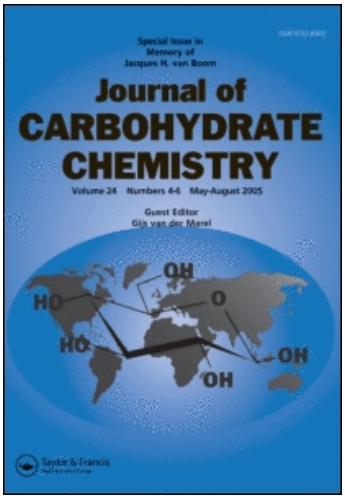

Journal of Carbohydrate Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713617200

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Online publication date: 02 July 2002

To cite this Article Gerbst, Alexey G. , Ustuzhanina, Nadezhda E. , Grachev, Alexey A. , Khatuntseva, Elena A. , Tsvetkov, Dmitry E. , Whitfield, Dennis M. , Berces, Attila and Nifantiev, Nikolay E.(2001) 'SYNTHESIS, NMR, AND CONFORMATIONAL STUDIES OF FUCOIDAN FRAGMENTS. III.[1] EFFECT OF BENZOYL GROUP AT O-3 ON STEREOSELECTIVITY OF GLYCOSYLATION BY 3-*O*- AND 3,4-DI-*O*-BENZOYLATED 2-*O*-BENZYLFUCOSYL BROMIDES', Journal of Carbohydrate Chemistry, 20: 9, 821 — 831
To link to this Article: DOI: 10.1081/CAR-100108659
URL: http://dx.doi.org/10.1081/CAR-100108659

J. CARBOHYDRATE CHEMISTRY, 20(9), 821–831 (2001)

SYNTHESIS, NMR, AND CONFORMATIONAL STUDIES OF FUCOIDAN FRAGMENTS. III.[1] EFFECT OF BENZOYL GROUP AT O-3 ON STEREOSELECTIVITY OF GLYCOSYLATION BY 3-*O*- AND 3,4-DI-*O*-BENZOYLATED 2-*O*-BENZYLFUCOSYL BROMIDES

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ABSTRACT

The effect of a benzoyl group at O-3 on stereoselectivity of glycosylation by 3-*O*- and 3,4-di-*O*-benzoylated 2-*O*-benzyl-L-fucopyranosyl bromides was studied by direct chemical experiments and computational chemistry. The influence of a benzoyl group at O-3 of the fucosyl donors was shown to have a larger effect on the efficiency of α-fucosylation than a benzoyl group at O-4. It is hypothesized that this is a result of the ability of a benzoyl group at O-3 to participate in glycosyl cation stabilization.

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INTRODUCTION

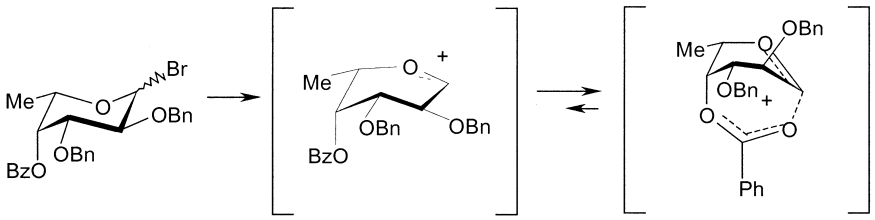
It is known that protective groups in the glycosyl donor influence the stereochemistry of glycosylation. Mechanistic studies revealing the origin of this influence were focused mainly on the "1,2-*trans*" directing effect of acyl substituents at O-2 (see Ref. 2 and papers cited herein) which is widely employed in oligosaccharide synthesis. However, there is some experimental evidence that acyl groups at other positions may also influence the stereoselectivity of glycosylation. Particularly such effects were observed for 4-*O*-acylated fucosyl bromides[1,3,4] and ethylthio galactosides[5] with a non-participating group at O-2.

Recently,[1] by using a series of 2,3-di-*O*-benzylated fucosyl bromides bearing substituted benzoyl groups at O-4, we have shown that the stereochemical outcome of a glycosylation reaction depends on the electronegativity of the substituents of the benzoyl group at O-4. These data in combination with molecular mechanics calculations suggest that the acyl group at O-4, e.g., in bromide **1**, may share the positive charge in the initial glycosyl cation **I** by forming a stabilized bicyclic cationic intermediate **II** (Fig. 1). Such intramolecular interaction favors further nucleophilic attack from the α-side as compared with the case of glycosyl cation **I** whose interaction with nucleophile is not specifically stereocontrolled from α- or β-sides.

