Construction of an Optically Active 7-Oxabicyclo[4.3.0]non-4-en-3-one Skeleton from D-Glucose, and Its Transformation to Some Pseudo-Hexopyranoses

Kin-ichi TADANO,* Yoshihide UENO, Chiyoko FUKABORI, Yukinori HOTTA, and Tetsuo SUAMI*

Department of Applied Chemistry, Faculty of Science and Technology, Keio University, Hiyoshi, Kohoku-ku, Yokohama 223

(Received August 27, 1986)

A versatile chiral compound, (1*R*,6*R*,8*R*,9*R*)-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]non-4-en-3-one (**6**), was efficiently synthesized from D-glucose. The synthesis featured an intramolecular aldol cyclization of 3-*C*-acetylmethyl-3-deoxy-1,2-*O*-isopropylidene-α-D-*ribo*-pentodialdo-1,4-furanose, which was readily derivatized from the known Wittig adducts of 1,2:5,6-di-*O*-isopropylidene-α-D-*ribo*-hexofuranos-3-ulose. The utility of this highly functionalized chiral synthon **6** was embodied by conversion to four optically active pseudo-sugars, these are pentaacetyl derivatives of pseudo-α-L-altropyranose, pseudo-β-D-glucopyranose, pseudo-2-amino-2-deoxy-β-L-altropyranose, and pseudo-2-amino-2-deoxy-α-D-glucopyranose (a derivative of pseudo-glucosamine). The transformation of **6** to the pseudo sugars involved 1) a stereospecific epoxidation of the double bond in **6** providing (1*R*,4*S*,5*S*,6*S*,8*R*,9*R*)-4,5-epoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]-nonan-3-one (**8**), and 2) an exclusive diaxial ring opening of the β-epoxy alcohols, which were derived from **8**, providing (1*R*,3*R*,4*S*,5*S*,6*S*,8*R*,9*R*)-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane-3,4,5-triol (**11**) or (1*R*,3*S*,4*S*,5*R*,6*S*,8*R*,9*R*)-4-azido-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane-3,5-diol. Treatment of (1*R*,2*S*,3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-2-hydroxycyclohexanecarbaldehyde, which was derived from **11**, with methanesulfonyl chloride, and successive sodium borohydride reduction provided (3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-1-cyclohexene-1-methanol (**19**). Hydroboration of **19** proceeded from the less hindered side stereoselectively.

1-Hydroxymethyl-2,3,4,5-cyclohexanetetrols, known as "pseudo-sugars," may be regarded as carbocyclic analogues of carbohydrates (mainly, hexopyranoses). They are of current interest in the field of biological chemistry. The pseudo-sugars are found in partial components of antibiotics (validamycins) and enzyme inhibitors (adiposins).[1] In addition to the biological studies, the synthesis of pseudo-sugars is also of current interest. Several approaches directed toward optically active pseudo-sugars synthesis have appeared in the literatures. Ogawa and Suami demonstrated the preparation of the optically active *endo*-7-oxabicyclo[2.2.1]hept-5-ene-2-carboxylic acid, a common intermediate for the synthesis of pseudo-sugars, by optical resolution of the Diels-Alder adduct of furan and acrylic acid.[2] Paulsen and Heiker reported the synthesis of chiral valienamine, a component of validamycin type antibiotics, from quebrachitol (2-*O*-methyl-L-chiroinositol).[3] Paulsen and co-workers also successfully transformed the L-chiroinositol, which was derived from quebrachitol, to pseudo-α-D-galactopyranose and pseudo-β-D-mannopyranose.[4] In connection with the synthesis of prostaglandins employing carbohydrates as chiral starting materials, Ferrier and co-workers extensively pursued chiral cyclopentanoids and cyclohexanoids syntheses. The remarkable strategy developed by their group was the mercury(II)-promoted intramolecular cyclization of the 5,6-unsaturated hexopyranose derivative to the optically active polyhydroxylated cyclohexanone.[5] Applying Ferrier's strategy, Kuzuhara and Sugawara achieved the synthesis of aminocyclitol-containing pseudo-disaccharides by the partial conversion of maltose into cyclohexane derivatives.[6] Recently, Wilcox and co-workers realized an elegant approach towards an optically active carbocycle synthesis. This featured "the radical cyclization" of unsaturated halo sugars.[7] Carbocyclic analogues of D-fructofuranose (pseudo-D-fructofuranose) and D-fructofuranose 6-phosphate were synthesized by this radical cyclization strategy.[8]

In our continuing research on the synthesis of optically active carbocyclic compounds and pseudo-sugars from carbohydrates,[9] we wish to describe herein a novel and utilizable approach directed toward synthesis of pseudo-hexopyranoses.[10] The new approach features an efficient access to the versatile chiral synthon **6** from the readily available **5** by an intramolecular aldol cyclization, and a stereoselective introduction of a triol or an azido diol system on the 2-cyclohexenone moiety of **6** providing the compounds **11** and **22**. From compounds **11** and **22**, four pseudo-hexopyranoses were synthesized in acceptable overall yields.

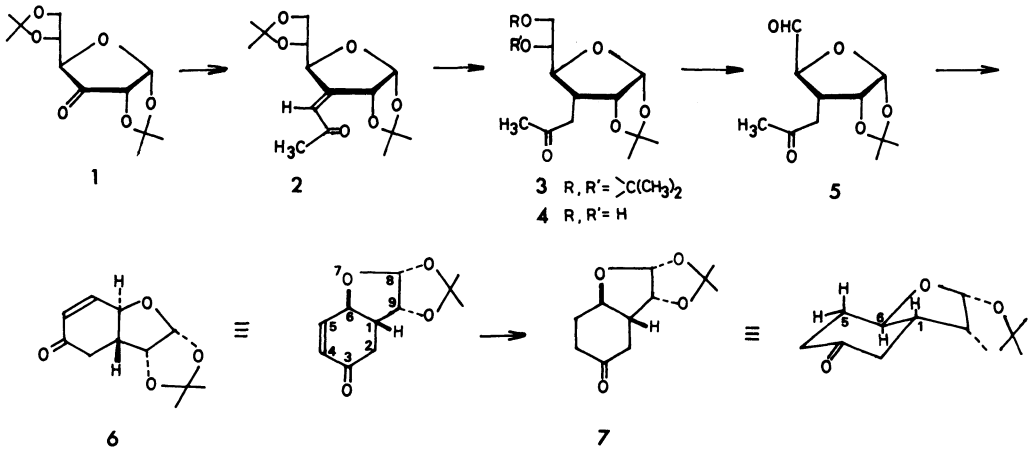
Results and Discussion

Synthesis of the Chiral Synthon 6 from D-Glucose (Scheme 1). 1,2:5,6-Di-*O*-isopropylidene-α-D-*ribo*-hexofuranos-3-ulose (**1**) was subjected to Wittig olefination with (acetylmethylene)triphenylphosphorane in refluxing benzene according to the literature.[11] This provided an approximately 3 to 1 [(*Z*) to (*E*)] geometrical mixture of the adduct **2** in 96% yield.

Hydrogenation of the mixture **2** in the presence of Raney nickel furnished a diastereomeric mixture of the 3-*C*-(2-hydroxypropyl) derivative. This was directly oxidized with pyridinium chlorochromate (PCC) to provide 3-*C*-acetylmethyl-3-deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (**3**) as crystals in 88% yield. As expected, based on the result of the hydrogenation of the corresponding 3-*C*-methylene derivative,[12] the hydrogenation of **2** proceeded from the β-side to give the α-D-allo derivative **3** exclusively. In the initial stage of the hydrogenation, the presence of **3** was detected in the reaction mixture. However, the compound **3** was rapidly converted to over-hydrogenated products. Selective hydrolysis of the 5,6-*O*-isopropylidene group in **3** with 60% aqueous acetic acid afforded compound **4** in 98% yield. The glycol cleavage of **4** by an aqueous sodium periodate solution gave a 5-aldehyde **5** quantitatively, which was subjected to the next aldol cyclization without purification. The crucial aldol cyclization of **5** to the synthon **6** was examined under the following conditions; 1) with sodium methoxide in methanol; 2) in 1 mol dm^{-3} aqueous NaOH; 3) with triethylamine in refluxing benzene; 4) lithium diisopropylamide (LDA) in THF from −78 to 0 °C; 5) with sodium hydride in refluxing benzene; 6) with BF_3–Et_2O in CH_2Cl_2. None of these reactions gave compound **6** in a practical yield. However, we found finally that 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) was an effective base for the cyclization. By refluxing **5** in benzene in the presence of 0.05 molar equivalent of DBU for 35 h followed by an acetic anhydride–pyridine treatment of the cyclization products, compound **5** was converted to compound **6** in 45% yield after chromatographic purification on silica gel. For the complete β-elimination of the cyclization products (α,β-enone formation), the acetic anhydride–pyridine treatment was necessary. The β-elimination was presumably proceeded via the β-acetate, which could not be isolated from the reaction mixture. For the Dieckmann cyclization of methyl 3-*C*-(methoxycarbonylmethyl)-1,2-*O*-isopropylidene-3,5,6-trideoxy-α-D-*ribo*-heptofuranuronate (a structurally similar model to the compound **5**), Fraser-Reid and co-workers found potassium *t*-butoxide to be an effective base.[13] We were able to find optimal conditions for the aldol cyclization, but an occurrence of epimerization at C-4 in **5** (an α-position of the aldehyde) under the basic conditions could not be excluded. Accordingly it was necessary to confirm the structure of **6**. Hydrogenation of **6** in the presence of Raney nickel and successive PCC oxidation of a cyclohexanols mixture afforded 7-oxabicyclo[4.3.0]nonan-3-one **7** in 82% yield. In the ^1H NMR spectrum of **7**, a doublet of triplets, which was attributable to H-6, appeared at δ 4.10 with $J_{1,6}=J_{5ax,6}=10.5$ Hz and $J_{5eq,6}=4.5$ Hz. This fact indicated that H-1 and H-6 of **6** (those are H-3 and H-4 of **5**) were in a trans diaxial relationship and no epimerization had occurred under the cyclization conditions. Consequently, the structure of the compound **6** was established.

The Transformation of Compound 6 to Pseudo-α-L-altropyranose Pentaacetate (17) (Scheme 2). Compound **6** possesses the proper functional groups for an introduction of hydroxyl groups (for instance, the carbonyl group or the double bond in the cyclohexenone moiety are convertible to the hydroxyl groups by reduction or oxidation). In addition, a portion of C-1 to C-8 via C-9 is convertible to a hydroxymethyl pseudo-sugar side chain by one-carbon degradation.

