Synthesis of Spacer-Armed Glucodendrimers Based on the Modification of Poly(propylene Imine) Dendrimers[+]

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The use of preformed poly(propylene imine) dendrimers [DAB(Pa)$_x$] with reactive primary amine end groups proved to be very useful for the construction of saccharide surface-coated dendrimers. For this purpose, amide bonds were introduced by a reaction between the primary amine end groups of the dendrimers with *N*-succinimidyl-activated esters of spacer-armed acetyl-protected thioglucopyranoside units. The linear alkyl chain spacers between the dendrimer surface and the saccharide units was increased in length with 1, 5 and 10 carbon atoms. These spacer arms were introduced to determine the influence of local saccharide surface concentration variations on the dendrimer properties. After modification of the dendrimers with these saccharide units, the acetyl protecting groups were removed. Purification of these derivatives was accomplished by using dialysis either in water or in aqueous methanol. The solubility behavior of the resulting glucodendrimers proved to be strongly dependent on the hydrophobic part, i.e. the alkyl chain spacers in the molecule. Therefore, these nanosized multivalent structures, appropriate for studying carbohydrate-protein interactions, are also proposed useful for investigating amphiphilic properties.

Introduction

Dendrimers[1] are known for their well-defined, highly branched architectures that are built in a stepwise manner. When functionalized nanosized globular structures are desired, mostly divergently synthesized dendrimers such as the PAMAM[2], arborols[3] and the poly(propylene imine) dendrimers[4] are employed, because of their availability on a reasonably large scale, even for higher generations of dendrimers. Modification of the end groups of these dendrimers has received enormous attention and has led to the disclosure of the dendritic box[5], the unimolecular (inverted) micelle[6] and metallodendrimers,[7] leading to applications foreseen[8] in areas like (chiral) clathration,[9] catalysis[10] and biology. Many of the unique dendritic properties, like guest-host interactions and dense surface packing, only arise at higher generations of dendrimers, indicating that cooperative effects are present in these nanosized structures.[9][11][12] These cooperative recognition effects are even more prominent in biological situations, especially when clustering effects within a molecule are important.[13] Therefore, dendrimers could be good candidates for biological investigations where these cooperative effects might be operating.

Since the first patents lodged by Denkewalter,[14] many macromolecular components have been reported based on dendrimers incorporating biologically active entities such as antibodies,[15] amino acids,[11][16] oligonucleotides[17] and mono- and oligosaccharide residues.[18] In recent years, several groups have described[19][20][21][22][23] their particular approaches to the construction of carbohydrate-containing dendrimers or − as they have become known − glycodendrimers.[24] This new family of neoglycoconjugates has proved to be extremely useful when studying multiple carbohydrate−protein interactions. The enhancement in binding of saccharide residues to protein receptors as a result of increasing the saccharide "valency" is a well-known phenomenon in glycobiology[25] which is often referred to as the cluster glycoside or multivalency effect. It has already been shown that some carbohydrate-containing dendrimers possess much higher activities in binding towards lectins than their corresponding individual saccharide residues. Some researchers claim to have evidence that this effect is

[+] A list of abbreviations used in this paper is given in ref.[33].

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only displayed in the case of relatively small dendritic saccharides − and that no significant increase in biological activity has been observed in the case of large glycodendrimers.[26] One can speculate that fully substituted high generation dendrimers are too crowded to provide efficient multivalent binding of their carbohydrate residues. Analogous results have been obtained by Seebach et al.[27] when studying the enzymatic hydrolysis of a series of dendrimers incorporating ester bonds susceptible to the action of enzymes: enzyme-catalyzed hydrolysis was only possible in the case of the lower generation dendrimers.

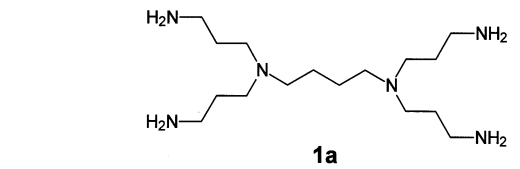
With these results foremost in our minds, we now report on the synthesis of large dendritic structures with variations of the local saccharide "concentrations" on the dendrimer surface. Control of "concentrations" was achieved by the introduction of a linear alkyl chain spacer between the dendrimer surface and the saccharide units. By increasing the linear alkyl chain spacer length with 1, 5 and 10 carbon atoms we were also able to study the relationship between structure and water solubility. Based on the unimolecular micelle concept,[6c] it should also be possible to investigate the hydrophilic and hydrophobic interactions within these types of structures since we are increasing the hydrophobic contribution in the molecule on going to longer alkyl chain spacer lengths.

