Substituent Effects of the C6-Position on Ring-Opening Polymerization of Glucose Ortho Esters: Synthesis of Stereoregular 6-Deoxy-(1→4)-*β*-D-glucopyranan

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ABSTRACT: We studied the effect of the C6-substituent on the ring-opening polymerizations of ortho esters using the novel starting ortho ester derivative, 3-*O*-benzyl-6-deoxy-α-D-glucopyranose 1,2,4-orthopivalate (**1**). The ring-opening polymerization of orthopivalate **1** by Ph_3CBF_4 gave the new stereoregular polysaccharide derivative, 3-*O*-benzyl-6-deoxy-2-*O*-pivaloyl-(1→4)-*β*-D-glucopyranan with $[\alpha]_D^{25}$ −26.7° and a number-average degree of polymerization ($\overline{DP_n}$) of approximately 34. Thus, the electronic, not steric, effect of the substituent at the C6-position was the important factor for forming stereoregular (1→4)-*β*-pyranan in the ring-opening polymerization of ortho esters.

Introduction

We have chemically synthesized cellulose by the ring-opening polymerization of 3-*O*-benzyl-α-D-glucopyranose 1,2,4-orthopivalate[1] and found that the substituents on the monomer played an important role in stereo- and regioregularities of the resulting polymer. Both the 3-*O*-benzyl and orthopivaloyl groups are indispensable substituents for the synthesis of stereoregular (1→4)-*β*-pyranan in the ring-opening polymerizations of glucose ortho ester derivatives.[2,3] Several additional 3-*O*-benzylglucose orthopivalate derivatives with the different substituents at C6-position in our laboratory:[4] 6-*O*-benzyl, methyl, acetyl, pivaloyl, *DL*-2-methylbutyloyl, tosyl, 6-iodo, and chloro derivatives were polymerized. Only 6-*O*-benzyl, methyl, and pivaloyl derivatives gave stereoregular (1→4)-*β*-pyranan. This indicates that the electron-donating (benzyl and methyl) or slightly withdrawing (pivaloyl: less than acetyl) group at the 6-*O*-position, regardless of the molecular bulk, may be necessary in order to obtain stereoregular (1→4)-*β*-pyranan.

Substituent effects are generally due to the electronic and/or steric factor. We supposed that the effects of the substituent at C6-position in glucose may be due to the electronic factor, not steric factor. Therefore, the 6-deoxyglucose (quinovose) ortho ester derivative with the CH_3 group at C5-position may produce stereoregular (1→4)-*β*-pyranan by a ring-opening polymerization; the CH_3 group is more electron-donating and has less steric repulsion than the CH_2OR group.

Thus, we used 3-*O*-benzyl-6-deoxy-α-D-glucopyranose 1,2,4-orthopivalate (**1**) as a starting material for the ring-opening polymerization. Structural analyses of the polymer from 6-deoxyorthopivalate **1** should clarify the role of the C6-substituent on the ring-opening polymerization of glucose ortho esters. That is, if the substituent effects of the CH_2OR group on the ring-opening polymerization of glucose ortho esters are due to the electronic effect, the polymerization of **1** with the CH_3 group, which has stronger electron-donating effect than CH_2OR group, will afford stereoregular 6-deoxy-(1→4)-*β*-D-glucopyranan. On the other hand, if the substituent effects are due to the steric effect, the ring-opening polymerization of **1** with the CH_3 group, which has a smaller steric repulsion than CH_2OR group, will not afford a stereoregular polymer. The polymerization of **1** may also produce a stereoregular 6-deoxy-(1→4)-*β*-D-glucopyranan that has not been chemically synthesized yet. Since stereoregular 6-deoxy-(1→4)-*β*-D-glucopyranan does not occur in nature, we are interested in comparing its physical structure, properties, and biological activities with those of natural cellulose.

Results and Discussion

Synthesis and Polymerization of 3-*O*-Benzyl-6-deoxy-α-D-glucopyranose 1,2,4-Orthopivalate (1). 6-Deoxyorthopivalate **1** was newly synthesized via six reaction steps from allyl 3-*O*-benzyl-4-*O*-*p*-methoxybenzyl-*β*-D-glucopyranoside (**2**)[5] as shown in Scheme 1. The ^1H NMR signal of the CH_3 group at the C5-position appeared at δ 1.44 ppm as a doublet with a coupling constant of about 7.2 Hz. The ^{13}C NMR peak for the quaternary carbon in the orthopivaloyl group appeared at δ 122.9 ppm. These spectra support the structure of 6-deoxyorthopivalate **1**.

To clarify the effect of only the C6-substituent, the ring-opening polymerization of 6-deoxyorthopivalate **1** was carried out under the same reaction conditions as those of the other derivatives previously described:[4] at 20 °C in dichloromethane, using Ph_3CBF_4 as the initiator. When the reaction finished, 6-deoxyorthopivalate **1** did not exist in the reaction mixture. Number-averaged molecular weights of the polymer determined by gel permeation chromatography (GPC) in THF using polystyrene standards was 9900 ($\overline{DP_n} = \sim 34$, $M_w/M_n = 1.5$). The specific rotation of the polymer was $[\alpha]_D^{25}$ −26.7°.

