Hz), 10.18 (br s, 5ξ-OH), 10.32 (s, 5′ξ-OH).

**3β-Acetoxy-5,6ξ-epidioxy-6ξ-(5′,6′α-epoxy-5′α-cholestan-3′β-yloxy)-5ξ-5,6-secocholestan-5-ol (13 3β-Acetate). A. From Acetylated Mixed Organization Products.** Acetylation of 600 mg of mixed cholesterol ozonization products and HPLC in system B at 2.5 mL/min, then in system C, and in system J gave 4.2 mg of **13** 3β-acetate as an amorphous solid: mp 154–155 °C; $t_R$ 16.1 min; $R_f$ 0.58 (system VI); IR (KBr) 3450, 3315, 1745, 1305, 1250, 1192, 1178, 1145, 1113, 1062, 1020, 984, 959, 930, 908, 874, 819, 800, 750, 735, 668, 607, 561, 527 cm$^{-1}$; IR ($CCl_4$) 3320, 1740 cm$^{-1}$; NMR δ 0.60 (3 H, s, 18′-H), 0.64 (3 H, s, 18-H), 1.04 (6 H, s, 19-H, 19′-H), 2.03 (3 H, s, $CH_3CO$), 2.31 (1 H, dd, $J$ = 7.8, 15.5 Hz, 4′α-H), 2.62 (1 H, dd, $J$ = 3.1, 13.6 Hz, 4α-H), 2.89 (1 H, d, $J$ = 4.1 Hz, 6′β-H), 3.96 (1 H, m, $W_{1/2}$ = 24 Hz, 3′α-H), 4.82 (1 H, dd, $J$ = 5.9, 9.9 Hz, 6ξ-H), 4.88 (1 H, m, $W_{1/2}$ = 27 Hz, 3α-H), 10.25 (1 H, s, 5ξ-OH). Anal. Calcd for $C_{56}H_{94}O_7$: C, 76.49; H, 10.78; O, 12.73. Found: C, 76.48; H, 11.04; O, 12.76.

**B. From 4b.** A solution of 5 mg of **4b** in 1 mL of $CCl_4$ was treated with 3.6 mg of *m*-chloroperbenzoic acid at 7 °C for 14 h and then was poured onto ice and products were extracted with benzene–diethyl ether (1:1, v/v). The organic layer was washed with saturated $NaHCO_3$ solution three times, with 1 M $H_2SO_4$ twice, with half-saturated $(NH_4)_2SO_4$, and with water and was dried over anhydrous $Na_2SO_4$. After removal of solvent under vacuum, chromatography on silica gel (230–400 mesh) with benzene–ethyl acetate (40:1, v/v) and HPLC in system I yielded 2.8 mg of **13** 3β-acetate as an amorphous solid, mp 150–154 °C, identical in spectral and chromatographic properties with **13** 3β-acetate recovered from section A.

**C. From 5,6α-Epoxy-5α-cholestan-3β-ol.** A solution of 46 mg of cholesterol 3β-acetate and 474 mg of 5,6α-epoxy-5α-cholestan-3β-ol (**15**) in 50 mL of $CCl_4$ was ozonized for 10 min in the usual manner. After removal of solvent under vacuum and chromatography on 230–400-mesh silica gel with benzene–ethyl acetate (40:1, v/v) there was recovered a major fraction (165 mg) containing **13** 3β-acetate, which upon HPLC in system J yielded 69.2 mg of pure **13** 3β-acetate, mp 154–156 °C, identical in spectral and chromatographic properties with **13** 3β-acetate prepared in A and B.

**5,6ξ-Epidioxy-6ξ-(5′,6′β-epoxy-5′β-cholestan-3′β-yloxy)-5ξ-5,6-secocholestane-3β,5-diol (14).** Rechromatography in system I of the HPLC fractions from which **8** and **9** had been recovered yielded 2.0 mg of pure **14** as an amorphous solid, $t_R$ 18.2 min: IR (KBr) 3450, 3320, 1250, 1230, 1214, 1177, 1150, 1115, 1072, 1050, 1013, 993, 980, 958, 924, 880, 825, 790 cm$^{-1}$; IR ($CCl_4$) 3640, 3315 cm$^{-1}$; NMR δ 0.63 (3 H, s, 18′-H), 0.64 (3 H, s, 18-H), 0.98 (3 H, s, 19′-H), 1.04 (3 H, s, 19-H), 2.04 (1 H, m, 4′α-H), 2.62 (1 H, d, $J$ = 14.1 Hz, 4α-H), 3.05 (1 H, s, 6′α-H), 3.86 (2 H, m, 3α-H, 3′α-H), 4.83 (1 H, dd, $J$ = 5.2, 9.9 Hz, 6ξ-H), 10.24 (1 H, s, 5ξ-OH).

**3β-Acetoxy-5,6ξ-epidioxy-6ξ-(5′,6′-β-epoxy-5′β-cholestan-3′β-yloxy)-5ξ-5,6-secocholestan-5-ol (14 3β-Acetate).** Following acetylation of 600 mg of total ozonization products of cholesterol as previously described and HPLC in system B at 2.5 mL/min, then in system C, and system J there was obtained 3.4 mg of **14** 3β-acetate as an amorphous solid: mp 171–173 °C; $t_R$ 16.9 min; $R_f$ 0.64 (system VI); IR (KBr) 3450, 3315, 1740, 1254, 1225, 1195, 1182, 1151, 1065, 1045, 1028, 1015, 996, 985, 963, 925, 883, 873, 823, 790, 670, 610 cm$^{-1}$; IR ($CCl_4$) 3320, 1740 cm$^{-1}$; NMR δ 0.63 (3 H, s, 18′-H), 0.64 (3 H, s, 18-H), 0.98 (3 H, s, 19′-H), 1.05 (3 H, s, 19-H), 2.04 (3 H, s, $CH_3CO$), 2.10 (1 H, m, 4′α-H), 2.63 (1 H, dd, $J$ = 3.1, 13.7 Hz, 4α-H), 3.06 (1 H, s, 6′α-H), 3.81 (1 H, m, $W_{1/2}$ = 24 Hz, 3′α-H), 4.84 (1 H, dd, $J$ = 5.8, 10.2 Hz, 6ξ-H), 4.90 (1 H, m, $W_{1/2}$ = 26 Hz, 3α-H), 10.22 (1 H, s, 5ξ-OH).

**Unidentified Components.** Material recovered from the $t_R$ 12.6 min and 12.8 min fractions was rechromatographed in system K, yielding a component with $t_R$ 8.6 min: IR (KBr) 3450, 3310, 1317, 1305, 1265, 1246, 1230, 1217, 1180, 1145, 1112, 1065, 1050, 1015, 955, 938, 878, 868, 837, 825, 796, 630, 607, 580, 565 cm$^{-1}$; IR ($CCl_4$) 3305 cm$^{-1}$; NMR δ 0.68 (6 H, s, 18-H, 18′-H), 1.05 and 1.10 (6 H, s, 19-H, 19′-H), 2.60 (1 H, m), 3.00 (1 H, d, $J$ = 7.0 Hz), 4.07 (1 H, m), 5.08 (1 H, t, $J$ = 7.0 Hz), 10.56 (1 H, s, 5ξ-OH).

Material recovered from the $t_R$ 13.2 min component from HPLC in system G was a mixture of components not further investigated.

# Chemistry of O-Silylated Ketene Acetals:[1] Stereocontrolled Synthesis of 2-Deoxy- and 2-Deoxy-2-*C*-alkyl-*erythro*-pentoses

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Diastereoselective aldol reactions of 2,3-*O*-isopropylidene-D-(and L-)-glyceraldehydes (D- and L-**2**) with ketene silyl acetal **1a** occurred in acetonitrile under mild conditions to give the corresponding *anti*-β-siloxy esters (D- and L-**3a**) as major products, which were converted to 2-deoxy-D-(and L-)-riboses through a few additional steps. The aldol reactions of D-**2** with α-monoalkyl-substituted ketene silyl acetals **1c–f** proceeded similarly to give all *anti*-α-alkyl-β-siloxy esters (**11a–14a**) as major products, which were converted into 2-deoxy-2-*C*-alkyl-*erythro*-pentoses (**17a,b**).

Although the aldol and the Michael reactions are important methods for carbon–carbon bond formation, these reactions with ester enolates are often complicated due to the occurrence of undesired side reactions. To overcome these problems, ketene silyl acetals are successfully used as the functional equivalents of ester enolates. Thus, ketene silyl acetals can react with carbonyl[2] and α,β-unsaturated carbonyl compounds[3] in the presence of Lewis acids [$TiCl_4$ and/or $Ti(i\text{-}PrO)_4$] to give the corresponding adducts in good yields. With Lewis acid, however, the synthetically useful O-silylated adducts could not be isolated. We have found that the use of acetonitrile as a solvent can greatly enhance the reactivity of ketene silyl acetals toward the α,β-unsaturated carbonyl compounds to give the corresponding O-silylated Michael adducts in

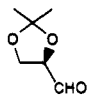
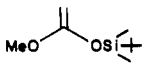
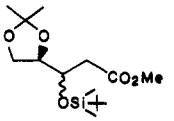
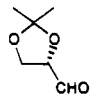
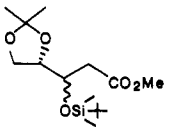
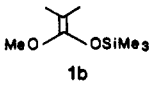
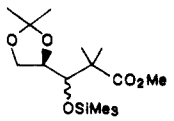
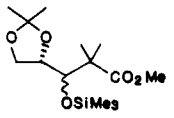
(1) For a recent review on the chemistry of O-silylated ketene acetals, see: Kita, Y.; Tamura, O.; Tamura, Y. *Yuki Gosei Kagaku Kyokaishi* **1986**, *44*, 1128.

(2) (a) Saigo, K.; Osaki, M.; Mukaiyama, T. *Chem. Lett.* **1975**, 989. (b) Reetz, M. T. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 556. (c) Gennari, C.; Beretta, M. G.; Bernardi, A.; Moro, G.; Scolastico, C.; Todeschini, R. *Tetrahedron* **1986**, *42*, 893 and references cited therein.

(3) (a) Saigo, K.; Osaki, M.; Mukaiyama, T. *Chem. Lett.* **1976**, 163. (b) Matsuda, I.; Murata, S.; Izumi, Y. *J. Org. Chem.* **1980**, *45*, 237. (c) Danishefsky, S.; Vaughan, K.; Gadwood, R.; Tsuzuki, K. *J. Am. Chem. Soc.* **1981**, *103*, 4136. (d) Heathcock, C. H.; Norman, M. H.; Uehling, D. E. *Ibid.* **1985**, *107*, 2797. (e) Heathcock, C. H.; Uehling, D. E. *J. Org. Chem.* **1986**, *51*, 279.