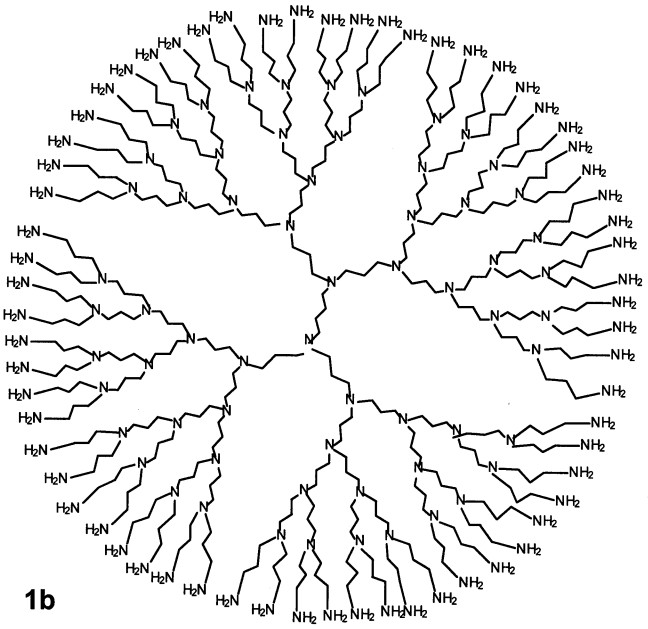
Results and Discussion

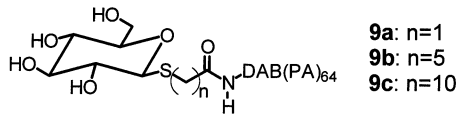
Synthetic Strategy

As the basis for our modification, we used the divergently synthesized poly(propylene imine) dendrimers[4], which are generally known for their ease of undergoing modifications at the peripheral primary amine groups. Here, we only studied the modification of the dendrimer of the first generation (**1a**) with 4 primary amine end groups and of the fifth generation (**1b**) with 64 end groups (Figure 1). Although the end groups are reactive toward many reagents, we chose a mild coupling method well-known from peptide chemistry, namely, the reaction with the *N*-succinimidyl-activated ester species. This method leads smoothly to the formation of an amide bond by a very mild coupling procedure. Previously, we have used this coupling method successfully for the construction of the unimolecular micelles,[6c] the dendritic box[5][11] and derivatized saccharide dendrimers[21]. In our present synthetic strategy, we have to use acetyl protective groups on the saccharide unit to circumvent side reactions from taking place during subsequent chemical modifications. These acetyl protecting groups can be easily removed after attachment of the monosaccharide units to the dendrimers, using standard deprotection techniques, leading to compounds **9a−9c** (Figure 1).

Figure 1. Structural formulas of the first (**1a**) and fifth generation (**1b**) poly(propylene imine) dendrimers and glucodendrimers **9a−9c** obtained according to Scheme 2







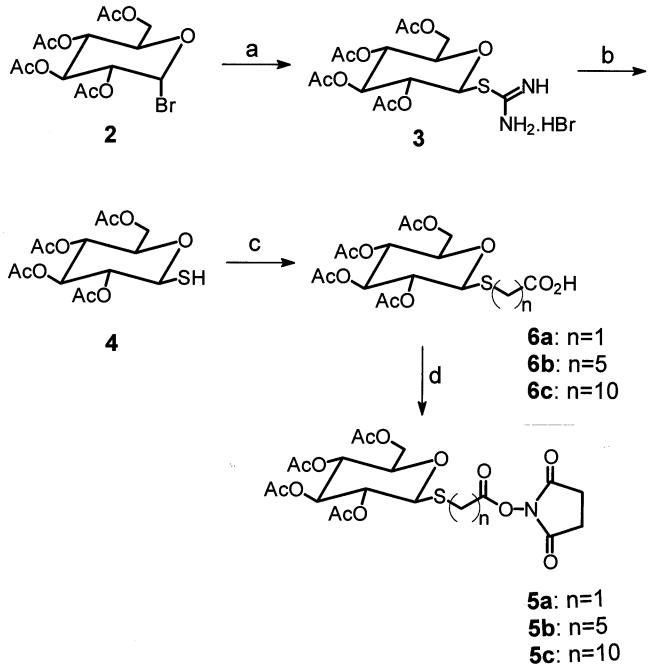
Saccharide Residues

D-(+)-Glucose was used as the source of the saccharide precursors (Scheme 1 and Table 1). Starting from 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide (**2**), the thiouronium salt **3** was prepared by a reaction of this bromide with thiourea in acetone, following a literature procedure[28]. The salt was converted into the thiol by reaction of **3** with sodium hydrogen sulphite in water, which furnished **4** in a quantitative yield.[28] Compound **4** was a key intermediate in the synthesis of all spacer-armed thioether-linked saccharide residues.[29] They could be prepared by reaction of **4** with bromoacetic acid to give **5a**, 6-bromohexanoic acid to give **5b** and 11-bromoundecanoic acid to give **5c** using K_2CO_3 as a base.[30] Purification of these compounds was accomplished by using column chromatography, **5a**, **5b** and **5c** were obtained in yields of 85, 76 and 62%, respectively. The *N*-succinimidyl-activated esters **6a**, **6b** and **6c** were obtained by a reaction of **5a**, **5b** and **5c** with *N*-hydroxysuccinimide under the influence of DCC using dimethoxyethane as a solvent[31] in yields of 91, 87 and 84%, respectively.

Modification of the Poly(propylene imine) Dendrimers with Saccharide Residues

The desired acetylated glucodendrimers were obtained by coupling of the *N*-succinimidyl esters **6a−6c** to the poly-

Scheme 1. Syntheses of glucose derivatives **6a−6c** for attachment to the poly(propylene imine) dendrimers



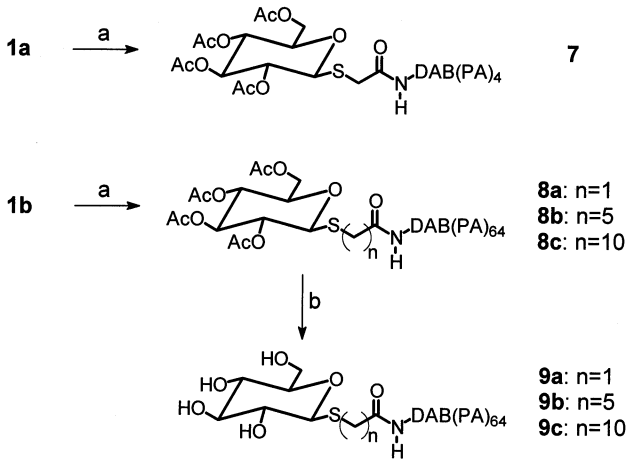
Reagents and conditions: a) $SC(NH_2)_2$, Me_2CO, reflux, 30 min, 74% (**3**). − b) $NaHSO_3$, H_2O, 2h, 100% (**4**). − c) $Br(CH_2)_nCO_2H$, K_2CO_3, Me_2CO/H_2O, 3h, 85% (**5a**), 76% (**5b**), 62% (**5c**). − d) *N*-hydroxysuccinimide/DCC/$MeO(CH_2)_2OMe$, 0−5°C, 20 h, 91% (**6a**), 86% (**6b**), 84% (**6c**).