Structure of the Polymer. As shown in Scheme 2, there are four possible structural units in the polymer prepared by ring-opening polymerization of 6-deoxyorthopivalate **1**, namely, (1→4)-α-, *β*-, (1→2)-α-, and *β*-pyranose units. In addition, isomerization of the ortho ester may produce the corresponding 1,4-anhydro-6-deoxyglucose derivative leading to the (1→5)-*β*-furanose unit. This isomerization has already been reported by Bochkov et al.[6]

The ^1H and ^{13}C NMR spectra of the polymer are shown in Figures 1 and 2, respectively. The ^1H NMR

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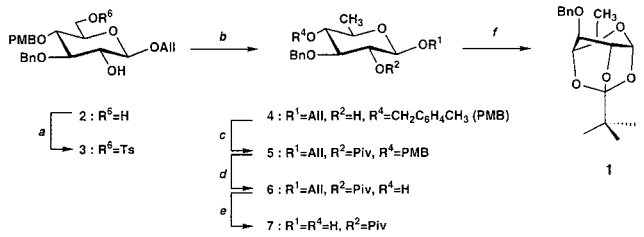
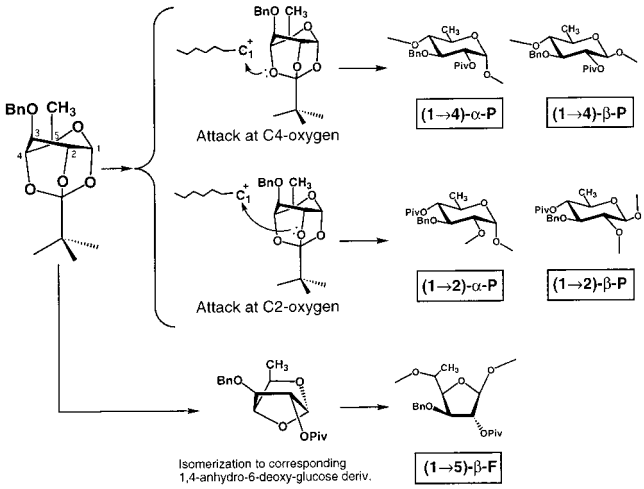
Scheme 1. Synthesis of 3-*O*-benzyl-6-deoxy-α-D-glucopyranose 1,2,4-orthopivalate



[a] TsCl/pyridine, 60 °C, overnight, 90%. [b] $LiAlH_4$/anhydrous THF, room temperature to reflux, 2.5 h. [c] PivCl/pyridine, 80 °C, overngiht, 93% overall yield from **3**. [d] $CAN/CH_3CN:H_2O$ (9:1), room temperature, 0.5 h, 87%. [e] $PdCl_2$, NaOAc/AcOH: H_2O(20:1), 60 °C, 1 day. [f] *N*,*N*′-Carbonyldiimidazole/benzene, reflux, overnight, 25% overall yield from **6**.

Scheme 2. Possible Structures in the Ring-Opening Polymerization of 6-Deoxyorthopivalate 1



spectrum shows very clear resonances for each ring proton. The ^{13}C NMR spectra shows sharp peaks for each ring carbon and only one single peak for the anomeric carbon at about 100 ppm. These results clearly indicate that the polymer is highly stereoregular and consists of only one intermonomeric linkage.

The ^1H NMR resonances of the polymer were assigned via their cross-peaks in a HH−COSY spectrum. The relatively large coupling constant of the ring protons (J = approximately 9 Hz) suggests that the polymer consists of glucopyranose repeating units, not furanose units.[7] The signal of the C2-proton appears at the lowest magnetic field (δ 4.93 ppm, J = 8.7 Hz) of the ring protons. This supports that the pivaloyl group exists at the C2-position, and the polymer has the (1→4)-glycosidic linkages. The signal of the anomeric proton appears at δ 4.45 ppm with a coupling constant of 8.7 Hz, suggesting β-glycosidic linkages. An α-pyranose unit would have a coupling constant of about 3.0 Hz.[7]

In addition, the specific rotation of the polymer ($[\alpha]_D^{25}$ −26.7°) was negative. This suggests that the polymer has β-glucosidic linkages. Thus, all of the data strongly indicate that the polymer consists exclusively of the 6-deoxy-(1→4)-β-glucopyranose repeating unit.

Scheme 3 illustrates the proposed propagation mechanism of the polymerization of 6-deoxyorthopivalate **1** to yield stereoregular 6-deoxy-(1→4)-β-glucopyranan. The initiator, triphenylcarbenium ion, preferentially attacks the C4-oxygen to afford the oxoniumion intermediate (A), which is then converted to the five-membered ring dioxalenium ion intermediate (B), via O4−C7 bond breaking. S_N2 attack of the next monomer to the intermediate (B) results in only (1→4)-β-bond formation.

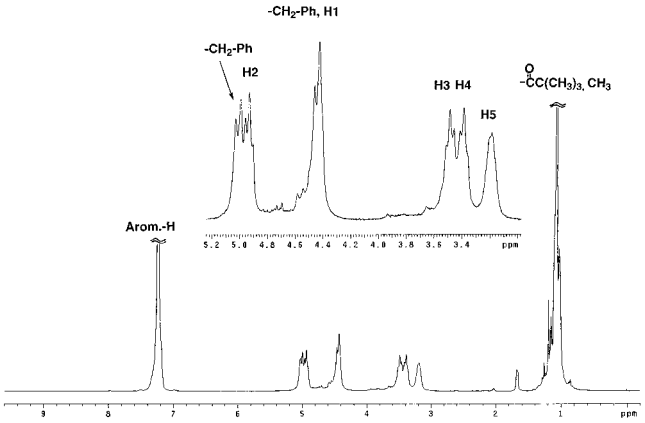


Figure 1. 300 MHz ^1H NMR spectrum of 3-*O*-benzyl-6-deoxy-2-*O*-pivaloyl-(1→4)-α-D-glucopyranan.