In the course of the synthesis of fucoidan fragments[6] we investigated the glycosylation of allyl 3,4-di-*O*-isopropylidene-α-L-fucopyranoside **9**[7] by 3-*O*- and 3,4-di-*O*-benzoylated 2-*O*-benzyl-L-fucopyranosyl bromides **6** and **7**.[6] In this paper we present the results of these reactions and theoretical calculations of plausible intermediates which demonstrate a larger influence on the efficiency of α-fucosylation of a benzoyl group at O-3 in a fucosyl donor than of that at O-4.

RESULTS AND DISCUSSION

To prepare fucosyl bromide **6**, allyl fucoside **2**[8] was regioselectively 3-*O*-*p*-methoxybenzylated via a stannylidene derivative to give diol **3**, which was further 2,4-di-*O*-benzylated (BnBr, NaH, DMF), de-*O*-methoxybenzylated in the presence

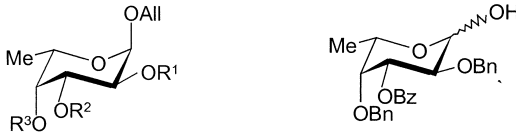


1 "non-stabilized" cation **I** "stabilized" cation **II**

Figure 1. Delocalization of the positive charge in the initial glycosyl cation **I** via intramolecular participation of benzoyl group at O-4.

of 90% aqueous trifluoroacetic acid, and finally 3-*O*-benzoylated to give compound **4**. The presence of the benzoyl group at O-3 was confirmed by the downfield chemical shift of H-3 in the ^{1}H NMR spectrum of **4**.

The target bromide **6** was obtained by deallylation of allyl glycoside **4** in the presence of $PdCl_2$ in methanol followed by bromination of the formed semiacetal **5** with CBr_4 in the presence of Ph_3P.

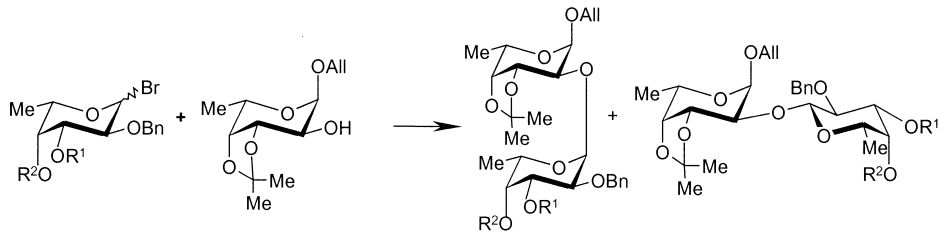


2 $R^1 = R^2 = R^3 = H$ **5**

3 $R^1 = R^3 = OH$, $R^2 = p$-MeOBn

4 $R^1 = R^3 = Bn$, $R^2 = Bz$

Glycosylations of acetonide **9** by fucosyl bromides **6** and **7** were performed in CH_2Cl_2 in the presence of $Hg(CN)_2$ and a catalytic amount of $HgBr_2$. The same reaction conditions were used in our previous[1] work to investigate the effect of the substituent at O-4 on the stereoselectivity of α-fucosylation.



6 $R^1 = Bz$, $R^2 = Bn$ **9** **10** $R^1 = Bz$, $R^2 = Bn$ **12** $R^1 = Bz$, $R^2 = Bn$

7 $R^1 = R^2 = Bz$ **11** $R^1 = R^2 = Bz$ **13** $R^1 = R^2 = Bz$

8 $R^1 = R^2 = Bn$

Glycosylation of acetonide **9** with 3-*O*- and 3,4-di-*O*-benzoylated fucosyl bromides **6** and **7** gave the pairs of 1,2-*cis*- and 1,2-*trans*-linked disaccharide products (**10**,**12** and **11**,**13**) in the ratio of 13:1 and >20:1, respectively (Table 1, Entries 1,2). It is worth noting that both these reactions were much more stereoselective as compared with the results of fucosylation with both 2,3,4-tri-*O*-benzylated fucosyl bromide **8** (Table 1, Entry 4) and 4-*O*-benzoylated 2,3-di-*O*-benzylfucosyl bromide **1** (Table 1, Entry 3). These results provide evidence that a benzoyl group at O-3 has a more pronounced α-stereocontrolling effect than that of a benzoyl group at O-4.