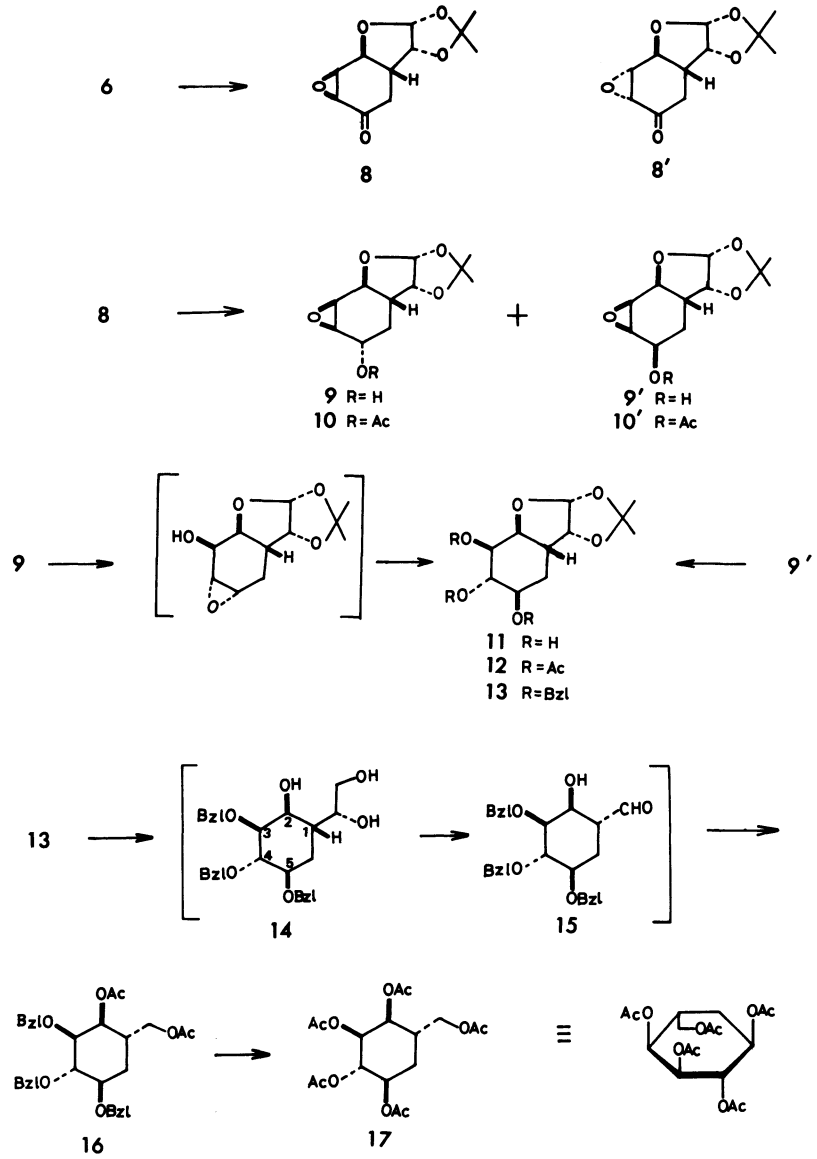
Epoxidation of **6** with 35% aqueous hydrogen peroxide in slightly alkaline methanol solution gave a β-epoxy ketone **8** stereospecifically in 96% yield. An α-epoxy ketone **8′** was isoltated in 3% yield. Although the structure of the β-epoxy ketone **8** [(4S,5S)-configuration] could not be determined unambiguously from the ^1H NMR spectrum, it was confirmed at a later stage. Sodium borohydride reduction of the carbonyl group in **8** gave a 5 to 1 mixture of the epoxy alcohols **9** and **9′**, which were cleanly separated by



Scheme 1.

silica-gel chromatograpy, in 84% combined yield. The compounds **9** and **9′** were acetylated to afford **10** and **10′**. The ^{1}H NMR spectra of **10** and **10′** revealed a quartet with $J_{2,3}=J_{2',3}=J_{3,4}=4$ Hz for H-3 of **10′** and a triplet with $J_{2,3}=J_{2',3}=8.5$ Hz, $J_{3,4}=0$ Hz for H-3 of **10**. Unfortunately, from these results, we were not able to establish the configurations of the newly introduced acetoxyl groups of **10** and **10′** (therefore hydroxyl groups of **9** and **9′**) unambiguously, since the conformation of the cyclohexane moiety of **10** and **10′** (pseudo-boat form or pseudo-chair form) remained unclear. We tentatively assigned it to a (*S*)-configuration for the major 3-hydroxyl derivative **9** as depicted,[14] and this was confirmed on azidolysis of **9** and **9′** and successive conversion to pseudo-amino sugars (vide infra).

The epoxide-ring opening of **9** and **9′** by solvolysis in refluxing aqueous 2-methoxyethanol in the presence of sodium acetate provided the same triol **11** as a single product in 73 and 81% yield, respectively. Acetylation of **11** afforded the triacetate **12** in 80% yield. In the ^{1}H NMR spectrum of **12**, the protons on carbons bearing acetoxyl groups, (at H-3, 4, and 5), appeared as a quartet at δ 5.00 for H-3 ($J_{2,3}=J_{2',3}=J_{3,4}=3$ Hz) and two triplets at δ 5.12 and 5.37 for H-4 and 5 (or H-5 and 4) ($J_{3,4}=J_{4,5}=J_{5,6}=3$ Hz). This fact supported the view that three acetoxyl groups were in a trans diaxial relationship to one another. Accordingly the structure of **11** [(3*R*,4*S*,5*S*)-configuration] was established. The formation of **11** from **9** is explainable as follows. A neighboring group participation of the α-hydroxyl group in **9** on the



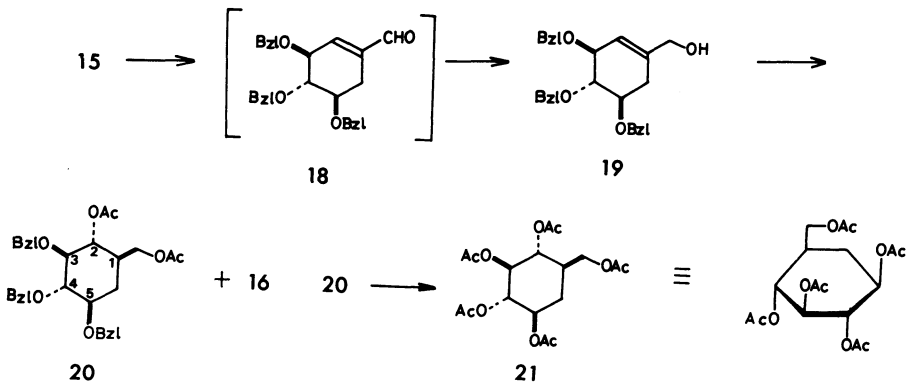
Scheme 2.

occasion of the epoxy-ring opening resulted in the formation of 3,4-α-epoxy-5-β-hydroxyl derivative as an intermediate, which could not be isolated. The intermediate was then attacked by hydroxide anion in a diaxial opening manner providing the compound **11**. The formation of **11** from **9'** was a result of direct diaxial opening of the epoxy ring. Therefore, we could introduce three hydroxyl groups into the cyclohexane moiety of **11** stereospecifically from both compounds **9** and **9'**.

The transformation of compound **11** to pseudo-α-L-altropyranose pentaacetate (**17**) was achieved as follows. Benzylation of **11** furnished a tri-*O*-benzyl derivative **13** in 93% yield. By acid hydrolysis and successive sodium borohydride reduction, the compound **13** was converted to a branched cyclohexane tetrol **14** (a derivative of pseudo-heptopyranose). The glycol cleavage of **14** by periodate gave (1*R*,2*S*,3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-2-hydroxycyclohexanecarbaldehyde (**15**), which was reduced with sodium borohydride, then acetylated providing a fully protected pseudo-α-L-altropyranose **16** in 52% overall yield from **13**. *O*-Debenzylation of **16** with sodium in liquid ammonia and successive acetylation furnished (1*S*,2*S*,3*S*,4*S*,5*R*)-2,3,4,5-tetraacetoxy-1-(acetoxymethyl)cyclohexane, pseudo-α-L-altropyranose pentaacetate (**17**) in 33% yield. The ^{1}H NMR spectrum of **17** was superimposable on that of the known DL-**17**,[15] therefore, the structure of **17** was confirmed.

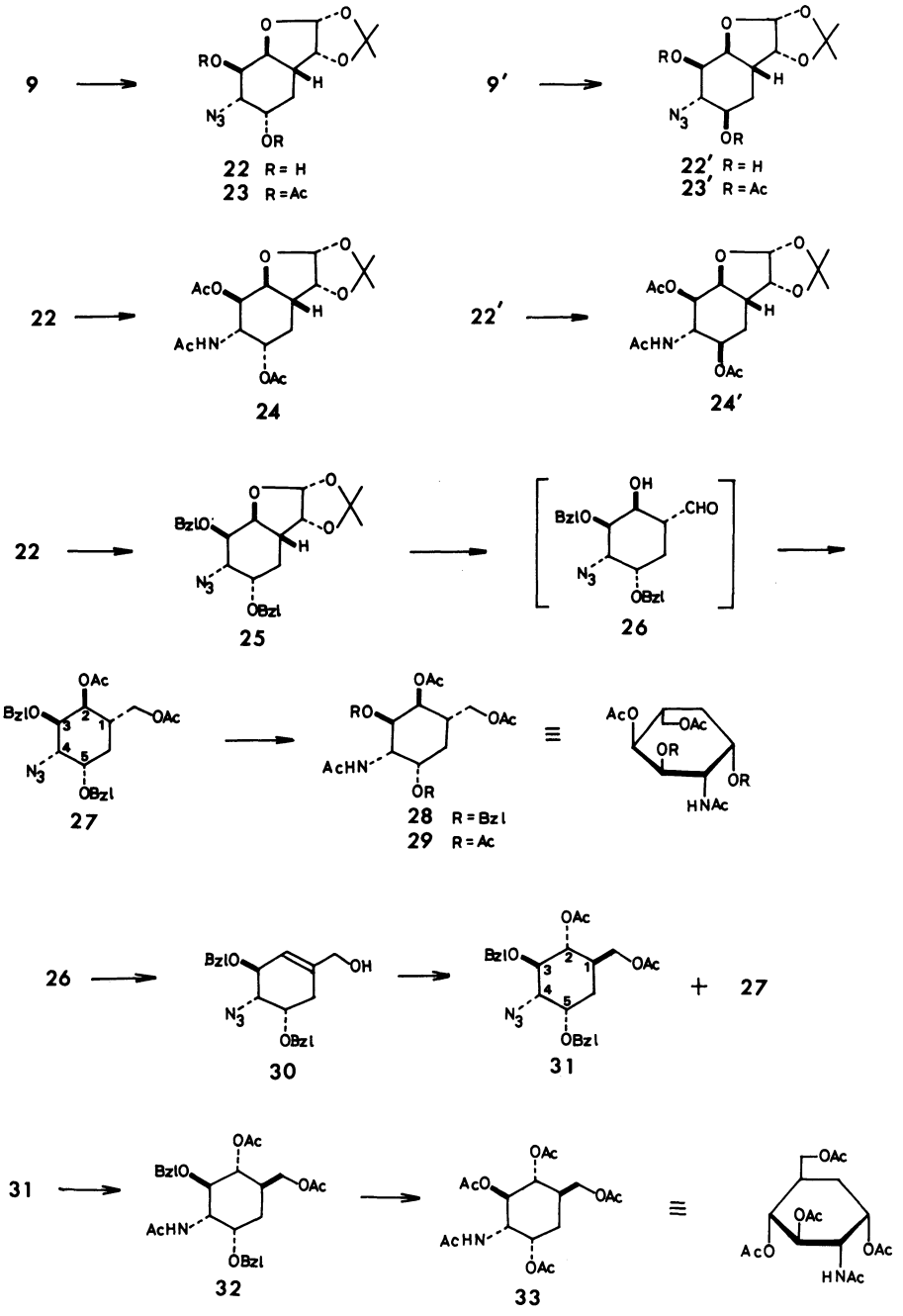
Synthesis of Pseudo-β-D-glucopyranose Pentaacetate 21 from Compound 15 (Scheme 3). The inversion of the configurations of C-1 and C-2 in compound **17** was next investigated. Treatment of compound **15** with excess methanesulfonyl chloride in pyridine at ambient temperature afforded the α,β-unsaturated aldehyde **18**, which was subjected to the next step without purification. Although we could not detect an intermediate of the reaction, we assumed the β-elimination proceeded via a β-methanesulfonate. Sodium borohydride reduction of compound **18** gave (3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-1-cyclohexene-1-methanol (**19**) in 22% overall yield from **13**. Hydroboration of **19** with borane–THF complex at 0 °C, oxidative work-up with 35% hydrogen peroxide in an alkaline solution, and successive acetylation afforded a pseudo-β-D-glucopyranose derivative **20** accompanied by compound **16**. These were separated on a silica-gel chromatography in 63 and 11% yield, respectively. This result indicates that the hydroboration of **19** proceeded from the α-side preferentially. In this case, a stereocontrolling factor for the attack of borane was probably the configuration of the benzyloxy group at C-3. Consequently, we could establish a methodology for the configurational inversion at the branched carbon. *O*-Debenzylation of compound **20** by hydrogenolysis in the presence of palladium on charcoal and successive acetylation gave the known (**21**), (1*R*,2*R*,3*S*,4*S*,5*R*)-2,3,4,5-tetraacetoxy-1-(acetoxymethyl)cyclohexane, pseudo-β-D-glucopyranose pentaacetate, in 98% yield. The ^{1}H NMR spectrum of **21** was superimposable on that of an authentic sample.[2,16]

