyloxy-3-chloromethyl-2-chloro-4-hydroxyvaleric Acid Lactone (11) (a) at highter reaction temperature: A mixture of the trichlorolactone (8, 100 mg (0.31 mmol) and tri-n-butyltin hydride (0.10 ml) in benzene (5.5 ml) was heated at 80 °C for 4 h in the presence of AIBN (2.1 mg (0.013 mmol)). After removal of the solvent, the residue was taken into ether and the solution was washed with 10 % aqueous potassium fluoride solution, and dried with magnesium sulfate. After removal of the solvent, the residue was chromatographed on silica gel (7 g) using a mixture of ether and n-hexane (1 : 3) as an eluent to give the dichlorolactone (11, 33 mg (37.3 %)) and the monochlorolactone (13, 28 mg (35.3 %)). The dichlorolactone (11); IR ν_{max}^{neat} cm^{-1}: 1792; NMR δ: 7.30 (5H, s), 4.78-4.42 (2H, m), 4.58 (2H, s), 3.89-3.69 (4H, m), 3.29-2.79 (1H, m); MS m/e: 288 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{14}O_3Cl_2$: m/e 288.0319. Found: m/e 288.0303. The monochlorolactone (13); IR ν_{max}^{neat} cm^{-1}: 1780; NMR δ: 7.24 (5H, s), 4.54 (2H, s), 4.54-4.39 (1H, m), 3.79-3.51 (4H, m), 3.19-2.10 (3H, m); MS m/e: 254 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{15}O_3Cl$: m/e 254.0708. Found: 254.0705.

(b) at lower reaction temperature: A mixture of the trichlorolactone (8, 1.00 g (3.1 mmol)) and tri-n-butyltin hydride (0.99 ml (3.8 mmol) in benzene (50 ml) was stirred at 40 °C for 48 h in the presence of AIBN (21.0 mg (0.13 mmol)). The reaction mixture was treated as in (a) and the crude product was chromatographed on silica gel (50 g) to give the dichlorolactone (11, 430 mg (68.7 % based on consumed starting material (8)), the monochlorolactone (13, 87 mg (15.8 % based on consumed starting material (8)), and the starting trichlorolactone (8, 300 mg (30.0 %)).

4-Benzyloxy-3-chloromethyl-4-hydroxyvaleric Acid Lactone (13) A mixture of the trichlorolactone (8, 100 mg (0.31 mmol)) and tri-n-butyltin hydride (0.17 ml (0.63 mmol)) in benzene (5.5 ml) was refluxed for 1 h in the presence of AIBN (2.1 mg (0.013 mmol)). The reaction mixture was treated as above and the crude product was chromatographed on silica gel (7 g) using a mixture of ether and n-hexane (1 : 1) as an eluent to give the pure monochlorolactone (13, 60 mg (76.2 %)); IR ν_{max}^{neat} cm^{-1}: 1780; NMR δ: 7.27 (5H, s), 4.54 (2H, s), 4.54-4.39 (1H, m), 3.79-3.51 (4H, m), 3.19-2.10 (3H, m); MS m/e 254 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{15}O_3Cl$: m/e 254.0708. Found: m/e 254.0705.

4-Benzyloxy-3-methyl-4-hydroxyvaleric Acid Lactone (15) A mixture of the trichlorolactone (8, 150 mg (0.47 mmol) and tri-n-butyltin hydride (0.75 ml (2.8 mmol)) in benzene (5.5 ml) was refluxed for 36 h in the presence of AIBN (3.2 mg (0.020 mmol)). The reaction mixture was treated as above and the crude product was chromatographed on silica gel (9 g) using a mixture of ether and n-hexane (1 : 1) as an eluent to give the pure lactone (15, 102 mg (99.9 %)); IR ν_{max}^{neat} cm^{-1}: 1778; NMR δ: 7.27 (5H, s), 4.53 (2H, s), 4.27-4.05 (1H, m), 3.71-3.58 (2H, m), 2.86-2.03 (3H, m), 1.14 (3H, d, J=6.0 Hz); MS m/e: 220 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{16}O_3$: m/e 220.1099. Found: m/e 220.1105.