To investigate possible intramolecular interactions which may favor α-stereoselectivity of glycosylation by fucosyl bromides **6** and **7** we performed molecular

Table 1. Stereoselectivity of Fucosylation of Acetonide **3** and Glycosyl Cation Stabilization Energy Values (kcal/mol) for Fucosyl Bromides **1** and **6–8**

Entry	Fucosyl Donor	Substituent O-3	Substituent O-4	Ratio of α- and β-disaccharide Products	Intermediate	Stabilization Energy MM+	Stabilization Energy DFT
1	**6**	Bz	Bn	13:1	III	8.9	14.3
2	**7**	Bz	Bz	20:1	**II**	9.9	n.d.
					III	4.1	n.d.
3	**8**	Bn	Bn	1:1	**I**	0[1]	1.4
4	**1**	Bn	Bz	3.5:1	**II**	3.6[1]	7.3

mechanics calculations by employing the MM+ force field (developed by HyperCube using Allinger's MM2 as basis[9]). The calculations revealed transformation of non-stabilized monocyclic glycosyl cations of type **I** into bicyclic ones in which the positive charge is stabilized by intramolecular interaction with benzoate groups. In the case of monobenzoylated bromide **6**, stabilization involves the formation of the intermediate of type **III** while in the case of dibenzoate **7** two sorts of stabilized intermediates of types **II** and **III** are possible (Fig. 2). Both stabilized intermediates (**II**, **III**) are not able to interact with nucleophiles from the β-side while the α-side is readily accessible to nucleophilic attack.

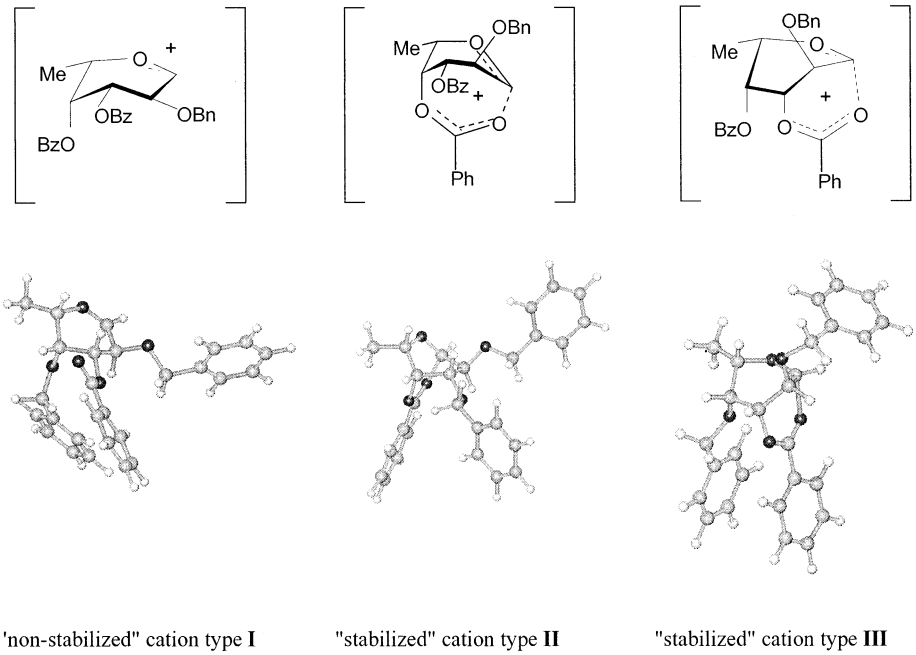


Figure 2. Structures and 3D models of glycosyl cation intermediates of types **I–III**.

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It has been suggested before,[10] that substituents on the axial O-4 of a fucosyl cation could interact with the anomeric carbon as in our type **II** cations. Such an interaction requires the pyranose ring to adopt an unfavourable $B_{1,4}$ ring conformation. Similarly, for the formation of type **III** cations, the pyranose ring must adopt a conformation that allows O-3 to become *pseudo*-axial and therefore also appears unfavourable.

