Probing the Heparin−Antithrombin III Interaction Using Synthetic Pentasaccharides Bearing Positively Charged Groups

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Keywords: Antithrombotics / Heparin / C-Glycosides / Inhibitors / Oligosaccharides / Carbohydrates

Four heparin pentasaccharides bearing either one (i.e. **3b** and **4b**) or two (i.e. **3c** and **4c**) positively charged amino groups at the reducing end have been synthesized and evaluated for their antithrombin III mediated anti-Xa activity. The positively charged groups were introduced to interact specifically with the negatively charged amino acid residues Glu113 and Asp117 of antithrombin III, which are located in the heparin binding site in close proximity to the reducing end of the saccharide. It turned out that the target compounds **3b**,**c** and **4b**,**c** exhibited relatively low anti-Xa activities, indicating unfavorable interactions between the new pentasaccharides and antithrombin III rather than the anticipated enhancement of association.

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Introduction

Pentasaccharide **1a** (see Figure 1) constitutes the antithrombin III (AT III) binding domain of heparin, an anticoagulant polysulfated glycosaminoglycan.[1,2] AT III requires activation by heparin to exert its activity as a crucial inhibitor of coagulation factors Xa and thrombin (IIa). The action of the heterogeneous drug heparin is mainly governed by a unique pentasaccharide domain, also known as fragment **DEFGH**, in some of the polysaccharide chains. The pentasaccharide moiety has a distinct mode of action in that it solely activates AT III towards inhibition of factor Xa, but not of thrombin. On the basis of this knowledge, pentamer **1b** (Org 31540/SR 90107A or *Fondaparinux Sodium*), the α-*O*-methyl glycoside of **1a**, has been developed as a new antithrombotic drug (*Arixtra*®).[3] In addition, a vast array of analogs[4] such as desulfated,[5] decarboxylated,[4] epimeric,[4] flexible,[6] conformationally constrained[7] and non-glycosaminoglycan[8] derivatives of the pentasaccharide have been synthesized and tested for their biological activity. In this respect it is noteworthy that of all derivatives the binding to AT III (Kd) is proportional to the anti-factor Xa activity measured. The outcome of the structure-activity relationship (SAR) studies revealed whether the mode of interactions of the individual carboxylate and sulfate groups in **1** and **2** with AT III are either essential (marked with an exclamation mark "!" in Figure 1), contributing (marked with an asterisk "*") or nonessential. The latter insight led inter alia to the design and synthesis of the highly potent pentamer **2a** (SanOrg 34006 or *Idraparinux Sodium*).[9]

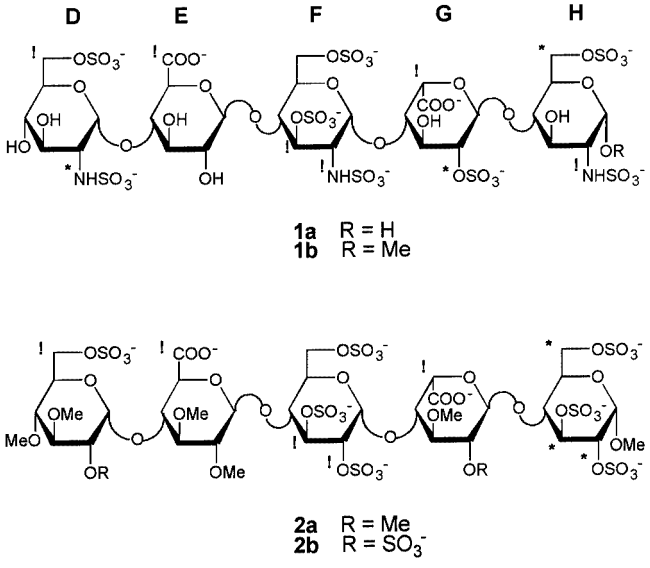

Figure 1. Pentasaccharides **1a**,**b** and **2a**,**b**; groups highlighted with "!" are essential for AT III activation, whilst the groups with "*" increase the biological activity

Recently, the crystal structure[10] of AT III in complex with pentasaccharide **2b** nicely corroborated the interactions of the pentasaccharide with the antithrombin binding site. Thus, all essential sulfate and carboxylate groups inter-

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act directly with various positively charged Lys and Arg residues of AT III. However, the crystal structure does not explain why several analogs, in which particular sulfates are replaced by phosphates or carboxylates, are hardly active.[4] Furthermore, close inspection of the binding site not only revealed the presence of positively charged amino acids, but also negatively charged amino acid residues in the proximity of the anomeric center of unit **H**. As shown in Figure 2, the carboxylate groups of Glu113 and Asp117 are separated from the α-*O*-methyl group and the anomeric center in **2b** by approximately 6−8 Å.

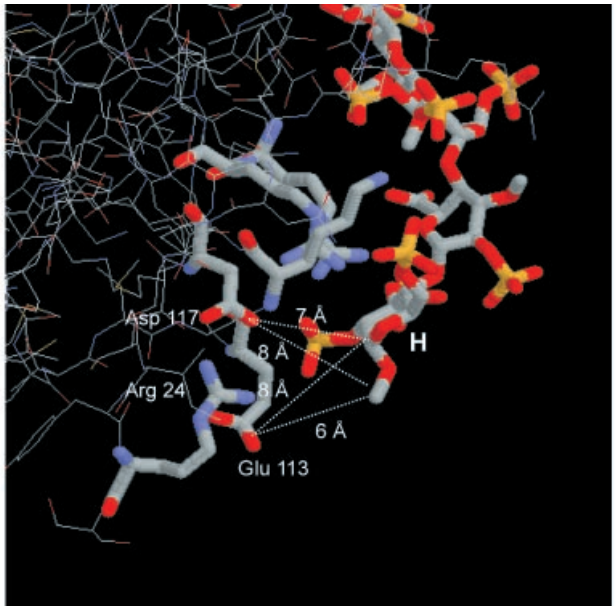


Figure 2. Part of the AT III−pentasaccharide binding site showing Glu113 and Asp117 in proximity of the anomeric region of **2b** in the crystal structure of the AT III−pentasaccharide complex

Based on the above observation, it was envisaged that replacement of the α-*O*-methyl group in **2a** by an α-*C*-glycosidic ethylamine tether, as in compound **3a** (see Figure 3), may result in additional binding interactions with the negatively charged amino acid residues Glu113 and Asp117 in AT III. The crystal structure also shows the possibility of accommodating the corresponding β-*C*-anomer, implying that **4a** may give rise to similar binding interactions with the same amino acids.

The presence, however, of the terminal amino group in both **3a** and **4a** may also lead to unwanted intramolecular salt bridge formation with proximal sulfate groups. In order to reduce such undesired intramolecular interactions, the proximal R^1 sulfate in **3a**, as well as both sulfates R^1 and R^2 in **4a**, were replaced by methyl groups resulting in new pentasaccharide derivatives **3b** and **4b**, respectively.

Apart from this, it is evident that the ethylamino tether in **3b** and **4b** also opens the way of introducing additional positive charges through further functionalization. For instance, pentasaccharide analogs bearing two positively charged amino groups (i.e. pentamers **3c** and **4c**) are accessible by condensation of **3b** and **4b**, with a diaminopropionic acid derivative.

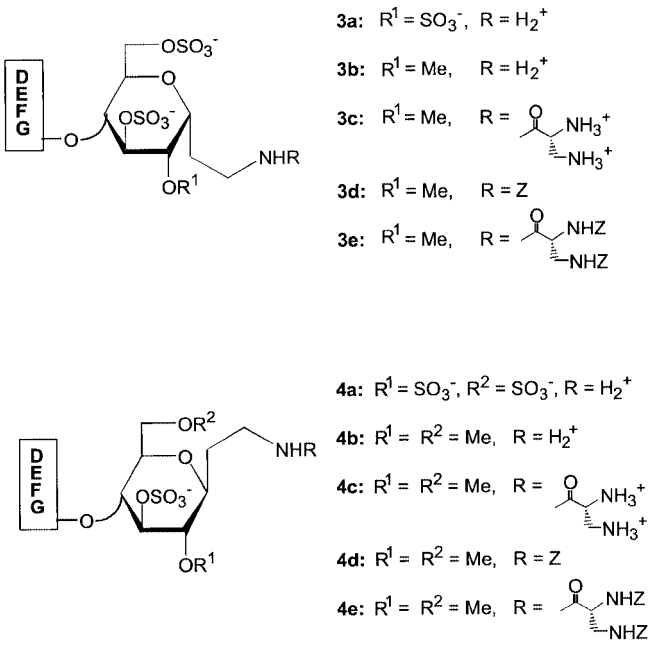


Figure 3. Structure of pentasaccharides **3a**−**e** and **4a**−**e**

At this stage it is noteworthy that the target pentamers **3b**,**c** and **4b**,**c** have an unprecedented sulfation pattern, which prevents the use of the parent pentasaccharide **2a** as a reference in assessing the contribution of the positively charged groups of the pentasaccharides **3b**,**c** and **4b**,**c** in their interaction with AT III. This drawback has been overcome by using the easily accessible *N*-benzyloxycarbonylated (Z) counterparts **3d**,**e** and **4d**,**e** as reference compounds.

We here report the synthesis and anti-Xa activity of the four pentasaccharides **3b**,**c** and **4b**,**c**, as well as their reference compounds **3d**,**e** and **4d**,**e**.

Results and Discussion

It was expected, based on the well-established synthetic route[11] of the pentasaccharide **2a**, that the assembly of the target compounds **3b**,**c** as well as **4b**,**c** could be accomplished using the appropriately protected and functionalized monomeric **H**-building blocks **5** and **6** (see Figure 4), respectively. Retrosynthetic analysis revealed that the preparation of both the α- and the β-*C*-glycoside could be effected by a stereoselective transformation of a 1,2-anhydro

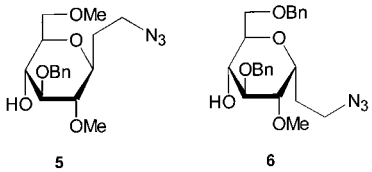
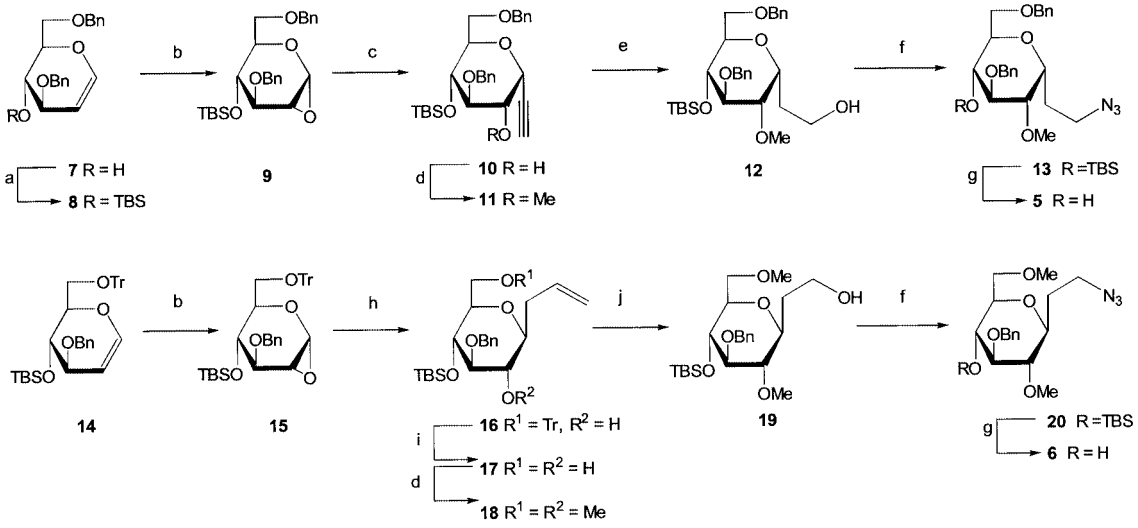