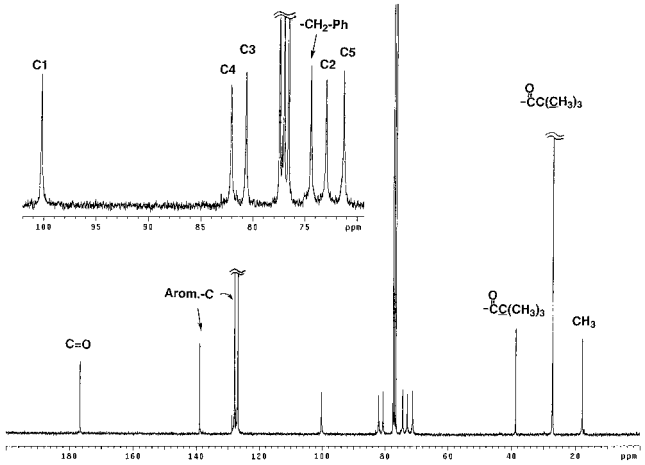


Figure 2. 75 MHz ^{13}C NMR spectrum of 3-*O*-benzyl-6-deoxy-2-*O*-pivaloyl-(1→4)-β-D-glucopyranan.

Conversion of the Polymer into the Acetyl Derivative. The structure of the polymer was further characterized by analysis of the ^{13}C NMR spectrum of the acetyl derivative obtained after deprotection and subsequent acetylation: depivaloylation, acetylation, debenzylation and acetylation. According to GPC analysis, the polymer did not depolymerize during the deprotection processes. (Figure 3) The ^{13}C NMR spectrum of the acetyl polymer is shown in Figure 4. The ^{13}C resonances were assigned via the cross-peaks in a CH−HETCOR spectrum.

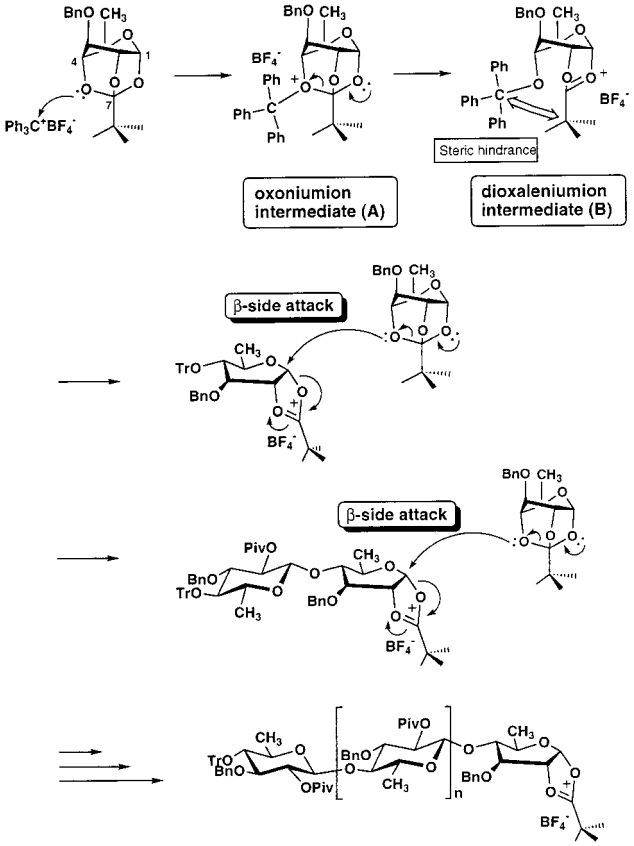
Structure of the Acetyl Derivative. For comparison with the present acetylated polymer, cellulose was converted into 6-deoxycellulose acetate as a model of the (1→4)-β-glucopyranose linkage. Microcrystalline cellulose (Avicel) was 6-*O*-tosylated by the method of Rahn et al.,[8] reduced by the method of Kurita et al.[9] and then acetylated to afford polymer **10**. (Scheme 4) ^1H NMR of polymer **10** indicated that the C6-position was almost (over 80%) regioselectively deoxidized, the but C2-position (less 20%) was also deoxidized.

Table 1 shows the ^{13}C chemical shifts measured in $CDCl_3$ of 2,3-di-*O*-acetyl-6-deoxy-(1→4)-β-glucopyranan and polymer **10** from Avicel. They are almost identical.

Table 1. ^{13}C NMR Chemical Shifts Measured in $CDCl_3$ of 2,3-Di-*O*-acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan and Polymer 10 from Avicel

	δ (ppm)					
	C1	C2	C3	C4	C5	CH_3
2,3-di-*O*-acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan	100.77	72.20	73.08	81.41	71.05	17.30
polymer **10** from Avicel	100.72	72.03	72.65	81.29	71.01	17.31

Scheme 3. Mechanism of the Ring-Opening Polymerization of 6-Deoxyorthopivalate 1



Thus, all above results strongly indicate that the polymer prepared by the present ring-opening polymerization of 6-deoxyorthopivalate **1** is stereoregular polysaccharide, 6-deoxy-(1→4)-*β*-D-glucopyranan derivative.

Conversion of the Acetate into 6-Deoxy-(1→4)-*β*-D-glucopyranan. 2,3-Di-*O*-acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan was deacetylated with 1,8-diazabicyclo-[5.4.0]-7-undecene (DBU) in 20% methanol/dichloromethane (v/v) to give 6-deoxy-(1→4)-*β*-D-glucopyranan. The ^{1}H and ^{13}C NMR spectra in DMSO-d_6 showed that the acetyl group was completely removed. (Figures 4 and 5).