0022-3263/88/1953-0554$01.50/0 

**Table I. Aldol Reaction of 2,3-*O*-Isopropylidene-D-(and L-)-glyceraldehydes**

| entry | aldehydes | ketene silyl acetals | reaction conditions[a] | yield,[b] % | products | diastereoselectivity, anti:syn |
|---|---|---|---|---|---|---|
| 1 |  D-2 |  1a | no catalyst, 70 °C, 48 h | 73 |  D-3a,b | 83:17 |
| 2 | | | 0.05 equiv $ZnI_2$, 0 °C–rt, 48 h | 69 | | 93:7 |
| 3 | | | 1 equiv $ZnI_2$, rt–50 °C, 48 h | 36 | | 93:7 |
| 4 | | | 0.05 equiv $ZnBr_2$, 0 °C–rt, 48 h | 39 | | 85:15 |
| 5 | | | 0.05 equiv $ZnCl_2$, 0 °C–rt, 48 h | 44 | | 88:12 |
| 6 | | | 0.05 equiv $ZrCl_4$ ($CH_3CN$–$CH_2Cl_2$, 1:1), 0 °C–rt, 48 h | 13 | | 95:5 |
| 7 |  L-2 | 1a | no catalyst, 70 °C, 48 h | 69 |  L-3a,b | 85:15 |
| 8 | | | 0.05 equiv $ZnI_2$, 0 °C–rt, 48 h | 67 | | 96:4 |
| 9 | D-2 |  1b | no catalyst, 70 °C, 48 h | 65 |  D-9a,b | 75:25 |
| 10 | | | 0.05 equiv $ZnI_2$, 0 °C–rt, 48 h | 79 | | 90:10 |
| 11 | L-2 | 1b | no catalyst, 70 °C, 48 h | 62 |  L-9a,b | 77:23 |
| 12 | | | 0.05 equiv $ZnI_2$, 0 °C–rt, 48 h | 70 | | 91:9 |

[a] The use of catalytic amounts of other Lewis acids such as $SnCl_4$, $AlCl_3$, $TiCl_4$, $BF_3$·$Et_2O$, $MgBr_2$, and $FeCl_3$ in $CH_3CN$ gave no satisfactory result. [b] Distilled yields are given.

high yields.[4] Since then, considerable attention has been focused on the development of methodology for the aldol and the Michael addition reactions of ketene silyl acetals under neutral or nearly neutral conditions, and many useful methods have been reported. Thus, under high-pressure conditions[5] or in the presence of catalytic amounts of fluorine anion,[6] catalytic amounts of tris(dimethylamino)sulfonium difluorotrimethylsiliconate,[7] trityl perchlorate,[8] dimethylaluminum chloride,[9] or zinc chloride,[10] the silyl group transferred adducts could be obtained in good yields. In connection with this study, we have recently communicated[11] that the aldol reaction of 2,3-*O*-isopropylidene-D-(and L-)-glyceraldehydes (D- and L-**2**)[12] with ketene silyl acetal **1a** in acetonitrile proceeded high diastereoselectively to give the *anti*-β-siloxy esters (D- and L-**3a**), which were converted to 2-deoxy-D-(and L-)-riboses. We now give a full account of this work and additional studies on the aldol reactions of D-**2** with α-monoalkyl-substituted ketene silyl acetals leading to 2-deoxy-2-*C*-alkyl-*erythro*-pentoses.

**Diastereoselective Aldol Reaction of O-Silylated Ketene Acetals (1a,b) with 2,3-*O*-Isopropylidene-D-(and L-)-glyceraldehydes (D- and L-2).** The starting aldehydes (D- and L-**2**) were prepared from D-mannitol[13] and L-arabinose[14] by the reported methods. O-Silylated ketene acetal **1a** reacts smoothly with the aldehydes in acetonitrile to give the corresponding O-silylated 1,2-addition products **3a,b** in high yields. The effect of reaction conditions on the stereochemistry of the adducts was studied extensively (Table I), and the best result was achieved when the reaction was carried out at 0 °C to room temperature in the presence of catalytic amounts of zinc iodide in acetonitrile. Thus, **1a** added to D-**2** to give a 93:7 mixture of diastereomers, β-*tert*-butyldimethylsiloxy esters (D-**3a,b**) in 69% yield (entry 2), which were converted to (4*R*)-4-hydroxy-3,5-bis(phenoxyacetoxy)pentanoic acid 1,4-lactones (D-**4a,b**, R = $CH_2OPh$) by deblocking with

(4) (a) Kita, Y.; Segawa, J.; Haruta, J.; Fujii, T.; Tamura, Y. *Tetrahedron Lett.* **1980**, *21*, 3779. (b) Kita, Y.; Segawa, J.; Haruta, J.; Yasuda, H.; Tamura, Y. *J. Chem. Soc., Perkin Trans 1* **1982**, 1099.

(5) (a) Bunce, R. A.; Schlecht, M. F.; Dauben, W. G.; Heathcock, C. H. *Tetrahedron Lett.* **1983**, *24*, 4943. (b) Heathcock, C. H.; Mahain, C.; Schlecht, M. F.; Utawanit, T. *J. Org. Chem.* **1984**, *49*, 3264. (c) Yamamoto, Y.; Maruyama, K.; Matsumoto, K. *Tetrahedron Lett.* **1984**, *25*, 1075. (d) Matsumoto, K.; Sera, A.; Uchida, T. *Synthesis* **1985**, 1.

(6) Webster, O. W.; Hertler, W. R.; Sogah, D. Y.; Farnham, W. B.; RajanBabu, T. V. *J. Am. Chem. Soc.* **1983**, *105*, 5706.

(7) RajanBabu, T. V. *J. Org. Chem.* **1984**, *49*, 2083.

(8) (a) Mukaiyama, T.; Kobayashi, S.; Murakami, M. *Chem. Lett.* **1984**, *1759*. (b) Kobayashi, S.; Murakami, M.; Mukaiyama, T. *Ibid.* **1985**, 1535.

(9) Naruse, Y.; Ukai, J.; Ikeda, N.; Yamamoto, H. *Chem. Lett.* **1985**, 1451.

(10) Gray, B. D.; White, J. D. *J. Chem. Soc., Chem. Commun.* **1985**, 20.

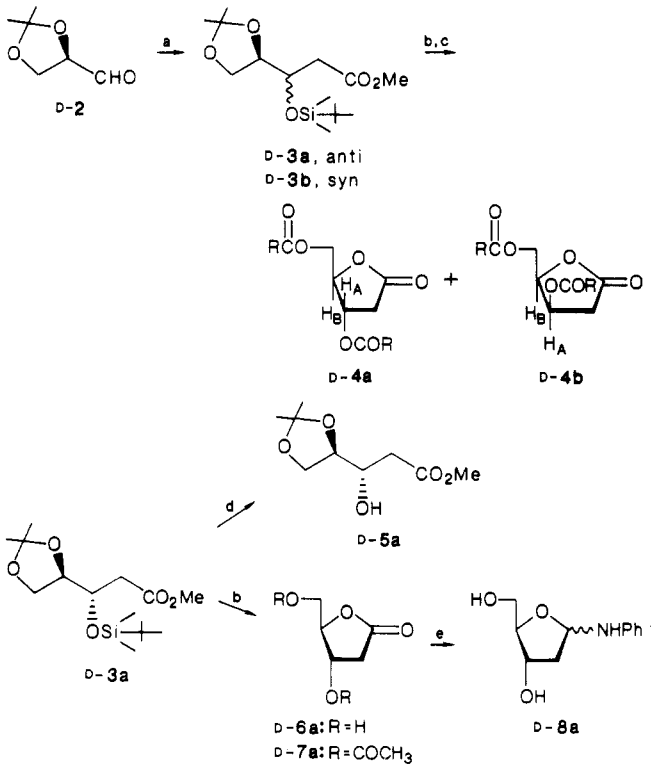
(11) Kita, Y.; Yasuda, H.; Tamura, O.; Itoh, F.; Ke, Y. Y.; Tamura, Y. *Tetrahedron Lett.* **1985**, *26*, 5777. Very recently, we have successfully applied this method to a synthesis of optically pure *N*-benzoyl-L-daunosamine: Kita, Y.; Itoh, F.; Tamura, O.; Ke, Y. Y.; Tamura, Y. *Tetrahedron Lett.* **1987**, *28*, 1431.

(12) 2,3-*O*-Isopropylidene-D-(and L-)-glyceraldehyde has became an extremely valuable chiral building block for organic synthesis. For reviews, see: (a) McGarvey, G. J.; Kimura, M.; Oh, T.; Williams, J. M. *Carbohydr. Chem.* **1984**, *3*, 125. (b) Jurczak, J.; Pikul, S.; Bauer, T. *Tetrahedron* **1986**, *42*, 447.

(13) (a) Baer, E.; Fischer, H. O. L. *J. Am. Chem. Soc.* **1939**, *61*, 761. (b) Debost, J.-L.; Gelas, J.; Horton, D. *J. Org. Chem.* **1983**, *48*, 1381.

(14) Baker, S. B. *J. Am. Chem. Soc.* **1952**, *74*, 827.

**Scheme I**[a]




[a] a, **1a**, $CH_3CN$; b, $CF_3CO_2H$, $H_2O$; c, $(RCO)_2O$, Pyr; d, *n*-$Bu_4NF$; e, $(Sia_2BH)_2$, $PhNH_2$.

aqueous trifluoroacetic acid followed by treatment with phenoxyacetic anhydride in pyridine (Scheme I). The stereostructure of D-**3a,b** was tentatively assigned by the comparison of the *J* values of the $^1H$ NMR coupling constant between $H_A$ and $H_B$ of D-**4a,b** with those of anti-*O,O'*-diacylated analogues (D-**4a**, R = Ph, *J* = 2 Hz; D-**4a**, R = Me; *J* = 1.75 Hz)[15] and was finally established by the chemical transformation of D-**3a** to the known compounds: The pure D-**3a** readily obtained from the mixture of diastereomers (D-**3a**/D-**3b** = 93:7) by column chromatography on silica gel was desilylated with tetra-*n*-butylammonium fluoride in tetrahydrofuran (THF) to give a 92% yield of the known β-hydroxy ester (D-**5a**).[16] Furthermore, D-**3a** was deblocked with aqueous trifluoroacetic acid at room temperature to give a quantitative yield of 2-deoxy-D-ribono-1,4-lactone (D-**6a**), which was acetylated with acetic anhydride and 4-(dimethylamino)pyridine (DMAP) in pyridine to give the diacetate (D-**7a**).[15b] All these spectral and physical data are in good accord with those of the corresponding anti derivatives. Reduction of D-**6a** by disiamylborane [$(Sia_2BH)_2$] in THF followed by treatment with aniline in aqueous ethanol gave a 66% yield of 2-deoxy-D-ribose anilide (D-**8a**). Similarly, reaction of 2,3-*O*-isopropylidene-L-glyceraldehyde (L-**2**) with **1a** gave a mixture of diastereomers of the β-*tert*-butyldimethylsiloxy esters (L-**3a,b**) in a similar high diastereoselection (entries 7 and 8). The separated L-**3a** was readily converted to 2-deoxy-L-ribose anilide (L-**8a**) in 64% overall yield by a series of reactions mentioned in the D series. The present method for 2-deoxy-D-(and L-)-riboses is advantageous over

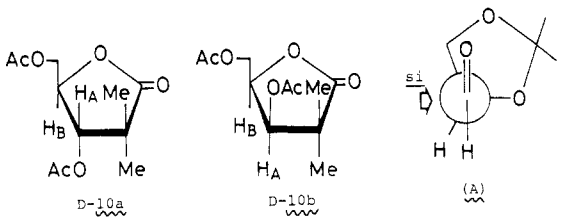



**Figure 1.**

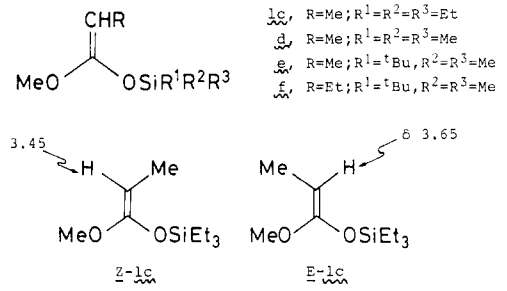



**Figure 2.**

the reported methods[16-18] in terms of highly asymmetric induction, ease of performance and workup, short reaction step, and high overall yield of the product.