Figure 4. **H**-building blocks **5** and **6**



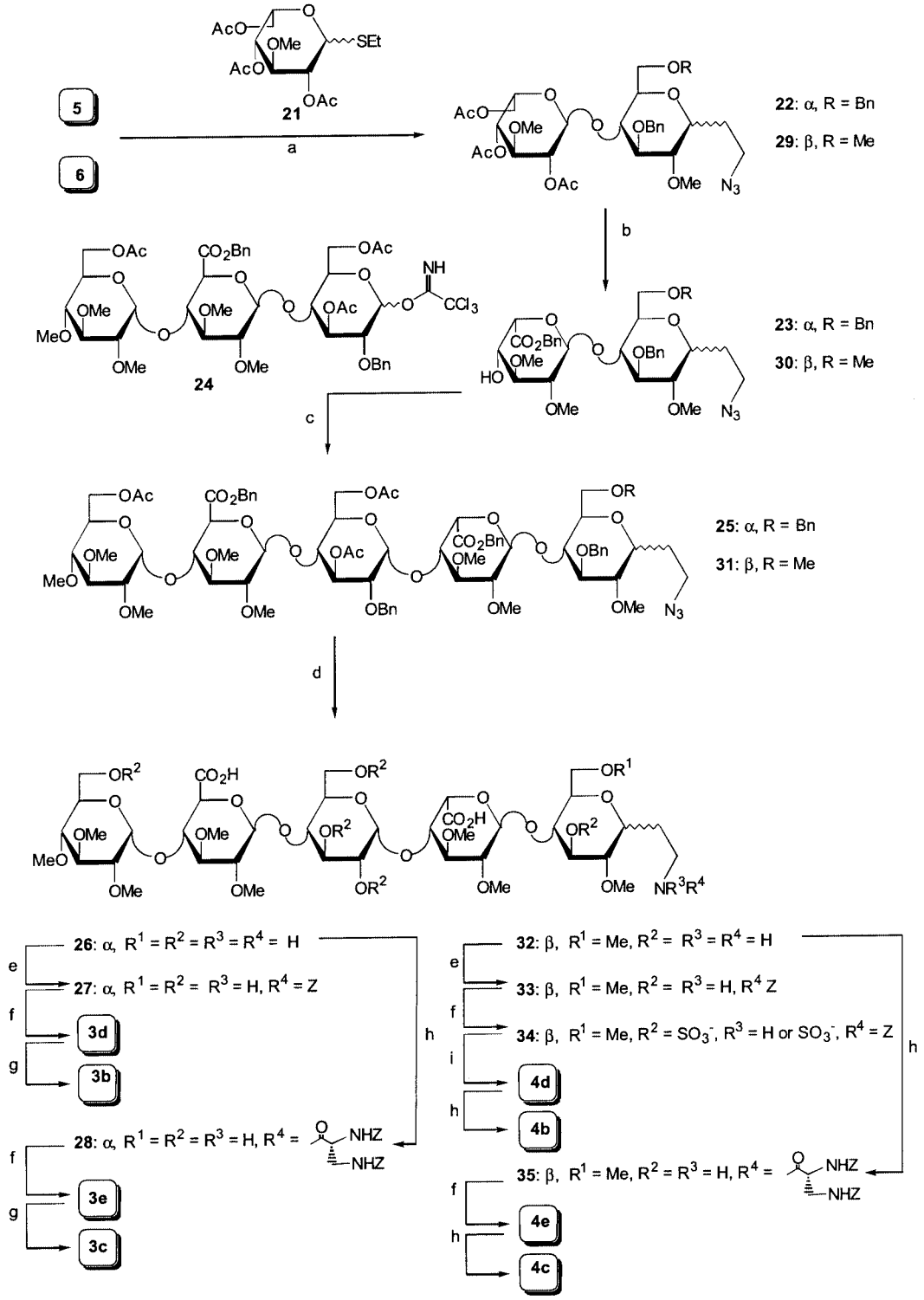
Scheme 1. a) TBSCl, imidazole, DMF, 60 °C, 16 h, **8**: 75%; b) DMDO, acetone, CH_2Cl_2, 0 °C, 5 min; c) NaCCH, $ZnCl_2$, THF, 0 °C to room temp., 1 h, **10**: 75% in 2 steps; d) MeI, NaH, DMF, 0 °C, 1 h, **11**: 93%, **18**: 93%; e) *i*. BH_3·THF, 2-methyl-2-butene, THF, 0 °C, 1 h; *ii*. H_2O_2, NaOH, H_2O, 1 h; *iii*. $LiAlH_4$, THF, 0 °C, 5 min, **12**: 81% in 3 steps; f) *i*. MsCl, pyridine, 16 h; *ii*. NaN_3, DMF, 60 °C, 3 h, **13**: 87%, **20**: 85% in 2 steps; g) TBAF, THF, 3 h, **5**: 99% **6**: 86%; h) allylMgCl, THF, mol. sieves 4 Å, 30 min, **16**: 93% in 2 steps; i) TFA, pyrrole, CH_2Cl_2, 1 min, **17**: 90%; j) *i*. O_3, CH_2Cl_2, MeOH, −70 °C, 2 h; *ii*. DMS, −50 °C to room temp., 16 h; *iii*. $LiAlH_4$, 30 min, **19**: 72% in 3 steps

sugar into either the α-ethynyl or the β-allyl-*C*-glycoside following the protocol developed by Leeuwenburgh et. al.[12a,12b]

Accordingly, the known[13] dibenzylated D-glucal **7** was converted into the required **H**-α unit **5** by the sequence of events depicted in Scheme 1. Thus, silylation of **7**, followed by epoxidation of fully protected **8** with dimethyldioxirane (DMDO),[14] afforded the key 1,2-anhydro derivative **9** in an excellent yield. Ring opening of the epoxide with sodium acetylide in the presence of zinc chloride[12a,12b] gave, after methylation of the newly introduced hydroxy group in **10**, the α-ethynyl-*C*-glucoside **11**. Hydroboration of **11** with disiamylborane, and subsequent in situ oxidation of the intermediate vinylborane with hydrogen peroxide, was followed by reduction of the resulting crude aldehyde leading to isolation of alcohol **12** in a yield of 81% over the three steps. Reaction of the mesyl derivative of **12** with sodium azide afforded, after desilylation, the **H**-α unit **5** in an overall yield of 36% based on **7**.

In a similar fashion, the **H**-β unit **6** was prepared (see Scheme 1) from the known fully protected glucal **14**.[12b] The sequence of events commenced by ring-opening of epoxide **15** with allylmagnesium chloride[12] to afford the β-allyl-*C*-glucoside **16** as the sole product in an excellent yield. Acidolysis[15] of the trityl protecting group in **16** and subsequent bis-methylation of **17** gave the fully protected alkene derivative **18** in 84% yield over the two steps. Ozonolysis of the terminal alkene moiety and reduction of the resulting aldehyde led to the primary alcohol **19**, which was transformed, by the same sequence of reactions employed earlier in the transformation of **12** into **5**, into building block **6** in an overall yield of 41% (based on **14**).

Having the terminal β-*C*-glycoside building unit **5** in hand, the construction of the pentasaccharides **3b**,**c** commenced, as outlined in Scheme 2, with the synthesis of the fully protected α(1→4)-linked dimer **22**. Thus, glycosylation of **5** at low temperature (−20 °C) with known[16] ethyl 2,4,6-tri-*O*-acetyl-3-*O*-methyl-1-thio-α/β-L-idopyranose (**21**) using *N*-iodosuccinimide (NIS) and a catalytic amount of triflic acid (TfOH), proceeded with a high degree of stereoselectivity to give the α-linked dimer **22**, as gauged by NMR spectroscopy, in an excellent yield. Zemplén deacetylation of **22** and transient protection of the 4′,6′-diol in the resulting triol derivative with an acetonide group was followed by methylation and then unmasking of the acetal functionality. Subsequent chemoselective TEMPO oxidation[17] of the primary alcohol function gave, after esterification, the benzyl ester derivative **23** in an overall yield of 49% based on **22**. The crucial introduction of the α-glycosidic bond between the iduronic acid acceptor **23** and the known[11] trimeric α/β-imidate donor **24** in the presence of the activating agent trimethylsilyl triflate (TMSOTf) proceeded uneventfully to give the expected[11] fully protected pentamer **25** in a yield of 77% based on **24**. Unmasking of the benzyl protecting groups by hydrogenation and concomitant reduction of the azide function in **25** gave, after deacetylation, pentamer **26** which, in turn, could be readily transformed into the required reference pentamers **3d**,**e**, as well as the target compounds **3b**,**c**. Thus, masking of the amino function in **26** with the benzyloxycarbonyl (Z) group was followed by sulfation of the six hydroxy groups (i.e. both three primary and secondary OH groups in **27**) led to the isolation of **3d**. Removal of the temporary Z protecting group in the latter pentamer completed the synthesis of the first target compound **3b**. Condensation of **26** with the *O*-succinimidyl ester of 2,3-bis(Z-amino)propionic acid[18] gave pentamer **28** in a yield of 50%. Subjection of **28** to the same sulfation conditions as mentioned above gave the



Scheme 2. a) NIS, TfOH, mol. sieves 4 Å, toluene, −20 °C, 30 min, **22** 96%, **29** 88%; b) *i*. KO*t*Bu, MeOH, 2 h; *ii*. dimethoxypropane, *p*TsOH, DMF, 1 h; *iii*. MeI, NaH, DMF, 0 °C, 30 min; *iv*. HOAc, H_2O, 60 °C, 1 h; *v*. TEMPO, NaOCl, $NaHCO_3$, TBACl, NaCl, CH_2Cl_2/H_2O, 0 °C, 3 h; *vi*. BnBr, $KHCO_3$, DMF, 2 h, **23**: 49% **30**: 50% in 6 steps; c) TMSOTf, mol. sieves 4 Å, CH_2Cl_2, −20 °C, 1 h, **25**: 77%, **31**: 75%; d) *i*. H_2. Pd/C, *t*BuOH/H_2O, 16 h; *ii*. NaOH, MeOH/H_2O, 16 h, **26**: 77%, **32**: 80%; e) Z−OSu, *N*-methylmorpholine, DMF/H_2O, 30 min, **27**: 50%, **33**: 50%; f) SO_3.Et_3N, DMF, 55 °C, 16 h, **3d**: 100%, **3e**: 100%, **4d**: 100%; g) H_2, Pd/C, H_2O, 4 h, **3b**: 100%, **3c**: 100%, **4b**: 100%, **4c**: 100%; h) 2,3-bis(Z-amino)propionic acid succinimidyl ester, *N*-methylmorpholine, DMF, 30 min, **28**: 55%, **34**: 60%; i) 0.2 M HCl, 4 °C, 16 h, **4d**: 90% in 2 steps

additional reference compound **3e**. Moreover, removal of both Z protecting groups from **3e** resulted in the isolation of the second target pentamer **3d** containing two, instead of one, terminal amino groups.

The corresponding β-pentasaccharides **4b**,**c** and their benzyloxycarbonylated counterparts were synthesized in an analogous manner starting from the β-*C*-glycoside **6** (Scheme 2). Thus, glycosylation of **6** with the L-idose donor **21**[16] furnished the α-linked disaccharide **29**, which was converted into the iduronic acid acceptor **30** and subsequently coupled with imidate donor **24** to provide pentamer **31**. Complete deprotection led to pentasaccharide **32**, of which the amine function was capped with a Z group. Interestingly, sulfation of the hydroxy groups in **3** under the same conditions used in the sulfation of **27** was accompanied, as evidenced by NMR spectroscopy, by unwanted partial *N*-sulfation to give **34**. Fortunately, the *N*-sulfate group could be removed selectively under mild acidic conditions[19] to yield the reference pentasaccharide **4d**. Reduction of the benzyloxycarbonyl function provided the target pentamer **4b**. To complete the set of target compounds, pentamer **32** was transformed into compounds **4c**,**d** as described for the conversion of **26** into **3c**,**d**.

Inhibition of Factor Xa

The AT III mediated anti-factor Xa activities of the pentasaccharides **3b**−**e** and **4b**−**d** and of pentamers **1b** and **2a** are recorded in Table 1. It is evident that saccharides **3b**−**e** and **4b**−**e** display a lower activity than the parent pentasaccharide **2a** and natural **1b**. Furthermore, it can be seen that the activity of compounds **3b** and **4b**, having one positively charged amino function, is lower than their benzyloxycarbonylated counterparts **3d** and **4d**. For this reason it is unlikely that the incorporated amino function interacts favorably with the negatively charged target amino acids Glu113 and Asp117. Possibly, the positively charged Arg24, positioned between Glu113 and Asp117, prevents these residues from interaction with the pentamer, whilst being essential for the integrity of the AT III conformation.[20] Notwithstanding our intentions, it cannot be excluded that the amino function in both pentamers **3b** and **4b**, forms an intramolecular salt bridge with the *O*-sulfate at the 3-position. This phenomenon would not only prevent the interaction of the amino group in **3b**, **4b** with the residues Glu113 and Asp117, but would also hinder the 3-*O*-sulfate binding[10] with Arg46 and Arg47 of AT III.[21] The 6-*O*-sulfate in **3b** can likewise form an intramolecular salt bridge with the proximal amino function, which may explain the lower activity of compound **4b** as compared to **3b**. In addition, analogs, **3c** and **4c**, comprising two positively charged groups have lost almost all anti-Xa activity, probably due to similar reasons.

Table 1. Anti-Xa activities of compounds **3** and **4**

Pentamer (α anomers)	Anti-Xa activity[a] [U/Mg]	Pentamer (β anomers)	Anti-Xa Activity [U/Mg]
3b	77 ± 4	**4b**	21 ± 4
3d (reference)	105 ± 14	**4c** (reference)	183 ± 23
3c	18 ± 2	**4d**	18 ± 1
3e (reference)	28 ± 4	**4e** (reference)	49 ± 1
1b	440	**2a**	938 ± 18

[a] AT III mediated anti-Xa activities were determined by an amidolytic method adapted from Teien and Lie.[22]

Conclusion

This paper describes the synthesis and biological evaluation of four heparin pentasaccharide analogs **3b**,**c** and **4b**,**c**, containing positively charged groups tethered to their reducing end and designed to interact specifically with the amino acid residues Glu113 and Asp117 in the AT III heparin binding site. The biological activities of our pentasaccharides reveal that these specific amino acid residues are not readily available for additional binding interactions as was anticipated on basis of the crystal structure of pentamer **2b** in complex with AT III. It is assumed that the formation of intramolecular salt bridges between the newly introduced amine functions and the sulfate groups of the pentasaccharide is more favorable than the formation of intermolecular salt bridges with the amino groups with Glu113 and Asp117. It is tempting to speculate that the incorporation of a rigid spacer between the positively charged amino groups and the pentamer can lead to the required additional interactions with the target amino acids. On the other hand, previous studies[4−9] show that the interaction of pentasaccharides with AT III is highly specific in nature and not merely based on straightforward electrostatic interactions. In conclusion, even with a very detailed crystal structure of the AT III pentasaccharide complex at our disposal it remains a fascinating game of trial and error to construct more potent and simplified analogs of the unique heparin pentasaccharide domain.