Table 1. Yields, optical rotations and mass data for the dendrimer precusors

Compound	Yield [%]	$[\alpha]_D^{20}$ (CH_2Cl_2)	Calcd. molecular mass	MALDI-TOF-MS
4	100	+3.6	364.4	365 $[M + H]^+$ 387 $[M + Na]^+$
5a	85	−48	422.4	445 $[M + Na]^+$ 467 $[M + 2\ Na]^+$
5b	76	−33	478.5	501 $[M + Na]^+$
5c	62	−29	548.7	571 $[M + Na]^+$ 593 $[M + 2\ Na]^+$
6a	91	−59	519.5	541 $[M + Na]^+$ 557 $[M + 2\ Na]^+$
6b	87	−24	575.6	597 $[M + Na]^+$
6c	84	−20	645.7	668 [M + NM+Na]$^+$ 685 $[M + K]^+$

(propylene imine) dendrimers (**1a** and **1b**) using CH_2Cl_2 as the solvent (Scheme 2). Work-ups were accomplished by extraction of the diluted reaction mixtures with saturated aqueous Na_2CO_3 solutions. The glucodendrimer **7** was constructed as a model compound from the first generation dendrimer (**1a**) modified with **6a**, and **7** was fully characterized by ^{1}H-, ^{13}C-NMR and IR spectroscopy and MALDI-TOF-MS. As in the case of **7**, the other glucodendrimers **8a−8c** were synthesized (Scheme 2) starting from the fifth generation dendrimer with 64 primary amine end groups (**1b**) by allowing it to react with the activated esters **6a−6c**, using the same reaction conditions and work-up procedures. Removal of the acetyl protecting groups was accomplished by subjecting them to standard Zemplén deacetylation[32] leading to **9a−9c**, which could be purified using dialysis either in water (for **9a** and **9b**) or aqueous methanol (for **9c**).

Scheme 2. Coupling of saccharide units with the primary amine groups in the dendrimers



Reagents and conditions: a) $DAB(PA)_x$, CH_2Cl_2, 25°C, 18 h, 86% (**7**), 95% (**8a**), 95% (**8b**), 93% (**8c**). − b) 1. MeONa/MeOH/CH_2Cl_2, 25°C, 10−15 min, 2. NaOH/H_2O/MeOH, 25°C, 16 h, dialysis, 85% (**9a**), 76% (**9b**), 58% (**9c**).

Structure Determinations of the Glucodendrimer Series

Successful coupling between the activated esters **6a−6c** and dendrimers **1a** and **1b** was established by NMR and IR spectroscopy. Compound **7** was characterized fully using ^{1}H- and ^{13}C-NMR spectroscopy, as well as IR spectroscopy and MALDI-TOF-MS. In the ^{1}H-NMR spectrum signals for the CH_2 part of the dendrimer resonate at δ = 1.45, 1.69, 2.47, 2.51 and 3.28, whereas the newly formed amide bond NH proton gives a triplet in the spectrum at δ = 7.34. Also the absorptions of the saccharide part, as well as of the acetyl protecting groups, appear as a set of well-resolved signals in the regions at δ = 3.27−5.24 and δ = 2.01−2.09, respectively. The ^{13}C-NMR spectrum of **7** shows characteristic signals for the dendrimer part at δ = 24.0, 26.2, 38.0, 51.0 and 53.2. The absorptions of the methyl carbon atoms of the acetyl protecting groups are found in the region δ = 20.5−20.7, whereas the saccharide part shows 6 signals at δ = 62−83. The carbonyl absorptions of the newly formed amide bond, as well as the acetyl protecting groups, overlap in the region of δ = 169−171. In the IR spectrum, the newly formed amide bond has an (−NH) absorption band at a wave number of 3388 cm^{-1}. Characterization of this compound by MALDI-TOF-MS showed nicely peaks at *m/z* 1937 and 1959, corresponding to the $[M + H]^+$ and $[M + Na]^+$ species, respectively. The assignments of the resonances for the saccharide part in the NMR spectra were based the unambiguous peak assignments deduced from COSY and XHCORRD measurements carried out on compound **5a**. No large shifts in the ^{1}H- and ^{13}C-NMR spectra for the succinimide esters **6a−6c** and the dendrimers **7** and

8a−8c were observed, making good characterization and peak assignments of these derivatives possisible.

Dendrimers **8a−8c** were characterized solely by ^{13}C-NMR and IR spectroscopy, since in the ^{1}H-NMR spectra the absorptions were considerably broadened with signals overlapping, even when the spectra were recorded at elevated temperatures.[21] The saccharide part is found as six separate nicely resolved signals in the region δ = 62−83. Signals for the spacer part of the molecule resonate at δ = 25−36. The newly formed amide bond is found in the area δ = 168.9−170.7, at approximately the same values as the absorptions for the acetyl protecting groups. Typical absorptions for the dendrimer part of the molecules in the ^{13}C-NMR spectrum are found at δ = 24 and 53 approximately, with an absorption at δ = 37 (CH_2NHCO). ^{13}C-NMR spectroscopy also provide information on the completeness of the reaction, since unreacted CH_2NH_2 functions give rise to signals at δ = 40. In the cases of dendrimers **8a−8c**, no signal could be detected in this region, indicating that the reaction was at least near completion.