We also investigated the reaction of D- and L-**2** with the 1-methoxy-2-methyl-1-(trimethylsiloxy)propene (**1b**) under similar conditions, which proceeded anti selectively to give a mixture of diastereomers of the corresponding β-trimethylsiloxy esters (D-**9a,b** and L-**9a,b**). These results are listed in Table I. The stereochemistry of these compounds is assigned by the comparison of the chemical shift and the coupling constant of $H_A$ of 3,5-diacetoxy-2,2-dimethyl-4-hydroxypentanoic acid 1,4-lactones (D- and L-**10**) with those of the related anti and syn diastereomers[18a] (Figure 1).

The possibility of epimerization under the reaction conditions was examined by careful NMR study of D-(and L)-**10** by using tris[3-[(trifluoromethyl)hydroxymethylene]-*d*-camphorato]europium(III) derivative [Eu(tfc)$_3$] as the chiral shift reagent. The methine doublet ($H_A$) at δ 5.33 (*J* = 3.8 Hz) of racemic **10b** (1:1 mixture of D- and L-**10b**) shifted to doublets at δ 5.98 and 6.03 in contrast to the fact that the optically active D-**10b** shifted the resonance only to δ 5.98 (no detectable peak at δ 6.03) and L-**10b** only to δ 6.03 (no detectable peak at δ 5.98). These results clearly show that epimerization was not observed in the present reaction of **1** and **2**.

The observed diastereoselective may arise from the *si* face addition via a Felkin–Anh type transition state (A).[19]

**Diastereoselective Aldol Reaction of α-Monoalkyl-Substituted Ketene Silyl Acetals (1c–f) with 2,3-*O*-Isopropylidene-D-glyceraldehyde (D-2).** Our attention has been focused on the stereochemistry of the aldol reaction of α-monoalkyl-substituted ketene silyl acetals (**1c–f**) with D-**2**. One may anticipate that the ge-

(15) It has been reported that the erythro isomer of 3,5-bis(benzoyloxy)- and -diacetoxy-4-hydroxypentanoic acid 1,4-lactones have the smaller coupling constants (*J* = 2 and 1.75 Hz) than those (*J* = 4.6 and 4.75 Hz) of threo isomers: (a) Bock, K.; Lundt, I.; Pedersen, C. *Carbohydr. Res.* **1981**, *90*, 17. (b) Rague, B.; Chapleur, Y.; Castro, B. *J. Chem. Soc., Perkin Trans. 1* **1982**, 2063.

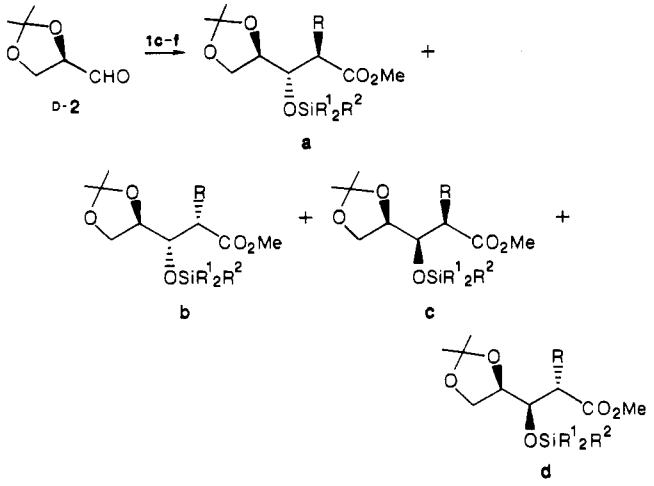
(16) Kozikowski, A. P.; Ghosh, A. K. *J. Org. Chem.* **1984**, *49*, 2762.

(17) (a) Murakami, M.; Mukaiyama, T. *Chem. Lett.* **1982**, 241. (b) Nakaminami, G.; Shioi, S.; Sugiyama, Y.; Isemura, S.; Shibuya, M.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1972**, *45*, 2624.

(18) (a) Shono, T.; Kise, N.; Suzumoto, T. *J. Am. Chem. Soc.* **1984**, *106*, 259. (b) Heathcock, C. H.; Young, S. D.; Hagen, J. P.; Pirrung, M. C.; White, C. T.; VanDerveer, D. *J. Org. Chem.* **1980**, *45*, 3846. (c) Harada, T.; Mukaiyama, T. *Chem. Lett.* **1981**, 1109. (d) Mulzer, J.; Kappert, M.; Huttner, G.; Jibril, I. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 704.

(19) (a) Chérest, M.; Felkin, H.; Prudent, N. *Tetrahedron Lett.* **1968**, 2199. (b) Anh, N. T.; Eisentein, O. *Nouv. J. Chim.* **1977**, *1*, 61. Although we proposed[11] the β-chelated[2b] model for the enhancement of the anti selectivity, it might not be significant by considering the stereochemical results of α-monoalkyl-substituted ketene silyl acetals (**1c–f**) with D-**2** (vide infra).

**Table II. Aldol Reaction of D-2 with Monoalkylated Ketene Silyl Acetals 1c–f**




| entry | ketene silyl acetals | products | yield, % | ratio a:b:(c + d) |
|---|---|---|---|---|
| 1 | (*Z*)-**1c** | **11**: R = Me; $R^1 = R^2$ = Et | 51 | 77:15:8 |
| 2 | (*E*)-**1c** (*E*/*Z* = 2/1) | | 60 | 65:30:5 |
| 3 | (*E*)-**1d** | **12**: R = $R^1 = R^2$ = Me | 50 | 64:24:12 |
| 4 | (*Z*)-**1e** | **13**: R = $R^1$ = Me; $R^2$ = *t*-Bu | 65 | 76:14:10 |
| 5 | (*Z*)-**1f** | **14**: R = Et; $R^1$ = Me; $R^2$ = *t*-Bu | 45 | 84:10:6 |
| 6 | (*E*)-**1f** | | 57 | 83:9:8 |

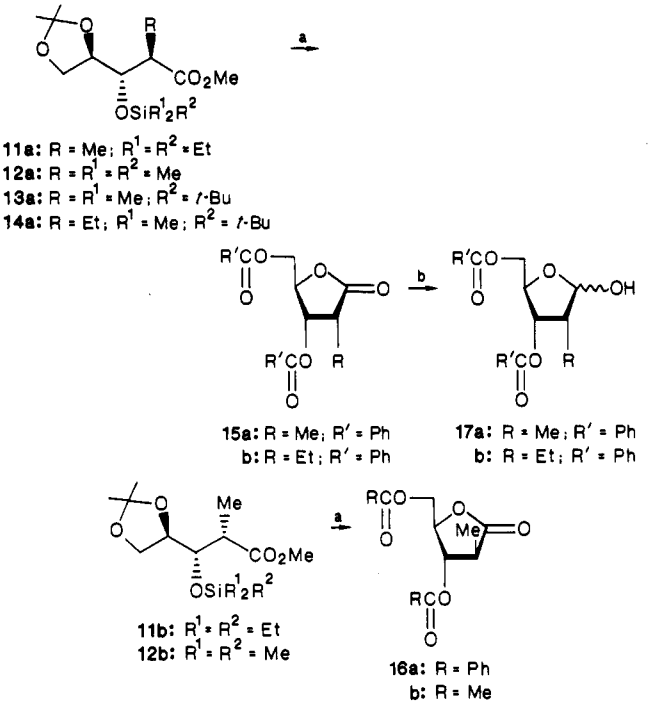
ometry of the α-substituent plays an important role in the stereochemistry of the reactions. In the aldol reaction of **1c–f** with D-**2**, however, the stereochemistry of the adducts is independent of the geometry of the acetals, and the all-anti adducts (**11a–14a**) are obtained as major products in every entry. The preparation of the (*Z*)- and (*E*)-acetals [(*Z*)- and (*E*)-**1c–f**], the stereochemistry of the addition, and the mechanism are described in this paper.

The starting α-monoalkyl-substituted (*Z*)- and (*E*)-ketene silyl acetals [(*Z*)- and (*E*)-**1c–f**] were prepared from the corresponding esters by the known methods or by minor modification of standard procedures and are described in the Experimental Section. The assignment of the geometry of ketene silyl acetals was made by $^1$H NMR spectroscopy on the basis of the resonance of the vinyl protons of (*E*)-ketene silyl acetals at more downfield than those of (*Z*)-ketene acetals;[20] for example, the vinyl proton of (*Z*)-**1c** was observed at δ 3.45 and that of (*E*)-**1c** at δ 3.65 (Figure 2).

The aldol reaction of α-monoalkyl-substituted ketene silyl acetals (**1c–f**) with D-**2** is generally carried out at 0 °C to room temperature in acetonitrile in the presence of catalytic amounts of zinc iodide. Thus, (*Z*)-**1c** reacted with D-**2** to give a 77:15:4:4 mixture of diastereomers of β-triethylsiloxy esters (**11a–d**) in 51% yield as shown by 500-MHz $^1$H NMR spectroscopy (Table II, entry 1). On the other hand, the reaction of (*E*)-**1c** (*E*/*Z* = 2/1) with D-**2** under similar conditions gave a 65:30:3:2 mixture of diastereomers of **11a–d** in 60% yield (entry 2), and the ratio of products was nearly the same order. Two major products (**11a** and **11b**) were isolated by column chromatography on silica gel. The stereostructure of main products **11a** and **11b** was tentatively assigned by the consideration

(20) (a) Wilcox, C. S.; Babston, R. E. *J. Org. Chem.* **1984**, *49*, 1451. (b) Ireland, R. E.; Mueller, R. H.; Willard, A. K. *J. Am. Chem. Soc.* **1976**, *98*, 2868.