Syntheses of Pentaacetyl Derivatives, 29 and 33, of Pseudo-2-amino-2-deoxy-β-L-altropyranose and of Pseudo-2-amino-2-deoxy-α-D-glucopyranose (Scheme 4). Our interest next turned to an access to pseudo-amino sugars from compound **9**. In order to introduce an amino group at an appropriate position in the cyclohexane moiety, azidolysis of **9** was investigated. By refluxing **9** in aqueous 2-methoxyethanol with excess sodium azide in the presence of ammonium chloride, the epoxy ring was cleaved by the azide anion in a diaxial-opening manner providing compound **22** in 84% yield as crystals. No other azido-containing compounds were detected. The structure of **22** was estimated as depicted from the ^{1}H NMR spectrum of the di-*O*-acetyl derivative **23**, in which the H-5 signal revealed at δ 5.38 as a triplet with $J_{4,5}=J_{5,6}=3$ Hz and the H-4 (H–C–N_3) signal revealed at δ 4.02 as a triplet with $J_{3,4}=J_{4,5}=3$ Hz. Azidolysis of the other epoxy alcohol **9'** under the same reaction conditions described above gave another azido containing compound **22'** in 87% yield. The structure of **22'** was determined from the ^{1}H NMR spectrum of the



Scheme 3.

di-*O*-acetyl derivative **23′**, in which the H-5 signal appeared at δ 5.32 as a triplet with $J_{4,5}=J_{5,6}=3$ Hz and the H-4 (H–C–N_3) signal appeared at δ 4.09 as a triplet with $J_{3,4}=J_{4,5}=3$ Hz. The structures of **22** and **22′** were confirmed by the ^{1}H NMR spectra (400 MHz) of compounds **24** and **24′**, which were prepared from **22** and **22′** by hydrogenation in the presence of 10% palladium on charcoal and successive acetylation (**24** from **22**, 71%, and **24′** from **22′**, 80%). In the ^{1}H NMR spectrum of **24**, the H-4 signal (H–C–NHAc) appeared at δ 4.47 with $J_{3,4}=J_{4,5}=2.9$ Hz and $J_{NH,4}=7.8$ Hz, which changed to a triplet ($J=2.9$ Hz) on adding D_2O. The H-3 signal appeared at δ 5.20 as a double triplet with $J_{2ax,3}=12.2$ Hz and $J_{2eq,3}=J_{3,4}=2.9$ Hz and H-5 signal appeared at δ 5.59 as a triplet with $J_{4,5}=J_{5,6}=2.9$ Hz. This fact indicated that the acetamido group located at C-4 axially and the acetoxyl groups at C-3 and C-5 were equatorial- and axial-orientation. Therefore, two possibilities that 1) azidolysis of **9** proceeded via a neighboring group participation of the hydroxyl group in the epoxide ring opening, and 2) attack of the azide anion at C-3 in a diaxial opening manner of



Scheme 4.

the formed 3,4-epoxide were excluded. The azidolysis of **9** proceeded in a diaxial ring opening manner without migration of the epoxide providing **22** exclusively. The ^{1}H NMR spectrum of **24'** was also consistent with the assigned structure. The H-4 signal appeared at δ 4.43 as a broad doublet with $J_{NH,4}$= 8.3 Hz, which changed to a broad singlet (less than 3 Hz for $J_{3,4}$ and $J_{4,5}$). The H-3 appeared at δ 5.00 with less than 3 Hz coupling constants for $J_{2ax,3}$, $J_{2eq,3}$, and $J_{3,4}$. Consequently, compound **22'** was a diaxial ring opening product of **9'**. The compounds **22** and **22'** were considered to be promising precursors for pseudo-2-amino-2-deoxy sugars. The conversion of **22** to two pseudo-amino sugars proceeded as follows. *O*-Benzylation of the compound **22** gave a di-*O*-benzyl derivative **25** in 82% yield. By the reaction sequence described for transformation of **13** to **16**, [1) refluxing in 1 mol dm^{-3} aqueous HCl, 2) sodium borohydride reduction, 3) periodate glycol cleavage, 4) sodium borohydride reduction, and 5) acetylation], the compound **25** was converted to (1*S*,2*S*,3*R*,4*S*,5*S*)-2-acetoxy-1-acetoxymethyl-4-azido-3,5-bis(benzyloxy)cyclohexane (**27**) in 56% overall yield via compound **26**. Hydrogenation of **27** in the presence of Raney nickel and successive acetylation gave an acetamido derivative **28** in 80% yield. *O*-Debenzylation of **28** by hydrogenolysis followed by acetylation afforded pentaacetyl derivative of pseudo-2-amino-2-deoxy-β-L-altropyranose **29** in 96% yield.

Treatment of compound **26**, which was prepared from **25**, with excess methanesulfonyl chloride for formation of an α,β-unsaturated aldehyde and successive diisobutylaluminium hydride reduction afforded (3*S*,4*S*,5*S*)-4-azido-3,5-bis(benzyloxy)-1-cyclohexene-1-methanol (**30**) in 27% yield from **25**. Hydroboration of **30** with borane–THF complex at 0 °C, oxidative work-up with 35% aqueous hydrogen peroxide in an alkaline solution, and successive acetylation provided a pseudo-α-D-glucopyranose derivative **31** and **27** in 21 and 49% yield, respectively. The hydroboration of **30** proceeded from the less hindered side providing **27** as a major product. In this case, the configuration of the 5-*O*-benzyl group was presumably a stereocontrolling factor. Hydrogenation of **31** followed by acetylation afforded compound **32** in 66% yield. *O*-Debenzylation of **32** and successive acetylation provided the pentaacetyl derivative **33** of pseudo-2-amino-2-deoxy-α-D-glucopyranose in 92% yield. Compound **33** is a derivative of pseudo-glucosamine.[17]

Experimental

General. Evaporations were performed under diminished pressure below 40 °C (bath). Melting points were determined with a Mitamura Riken micro mp apparatus and are uncorrected. Specific rotations were measured in a 10 mm cell with a Jasco DIP-4 polarimeter. Column chromatography was performed on Kieselgel 60 (Merck), and thin-layer chromatography (TLC) was performed on a glass plate coated with Kieselgel 60 GF_{254} (Merck) followed by detection by UV light and charring with sulfuric acid. Preparative TLC (PTLC) was performed on a glass plate (20×20 cm) coated with Kieselgel PF_{254} (Merck) and the compounds were extracted with $CHCl_3$. IR spectra were recorded with a Hitachi Model 225 (KBr) or with a Jasco Model A-202 ($CHCl_3$) spectrometer. ^{1}H NMR spectra were recorded with a Varian EM-390 (90 MHz) or with a JEOL JNM-GX FT NMR for compounds **24** and **24'** (400 MHz) spectrometer for solutions in $CDCl_3$ (internal standard Me_4Si). High resolution mass spectra were obtained using a Hitachi Model M-80 spectrometer. Elemental analyses were performed by Messrs. Saburo Nakada and Akio Takahashi of the university to whom our thanks are due.

Dichloromethane and benzene were dried over CaH_2, then distilled. Pyridine was distilled from NaOH. Tetrahydrofuran (THF) was distilled from $LiAlH_4$.

Mixture of (*E*)- and (*Z*)-3-*C*-Acetylmethylene-3-deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-*ribo*-hexofuranose (2). An approximately 3 to 1 [(*Z*) to (*E*)] mixture, **2**, was prepared according to the reported procedure.[11] A mixture of 1,2:5,6-di-*O*-isopropylidene-α-D-*ribo*-hexofuranos-3-ulose (**1**) (8.93 g, 34.6 mmol) and (acetylmethylene)triphenylphosphorane (22.0 g, 69.2 mmol) in benzene (150 ml) was refluxed for 2 h and evaporated. The residue was partitioned between ethyl acetate (500 ml) and water (250 ml). The aqueous layer was extracted with ethyl acetate (500 ml×2). The organic layers were dried (Na_2SO_4) and evaporated. The residue was triturated with petroleum ether (450 ml) at 40 °C and cooled at 5 °C overnight. The precipitated triphenylphosphine oxide was removed by filtration, and the filtrate was evaporated. The residue was chromatographed on silica gel (220 g, ethyl acetate–toluene=1:20). Fractions corresponding to R_f 0.55 to 0.60 (ethanol–toluene=1:10) were evaporated to afford the mixture **2** (9.88 g, 96%) as a colorless syrup.

3-*C*-Acetylmethyl-3-deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (3). A solution of the mixture **2** (9.88 g, 33.1 mmol) in methanol (50 ml) was hydrogenated in the presence of Raney nickel T-4 (ca. 6 g) under atmospheric hydrogen pressure at ambient temperature for 20 h. The catalyst was removed by filtration through a Celite-pad and washed with methanol. The combined filtrate and washing were evaporated to afford a diastereomeric mixture of 3-deoxy-3-*C*-(2-hydroxypropyl)-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (TLC R_f 0.24 and 0.29, ethyl acetate–hexane=1:2, 10.3 g) as a colorless syrup. To a solution of the mixture in dichloromethane (150 ml) were added PCC (17.8 g, 82.8 mmol) and molecular sieves (3A, powder, 15.0 g). After stirring at the ambient temperature for 18 h, the mixture was diluted with ether (150 ml), then stirred for 1 h. The mixture was applied to a silica-gel column (200 g), and the column was eluted with ether (3 l). The eluate was evaporated and the residue was chromatographed on silica gel (200 g, ethyl acetate–toluene=1:15). Fractions corresponding to R_f 0.47 (ethyl acetate–toluene=1:2) were evaporated to afford **3** as a colorless syrup which was crystallized gradually upon standing at 5 °C, 8.77 g (88%). Mp 36.5—37 °C; $[\alpha]_D^{20}$ +82.1° (*c* 1.35, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3000, 2950, 2890, 1720, 1455, 1410, 1380, 1250, 1215, 1165, 1100, 1065 cm^{-1};

^{1}H NMR ($CDCl_3$) δ=1.27, 1.30, 1.40, 1.47 (3H×4, each s, 2×C(CH_3)$_2$), 2.17 (3H, s, $COCH_3$), 2.25—2.60 (1H, m, H-3), 2.67—2.93 (2H, m, CH_2COCH_3), 3.40—4.23 (4H, m, H-4,5,6,6′), 4.77 (1H, t, J=4.5 Hz, H-2), 5.75 (1H, d, J=4.5 Hz, H-1). Found: C, 59.77; H 8.02%. Calcd for $C_{15}H_{24}O_6$: C, 59.98; H, 8.05%.

3-*C*-Acetylmethyl-3-deoxy-1,2-*O*-isopropylidene-α-D-allofuranose (4). A solution of **3** (8.26 g, 28.0 mmol) in 60% aqueous acetic acid (120 ml) was stirred at the ambient temperature for 17 h and evaporated. The residue was chromatographed on silica gel (230 g, ethanol–toluene=1:12). Fractions corresponding to R_f 0.11 (ethyl acetate–toluene=1:2) were evaporated to afford **4** (7.00 g, 98%) as crystals, mp 69—69.5 °C; $[\alpha]_D^{24}$ +79.7° (*c* 1.82, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3450, 2980, 2930, 1715, 1405, 1370, 1245, 1215, 1165 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.23, 1.43 (3H×2, each s, C(CH_3)$_2$), 2.13 (3H, s, $COCH_3$), 2.20—2.60 (1H, m, H-3), 2.81 (2H, d, J=6 Hz, CH_2COCH_3), 2.93—3.90 (6H, m, H-4,5,6,6′,2×OH), 4.70 (1H, t, J=4.5 Hz, H-2), 5.73 (1H, d, J=4.5 Hz, H-1). Found: C, 55.47; H, 7.52%. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.75%.