Experimental Section

General Methods: Dichloromethane and toluene were refluxed with P_2O_5 for 3 h and then distilled. THF and diethyl ether were refluxed with $LiAlH_4$ and distilled directly before use. All anhydrous solvents were stored over molecular sieves (3 or 4 Å). All chemicals (Fluka, Acros, Merck) were used as received. Reactions were performed under an inert gas under strictly anhydrous conditions at ambient temperature. Traces of water in the reagents were removed by coevaporation with toluene or DMF. ^1H and ^{13}C NMR spectra were recorded with a Jeol JNM FX 200 (200 and 50.1 MHz, respectively), a Bruker DPX 300 (300 and 75.1 MHz) or a Bruker DMX 600 (600 MHz). ^1H NMR chemical shifts (δ) in $CDCl_3$ are reported relative to tetramethylsilane. For proton spectra in aqueous solutions (D_2O) the residual HDO peak was set at δ = 4.80 ppm. Mass spectra were recorded with a PE/SCIEX API 165 equipped with an Electrospray Interface (Perkin−Elmer). Column chromatography was performed on Merck silica gel 60 (0.040−0.063 mm). TLC analysis was conducted on DC-Fertigfol-

ien (Schleicher & Schuell, F1500, LS254) or HPTLC aluminum sheets (Merck, silica gel 60, F254). Compounds were visualized by UV absorption (254 nm), and by spraying with 20% H_2SO_4 in ethanol or with a solution of $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$ (25 g/L) and $(NH_4)_4Ce(SO_4)_4\cdot 2H_2O$ (10 g/L) in water or 3% ninhydrin in ethanol followed by charring at 140 °C. Gel permeation chromatography was accomplished on Toyopearl HW40S. Preparative HPLC was performed with a Biocad® Vision (Applied Biosystems, Inc.) using an Alltima C-18 5μ encapped semi-preparative column. Gradient elution was performed at 20 °C by building up a gradient of acetonitrile in 0.1% aqueous TFA at a flow rate of 5 mL/min.

Glucal 8: *tert*-Butyldimethylsilyl chloride (5.21 g, 34.6 mmol) and imidazole (4.71 g, 69.2 mmol) were added to a solution of 3,6-*O*-dibenzylglucal[13] (5.64 g, 17.3 mmol) in DMF (80 mL). The reaction mixture was brought to 60 °C and stirred for 16 h, after which methanol (5 mL) was added and the mixture was concentrated. The residue was dissolved in diethyl ether and washed with water, after which the aqueous layer was extracted three times with diethyl ether. The organic layers were dried ($MgSO_4$) and the solvents evaporated in vacuo. The crude product was purified by silica gel column chromatography (0 to 2% EtOAc in toluene) to give the fully protected glucal **8** (5.71 g, 13.0 mmol) in 75% yield. $R_f = 0.90$ (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 0.055 (s, 3 H, CH_3 TBS), 0.073 (s, 3 H, CH_3 TBS), 0.85 (s, 9 H, *t*Bu), 3.76, 3.95 (m, 5 H, 3,4,5,6,6′-H), 4.58 (AB, 2 H, CH_2Bn), 4.59 (AB, 2 H, CH_2Bn), 4.86 (dd, $J_{2,1} = 5.9$, $J_{2,3} = 2.2$ Hz, 1 H, 2-H), 6.44 (d, $J_{1,2} = 5.9$ Hz, 1 H, 1-H), 7.27 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.0, −4.0 (CH_3, TBS), 18.2 (C_q *t*Bu), 26.0 (CH_3 *t*Bu), 68.9, 70.0, 73.4 (CH_2 Bn, C-6), 68.7, 77.2, 78.5 (C-3,4,5), 99.4 (C-2), 127.5−129.1 (CH_{arom}), 138.3, 138.5 ($C_{q,arom}$), 144.8 (C-1) ppm.

1,2-Anhydro-α-D-glucopyranose 9: Glucal **8** (4.50 g, 10.2 mmol) was dissolved in dichloromethane (30 mL) and the solution was cooled to 0 °C. A solution of DMDO in acetone[16] (ca. 0.08 M, 150 mL, 12 mmol) was added and after stirring for 5 min the reaction mixture was concentrated to provide epoxide **9** as a yellow oil (4.65 g, 10.2 mmol, 100%). ^{1}H NMR ($CDCl_3$): δ = 0.037 (s, 3 H, CH_3 TBS), 0.039 (s, 3 H, CH_3 TBS), 0.83 (s, 9 H, *t*Bu), 3.00 (d, $J_{2,1} = 2.2$ Hz, 1 H, 2-H), 3.70 (m, 5 H, 3,4,5,6,6′-H), 4.64 (AB, 2 H, CH_2Bn), 4.65 (AB, 2 H, CH_2Bn), 4.97 (d, $J_{1,2} = 2.9$ Hz, 1 H, 1-H), 7.31 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.3, −4.2 (CH_3, TBS), 18.0 (C_q *t*Bu), 25.8 (CH_3 *t*Bu), 51.9 (C-2), 68.4, 71.6, 73.2 (CH_2 Bn, C-6), 67.8, 70.2 (C-3,4,5), 79.8 (C-1), 127.4−128.3 (CH_{arom}), 137.5, 138.0 ($C_{q,arom}$) ppm.

α-Ethynyl-*C*-glucoside 10: A solution of $ZnCl_2$ in THF (2 M, 26 mL, 52 mmol) was added to a suspension of sodium acetylide (18 wt% in xylenes/mineral oil, 16 mL, 51 mmol) in THF (50 mL) at 0 °C, after which the mixture was stirred for 10 min. The resulting solution was added at 0 °C to a mixture of the crude 1,2-anhydroglucose **9** (10.2 mmol) in THF (50 mL) and the reaction mixture was stirred for 1 h. The mixture was poured into saturated aqueous NH_4Cl, washed with water, dried with $MgSO_4$ and concentrated. Silica gel column chromatography (10−20% EtOAc in light petroleum ether) gave the pure α-ethynyl adduct (3.69 g, 7.65 mmol, 75%). $R_f = 0.60$ (light petroleum ether/EtOAc, 2:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 0.011 (s, 3 H, CH_3 TBS), 0.048 (s, 3 H, CH_3 TBS), 0.86 (s, 9 H, *t*Bu), 2.16 (d, $J = 7.3$ Hz, 1 H, OH), 2.63 (d, $J = 2.2$ Hz, 1 H, 1-H), 3.67 (m, 5 H), 3.95 (m, 1 H, 3, 4,5,6,7,8,8′-H), 4.58 (AB, 2 H, CH_2Bn), 4.77 (dd, $J_{3,4} = 5.1$, $J = 2.2$ Hz, 1 H, 3-H), 4.80 (AB, 2 H, CH_2Bn), 7.32 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.1, −4.1 (CH_3, TBS), 17.8 (C_q *t*Bu), 25.7 (CH_3 *t*Bu), 68.6, 73.0, 74.4 (CH_2 Bn, C-8), 77.5 (C_q C≡C) 67.5, 70.0, 71.0, 75.3, 82.9 (C-3,4,5,6,7), 127.3−128.1 (CH_{arom}), 137.9, 138.4 ($C_{q,arom}$) ppm.

α-Ethynyl-C-glucoside 11: Alcohol **10** (3.33 g, 6.91 mmol) and methyl iodide (0.94 mL, 13.8 mmol) were dissolved in DMF (35 mL) and cooled in an ice bath. Sodium hydride (0.331 g, 7.60 mmol) was added and stirring was continued for 1 h. The mixture was diluted with diethyl ether (100 mL) and washed once with saturated aqueous NH_4Cl and water. The aqeous layers were combined and extracted three times with diethyl ether. The combined organic layers were dried ($MgSO_4$) and the solvents evaporated to dryness. Silica gel column chromatography (0−10% EtOAc in light petroleum ether) gave pure **11** (3.18 g, 6.40 mmol, 93%). $R_f = 0.80$ (light petroleum ether/EtOAc, 4:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 0.039 (s, 6 H, CH_3 TBS), 0.84 (s, 9 H, *t*Bu), 2.65 (d, $J = 2.2$ Hz, 1 H, 1-H), 3.43 (s, 3 H, OMe), 3.43 (m, 1 H), 3.65 (m, 4 H) 3.93 (m, 1 H, 4, 5, 6, 7, 8, 8′-H), 4.62 (AB, 2 H, CH_2Bn), 4.93 (dd, $J_{3,4} = 5.9$, $J = 2.2$ Hz, 1 H, 3-H), 5.02 (AB, 2 H, CH_2Bn), 7.36 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.11, −3.87 (CH_3, TBS), 17.94 (C_q *t*Bu), 25.88 (CH_3 *t*Bu), 58.18 (OMe), 68.88, 73.10, 74.52 (CH_2 Bn, C-8), 77.46 (C_q C≡C), 65.42, 70.31, 74.92, 81.59, 82.41 (C-3,4,5,6,7), 126.95−128.14 (CH_{arom}), 138.02, 139.08 ($C_{q,arom}$) ppm.

α-Hydroxyethyl-*C*-glycoside 12: Freshly distilled 2-methyl-2-butene (3.4 mL, 32.0 mmol) was added to a chilled borane solution in THF (1.0 M, 12.8 mL, 12.8 mmol) and the mixture was stirred for 1 h, after which a solution of alkyne **11** (3.178 g, 6.40 mmol) in THF (6 mL) was added and stirring was continued for 30 min, after which TLC analysis showed complete conversion of the starting material. Aqueous sodium hydroxide (3 M, 12.8 mL, 38.4 mmol) was added dropwise, immediately followed by a solution of hydrogen peroxide (35% in water, 4.0 mL, 46.12 mmol). The mixture was stirred for 1 h after which it was diluted with diethyl ether, washed with water and brine. The aqueous layers were collected, extracted twice with EtOAc and the combined organic layers were dried with $MgSO_4$, filtered and concentrated. The resulting oil was coevaporated thrice with toluene, dissolved in THF (20 mL) and cooled to 0 °C. Lithium aluminum hydride (267 mg, 7.04 mmol) was added and the mixture was stirred for 5 min. The reaction was quenched by dropwise addition of aqueous sodium hydroxide (3 M) until gas evolution had ceased. Dilution of the mixture with EtOAc was followed by the addition of $MgSO_4$, the mixture was stirred for 10 min and filtered through Celite®. The filter cake was rinsed thoroughly with EtOAc and the solution was concentrated in vacuo. The crude product was purified by silica gel column chromatography (10−50% EtOAc in light petroleum ether) to give pure alcohol **12** (2.66 g, 5.15 mmol) in 81% yield. $R_f = 0.20$ (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = −0.03 (s, 3 H, CH_3 TBS), −0.01 (s, 3 H, CH_3 TBS), 0.85 (s, 9 H, *t*Bu), 1.82 (m, 1 H, 2-H), 2.15 (m, 1 H, 2′-H) 3.40 (s, 3 H, OMe), 3.44 (m, 4 H), 3.79 (m, 4 H), 4.34 (m, 1 H, 1,1′,3,4,5,6,7,8,8′-H), 4.62 (AB, 2 H, CH_2Bn), 4.93 (AB, 2 H, CH_2Bn), 7.36 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.0, −3.8 (CH_3, TBS), 17.9 (C_q *t*Bu), 25.8 (CH_3 *t*Bu), 27.7 (C-2), 58.32 (OMe), 61.4 (C-1), 70.0, 73.3, 74.6 (CH_2 Bn, C-8), 71.5, 72.6, 73.5, 81.7, 82.4 (C-3,4,5,6,7), 127.1−128.3 (CH_{arom}), 137.8, 139.0 ($C_{q,arom}$) ppm.