**Scheme II**[a]




[a] a, $CF_3CO_2H$, $H_2O$; PhCOCl, Pyr; b; DIBAL-H, THF.

of their coupling constants between $C_2$ and $C_3$ protons in the $^1$H NMR spectra: It is known that the methine protons at the 3-position of 2,3-*anti*-β-siloxy esters resonate more upfield with larger *J* values than those of 2,3-*syn*-β-siloxy esters.[10,18b] The methine proton at the 3-position of **11a** was observed at δ 4.26 ($J_{2,3}$ = 4.1 Hz), while that of **11b** was observed at δ 4.37 ($J_{2,3}$ = 2.8 Hz). These results suggest that **11a** is a 2,3-anti adduct and **11b** is a 2,3-syn adduct. Finally, these structures were confirmed by the conversion of **11a** and **11b** into the known lactones:[21] The ester **11a** was deblocked with aqueous trifluoroacetic acid to give the 2-deoxy-2-methyl-D-*ribo* 1,4-lactone, which was acylated with benzoyl chloride in pyridine to give the *O,O'*-dibenzoyl lactone **15a** in 63% overall yield (Scheme II). Similarly, **11b** was converted to the *O,O'*-dibenzoyl-2-deoxy-2-methyl-D-*arabino* 1,4-lactone **16a** in 52% yield.

Other (*Z*)- and (*E*)-α-monoalkyl-substituted ketene silyl acetals (**1d–f**) react similarly with D-**2** to give the all-anti adducts (**12a–14a**) as main products (entries 3–6). The large α-substituent (R) makes a high diastereoselection to afford the all-anti adduct predominantly (entries 5 and 6).

While the details of the diastereoselection of these reactions remain unknown, the mechanism can be rationalized as follows. The aldol reaction of α-monoalkyl-substituted ketene silyl acetals (**1c–f**) with D-**2** may proceed via acyclic transition state because the aldol reaction gave the 2,3-anti adducts (**12a–14a**) as main products, which were independent of the geometry of the ketene silyl acetals. The diastereofacial selection (3,4-anti selection) arises from the *si* face addition via a Felkin–Anh type transition state. If zinc iodide could form the β-chelation between oxygen of the carbonyl group and β-oxygen of the dioxolane ring, the reaction should give 2,3-syn adducts as main products via acyclic transition state.[22] Conse-

(21) Bernardi, A.; Beretta, M. G.; Colombo, L.; Gennari, C.; Poli, G.; Scolastico, C. *J. Org. Chem.* **1985**, *50*, 4442.

(22) (a) Reetz, M. T.; Jung, A. *Tetrahedron* **1984**, *40*, 4327. (b) Oppolzer, W.; Marco-Contelles, J. *Helv. Chim. Acta* **1986**, *69*, 1699 and see ref 2b.

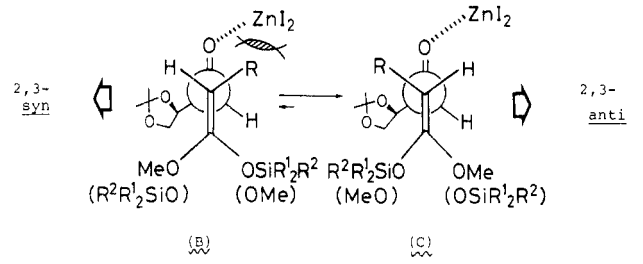



**Figure 3.**

quently, zinc iodide may coordinate to oxygen of the aldehyde with anti geometry for the dioxolane ring adjacent to aldehyde, and the following two transition states (B and C) are considered as picture in Figure 3.

Transition state B has severe steric repulsion between the $\alpha$-substituent (R) of ketene silyl acetal and zinc iodide.[22] On the other hand, transition state C has no such severe repulsion and is sterically demanding. Thus, ketene silyl acetals may attack from the *si* face of the aldehyde via transition state C to give the all-anti adducts as main products.

The structure of the siloxy esters **12a–14a** was assigned from their spectral data and their conversion into the corresponding *ribo* lactones (**15a,b**). Very recently, a mixture of *ribo* and *arabino* lactones (**15a,c** and **16a,b**) was obtained from D-**2** by different two methods,[18b,21] both of which gave an unseparable mixture of diastereomers of *ribo* and *arabino* lactones in which *arabino* isomers **16a,b** are major products. It should be noted that our aldol reaction gives the all anti adducts **11a–14a** predominantly, which could be converted into the *ribo* lactones **15a,b**. Reduction of **15a,b** by diisobutylaluminum hydride gave the corresponding 2-deoxy-2-*C*-alkyl-substituted *erythro*-D-pentoses (**17a,b**) in 51%[23] and 34% yields, respectively. Further studies on the aldol reaction of some $\alpha$-monoheteroatom substituted ketene silyl acetals with D-**2** are in progress.

## Experimental Section

All melting and boiling points are uncorrected. $^1$H NMR spectra were recorded on a Hitachi R-22 (90 MHz) or a JEOL JNM-GX 500 (500 MHz) spectrometer (with tetramethylsilane as an internal standard unless otherwise noted). IR absorption spectra were recorded on a JASCO HPIR-102 spectrometer. Low- and high-resolution mass spectra (MS) were obtained with a JEOL JMS D-300 instrument, with a direct inlet system at 70 eV. Optical rotations were measured in 1-dm cells of 1-mL capacity with a Perkin-Elmer 241 instrument. GLC analyses were performed on a Shimazu GC-4B instrument with a butanediol succinate polyester packed column. For column chromatography, E. Merck silica gel (70–230 mesh ASIM) was used. The known ketene silyl acetals and 2,3-*O*-isopropylidene-D-(and L-)-glyceraldehydes were prepared by the reported methods: **1a**,[4] **1b**,[24] **1d**,[4] **1e**,[20a] **1f**,[20b] D-**2**,[13] L-**2**.[14]

**(*Z*)-1-Methoxy-1-(triethylsiloxy)propene [(*Z*)-1c].** This was obtained by minor modification of the reported method.[25] To a stirred suspension of trityl perchlorate (1.147 g, 3.34 mmol) in dry $CH_2Cl_2$ (7 mL) was added dropwise triethylsilane (0.57 mL, 3.67 mmol) at −50 °C under nitrogen. The mixture was further stirred for 5 min and allowed to warm to room temperature. After being stirred for additional 1 h, this solution was ready for use as triethylsilyl perchlorate. Excess (7 mL) $CCl_4$ was added, and the mixture was cooled to −50 °C. *N,N*-Diisopropylethylamine (0.79 mL, 4.54 mmol) and methyl propionate (0.29 mL, 3.01 mmol) were added to the solution. After the mixture was stirred at −50 °C for 5 h, 1,1,3,3-tetramethylguanidine (1.37 mL, 10.9 mmol) was added to the solution at −50 °C. After the mixture was stirred for 10 min, methanol (0.24 mL) was added to the solution. After 30 min, the mixture was diluted with pentane (12 mL), poured into ice-cooled pentane (70 mL), and then washed with 0.01 N NaOH (12 mL × 2). The organic layer was dried over $MgSO_4$ and concentrated under reduced pressure. The residue was distilled to give a 57% yield (350 mg) of (*Z*)-**1c** as a colorless liquid: bp 60–65 °C/(1 mmHg); $^1$H NMR ($CDCl_3$) $\delta$ 0.4–1.3 (m, 15 H, $SiEt_3$), 1.51 (d, 3 H, $J$ = 7 Hz, *Me*CH=), 3.45 (q, 1 H, $J$ = 7 Hz, MeC*H*=), 3.48 (s, 3 H, OMe); IR ($CHCl_3$) 1680, 1010, 895 cm$^{-1}$. Anal. Calcd for $C_{10}H_{22}O_2Si$: C, 59.35; H, 10.96. Found: C, 59.25; H, 11.15.

**(*E*)-1-Methoxy-1-(triethylsiloxy)propene [(*E*)-1c].** A 1.5 M solution of *n*-butyllithium in hexane (20 mL, 30 mmol) was added dropwise to a stirred solution of diisopropylamine (4.2 mL, 30 mmol) in dry THF (30 mL) at 0 °C under nitrogen. The mixture was further stirred for 15 min and subsequently cooled to −78 °C. Methyl propionate (2.88 mL, 30 mmol) was added dropwise to the solution at −78 °C under nitrogen, and the mixture was stirred for an additional 1 h. Triethylsilyl chloride (4.52 g, 30 mmol) was added dropwise with stirring at −78 °C over 7 min, and the mixture was stirred for 6 h under the conditions, allowed to warm to room temperature, and stirred for 10 h. Methyl iodide (5 g) and pentane (20 mL) were added. The flask was left in a refrigerator for 12 h, and precipitates were removed by filtration under reduced pressure with exclusion of moisture. The filtrate was concentrated under reduced pressure. The residual oil was distilled to give a 53% yield (3.23 g) of (*E*)-**1c** as a mixture of geometrical isomers (*E*/*Z* = 2/1): bp 76–85 °C (1.7 mmHg); $^1$H NMR ($CDCl_3$) $\delta$ 0.4–1.3 (m, 15 H, $SiEt_3$), 1.48 [d, 2 H, $J$ = 7 Hz, *Me*CH=, (*E*)], 1.51 [d, 1 H, $J$ = 7 Hz, *Me*CH=, (*Z*)], 3.45 [q, 0.33 H, $J$ = 7 Hz, MeC*H*=, (*Z*)], 3.48 [s, 1 H, OMe, (*Z*)], 3.54 [s, 2 H, OMe, (*E*)], 3.65 [q, 0.66 H, $J$ = 7 Hz, MeC*H*=, (*E*)]; IR ($CHCl_3$) 1680, 1010, 895 cm$^{-1}$. Anal. Calcd for $C_{10}H_{22}O_2Si$: C, 59.35; H, 10.96. Found: C, 59.13; H, 10.81.

**General Procedure for the Reaction of Ketene Silyl Acetals (1) with Aldehydes (2). (i) Aldol Reaction in the Absence of Lewis Acid.** To a stirred solution of aldehyde (**2**; 2.6 g, 20 mmol) in dry $CH_3CN$ (20 mL) was added ketene silyl acetal (**1**; 20 mmol) under nitrogen. The mixture was stirred at 70 °C for the period indicated in Table I and concentrated under reduced pressure. The residual oil was distilled under reduced pressure to give the methyl 3-siloxy-4,5-(isopropylidenedioxy)-pentanoate (**3**, **9**).

**(ii) Aldol Reaction in the Presence of Catalytic Amounts of Lewis Acid.** To a stirred solution of aldehyde (**2**; 20 mmol) and Lewis acid (1 mmol) in dry $CH_3CN$ (20 mL) was added ketene silyl acetal (**1**; 24 mmol) at 0 °C. After the mixture was stirred at room temperature for the period indicated in Tables I and II, pyridine (178 mg, 2 mmol) was added. The mixture was concentrated under reduced pressure. *n*-Hexane–ether (1:1, 50 mL) was added to the residue, and the mixture was stirred vigorously. Precipitates were removed by filtration. The filtrate was work up in the same manner as described in (i) to give the methyl 3-siloxy-4,5-(isopropylidenedioxy)pentanoate (**3**, **9**, **11–14**).