Solubility of 6-Deoxy-(1→4)-*β*-D-glucopyranan. Recent studies have reported the relationship between hydrogen bonds and solubility of regioselectively substituted cellulose derivatives.[10] In general, the physical properties including solubility of cellulose and its derivatives are strongly influenced by formation of inter- and intramolecular hydrogen bonds. In particular, in selectively substituted celluloses, the hydroxyl groups should form controlled intra- and intermolecular hydrogen bonds. Kondo reported that the amount of free OH groups at the C6-position may be more important at determining the solubility of the material than those at the C2- or C3-position; i.e., intermolecular hydrogen bonds, favorably formed by the primary OH group at

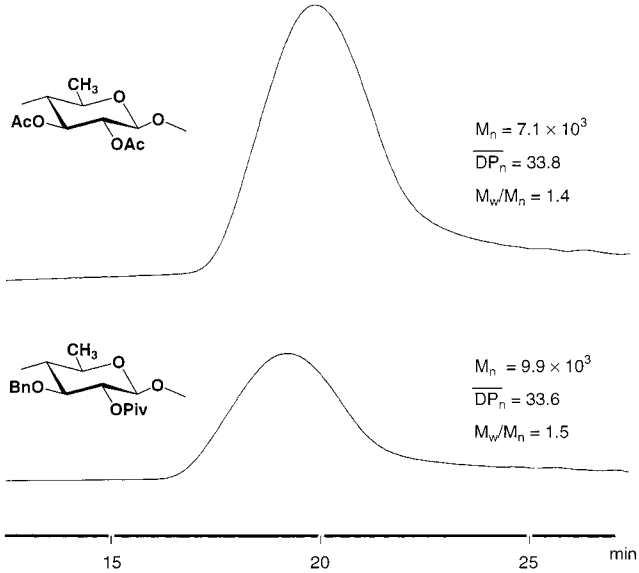


Figure 3. GPC analyses of 3-*O*-benzyl-6-deoxy-2-*O*-pivaloyl-(1→4)-*β*-D-glucopyranan and 2,3-di-*O*-acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan. [Column: Shodex KF802, KF802.5 and KF803. Solvent: THF (1.0 mL/min). Temperature: 40 °C.]

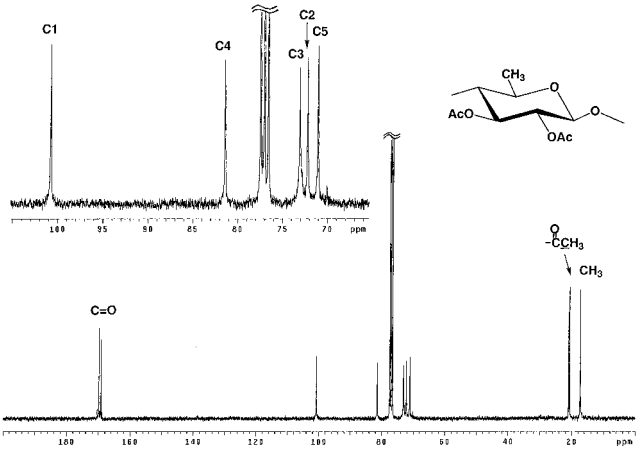
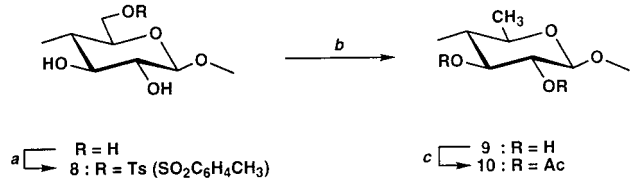


Figure 4. 75 MHz ^{13}C NMR spectrum of 2,3-di-*O*-acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan.

Scheme 4. Synthesis of 6-Deoxycellulose from Avicel



[a] TsCl,Et_3N/DMA-LiCl, 8 °C, 35 h, 79%. [b] $NaBH_4$/DMSO, 80 °C, total reaction time 64 h. [c] Ac_2O/pyridine, 60 °C, overnight, 83% overall yield from **8**.

the C6-position, cause poor solubility of the material to solvents. Actually, 6-*O*-methylcellulose (6MC), which has only two intramolecular hydrogen bonds between ether oxygen and OH groups (6O−HO-2′ and 3-OH−O5′), exhibited higher solubility than 2,3-di-*O*-methyl-

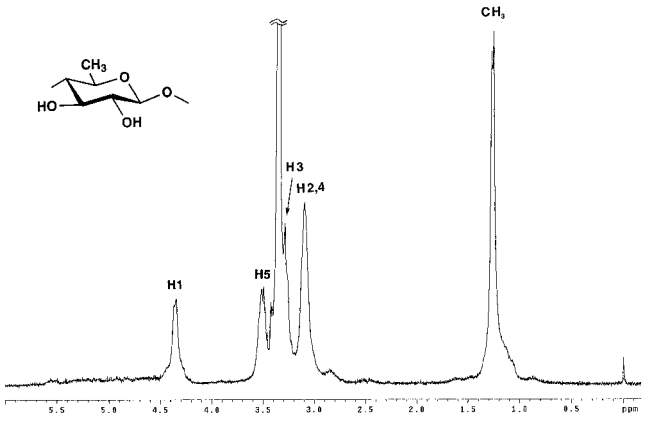


Figure 5. 300 MHz ^{1}H NMR spectrum of 6-deoxy-(1→4)-*β*-D-glucopyranan.

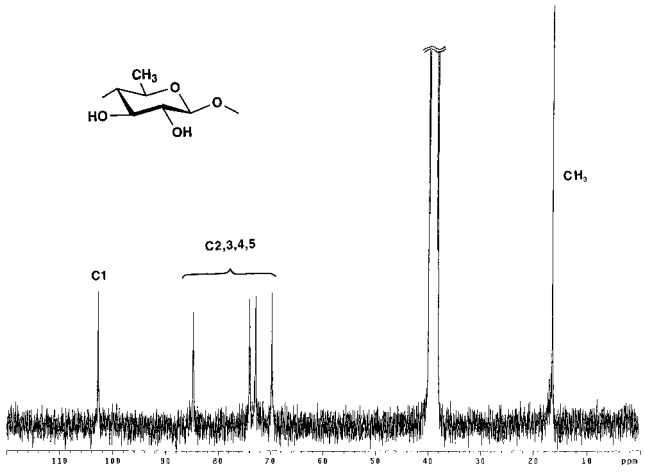


Figure 6. 75 MHz ^{13}C NMR spectrum of 6-deoxy-(1→4)-*β*-D-glucopyranan.

cellulose despite the lower DS.[11] From this report, we expect that 6-deoxy-(1→4)-*β*-D-glucopyranan which lacks free OH groups at C6 and is similar to 6MC in the absence of intermolecular hydrogen bonds, will be highly soluble. However, the 6-deoxy-(1→4)-*β*-D-glucopyranan had poor solubility in common organic solvents such as acetone, methanol, ethanol, THF, dichloromethane, *n*-hexane, and ethyl acetate. It dissolved only in DMSO and DMAc and did not dissolve in water.