(1*R*,6*R*,8*R*,9*R*)-8,9-Isopropylidenedioxy-7-oxabicyclo[4.3.0]-non-4-en-3-one (6). To a stirred solution of **4** (11.1 g, 42.6 mmol) in methanol (200 ml), an aqueous (50 ml) solution of sodium periodate (10.0 g, 46.9 mmol) was added. After stirring at the ambient temperature for 30 min, the solution was evaporated to ca.50 ml, then diluted with water (300 ml). The aqueous solution was extracted with dichloromethane (500 ml×3). The aqueous layer was saturated with NaCl and extracted with dichloromethane (400 ml×2). The combined organic layers were dried (Na_2SO_4) and evaporated to afford a TLC homogeneous **5** (10.2 g, quantitatively) as a colorless syrup, which was subjected to the next step without purification. **5**: TLC, R_f 0.52, ethanol–toluene=1:5; ^{1}H NMR ($CDCl_3$) δ=1.30, 1.48 (3H×2, each s, C(CH_3)$_2$), 2.17 (3H, s, $COCH_3$), 2.25—2.67 (1H, m, H-3), 2.67—3.00 (2H, m, CH_2COCH_3), 3.33—4.15 (1H, m, H-4), 4.47—4.93 (1H, m, H-2), 5.67—6.03 (1H, m, H-1), 9.67 (1H, d, J=3 Hz, CHO).

A solution of **5** (10.2 g, 42.6 mmol) in benzene (200 ml) containing DBU (0.33 ml, 2.24 mmol) was refluxed for 35 h and evaporated. The residue was dissolved in pyridine (50 ml) and acetic anhydride (50 ml) was added. The mixture was stirred for 19 h and evaporated. The residue was dissolved in water (300 ml) and extracted with dichloromethane (600 ml×3). The extracts were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (500 g, ethyl acetate–hexane=1:6). Fractions corresponding to R_f 0.50 (ethanol–toluene=1:10) were evaporated to afford **6** (4.01 g, 45%) as crystals, mp 61—62 °C (from hexane); $[\alpha]_D^{17}$ −45.3° (*c* 0.92, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3050, 2980, 2850, 1675, 1600, 1450, 1380, 1335, 1295, 1255, 1210, 1160, 1140 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.35, 1.53 (3H×2, each s, C(CH_3)$_2$), 1.90—2.35 (1H, m, H-1), 2.35—3.00 (2H, m, H-2,2′), 4.47—4.80 (2H, m, H-6,9), 5.73—6.10 (2H, m, H-4,8), 7.28 (1H, d, J=9 Hz, H-5). Found: C, 62.96, H, 6.80%. Calcd for $C_{11}H_{14}O_4$:C, 62.85; H, 6.71%.

(1*R*,6*R*,8*R*,9*R*)-8,9-Isopropylidenedioxy-7-oxabicyclo[4.3.0]-nonan-3-one (7). A solution of **6** (40.0 mg, 0.19 mmol) in ethanol (2 ml) was hydrogenated in the presence of Raney nickel T-4 under hydrogen at atmospheric pressure for 2 h. After removal of the catalyst through a Celite-pad, the filtrate was evaporated to afford a syrupy diastereomeric mixture of (1*R*,6*R*,8*R*,9*R*)-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonan-3-ol, which was oxidized without purification. To a stirred solution of the mixture in dichloromethane (2 ml) was added PCC (102 mg, 0.48 mmol). After stirring at ambient temperature for 15 h, the mixture was evaporated. The residue was applied to a silica-gel column (3 g), and the column was eluted with ether to afford **7** (33.2 mg, 82%), TLC R_f=0.66 (ethanol–toluene=1:5); mp 98—98.5 °C; $[\alpha]_D^{21.5}$ −33.7° (*c* 1.66, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2980, 2875, 1710, 1450, 1415, 1375, 1325, 1305, 1270, 1245, 1210, 1165, 1150, 1120, 1095 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.35, 1.57 (3H×2, each s, C(CH_3)$_2$), 1.59—2.05 (2H, m, 5,5′), 2.10—2.73 (5H, m, H-1,2,2′,4,4′), 4.10 (1H, dt, $J_{1,6}$=$J_{5ax,6}$= 10.5Hz, $J_{5eq,6}$=4.5 Hz, H-6), 4.60 (1H, t, $J_{1,9}$=$J_{8,9}$=4 Hz, H-9), 5.93 (1H, d, $J_{8,9}$=4 Hz, H-8). Found: C, 62.01; H, 7.42%. Calcd for $C_{11}H_{16}O_4$: C, 62.25; H, 7.60%.

(1*R*,4*S*,5*S*,6*S*,8*R*,9*R*)-4,5-Epoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonan-3-one (8) and the (1*R*,4*R*,5*R*,6*S*,8*R*, 9*R*) stereomer (8′). To a stirred solution of **6** (450 mg, 2.14 mmol) in methanol (3 ml), hydrogen peroxide (35 wt% aqueous solution, 0.56 ml, 6.42 mmol) and an aqueous NaOH solution (1 mol dm^{-3}, 0.07 ml) (pH 9) were added. After stirring at the ambient temperature for 3 h, the mixture was diluted with water (10 ml) and extracted with ethyl acetate (30 ml×5). The extracts were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (35 g, ethyl acetate–hexane=1:12). Fractions corresponding to R_f 0.62 (ethanol–toluene=1:10) were evaporated to afford **8** (467 mg, 96%) as a colorless syrup, and fractions corresponding to R_f 0.52 were evaporated to afford **8′** (16 mg, 3%) as a colorless syrup. **8**:$[\alpha]_D^{18.5}$ −108.8° (*c* 1.77, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2980, 2940, 2870, 1715, 1450, 1410, 1375, 1320, 1300, 1260, 1210, 1160, 1085 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.32, 1.50 (3H×2, each s, C(CH_3)$_2$), 2.28—2.76 (3H, m, H-1,2,2′), 3.37 (1H, d, J=5 Hz, H-5), 3.90 (1H, d, J=5 Hz, H-4), 4.30 (1H, d, J=10.5 Hz, H-6), 4.57 (1H, t, J=3.5 Hz, H-9), 5.94 (1H, d, J=3.5 Hz, H-8). High-resolution mass spectrum, calcd for $C_{11}H_{15}O_5$: *m/z* 227.0918, found: M+H, 227.0917. **8′**: $[\alpha]_D^{17}$ −11.0° (*c* 0.82, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2990, 2940, 2870, 1715, 1450, 1415, 1375, 1300, 1260, 1240, 1210, 1160, 1115 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.31, 1.52 (3H×2, each s, C(CH_3)$_2$), 1.73—2.18 (1H, m, H-1), 2.42—2.73 (2H, m, H-2,2′), 3.19 (1H, d, J=4 Hz, H-5), 3.79 (1H, d, J=4 Hz, H-4), 4.05 (1H, d, J=10.5 Hz, H-6), 4.57 (1H, t, J=3.5 Hz, H-9), 5.91 (1H, d, J=3.5 Hz, H-8).

(1*R*,3*S*,4*R*,5*S*,6*S*,8*R*,9*R*)- (9) and (1*R*,3*R*,4*R*,5*S*,6*S*,8*R*,9*R*)-(9′) 4,5-Epoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonan-3-ol. The compound **6** (991 mg, 4.72 mmol) was converted to **8** containing a trace of **8′** as described above. The syrupy crude **8** was dissolved in ethanol (10 ml) and sodium borohydride (176 mg, 4.65 mmol) was added. After stirring at 0 °C for 40 min, the mixture was neutralized by addition of 1 mol dm^{-3} HCl, then evaporated. The residue was triturated with chloroform (20 ml) and an insoluble solid was removed by filtration. The filtrate was evaporated and the residue was chromatographed on silica gel (110 g, ethyl acetate–hexane=1:3). Fractions corresponding to R_f 0.29 (ethyl acetate–hexane=1:1) were evaporated to afford **9** (758 mg, 70%) as a colorless syrup, and fractions corresponding to R_f 0.16 were evaporated to afford **9′** (153 mg, 14%) as crystals. **9**: $[\alpha]_D^{27}$ +26.1° (*c* 1.05, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3600, 2990, 2930, 2880, 1450, 1390, 1370, 1300, 1240, 1170,

1130, 1070, 1050 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.36, 1.55 (3H×2, each s, $C(CH_3)_2$), 1.47—2.47 (3H, m, H-1,2,2'), 2.62 (1H, br s, OH), 3.25 (1H, d, $J_{4,5}$=4 Hz, $J_{3,4}$=0 Hz, H-4), 3.67 (1H, d, $J_{4,5}$=4 Hz, $J_{5,6}$=0 Hz, H-5), 4.21 (1H, $J_{1,6}$=10.5 Hz, $J_{5,6}$=0 Hz, H-6), 4.05—4.40 (1H, m, H-3; changed to triplet with $J_{2,3}$=$J_{2',3}$=8 Hz, $J_{3,4}$=0 Hz centered at δ 4.15 by addition of D_2O), 4.57 (1H, t, J=4 Hz, H-9), 5.87 (1H, d, J=4 Hz, H-8). High-resolution mass spectrum, calcd for $C_{11}H_{17}O_5$: m/z 229.1075, found: M+H, 229.1078. **9'**: mp 141—144 °C; $[\alpha]_D^{27}$ +63.2° (c 0.89, $CHCl_3$); IR ν_{max}^{KBr} 3490, 2980, 2930, 2860, 1460, 1440, 1410, 1390, 1380, 1280, 1250, 1210, 1170, 1150, 1130, 1085, 1015 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.30, 1.48 (3H×2, each s, $C(CH_3)_2$), 1.60—2.21 (3H, m, H-1,2,2'), 2.67 (1H, br s, OH), 3.44 (1H, t, $J_{3,4}$=$J_{4,5}$=4 Hz, H-4), 3.72 (1H, d, $J_{4,5}$=4 Hz, $J_{5,6}$=0 Hz, H-5), 4.04 (1H, d, $J_{1,6}$=10 Hz, $J_{5,6}$=0 Hz, H-6), 4.13—4.37 (1H, m, H-3; changed to triplet with J=4 Hz centered at δ 4.24 by addition of D_2O), 4.53 (1H, t, J=4 Hz, H-9), 5.84 (1H, d, J=4 Hz, H-8). Found: C,57.62; H, 7.09%. Calcd for $C_{11}H_{16}O_5$: C, 57.88; H, 7.06%.

(1*R*,3*S*,4*R*,5*S*,6*S*,8*R*,9*R*)-3-Acetoxy-4,5-epoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (10). The compound **9** (33 mg, 0.14 mmol) was acetylated with acetic anhydride (1 ml) and pyridine (1 ml) for 3 h. After removal of the reagents, the residue was chromatographed on silica gel (2 g, ethyl acetate–hexane=1:8) to give **10** (TLC R_f=0.32, ethanol–toluene=1:10) (19 mg, 50%) as a colorless syrup, $[\alpha]_D^{27}$ +50.1° (c0.77, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2980, 2930, 1740, 1455, 1370, 1220, 1165, 1130, 1110, 1055 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.30, 1.50 (3H×2, each s, $C(CH_3)_2$), 1.58—2.58 (3H, m, H-1,2,2'), 2.09 (3H, s, $OCOCH_3$), 3.15 (1H, d, $J_{4,5}$=4 Hz, $J_{3,4}$=0 Hz, H-4) 3.61 (1H, d, $J_{4,5}$=4 Hz, $J_{5,6}$=0 Hz, H-5), 4.15 (1H, d, $J_{1,6}$=10 Hz, $J_{5,6}$=0 Hz, H-6), 4.52 (1H, t, J=4 Hz, H-9), 5.11 (1H, t, $J_{2,3}$=$J_{2',3}$=8.5 Hz, $J_{3,4}$=0 Hz, H-3), 5.83 (1H, d, J=4 Hz, H-8). High-resolution mass spectrum, calcd for $C_{13}H_{19}O_6$: m/z 271.1180, found: M+H, 271.1209.