However, the molecular mechanics calculations show that a cation type **III** formed from **6** is indeed much more stable than the open type **I** cation (Table 1, Entry 1). Since molecular mechanics is designed to find structures of neutral compounds with "normal" bond lengths, bond angles, dihedral angles etc., we decided to further study these hypothetical intermediates at a higher level of calculation, namely using Density Functional Theory (DFT) calculations.[11–13] Thus, the structures found by MM+ calculations were used as input and reoptimized using the Amsterdam Density Functional implementation of DFT as described previously.[14] It is expected that such calculations are as accurate as the model and therefore the differences between calculated and experimental results will reflect the neglect of solvent, counterions etc. in the calculations. It is readily apparent that trends observed with the MM+ force field are reproduced by the DFT calculations. Most importantly the cations of type **III** are predicted to be more stable than those of type **II** (Table 1, Entry 1 versus Entry 4).

Further insight was obtained by performing conformational analysis of the ring conformations of cations **I** to **III** (Table 2). As expected all cations of type **I** prefer the $^3H_4$ ring conformation. Similarly cation **II** prefers the $B_{1,4}$ conformation. Cations **III** exhibit the E_4 ring conformation that puts O-3 in a *pseudo*-axial position that allows participation with C-1. Surprisingly, this change only requires small changes to the ring conformation as E_4 is close in conformational space to $^3H_4$. This can be seen by the small changes in the Cremer-Pople parameters between **I** and **III** (Table 2).

We assumed that formation of such β-hindered intermediates leads to α-selectivity. In this case the amount of α-anomer should be approximately proportional to the amount of forms **II** or **III**, i. e., to their stability compared to that of form **I**. This stability can be estimated in terms of computational chemistry as the energy difference between these forms. We called this difference "stabilization energy".[1]

Such stabilization energies are an estimate of the enthalpic contributions and do not include entropy factors necessary to estimate free energies. Both the calcu-

Table 2. Results of the Conformational Analysis of Cations **I–III** According to the IUPAC Descriptors[15]

		Cremer-Pople Parameters		
Cation	Conformation	Q	Θ	Φ
I	$^3H_4$ (1.093), $^{2,5}B$(0.121), $^3S_1$ (0.060)	0.81	−17	48
II	$B_{1,4}$ (0.824), $^2S_0$ (0.209), $^1C_4$ (0.080)	0.93	−12	85
III	E_4 (1.044), $^0S_2$ (0.111), $B_{1,4}$ (0.003)	0.78	−10	48

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lation of entropies and the experimental determination of free energies remain as challenges for further refinement of the existing model.

The 3D structures of cations of types **I–III** predicted by DFT calculations are presented in Figure 2. The calculated energy values for intermediate cations formed from fucosyl bromides **1** and **6–8** are shown in Table 1. Comparison of the data from Entries 1–4 shows correlation between the stabilization energies for cations of types **I** and **III** and experimental α/β selectivity of fucosylations. This correlation strongly supports the hypothesis that stabilization of an intermediate glycosyl cation by a benzoyl group at O-3 or O-4 assists the formation of the 1,2-*cis*-linked disaccharide.

The stabilization energy for cation **III** was always higher than for cation **II** (Table 1, Entries 1, 2, 4). This explains the higher α-selectivity of fucosylation with 3-*O*-benzoylated fucosyl bromides **6** and **7** and shows that the benzoyl group at O-3 in fucose influences the α-selectivity of glycosylation more effectively than that at O-4. It is possible to expect that intramolecular participation of 3-*O*-benzoyl groups is one of key stereoelectronic factors which control the previously observed α-glycosylation by per-*O*-benzoylated D-galactopyranosyl[16] and L-fucopyranosyl bromides.[17,18]

CONCLUSION

The results presented here show that stereoselectivity of glycosylation with fucosyl bromides is strongly influenced by the presence of benzoyl protective groups at O-3, which were shown to effectively stabilize the intermediate glycosyl cation. Computer modeling with MM+ and DFT can be employed for the estimation of intramolecular participation of protecting groups in stabilization of cationic intermediates. This approach may be useful for the explanation and prediction of selectivity of some glycosylation reactions.