Azide 13: Alcohol **12** (0.880 g, 1.71 mmol) was dissolved in dichloromethane (10 mL). Mesyl chloride (0.34 mL, 3.41 mmol) and pyridine (0.68 mL, 8.53 mmol) were added and the reaction mixture was stirred for 16 h, after which TLC analysis showed clean conversion into a faster running product; $R_f = 0.50$ (light petroleum ether/EtOAc, 3:1, v/v). The mixture was diluted with diethyl ether and washed with water. After the organic phase was dried ($MgSO_4$) and

concentrated, the crude mesylate was coevaporated three times with toluene and taken up in DMF (5 mL). Sodium azide (290 mg, 4.46 mmol) was added and the mixture was heated for 3 h at 60 °C. The solution was allowed to cool to room temperature, diluted with diethyl ether and washed with water, after which the aqueous layer was extracted thrice with diethyl ether. The combined organic phases were dried ($MgSO_4$) and concentrated. The azide was purified by silica gel column chromatography (10% EtOAc in light petroleum ether) and obtained as a yellow oil (0.805 g, 1.49 mmol) in 87% yield. R_f = 0.80 (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = −0.020 (s, 3 H, CH_3 TBS), −0.015 (s, 3 H, CH_3 TBS), 0.82 (s, 9 H, *t*Bu), 1.93 (m, 2 H, 2,2′-H), 3.36 (s, 3 H, OMe), 3.53 (m, 8 H), 4.24 (m, 1 H, 1,1′,3,4,5,6,7,8,8′-H), 4.57 (AB, 2 H, CH_2Bn), 4.79 (AB, 2 H, CH_2Bn), 7.31 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.0, −3.8 (CH_3, TBS), 24.5 (C_q *t*Bu), 25.9 (CH_3 *t*Bu), 29.6 (C-2), 47.8 (C-1), 58.2 (OMe), 69.7, 73.3, 74.5 (CH_2 Bn, C-8), 70.2, 71.0, 73.0, 81.7, 82.2 (C-3,4,5,6,7), 127.1−128.7 (CH_{arom}), 139.0 ($C_{q,arom}$) ppm.

H-α Building Block 5: A solution of tetrabutylammonium fluoride in THF (1 M, 1.8 mL, 1.8 mmol) was added to Azide **13** (0.805 g, 1.49 mmol) in THF (10 mL). The mixture was stirred for 3 h after which it was washed twice with water. The organic layer was dried ($MgSO_4$), concentrated and the crude product was purified by silica gel column chromatography (10−50% EtOAc in light petroleum ether) to give the pure **5** in 99% yield (0.630 g, 1.48 mmol). R_f = 0.35 (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 1.90 (m, 2 H, 2,2′-H), 2.76 (br. s, 1 H, OH), 3.50 (s, 3 H, OMe), 3.53 (m, 8 H), 4.18 (m, 1 H, 1,1′,3,4,5,6,7,8,8′-H), 4.56 (s, 2 H, CH_2Bn), 4.77 (AB, 2 H, CH_2Bn), 7.31 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = 35.0 (C-2), 47.5 (C-1), 58.1 (OMe), 69.3, 73.1, 73.9 (CH_2 Bn, C-8), 69.3, 69.7, 72.4, 79.3, 80.5 (C-3,4,5,6,7), 127.2−128.1 (CH_{arom}), 137.8, 138.3 ($C_{q,arom}$) ppm.

β-Allyl-*C*-glucoside 17: β-Allyl-C-glycoside **16**[12b] (7.15 g, 11.0 mmol) and pyrrole (4.58 mL, 66.0 mmol) were dissolved in dichloromethane (250 mL) and trifluoroacetic acid (1.67 mL, 22.0 mmol) was added dropwise to the resulting solution. After 1 min, saturated aqueous $NaHCO_3$ (100 mL) was added. The organic layer was extracted and washed with water, dried with $MgSO_4$ and the solvents were evaporated. Silica gel column chromatography (0−15% EtOAc in light petroleum ether) yielded pure **17** (4.039 g, 9.90 mmol, 90%). R_f = 0.50 (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 0.10 (s, 3 H, CH_3 TBS), 0.12 (s, 3 H, CH_3 TBS), 0.92 (s, 9 H, *t*Bu), 2.20 (m, 1 H, 3-H), 2.51 (m, 1 H, 3′-H), 3.28 (m, 4 H), 3.56 (m, 2 H) 3.80 (m, 1 H, 4,5,6,7,8,9,9′-H), 4.79 (AB, 2 H, CH_2Bn), 5.08 (m, 2 H, 1, 1′-H), 5.83 (m, 1 H, 2-H), 7.36 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −4.7, −3.9 (CH_3, TBS), 17.9 (C_q *t*Bu), 25.9 (CH_3 *t*Bu), 37.0 (C-3), 62.2 (C-9), 75.2 (CH_2 Bn) 71.1, 73.6, 78.4, 80.1, 87.2 (C-4,5,6,7,8), 117.1 (C-1), 127.3, 127.6, 128.5 (CH_{arom}), 134.3 (C-2), 138.7 ($C_{q,arom}$) ppm.

β-Allyl-*C*-glucoside 18: β-Allyl-C-glucoside **17** was methylated as described for **11**. Yield: 93%. R_f = 0.85 (light petroleum ether/EtOAc, 4:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 0.00 (s, 3 H, CH_3 TBS), 0.051 (s, 3 H, CH_3 TBS), 0.88 (s, 9 H, *t*Bu), 2.26 (m, 1 H, 3-H), 2.52 (m, 1 H, 3′-H), 2.91 (m, 1 H), 3.00−3.56 (m, 3 H), 3.81 (m, 3 H, 4,5,6,7,8,9,9′-H), 3.56 (s, 6 H, OMe), 4.85 (AB, 2 H, CH_2Bn), 5.07 (m, 2 H, 1,1′-H), 5.90 (m, 1 H, 2-H), 7.40 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.4, −5.1 (CH_3, TBS), 18.3 (C_q *t*Bu), 25.8 (CH_3 *t*Bu), 36.1 (C-3), 60.4, 60.7 (OMe), 62.1 (C-9), 75.4 (CH_2Bn), 78.3, 78.8, 83.3, 86.9 (C-4,5,6,7,8), 116.8 (C-1), 127.5, 128.0, 128.3 (CH_{arom}), 134.7 (C-2), 138.8 ($C_{q,arom}$) ppm.

β-Hydroxyethyl-*C*-glucoside 19: Alkene **18** (1.31 g, 3.02 mmol) was dissolved in dichloromethane/methanol (7:1, 30 mL) and cooled to −70 °C. An ozone/oxygen mixture was bubbled through the solution until a blue color persisted. Then oxygen was passed through for 30 min, after which the mixture was brought to −50 °C, dimethyl sulfide (3 mL) was added and the mixture was allowed to reach room temperature overnight. The mixture was concentrated, coevaporated three times with toluene, dissolved in THF and cooled in an ice bath. Lithium aluminum hydride (126 mg, 3.32 mmol) was added and the mixture was stirred for 30 min, after which the reaction was quenched by dropwise addition of aqueous sodium hydroxide (3 M, 1.5 mL). The mixture was diluted with EtOAc, $MgSO_4$ was added and stirring was continued for 10 min, after which the mixture was filtered through Celite®. The filter cake was rinsed thoroughly with EtOAc and the solution was concentarted in vacuo. The crude alcohol was purified by silica gel column chromatography (10−50% EtOAc in light petroleum ether) to give **19** (0.952 g, 2.16 mmol) in 72% yield. R_f = 0.20 (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 0.055 (s, 6 H, CH_3 TBS), 0.89 (s, 9 H, *t*Bu), 1.76 (m, 1 H), 2.01 (m, 1 H, 2,2′-H), 2.72 (br. s, 1 H, OH), 2.95 (t, *J* = 9.5 Hz, 1 H), 3.12−3.56 (m, 4 H), 3.80 (m, 4 H, 1,1′,3,4,5,6,7,8,8′-H), 3.56 (s, 6 H, OMe), 4.85 (AB, 2 H, CH_2Bn), 7.37 (m, 5 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.5, −5.4 (CH_3, TBS), 18.1 (C_q *t*Bu), 25.7 (CH_3 *t*Bu), 33.8 (C-2), 60.1, 60.5 (OMe), 61.1, 62.2 (C-1,8), 75.4 (CH_2 Bn), 79.1, 79.6, 83.8, 86.6(C-3,4,5,6,7), 127.6, 127.9, 128.3 (CH_{arom}), 138.5 ($C_{q,arom}$) ppm.

Azide 20: Azide **20** was synthesized from alcohol **19** as was described for **13** in 85%: R_f = 0.75 (light petroleum ether/EtOAc, 3:1, v/v).^{1}H NMR ($CDCl_3$): δ = 0.051 (s, 6 H, CH_3 TBS), 0.89 (s, 9 H, *t*Bu), 1.65 (m, 1 H), 2.10 (m, 1 H, 2,2′-H), 2.86 (t, *J* = 9.5 Hz, 1 H), 3.07−3.57 (m, 5 H), 3.81 (m, 3 H, 1,1′,3,4,5,6,7,8,8′-H), 3.57 (s, 6 H, OMe), 4.85 (AB, 2 H, CH_2Bn), 7.32 (m, 5 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = −5.6, −5.2 (CH_3, TBS), 18.1 (C_q *t*Bu), 25.7 (CH_3 *t*Bu), 31.3 (C-2), 47.7 (C-1), 60.3, 60.7 (OMe), 61.9 (C-8), 75.2 (CH_2 Bn), 75.5, 79.3, 79.4, 84.0, 86.6 (C-3,4,5,6,7), 127.5, 127.9, 128.2 (CH_{arom}), 138.5 ($C_{q,arom}$) ppm.

H-β Building Block 6: Desilylation of **20** was performed as described for **5** to give **6** in 86% yield: R_f = 0.25 (light petroleum ether/EtOAc, 3:1, v/v). ^{1}H NMR ($CDCl_3$): δ = 1.70 (m, 1 H, 2-H), 2.14 (m, 1 H, 2′-H), 1.87 (br. t, *J* = 4.9 Hz, 1 H, OH), 2.90 (t, *J* = 8.8 Hz, 1 H), 3.17−3.72 (m, 7 H), 3.87 (m, 1 H, 1,1′,3,4,5,6,7,8,8′-H), 3.56 (s, 6 H, OMe), 4.85 (s, 2 H, CH_2Bn), 7.38 (m, 5 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = 31.1 (C-2), 47.8 (C-1), 60.5, 60.8 (OMe), 61.7 (C-8), 75.0 (CH_2Bn), 76.0, 78.9, 79.8, 83.9, 86.4 (C-3,4,5,6,7), 127.5, 127.8, 128.2 (CH_{arom}), 138.4 ($C_{q,arom}$) ppm.

Disaccharide 22: C-Glycoside **5** (0.371 g, 0.869 mmol) and idose donor **21**[12] (0.411 g, 1.13 mmol) were dissolved in toluene (10 mL) and molecular sieves (4 Å) were added. The suspension was cooled to −20 °C and stirred for 30 min. A solution of *N*-iodosuccinimide (0.391 g, 1.74 mmol) and TfOH (11μL, 0.130 mmol) in dioxane/dichloromethane (1:1, 10 mL) was added dropwise. After 30 min, the reaction mixture was filtered through Celite® into an aqueous $NaHCO_3$/$Na_2S_2O_3$ solution, diluted, extracted and washed with water. The organic layer was dried with $MgSO_4$, filtered and concentrated in vacuo to give the crude disaccharide, which was purified by silica gel column chromatography (10−20% EtOAc in light petroleum ether) to give pure **22** (0.608 g, 0.834 mmol, 96%): R_f = 0.60 (toluene/EtOAc, 1:1, v/v),^{1}H NMR ($CDCl_3$, HH-COSY): δ = 1.89 (m, 2 H, 2_H,$2'_H$-H), 1.89 (s, 3 H, CH_3 Ac), 2.00 (s, 3 H, CH_3 Ac), 2.07 (s, 3 H, CH_3 Ac), 3.39 (m, 2 H, 1_H,$1'_H$-H), 3.40 (s, 3 H, OMe), 3.46 (m, 1 H, 3_G-H), 3.47 (m, 1 H, 4_H-H), 3.49 (s, 3 H,

OMe), 3.60 (m, 2 H), 3.69 (m, 2 H, 5_H,6_H,7_H,8_H-H), 3.90 (m, 3 H, $8'_H$,6_G,$6'_G$-H), 4.21 (m, 1 H, 3_H-H), 4.54 (AB, 2 H, CH_2 Bn), 4.59 (m, 1 H, 5_G-H), 4.74 (m, 1 H, 4_G-H), 4.80 (m, 1 H, 2_G-H), 4.80 (AB, 2 H, CH_2 Bn), 4.98 (br. s, 1 H, 1_G-H), 7.27−7.36 (m, 10 H, CH Ph) ppm. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 20.5−20.7 (CH_3 Ac), 24.6 (C-2_H), 48.5 (C-1_H), 58.2, 58.5 (CH_3 OMe), 61.9, 68.7, 73.1, 74.6 (CH_2 Bn, C-6_G,8_H), 63.1, 65.9, 67.1, 70.3, 71.6, 73.4, 74.5, 79.5, 81.7 (C-3_H,4_H,5_H,6_H,7_H,2_G,3_G,4_G,5_G), 96.6 (C-1_G), 127.3, 128.1 (CH_{arom}), 137.9, 138.6 ($C_{q,arom}$), 169.5, 170.1 (C=O Ac) ppm.