**Methyl (4*R*)-3-(*tert*-Butyldimethylsiloxy)-4,5-(isopropylidenedioxy)pentanoates (D-3a,b).** An 83:17 mixture of diastereomers (232 mg) of D-**3a,b** was obtained from **1a** (282 mg, 1.5 mmol) and D-**2** (130 mg, 1 mmol) in dry $CH_3CN$ (3 mL). A 93:7 mixture of diastereomers (4.40 g) of D-**3a,b** was obtained from **1a** (4.51 g, 24 mmol), D-**2** (2.60 g, 20 mmol), and $ZnI_2$ (319 mg, 1 mmol) in dry $CH_3CN$ (20 mL). These mixtures were subjected to column chromatography on silica gel with *n*-hexane–ether, 10:1, to give methyl (3*S*,4*R*)-3-(*tert*-butyldimethylsiloxy)-4,5-(isopropylidenedioxy)pentanoate (D-**3a**) and methyl (3*R*,4*R*)-3-(*tert*-butyldimethylsiloxy)-4,5-(isopropylidenedioxy)pentanoate (D-**3b**). D-**3a**: bp 130–140 °C (0.3 mmHg) (bath temperature); $[\alpha]^{22}_D$ −3.3° (*c* 1.205, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) $\delta$ 0.05 (s, 3 H, SiMe), 0.09 (s, 3 H, SiMe), 0.85 (s, 9 H, Si-*t*-Bu), 1.33 (s, 3 H, *Me*CMe), 1.39 (s, 3 H, MeC*Me*), 2.4–2.7 (m, 2 H, 2,2′-H), 3.67 (s, 3 H, OMe), 3.8–4.3 (m, 4 H, 3,4,5,5′-H); IR ($CHCl_3$) 1730, 1260, 1085, 840 cm$^{-1}$. Anal. Calcd for $C_{15}H_{30}O_5Si$: C, 56.57; H, 9.49. Found: C, 56.39; H, 9.77. D-**3b**: bp 125–135 °C (0.5 mmHg) (bath temperature); $[\alpha]^{22}_D$ +35° (*c* 0.736, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) $\delta$ 0.04 (s, 3 H, SiMe), 0.08 (s, 3 H, SiMe), 0.85 (s, 9 H, Si-t-Bu),

(23) Cf.: Novák, J. J. K.; Smejkae, J.; Sorm, F. *Collect. Czech. Chem. Commun.* **1971**, *36*, 3670.
(24) Ainsworth, C.; Chen, F.; Kuo, Y.-N. *J. Organomet. Chem.* **1972**, *46*, 59.
(25) (a) Wilcox, C. S.; Babston, R. E. *Tetrahedron Lett.* **1984**, *25*, 699. (b) Wilcox, C. S.; Babston, R. E. *Synthesis* **1985**, 941.

1.33 (s, 3 H, *Me*CMe), 1.40 (s, 3 H, MeC*M*), 2.3–2.6 (m, 2 H, 2,2′-H), 3.67 (s, 3 H, OMe), 3.8–4.6 (m, 4 H, 3,4,5,5′-H); IR ($CHCl_3$) 1730, 1260, 1085, 840 $cm^{-1}$. Anal. Calcd for $C_{15}H_{30}O_5Si$: C, 56.57; H, 9.49. Found: C, 56.35; H, 9.72.

**(4*R*)-4-Hydroxy-3,5-bis(phenoxyacetoxy)pentanoic Acid 1,4-Lactones (D-4a,b).** To a 93:7 mixture of diastereomers (3.5 g, 11 mmol) of D-**3a,b** was added $CF_3CO_2H$–$H_2O$ (3:2, 30 mL) at room temperature. The mixture was stirred for 15 h, concentrated under reduced pressure, and diluted with ethyl acetate (70 mL). The organic layer was washed with saturated aqueous NaCl, dried over $MgSO_4$, and concentrated under reduced pressure. To the residual oil were added pyridine (12 g, 154 mmol) and phenoxyacetic anhydride (4.4 g, 43 mmol) at room temperature, and the mixture was stirred for 20 h under the same conditions. The mixture was concentrated under reduced pressure and diluted with ethyl acetate (70 mL). The organic layer was washed with saturated aqueous NaCl, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was subjected to column chromatography on silica gel with benzene–ethyl acetate, 5:1, to give a 43% yield (1.9 g) of the lactones D-**4a,b**: $^1H$ NMR ($CDCl_3$–$CD_3OD$, 1:1) $\delta$ 2.58 (dd, 1 H, $J$ = 18.5 and 7.4 Hz, 2-H), 2.95 (dd, 1 H, $J$ = 18.5 and 2 Hz, 2′-H), 4.43 (dd, 1 H, $J$ = 12 and 3.5 Hz, 5-H), 4.54 (dd, 1 H, $J$ = 12 and 3 Hz, 5′-H), 4.75 (s, 4 H, $PhOCH_2CO$ × 2), 4.79 (ddd, 1 H, $J$ = 3.5, 3, and 2 Hz, 4-H), 5.44 (dt, 1 H, $J$ = 7.4, and 2 Hz, 3-H), 6.86–7.06 (m, 6 H, Ar H), 7.24–7.36 (m, 4 H, Ar H); IR ($CHCl_3$) 1790, 1765 $cm^{-1}$. Anal. Calcd for $C_{21}H_{20}O_8$: C, 63.00; H, 5.03. Found: C, 62.90; H, 5.01.

**Methyl (3*S*,4*R*)-3-Hydroxy-4,5-(isopropylidenedioxy)pentanoate (D-5a).** To a stirred solution of D-**3a** (32 mg, 0.1 mmol) in dry THF (0.5 mL) was added a solution of tetra-*n*-butylammonium fluoride (26.3 mg 0.1 mmol) in dry THF (0.5 mL) at room temperature under nitrogen. The mixture was further stirred for 30 min and concentrated in vacuo. The residue was subjected to column chromatography on silica gel with *n*-hexane–ethyl acetate, 3:1, to give a 92% yield (19 mg) of D-**5a** as a colorless liquid, $[\alpha]^{24}_D$ −11.5° *c* 0.755, $CH_2Cl_2$) [Lit.[16] $[\alpha]^{24}_D$ −11.2° (*c* 0.602, $CH_2Cl_2$)]. All spectral data were identical with those of an authentic sample.

**(3*S*,4*R*)-3,5-Diacetoxy-4-hydroxypentanoic Acid 1,4-Lactone (D-7a).** A solution of the siloxy ester D-**3a** (96 mg, 0.302 mmol) in $CF_3CO_2H$–$H_2O$ (10:1, 2.75 mL) was stirred at room temperature for 3 h and concentrated under reduced pressure. The residue was subjected to column chromatography on silica gel with $CHCl_3$–MeOH, 9:1, to give a quantitative yield (42 mg) of D-**6a**: $^1H$ NMR [$D_2O$, 2,2-dimethyl-2-silapentane-5-sulfonic acid sodium salt (DSS) as an internal standard] $\delta$ 2.55 (dd, 1 H, $J$ = 18.5 and 3 Hz, 2-H), 3.02 (dd, 1 H, $J$ = 18.5 and 6.5 Hz, 2′-H), 3.5–4.0 (m, 2 H, 5,5′-H), 4.4–4.8 (m, 2 H, 3,4-H); IR (neat) 3500, 1750 $cm^{-1}$. Acetylation of D-**6a** by a usual method with acetic anhydride and DMAP in pyridine gave the acetate, which was purified by column chromatography on silica gel with *n*-hexane–ethyl acetate, 3:2, to give a pure D-**7a** as a colorless oil; $[\alpha]^{25}_D$ −5.2° (*c* 0.929, EtOH) [lit.[15b] $[\alpha]^{25}_D$ −5.2° (*c* 0.93, EtOH)]. All spectral data were identical with those of an authentic sample.

**2-Deoxy-D-ribose Anilide (D-8a).** A 0.5 M solution of disiamylborane in dry THF (6 mL, 3 mmol) was added dropwise to a stirred solution of D-**6a** (68 mg, 0.52 mmol) in dry THF (1.5 mL) at room temperature under argon. The mixture was stirred for 20 h under the same conditions, quenched with water (11.5 mL), and diluted with ether (15 mL). The mixture was stirred vigorously, and the organic layer was extracted with water (15 mL × 3). The combined aqueous layer was washed with ether (20 mL × 4) and concentrated under reduced pressure below 30 °C. The resulting residue was dissolved in methanol, and the solvent was azeotropically removed under reduced pressure. The residue was mixed with an aqueous ethanolic aniline solution [0.61 mL, prepared from aniline (1.8 mL), ethanol (15 mL), and water (7 mL)], and the mixture was placed in a refrigerator. The crystals deposited were collected by filtration and washed with 50% aqueous methanol to give a 66% yield (72 mg) of D-**8a** as colorless needles: mp 167–167.5 °C (EtOH); $[\alpha]^{20}_D$ +57° (after 30 h, *c* 0.873, pyridine) [lit.[17] mp 167–169 °C; $[\alpha]^{20}_D$ +56° (after 30 h, *c* 0.99, pyridine)].

**Methyl (4*S*)-3-(*tert*-Butyldimethylsiloxy)-4,5-(isopropylidenedioxy)pentanoates (L-3a,b).** An 85:15 mixture of diastereomers (877 mg) of L-**3a,b** was obtained from **1a** (893 mg, 4.75 mmol) and L-**2** (520 mg, 4 mmol) in dry $CH_3CN$ (10 mL). A 96:4 mixture of diastereomers (851 mg) of L-**3a,b** was obtained from **1a** (893 mg, 4.75 mmol), L-**2** (520 mg, 4 mmol), and $ZnI_2$ (63 mg, 0.20 mmol) in dry $CH_3CN$ (10 mL). These mixtures were separated by the same way as in the case of D-**3a,b** to give methyl (3*R*,4*S*)-3-(*tert*-butyldimethylsiloxy)-4,5-(isopropylidenedioxy)-pentanoate (L-**3a**) and methyl (3*S*,4*S*)-3-(*tert*-butyldimethylsiloxy)-4,5-(isopropylidenedioxy)pentanoate (L-**3b**). L-**3a**: bp 150–160 °C (1 mmHg) (bath temperature); $[\alpha]^{22}_D$ +3.4° (*c* 0.990, $CH_2Cl_2$). L-**3b**: bp 140–160 °C (0.8 mmHg) (bath temperature); $[\alpha]^{22}_D$ −35° (*c* 0.565, $CH_2Cl_2$). All spectral data for L-**3a** and L-**3b** were identical with those of D-**3a** and D-**3b**.

**(3*R*,4*S*)-3,5-Diacetoxy-4-hydroxypentanoic Acid 1,4-Lactone (L-7a).** This was prepared from L-**3a** by the same method as described for the preparation of D-**7a**, $[\alpha]^{25}_D$ +5.1° (*c* 0.642, EtOH). All spectral data were identical with those of D-**7a**.

**2-Deoxy-L-ribose Anilide (L-8a).** This was prepared from L-**6a** by the same method as described for the preparation of D-**8a**: mp 167–168 °C (EtOH); $[\alpha]^{20}_D$ −56° (after 38 h, *c* 0.686, pyridine).