(1*R*,3*R*,4*R*,5*S*,6*S*,8*R*,9*R*)-3-Acetoxy-4,5-epoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (10'). The compound **9'** (29 mg, 0.13 mmol) was acetylated with acetic anhydride (1 ml) and pyridine (1 ml) for 3 h. After removal of the reagents, the residue was chromatographed on silica gel (2 g, ethyl acetate–hexane=1:8) to give **10'** (R_f=0.32, ethanol–toluene=1:10) (25 mg, 73%), mp 136—138 °C; $[\alpha]_D^{27}$ +84.6° (c 1.04 $CHCl_3$); IR ν_{max}^{KBr} 2990, 1725, 1375, 1320, 1280, 1245, 1210, 1165, 1150, 1125, 1100, 1075, 1050 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.30, 1.50 (3H×2, each s, $C(CH_3)_2$), 1.66—2.32 (3H, m, H-1,2,2'), 2.11 (3H, s, $OCOCH_3$), 3.52 (1H, t, $J_{3,4}$=$J_{4,5}$=4 Hz, H-4), 3.60 (1H, d, $J_{4,5}$=4 Hz, $J_{5,6}$=0 Hz, H-5), 4.06 (1H, d, $J_{1,6}$=10.5 Hz, $J_{5,6}$=0 Hz, H-6), 4.53 (1H, t, J=4 Hz, H-9), 5.25 (1H, q, $J_{2,3}$=$J_{2',3}$=$J_{3,4}$=4 Hz, H-3), 5.83 (1H, d, J=4 Hz, H-8). High-resolution mass spectrum, calcd for $C_{13}H_{19}O_6$: m/z 271.1180, found: M+H, 271.1178.

(1*R*,3*R*,4*S*,5*S*,6*S*,8*R*,9*R*)-8,9-Isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane-3,4,5-triol (11). From **9**. A solution of **9** (153 mg, 0.67 mmol) in a mixture of 2-methoxyethanol and water (10:3, v/v, 7.5 ml) containing sodium acetate (110 mg, 1.34 mmol) was refluxed for 9 h and evaporated. The residue was chromatographed on silica gel (20 g, ethanol–hexane=1:9), and fractions corresponding to R_f 0.26 (ethanol–toluene=1:5) were evaporated to afford **11** (120 mg, 73%), mp 160—162 °C; $[\alpha]_D^{25}$ −6.6° (c 1.00, MeOH); IR ν_{max}^{KBr} 3420, 3250, 2990, 2940, 2910, 1450, 1380, 1370, 1265, 1210, 1170, 1140, 1105, 1075, 1025 cm^{-1}; ^{1}H NMR (CD_3OD) δ=1.32, 1.47 (3H×2, each s, $C(CH_3)_2$), 1.71—2.41 (3H, m, H-1,2,2'), 3.81—4.80 (8H, m, H-3,4,5,6,9, 3×OH), 5.79 (1H, d, J=4 Hz, H-8). Found: C, 49.66; H, 7.51%. Calcd for $C_{11}H_{18}O_6 \cdot H_2O$: C, 49.99; H, 7.63%.

From **9'**. A solution of **9'** (63 mg, 0.67 mmol) in a mixture of 2-methoxyethanol and water (10:3, 4 ml) containing sodium acetate (45 mg) was refluxed for 9 h and evaporated. After chromatographic purification as described above, **11** was obtained (55 mg, 81%).

(1*R*,3*R*,4*S*,5*S*,6*S*,8*R*,9*R*)-3,4,5-Triacetoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (12). A solution of **9** (85 mg, 0.37 mmol) in a mixture of 2-methoxyethanol and water (10:3, 5 ml) containing sodium acetate (61 mg) was refluxed for 8 h and evaporated. The residue was acetylated with acetic anhydride (5 ml) and pyridine (5 ml) for 12 h and evaporated. The residue was partitioned between dichloromethane (40 ml) and water (40 ml). The aqueous layer was extracted with dichloromethane (40 ml×2). The combined organic layers were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (15 g, ethyl acetate–hexane=1:5), and fractions corresponding to R_f 0.77 (ethanol–toluene=1:5) were evaporated to afford **12** (112 mg, 80%), mp 56—58 °C; $[\alpha]_D^{26}$−7.8° (c 1.26, $CHCl_3$); IR ν_{max}^{KBr} 2985, 2940, 1755, 1745, 1440, 1375, 1250, 1170, 1125, 1115, 1085, 1030 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.32, 1.51 (3H×2, each s, $C(CH_3)_2$), 2.05 (3H, s, $OCOCH_3$), 2.08 (6H, s, 2×$OCOCH_3$), 1.84—2.48 (3H, m, H-1,2,2'), 4.00 (1H, dd, $J_{1,6}$=11 Hz, $J_{5,6}$=3 Hz, H-6), 4.60 (1H, t, J=4 Hz, H-9), 5.00 (1H, q, $J_{2,3}$=$J_{2',3}$=$J_{3,4}$=3 Hz, H-3), 5.12 (1H, t, $J_{4,5}$=$J_{5,6}$=3 Hz, H-5), 5.37 (1H, t, $J_{3,4}$=$J_{4,5}$=3 Hz, H-4), 5.83 (1H, d, J=4 Hz H-8). Found: C, 54.71; H, 6.39%. Calcd for $C_{17}H_{24}O_9$: C, 54.83; H, 6.50%.

(1*R*,3*R*,4*S*,5*S*,6*S*,8*R*,9*R*)-3,4,5-Tris(benzyloxy)-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (13). A stirred suspension of sodium hydride (60% in mineral oil, 431 mg, 10.8 mmol, washed with hexane 10 ml×3 then dried) in dry DMF (5 ml) was added a DMF (10 ml) solution of **11** (442 mg, 1.79 mmol). After stirring for 15 min, benzyl bromide (1.28 ml, 10.8 mmol) was added. The mixture was stirred at ambient temperature for 16 h. The mixture was evaporated and the residue was partitioned between dichloromethane (60 ml) and water (60 ml). The aqueous layer was extracted with dichloromethane (60 ml×2). The organic layers were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (50 g, ethyl acetate–hexane=1:12), and fractions corresponding to R_f 0.40 (ethyl acetate–hexane=1:5) were evaporated to afford **13** (858 mg, 93%) as a colorless syrup, $[\alpha]_D^{27}$ −0.8° (c 1.22, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3050, 3025, 2995, 2930, 2870, 1600, 1495, 1450, 1380, 1370, 1265, 1240, 1210, 1165, 1120, 1065 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.31, 1.48 (3H×2, each s, $C(CH_3)_2$), 1.79—2.67 (3H, m, H-1,2,2'), 3.69 (1H, q, $J_{2,3}$=$J_{2',3}$=$J_{3,4}$=3 Hz, H-3), 3.84 (1H, t, $J_{3,4}$=$J_{4,5}$=3 Hz or $J_{4,5}$=$J_{5,6}$=3 Hz, H-4 or H-5), 4.08 (1H, dd, $J_{1,6}$=11.5 Hz, $J_{5,6}$=3 Hz, H-6), 4.17 (1H, t, $J_{3,4}$=$J_{4,5}$=3 Hz or $J_{4,5}$=$J_{5,6}$=3 Hz, H-4 or H-5), 4.44—4.69 (6H, m, 3×$OCH_2C_6H_5$), 4.56 (1H, t, J=4 Hz, H-9), 5.84 (1H, d, J=4 Hz, H-8), 7.28 (15H, s, 3×$OCH_2C_6H_5$). High-resolution mass spectrum, calcd for $C_{32}H_{36}O_6$: m/z 516.2509, found: M, 516.2505.

(1*S*,2*S*,3*S*,4*S*,5*R*)-2-Acetoxy-1-acetoxymethyl-3,4,5-tris(benzyloxy)cyclohexane (16). A solution of **13** (648 mg, 1.26 mmol) in a mixture of 80% aqueous acetic acid (20 ml) and

1,4-dioxane (7 ml) was refluxed for 2 h and evaporated. The resulting crude *O*-deisopropylidene derivative (TLC, R_f= 0.41, ethanol–toluene=1:8) was used in the next step directly. To a stirred solution of the residue in methanol (30 ml) was added sodium borohydride (143 mg, 3.78 mmol) at 0 °C. After stirring at the same temperature for 3 h, 35% aqueous hydrogen peroxide (5 ml) was added. After stirring at 0 °C for 1 h, the solution was diluted with saturated aqueous sodium sulfite (25 ml), then acidified (pH 5) with 1 mol dm^{-3} HCl solution. The resulting white precipitate was removed by filtration and washed with ethanol (100 ml). The combined filtrate and washing were evaporated to ca. 20 ml and extracted with dichloromethane (50 ml×5). The extracts were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (30 g, ethyl acetate–hexane=1:3, 1:2, 1:1, then ethyl acetate–ethanol=1:1). Fractions corresponding to R_f 0.35 (ethanol–toluene=1:8) were evaporated afford (1*R*)-1-[(1*S*,2*S*,3*S*,4*S*,5*R*)-3,4,5-tris-(benzyloxy)-2-hydroxycyclohexyl]-1,2-ethanediol (**14**) (419 mg) as a colorless syrup. To a stirred solution of **14** in methanol (9 ml), an aqueous (1.9 ml) solution of sodium periodate (207 mg, 0.97 mmol) was added. After stirring at the ambient temperature for 1 h, the precipitated solid was removed and the filtrate was evaporated. The residue was dissolved in water (10 ml) and extracted with dichloromethane (10 ml×4). The extracts were dried (Na_2SO_4) and evaporated to afford curde (1*R*,2*S*,3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-2-hydroxycyclohexanecarbaldehyde (**15**) as a colorless syrup, which was reduced directly. To a solution of **15** in ethanol (10 ml), sodium borohydride (73 mg, 1.93 mmol) was added. After stirring at the ambient temperature for 5 h, 35% aqueous hydrogen peroxide (3 ml) was added. After stirring for 1 h, saturated sodium sulfite (15 ml) and 1 mol dm^{-3} HCl (pH 7) were added. The solution was diluted with water (5 ml) and extracted with dichloromethane (100 ml×3, 80 ml×3). The combined extracts were dried (Na_2SO_4) and evaporated. The residue was acetylated with acetic anhydride (3 ml) in pyridine (3 ml) for 5 h. After evaporation of the mixture, the residue was chromatographed on silica gel (20 g, ethyl acetate–hexane=1:10). Fractions corresponding to R_f 0.67 (ethyl acetate–hexane=1:2) were evaporated to afford **16** (350 mg, 52%) as a colorless syrup, $[\alpha]_D^{26}$ −25.7° (*c* 0.74, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3060, 2900, 1735, 1495, 1450, 1365, 1230, 1110, 1085, 1070 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.87 (2H, dd, *J*=5 and 6.5 Hz, H-6,6′), 2.00, 2.06 (3H×2, each s, 2×OCOCH_3), 2.42 (1H, q, *J*=6 Hz, H-1), 3.47—3.82 (3H, m, H-3,4,5), 4.00 (2H, dd, *J*=2.5 and 6.5 Hz, CH_2OAc), 4.59 (4H, s, 2×OCH_2C$_6$H$_5$), 4.72 (2H, s, OCH_2C$_6$H$_5$), 5.28 (1H, dd, *J*=2.5 and 6 Hz, H-2), 7.30 (15H, s, 3×OCH$_2$C$_6$H$_5$). High-resolution mass spectrum, calcd for $C_{32}H_{36}O_7$: *m/z* 532.2466, fornd: M, 532.2459.