Effects of the Substituent at C6−Position on Ring-Opening Polymerization of Ortho Esters. The present and previous results clarified that the electron donating group at 6-*O*-position or C5-position affects on the stereo- and regioregularities of the resulting polymer due to the electronic factor, not steric factor. Thus, the CH_2OR (R = electron-donating or slightly withdrawing group) or CH_3 group at C5, which increases the electron density of the C4-oxygen, seems to be essential for (1→4)-*β*-glycosidic bond formation.

Consequently, the substituent at the C6-position is also the important factor leading to stereoregular (1→4)-*β*-glucopyranan, including 3-*O*-benzyl and orthopivaloyl groups by the ring-opening polymerization of glucose ortho esters.

Conclusions

The novel stereoregular polysaccharide 6-deoxy-(1→4)-*β*-glucopyranan was first synthesized from the starting material, 6-deoxyorthopivalate **1**, selected in consideration of the substituent effects of not only C2- and C3-positions derived from previous results, but also the C6-position.

Experimental Section

Materials. Triphenylcarbenium tetrafluoroborate and palladium hydroxide on carbon were purchased from Aldrich (Milwaukee, WI). The other reagents were purchased from Nakarai Tesque Inc. (Kyoto, Japan) or WAKO (Osaka, Japan). Allyl 3-*O*-benzyl-4-*O*-*p*-methoxybenzyl-*β*-D-glucopyranoside (**2**) was prepared according to the literature method.[5] Anhydrous tetrahydrofuran was distilled over potassium metal/benzophenone. Anhydrous dichloromethane was distilled from CaH_2. The detailed procedures for the preparations of other compounds are as follows.

Synthesis of Allyl 3-*O*-Benzyl-4-*O*-*p*-methoxybenzyl-6-*O*-*p*-toluenesulfonyl-*β*-D-glucopyranoside (3). *p*-Toluenesulfonyl chloride (782 mg, 4.10 mM) was added to a solution of allyl 3-*O*-benzyl-4-*O*-*p*-methoxybenzyl-*β*-D-glucopyranoside (**2**)[5] (1.5 g, 3.49 mM) in pyridine (15 mL). The reaction mixture was stirred at 60 °C overnight. The reaction mixture was diluted with ethyl acetate, washed with aqueous $NaHCO_3$ and brine, dried over Na_2SO_4, and concentrated in vacuo to give a yellow oil. Compound **3** was purified on a silica gel column (Wakogel C-200) eluted with ethyl acetate/*n*-hexane (1/2, v/v), to give a yellow syrup (1.84 g, 90.4% yield): $[\alpha]_D^{25}$ −9.26° (*c* = 1, in chloroform). ^{1}H NMR ($CDCl_3$): *δ* 4.16 (d, 1 H, $J_{1,2}$ = 7.8 Hz, H-1), 3.3−3.5 (4 H, overlapped, H-2, H-3, H-4, H-5), 4.13 (dd, 1 H, $J_{5,6a}$ = 2.1 Hz, H-6a), 4.0 (dd, 1 H, J_{gem} = 10.8 Hz, $J_{5,6b}$ = 5.1 Hz, H-6b), 5.81 (m, 1H, CH_2CH=CH_2), 5.18 (m, 2H, CH_2CH=CH_2), 4.19, 3.15 (m, 1H, respectively, CH_2CH=CH_2), 4.69, 4.38 (d, 1 H, respectively, *J* = 10.5 Hz, $CH_2C_6H_5$), 4.86, 4.76 (d, 1 H, respectively, *J* = 11.4 Hz, *p*-$CH_3OC_6H_4CH_2$), 7.69, 7.76, 7.19−7.30, 7.05, 6.77(aromatic), 2.36 (s, 3 H, $CH_3C_6H_4SO_2$). ^{13}C NMR ($CDCl_3$): *δ* 101.4 (C-1), 84.2, 76.2, 75.2, 74.6, 74.4, 72.9, 70.2, 68.6 (C-2, C-3, C-4, C-5, C-6, $CH_2C_6H_5$, *p*-$CH_3OC_6H_4CH_2$, CH_2CH=CH_2), 55.3 (*p*-$CH_3OC_6H_4CH_2$), 118.1 (CH_2CH=CH_2), 113.9 (PMB aromatic), 21.7 ($CH_3C_6H_4SO_2$), 144.8, 138.4, 127.9−130.0 (aromatic). Anal. Calcd for $C_{31}H_{36}O_9S$: C, 63.68; H, 6.21; S, 5.48. Found: C, 63.60; H, 6.13; S, 5.55.