3-(2-Benzyloxy-1-chloroethyl)-2-chloro-4-hydroxybutyric Acid Lactone (12) A mixture of the

trichlorolactone (9, 420 mg (1.3 mmol)) and tri-n-butyltin hydride (0.33 ml (1.30 mmol)) in benzene (10 ml) was refluxed for 3 h in the presence of AIBN (8.7 mg, 0.052 mmol). The reaction mixture was treated as above and the crude product was chromatographed on silica gel (20 g) using a mixture of ether and n-hexane (1 : 2) as an eluent to give the dichlorolactone (12, 270 mg (71.9 %)); IR ν_{max}^{neat} cm^{-1}: 1790; NMR δ: 7.28 (5H, s), 4.57 (2H, s), 4.70-4.07 (4H, m), 4.03-3.57 (2H, m), 3.57-2.97 (1H, m); MS m/e: 288 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{14}O_3Cl_2$: m/e 288.0318. Found: m/e 288.0311.

3-(2-Benzyloxy-1-chloroethyl)-4-hydroxybutyric Acid Lactone (14) A mixture of the trichlorolactone (9, 207 mg (0.64 mmol)) and tri-n-butyltin hydride (0.33 ml (1.30 mmol)) in benzene (10 ml) was refluxed for 4 h in the presence of AIBN (4.34 mg (0.026 mmol)). The reaction mixture was treated as above and the crude product was chromatographed on silica gel (15 g) using a mixture of ether and n-hexane (1 : 1) as an eluent to give the monochlorolactone (14, 125 mg (76.7 %)); IR ν_{max}^{neat} cm^{-1}: 1772; NMR δ: 7.27 (5H, s), 4.52 (2H, s), 4.48-3.90 (3H, m), 3.66-3.56 (2H, m), 3.39-2.87 (1H, m), 2.57-2.40 (2H, m); MS m/e: 254 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{15}O_3Cl$: m/e 254.0708. Found: m/e 254.0701.

5-Benzyloxymethyl-3-chloromethyl-2-chloro-2,5-dihydro-2-furanone (16) A mixture of the trichlorolactone (8, 647 mg (2.0 mmol)) and DBU (0.33 ml (2.2 mmol)) in benzene (20 ml) was refluxed for 8 h. The reaction mixture was diluted with benzene and was washed with 5 % hydrochloric acid, 5 % sodium hydrogen carbonate, and dried with magnesium sulfate. After removal of the solvent, the residue was chromatographed on silica gel (20 g) using a mixture of ether and n-hexane (1 : 3) as an eluent to give the dichlorodihydro-2-furanone (16, 430 mg (75.1 %)); IR ν_{max}^{neat} cm^{-1}: 1772, 1646; NMR δ: 7.26 (5H, s), 5.27-5.15 (1H, m), 4.91-4.06 (2H, m), 4.51 (2H, s), 3.84 (2H, d, J=3.0 Hz); MS m/e: 286 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{12}O_3Cl_2$: m/e 286.0162. Found: m/e 286.0154.

5-Benzyloxymethyl-3-methyl-2-chloro-2,5-dihydro-2-furanone (18) A mixture of the dichlorodihydro-2-furanone (16, 150 mg (0.52 mmol)) and tri-n-butyltin hydride (0.17 ml (0.52 mmol)) in benzene (20 ml) was refluxed for 3 h in the presence of AIBN (3.4 mg (0.021 mmol)). The reaction mixture was treated as for the compound (8) and the crude product was chromatographed on silica gel (15 g) using a mixture of ether and n-hexane (1 : 3) as an eluent to give the monochloride (18, 78 mg (59.1 %)); IR ν_{max}^{neat} cm^{-1}: 1764, 1660; NMR δ: 7.27 (5H, s), 5.09-4.81 (1H, m), 4.53 (2H, s), 3.82-3.71 (2H, d, J=3.8 Hz), 2.06 (3H, s); MS m/e: 252 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{13}O_3Cl$: m/e 252.0553. Found: m/e 252.0568.