(1*S*,2*S*,3*S*,4*S*,5*R*)-2,3,4,5-Tetraacetoxy-1-(acetoxymethyl)-cyclohexane, Pentaacetate of Pseudo-α-L-altropyranose (17). Sodium (180 mg, 7.88 mmol) was added to a liquid ammonia (30 ml) at −78 °C. To the resulting blue solution, a THF (3 ml) solution of **16** (350 mg, 0.66 mmol) was added. After stirring at the same temperature for 25 min, 180 mg of sodium was added. The mixture was stirred for 3 h at −78 °C. Ammonium chloride (200 mg) was added to this, and the mixture was allowed to warm to the ambient temperature. The resulting solid was dried, then acetylated with acetic anhydride (7 ml) in pyridine (7 ml) for 5 h. The mixture was evaporated, and the residue was partitioned between ethyl acetate (50 ml) and water (10 ml). The aqueous layer was extracted with ethyl acetate (50 ml×3). The combined organic layers were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (12 g, ethyl acetate–hexane=1:4) and fractions corresponding to R_f 0.49 (ethyl acetate–hexane=1:2) were evaporated to afford **17** (85 mg, 33%), mp 84—85 °C, $[\alpha]_D^{26.5}$ −13.7° (*c* 1.36, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2930, 2855, 1740, 1435, 1370, 1220, 1040 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.96 (2H, dd, *J*=5 and 6 Hz, H-6,6′), 2.00, 2.01, 2.04, 2.06, 2.08 (3H×5, each s, 5×OCOCH_3), 2.40 (1H, q, *J*=6 Hz, H-1), 4.15 (2H, d, *J*=6.5 Hz, CH_2OAc), 4.88—5.40 (4H, m, H-2,3,4,5). High-resolution mass spectrum, calcd for $C_{17}H_{25}O_{10}$: *m/z* 389.1446, found: M+H, 389.1463.

(3*S*,4*S*,5*R*)-3,4,5-Tris(benzyloxy)-1-cyclohexene-1-methanol (19). The compound **13** (945 mg, 1.83 mmol) was converted to the crude **15** (326 mg) as described in the preparation of **16**. To a stirred solution of the crude **15** in pyridine (7 ml) was added methanesulfonyl chloride (0.34 ml, 4.40 mmol). After stirring at ambient temperature for 24 h, the mixture was evaporated. The residue was diluted with water (25 ml) and extracted with dichloromethane (40 ml×3). The extracts were dried (Na_2SO_4) and evaporated to give crude α,β-unsaturated aldehyde (**18**) (TLC R_f=0.62, ethyl acetate–hexane=1:2), which was reduced without purification. To a stirred solution of the crude **18** (syrup) in ethanol (7 ml) was added sodium borohydride (51 mg, 1.35 mmol). After stirring at ambient temperature for 3.5 h, the mixture was evaporated. The residue was partitioned between dichloromethane (40 ml) and water (40 ml), and the aqueous layer was extracted with dichloromethane (40 ml×2). The organic layers were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (30 g, ethyl acetate–hexane=1:10, 1:8, then 1:5). Fractions corresponding to R_f 0.34 (ethyl acetate–hexane=1:2) were evaporated to afford **19** (173 mg, 22% overall yield from **13**) as a colorless syrup, $[\alpha]_D^{26}$ +12.3° (*c* 1.11, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3590, 3000, 2910, 2870, 1590, 1490, 1450, 1360, 1080 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.54—1.80 (1H, m, OH), 1.90—2.64 (2H, m, H-6,6′), 3.63—4.26 (5H, m, H-3,4,5,CH_2OH), 4.50—5.00 (6H, m, 3×OCH_2C$_6$H$_5$), 5.52—5.80 (1H, m, H-2), 7.33 (15H, s, 3×OCH$_2$C$_6$H$_5$). High-resolution mass spectrum, calcd for $C_{28}H_{30}O_4$: *m/z* 430.2142, found: M, 430.2134.

(1*R*,2*R*,3*S*,4*S*,5*R*)-2-Acetoxy-1-acetoxymethyl-3,4,5-tris(benzyloxy)cyclohexane (20) and the (1*S*,2*S*,3*S*,4*S*,5*R*)-Stereoisomer 16. To a stirred solution of **19** (163 mg, 0.38 mmol) in THF (5 ml), borane–THF complex (1 mol dm^{-3} in THF, 1.33 ml, 1.33 mmol) at 0 °C was added under argon atmosphere. After stirring at 0 °C for 20 min, then at ambient temperature for 90 min, 0.20 ml (0.20 mmol) of the reducing reagent was added and stirred for another 1 h. After addition of water (0.8 ml), aqueous NaOH (3 mol dm^{-3}, 1.26 ml) and aqueous hydrogen peroxide (35%, 1.44 ml) were added successively. The mixture was stirred for 3 h, neutralized with 1 mol dm^{-3} HCl, and evaporated. The mixture was diluted with water (30 ml) and extracted with dichloromethane (40 ml×3). The extracts were dried (Na_2SO_4) and evaporated. The residue was acetylated with acetic anhydride (3 ml) in pyridine (3 ml) for 12 h, then evaporated. The residue was chromatographed on silica gel (20 g, ethyl acetate–hexane=1:6). Fractions corresponding

to R_f 0.74 (ethyl acetate–hexane=1:2) were evaporated to afford **16** (17 mg), and fractions corresponding to R_f 0.72 were evaporated to afford **20** (111 mg). In addition, a mixture of **16** and **20** (27 mg) was obtained, from which pure **16** (5 mg) and **20** (17 mg) were separated by repeated PTLC (ethyl acetate–hexane=1:5) [**16** (22 mg, 11%) and **20** (128 mg, 63%)]. **20**: Mp 56—57 °C; $[\alpha]_D^{24}$ +1.9° (*c* 1.03, $CHCl_3$); IR ν_{max}^{KBr} 3080, 2850, 1740, 1490, 1450, 1360, 1240 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.71—2.26 (3H, m, H-1,6,6'), 1.89, 2.01 (3H×2, each s, 2×$OCOCH_3$), 3.31—3.70 (3H, m, H-3,4,5), 3.86—4.17 (2H, m, CH_2OAc), 4.52—5.19 (7H, m, H-2, 3×$OCH_2C_6H_5$), 7.29, 7.32, 7.37 (15H, each s, 3×$OCH_2C_6H_5$). Found: C, 71.91; H, 6.77%. Calcd for $C_{32}H_{36}O_7$: C, 72.16; H, 6.81%.

(1*R*,2*R*,3*S*,4*S*,5*R*)-2,3,4,5-Tetraacetoxy-1-(acetoxymethyl)cyclohexane, Pentaacetate of Pseudo-β-D-glucopyranose (21). A solution of **20** (80 mg, 0.15 mmol) in methanol (2 ml) was hydrogenolyzed in the presence of 10% palladium on charcoal using a Parr apparatus for 14 h. The catalyst was removed by filtration, washed with methanol, and the filtrate and washing were combined, then evaporated. The residue was acetylated with acetic anhydride (1 ml) in pyridine (1 ml) for 7 h and evaporated. The residue was chromatographed on silica gel (6 g, ethyl acetate–hexane=1:4), and fractions corresponding to R_f 0.58 (ethyl acetate–hexane=1:1) were evaporated to afford **21** (57 mg, 98%), mp 114—116 °C, lit,[2] mp 115—116 °C; $[\alpha]_D^{23}$ +4.4° (*c* 1.23, $CHCl_3$), lit.,[2] $[\alpha]_D^{20}$ +13.8° (*c* 1.0, $CHCl_3$); IR ν_{max}^{KBr} 2860, 1740, 1430, 1370, 1230, 1030 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.23—2.60 (3H, m, H-1,6,6'), 1.97, 1.99, 2.02, 2.03 (3H, 3H, 6H, 3H, each s, 5×$OCOCH_3$), 3.84—4.26 (2H, m, CH_2OAc), 4.76—5.54 (4H, m, H-2,3,4,5). Found: C, 52.41; H, 6.08%. Calcd for $C_{17}H_{24}O_{10}$: C, 52.57; H, 6.23%.

(1*R*,3*S*,4*S*,5*R*,6*S*,8*R*,9*R*)-4-Azido-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane-3,5-diol (22). A solution of **9** (1.24 g, 5.43 mmol) in a mixture of 2-methoxyethanol and water (4:1, v/v, 20 ml) containing sodium azide (1.412 g, 21.7 mmol) and ammonium chloride (581 mg, 10.9 mmol) was refluxed for 4 h, and evaporated. To the residue, ethyl acetate (150 ml) was added and the mixture was stirred for 30 min. Insoluble material was removed by filtration through a Celite-pad, and the filtrate was evaporated to afford a crystalline **22**. Recrystallization from ethyl acetate and hexane gave 1.24 g (84%) of **22**, mp 172—173 °C; TLC R_f 0.18 (ethyl acetate–hexane=1:2); $[\alpha]_D^{27}$ +66.2° (*c* 1.00, MeOH); IR ν_{max}^{KBr} 3460, 3350, 3000, 2910, 2110, 1390, 1380, 1270, 1240, 1210, 1120 cm^{-1}. Found: C, 48.94; H, 6.34; N, 15.23%. Calcd for $C_{11}H_{17}N_3O_5$: C, 48.70; H, 6.32; N, 15.49%.

(1*R*,3*S*,4*S*,5*R*,6*S*,8*R*,9*R*)-3,5-Diacetoxy-4-azido-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (23). The compound **22** (17 mg, 0.06 mmol) was acetylated with acetic anhydride (1 ml) in pyridine (1 ml) for 4 h. After removal of the reagents, the residue was chromatographed on silica gel (2 g, ethyl acetate–hexane=1:6). Fractions corresponding to R_f 0.48 (ethyl acetate–hexane=1:2) were evaporated to afford **23** (21 mg, 96%) as a colorless syrup, $[\alpha]_D^{28}$ +39.6° (*c* 0.89, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2990, 2930, 2110, 1750, 1390, 1380, 1250, 1210, 1130, 1120 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.31, 1.50 (3H×2, each s, $C(CH_3)_2$), 1.78—2.20 (3H, m, H-1,2,2'), 2.09 (6H, s, 2×$OCOCH_3$), 3.95 (1H, dd, *J*=10.5 and 3 Hz, H-6), 4.02 (1H, t, $J_{3,4}=J_{4,5}$=3 Hz, H-4), 4.54 (1H, t, *J*=4 Hz, H-9), 4.96—5.26 (1H, m, H-3), 5.38 (1H, t, $J_{4,5}=J_{5,6}$=3 Hz, H-5), 5.80 (1H, d, *J*=4 Hz, H-8).

(1R,3*R*,4*S*,5*R*,6*S*,8*R*,9*R*)-4-Azido-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane-3,5-diol (22'). A solution of **9'** (220 mg, 0.96 mmol) in a mixture of 2-methoxyethanol and water (4:1, v/v, 5 ml) containing sodium azide (251 mg, 3.86 mmol) and ammonium chloride (103 mg, 1.93 mmol) was refluxed for 6 h, and evaporated. To the residue, ethyl acetate (40 ml) was added and the mixture was stirred for 30 min. Insoluble material was removed by filtration through a Celite-pad, and the filtrate was evaporated to afford crystalline **22'**. Recrystallization from ethyl acetate gave 228 mg (87%) of **22'**, mp 157—159 °C; TLC R_f=0.61 (ethanol–toluene=1:4); $[\alpha]_D^{24}$ −22.0° (*c* 1.00, MeOH); IR ν_{max}^{KBr} 3420, 3260, 2990, 2900, 2110, 1440, 1390, 1380, 1310, 1250, 1220 cm^{-1}.