EXPERIMENTAL

General Methods. TLC was performed on Silica Gel 60 F_{254} (Merck) with toluene-EtOAc (A, 3:1; B, 2:1), and with detection by charring with H_3PO_4. Column chromatography was performed on Silica Gel L 63–200 mkm (Fluka) by gradient elution with toluene-EtOAc. Optical rotations for synthesized compounds were determined with a Jasco DIP-360 digital polarimeter at 26–30°C. All solvents used for syntheses were purified according to conventional procedures.[6,16] NMR spectra for compounds **3–5**, **9–11** were recorded in $CDCl_3$ on Bruker spectrometers WM-250 and AM-300 at 303 K. One and two dimensional spectra were acquired using standard Bruker software for ASPECT-2000. Molecular mechanics calculations were performed using the MM+ force field[9] as implemented in HyperChem 5.01 program[19] with the built-in dielectric constant ε of 1.5. Electrostatic

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terms of the total energy were considered in point atomic charges approximation, as it satisfactorily describes ionic structures. Values of partial atomic charges were obtained from AM1[19,20] semi-empirical calculations. All geometry optimization procedures were carried out till the RMS gradient reached the value of ~0.1 kcal/mol Å. To obtain energy values for the non-stabilized cations, we chose as starting geometry a model with torsion angle (H3-C3)—(O3-C) set to 0°. Consequently, when computing values for the stabilized cations, this angle was set to 180°. After the structures were optimized using MM+ via the Polak-Ribiere algorithm, single point energy calculations were carried out without changing the force field. In all the calculations, we observed only slight changes of torsion values (not more than 15°). The reported DFT calculations were carried out with the Amsterdam Density Functional (ADF) program version 2.3 derived from the work of Baerends *et al*,[11] and developed at the Free University of Amsterdam[12] and at the University of Calgary.[13] Details can be found in Ref. 2. The basis set used was double zeta with a single polarization function. The conformational analysis of 6-membered rings was performed as outlined in Ref. 15.

Allyl 3-*O*-(4-Methoxybenzyl)-α-L-fucopyranoside (3). A mixture of allyl fucoside **2** (306 mg, 1.5 mmol), $(Bu_3Sn)_2O$ (1.14 mL, 2.25 mmol) and toluene (36 mL) was refluxed until complete dissolution and then concentrated to the volume of 18 mL. Bu_4NBr (533 mg, 1.65 mmol) and 4-methoxybenzyl chloride (0.46 mL, 3.3 mmol) were added, the solution was refluxed for 3 h and then concentrated *in vacuo*. Column chromatography of the residue gave amorphous **3** (297 mg, 61%): $[\alpha]_D$ −172° (*c* 3, EtOAc); R_F 0.2 (solvent A); ^{1}H NMR ($CDCl_3$) δ 1.28 (d, 3H, $J_{5,6}$ = 7.0 Hz, H-6), 3.63 (dd, 1H, $J_{3,4}$ = 3.4 Hz, H-3), 3.78 (d, 1H, H-4), 3.79 (s, 3H, $CH_2C_6H_4OCH_3$), 3.90 (q, 1H, H-5), 3.93 (dd, 1H, $J_{2,3}$ = 10.0 Hz, H-2), 4.02 (m, 1H, $CH_2CH{=}CH_2$), 4.19 (m, 1H, $CH_2CH{=}CH_2$), 4.65 (s, 2H, $CH_2C_6H_4OCH_3$), 4.91 (d, 1H, $J_{1,2}$ = 4.3 Hz, H-1), 5.20, 5.30 (2m, 2H, $CH_2CH{=}CH_2$), 5.90 (m, 1H, $CH_2CH{=}CH_2$), 6.87, 7.30 (2d, 4H, $CH_2C_6H_4OCH_3$).

Anal. Calcd for $C_{17}H_{24}O_6$: C, 62.95%; H, 7.46%. Found: C, 62.76%; H, 7.41%.