Deprotections of the acetyl groups were performed using standard Zemplén procedures[32], furnishing dendrimers **9a−9c** in yields of 85, 76 and 58%, respectively. Characterization was accomplished by ^{13}C-NMR and IR spectroscopy. Nicely resolved spectra are obtained (Figure 2) for **9a** and **9b** using D_2O as solvent, where, for **9c**, difficulties in solubility were encountered as this compound did not dissolve in D_2O or CD_3OD. The best solubility has been obtained so far with mixtures of D_2O and CD_3OD at elevated temperatures (60°C). Even at these temperatures, the sample is still turbid and does not dissolve completely. The ^{13}C-NMR spectrum of **9c** shows some well-resolved absorptions for the saccharide part in the range δ = 63−87. The absorptions arising from the spacer part, as well as from the dendrimer part, are considerably broadened compared to those in other glucodendrimers, especially for the carbonyl group, which is found as a very broad signal at δ = 177 in the ^{13}C-NMR spectrum. Generally for the deprotected compounds **9a−9c**, the signals of the dendrimer part can be found at δ ≈ 25, 39 and 53, whereas those of the spacer at δ = 27−38. The signals of the saccharide part may be found as a set of well-resolved signals at δ = 63−87 with the amide carbonyl absorption to be found in the region of δ = 175−180. Removal of the protective groups can be monitored by the absence of absorptions at δ = 20−21 and 169−171.

Table 2. Yields and chiroptical data of the spacer armed glucose dendrimers

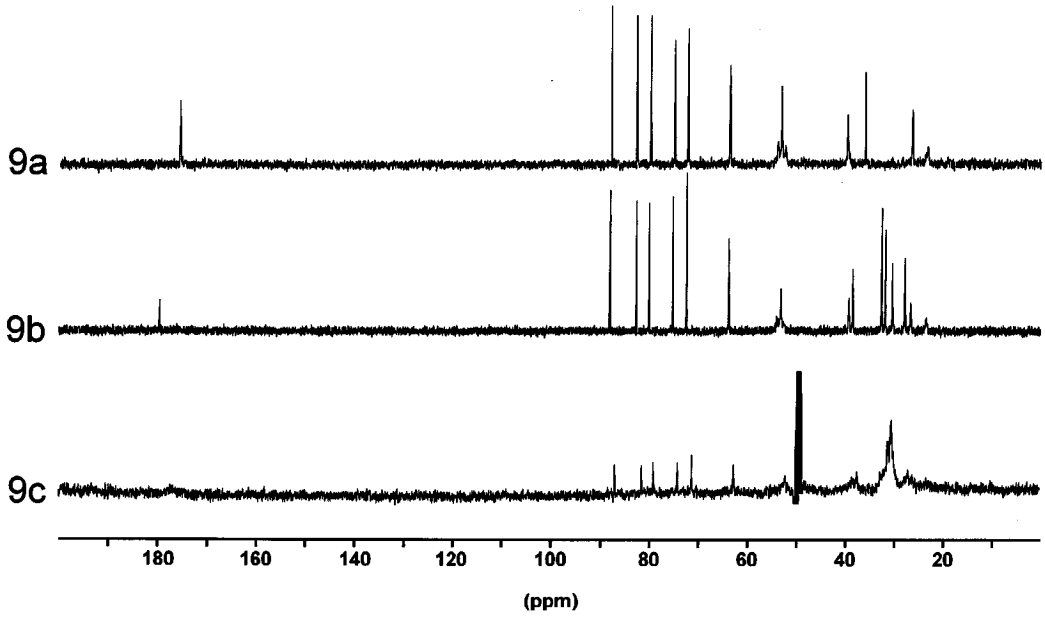
Compound	Yield [%]	$[\alpha]_D^{20}$	Calcd. molecular mass	$[\Phi]_D/n$
7	86	−34	1,934.10	−164
8a	95	−37	33,048.89	−191
8b	95	−28	36,639.93	−160
8c	93	−17	41,128.25	−109
9a	85	−31	22,287.50	−108
9b	76	−29	25,878.36	−117

The chiroptical features of these compounds (Table 2) were also studied by polarimetry. However, for a good comparison it is better to compare the molar rotations per saccharide unit ($[\Phi]_D/n$) for these compounds. The optical rotation of **9c** could not be determined on account of the insolubility and turbidity of the solution. From the molar rotation per end group, ranging between −108 to −191, no clear trend can be observed within these series.

Conclusion

In conclusion, we have described a synthetic approach toward globular nanosized structures with low surface densities of biologically active saccharide residues, thus making

Figure 2. ^{13}C-NMR spectra of glucosedendrimers **9a−9c** recorded at 100.6 MHz in D_2O or D_2O/CD_3OD (for **9c** at 60°C)



interactions with specific carbohydrate binding sites in proteins possible. Moreover, these compounds should be very useful in probing hydrophilic and hydrophobic interactions since the hydrophobic part of the molecule increases on going to the longer alkyl chain spacers. This feature was exemplified by the solubility behavior of the dendrimer with the C-10 spacer arm, which proved only to be barely soluble in both water and methanol. In order to realize water-soluble saccharide-coated dendritic surfaces, having low local concentrations of biologically active surface end groups, we intend to focus our attention on making dendrimers with long alkyl chain spacers bearing oligosaccharides as end groups. We expect the introduction of oligosaccharides to influence the balance between hydrophobicity and hydrophilicity in a positive sense, thus making water-soluble systems possible again.

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Experimental Section

General Techniques: Compound **2** was obtained from Aldrich and **3** was prepared following a literature procedure.[28] The poly(propylene imine) dendrimers **1a−1b** were supplied by DSM Research (The Netherlands). − Thin layer chromatography (TLC) was used on aluminium sheets coated with Kieselgel 60 F_{254} (Merck). The plates were developed by treatment with 5% H_2SO_4 in EtOH at 120°C. − Column chromatography was carried out using silica gel 60 F (Merck 40−63 μm). − Dialysis was performed using Medicell dialysis tubing with size 2 Inf Dia 18/32″ − 14.3 mm and a molecular weight cutoff of 12−14,000 Dalton. − Melting points are uncorrected and were determined with a Jeneval microscope equipped with a Linkam hot stage. − Optical rotations ($[\alpha]_D^{20}$) were measured with a Jasco DIP-370. − NMR spectra: Bruker AM-400 spectrometer at 400.1 MHz and 100.6 MHz for ^1H and ^{13}C nuclei, respectively. Tetramethylsilane (TMS) was used as an internal standard and data are given in ppm. − IR: Perkin Elmer 1600 series FT-IR in cm^{-1}. − Matrix-assisted laser desorption ionization/time-of-flight mass measurements (MALDI-TOF-MS): Kratos Kompact MALDI III instrument using a 2,5-dihydroxybenzoic acid matrix.