Allyl 3-*O*-Benzyl-6-deoxy-4-*O*-*p*-methoxybenzyl-2-*O*-pivaloyl-*β*-D-glucopyranoside (5). A solution of compound **3** (1.84 g, 3.15 mM) in anhydrous THF (17 mL) was added dropwise to a stirred suspension of lithium aluminum hydride ($LiAlH_4$) (1.2 g, 31.5 mM) in anhydrous THF (8 mL) under N_2 atmosphere at room temperature during 30 min. Then the mixture was refluxed for 2 h. The reaction mixture was cooled to 0 °C, and 5 mL of THF/H_2O (10/1, v/v) was carefully added. The colorless salts were filtered off, the filtrate was diluted with ethyl acetate, washed with H_2O, aqueous 1 N HCl, and brine, dried over Na_2SO_4 and evaporated in vacuo to give allyl 3-*O*-benzyl-6-deoxy-4-*O*-*p*-methoxybenzyl-2-*O*-pivaloyl-*β*-D-glucopyranoside (**4**) as a crude colorless syrup (1.29 g). Pivaloyl chloride (2.04 mL, 16.6 mM) was added to a solution of the crude compound **4** (1.29 g, 3.31 mM) in pyridine (10 mL), and the mixture was heated at 80 °C overnight. Then 1 mL of MeOH was added, and the mixture was diluted with ethyl acetate, washed with aqueous $NaHCO_3$ and brine, dried over Na_2SO_4, and concentrated in vacuo. Compound **5** was purified on a silica gel column (Wakogel C-200) eluted with ethyl acetate/*n*-hexane (1/4, v/v), to give a colorless syrup (1.39 g, 2.92 mM, 93% overall yield from compound **3**): $[\alpha]_D^{25}$ −55.47° (*c* = 0.1, in chloroform). ^{1}H NMR ($CDCl_3$): *δ* 4.40 (d, 1 H, $J_{1,2}$ = 8.4 Hz, H-1), 5.07 (dd, 1H, $J_{2,3}$ = 8.7 Hz, H-2), 3.65 (t, 1H, H-3), 3.28 (t, 1H, $J_{3,4}$ = 8.7 Hz, H-4), 3.41 (m, 1H, $J_{4,5}$ = 9.3 Hz, H-5), 5.84 (m, 1H, CH_2CH=CH_2), 5.21 (m, 2H, CH_2CH=CH_2), 4.32, 4.01 (m, 1H, respectively, CH_2CH=CH_2) 4.75, 4.55 (d, 1 H, respectively, *J* = 10.5 Hz, $CH_2C_6H_5$), 4.77, 4.68 (d, 1 H, respectively, *J* = 11.1 Hz, *p*-$CH_3OC_6H_4CH_2$), 3.80 (3H, OCH_3), 7.26−7.30, 7.21, 7.18, 6.86, 6.83 (aromatic), 1.32 (d, 3H, *J* = 6.0 Hz, CH_3), 1.19 (9H, C=$OC(CH_3)_3$). ^{13}C NMR ($CDCl_3$): *δ* 100.0 (C-1), 83.1, 82.9, 77.2, 75.0, 73.3, 71.4, 69.9 (C-2, C-3, C-4, C-5, C-6, $CH_2C_6H_5$, *p*-$CH_3OC_6H_4CH_2$, CH_2CH=CH_2), 55.3 (*p*-$CH_3OC_6H_4CH_2$), 117.3 (CH_2CH = CH_2), 113.8

(PMB aromatic), 27.1 (C═OC(CH_3)$_3$), 38.8 (C═OC(CH_3)$_3$), 17.8 (CH_3), 138.1, 133.7, 127.4−130.0 (aromatic), 176.8 (C═O). Anal. Calcd for $C_{24}H_{30}O_6$: C, 69.54; H, 7.30. Found: C, 69.44; H, 7.29.

Allyl 3-*O*-benzyl-6-deoxy-2-*O*-pivaloyl-*β*-D-glucopyranoside (6). Diammonium cerium(IV) nitrate (CAN) (4.8 g, 8.76 mM) was added to a solution of compound **5** (1.39 g, 2.92 mM) in acetonitrile/water (10 mL, 9/1, v/v). The solution was stirred at room temperature for 0.5 h. The reaction mixture was diluted with ethyl acetate, washed with aqueous $NaHCO_3$ and brine, dried over Na_2SO_4, and concentrated in vacuo to give a yellow oil. Compound **6** was purified on a silica gel column (Wakogel C-200) eluted with ethyl acetate/*n*-hexane (1/4, v/v), to give a yellow syrup (902.4 mg, 87.3% yield): $[\alpha]_D^{25}$ −41.07° (c = 0.2, in chloroform). ^{1}H NMR ($CDCl_3$): δ 4.43 (d, 1 H, $J_{1,2}$ = 8.1 Hz, H-1), 5.07 (dd, 1H, $J_{2,3}$ = 8.7 Hz, H-2), 3.51 (t, 1H, $J_{3,4}$ = 9.3 Hz, H-3), 3.33−3.40 (2H, overlapped, H-4, H-5), 5.85 (m, 1H, CH_2CH═CH_2), 5.22 (m, 2H, CH_2CH═CH_2), 4.32, 4.01 (m, 1H, respectively, CH_2CH═CH_2) 4.77, 4.56 (d, 1 H, respectively, J = 11.4 Hz, C$H_2C_6H_5$), 7.26−7.35 (aromatic), 1.33 (d, 3H, J = 5.7 Hz, CH_3), 1.22 (9H, C═OC(CH_3)$_3$). ^{13}C NMR ($CDCl_3$): δ 100.0 (C-1), 82.9, 74.8, 74.3, 73.1, 71.5, 69.9 (C-2, C-3, C-4, C-5, $CH_2C_6H_5$, CH_2CH═CH_2), 117.4 (CH_2CH═CH_2), 27.2 (C═OC(CH_3)$_3$), 38.8 (C═OC(CH_3)$_3$), 17.7 (CH_3), 133.5, 128.7, 128.1, 127.7 (aromatic), 176.8 (C═O). Anal. Calcd for $C_{21}H_{36}O_6$: C, 66.65; H, 7.99. Found: C, 66.62; H, 7.92.