3-(2-Benzyloxy-1-chloroethyl)-2-chloro-2,5-dihydro-2-furanone (17) A mixture of the trichlorolactone (9, 500 mg (1.55 mmol)) and DBU (0.25 ml (1.71 mmol)) in benzene (20 ml) was refluxed for 18 h and the reaction mixture was treated as for the compound (16). The crude product was chromatographed on silica gel (15 g) using a mixture of ether and n-hexane (1 : 2) as an eluent to give the dichlodihydro-2-furanone (17, 300 mg (67.6 %)); IR ν_{max}^{neat} cm^{-1}: 1780, 1644; NMR δ: 7.27 (5H, s), 5.26-5.01 (1H, m), 4.93 (2H, s), 4.57 (2H, s), 3.87-3.77 (2H, m); MS m/e: 286 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{12}O_3Cl_2$: m/e

286.0162. Found: m/e 286.0145.

3-(2-Benzyloxyethyl)-2-chloro-2,5-dihydro-2-furanone (19) A mixture of the dichlorodihydro-2-furanone (17, 101 mg (0.35 mmol)) and tri-n-butyltin hydride (0.11 ml (0.35 mmol)) in benzene (5.5 ml) was refluxed for 4 h in the presence of AIBN (2.4 mg (0.015 mmol)). The reaction mixture was treated as for the compound (8) and the crude product was chromatographed on silica gel (10 g) using a mixture of ether and n-hexane (1 : 2) as an eluent to give the monochloride (19, 50 mg (56.3 %)); IR ν_{max}^{neat} cm^{-1}: 1762, 1648; NMR δ: 7.26 (5H, s), 4.81 (2H, s), 4.48 (2H, s), 3.65 (2H, t, J=5.4 Hz), 2.78 (2H, t, J=5.4 Hz); MS m/e: 252 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{13}O_3Cl$: m/e 252.0551. Found: m/e 252.0525.

5-Benzyloxymethylidene-3-methyl-2,5-dihydro-2-furanone (25) A mixture of the dichlorolactone (11, 200 mg (0.69 mmol)) and DBU (0.12 ml, 0.76 mmol) in benzene (10 ml) was refluxed for 12 h and the reaction mixture was treated as for the compound (16). The crude product was chromatographed on silica gel (10 g) using a mixture of ether and n-hexane (1 : 2) as an eluent to give the dienelactone (25, 65 mg (43.5 %)); IR ν_{max}^{neat} cm^{-1}: 1740; NMR δ: 7.40 (5H, s), 6.17 (1H, s), 5.67 (1H, s), 5.09 (2H, s), 2.06 (3H, s); MS m/e: 216 (M^+), 91 (100 %).

cis-2-(2-Benzyloxy-1-hydroxyethyl)cyclopropane-1-carboxylic Acid Lactone (26) To a solution of potassium tert-butoxide (31 mg (0.28 mmol) in tetrahydrofuran (3 ml) was added dropwise a solution of the monochlorolactone (13, 54 mg (0.21 mmol)) in tetrahydrofuran (5 ml) at 0 °C with stirring. After 5 min. brine was added to the reaction mixture and the mixture was extracted with methylene chloride. The extract was washed with brine and dried with magnesium sulfate. Evaporation of the solvent, followed by purification by silica gel preparative thin layer chromatography (ether-n-hexane 1 : 1) afforded the pure lactone (26, 40 mg (86.5 %)); IR ν_{max}^{neat} cm^{-1}: 1764; NMR δ: 7.29 (5H, s), 4.57 (2H, s), 4.45 (1H, t, J=4.0 Hz), 3.59 (2H, d, J=4.0 Hz), 2.35-1.91 (2H, m), 1.42-1.12 (1H, m), 1.03-0.73 (1H, m); MS m/e: 218 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{14}O_3$: m/e 218.0944. Found: m/e 218.0949.

cis-3-Benzyloxymethyl-2-hydroxymethylcyclopropane-1-carboxylic Acid Lactone (27) To a solution of potassium tert-butoxide (34 mg (0.31 mmol)) in tetrahydrofuran (7 ml) was added dropwise a solution of the monochlorolactone (14, 60 mg (0.24 mmol)) in tetrahydrofuran (5 ml) at 0 °C with stirring. After 5 min, brine was added to the reaction mixture and the mixture was extracted with methylene chloride. The extract was washed with brine, dried with magnesium sulfate, and evaporated to leave the pure lactone (27, 50 mg (97.3 %)); IR ν_{max}^{neat} cm^{-1}: 1776; NMR δ: 7.25 (5H, s), 4.47 (2H, s), 4.28-4.21 (2H, m), 3.72-3.20 (2H, m), 2.35-1.92 (2H, m), 1.63-1.32 (1H, m); MS m/e: 218 (M^+), 91 (100 %); Anal. Calcd. for $C_{13}H_{14}O_3$: m/e 218.0942. Found: m/e 218.0939.

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