2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthiol (**4**): An aqueous solution of sodium hydrogen sulphite (10.50 g, 10.0 mmol in 35 ml of water) was added to a solution of **3** (9.75 g, 20.0 mmol) in water (100 ml). This mixture was allowed to stand for 5 min and subsequently placed in an ice bath for 2 h. A white precipitate was formed which was extracted with CH_2Cl_2 (3 × 50 ml). The organic layers were combined, washed with water (2 × 25 ml), dried with Na_2SO_4. Evaporation of the solvent furnished pure **4** (7.29 g, 20.0 mmol, 100%) as a white solid, m.p. 118°C. − $[\alpha]_D^{20}$ = +3.6 (*c* = 1.07, CH_2Cl_2). − ^1H NMR (400.1 MHz, $CDCl_3$): δ = 2.01, 2.03, 2.07, 2.09 (4 s, 4 × 3 H, CH_3CO), 2.34 (d, *J* = 10.0 Hz, 1 H, SH), 3.75 (ddd, $J_{4,5}$ = 9.9 Hz; $J_{5,6a}$ = 4.7 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 5-H), 4.13 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.0 Hz, 1 H, 6b-H), 4.26 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6a}$ = 4.8 Hz, 1 H, 6a-H), 4.57 (pt, $J_{1,SH} \approx J_{1,2}$ = 9.9 Hz, 1 H, 1-H), 4.98 (pt, $J_{1,2} \approx J_{2,3}$ = 9.5 Hz, 1 H, 2-H), 5.11 (pt, $J_{3,4} \approx J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 5.20 (pt, $J_{2,3} \approx J_{3,4}$ = 9.4 Hz, 1 H, 3-H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.5, 20.6 (CH_3CO), 61.9 (C-6), 68.0 (C-4), 73.4 (2×, C-2, C-3), 76.2 (C-5), 78.6 (C-1), 169.2, 169.5, 170.0, 170.5 (CH_3CO). − IR (KBr): $\tilde{\nu}$ = 2969 and 2890 (CH_3), 1741 (C=O), 1240 ($OCOCH_3$). − MALDI-TOF-MS; *m/z*: 365 [M], 387 $[M + Na]^+$; calcd. for $C_{14}H_{20}O_9S$ 364.37.

1-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthio)acetic Acid (**5a**): A K_2CO_3 solution (0.69 g, 5.0 mmol in 5 ml of water) was added to a stirred solution of **4** (1.82 g, 5.00 mmol) and bromoacetic acid (0.70 g, 5.0 mmol) in acetone (5 ml). Stirring was continued for 120 min, after which the reaction mixture was acidified with acetic acid (0.5 ml) and subsequently extracted with CH_2Cl_2 (3 × 30 ml). The combined organic layers were dried with Na_2SO_4 and purification was accomplished by column chromatography (SiO_2; PhMe/EtOAc/AcOH, 50:50:2), which furnished pure **5a** (1.80 g, 4.26 mmol, 85%) as a white solid. R_f = 0.3 (PhMe/EtOAc/AcOH, 50:50:2), m.p. 123−124°C − $[\alpha]_D^{20}$ = −48 (*c* = 0.99, CH_2Cl_2). − ^1H NMR (400.1 MHz, $CDCl_3$): δ = 2.02, 2.04, 2.07, 2.10 (4 s, 4 × 3 H, CH_3CO), 3.33, 3.57 (2 d, *J* = 15.4 Hz, 2 H, CH_2CO_2H), 3.76 (ddd, $J_{4,5}$ = 10.0 Hz; $J_{5,6a}$ = 4.5 Hz; $J_{5,6b}$ = 2.3 Hz, 1 H, 5-H), 4.15 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 6b-H), 4.22 (dd, $J_{6a,6b}$ = 12.5 Hz; $J_{5,6a}$ = 4.7 Hz, 1 H, 6a-H), 4.69 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.07 (pt, $J_{1,2} \approx J_{2,3}$ = 9.5 Hz, 1 H, 2-H), 5.11 (pt, $J_{3,4} \approx J_{4,5}$ = 9.8 Hz, 1 H, 4-H), 5.26 (pt, $J_{2,3} \approx J_{3,4}$ = 9.3 Hz, 1 H, 3-H), 10.62 (s, 1 H, CO_2H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.5, 20.6 (CH_3CO), 30.9 (CH_2CO_2 H), 61.8 (C-6), 68.0 (C-4), 69.5 (C-2), 73.5 (C-3), 75.9 (C-5), 82.1 (C-1), 169.4, 169.5, 170.1, 170.9 (CH_3CO), 174.7 (CO_2H). − IR (KBr): $\tilde{\nu}$ = 3167 (CO_2H), 2967 (CH_3), 1745, 1255 (C=O), 1227 ($OCOCH_3$). − MALDI-TOF-MS; *m/z*: 445 $[M + Na]^+$, 467 $[M + 2 Na]^{2+}$; calcd. for $C_{16}H_{22}O_{11}S$ 422.41.