Allyl 3-*O*-Benzoyl-2,4-di-*O*-benzyl-α-L-fucopyranoside (4). A solution of **3** (290 mg, 0.89 mmol) in DMF (2.6 mL) was added at 0°C under stirring to a 60% oil suspension of NaH (100 mg, 2.49 mmol). The mixture was stirred at 0° for 30 min and benzyl bromide (0.3 mL, 2.5 mmol) was added. Stirring was continued for 2 h at rt. The mixture was diluted with chloroform (40 mL) and washed with water (2×500 mL). The organic layer was separated and concentrated. The solution of 90% aqueous CF_3COOH (0.5 mL) in CH_2Cl_2 (5 mL) was added to the residue, the mixture was kept at rt for 30 min, and then concentrated and co-evaporated with toluene (2×5 mL). Flash column chromatography of the residue gave the 3-OH intermediate, which was dissolved in pyridine (2.4 mL), and benzoyl chloride (0.1 mL, 0.78 mmol) was added. The solution was stirred at rt for 1 h, concentrated, diluted with CH_2Cl_2 (100 mL) and washed with water (2×200 mL). The

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organic layer was separated and concentrated. Column chromatography of the residue gave **4** (291 mg, 67%): $[\alpha]_D$ −145° (*c* 3, EtOAc); R_F 0.64 (solvent A); ^{1}H NMR ($CDCl_3$) δ 1.21 (d, 3H, $J_{5,6}$ = 6.9 Hz, H-6), 3.96 (d, 1H, H-4), 4.07 (m, 1H, $CH_2CH{=}CH_2$), 4.15 (q, 1H, H-5), 4.22 (m, 1H, $CH_2CH{=}CH_2$), 4.24 (dd, 1H, $J_{2,3}$ = 11.0 Hz, H-2), 4.53–4.77 (m, 4H, 2×$CH_2C_6H_5$), 4.99 (d, 1H, $J_{1,2}$ = 3.9 Hz, H-1), 5.25, 5.40 (2m, 2H, $CH_2CH{=}CH_2$), 5.63 (dd, 1H, $J_{3,4}$ = 3.0 Hz, H-3), 5.99 (m, 1H, $CH_2CH{=}CH_2$), 7.20–8.10 (m, 15H, 2×$CH_2C_6H_5$, $OCOC_6H_5$).

Anal. Calcd for $C_{30}H_{32}O_6$: C, 73.75%; H, 6.60%. Found: C, 73.64%; H, 6.56%.

3-*O*-Benzoyl-2,4-di-*O*-benzyl-α- and -β-L-fucopyranose (5). A solution of **4** (170 mg, 0.35 mmol) in MeOH (2.3 mL) was stirred for 3 h at rt with $PdCl_2$ (27.8 mg, 0.14 mmol). Triethylamine (0.5 mL) was then added, and the mixture was filtered through a Celite pad and concentrated. Column chromatography of the residue gave the mixture of α- and β-isomers **5** (143 mg, 92%): R_F 0.27 (solvent A); ^{1}H NMR ($CDCl_3$) for α-isomer δ 1.20 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6), 3.90 (d, 1H, $J_{3,4}$ = 3.0 Hz, H-4), 4.20 (dd, 1H, $J_{2,3}$ = 10.3 Hz, H-2), 4.33 (q, 1H, H-5), 4.51–5.01 (m, 4H, $CH_2C_6H_5$), 5.38 (d, 1H, $J_{1,2}$ = 3.6 Hz, H-1), 5.55 (dd, 1H, H-3), 7.20–7.67, 7.97–8.10 (m, 15H, 2×$CH_2C_6H_5$, $OCOC_6H_5$); ^{1}H NMR ($CDCl_3$) for β-isomer δ 1.25 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6), 3.75 (q, 1H, H-5), 3.83 (d, 1H, $J_{3,4}$ = 3.1 Hz, H-4), 3.92 (dd, 1H, $J_{2,3}$ = 10.2 Hz, H-2), 4.51–5.01 (m, 4H, $CH_2C_6H_5$), 4.72 (d, 1H, $J_{1,2}$ = 7.6 Hz, H-1), 5.20 (dd, 1H, H-3), 7.20–7.67, 7.97–8.10 (m, 15H, 2×$CH_2C_6H_5$, $OCOC_6H_5$).

Anal. Calcd for $C_{27}H_{28}O_6$: C, 72.30%; H, 6.29%. Found: C, 72.41%; H, 6.26%.