3-*O*-Benzyl-6-deoxy-α-D-glucopyranose 1,2,4-Orthopivalate (1). A mixture of compound **6** (902.4 mg, 2.55 mM), NaOAc (522.8 mg, 6.37 mM), and $PdCl_2$ (497.2 mg, 2.8 mM) in AcOH (4 mL) and H_2O (0.2 mL) was stirred for 1 day at 60 °C. Then the reaction mixture was filtered through Celite 535, and the residue was washed with ethyl acetate. The combined filtrate and washings were diluted with ethyl acetate, washed with aqueous $NaHCO_3$ and brine, dried over Na_2SO_4, and concentrated in vacuo to give a yellow powder. The product was purified on a silica gel column (Wakogel C-200) eluted with ethyl acetate/*n*-hexane (1/2, v/v), to give a crude colorless powder (580.5 mg). The crude compound **7** (580.5 mg, 1.85 mM) was dissolved in benzene (100 mL), and then *N*,*N*′-carbonyldiimidazole (321.2 mg, 1.94 mM) was added. The solution was stirred at reflux overnight. The reaction mixture was concentrated in vacuo. 6-Deoxyorthopivalate **1** was purified on a silica gel column (Wakogel C-200) eluted with ethyl acetate/*n*-hexane (1/4, v/v) to give a colorless syrup (185.6 mg, 24.6% overall yield from compound **6**): $[\alpha]_D^{25}$ +22.60° (c = 0.1, in chloroform). ^{1}H NMR ($CDCl_3$): δ 5.77 (d, 1H, $J_{1,2}$ = 4.8 Hz, H-1), 4.41 (dt, 1H, $J_{2,3}$ = 2.1 Hz, H-2), 4.06 (dd, 1H, $J_{3,4}$ = 4.8 Hz, H-3), 3.97 (dt, 1H, $J_{2,4}$ = 0.9 Hz, H-4), 4.51 (m, 1H, H-5), 4.64 (s, 2H, $CH_2C_6H_5$) 1.44 (d, 3H, J = 7.2 Hz, CH_3), 1.02 (9H, C═OC(CH_3)$_3$), 7.26−7.36 (aromatic). ^{13}C NMR ($CDCl_3$): δ 97.7 (C-1), 74.5, 73.0, 72.1, 71.9, 71.9 (C-2, C-3, C-4, C-5, $CH_2C_6H_5$), 24.9 (C(CH_3)$_3$), 35.7 (C(CH_3)$_3$), 18.5 (CH_3), 137.6, 128.6, 128.0, 127.5 (aromatic), 122.9 ((−O$_3$)C(CH_3)$_3$). Anal. Calcd for $C_{18}H_{24}O_5$: C, 67.48; H, 7.55. Found: C, 67.52; H, 7.52.

3-*O*-Benzyl-6-deoxy-2-*O*-pivaloyl-(1→4)-*β*-D-glucopyranan. Ring-opening polymerization was performed under the same procedure as in ref 1. 6-Deoxyorthopivalate **1** (50 mg) was dried in a polymerization ampule by evacuating for ca. a day. Methylene chloride (71 μL, monomer concentration: 70 g/100 mL) was distilled from CaH_2, and degassed by freezing and thawing three times in a high-vacuum line. The solvent was transferred under high vacuum. Triphenylcarbenium tetrafluoroborate (2.5 mg, 5 mol %) was placed on a small glass plate in the reaction ampule with 6-deoxyorthopivalate **1**. The reaction apparatus was then separated by melting off and placed in a water bath at 20 °C. After 42 h, the reaction mixture was diluted with dichloromethane, washed with saturated aqueous $NaHCO_3$, water, and brine, dried over anhydrous sodium sulfate, and concentrated to dryness. The polymer mixture was dissolved in a small amount of dichloromethane. To the solution was added *n*-hexane, and then solidified residual polymer was collected by filtration and finally dried in vacuo to give a colorless powder (42 mg, 84% yield): $[\alpha]_D^{25}$ −26.7° (c = 1, in chloroform). ^{1}H NMR ($CDCl_3$): δ 4.45 (d, 1H, $J_{1,2}$ = 8.7 Hz, H-1), 4.93 (t, 1H, $J_{2,3}$ = 8.7 Hz, H-2), 3.49 (dd, 1H, $J_{3,4}$ = 8.7 Hz, H-3), 3.40 (broad, 1H, H-4), 3.19 (broad, 1H, H-5), 4.96, 4.45 (d, 1H, respectively, J = 10.8 Hz, C$H_2C_6H_5$), 1.03−1.20 (12H, CH_3, C═OC(CH_3)$_3$), 7.24−7.27 (aromatic). ^{13}C NMR ($CDCl_3$): δ 100.2 (C-1), 82.1 (C-4), 80.7 (C-3), 74.4 ($CH_2C_6H_5$), 73.0 (C-2), 71.3 (C-5), 27.1 (C═OC(CH_3)$_3$), 38.7 (C═OC(CH_3)$_3$), 17.9 (CH_3), 126.8, 127.9, 138.9 (aromatic), 176.8 (C═O). Anal. Calcd for $(C_{18}H_{24}O_5)_{33.6}\cdot 2H_2O$: C, 53.29; H, 10.79. Found: C, 53.33; H, 10.70.