6-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthio)hexanoic Acid (**5b**): A K_2CO_3 solution (1.38 g, 10.0 mmol in 10 ml of water) was added to a stirred solution of **4** (3.64 g, 10.0 mmol) and 6-bromohexanoic acid (1.95 g, 10.0 mmol) in acetone (10 ml). Stirring was continued for 150 min, after which the reaction mixture was acidified with acetic acid (0.5 ml) and subsequently extracted with CH_2Cl_2 (3 × 30 ml). The combined organic layers were dried with Na_2SO_4 and the solvent was evaporated. Purification was accomplished by column chromatography (SiO_2; chloroform/AcOH, 98:2), which furnished pure **5b** (3.65 g, 7.63 mmol, 76%) as a white solid. R_f = 0.3 ($CHCl_3$/AcOH, 98:2), m.p. 82−83°C. − $[\alpha]_D^{20}$ = −33 (*c* = 0.97, CH_2Cl_2). − ^1H NMR (400.1 MHz, $CDCl_3$): δ = 1.44 (quint, *J* = 7.7 Hz, 2 H, $CH_2CH_2CH_2CO_2$ H), 1.64 (pseudo sept, *J* = 7.4 Hz, 4 H, $CH_2CH_2CH_2CH_2CO_2$ H), 2.01, 2.03, 2.06, 2.09 (4 s, 4 × 3 H, CH_3CO), 2.36 (t, *J* = 7.4 Hz, 2 H, CH_2CO_2H) 2.68 (m, 2 H, SCH_2), 3.71 (ddd, $J_{4,5}$ = 10.0 Hz; $J_{5,6a}$ = 4.8 Hz; $J_{5,6b}$ = 2.3 Hz, 1 H, 5-H), 4.14 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 6b-H), 4.25 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6a}$ = 4.9 Hz, 1 H, 6a-H), 4.48 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.03 (pt, $J_{1,2} \approx J_{2,3}$ = 9.4 Hz, 1 H, 2-H), 5.09 (pt, $J_{3,4} \approx J_{4,5}$ = 9.9 Hz, 1 H, 4-H), 5.23 (pt, $J_{2,3} \approx J_{3,4}$ = 9.3 Hz, 1 H, 3-H), 10.45 (s, 1 H, CO_2H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.6, 20.7 (CH_3CO), 24.1, 28.0, 29.2, 29.6 (CH_2 spacer), 33.7 (SCH_2), 62.1 (C-6), 68.2 (C-4), 69.7 (C-2), 73.8 (C-3), 75.8 (C-5), 83.5 (C-1), 169.4, 170.2, 170.7 (CH_3CO), 179.2 (CO_2H). − IR (KBr): $\tilde{\nu}$ = 2955 (CH_3), 1744, 1720 and 1260 (C=O), 1233 ($OCOCH_3$). − MALDI-TOF-MS; *m/z*: 501 $[M + Na]^+$; calcd. for $C_{20}H_{30}O_{11}S$ 478.51.

11-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthio)undecanoic Acid (**5c**): A K_2CO_3 solution (1.80 g, 13.0 mmol in 13 ml of water) was added to a stirred solutionof **4** (4.75 g, 13.0 mmol) and 11-

bromoundecanoic acid (3.45 g, 13.0 mmol) in acetone (13 ml). Stirring was continued for 90 min, after which the reaction mixture was acidified with acetic acid (0.5 ml) and subsequently extracted with CH_2Cl_2 (3 × 30 ml). The combined organic layers were dried with Na_2SO_4 and the solvent evaporated. Purification was accomplished by column chromatography (SiO_2; PhMe/EtOAc/AcOH, 80:20:2), which furnished pure **5c** (4.43 g, 8.07 mmol, 62%) as a white solid, m.p. 87−88°C, R_f = 0.32 (PhMe/EtOAc/AcOH, 80:20:2). − $[\alpha]_D^{20}$ = −29 (c = 1.00, CH_2Cl_2). − ^{1}H NMR (400.1 MHz, $CDCl_3$): δ = 1.27 (br., 12 H, CH_2 spacer), 1.61 (m, 4 H, CH_2CH$_2$CO$_2$ H, SCH$_2$CH_2), 2.01, 2.03, 2.06, 2.09 (4 s, 4 × 3 H, CH_3CO), 2.35 (t, J = 7.4 Hz, 2 H, CH_2CO$_2$H), 2.67 (m, 2 H, SCH_2), 3.72 (ddd, $J_{4,5}$ = 9.9 Hz; $J_{5,6a}$ = 4.7 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 5-H), 4.13 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.1 Hz, 1 H, 6b-H), 4.25 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6a}$ = 4.8 Hz, 1 H, 6a-H), 4.49 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.03 (pt, $J_{1,2} \approx J_{2,3}$ = 9.7 Hz, 1 H, 2-H), 5.09 (pt, $J_{3,4} \approx J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 5.23 (pt, $J_{2,3} \approx J_{3,4}$ = 9.3 Hz, 1 H, 3-H), 10.20 (s, 1 H, CO_2H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.6, 20.7 (CH$_3$CO), 24.7, 28.7, 29.0, 29.0, 29.1, 29.3, 29.3, 29.5, 30.0 (CH_2 spacer), 33.9 (SCH_2), 62.2 (C-6), 68.3 (C-4), 69.9 (C-2), 73.9 (C-3), 75.8 (C-5), 83.6 (C-1), 169.4, 170.3, 170.7 (CH_3CO), 179.1 (CO_2H). − IR (KBr): $\tilde{\nu}$ = 2926 (CH_3), 2853 (CH_2), 1746 and 1707 (C=O), 1228 ($OCOCH_3$). − MALDI-TOF-MS; m/z: 571[M + Na]$^+$, 593 [M + 2 Na]$^{2+}$; calcd. for $C_{25}H_{40}O_{11}S$ 548.65.