Allyl 2-*O*-(3-*O*-Benzoyl-2,4-di-*O*-benzyl-α- (10) and -β-L-fucopyranosyl)-3,4-*O*-isopropylidene-α-L-fucopyranoside (12). A solution of semiacetal **5** (90 mg, 0.26 mmol), PPh_3 (89 mg, 0.34 mmol) and CBr_4 (113 mg, 0.34 mmol) in 3 mL of CH_2Cl_2 was refluxed for 3 h and then cooled to room temperature to give a solution of bromide **6** which was used in the next step without any purification. A mixture of acetonide **9** (43 mg, 0.17 mmol), $Hg(CN)_2$ (66 mg, 0.26 mmol), $HgBr_2$ (catalytic amount), and molecular sieves 4 Å (370 mg) in CH_2Cl_2 (3 mL) was stirred for 1 h at 20°C under Ar. Using a syringe, a solution of fucosyl bromide **6** was added portionwise during 1 h. The mixture was stirred for 24 h, then filtered through Celite, diluted with CH_2Cl_2, washed with satd aq KBr and $NaHCO_3$ solutions and concentrated. Column chromatography of the residue gave the mixture (94 mg, 82%) of α- and β-isomers **10** and **12** 13:1 (^{1}H NMR)

Data of **10**: R_F 0.51 (solvent A); ^{1}H NMR ($CDCl_3$) δ 1.18 (d, 3H, $J_{5',6'}$ = 6.2 Hz, H-6′), 1.28 (d, 3H, $J_{5,6}$ = 6.2 Hz, H-6), 1.34, 1.38 (2×s, 2×3H, $C(CH_3)_2$), 3.88 (dd, 1H, $J_{2,3}$ = 8.0 Hz, H-2), 3.97 (d, 1H, $J_{3',4'}$ = 5.3 Hz, H-4′), 4.04 (m, 1H, $CH_2CH{=}CH_2$), 4.09 (d, 1H, $J_{3,4}$ = 6.0 Hz, H-4), 4.18 (m, 1H, $CH_2CH{=}CH_2$), 4.24 (dd, 1H, $J_{2',3'}$ = 10.5 Hz, H-2′), 4.39 (dd, 1H, H-3), 4.50–4.70 (m, 4H, 2×$CH_2C_6H_5$), 4.95 (d, 1H, $J_{1,2}$ = 3.9 Hz, H-1), 5.11 (d, 1H, $J_{1',2'}$ = 4.0 Hz, H-1′),

5.13–5.35 (m, 2H, $CH_2CH{=}CH_2$), 5.64 (dd,1H, H3′), 5.86 (m, 1H, $CH_2CH{=}CH_2$), 7.10–8.10 (m, 15H, $2{\times}CH_2C_6H_5$, $OCOC_6H_5$).

Data of **12**: R_F 0.56 (solvent A); ^{1}H NMR ($CDCl_3$) δ 1.19 (d, 3H, $J_{5',6'}$ = 6.2 Hz, H-6′), 1.38 (d, 3H, $J_{5,6}$ = 6.2 Hz, H-6), 1.38, 1.50 ($2{\times}$s, $2{\times}$3H, $C(CH_3)_2$), 3.65 (m, 1H, $CH_2CH{=}CH_2$), 3.77 (s, 1H, H-4′), 3.91 (t, 1H, $J_{2',3'}$ = 7.7 Hz, H-2′), 3.97 (dd, 1H, $J_{2,3}$ = 8.1 Hz, H-2), 4.06 (d, 1H, $J_{3,4}$ = 5.3 Hz, H-4), 4.18 (m, 1H, $CH_2CH{=}CH_2$), 4.42 (dd, 1H, H-3), 4.50–5.00 (m, 4H, $2{\times}CH_2C_6H_5$), 4.91 (d, 1H, $J_{1',2'}$ = 7.7 Hz, H-1′), 5.02 (d, 1H, $J_{1,2}$ = 3.3 Hz, H-1), 5.15 (d, 1H, H-3′), 5.16–5.35 (m, 2H, $CH_2CH{=}CH_2$), 5.93 (m, 1H, $CH_2CH{=}CH_2$), 7.25–8.10 (m, 15H, $2{\times}CH_2C_6H_5$, $OCOC_6H_5$).

Anal. Calcd. for $C_{39}H_{46}O_{10}$: C, 69.42%; H, 6.87%. Found: C, 69.50%; H, 6.95%.