2,3-di-*O*-Acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan. Tetramethylammonium hydroxide (25% in methanol) (0.7 mL) was added to a solution of 3-*O*-benzyl-6-deoxy-2-*O*-pivaloyl-(1→4)-*β*-D-glucopyranan (55 mg) in dioxane/methanol (10/1, v/v) (5 mL). The reaction mixture was kept at 80 °C for 40 h. Then the mixture was neutralized by acetic acid and concentrated in vacuo., Water was added to the concentrated mixture, and then residual polymer was collected by filtration and finally dried in vacuo. The product was treated with acetic anhydride and pyridine for 3 h at 80 °C. The reaction mixture was concentrated in vacuo. Palladium hydroxide on carbon (90 mg) was added to the crude 3-*O*-benzyl-6-deoxy-2-*O*-acetyl-(1→4)-*β*-D-glucopyranan (29.9 mg) in THF/acetic acid (1/1, v/v) (5 mL). The reaction mixture was stirred under 4.5 kgf/cm^2 hydrogen gas for 3 h at 80 °C, for 15 h at room temperature, for 1 h at 80 °C, and finally for 5 h at room temperature. Then the mixture was concentrated and treated with acetic anhydride and pyridine at 50 °C overnight. Palladium hydroxide on carbon was filtered off and washed with dichloromethane. The combined washings and filtrate were concentrated to dryness. The polymer mixture was dissolved in a small amount of dichloromethane. *n*-Hexane was added to the solution, and then precipitated polymer was collected by filtration, washed with ethanol, and finally dried in vacuo to give the acetylated polymer as a colorless powder (23.4 mg, 66.1% overall yield): $[\alpha]_D^{25}$ −29.0° (c = 1, in chloroform). ^{1}H NMR ($CDCl_3$): δ 4.41 (d, 1H, $J_{1,2}$ = 7.2 Hz, H-1), 4.80 (t, 1H, $J_{2,3}$ = 7.8 Hz, H-2), 5.02 (t, 1H, $J_{3,4}$ = 8.1 Hz, H-3), 3.34 (broad, 2H, H-4, H-5), 1.29 (3H, CH_3), 1.98 (C═OCH_3). ^{13}C NMR ($CDCl_3$): δ 100.8 (C-1), 81.4 (C-4), 73.1 (C-3), 72.2 (C-2), 71.0 (C-5), 20.7, 21.0 (C═OCH$_3$), 17.3 (CH_3), 169.2, 169.8 (C═O). Anal. Calcd for $(C_{10}H_{14}O_6\cdot 0.3H_2O)_{33.6}\cdot H_2O$: C, 50.86; H, 6.26. Found: C, 50.95; H, 6.15.

6-Deoxy-(1→4)-*β*-D-glucopyranan. 1,8-Diazabicyclo[5.4.0]-7-undecene (DBU) (10 μL) was added to a solution of 2,3-di-*O*-acetyl-6-deoxy-(1→4)-*β*-D-glucopyranan (13.4 mg) in 20% methanol/dichloromethane (v/v, 1.5 mL). The solution was stirred for 2 days at room temperature, and the colorless powder was precipitated. Then the mixture was centrifuged at 3000 rpm for 5 min, and the supernatant solution was removed. The colorless powder was washed with *n*-hexane and ethanol to give 6-deoxy-(1→4)-*β*-D-glucopyranan (5.8 mg, 73.1% yield). ^{1}H NMR ($CDCl_3$): δ 4.36 (d, 1H, $J_{1,2}$ = 6.3 Hz, H-1), 3.10 (broad, 2H, H-2, H-4), 3.29 (overlapped, H-3), 3.50 (m, 1H, H-5), 3.19 (broad, 1H, H-5), 1.27 (d, 3H, J = 4.8 Hz, CH_3). ^{13}C NMR ($CDCl_3$): δ 102.8 (C-1), 84.9, 74.2, 73.1, 70.0 (C-2, C-3, C-4, C-5), 17.1 (CH_3). Anal. Calcd for $(C_6H_{10}O_4\cdot 0.5H_2O)_{33.6}\cdot 3H_2O$: C, 45.97; H, 7.19. Found: C, 45.90; H, 7.17.

Synthesis of 6-Deoxycellulose Acetate from Cellulose. Microcrystalline cellulose ($\overline{DP_n}$ = approximately 200, Avicel, MERK) was used. The cellulose was almost regioselectively 6-*O*-tosylated by the method of Rahn et al.[8] The degree of substitution DS_s = 0.8 was determined by ^{1}H NMR. The resulting tosylated cellulose **8** (310 mg) was treated with 170 mg of $NaBH_4$ in DMSO (10 mL) for 32 h at 80 °C according to the method of Kurita et al.[9] Then ethanol was added, and the mixture was freeze-dried. The residue was dialyzed against distilled water and freeze-dried to obtain a colorless powder. This product was reduced again under the same reaction condition to give almost regioselective 6-deoxycellulose (**9**). Polymer **9** was subsequently acetylated with acetic anhydride and pyridine at 60 °C overnight, and the mixture was poured into ethanol. The precipitate was filtered, washed with water and ethanol, and dried in vacuo to give almost (over 80%)

regioselective 6-deoxycellulose acetate (**10**) as a colorless powder (168 mg).

Measurements. ^{1}H and ^{13}C NMR, HH−COSY, and CH−HETCOR spectra were recorded with a Varian INOVA300 FT-NMR (300 MHz) spectrometer in chloroform-*d* or dimethyl sulfoxide-d_6 with tetramethylsilane (TMS) as internal standard. Chemical shifts (δ) and coupling constants (J) are given in δ values (ppm) and Hz, respectively. Optical rotations were measured at 25 °C using a JASCO Dip-1000 digital polarimeter. Molecular weight distribution of the polymer was analyzed by gel permeation chromatography (GPC) in THF at 40 °C. Calibration curves were obtained by using polystyrene standards (Shodex). A Shimadzu liquid chromatograph injector (LC-10ATvp), a Shimadzu column oven (CTO-10Avp), a Shimadzu UV−vis detector (SPD-10Avp), a Shimadzu refractive index detector (RID-10A), a Shimadzu communication bus module (CBM-10A), a Shimadzu LC workstation (CLASS-LC10), and Shodex columns (8.0 × 300 mm; KF802, KF802.5, and KF803) were used. The flow rate was 1.0 mL/min.

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