N-Succinimidyl 1-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthio)acetate (**6a**): DCC (0.97 g, 4.70 mmol) was added to a stirred and cooled (0−5°C) mixture of **5a** (1.66 g, 3.92 mmol) and *N*-hydroxysuccinimide (0.48 g, 4.17 mmol) in dimethoxyethane (8 ml). The mixture was stirred overnight, the solids were filtered off and the solvent was evaporated. The residue was precipitated twice from cyclohexane, yielding **6a** (1.86 g, 3.58 mmol, 91%) as a viscous syrup. − $[\alpha]_D^{20}$ = −59 (c = 5, CH_2Cl_2). − ^{1}H NMR (400.1 MHz, $CDCl_3$): δ = 2.01, 2.03, 2.07, 2.09 (4 s, 4 × 3 H, CH_3CO), 2.89 (s, 4 H, CH_2-suc), 3.56, 3.86 (2 × d, J = 15.4 Hz, 2 H, SCH_2), 3.80 (ddd, $J_{4,5}$ = 10.0 Hz; $J_{5,6a}$ = 4.5 Hz; $J_{5,6b}$ = 2.3 Hz, 1 H, 5-H), 4.15 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 6b-H), 4.21 (dd, $J_{6a,6b}$ = 12.5 Hz; $J_{5,6a}$ = 4.7 Hz, 1 H, 6a-H), 4.85 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.04 (pt, $J_{1,2} \approx J_{2,3}$ = 9.5 Hz, 1 H, 2-H), 5.11 (pt, $J_{3,4} \approx J_{4,5}$ = 9.8 Hz, 1 H, 4-H), 5.25 (pt, $J_{2,3} \approx J_{3,4}$ = 9.3 Hz, 1 H, 3-H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.3, 20.4 (CH$_3$CO), 25.3 (CH$_2$-suc), 27.7 (SCH$_2$), 61.7 (C-6), 67.9 (C-4), 69.6 (C-2), 73.3 (C-3), 75.5 (C-5), 81.3 (C-1), 165.0 (SCH$_2C$O$_2$), 169.0 (CO-suc), 169.4, 169.6, 170.0, 170.8 (CH_3CO). − IR (KBr): $\tilde{\nu}$ = 2946 (CH_3 and CH_2), 1740 (C=O), 1223 ($OCOCH_3$). − MALDI-TOF-MS; m/z: 541 [M + Na]$^+$, 557 [M + K]$^+$; calcd. for $C_{20}H_{25}NO_{13}S$ 519.48.

N-Succinimidyl 6-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthio)hexanoate (**6b**): DCC (0.60 g, 2.91 mmol) was added to a stirred and cooled (0−5°C) solution of **5b** (1.39 g, 2.90 mmol) and *N*-hydroxysuccinimide (0.333 g, 2.90 mmol) in dimethoxyethane (5 ml). This mixture was stirred overnight, the solids were filtered off and the solvent was evaporated. The residue was precipitated twice from cyclohexane, yielding **6b** (1.45 g, 2.52 mmol, 87%) as a glass-like compound. − $[\alpha]_D^{20}$ = −24 (c = 3.0, CH_2Cl_2). − ^{1}H NMR (400.1 MHz, $CDCl_3$): δ = 1.51 (quint, J = 7.6 Hz, 2 H, CH_2CH$_2$CH$_2$CO$_2$), 1.63 (m, 2 H, SCH$_2$CH_2), 1.76 (quint, J = 7.5 Hz, 2 H, CH_2CH$_2$CO$_2$), 2.01, 2.03, 2.06, 2.09 (4 s, 4 × 3 H, CH_3CO), 2.63 (t, J = 7.4 Hz, 2 H, CH_2CO$_2$) 2.68 (m, 2 H, SCH_2), 2.88 (s, 4 H, CH_2-suc), 3.75 (ddd, $J_{4,5}$ = 10.0 Hz; $J_{5,6a}$ = 4.8 Hz; $J_{5,6b}$ = 2.3 Hz, 1 H, 5-H), 4.13 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 6b-H), 4.24 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6a}$ = 4.9 Hz, 1 H, 6a-H), 4.53 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.02 (pt, $J_{1,2} \approx J_{2,3} \approx$ 9.4 Hz, 1 H, 2-H), 5.07 (pt, $J_{3,4} \approx J_{4,5}$ = 9.9 Hz, 1 H, 4-H), 5.23 (pt, $J_{2,3} \approx J_{3,4}$ = 9.3 Hz, 1 H, 3-H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.3, 20.4 (CH$_3$CO), 23.7, 27.4, 28.8, 29.3, 30.4 (CH_2 spacer), 25.3 (CH_2-suc), 61.9 (C-6), 68.0 (C-4), 69.6 (C-2), 73.5 (C-3), 75.4 (C-5), 83.1 (C-1), 168.3 (CO_2-suc), 169.2 (CO-suc), 169.2, 169.3, 170.0, 170.5 (CH_3CO). − IR (KBr): $\tilde{\nu}$ = 2941 (CH_3), 2862 (CH_2), 1740 (C=O), 1224 ($OCOCH_3$). − MALDI-TOF-MS; m/z: 597 [M + Na]$^+$; calcd. for $C_{24}H_{33}NO_{13}S$ 575.59.