(1*R*,3*R*,4*S*,5*R*,6*S*,8*R*,9*R*)-3,5-Diacetoxy-4-azido-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (23'). The compound **22'** (22 mg, 0.08 mmol) was acetylated with acetic anhydride (0.5 ml) in pyridine (1 ml) for 10 h. After removal of the reagents, the residue was chromatographed on silica gel (1.5 g, ethyl acetate–hexane=1:6). Fractions corresponding to R_f 0.40 (ethyl acetate–hexane=1:2) were evaporated to afford **23'** (27 mg, 94%) as crystals, mp 95—96 °C; $[\alpha]_D^{22}$ −17.2° (*c* 1.35, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2980, 2960, 2930, 2120, 1740, 1380, 1300, 1250, 1220, 1200 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.32, 1.51 (3H×2, each s, $C(CH_3)_2$), 1.80—2.44 (3H, m, H-1,2,2'), 2.05, 2.07 (3H×2, each s, 2×$OCOCH_3$), 3.95 (1H, dd, $J_{1,6}$=11.5 Hz and $J_{5,6}$=3 Hz), 4.09 (1H, t, $J_{3,4}=J_{4,5}$=3 Hz, H-4), 4.58 (1H, t, *J*=4 Hz, H-9), 5.04 (1H, q, $J_{2ax,3}=J_{2eq,3}=J_{3,4}$=3 Hz, H-3), 5.32 (1H, t, $J_{4,5}=J_{5,6}$=3 Hz, H-5), 5.81 (1H, d, *J*=4 Hz, H-8).

(1*R*,3*S*,4*S*,5*R*,6*S*,8*R*,9*R*)-4-Acetamido-3,5-diacetoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (24). A solution of **22** (87 mg, 0.32 mmol) in methanol (6 ml) was hydrogenated in the presence of 10% palladium on charcoal (40 mg) under atmospheric hydrogen pressure for 3 h. After removal of the catalyst, the filtrate was evaporated. The residue was acetylated with acetic anhydride (1 ml) in pyridine (3 ml) for 10 h. The solution was evaporated, and the residue was chromatographed on silica gel (3 g, ethanol–toluene=1:30). Fractions corresponding to R_f 0.41 (ethanol–toluene=1:5) were evaporated to afford **24** (84 mg, 71%), mp 110—112 °C; $[\alpha]_D^{24}$ +9.5° (*c* 0.84, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2980, 2930, 1740, 1670, 1490, 1460, 1370, 1300, 1240 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.33, 1.53 (3H×2, each s, $(CH_3)_2$), 1.68 (1H, q, *J*=12.2 Hz, H-2ax), 2.03, 2.05, 2.09 (3H×3, each s, 2×$OCOCH_3$ and $NCOCH_3$), 1.99—2.18 (2H, m, H-1 and 2eq), 3.83 (1H, dd, $J_{1,6}$=11.2 Hz, $J_{5,6}$=2.9 Hz, H-6), 4.47 (1H, dt, $J_{3,4}=J_{4,5}$=2.9 Hz, $J_{NH,4}$=7.8 Hz, H-4, changed to t with *J*=2.9 Hz by D_2O), 4.58 (1H, t, $J_{1,9}=J_{8,9}$=3.4 Hz, H-9), 5.20 (1H, dt, $J_{2ax,3}$=12.2 Hz, $J_{2eq,3}=J_{3,4}$=2.9 Hz, H-3), 5.43 (1H, d, $J_{NH,3}$=7.8 Hz, NH), 5.59 (1H, t, $J_{4,5}=J_{5,6}$=2.9 Hz, H-5), 5.83 (1H, d, $J_{8,9}$=3.4 Hz, H-8). High-resolution mass spectrum, calcd for $C_{17}H_{25}NO_8$: *m/z* 371.1579, found: M, 371.1595.

(1*R*,3*R*,4*S*,5*R*,6*S*,8*R*,9*R*)-4-Acetamido-3,5-diacetoxy-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (24'). The compound **22'** (100 mg, 0.37 mmol) was converted to **24'** (110 mg, 80%) as described in preparation of **24**. **24'** as a colorless syrup; TLC R_f 0.41 (ethanol–toluene=1:5); $[\alpha]_D^{25}$ −15.1° (*c* 1.32, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2990, 2940, 1740, 1680, 1490,

1440, 1370, 1300, 1240, 1200 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ=1.34, 1.52 (3H×2, each, s, $(CH_3)_2$), 2.01, 2.07, 2.08 (3H×3, each s, 2×$OCOCH_3$ and $NCOCH_3$), 1.80—2.36 (3H, m, H-1 and H-2ax, 2-eq), 3.79 (1H, dd, $J_{1,6}$=11.2 Hz, $J_{5,6}$=2.9 Hz, H-6), 4.43 (1H, broad d, $J_{NH,4}$=8.3 Hz, changed to broad singlet with less than 3 Hz of $J_{3,4}$, $J_{4,5}$ by D_2O, H-4), 4.60 (1H, t, $J_{1,9}$=$J_{8,9}$=3.9 Hz, H-9), 5.00 (1H, q, $J_{2ax,3}$, $J_{2eq,3}$, $J_{3,4}$ less than 3 Hz, H-3), 5.37 (1H, broad singlet, $J_{4,5}$ less than 3 Hz, $J_{5,6}$=2.9 Hz, H-5), 5.47 (1H, d, $J_{NH,3}$=8.3 Hz, NH), 5.83 (1H, d, $J_{8,9}$=3.9 Hz, H-8). High-resolution mass spectrum, calcd for $C_{17}H_{25}NO_8$: m/z 371.1577, found: M, 371.1558.

(1*R*,3*S*,4*S*,5*R*,6*S*,8*R*,9*R*)-4-Azido-3,5-bis(benzyloxy)-8,9-isopropylidenedioxy-7-oxabicyclo[4.3.0]nonane (25). To a stirred suspension of sodium hydride (60%, 416 mg, 10.4 mmol, washed with hexane, then dried) in DMF (10 ml), a DMF (10 ml) solution of **22** (564 mg, 2.08 mmol) was added. After stirring for 20 min, benzylbromide (1.24 ml, 10.4 mmol) was added to the mixture. The mixture was stirred for 5 h at ambient temperature, then ethanol (10 ml) was added. After evaporation of the mixture, the residue was partitioned between dichloromethane (60 ml) and water (60 ml). The aqueous layer was extracted with dichloromethane (60 ml×2). The organic layers were dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel (20 g, ethyl acetate–hexane=1:20), and fractions corresponding to R_f 0.40 (ethyl acetate–hexane=1:6) were evaporated to afford **25** (772 mg, 82%) as a colorless syrup, $[\alpha]_D^{27}$ +48.2° (*c* 1.02, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3000, 2930, 2880, 2110, 1450, 1390, 1380, 1270, 1170, 1140 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.30, 1.51 (3H×2, each s, $C(CH_3)_2$), 1.66—2.14 (3H, m, H-1,2,2'), 3.80—4.10 (4H, m, H-3,4,5,6), 4.43—4.88 (5H, m, H-9,2×$OCH_2C_6H_5$), 5.81 (1H, d, *J*=4 Hz, H-8), 7.32, 7.34 (10H, each s, 2×$OCH_2C_6H_5$). High-resolution mass spectrum, calcd for $C_{24}H_{26}N_3O_5$: m/z 436.1860, found: M−CH_3, 436.1870.

(1*S*,2*S*,3*R*,4*S*,5*S*)-2-Acetoxy-1-acetoxymethyl-4-azido-3,5-bis(benzyloxy)cyclohexane (27). A solution of **25** (600 mg, 1.33 mmol) in a mixture of 1 mol dm^{-3} HCl (2 ml) and 1,4-dioxane (8 ml) was refluxed for 30 min, neutralized with saturated aqueous $NaHCO_3$, then evaporated. To the residue, ethyl acetate (80 ml) was added and insoluble solids were removed by filtration through a Celite-pad. The filtrate was evaporated to afford crude *O*-deisopropylidene derivative. To a stirred solution of the residue in ethanol (10 ml), sodium borohydride (101 mg, 2.66 mmol) was added. The mixture was stirred at 0 °C for 1 h, diluted with water (2 ml), neutralized with 1 mol dm^{-3} HCl, and evaporated. To the residue, ethyl acetate (80 ml) was added, and insoluble solids were removed by filtration through a Celite-pad. The filtrate was evaporated to afford a foam. The foam was dissolved in methanol (10 ml), and an aqueous (2 ml) solution of sodium periodate (568 mg, 2.66 mmol) was added. The mixture was stirred at the ambient temperature for 1 h and evaporated. To the residue, ethyl acetate (60 ml) was added, and insoluble materials were removed. The filtrate was evaporated to afford crude (1*R*,2*S*,3*R*,4*S*,5*S*)-4-azido-3,5-bis(benzyloxy)-2-hydroxycyclohexanecarbaldehyde (**26**) (TLC R_f 0.70, ethanol–toluene=1:5). To a solution of the crude **26** in ethanol (10 ml), sodium borohydride (101 mg, 2.66 mmol) was added, and the mixture was stirred for 2 h. The mixture was diluted with water (2 ml), neutralized with 1 mol dm^{-3} HCl, and evaporated. To the residue, ethyl acetate (60 ml) was added, and insoluble solids were removed. The filtrate was evaporated. The residue was chromatographed on silica gel (20 g, toluene, then ethanol–toluene=1:5). Fractions corresponding to R_f 0.56 (ethanol–toluene=1:5) were evaporated to afford (1*S*,2*S*,3*R*,4*S*,5*S*)-4-azido-3,5-bis(benzyloxy)-2-hydroxycyclohexanemethanol as a colorless syrup, which was acetylated with acetic anhydride (4 ml) in pyridine (8 ml) for 10 h. The mixture was evaporated, and the residue was chromatographed on silica gel (35 g, ethyl acetate–hexane=1:8). Fractions corresponding to R_f 0.45 (ethyl acetate–hexane=1:3) were evaporated to afford **27** (348 mg, 56% from **25**) as a colorless syrup, $[\alpha]_D^{27}$ −29.1° (*c* 0.70, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2920, 2110, 1730, 1450, 1370, 1320, 1250, 1210 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.47—2.52 (3H, m, H-1,6,6'), 1.97, 2.02 (3H×2, each s, 2×$OCOCH_3$), 3.78—4.13 (5H, m, H-3,4,5, OH_2OAc), 4.34—4.72 (4H, m, 2×$OCH_2C_6H_5$), 4.92 (1H, dd, *J*=12 and 3 Hz, H-2), 7.30, 7.33 (10H, each s, 2×$OCH_2C_6H_5$).

(1*S*,2*S*,3*R*,4*S*,5*S*)-4-Acetamido-2-acetoxy-1-acetoxymethyl-3,5-bis(benzyloxy)cyclohexane (28). A solution of **27** (198 mg, 0.42 mmol) in ethanol (10 ml) was hydrogenated in the presence of Raney nickel T-4 under hydrogen at atmospheric pressure for 2 h. The catalyst was removed by filtration through a Celite-pad, and the filtrate was evaporated. The residue was acetylated with acetic anhydride (3 ml) in pyridine (6 ml) for 2 h. The mixture was evaporated, and the residue was chromatographed on silica gel (14 g, ethanol–toluene=1:20), and fractions corresponding to R_f 0.35 (ethanol–toluene=1:10) were evaporated to afford **28** (164 mg, 80%) as a colorless syrup, $[\alpha]_D^{24}$ −3.6° (*c* 1.10, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 3000, 2930, 2870, 1730, 1670, 1490, 1450, 1370, 1250 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.44—2.58 (3H, m, H-1,6,6'), 1.91 (3H, s, $NCOCH_3$), 1.97, 2.02 (3H×2, each s, 2×$OCOCH_3$), 3.80—4.26 (4H, m, H-3,5, CH_2OAc), 4.34—4.74 (1H, m, H-4), 4.43, 4.62 (4H, each s, 2×$OCH_2C_6H_5$), 5.06 (1H, dd, *J*=9 and 3 Hz, H-2), 5.69 (1H, d, *J*=7 Hz, NH), 7.30, 7.33 (10H, each s, 2×$OCH_2C_6H_5$). High-resolution mass spectrum, calcd for $C_{27}H_{34}NO_7$: m/z 484.2333, found: M+H, 484.2317.