Disaccharide 23: Disaccharide **22** (0.250 g, 0.343 mmol) was dissolved in methanol/dioxane (1:1, 4 mL) and a catalytic amount of KO*t*Bu (4 mg) was added. The mixture was stirred for 3 h, neutralized with Dowex-H^+, filtered and concentrated. The triol was coevaporated three times with toluene and dissolved in DMF/dimethoxypropane (5:1, 5 mL). A catalytic amount of *p*-toluenesulfonic acid was added and the mixture was stirred for 1 h and subsequently diluted with diethyl ether (20 mL), washed with saturated aqueous $NaHCO_3$ and water, dried ($MgSO_4$), filtered and concentrated to give the crude acetonide [R_f = 0.60 (toluene/EtOAc, 3:1, v/v)], which was coevaporated three times with toluene, dissolved in DMF (4 mL) and methylated with iodomethane (43 μL, 0.68 mmol) and sodium hydride (15 mg, 0.38 mmol) at 0 °C. The mixture was diluted with diethyl ether (20 mL) and washed with saturated aqueous NH_4Cl (10 mL). The aqueous layer was extracted three times with diethyl ether and the organic phases were combined, dried ($MgSO_4$), filtered and concentrated. The residual oil was dissolved in 80% aqueous acetic acid (4 mL), heated at 60 °C for 1 h and coevaporated with toluene (4 × 5 mL). Silica gel column chromatography (50−100% EtOAc in light petroleum ether) yielded the pure diol [R_f = 0.10 (toluene/EtOAc, 3:1, v/v)]. The diol was dissolved in dichloromethane (2.5 mL) and a catalytic amount (1 mg) of 2,2,6,6-tetramethylpiperidin-1-oxyl (TEMPO) was added, followed by a solution of potassium bromide (8 mg) and tetrabutylammonium chloride (10 mg) in saturated aqueous $NaHCO_3$ (1.5 mL). The mixture was brought to 0 °C and a mixture of 13% aqueous NaOCl (1.3 mL), saturated aqueous $NaHCO_3$ (0.76 mL) and saturated aqueous NaCl (1.5 mL) was added dropwise over a period of 2 h after which the mixture was stirred for another hour. The layers were separated, and the dichloromethane fraction was extracted three times with water. The aqueous phases were combined, brought to pH = 1 with 1 N HCl and extracted five times with EtOAc. The organic phases were dried ($MgSO_4$) and concentrated to give the crude acid, which was transformed into its benzyl ester by treatment with benzyl bromide (0.12 mL, 1.01 mmol) and $KHCO_3$ (69 mg, 0.69 mmol) in DMF (5 mL) for 2 h. The reaction mixture was diluted with EtOAc (20 mL), washed with water, dried ($MgSO_4$), filtered and concentrated to dryness. Silica gel column chromatography (50−100% EtOAc in light petroleum ether) yielded pure disaccharide **23** (0.121 mg, 0.168 mmol, 49%): R_f = 0.85 (EtOAc).^{1}H NMR ($CDCl_3$, HH-COSY): δ = 1.65 (br. s, 1 H, OH), 1.83 (m, 1 H, 2_H-H), 1.92 (m, 1 H, $2'_H$-H), 3.23 (m, 1 H, 2_G-H), 3.24 (s, 3 H, OMe),3.35 (s, 3 H, OMe), 3.39 (m, 3 H, 1_H,$1'_H$,4_H-H), 3.41 (s, 3 H, OMe), 3.52 (m, 1 H, 3_G-H), 3.65 (m, 4 H), 3.87 (m, 1 H, 5_H,6_H,7_H,8_H,$8'_H$-H), 3.99 (br. d, J = 10.1 Hz, 1 H, 4_G-H), 4.15 (m, 1 H, 3_H-H), 4.57 (s, 2 H, CH_2 Bn), 4.73 (AB, 2 H, CH_2 Bn), 4.87 (br. s, 1 H, 5_G-H), 5.01 (AB, 2 H, CH_2 Bn), 5.16 (br. s, 1 H, 1_G-H), 7.26−7.34 (m, 15 H, CH Ph) ppm. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 25.1 (C-2_H), 47.9 (C-1_H), 58.1, 58.2, 58.4 (OMe), 66.3, 69.1, 73.5, 74.0 (CH_2 Bn, C-8_H), 67.1, 68.4, 69.9, 71.8, 74.5, 75.6, 76.0, 78.8, 81.2 (C-3_H,4_H,5_H,6_H,7_H,2_G,3_G,4_G,5_G), 97.2 (C-1_G), 127.2−128.3 (CH_{arom}), 137.8, 138.5 ($C_{q,arom}$), 169.4 (C=O) ppm.

Pentasaccharide 25: GH acceptor **23** (87 mg, 0.12 mmol) and DEF donor **24**[11] (166 mg, 0.16 mmol) were dissolved in dichloromethane (2 mL) and molecular sieves (4 Å) were added. The suspension was cooled to −20 °C and stirred for 30 min. A solution of trimethylsilyl trifluoromethanesulfonate (3.3 μL, 18 μmol) in dichloromethane (0.1 mL) was added dropwise. After 30 min, the reaction mixture was filtered through Celite® into an aqueous $NaHCO_3$ solution, diluted, extracted and washed with water. The organic layer was dried with $MgSO_4$, filtered and concentrated in vacuo to give the crude pentasaccharide, which was purified by silica gel column chromatography (0−10% acetone in dichloromethane) followed by passage through a column of Sephadex LH-20, which was eluted with dichloromethane/methanol (1:1). The appropriate fractions were pooled to give pure **25** (148 mg, 0.093 mmol, 77%). R_f = 0.40 (dichloromethane/acetone, 9:1, v/v). ^{1}H NMR ($CDCl_3$, HH-COSY, HH-TOCSY): **D:** δ = 3.05 (t, $J_{4,3}$ = $J_{4,5}$ = 9.1 Hz, 1 H, 4-H), 3.13 (dd, $J_{2,1}$ = 3.7, $J_{2,3}$ = 9.8 Hz, 1 H, 2-H), 3.33 (t, $J_{3,2}$ = $J_{3,4}$ = 9.4 Hz, 1 H, 3-H), 3.43 (m, 1 H, 5-H), 4.24 (m, 1 H, 6-H), 4.31 (m, 1 H, 6′-H), 5.54 (d, $J_{1,2}$ = 3.7 Hz, 1-H) ppm; **E:** 2.88 (t, $J_{2,1}$ = $J_{2,3}$ = 8.1 Hz, 1 H, 2-H), 3.30 (t, $J_{3,2}$ = $J_{3,4}$ = 9.0 Hz, 1 H, 3-H), 3.84 (d, $J_{5,4}$ = 9.8 Hz, 1 H, 5-H), 3.93 (t, $J_{4,3}$ = $J_{4,5}$ = 9.2 Hz, 1 H, 4-H), 4.10 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H) ppm; **F:** 3.41 (m, 1 H, 2-H), 3.56 (m, 1 H, 4-H), 4.02 (m, 1 H, 5-H), 4.21 (m, 1 H, 6-H), 4.45 (m, 1 H, 6′-H), 5.17 (d, $J_{1,2}$ = 4.0 Hz, 1 H, 1-H), 5.38 (t, $J_{3,2}$ = $J_{3,4}$ = 9.6 Hz, 1 H, 3-H) ppm; **G:** 2.97 (t, $J_{2,1}$ = $J_{2,3}$ = 6.8 Hz, 1 H, 2-H), 3.66 (t, $J_{3,2}$ = $J_{3,4}$ = 8.0 Hz, 1 H, 3-H), 3.87 (dd, $J_{4,3}$ = 8.1, $J_{4,5}$ = 6.1 Hz, 1 H, 4-H), 4.47 (d, $J_{5,4}$ = 6.0 Hz, 1 H, 5-H), 5.26 (d, $J_{1,2}$ = 6.0 Hz, 1 H, 1-H) ppm; **H:** 1.83 (m, 1 H, 2-H), 1.93 (m, 1 H, 2′-H), 3.37 (m, 3 H, 1, 1′, 4′-H), 3.61 (m, 2 H, 5, 7-H), 3.70 (m, 2 H, 8, 8′-H), 3.78 (t, $J_{6,5}$ = $J_{6,7}$ = 8.4 Hz, 1 H, 6-H), 4.16 (m, 1 H, 3-H) ppm; OMe: 3.21, 3.38, 3.44, 3.45, 3.49, 3.52, 3.53, 3.55 (8 × s, 3 H); Ac: 1.90, 2.01, 2.12 (3 × s, 3 H) ppm; CH_2 Bn: 4.57, 4.60, 4.72, 5.11, 5.14 (5 × AB, 2 H) ppm; CH Ph: δ = 7.73 (m, 25 H) ppm. ES-MS: m/z = 1621.0 [M + Na]$^+$.

Pentasaccharide 26: Fully protected pentamer **25** (89 mg, 0.056 mmol) was dissolved in *tert*-butyl alcohol/water (2:1, 3 mL) and two drops of acetic acid and 10% palladium on carbon (100 mg) were added. The heterogeneous mixture was stirred under hydrogen for 16 h, after which the catalyst was filtered off and the solvents were evaporated. The resulting oil was taken up in a mixture of 0.4 N NaOH (2.6 mL) and methanol (0.9 mL) and stirred overnight. The reaction mixture was neutralized with 1 N HCl and concentrated to 1 mL. The solution was passed through a Toyopearl HW40S column, which was eluted with acetonitrile/water (1:9). The appropriate fractions were pooled and lyophilized to give the fully deprotected pentamer **26** as a fluffy white solid (43 mg, 0.043 mmol, 77%). R_f = 0.20 (EtOAc/pyridine/acetic acid/water, 8:7:1.6:4 v/v/v/v). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.27 (m, 1 H, 4-H), 3.29 (m, 1 H, 2-H), 3.51 (m, 1 H, 3-H), 3.67 (m, 1 H, 5-H), 3.72 (m, 2 H, 6, 6′-H), 5.44 (d, $J_{1,2}$ = 3.8 Hz, 1-H) ppm; **E:** 3.23 (m, 1 H, 2-H), 3.51 (m, 1 H, 3-H), 3.73 (m, 1 H, 5-H), 3.81 (m, 1 H, 4-H), 4.53 (d, $J_{1,2}$ = 7.8 Hz, 1-H) ppm; **F:** 3.47 (m, 1 H, 2-H), 3.56 (m, 1 H, 4-H), 3.74 (m, 1 H, 3-H), 3.78 (m, 1 H, 6-H), 3.84 (m, 2 H, 5, 6′-H), 5.10 (d, $J_{1,2}$ = 3.9 Hz, 1-H); **G:** 3.43 (m, 1 H, 2-H), 3.72 (m, 1 H, 3-H), 4.17 (m, 1 H, 4-H), 4.62 (d, $J_{5,4}$ = 2.4 Hz, 1 H, 5-H), 5.01 (d, $J_{1,2}$ = 2.1 Hz, 1 H, 1-H) ppm; **H:** 1.89 (m, 1 H, 2-H), 2.10 (m, 1 H, 2′-H), 3.09 (m, 2 H, 1, 1′-H), 3.40 (m, 1 H, 4-H), 3.59 (m, 1 H, 6-H), 3.62 (m, 1 H, 7-H), 3.75 (m, 2 H, 5, 8-H), 3.81(m, 1 H, 8′-H), 4.32 (m, 1 H, 3-H) ppm; OMe: 3.44, 3.47, 3.50, 3.51, 3.54, 3.60, 3.61, 3.62 (8 × s, 3 H) ppm. ES-MS: m/z = 996.3 [M + H]$^+$.

Pentasaccharide 27: Pentamer **26** (46 mg, 0.046 mmol) was dissolved in DMF/water (1:4, 1.25 mL). *N*-(Benzyloxycarbonyloxy)succinimide (17 mg, 0.069) and *N*-methylmorpholine (17 μL, 0.138 mmol) were added and the mixture was stirred for 30 min, concentrated to dryness and taken up in 2 mL of acetonitrile/water (1:9). The resulting mixture was chromatographed on a Toyopearl HW40S column, which was eluted with acetonitrile/water (1:9). The product fractions were pooled and lyophilized. The resulting pentamer (47 mg) was purified by preparative HPLC (elution was effected by applying a gradient of 25−30% acetonitrile) to give pure **27** (26 mg, 0.023 mmol, 50%). R_f = 0.40 (EtOAc/pyridine/acetic acid/water 8:7:1.6:4 v/v/v/v). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.26 (t, $J_{4,3} = J_{4,5}$ = 9.8 Hz, 1 H, 4-H), 3.30 (dd, $J_{2,1}$ = 3.8, $J_{2,3}$ = 10.0 Hz, 1 H, 2-H), 3.43 (m, 2 H, 3, 5-H), 3.69 (m, 2 H, 6, 6′-H), 5.47 (d, $J_{1,2}$ = 3.7 Hz, 1-H); **E:** 3.23 (dd, $J_{2,1}$ = 7.9, $J_{2,3}$ = 9.1 Hz, 1 H, 2-H), 3.55 (m, 1 H, 3-H), 3.87 (t, $J_{4,3} = J_{4,5}$ = 9.0 Hz, 1 H, 5-H), 4.04 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 4.59 (d, $J_{1,2}$ = 7.8 Hz, 1-H); **F:** 3.48 (m, 1 H, 2-H), 3.58 (m, 1 H, 4-H), 3.65 (m, 1 H, 5-H), 3.70 (m, 1 H, 3-H), 3.80 (m, 2 H, 6, 6′-H), 5.13 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **G:** 3.44 (m, 1 H, 2-H), 3.73 (m, 1 H, 3-H), 4.18 (m, 1 H, 4-H), 5.02 (br. s, 1 H, 5-H), 5.03 (br. s, 1 H, 1-H); **H:** 1.62 (m, 1 H, 2-H), 1.84 (m, 1 H, 2′-H), 3.18 (m, 2 H, 1, 1′-H), 3.33 (m, 1 H, 4-H), 3.58 (m, 2 H, 6, 7-H), 3.64 (br. s, 1 H, 8-H), 3.66 (m, 1 H, 5-H), 3.76 (m, 1 H, 8′-H), 4.22 (m, 1 H, 3-H); OMe: 3.34, 3.44, 3.47, 3.52, 3.52, 3.58, 3.58, 3.61 (8 × s, 3 H); CH_2 Bn: 5.07 (m, 2 H); CH Ph: 7.39 (m, 5 H); ES-MS: *m*/*z* = 1167.0 [M + Na]$^+$.