Allyl 2-*O*-(3,4-Di-*O*-benzoyl-2-*O*-benzyl-α (11) and β-L-fucosyl)-3,4-*O*-isopropylidene-α-L-fucopyranoside (13). Glycosylation of acetonide **9** (100 mg, 0.40 mmol) by fucosyl bromide **7** [prepared from 3,4-di-*O*-benzoyl-2-*O*-benzyl-α-L-fucopyranose[6] (277 mg, 0.6 mmol) as described above for bromide **6**] was performed analogous to preparation of **10** and **12** to give the mixture (223 mg, 81%) of α- and β-isomers **11** and **13** 20:1 (^{1}H NMR)

Data of **11**: R_F 0.73 (solvent B); ^{1}H NMR ($CDCl_3$) δ 1.20 (d, 3H, $J_{5',6'}$ = 6.2 Hz, H-6′), 1.40 (d, 3H, $J_{5,6}$ = 6.2 Hz, H-6), 1.43, 1.60 ($2{\times}$s, $2{\times}$3H, $C(CH_3)_2$), 3.93 (dd, 1H, $J_{2,3}$ = 8.1 Hz, H-2), 4.06 (m, 1H, $CH_2CH{=}CH_2$), 4.15 (dd, 1H, $J_{3,4}$ = 5.8 Hz, H-4), 4.20 (dd, 1H, $J_{2',3'}$ = 10.5 Hz, H-2′), 4.22 (m, 1H, $CH_2CH{=}CH_2$), 4.23 (q, 1H, H-5), 4.45 (dd, 1H, H-3), 4.70 (q, 1H, H-5′), 4.71 (s, 2H, $CH_2C_6H_5$), 5.01 (d, 1H, $J_{1,2}$ = 3.6 Hz, H-1), 5.16–5.35 (m, 2H, $CH_2CH{=}CH_2$) 5.23 (d, 1H, $J_{1',2'}$ = 3.4 Hz, H-1′), 5.74 (d, 1H, $J_{3',4'}$ = 3.0 Hz, H-4′), 5.85 (dd, 1H, H-3), 5.90 (m, 1H, $CH_2CH{=}CH_2$), 7.25–8.00 (m, 15H, $2{\times}CH_2C_6H_5$, $OCOC_6H_5$); ^{13}C NMR ($CDCl_3$) δ 15.9 (C-6′), 16.2 (C-6), 26.3, 28.4 ($C(CH_3)_2$), 63.4 (C-5), 64.8 (C-5′), 68.4 ($CH_2CH{=}CH_2$), 70.7 (C-3′), 72.3 ($CH_2C_6H_5$), 72.5 (C-4′), 72.9 (C-2′), 74.1 (C-2), 74.6 (C-3), 76.1 (C-4), 76.7–77.3 ($CDCl_3$), 94.9 (C-1), 95.6 (C-1′), 108.7 ($C(CH_3)_2$), 117.9 ($CH_2CH{=}CH_2$), 127.6–137.9 ($CH_2C_6H_5$, $2{\times}OCOC_6H_5$); 165.4, 165.9 ($2{\times}OCOC_6H_5$).

Data of **13**: R_F 0.75 (solvent B); ^{1}H NMR ($CDCl_3$) δ 4.00 (dd, 1H, $J_{1,2}$ = 3.7 Hz, H-2), 4.48 (dd, 1H, $J_{2,3}$ = 8.8 Hz, H-3), 4.99 (d, 1H, $J_{1',2'}$ = 7.9 Hz, H-1′), 5.11 (d, 1H, $J_{1,2}$ = 3.6 Hz, H-1); ^{13}C NMR ($CDCl_3$) δ 15.9 (C-6′), 16.2 (C-6), 26.7, 29.7 ($C(CH_3)_2$), 97.5 (C-1), 104.0 (C-1′), 108.7 ($C(CH_3)_2$), 117.2 ($CH_2CH{=}CH_2$).

Anal. Calcd for $C_{39}H_{44}O_{11}$: C, 68.01%; H, 6.44%. Found: C, 68.14%; H, 6.56%.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (grants 98-03-33025a and 01-03-33059).

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Received March 22, 2001
Accepted October 19, 2001

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