**Methyl (4*R*)-2,2-Dimethyl-4,5-(isopropylidenedioxy)-3-(trimethylsiloxy)pentanoates (D-9a,b).** A 3:1 mixture of diastereomers (3.95 g) of D-**9a,b** was obtained from **1b** (3.48 g, 20 mmol) and D-**2** (2.6 g, 20 mmol) in dry $CH_3CN$ (20 mL). A 9:1 mixture of diastereomers (4.8 g) of D-**9a,b** was obtained from **1b** (4.18 g, 24 mmol), D-**2** (2.6 g, 20 mmol), and $ZnI_2$ (320 mg), in dry $CH_3CN$ (20 mL): bp 130–140 °C (0.2 mmHg) (bath temperature); $^1H$ NMR ($CDCl_3$) $\delta$ 0.14 (s, 9 H, $SiMe_3$), 1.16 [s, 6 H, C-($Me$)$_2CO_2Me$], 1.31 (s, 3 H, *Me*CMe), 1.39 (s, 3 H, MeC*Me*), 3.65 (s, 3 H, OMe), 3.74–4.22 (m, 4 H); IR ($CHCl_3$) 1720 $cm^{-1}$. Anal. Calcd for $C_{14}H_{28}O_5Si$: C, 55.23; H, 9.27. Found: C, 55.19; H, 9.62.

**Methyl (4*S*)-4,5-(Isopropylidenedioxy)-2,5-dimethyl-3-(trimethylsiloxy)pentanoates (L-9a,b).** A 77:23 mixture of the diastereomers (3.77 g) of L-**9a,b** was obtained from 1b (3.48 g, 20 mmol) and L-**2** (2.6 g, 20 mmol) in dry $CH_3CN$ (20 mL). A 91:9 mixture of diastereomers (4.27 g) of L-**9a,b** was obtained from **1b** (4.18 g, 24 mmol, L-**2** (2.6 g, 20 mmol), and $ZnI_2$ (319 mg, 1 mmol) in dry $CH_3CN$ (20 mL): bp 130–140 °C (0.2 mmHg) (bath temperature). All spectra data were identical with those of D-**9a,b**.

**(4*R*)-3,5-Diacetoxy-4-hydroxy-2,2-dimethylpentanoic Acid 1,4-Lactones (D-10a,b).** A solution of D-**9a,b** (480 mg, 2.1 mmol) in $CF_3CO_2H$–$H_2O$ (3:2, 10 mL) was stirred at room temperature for 15 h, concentrated under reduced pressure, and diluted with ethyl acetate (50 mL). The organic layer was washed with saturated aqueous NaCl, dried over $MgSO_4$, and concentrated under reduced pressure. To the residual oil were added pyridine (1.0 g, 12.6 mmol) and acetic anhydride (1.2 g, 11.8 mmol) at room temperature. The mixture was further stirred for 20 h, concentrated under reduced pressure, and diluted with ethyl acetate (50 mL). The organic layer was washed with saturated aqueous NaCl, dried over $MgSO_4$, and concentrated under reduced pressure. The residual oil was subjected to column chromatography on silica gel with benzene–ethyl acetate, 5:1, to give a 62% yield (320 mg) of D-**10a,b**: $^1H$ NMR ($CDCl_3$) $\delta$ 1.22 (s, 3 H, *Me*CMe), 1.36 (s, 3 H, MeC*Me*), 2.10 (s, 3 H, OAc), 2.13 (s, 3 H, OAc), 4.00–4.55 (m, 3 H, 4,5,5′-H), 5.08 (d, $J$ = 5.7 Hz, major, 3-H, D-**10a**), 5.33 (d, $J$ = 3.8 Hz, minor, 3-H, D-**10b**), this assignment is in good accord with those of the related lactones;[18a] IR ($CHCl_3$) 1780, 1745 $cm^{-1}$. Anal. Calcd for $C_{11}H_{16}O_6$: C, 54.09; H, 6.60. Found: C, 54.31; H, 6.63.

**(4*S*)-3,5-Diacetoxy-4-hydroxy-2,2-dimethylpentanoic Acid 1,4-Lactones (L-10a,b).** This was obtained from L-**9a,b** by the same method as described for the preparation of D-**10a,b**. All spectral data were identical with those of D-**10a,b**.

**Methyl (4*R*)-4,5-(Isopropylidenedioxy)-2-methyl-3-(triethylsiloxy)pentanoate (11).** A 77:15:4:4 mixture of diastereomers (172 mg) of **11a–d** was obtained from (*Z*)-**1c** (262 mg, 1.3 mmol), D-**2** (131 mg, 1.01 mmol), and $ZnI_2$ (19 mg, 0.06 mmol) in dry $CH_3CN$ (1.5 mL): $^1H$ NMR ($CDCl_3$) $\delta$ 0.55–1.05 (m, 15 H, $SiEt_3$), 1.1–1.25 (m, 3 H, CH*Me*), 1.25–1.45 (m, 6 H, MeCMe), 2.24 (qd, $^4/_{100}$ H, $J$ = 7 and 5.5 Hz, 2-H), 2.58 (qd, $^4/_{100}$ H, $J$ = 7 and 5 Hz, 2-H), 2.67 (qd, $^{77}/_{100}$ H, $J$ = 7.3 and 4.3 Hz, 2-H), 2.77 (qd, $^{15}/_{100}$ H, $J$ = 6.7 and 3.3 Hz, 2-H), 3.66 (s, $^{77}/_{100}$ × 3 H, OMe), 3.672 (s, $^4/_{100}$ × 3H, OMe), 3.675 (s, $^4/_{100}$ × 3 H, OMe), 3.691 (s, $^{15}/_{100}$ × 3 H, OMe), 3.58–4.25 (m, 4 H, 3,4,5,5′-H).

A 65:30:3:2 mixture of diastereomers (402 mg) of **11a–d** was obtained from (*E*)-**1c** (485 mg, 2.4 mmol), D-**2** (262 mg, 2.02 mmol),

and $ZnI_2$ (74 mg, 0.23 mmol) in dry $CH_3CN$ (4 mL).

The mixture of diastereomers was subjected to column chromatography on silica gel with *n*-hexane–ether, 20:1, to give methyl (2*R*,3*S*,4*R*)-4,5-(isopropylidenedioxy)-2-methyl-3-(triethylsiloxy)pentanoate (**11a**) and methyl (2*S*,3*S*,4*R*)-4,5-(isopropylidenedioxy)-2-methyl-3-(triethylsiloxy)pentanoate (**11b**). **11a**: bp 140–150 °C (0.3 mmHg) (bath temperature); $[\alpha]^{18}_D$ −13.1° (*c* 1.21, $CH_2Cl_2$); $^1H$ NMR ($CDCl_3$) δ 0.633 [q, 6 H, *J* = 8 Hz, $Si(CH_2CH_3)_3$], 0.964 [t, 9 H, *J* = 8 Hz, $Si(CH_2CH_3)_3$], 1.184 (d, 3 H, *J* = 7.3 Hz, CH*Me*), 1.303 (s, 3 H, *Me*CMe), 1.352 (s, 3 H, MeC*Me*), 2.673 (qd, 1 H, *J* = 7.3 and 4.3 Hz, 2-H), 3.662 (s, 3 H, OMe), 3.82–4.08 (m, 3 H, 4,5,5′-H), 4.126 (dd, 1 H, *J* = 7.3 and 4.3 Hz, 3-H); $^1H$ NMR ($C_6D_6$) δ 0.4–1.1 (m, 15 H, $SiEt_3$), 1.21 (d, 3 H, *J* = 7 Hz, CH*Me*), 1.25 (s, 3 H, *Me*CMe), 1.37 (s, 3 H, MeC*Me*), 2.64 (qd, *J* = 7 and 4.1 Hz, 2-H), 3.40 (s, 3 H, OMe), 3.8–4.3 (m, 3 H, 4,5,5′-H), 4.26 (dd, 1 H, *J* = 6 and 4.1 Hz, 3-H); IR ($CHCl_3$) 1725, 1230, 1065, 1005 $cm^{-1}$. Anal. Calcd for $C_{16}H_{32}O_5Si$: C, 57.80; H, 9.70. Found: C, 57.57; H, 9.95. **11b**: bp 120–130 °C (0.23 mmHg) (bath temperature); $[\alpha]^{19}_D$ +25.1° (*c* 0.686, $CH_2Cl_2$); $^1H$ NMR ($CDCl_3$) δ 0.581 [q, 6 H, *J* = 7.9 Hz, $Si(CH_2CH_3)_3$], 0.940 [t, 9 H, *J* = 7.9 Hz, $Si(CH_2CH_3)_3$], 1.166 (d, 3 H, *J* = 6.7 Hz, CH*Me*), 1.330 (s, 3 H, *Me*CMe), 1.408 (s, 3 H, MeC*Me*), 2.773 (qd, 1 H, *J* = 6.7 and 3.3 Hz, 2-H), 3.691 (s, 3 H, OMe), 3.83–4.07 (m, 3 H, 4,5,5′-H), 4.162 (dd, 1 H, *J* = 7.9 and 3.3 Hz, 3-H); $^1H$ NMR ($C_6D_6$) δ 0.4–1.1 (m, 15 H, $SiEt_3$), 1.17 (d, 3 H, *J* = 7 Hz, CH*Me*), 1.82 (s, 3 H, *Me*CMe), 1.90 (s, 3H, MeC*Me*), 2.76 (qd, 1 H, *J* = 7 and 2.8 Hz, 2-H), 3.68 (s, 3 H, OMe), 3.7–4.4 (m, 3 H, 4,5,5′-H), 4.37 (dd, 1 H, *J* = 7.6 and 2.8 Hz, 3-H); IR ($CHCl_3$) 1725, 1230, 1065, 1005 $cm^{-1}$; exact mass calcd for $C_{16}H_{32}O_5Si$-Me 317.1791, found 317.1788.