Pentasaccharide 3d: Pentamer **27** (8.4 mg, 7.4 μmol) was dissolved in water (1 mL) and passed through a column of Dowex 50 WX-4H$^+$. The eluate was concentrated, lyophilized, coevaporated thrice with DMF and dissolved in DMF (1 mL). Triethylamine sulfur trioxide complex (5 equiv. for each hydroxy function, 40 mg, 0.022 mmol) was added under nitrogen. The flask was sealed and heated at 55 °C overnight. A solution of $NaHCO_3$ (4 equiv. for each triethylamine−sulfur trioxide complex, 75 mg, 0.089 mmol) in 1.5 mL of water was added at 0 °C, and the resulting mixture was stirred for 1 h, after which it was concentrated to a small volume and applied to a Toyopearl HW40S column, which was eluted with acetonitrile/water (1:9). The product fractions were pooled, concentrated and passed through a column of Dowex 50 WX-4 (Na$^+$ form). The eluate was lyophilized to give target pentasaccharide **3d** (13.2 mg, 100%). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.32 (m, 2 H, 2, 4-H), 3.51 (m, 1 H, 3-H), 3.86 (m, 1 H, 5-H), 4.10 (m, 1 H, 6-H), 4.27 (m, 1 H, 6′-H), 5.45 (d, $J_{1,2}$ = 3.7 Hz, 1-H); **E:** 3.26 (m, 1 H, 2-H), 3.51 (m, 1 H, 3-H), 3.71 (d, $J_{5,4}$ = 9.8 Hz, 1 H, 5-H), 3.87 (m, 1 H, 4-H), 4.65 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H); **F:** 3.98 (m, 1 H, 4-H), 4.18 (m, 1 H, 5-H), 4.26 (m, 1 H, 6-H), 4.31 (dd, $J_{2,1}$ = 3.6, $J_{2,3}$ = 10.1 Hz, 1 H, 2-H), 4.39 (m, 1 H, 6′-H), 4.54 (m, 1 H, 3-H), 5.40 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 1-H); **G**: 3.44 (br. s, 1 H, 2-H), 3.79 (t, $J_{3,2} = J_{3,4}$ = 3.5 Hz, 1 H, 3-H), 4.18 (m, 1 H, 4-H), 4.54 (br. s, 1 H, 5-H), 5.09 (br. s, 1 H, 1-H); **H:** 1.73 (m, 1 H, 2-H), 1.82 (m, 1 H, 2′-H), 3.23 (m, 2 H, 1, 1′-H), 3.32 (m, 1 H, 4-H), 3.93 (m, 1 H, 6-H), 3.98 (m, 1 H, 3-H), 4.10 (m, 1 H, 8-H), 4.26 (m, 1 H, 7-H), 4.54 (m, 1 H, 8′-H), 4.75 (m, 1 H, 5-H); OMe: 3.40, 3.51, 3.52, 3.54, 3.56, 3.60, 3.61, 3.62 (8 × s, 3 H); CH_2 Bn: 5.10 (AB, 2 H); CH Ph: 7.41 (m, 5 H). ESI-MS: *m*/*z* = 803.8 [M − 2 H]$^{2-}$, 535.8 [M − 3 H]$^{3-}$, 402.0 [M − 4 H]$^{4-}$.

Pentasaccharide 3b: Pentamer **3d** (3.6 mg, 2.0 μmol) was dissolved in 1 mL of water and one drop of acetic acid and 10% palladium on carbon (5 mg) were added. The heterogeneous mixture was stirred under hydrogen for 5 h, after which the catalyst was filtered off and the solvents were evaporated. The pentamer was taken up in 2 mL of acetonitrile/water (1:9) and passed through a column of Toyopearl HW40S, which was eluted with acetonitrile/water (1:9). The product fractions were pooled, concentrated and passed through a column of Dowex 50 WX-4 (Na$^+$ form). The eluate was lyophilized to give target pentasaccharide **3b** (3.3 mg, 2.0 μmol, 100%). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.28 (m, 2 H, 2, 4-H), 3.50 (m, 1 H, 3-H), 3.83 (m, 1 H, 5-H), 4.05 (m, 1 H, 6-H), 4.24 (m, 1 H, 6′-H), 5.42 (d, $J_{1,2}$ = 3.7 Hz, 1-H); **E:** 3.20 (t, $J_{2,1} = J_{2,3}$ = 8.0 Hz, 1 H, 2-H), 3.48 (m, 1 H, 3-H), 3.67 (d, $J_{5,4}$ = 9.8 Hz, 1 H, 5-H), 3.84 (m, 1 H, 4-H), 4.61 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1-H); **F:** 3.92 (t, $J_{4,3} = J_{4,5}$ = 9.6 Hz, 1 H, 4-H), 4.12 (m, 1 H, 5-H), 4.24 (m, 1 H, 6-H), 4.25 (m, 1 H, 2-H), 4.36 (m, 1 H, 6′-H), 4.51 (t, $J_{3,2} = J_{3,4}$ = 9.6 Hz, 1 H, 3-H), 5.34 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 1-H); **G:** 3.39 (br. s, 1 H, 2-H), 3.80 (br. s, 1 H, 3-H), 4.12 (m, 1 H, 4-H), 4.48 (br. s, 1 H, 5-H), 5.08 (br. s, 1 H, 1-H); **H:** 1.86 (m, 1 H, 2-H), 2.06 (m, 1 H, 2′-H), 3.16 (m, 2 H, 1, 1′-H), 3.39 (m, 1 H, 4-H), 3.88 (m, 1 H, 6-H), 4.04 (m, 1 H, 8-H), 4.07 (m, 1 H, 3-H), 4.33 (m, 1 H, 7-H), 4.58 (m, 1 H, 8′-H), 4.75 (m, 1 H, 5-H); OMe: 3.48, 3.48, 3.51, 3.53, 3.57, 3.58, 3.58, 3.59 (8 × s, 3 H). ESI-MS: *m*/*z* = 738.0 [M − 2 H]$^{2-}$, 491.0 [M − 3 H]$^{3-}$.

Pentasaccharide 28: Pentamer **26** (24 mg, 24 μmol) and 2,3-bis(Z-amino)propionic acid succinimidyl ester (70 mg, 145 μmol) were dissolved in DMF (1 mL) and *N*-methylmorpholine (9.2 μL, 72 μmol) was added. The mixture was stirred for 30 min, concentrated to dryness, taken up in 2 mL of acetonitrile/water (9:1) and applied to a Toyopearl HW40S column, which was eluted with the same solvent system. The appropriate fractions were collected and lyophilized. The resulting pentamer (24 mg) was purified by preparative HPLC (elution was effected applying a gradient of 30−35% acetonitrile) to give pentasaccharide **28** as a white fluffy solid (12 mg, 50%). R_f = 0.40 (EtOAc/pyridine/acetic acid/water, 8:7:1.6:4 v/v/v/v). ^{1}H NMR (D_2O, H-HCOSY, HH-TOCSY): **D:** δ = 3.27 (t, $J_{3,2} = J_{3,4}$ = 9.7 Hz, 1 H, 4-H), 3.30 (m, 1 H, 2-H), 3.49 (m, 2 H, 3, 5-H), 3.72 (m, 2 H, 6, 6′-H), 5.46 (d, $J_{1,2}$ = 3.7 Hz, 1-H); **E:** 3.24 (m, 1 H, 2-H), 3.55 (m, 1 H, 3-H), 3.87 (t, $J_{4,3} = J_{4,5}$ = 9.1 Hz, 1 H, 4-H), 3.96 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 4.59 (d, $J_{1,2}$ = 7.8); **F:** 3.49 (m, 1 H, 2-H), 3.60 (m, 1 H, 4-H), 3.72 (m, 2 H, 3, 5-H), 3.82 (m, 2 H, 6, 6′-H), 5.14 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **G:** 3.44 (br. s, 1 H, 2-H), 3.72 (m, 1 H, 3-H), 4.19 (m, 1 H, 4-H), 4.98 (br. s, 1 H, 5-H), 5.03 (br. s, 1-H); **H:** 1.67 (m, 1 H, 2-H), 1.79 (m, 1 H, 2′-H), 3.16 (m, 1 H, 1-H), 3.28 (m, 1 H, 1′-H), 3.32 (m, 1 H, 4-H), 3.58 (m, 2 H, 6, 7-H), 3.65 (m, 1 H, 5-H), 3.72 (m, 1 H, 8-H), 3.82 (m, 1 H, 8′-H), 4.19 (m, 1 H, 3); OMe: 3.33, 3.46, 3.47, 3.53, 3.54, 3.60, 3.60, 3.62 (8 × s, 3 H), CH_2 Bn: 5.07 (m, 4 H); CH Ph: 7.42 (m, 10 H), H-α: 4.19 (m, 1 H); H-β: 3.36 (m, 1 H); H-β′: 3.49 (m, 1 H). ES-MS: *m*/*z* = 1350.7 [M + H]$^+$.

Pentasaccharide 3e: Pentamer **28** was sulfated as described for **27**. ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.30 (m, 2 H, 2, 4-H), 3.50 (m, 1 H, 3-H), 3.85 (m, 1 H, 5-H), 4.07 (m, 1 H, 6-H), 4.24 (m, 1 H, 6′-H), 5.43 (d, $J_{1,2}$ = 3.7 Hz, 1-H); **E:** 3.22 (m, 1 H, 2-H), 3.49 (m, 1 H, 3-H), 3.69 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 3.85 (m, 1 H, 4-H), 4.62 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H); **F:** 3.94 (t, $J_{4,3} = J_{4,5}$ = 9.6 Hz, 1 H, 4-H), 4.14 (m, 1 H, 5-H), 4.25 (m, 1 H, 6-H), 4.28 (dd, $J_{2,1}$ = 3.5, $J_{2,3}$ = 10.1 Hz, 1 H, 2-H), 4.38 (m, 1 H, 6′-H), 4.51 (m, 1 H, 3-H), 5.36 (d, $J_{1,2}$ = 3.3 Hz, 1 H, 1); **G:** 3.30 (m, 1 H, 2-H), 3.75 (br. s, 1 H, 3-H), 4.14 (m, 1 H, 4-H), 4.51 (m, 1 H, 5-H), 5.03 (br. s, 1 H, 1-H); **H:** 1.66 (m, 1 H, 2-H), 1.80 (m, 1 H, 2′-H), 3.16 (m, 1 H, 1-H), 3.30 (m, 1 H, 4-H), 3.34 (m, 1 H, 1′-H), 3.85 (m, 2 H, 6-H), 3.92 (m, 1 H, 3-H), 4.09 (m, 1 H, 8-H), 4.24 (m, 1 H, 7-H), 4.51 (m, 1 H, 8′-H), 4.71 (br. s, 1 H, 5-H); OMe: 3.38, 3.51, 3.52, 3.54, 3.56, 3.60, 3.61, 3.62 (8 × s, 3 H); CH_2 Bn: 5.06 (m, 4 H); CH Ph: 7.37 (m, 10 H); H-α: 4.21 (m, 1 H); H-

β: 3.38 (m, 1 H); H-β′: 3.52 (m, 1 H). ESI-MS: *m/z* = 914.4 [M − 2 H]$^{2-}$, 609.2 [M − 3 H]$^{3-}$.