(1*S*,2*S*,3*R*,4*S*,5*S*)-4-Acetamido-2,3,5-triacetoxy-1-(acetoxymethyl)cyclohexane, Pentaacetate of Pseudo-2-amino-2-deoxy-β-L-altropyranose (29). A solution of **28** (140 mg, 0.29 mmol) in ethanol (10 ml) was hydrogenolyzed in the presence of palladium black in a Parr apparatus for 15 h. The catalyst was removed by filtration through a Celite-pad, and the filtrate was evaporated. The residue was acetylated with acetic anhydride (3 ml) in pyridine (8 ml) for 15 h. The mixture was evaporated, and the residue was chromatographed on silica gel (10 g, ethanol–toluene=1:20). Fractions corresponding to R_f 0.43 (ethanol–toluene=1:4) were evaporated to afford **29** (108 mg, 96%) as a colorless syrup, $[\alpha]_D^{18}$ +37.7° (*c* 0.87, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 1760, 1670, 1500, 1370, 1230 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.57—2.52 (3H, m, H-1,6,6'), 1.94 (3H, s, $NCOCH_3$), 2.06 (12H, s, 4×$OCOCH_3$), 3.98—4.23 (2H, m, CH_2OAc), 4.40—4.70 (1H, m, H-4), 5.10—5.37 (3H, m, H-2,3.5), 5.95 (1H, d, *J*=9 Hz, NH). High-resolution mass spectrum, calcd for $C_{17}H_{25}NO_9$: m/z 387.1528, found: M, 387.1533.

(3*S*,4*S*,5*S*)-4-Azido-3,5-bis(benzyloxy)-1-cyclohexene-1-methanol (30). The compound **25** (802 mg, 1.78 mmol) was converted to the crude **26** as described in preparation of **27**. To the solution of the crude **26** in pyridine (20 ml) was

added methanesulfonyl chloride (0.57 ml, 7.11 mmol). The mixture was stirred at the ambient temperature for 8 h and evaporated. The residue was partitioned between dichloromethane (60 ml) and water (60 ml), and the aqueous layer was extracted with dichloromethane (60 ml×2). The organic layers were dried (Na_2SO_4) and evaporated to afford a brown syrup [main product, R_f 0.63 (ethyl acetate-hexane=1:3)]. To a solution of the syrup in dichloromethane (10 ml) was added diisobutylaluminium hydride (1.5 mol dm^{-3} in toluene, 9.47 ml, 14.2 mmol) at −15 °C. The resulting insoluble materials were removed through a Celite-pad and washed with ethyl acetate. The combined filtrate and washings were evaporated. The residue was chromatographed on silica gel (30 g, ethyl acetate-hexane=1:4), and fractions corresponding to R_f 0.31 (ethyl acetate-hexane=1:2) were evaporated to afford **30** (176 mg, 27% from **25**) as a colorless syrup, $[\alpha]_D^{22}$ +68.1° (*c* 1.39, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2920, 2860, 2110, 1350, 1260 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.57—1.84 (1H, m, OH), 2.20—2.39 (2H, m, H-6,6′), 3.68—4.25 (5H, m, H-3,4,5,C*H*$_2$OH), 4.62 (4H, s, 2×OC*H*$_2$C$_6$H$_5$), 5.66—5.80 (1H, m, H-2), 7.34 (10H, s, 2×OCH$_2$C$_6$*H*$_5$).

(1*R*,2*R*,3*R*,4*S*,5*S*)-2-Acetoxy-1-acetoxymethyl-4-azido-3,5-bis(benzyloxy)cyclohexane (31) and the (1*S*,2*S*,3*R*,4*S*,5*S*)-stereoisomer 27. To a solution of **30** (170 mg, 0.47 mmol) in THF (2 ml) was added borane-THF complex (1.0 mol dm^{-3} in THF, 1.86 ml, 1.86 mmol) at 0 °C under argon atmosphere. The mixture was stirred for 3 h, then hydrogen peroxide (35% aqueous solution, 4 ml) and 3 mol dm^{-3} NaOH (1 ml) were added. After stirring for 6 h, the solution was neutralized with 1 mol dm^{-3} HCl and diluted with water (20 ml). The aqueous solution was extracted with dichloromethane (30 ml×3). The extracts were dried (Na_2SO_4) and evaporated. The residue was acetylated with acetic anhydride (2 ml) in pyridine (4 ml) for 14 h and evaporated. The residue was chromatographed on silica gel (20 g, ethyl acetate-hexane=1:20). Fractions corresponding to R_f 0.61 (ethyl acetate-hexane=1:2) were evaporated to afford **27** (106 mg, 49%), and fractions corresponding to R_f 0.54 were evaporated to afford **31** (46 mg, 21%) as a colorless syrup. **31**: $[\alpha]_D^{18}$ +20.0° (*c* 0.75, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 2920, 2100, 1730, 1450, 1360, 1250, 1200 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.16—2.57 (3H, m, H-1,6,6′), 1.92, 2.01 (3H×2, each s, 2×OCOC*H*$_3$), 3.23—3.47 (1H, m, H-5), 3.70—4.23 (4H, m, H-3,4, C*H*$_2$OAc), 4.46—5.30 (4H, m, 2×OC*H*$_2$C$_6$H$_5$), 5.01 (1H, t, *J*=9 Hz, H-2), 7.32, 7.37 (10H, each s, 2×OCH$_2$C$_6$*H*$_5$).

(1*R*,2*R*,3*R*,4*S*,5*S*)-4-Acetamido-2-acetoxy-1-acetoxymethyl-3,5-bis(benzyloxy)cyclohexane (32). A solution of **31** (43 mg, 0.09 mmol) in ethanol (4 ml) was hydrogenated in the presence of Raney nickel T-4 under hydrogen at atmospheric pressure for 1.5 h. After removal of the catalyst, the filtrate was evaporated. The residue was acetylated with acetic anhydride (1 ml) in pyridine (3 ml) for 2 h. The mixture was evaporated, and the residue was chromatographed on silica gel (3 g, ethanol-toluene=1:20). Fractions corresponding to R_f 0.56 (ethanol-toluene=1:6) were evaporated to afford **32** (29 mg, 66%), mp 154—156 °C (recrystallized from ethyl acetate); $[\alpha]_D^{18}$ +65.6° (*c* 0.90, $CHCl_3$); IR ν_{max}^{KBr} 1730, 1640, 1380, 1370, 1280, 1240 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.27—2.57 (3H, m, H-1,6,6′), 1.72 (3H, s, NCOC*H*$_3$), 2.00, 2.04 (3H×2, each s, 2×OCOC*H*$_3$), 3.55—4.74 (9H, m, H-3,4,5, C*H*$_2$OAc, 2×OC*H*$_2$C$_6$H$_5$), 5.08 (1H, dd, *J*=11 and 9 Hz, H-2), 5.46 (1H, d, *J*=8 Hz, NH), 7.30, 7.33 (10H, s, 2×OCH$_2$C$_6$*H*$_5$). High-resolution mass spectrum, calcd for $C_{27}H_{34}NO_7$: *m/z* 484.2333, found: M+H, 484.2345.

(1*R*,2*R*,3*R*,4*S*,5*S*)-4-Acetamido-2,3,5-triacetoxy-1-(acetoxymethyl)cyclohexane, Pentaacetate of Pseudo-2-amino-2-deoxy-α-D-glucopyranose (33). A solution of **32** (22 mg, 0.05 mmol) in ethanol (4 ml) was hydrogenolyzed in the presence of palladium-black in a Parr apparatus for 12 h. The catalyst was removed through a Celite-pad, and the filtrate was evaporated. The residue was acetylated with acetic anhydride (2 ml) in pyridine (4 ml) for 10 h. After evaporation of the mixture, the residue was chromatographed on silica gel (2 g, ethanol-toluene=1:15). Fractions corresponding to R_f 0.43 (ethanol-toluene=1:4) were evaporated to afford **33** (17 mg, 92%) as a colorless syrup, $[\alpha]_D^{23}$ +75.6° (*c* 0.81, $CHCl_3$); IR $\nu_{max}^{CHCl_3}$ 1740, 1670, 1510, 1380, 1370, 1240 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.14—2.66 (3H, m, H-1,6,6′), 1.90 (3H, s, NCOC*H*$_3$) 2.03, 2.05, 2.13 (6H, 3H, 3H, each s, 4×OCOC*H*$_3$), 3.72—4.38 (3H, m, H-4, C*H*$_2$OAc), 4.94—5.34 (3H, m, H-2,3,5), 5.83 (1H, d, *J*=10 Hz, NH). High-resolution mass spectrum, calcd for $C_{17}H_{25}NO_9$: *m/z* 387.1527, found: M, 387.1524.

The authors express their sincere thanks to Professor Seiichiro Ogawa of Keio University for his valuable discussion on the structural identification of the synthesized pseudo-sugars in the present work.

References

1) S. Ogawa, *Yuki Gosei Kagaku Kyokai Shi*, **43**, 26 (1985).
2) S. Ogawa, Y. Iwasawa, and T. Suami, *Chem. Lett.*, **1984**, 355; S. Ogawa, Y. Iwasawa, T. Nose, T. Suami, S. Ohba, M. Ito, and Y. Saito, *J. Chem. Soc., Perkin Trans. 1*, **1985**, 903.
3) H. Paulsen and F. R. Heiker, *Angew. Chem. Int. Ed. Engl.*, **19**, 904 (1980); *idem., Liebigs Ann. Chem.*, **1981**, 2180; *idem., Carbohydr. Res.*, **102**, 83 (1982).
4) H. Paulsen, W. v. Deyn, and W. Roben, *Liebigs Ann. Chem.*, **1984**, 433.
5) R. J. Ferrier and P. Prasit, *Pure Appl. Chem.*, **55**, 565 (1983) and references cited therein.
6) F. Sugawara and H. Kuzuhara, *Agric. Biol. Chem.*, **45**, 301 (1981).
7) C. S. Wilcox and L. M. Thomasco, *J. Org. Chem.*, **50**, 547 (1985).
8) C. S. Wilcox and J. J. Gaudino, *J. Am. Chem. Soc.*, **108**, 3102 (1986).
9) a) T. Suami, K. Tadano, Y. Kameda, and Y. Iimura, *Chem. Lett.*, **1984**, 1919; b) T. Suami, K. Tadano, Y. Ueno, and Y. Iimura, *Chem. Lett.*, **1985**, 37; c) K. Tadano, H. Maeda, M. Hoshino, Y. Iimura, and T. Suami, *Chem. Lett.*, **1986**, 1081; d) K. Tadano and T. Suami, *Yuki Gosei Kagaku Kyokai Shi*, **44**, 633 (1986).
10) A part of the present work was published in a preliminary form, T. Suami, K. Tadano, Y. Ueno, and C. Fukabori, *Chem. Lett.*, **1985**, 1557.
11) J. M. J. Tronchet and B. Gentile, *Carbohydr. Res.*, **44**, 23 (1975).
12) A. Rosenthal and M. Sprinzl, *Can. J. Chem.*, **47**, 3941

(1969).

13) M. Georges, T-F. Tam, and B. Fraser-Reid, *J. Org. Chem.*, **50**, 5747 (1985).

14) In previous papers, we incorrectly assigned the structures of compounds **9** and **9′**. The compounds **96** and **97** in reference 9d) and the compounds **9** (and **10**) and **9′** (and **10′**) in reference 10) should be interchanged.

15) T. Suami, S. Ogawa, T. Ishibashi, and I. Kasahara, *Bull. Chem. Soc. Jpn.*, **49**, 1388 (1976).

16) For DL-**21**: T. Suami, S. Ogawa, K. Nakamoto, and I. Kasahara, *Carbohydr. Res.*, **58**, 240 (1977); S. Ogawa, M. Ara, T. Kondoh, M. Saitoh, R. Masuda, T. Toyokuni, and T. Suami, *Bull. Chem. Soc. Jpn.*, **53**, 1121 (1980).

17) A derivative of pseudo-2-amino-2-deoxy-α-glucopyranose, tetra-*O*-acetyl-(1,2,4/3,5)-5-hydroxymethyl-2-(*p*-toluenesulfonamido)-1,3,4-cyclohexanetriol, was synthesized in a DL-form: S. Ogawa, T. Toyokuni, T. Kondoh, Y. Hattori, S. Iwasaki, M. Suetsugu, and T. Suami, *Bull. Chem. Soc. Jpn.*, **54**, 2739 (1981).