**Methyl (4*R*)-4,5-(Isopropylidenedioxy)-2-methyl-3-(trimethylsiloxy)pentanoate (12).** A 64:24:7:5 mixture of diastereomers (256 mg) of **12a–d** was obtained from (*E*)-**1d** (350 mg, 2.65 mmol), D-**2** (255 mg, 1.96 mmol), and $ZnI_2$ (80 mg, 0.25 mmol) in dry $CH_3CN$ (4 mL): $^1H$ NMR ($CDCl_3$) δ 0.094 (s, $^{29}/_{100}$ × 9 H, $SiMe_3$), 0.114 (s, $^{7}/_{100}$ × 9 H, $SiMe_3$), 0.134 (s, $^{64}/_{100}$ × 9 H, $SiMe_3$), 1.1–1.2 (m, 3 H, CH*Me*), 1.25–1.45 (m, 6 H, MeCMe), 2.65 (qd, $^{64}/_{100}$ H, *J* = 7 and 4 Hz, 2-H), 2.70 (qd, $^{24}/_{100}$ H, *J* = 7 and 3.5 Hz, 2-H), 3.672 (s, $^{64}/_{100}$, 3 H, OMe), 3.678 (s, $^{7}/_{100}$, 3 H, OMe), 3.682 (s, $^{5}/_{100}$, 3 H, OMe), 3.691 (s, $^{24}/_{100}$ 3 H, OMe), 3.7–4.25 (m, 4 H, 3,4,5,5′-H). This mixture of diastereomers was subjected to column chromatography on silica gel with *n*-hexane–ether, 20:1, to give methyl (2*R*,3*S*,4*R*)-4,5-(isopropylidenedioxy)-2-methyl-3-(trimethylsiloxy)pentanoate (**12a**) and methyl (2*S*,3*S*,4*R*)-4,5-(isopropylidenedioxy)-2-methyl-3-(trimethylsiloxy)pentanoate (**12b**). **12a**: bp 100–110 °C (0.2 mmHg) (bath temperature); $[\alpha]^{21}_D$ −13.7° (*c* 1.26, $CHCl_3$); $^1H$ NMR ($CDCl_3$) δ 0.13 (s, 9 H, $SiMe_3$), 1.17 (d, 3 H, *J* = 7 Hz, CH*Me*), 1.32 (s, 3 H, *Me*CMe), 1.36 (s, 3 H, MeC*Me*), 2.65 (qd, 1 H, *J* = 7 and 4 Hz, 2-H), 3.67 (s, 3 H, OMe), 3.75–4.23 (m, 4 H, 3,4,5,5′-H); IR ($CHCl_3$) 1725, 1250, 1070 $cm^{-1}$; exact mass calcd for $C_{13}H_{26}O_5Si$-Me 275.1312, found 275.1296. Anal. Calcd for $C_{13}H_{26}O_5Si$: C, 53.76; H, 9.02. Found: C, 53.66; H, 9.19. **12b**: bp 90–100 °C (0.2 mmHg) (bath temperature); $[\alpha]^{25}_D$ +23.2° (*c* 0.983, $CHCl_3$); $^1H$ NMR ($CDCl_3$) δ 0.09 (s, 9 H, $SiMe_3$), 1.15 (d, 3 H, *J* = 7 Hz, CH*Me*), 1.33 (s, 3 H, *Me*CMe), 1.40 (s, 3 H, MeC*Me*), 2.70 (qd, 1 H, *J* = 7 and 3.5 Hz, 2H), 3.69 (s, 3 H, OMe), 3.82–4.23 (m, 4 H, 3,4,5,5′-H); IR ($CHCl_3$) 1725, 1250, 1070 $cm^{-1}$; exact mass calcd for $C_{13}H_{26}O_5Si$-Me 275.1312, found 275.1294.

**Methyl (4*R*)-3-(*tert*-Butyldimethylsiloxy)-4,5-(isopropylidenedioxy)-2-methylpentanoate (13).** A 76:14:7:3 mixture of diastereomers (446 mg) of **13a–d** was obtained from (*Z*)-**1e** (532 mg, 2.63 mmol), D-**2** (271 mg, 2.08 mmol), and $ZnI_2$ (41 mg, 0.129 mmol) in dry $CH_3CN$ (3 mL); $^1H$ NMR ($CDCl_3$) δ −0.1–0.2 (m, 6 H, $SiMe_2$), 0.854 (s, $^{14}/_{100}$ × 9 H, Si-*t*-Bu), 0.859 (s, $^{7}/_{100}$ × 9 H, Si-*t*-Bu), 0.879 (s, $^{76}/_{100}$ × 9 H, Si-*t*-Bu), 0.885 (s, $^{3}/_{100}$ × 9 H, Si-*t*-Bu), 1.15–1.25 (m, 3 H, CH*Me*), 1.25–1.45 (m, 6 H, MeCMe), 2.692 (qd, $^{76}/_{100}$ H, *J* = 7.3 and 3.6 Hz, 2-H), 2.808 (qd, $^{14}/_{100}$ H, *J* = 7.3 and 3.3 Hz, 2-H), 3.670 (s, $^{76}/_{100}$ × 3 H, OMe), 3.673 (s, $^{7}/_{100}$ × 3 H, OMe), 3.691 (s, $^{14}/_{100}$ × 3 H, OMe), 3.729 (s, $^{3}/_{100}$ × 3 H, OMe), 3.7–4.2 (m, 4 H, 3,4,5,5′-H). This mixture of diastereomers was subjected to column chromatography on silica gel with *n*-hexane–ether, 10:1, to give methyl (2*R*,3*S*,4*R*)-3-(*tert*-butyldimethylsiloxy)-4,5-(isopropylidenedioxy)-2-methylpentanoate (**13a**): bp 140–150 °C (0.4 mmHg) (bath temperature); $[\alpha]^{29}_D$ −10.4° (*c* 1.45, $CHCl_3$); $^1H$ NMR ($CDCl_3$) δ 0.104 (s, 3 H, SiMe), 0.109 (s, 3 H, SiMe), 0.879 (s, 9 H, Si-*t*-Bu), 1.174 (d, 3 H, *J* = 7.3 Hz, CH*Me*), 1.302 (s, 3 H, *Me*CMe), 1.351 (s, 3 H, MeC*Me*), 2.692 (qd, 1 H, *J* = 7.3 and 3.6 Hz, 2-H), 3.670 (s, 3 H, OMe), 3.7–4.2 (m, 4 H, 3,4,5,5′-H); IR ($CHCl_3$) 1730 $cm^{-1}$. Anal. Calcd for $C_{16}H_{32}O_5Si$: C, 57.80; H, 9.70. Found: C, 57.83; H, 9.88.

**Methyl (4*R*)-3-(*tert*-Butyldimethylsiloxy)-2-ethyl-4,5-(isopropylidenedioxy)pentanoate (14).** An 84:10:3:3 mixture of diastereomers (189 mg) of **14a–d** was obtained from (*Z*)-**1f** (330 mg, 1.52 mmol), D-**2** (159 mg, 1.23 mmol), and $ZnI_2$ (22.7 mg, 0.07 mmol) in dry $CH_3CN$ (2 mL); $^1H$ NMR ($C_6D_6$) δ 0.073 (s, $^{84}/_{100}$ × 3 H, SiMe), 0.077 (s, $^{84}/_{100}$ × 3 H, SiMe), 0.01–0.2 (m, $^{16}/_{100}$ × 6 H, $SiMe_2$), 0.921 (s, $^{84}/_{100}$ × 9 H, Si-*t*-Bu), 0.9–1.1 (m, 3 H, $^{16}/_{100}$ × 9 H, $CH_2Me$, Si-*t*-Bu), 1.5–1.6 (m, $^{84}/_{100}$ H, *H*CHMe), 1.8–2.0 (m, $^{84}/_{100}$ H, HC*H*Me), 2.552 (dt, $^{84}/_{100}$ H, *J* = 11 and 4 Hz, 2-H), 2.678 (dt, $^{10}/_{100}$ H, *J* = 10.5 and 4 Hz, 2-H), 3.358 (s, $^{3}/_{100}$ × 3 H, OMe), 3.368 (s, $^{3}/_{100}$ × 3 H, OMe), 3.395 (s, $^{10}/_{100}$ × 3 H, OMe), 3.403 (s, $^{84}/_{100}$ × 3 H, OMe), 3.5–4.3 (m, 4 H, 3,4,5,5′-H). An 83:9:6:2 mixture of diastereomers (213 mg) of **14a–d** was obtained from (*E*)-**1f** (282 mg, 1.30 mmol), D-**2** (140 mg, 1.07 mmol), and $ZnI_2$ (24 mg, 0.075 mmol) in dry $CH_3CN$ (3 mL).

This mixture of diastereomers was subjected to column chromatography on silica gel with *n*-hexane–ether, 25:1, to give methyl (2*R*,3*S*,4*R*)-3-(*tert*-butyldimethylsiloxy)-2-ethyl-4,5-(isopropylidenedioxy)pentanoate (**14a**): bp 114–116 °C (0.28 mmHg) (bath temperature); $[\alpha]^{23}_D$ −5.8° (*c* 0.843, $CHCl_3$); $^1H$ NMR ($C_6D_6$) δ 0.073 (s, 3 H, SiMe), 0.769 (s, 3 H, SiMe), 0.921 (s, 9 H, Si-*t*-Bu), 0.925 (t, 3 H, *J* = 7 Hz, $CH_2Me$), 1.269 (s, 3 H, *Me*CMe), 1.394 (s, 3 H, MeC*Me*), 1.5–1.6 (m, 1 H, *H*CHMe), 1.8–2.0 (m, 1 H, HC*H*Me), 2.552 (dt, 1 H, *J* = 11 and 4 Hz, 2-H), 3.403 (s, 3 H, OMe), 3.5–4.3 (m, 4 H, 3,4,5,5′-H); IR ($CHCl_3$) 1735, 1260, 1085, 840 $cm^{-1}$. Anal. Calcd for $C_{17}H_{34}O_5Si$: C, 58.92; H, 9.89. Found: C, 59.28; H, 10.18.

**(2*R*,3*S*,4*R*)-3,5-Bis(benzoyloxy)-4-hydroxy-2-methylpentanoic Acid 1,4-Lactone (15a).** A solution of **11a** (77.6 mg, 0.233 mmol) in $CF_3CO_2H$–$H_2O$ (10:1, 1 mL) was stirred at room temperature for 4 h and concentrated under reduced pressure. To the residual oil were added pyridine (0.4 mL) and benzoyl chloride (0.1 mL, 0.83 mmol), and the mixture was stirred for 15 h at room temperature. The solvent was evaporated under reduced pressure, and the residue was taken up in $CHCl_3$ (20 mL), washed with 10% HCl and saturated aqueous $NaHCO_3$, and dried over $MgSO_4$. The solvent was evaporated to give a residue, which was subjected to column chromatography on silica gel with methylene chloride to give a 63% yield (52 mg) of **15a**: mp 77–78 °C (*n*-hexane); $[\alpha]^{20}_D$ −16.4° (*c*, 0.738, $CH_2Cl_2$); $^1H$ NMR ($CDCl_3$) δ 1.35 (d, 3 H, *J* = 7 Hz, CH*Me*), 3.14 (quin, 1 H, *J* = 7 Hz, 2-H), 4.51–5.01 (m, 3 H, 4,5,5′-H), 5.68 (dd, 1 H, *J* = 7 and 1 Hz, 3-H), 7.3–8.1 (m, 10 H, Ph × 2); IR ($CHCl_3$) 1790, 1720 $cm^{-1}$. Anal. Calcd for $C_{20}H_{18}O_6$: C, 67.79; H, 5.12. Found: C, 67.72; H, 5.05.

Compound **15a** was also prepared from **12a** and **13a** by the same method as described above in 73% and 53% yields, respectively.

**(2*R*,3*S*,4*R*)-3,5-Bis(benzoyloxy)-2-ethyl-4-hydroxypentanoic Acid 1,4-Lactone (15b).** This (20.3 mg, 70%) was prepared from **14a** (27 mg, 0.078 mmol) by the same method as described for the preparation of **15a** from **11a**: $[\alpha]^{25}_D$ −31.6° (*c* 1.01, $CHCl_3$); $^1H$ NMR ($CDCl_3$) δ 1.10 (t, 3 H, *J* = 7 Hz, $CH_2Me$), 1.6–2.7 (m, 2 H, $CH_2Me$), 2.98 (ddd, 1 H, *J* = 9, 7.5 and 6 Hz, 2-H), 4.5–5.0 (m, 3 H, 4,5,5′-H), 5.83 (dd, 1 H, *J* = 6 and 1.1 Hz, 3-H), 7.2–8.3 (m, 10 H, Ph × 2); IR ($CHCl_3$) 1780, 1720 $cm^{-1}$; exact mass calcd for $C_{21}H_{20}O_6$ 368.1260, found 368.1281.