Pentasaccharide 3c: Pentamer **3e** was deprotected as described for **3d**: ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.32 (m, 2 H, 2, 4-H), 3.51 (m, 1 H, 3-H), 3.83 (m, 1 H, 5-H), 4.06 (m, 1 H, 6-H), 4.25 (m, 1 H, 6′-H), 5.44 (d, $J_{1,2}$ = 3.3 Hz, 1-H); **E:** 3.22 (t, $J_{2,1} = J_{2,3}$ = 8.1 Hz, 1 H, 2-H), 3.50 (m, 1 H, 3-H), 3.69 (d, $J_{5,4}$ = 9.8 Hz, 1 H, 5-H), 3.85 (m, 1 H, 4-H), 4.63 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1); **F:** 3.95 (t, $J_{4,3} = J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.15 (m, 1 H, 5-H), 4.25 (m, 1 H, 6-H), 4.30 (m, 1 H, 2-H), 4.38 (m, 1 H, 6′-H), 4.52 (m, 1 H, 3-H), 5.37 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 1-H); **G:** 3.42 (m, 1 H, 2-H), 3.80 (m, 1 H, 3-H), 4.15 (br. s, 1 H, 4-H), 4.52 (br. s, 1 H, 5-H), 5.10 (br. s, 1 H, 1-H); **H:** 1.76 (m, 1 H, 2-H), 1.88 (m, 1 H, 2′-H), 3.34 (m, 1 H, 1-H), 3.37 (m, 2 H, 1′, 4-H), 3.90 (m, 1 H, 6-H), 4.00 (m, 1 H, 3-H), 4.06 (m, 1 H, 8-H), 4.30 (m, 1 H, 7-H), 4.56 (m, 1 H, 8′-H), 4.74 (m, 1 H, 5-H); OMe: 3.42, 3.49, 3.49, 3.52, 3.54, 3.58, 3.60, 3.60 (8 × s, 3 H); H-α: 3.53 (m, 1 H); H-β: 2.85 (m, 1 H); H-β′: 2.97 (m, 1 H). ESI-MS: *m/z* = 1560.2 [M − H]$^-$.

Disaccharide 29: The H-β anomer **29** was synthesized from **6** and **21** as described for **22** (88% yield): R_f = 0.60 (toluene/EtOAc, 1:1 v/v). ^{1}H NMR ($CDCl_3$, HH-COSY): δ = 1.65 (m, 1 H, 2_H-H), 2.07 (s, 3 H, CH_3 Ac), 2.08 (m, 1 H, $2'_H$-H), 2.09 (s, 3 H, CH_3 Ac), 2.12 (s, 3 H, CH_3 Ac), 2.88 (t, $J_{4,3} = J_{4,5}$ = 9.2 Hz, 1 H, 4_H-H), 3.10 (t, $J_{6,5} = J_{6,7}$ = 8.6 Hz, 1 H, 6_H-H), 3.24 (dt, $J_{3,2:2'}$ = 2.5, $J_{3,4}$ = 9.6 Hz, 3_H-H), 3.39 (m, 3 H, 1_H,$1'_H$,7_H-H), 3.47 (m, 1 H, 5_H-H), 3.49 (s, 3 H, OMe), 3.53 (s, 3 H, OMe), 3.56 (s, 3 H, OMe), 3.65 (dd, $J_{8,7}$ = 6.1, $J_{8,8'}$ = 11.2 Hz, 1 H, 8_H-H), 3.91 (dd, $J_{8',7}$ = 2.0, $J_{8',8}$ = 11.2 Hz, 1 H, $8'_H$-H), 4.19 (dd, $J_{6,6'}$ = 2.5, $J_{6/6',5}$ = 6.7 Hz, 2 H, 6_G,$6'_G$-H), 4.45 (dt, $J_{5,4}$ = 1.8, $J_{5,6/6'}$ = 6.5 Hz, 5_G-H), 4.84 (m, 1 H, 4_G-H), 4.84 (s, 2 H, CH_2 Bn), 4.89 (m, 1 H, 2_G-H), 4.90 (m, 1 H, 1_G-H), 7.27−7.41 (m, 5 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = 20.32 (CH_3 Ac), 30.75 (C-2_H), 47.22 (C-1_H), 57.62, 60.05, 60.38 (CH_3 OMe), 62.08, 66.81, 74.81 (CH_2 Bn, C-6_G,8_H), 63.05, 66.26, 74.15, 75.33, 77.87, 80.15, 83.64, 86.16 (C-3_H,4_H,5_H,6_H,7_H,2_G,3_G,4_G,5_G), 97.80 (C-1_G), 127.19, 127.49, 127.92 (CH_{arom}), 138.17 ($C_{q,arom}$), 168.91, 168.92, 169.52 (C=O Ac).

Disaccharide 30: Disaccharide **30** was obtained from **29** (50% yield): R_f = 0.85 (EtOAc). ^{1}H NMR ($CDCl_3$, H-HCOSY): δ = 1.51 (m, 1 H, 2_H-H), 1.97 (m, 1 H, $2'_H$-H), 2.81 (t, $J_{4,3} = J_{4,5}$ = 9.2 Hz, 1 H, 4_H-H), 3.13 (m, 2 H, 3_H,6_H-H), 3.29 (m, 3 H, 1_H, $1'_H$,7_H-H), 3.38 (m, 1 H, 2_G-H), 3.44 (s, 3 H, OMe), 3.44 (m, 1 H, 5_H-H), 3.46 (s, 3 H, OMe), 3.50 (s, 3 H, OMe), 3.52 (s, 3 H, OMe), 3.58 (m, 1 H, 3_G-H), 3.75 (dd, $J_{8,7}$ = 5.4, $J_{8,8'}$ = 11.4 Hz, 1 H, 8_H-H), 3.94 (dd, $J_{8',7}$ = 1.8, $J_{8',8}$ = 11.4 Hz, 1 H, $8'_H$-H), 4.03 (m, 1 H, 4_G-H), 4.80 (d, $J_{5,4}$ = 1.6 Hz, 1 H, 5_G-H), 4.83 (s, 2 H, CH_2 Bn), 5.09 (br. s, 1 H, 1_G-H), 5.26 (AB, 2 H, CH_2 Bn), 7.26−7.34 (m, 10 H, CH Ph) ppm. ^{13}C{^{1}H} NMR ($CDCl_3$): δ = 31.22 (C-2_H), 47.57 (C-1_H), 57.80, 58.36, 60.47, 60.86 (OMe), 66.65, 67.51, 75.30 (CH_2 Bn, C-8_H), 67.85, 68.08, 74.98, 75.67, 75.72, 78.29, 80.30, 84.02, 86.26 (C-3_H,4_H,5_H,6_H,7_H,2_G,3_G,4_G,5_G), 98.02 (C-1_G), 127.62−128.44 (CH_{arom}), 135.44, 138.44 ($C_{q,arom}$), 169.69 (C=O).

Pentasaccharide 31: Pentasaccharide **31** was obtained from **30** and **24** in 75% yield: R_f = 0.55 (dichloromethane/acetone, 9:1 v/v). ^{1}H NMR ($CDCl_3$, HH-COSY, HH-TOCSY): **D:** δ = 3.05 (t, $J_{4,3} = J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 3.11 (dd, $J_{2,1}$ = 3.8, $J_{2,3}$ = 9.7 Hz, 1 H, 2-H), 3.32 (t, $J_{3,2} = J_{3,4}$ = 9.7 Hz, 1 H, 3-H), 3.44 (m, 1 H, 5-H), 4.22 (m, 1 H, 6-H), 4.30 (m, 1 H, 6′-H), 5.53 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **E:** 2.94 (dd, $J_{2,1}$ = 7.9, $J_{2,3}$ = 9.0 Hz, 1 H, 2-H), 3.32 (t, $J_{3,2} = J_{3,4}$ = 9.0 Hz, 1 H, 3-H), 3.85 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 3.92 (dd, $J_{4,3}$ = 9.0, $J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.13 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H); **F:** 3.44 (dd, $J_{2,1}$ = 3.7 Hz $J_{2,3}$ = 9.7 Hz, 1 H, 2-H), 3.58 (t, $J_{4,3} = J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.08 (m, 1 H, 5-H), 4.22 (m, 1 H, 6-H), 4.53 (m, 1 H, 6′-H), 5.12 (1 H, $J_{1,2}$ = 3.7 Hz, 1 H, 1-H), 5.39 (t, $J_{3,2} = J_{3,4}$ = 9.7 Hz, 1 H, 3-H); **G:** 3.11 (dd, $J_{2,1}$ = 5.7, $J_{2,3}$ = 6.9 Hz, 1 H, 2-H), 3.68 (t, $J_{3,2} = J_{3,4}$ = 6.9 Hz, 1 H, 3-H), 3.96 (dd, $J_{4,3}$ = 6.9, $J_{4,5}$ = 5.2 Hz, 1 H, 4-H), 4.64 (d, $J_{5,4}$ = 5.2 Hz, 1 H, 5-H), 5.10 (d, $J_{1,2}$ = 5.7 Hz, 1 H, 1-H); **H:** 1.60 (m, 1 H, 2-H), 2.00 (m, 1 H, 2′-H), 2.85 (t, $J_{4,3} = J_{4,5}$ = 9.2 Hz, 1 H, 4-H), 3.10 (t, $J_{6,5} = J_{6,7}$ = 9.2 Hz, 1 H, 6-H), 3.17 (dt, $J_{3,4}$ = 9.2 Hz $J_{3,2/2'}$ = 2.4 Hz, 1 H, 3-H), 3.26 (ddd, $J_{7,6}$ = 10.0, $J_{7,8}$ = 2.0, $J_{7,8'}$ = 5.7 Hz, 1 H, 7-H), 3.36 (m, 3 H, 1, 1′, 4-H), 3.44 (t, $J_{5,4} = J_{5,6}$ = 9.2 Hz, 1 H, 5-H), 3.57 (m, 1 H, 8-H), 3.96 (m, 1 H, 8′-H); OMe: 3.36, 3.42, 3.48, 3.49, 3.50, 3.52, 3.54, 3.55 (9 × s, 3 H); Ac: 1.91, 2.08, 2.11 (3 × s, 3 H); CH_2 Bn: 4.61, 4.83, 5.12, 5.29 (5 × AB, 2 H); CH Ph: 7.40 (m, 20 H); ES-MS: *m/z* = 1546.0 [M + Na]$^+$.

Pentasaccharide 32: Pentamer **32** was obtained from **31** in 80% yield. R_f = 0.20 (EtOAc/pyridine/acetic acid/water, 8:7:1.6:4 v/v/v/v). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.26 (m, 2 H, 2, 4-H), 3.52 (m, 1 H, 3-H), 3.64 (m, 1 H, 5-H), 3.71 (m, 2 H, 6, 6′-H), 5.44 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **E:** 3.21(m, 1 H, 2-H), 3.52 (m, 1 H, 3-H), 3.81 (m, 2 H, 4, 5-H), 4.55 (d, $J_{1,2}$ = 8.1 Hz, 1-H); **F:** 3.50 (m, 1 H, 2-H), 3.57 (m, 1 H, 4-H), 3.72 (m, 1 H, 3-H), 3.81 (m, 3 H, 5, 6, 6′-H), 5.12 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **G:** 3.45 (m, 1 H, 2-H), 3.71 (m, 1 H, 3-H), 4.14 (br. s, 1 H, 4-H), 4.54 (br. s, 1 H, 5-H), 5.00 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **H:** 1.77 (m, 1 H, 2-H), 2.11 (m, 1 H, 2′-H), 2.94 (t, $J_{4,3} = J_{4,5}$ = 9.4 Hz, 1 H, 4-H), 3.11 (m, 2 H, 1, 1′-H), 3.26 (m, 1 H, 6-H), 3.36 (m, 2 H, 3, 7-H), 3.53 (m, 1 H, 5-H), 3.90 (m, 2 H, 8,8′-H); OMe: 3.45, 3.50, 3.51, 3.53, 3.53, 3.55, 3.59, 3.60, 3.61 (9 × s, 3 H); ES-MS: *m/z* = 1011.0 [M + H]$^+$.

Pentasaccharide 33: Pentasaccharide **33** was prepared as described for **27** and purified by HPLC analysis (elution was effected applying a gradient of 25−30% acetonitrile). R_f = 0.40 (EtOAc/pyridine/acetic acid/water, 8:7:1.6:4 v/v/v/v). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.27 (m, 1 H, 4-H), 3.31 (dd, $J_{2,1}$ = 3.8, $J_{2,3}$ = 10.0 Hz, 1 H, 2-H), 3.46 (m, 2 H, 3, 5-H), 3.71 (m, 2 H, 6, 6′-H), 5.47 (d, $J_{1,2}$ = 3.8 Hz, 1-H); **E:** 3.25 (m, 1 H, 2-H), 3.56 (m, 1 H, 3-H), 3.88 (m, 1 H, 4-H), 4.06 (d, $J_{5,4}$ = 9.2 Hz, 1 H, 5-H), 4.61 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1-H); **F:** 3.48 (m, 1 H, 2-H), 3.58 (m, 1 H, 4-H), 3.67 (m, 1 H, 5-H), 3.73 (m, 1 H, 3-H), 3.79 (m, 2 H, 6, 6′-H), 5.13 (1 H, $J_{1,2}$ = 3.8 Hz, 1 H, 1); **G:** 3.46 (m, 1 H, 2-H), 3.73 (m, 1 H, 3-H), 4.14 (br. s, 1 H, 4-H), 4.81 (br. s, 1 H, 5-H), 5.05 (br. s, 1 H, 1-H); **H:** 1.53 (m, 1 H, 2-H), 1.92 (m, 1 H, 2′-H), 2.91 (t, $J_{4,3} = J_{4,5}$ = 9.3 Hz, 1 H, 4-H), 3.20 (m, 4 H, 1, 1′, 3, 6-H), 3.27 (m, 1 H, 7-H), 3.53 (m, 1 H, 5-H), 3.73 (m, 2 H, 8,8′-H); OMe: 3.42, 3.46, 3.48, 3.52, 3.52, 3.53, 3.58, 3.59, 3.61 (9 × s, 3 H); CH_2 Bn: 5.08 (AB, 2 H); CH Ph: 7.40 (m, 5 H); ES-MS: *m/z* = 1144.8 [M + H]$^+$.

Pentasaccharide 4d: Pentamer **33** was sulfated as described for **3d**, followed by treatment with 0.2 N HCl at 4 °C for 16 h, after which the mixture was concentrated to a small volume and passed through a Toyopearl HW40S column, eluted with acetonitrile/water (1:9). The product fractions were pooled, concentrated and passed through a column of Dowex 50 WX-4 (Na^+ form). The eluate was lyophilized to give target pentasaccharide **4d**: ^{1}H NMR (D_2O_3, HH-COSY, HH-TOCSY): **D:** δ = 3.29 (m, 2 H, 2, 4-H), 3.51 (m, 1 H, 3-H), 3.85 (m, 1 H, 5-H), 4.09 (m, 1 H, 6-H), 4.25 (m, 1 H, 6′-H), 5.45 (d, $J_{1,2}$ = 3.7 Hz, 1-H); **E:** 3.24 (m, 1 H, 2-H), 3.50 (m, 1 H, 3-H), 3.70 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 3.87 (t, $J_{4,3} = J_{4,5}$ = 9.5 Hz, 1 H, 4-H), 4.65 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H); **F:** 3.95 (t, $J_{4,3} = J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.14 (m, 1 H, 5-H), 4.26 (m, 1 H, 6-H), 4.29 (m, 1 H, 2-H), 4.39 (m, 1 H, 6′-H), 4.55 (t, $J_{3,2} = J_{3,4}$ = 9.7 Hz, 1 H, 3-H), 5.35 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 1-H); **G:** 3.36 (br. s, 1 H, 2-H), 3.81 (br. s, 1 H, 3-H), 4.11 (m, 1 H, 4-H), 4.42 (br. s, 1

H, 5-H), 4.95 (br. s, 1 H, 1-H); **H:** 1.57 (m, 1 H, 2-H), 1.69 (m, 1 H, 2′-H), 3.24 (m, 1 H, 3-H), 3.25 (m, 2 H, 1, 1′-H), 3.09 (t, $J_{4,3}$ = $J_{4,5}$ = 9.0 Hz, 1 H, 4-H), 3.32 (m, 2 H, 6-H), 3.35 (m, 1 H, 7-H), 3.69 (m, 1 H, 8-H), 3.95 (m, 1 H, 8′-H), 4.31 (t, $J_{5,4}$ = $J_{5,6}$ = 9.0 Hz, 1 H, 5-H); OMe: 3.47, 3.47, 3.48, 3.51, 3.53, 3.55, 3.59, 3.60, 3.61 (9 × s, 3 H); CH_2 Bn: 5.10 (AB, 2 H); CH Ph: 7.40 (m, 5 H). ESI-MS: *m*/*z* = 770.8 [M − 2 H]$^{2-}$, 513.6 [M − 3 H]$^{3-}$.

Pentasaccharide 4b: Pentamer **4d** was deprotected as described for **3b**. ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.31 (m, 2 H, 2, 4-H), 3.50 (m, 1 H, 3-H), 3.82 (m, 1 H, 5-H), 4.11 (m, 1 H, 6-H), 4.25 (m, 1 H, 6′-H), 5.44 (d, $J_{1,2}$ = 3.6 Hz, 1-H) ppm; **E:** 3.23 (t, $J_{2,1}$ = $J_{2,3}$ = 8.0 Hz, 1 H, 2-H), 3.50 (m, 1 H, 3-H), 3.71 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 3.85 (m, 1 H, 4-H), 4.63 (d, $J_{1,2}$ = 8.0 Hz, 1 H, 1-H) ppm; **F:** 3.95 (t, $J_{4,3}$ = $J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.09 (m, 1 H, 5-H), 4.25 (m, 1 H, 6-H), 4.29 (m, 1 H, 2-H), 4.36 (m, 1 H, 6′-H), 4.53 (t, $J_{3,2}$ = $J_{3,4}$ = 9.7 Hz, 1 H, 3-H), 5.36 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 1-H) ppm; **G:** 3.39 (br. s, 1 H, 2-H), 3.81 (br. s, 1 H, 3-H), 4.13 (br. s, 1 H, 4-H), 4.50 (br. s, 1 H, 5-H), 4.97 (br. s, 1 H, 1-H) ppm; **H:** 1.79 (m, 1 H, 2-H), 2.13 (m, 1 H, 2′-H), 3.12 (m, 1 H, 4-H), 3.13 (m, 2 H, 1, 1′-H), 3.32 (m, 1 H 3-H), 3.39 (m, 2 H, 6, 7-H), 3.91 (m, 2 H, 8,8′-H) 4.32 (t, $J_{5,4}$ = $J_{5,6}$ = 8.9 Hz, 1 H, 5-H); OMe: 3.50, 3.50, 3.53, 3.53, 3.53, 3.55, 3.59, 3.60, 3.61 (9 × s, 3 H) ppm. ESI-MS: *m*/*z* = 703.8 [M − 2 H]$^{2-}$, 469.0 [M − 3 H]$^{3-}$.

Pentasaccharide 35: Pentamer **35** was prepared as described for **28** and purified by HPLC (elution was effected applying a gradient of 25−45% acetonitrile). R_f = 0.45 (EtOAc/pyridine/acetic acid/water, 8:7:1.6:4 v/v/v/v). ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.27 (m, 1 H, 4-H), 3.30 (dd, $J_{2,1}$ = 3.7, $J_{2,3}$ = 9.4 Hz, 1 H, 2-H), 3.46 (m, 2 H, 3, 5-H), 3.71 (m, 2 H, 6,6′-H), 5.46 (d, $J_{1,2}$ = 3.7 Hz, 1-H) ppm; **E:** 3.17 (m, 1 H, 2-H), 3.46 (m, 1 H, 3-H), 3.85 (m, 1 H, 4-H), 3.99 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 4.81 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1-H) ppm; **F:** 3.46 (m, 1 H, 2-H), 3.58 (m, 1 H, 4-H), 3.67 (m, 1 H, 5-H), 3.73 (m, 1 H, 3-H), 3.79 (m, 2 H, 6, 6′-H), 5.11 (1 H, $J_{1,2}$ = 3.4 Hz, 1 H, 1-H) ppm; **G:** 3.45 (m, 1 H, 2-H), 3.71 (m, 1 H, 3-H), 4.14 (br. s, 1 H, 4-H), 4.78 (br. s, 1 H, 5-H), 4.98 (br. s, 1 H, 1-H) ppm; **H:** 1.45 (m, 1 H, 2-H), 1.91 (m, 1 H, 2′-H), 2.83 (t, $J_{4,3}$ = $J_{4,5}$ = 9.3 Hz, 1 H, 4-H), 3.17 (m, 4 H, 1,1′,3,6-H), 3.27 (m, 1 H, 7-H), 3.55 (m, 1 H, 5-H), 3.59 (m, 1 H, 8-H), 3.71 (m, 1 H, 8′-H) ppm; OMe: 3.40, 3.45, 3.46, 3.50, 3.51, 3.52, 3.55, 3.58, 3.59 (9 × s, 3 H); CH_2 Bn: 5.08 (m, 4 H) ppm; CH Ph: 7.48 (m, 10 H); H-α: 4.21 (m, 1 H); H-β: 3.41 (m, 1 H) ppm; H-β′: 3.51 (m, 1 H) ppm. ES-MS: *m*/*z* = 1431 [M + 3 Na − 2 H]$^+$, 727 [M + 4 Na − 2 H]$^{2+}$.

Pentasaccharide 4e: Pentamer **35** was sulfated as described for **3d**. ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.30 (m, 2 H, 2, 4-H), 3.51 (m, 1 H, 3-H), 3.87 (m, 1 H, 5-H), 4.10 (m, 1 H, 6-H), 4.27 (m, 1 H, 6′-H), 5.45 (d, $J_{1,2}$ = 3.7 Hz, 1-H) ppm; **E:** 3.24 (m, 1 H, 2-H), 3.51 (m, 1 H, 3-H), 3.71 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 3.87 (t, $J_{4,3}$ = $J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.65 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1-H) ppm; **F:** 3.96 (t, $J_{4,3}$ = $J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.12 (m, 1 H, 5-H), 4.27 (m, 1 H, 6-H), 4.28 (m, 1 H, 2-H), 4.39 (m, 1 H, 6′-H), 4.56 (t, $J_{3,2}$ = $J_{3,4}$ = 9.7 Hz, 1 H, 3-H), 5.35 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1-H) ppm; **G:** 3.34 (br. s, 1 H, 2-H), 3.81 (br. s, 1 H, 3-H), 4.12 (br. s, 1 H, 4-H), 4.42 (br. s, 1 H, 5-H), 4.92 (br. s, 1 H, 1-H) ppm; **H:** 1.55 (m, 1 H, 2-H), 1.94 (m, 1 H, 2′-H), 3.02 (t, $J_{4,3}$ = $J_{4,5}$ = 9.0 Hz, 1 H, 5-H), 3.24 (m, 3 H, 1,1′,3-H), 3.30 (m, 2 H, 6-H), 3.34 (m, 1 H, 7-H), 3.67 (m, 1 H, 8-H), 3.93 (m, 1 H, 8′-H), 4.31 (t, $J_{5,4}$ = $J_{5,6}$ = 9.0 Hz, 1 H, 5-H) ppm; OMe: 3.47, 3.48, 3.51, 3.53, 3.56, 3.59, 3.61, 3.61, 3.61 (9 × s, 3 H) ppm; CH_2 Bn: 5.09 (m, 4 H) ppm; CH Ph: 7.41 (m, 10 H) ppm, H-α: 4.20 (dd, $J_{\alpha,\beta}$ = 5.5, $J_{\alpha,\beta'}$ = 7.1 Hz, 1 H) ppm; H-β: 3.45 (m, 1 H) ppm; H-β′: 3.50 (m, 1 H) ppm. ESI-MS: *m*/*z* = 880.8 [M − 2 H]$^{2-}$, 587.0 [M − 3 H]$^{3-}$.

Pentasaccharide 4c: Pentamer **4e** was deprotected as described for **3b**: ^{1}H NMR (D_2O, HH-COSY, HH-TOCSY): **D:** δ = 3.36 (m, 2 H, 2, 4-H), 3.54 (m, 1 H, 3-H), 3.88 (m, 1 H, 5-H), 4.16 (m, 1 H, 6-H), 4.30 (m, 1 H, 6′-H), 5.49 (d, $J_{1,2}$ = 3.5 Hz, 1-H) ppm; **E:** 3.28 (t, $J_{2,1}$ = $J_{2,3}$ = 8.7 Hz, 1 H, 2-H), 3.54 (m, 1 H, 3-H), 3.71 (d, $J_{5,4}$ = 9.7 Hz, 1 H, 5-H), 3.90 (m, 1 H, 4-H), 4.67 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1-H) ppm; **F:** 3.99 (t, $J_{4,3}$ = $J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 4.16 (m, 1 H, 5-H), 4.30 (m, 2 H, 2,6-H), 4.41 (m, 1 H, 6′-H), 4.56 (t, $J_{3,2}$ = $J_{3,4}$ = 9.7 Hz, 1 H, 3-H), 5.41 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1-H) ppm; **G:** 3.49 (br. s, 1 H, 2-H), 3.85 (m, 1 H, 3-H), 4.16 (br. s, 1 H, 4-H), 4.51 (br. s, 1 H, 5-H), 5.05 (br. s, 1 H, 1-H) ppm; **H:** 1.69 (m, 1 H, 2-H), 2.09 (m, 1 H, 2′-H), 3.16 (t, $J_{4,3}$ = $J_{4,5}$ = 9.0 Hz, 1 H, 4-H), 3.37 (m, 4 H, 1, 1′,3,6-H), 3.51 (m, 1 H, 7-H), 3.85 (m, 1 H, 8-H), 3.98 (m, 1 H, 8′-H), 4.37 (t, $J_{5,4}$ = $J_{5,6}$ = 9.0 Hz, 1 H, 5-H); OMe: 3.54, 3.54, 3.56, 3.57, 3.57, 3.59, 3.63, 3.65, 3.65 (9 × s, 3 H) ppm; H-α: 3.63 (m, 1 H) ppm; H-β: 3.02 (dd, $J_{\beta,\alpha/\beta'}$ = 7.1, $J_{\beta,\beta'/\alpha}$ = 13.1 Hz, 1 H) ppm; H-β′: 3.19 (m, 1 H) ppm. ESI-MS: *m*/*z* = 747.0 [M −2 H]$^{2-}$, 497.2 [M − 3 H]$^{3-}$.

Acknowledgments

This work was financially supported by the Council for Chemical Sciences of the Netherlands Organization for Scientific Research (CW-NWO), the Netherlands Technology Foundation (STW) and N. V. Organon. We are grateful to F. Lefeber and K. Erkelens (Leiden University) for recording NMR spectra, H. van den Elst (Leiden University) and W. Verweij (N. V. Organon) for recording mass spectra and T. G. van Dinther and J. G. H. W. Bovee−van de Pasch (N. V. Organon) for measuring anti-Xa activity.

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Received June 20, 2002
[O02340]