**(2*S*,3*S*,4*R*)-3,5-Bis(benzoyloxy)-4-hydroxy-2-methylpentanoic Acid 1,4-Lactone (16a).** This was prepared from **11b** and **12b** by the same method as described for the preparation of **15a** in 52% and 50% yields, respectively: mp 118–119 °C (*n*-hexane); $[\alpha]^{19}_D$ +35.6° (*c* 0.517, $CH_2Cl_2$); $^1H$ NMR ($CDCl_3$) δ 1.48 (d, 3 H, *J* = 8 Hz, CH*Me*), 3.00 (qd, 1 H, *J* = 8 and 6.1 Hz, 2-H), 4.4–4.9 (m, 3 H, 4,5,5′-H), 5.38 (dd, 1 H, *J* = 6.1 and 4.9 Hz, 3-H), 7.3–8.1 (m, 10 H, Ph × 2); IR ($CHCl_3$) 1790, 1720 $cm^{-1}$. Anal. Calcd for $C_{20}H_{18}O_6$: C, 67.79; H, 5.12. Found: C, 67.55; H, 4.92.

**3,5-*O*-Dibenzoyl-2-deoxy-2(*R*)-*C*-methyl-*erythro*-D-pentofuranose (17a).** A 1.75 M solution of diisobutylaluminum hydride (DIBAL) in toluene (65 μL, 0.114 mmol) was added to a stirred solution of **15a** (15 mg, 0.04 mmol) in dry THF (1 mL) at −78 °C under nitrogen. The mixture was stirred at −78 °C for 15 h and at −40 °C and 3 h. After aqueous methanol (MeOH–$H_2O$, 4:1, 0.3 mL) was added, the mixture was allowed to warm to room

temperature. Saturated aqueous $NaHCO_3$ (0.7 mL) was added, and then the resulting precipitates were removed by filtration and washed with ethyl acetate. The filtrate was dried over $MgSO_4$ and concentrated under reduced pressure. The residue was subjected to preparative TLC on silica gel with $CH_2Cl_2$ to give a 42% (6 mg) recovery of **15a** and 51% yield (7.3 mg) of **17a** (1:1 mixture of anomeric isomers) as colorless syrup: $[\alpha]^{20}_D$ +23.2° (*c* 0.293, $CHCl_3$); $^1H$ NMR ($CDCl_3$) δ 1.156 (d, 0.5 × 3 H, *J* = 7.32 Hz, CH*Me*), 1.214 (d, 0.5 × 3 H, *J* = 6.72 Hz, CH*Me*), 2.565 (dquin, 0.5 H, *J* = 6.72 and 4.89 Hz, 2-H), 2.632 (dquin, 0.5 H, *J* = 7.32 and 3.66 Hz, 2-H), 2.775 (br d, 0.5 Hz, *J* = 6.11 Hz, OH), 3.06 (br s, 0.5 H, OH), 4.47–4.65 (m, 3 H, 4,5,5′-H), 5.323 (br s, 0.5 H, 1-H), 5.48–5.52 (m, 1 H, 3-H, 1-H), 5.605 (dd, 0.5 H, *J* = 6.11 and 3.66 Hz, 3-H), 7.37–7.64 (m, 6 H, Ar H), 7.95–8.15 (m,, 4 H, Ar H); IR ($CHCl_3$) 1720, 1270 $cm^{-1}$; exact mass calcd for $C_{20}H_{20}O_6$-OH 339.1232, found 339.1247.

**3,5-*O*-Dibenzoyl-2-deoxy-2(*R*)-*C*-ethyl-*erythro*-D-pentofuranose (17b).** This (5.8 mg, 34%, 43:57 mixture of anomeric isomers) was prepared from **15b** (17 mg, 0.046 mmol) and 1.75 M solution of DIBAL in toluene (53 μL, 0.092 mmol) in dry THF (1 mL) by a similar method as described for **17a** from **15a**. There was a 25% (4.3 mg) recovery of **15b**. **17b**: $[\alpha]^{20}_D$ +10.8° (*c* 0.195, $CHCl_3$); $^1H$ NMR ($CDCl_3$) δ 1.017 (t, $^{43}/_{100}$ × 3 H, *J* = 7.32 Hz, $CH_2CH_3$), 1.036 (t, $^{57}/_{100}$ × 3 H, *J* = 7.33 Hz, $CH_2CH_3$), 1.56–1.80 (m, 2 H, $CH_2CH_3$), 2.27–2.45 (m, 1 H, 2-H), 2.6–2.9 (br s, $^{57}/_{100}$ H, OH), 2.9–3.4 (br s, $^{43}/_{100}$ H, OH), 4.454 (dt, $^{43}/_{100}$ H, *J* = 5.49 and 2.44 Hz, 4-H), 4.525 (dd, $^{57}/_{100}$ H, *J* = 11.59 and 4.88 Hz, 5-H), 4.547 (dd, $^{57}/_{100}$ H, *J* = 11.59 and 4.88 Hz, 5′-H), 4.57–4.67 (m, $^{43}/_{100}$ × 2 H, 5,5′-H), 4.57–4.64 (m, $^{57}/_{100}$ H, 4-H), 5.419 (d, $^{43}/_{100}$ H, *J* = 4.27 Hz, 1-H), 5.527 (d, $^{57}/_{100}$ H, *J* = 6.10 Hz, 3-H), 5.549 (d, $^{57}/_{100}$ H, *J* = 4.89 Hz, 1-H), 5.628 (dd, $^{43}/_{100}$ H, *J* = 6.1 and 2.44 Hz, 3-H), 7.35–7.65 (m, 6 H, Ar H), 7.95–8.10 (m, 4 H, Ar H); IR ($CHCl_3$) 1720, 1270 $cm^{-1}$; exact mass calcd for $C_{21}H_{22}O_6$-OH 353.1386, found 353.1381.

**Registry No.** **1a**, 77086-38-5; **1b**, 31469-15-5; (*E*)-**1c**, 89597-33-1; (*Z*)-**1c**, 90541-64-3; (*E*)-**1d**, 72658-09-4; (*Z*)-**1e**, 84784-64-5; (*E*)-**1f**, 58367-55-8; (*Z*)-**1f**, 58367-60-5; D-**2**, 15186-48-8; L-**2**, 22323-80-4; D-**3a**, 104578-83-8; L-**3a**, 104578-88-3; D-**3b**, 104578-84-9; L-**3b**, 104578-87-2; D-**4a**, 104578-85-0; D-**4b**, 104578-86-1; D-**5a**, 83159-90-4; D-**6a**, 34371-14-7; L-**6a**, 38996-14-4; D-**7a**, 84044-97-3; L-**7a**, 112021-04-2; D-**8a**, 81366-70-3; L-**8a**, 104578-89-4; D-**9a**, 104578-90-7; L-**9a**, 104578-92-9; D-**9b**, 104602-05-3; L-**9b**, 104578-91-8; D-**10a**, 104578-93-0; L-**10a**, 104578-94-1; D-**10b**, 111998-43-7; L-**10b**, 111998-44-8; **11a**, 111998-45-9; **11b**, 112021-05-3; **11c**, 111998-46-0; **11d**, 111998-47-1; **12a**, 111998-48-2; **12b**, 111998-49-3; **12c**, 111998-50-6; **12d**, 111998-51-7; **13a**, 111998-52-8; **13b**, 111998-53-9; **13c**, 111998-54-0; **13d**, 111998-55-1; **14a**, 111998-56-2; **14b**, 111998-57-3; **14c**, 111998-58-4; **14d**, 111998-59-5; **15a**, 98587-14-5; **15b**, 111998-60-8; **16a**, 98587-15-6; α-**17a**, 111998-61-9; β-**17a**, 111998-62-0; α-**17b**, 111998-63-1; β-**17b**, 111998-64-2; $Et_3SiH$, 617-86-7; $Et_3SiCl$, 994-30-9; $CH_3CH_2COOMe$, 554-12-1.

# The *p*-(Methylsulfinyl)benzyl Group: A TFA-Stable Carboxyl-Protecting Group Readily Convertible to a TFA-Labile Group[1,2]

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The *p*-(methylsulfinyl)benzyl or Msib ester is recommended as a selectively cleavable carboxyl-protecting group for peptide synthesis. Peptide or amino acid esters of *p*-(methylsulfinyl)benzyl alcohol, HO-Msib (**2**), or *p*-(methylthio)benzyl alcohol, HO-Mtb (**1**), are readily prepared from the corresponding alcohols or alkyl halides. Msib esters may also be obtained from Mtb esters by oxidation with *m*-chloroperbenzoic acid. Msib esters are readily deoxygenated by excess $Me_3SiCl/Ph_3P$, $Me_3SiCl/Me_2S$, or anhydrous hydrogen chloride. Msib esters are exceedingly stable to TFA while Mtb esters solvolyze rapidly. A sample peptide synthesis demonstrates the protection of the C-terminal carboxyl group during synthesis as the Msib ester followed by Msib group removal on completion of synthesis by deoxygenation and TFA solvolysis. The stability of Mtb and Msib esters to typical acid conditions of peptide synthesis is described. The stability of Msib esters to various peptide synthesis conditions suggests that the Msib group should be quite useful as a carboxyl-protecting group in peptide synthesis.

Of the many approaches toward the development of useful peptide synthesis protecting groups, the concept of converting a stable protecting group into a labile protecting group[3] has been quite useful. This concept was behind the development of the *p*-nitrobenzyl group (reduced with zinc in acetic acid),[4] the dihydroxyborylbenzyloxycarbonyl group (oxidized with peroxide),[5] the hydroxymethylanthraquinone group (reduced by photolysis or dihydroanthraquinone),[6] the *p*-thiophenyl group (oxidized with peroxide),[7] the 5-benzisoxazolylmethyleneoxycarbonyl or Bic Group (activated with base),[8] the [2-(trifluoromethyl)-6-chromonyl]methyleneoxycarbonyl group (activated with propylamine),[9] and several groups that become base labile following oxidation.[10] The utility of each of these groups is hampered variously by the requirement of an aqueous medium (unsuitable for polystyrene-anchored solid-phase peptide synthesis),[11] the danger of Met or Trp

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(2) A number of abbreviations are used in this paper. The abbreviations for natural amino acids and nomenclature for peptide structures follow the recommendations of the IUPAC–IUB Commission on Biochemical Nomenclature (*J. Biol. Chem.* **1971**, *247*, 997). Other abbreviations are as follows: Mtb = *p*-(methylthio)benzyl and Msib = *p*-(methylsulfinyl)benzyl, (previously abbreviated as B(S) and B(SO) esters[1]), TFA = trifluoroacetic acid, TFAA = trifluoroacetic anhydride, Fmoc = (9-fluorenylmethoxy)carbonyl, DCC = dicyclohexylcarbodiimide, MCPBA = *m*-chloroperbenzoic acid, EDCI = 1-ethyl-3-[3-(dimethylamino)propyl]carbodiimide, HOBt = *N*-hydroxybenzotriazole, DMF = dimethylformamide, BSA = bis(trimethylsilyl)acetamide, $Ph_3P$ = triphenylphosphine.

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