N-Succinimidyl 11-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosylthio)undecanoate (**6c**): DCC (0.90 g, 4.36 mmol) was added to a stirred and cooled (0−5°C) solution of **5c** (2.03 g, 3.70 mmol) and *N*-hydroxysuccinimide (0.46 g, 4.00 mmol) in dimethoxyethane (10 ml). This mixture was stirred overnight, the solids were filtered off and the solvent was evaporated. The residue was precipitated twice from cyclohexane, yielding **6c** (2.00 g, 3.10 mmol, 84%) as a glass-like compound. − $[\alpha]_D^{20}$ = −20 (c = 7.3, CH_2Cl_2). − ^{1}H NMR (400.1 MHz, $CDCl_3$): δ = 1.29 (m, 12 H, CH_2 spacer), 1.61 (m, 2 H, SCH$_2$CH_2), 1.73 (quint, J = 7.2 Hz, 2 H, CH_2CH$_2$CO$_2$-suc), 2.01, 2.03, 2.06, 2.09 (4 s, 4 × 3 H, CH_3CO), 2.61 (t, J = 7.3 Hz, 2 H, CH_2CO$_2$-suc), 2.68 (m, 2 H, SCH_2), 2.86 (s, 4 H, CH_2-suc), 3.77 (ddd, $J_{4,5}$ = 9.9 Hz; $J_{5,6a}$ = 4.7 Hz; $J_{5,6b}$ = 2.2 Hz, 1 H, 5-H), 4.12 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.1 Hz, 1 H, 6b-H), 4.23 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6a}$ = 4.8 Hz, 1 H, 6a-H), 4.56 (d, $J_{1,2}$ = 10.0 Hz, 1 H, 1-H), 5.01 (pt, $J_{1,2} \approx J_{2,3}$ = 9.7 Hz, 1 H, 2-H), 5.06 (pt, $J_{3,4} \approx J_{4,5}$ = 9.7 Hz, 1 H, 4-H), 5.22 (pt, $J_{2,3} \approx J_{3,4}$ = 9.3 Hz, 1 H, 3-H). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 19.9, 20.0, 20.1 (CH$_3$CO), 23.9, 28.0, 28.4, 28.6, 28.7, 29.0, 29.3, 30.2 (CH_2 spacer), 25.0 (CH_2-suc), 61.6 (C-6), 67.8 (C-4), 69.3 (C-2), 73.2 (C-3), 75.0 (C-5), 82.7 (C-1), 168.2, 168.8, 168.9, 169.2, 169.6 170.0 (C=O). − IR (KBr): $\tilde{\nu}$ = 2929 (CH_3), 2855 (CH_2), 1739 (C=O), 1223 ($OCOCH_3$). − MALDI-TOF-MS; m/z: 668 [M + Na]$^+$, 685 [M + K]$^+$; calcd. for $C_{29}H_{43}NO_{13}S$ 645.72.

Glucodendrimer **7**: Compound **6a** (483.5 mg, 0.931 mmol) was added to a solution of **1a** (73.7 mg, 0.233 mmol) in CH_2Cl_2 (10 ml) and the reaction mixture was stirred overnight. After dilution with CH_2Cl_2 (40 ml), the solution was washed with saturated aqueous Na_2CO_3 (5 × 30 ml, usually 1−3 h was required for the complete separation of layers), dried with Na_2SO_4, filtered and concentrated to give **7** (0.38 g, 0.20 mmol, 86%) as a white foam. − $[\alpha]_D^{20}$ = −34 (c = 1.2, CH_2Cl_2). − ^{1}H NMR (400.1 MHz, $CDCl_3$): δ = 1.45 (m, 4 H, NCH$_2$CH_2CH_2CH$_2$N), 1.69 (quint, J = 6.5 Hz, 8 H, NCH$_2$CH_2CH$_2$NH), 2.01, 2.04, 2.07, 2.09 (4 s, 48 H, CH_3CO), 2.47 (m, 4 H, NCH_2CH$_2$CH$_2$CH_2N), 2.51 (quint, J = 6.3 Hz, 8 H, NCH_2CH$_2$CH$_2$NH), 3.28 (m, 8 H, NCH$_2$CH$_2$CH_2NH), 3.27 and 3.47 (2 × d, J = 15.6 Hz, 8 H, CH_2CONH), 3.79 (ddd, $J_{4,5}$ = 10.0 Hz; $J_{5,6a}$ = 4.5 Hz; $J_{5,6b}$ = 2.3 Hz, 4 H, 5-H), 4.14 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6b}$ = 2.1 Hz, 4 H, 6b-H), 4.23 (dd, $J_{6a,6b}$ = 12.4 Hz; $J_{5,6a}$ = 4.7 Hz, 4 H, 6a-H), 4.70 (d, $J_{1,2}$ = 10.0 Hz, 4 H, 1-H), 5.04 (pt, $J_{1,2} \approx J_{2,3}$ = 9.5 Hz, 4 H, 2-H), 5.10 (pt, $J_{3,4} \approx J_{4,5}$ = 9.7 Hz, 4 H, 4-H), 5.24 (pt, $J_{2,3} \approx J_{3,4}$ = 9.4 Hz, 4 H, 3-H), 7.34 (t, J = 5.5 Hz, 4 H, NH). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.5, 20.6, 20.7 (CH$_3$CO), 24.0 (NCH$_2C$H$_2C$H$_2$CH$_2$N), 26.2 (NCH$_2C$H$_2$CH$_2$NH), 33.7 (SCH_2), 38.0 (CH_2NH), 51.0 (NCH$_2$CH$_2$CH$_2$NH), 53.2 (NCH$_2$CH$_2$CH$_2C$H$_2$N), 61.8 (C-6), 68.0 (C-4), 69.7 (C-2), 73.5 (C-3), 75.8 (C-5), 83.3 (C-1), 168.9, 169.4, 169.4, 169.9, 170.5 (C=O). − IR (KBr): $\tilde{\nu}$ = 3388 (NH), 2946 (CH_3 and CH_2), 1753 (C=O), 1226 ($OCOCH_3$). − MALDI-TOF-MS; m/z: 1937 [M], 1959 [M + Na]$^+$; calcd. for $C_{80}H_{120}N_6O_{40}S_4$ 1934.10.

Glucodendrimer **8a**: Compound **6a** (872 mg, 1.68 mmol) was added to a solution of **1b** (188.0 mg, 0.0262 mmol) in CH_2Cl_2 (10 ml)

and the reaction mixture was stirred overnight. After dilution with CH_2Cl_2 (40 ml), the solution was washed with saturated aqueous Na_2CO_3 (5 × 30 ml, usually 1−3 h was required for the complete separation of layers), dried with Na_2SO_4 , filtered and concentrated to give **8a** (0.82 g, 0.025 mmol, 95%) as a slightly yellow foam. − $[\alpha]_D^{20}$ = −37 (*c* = 0.54, $CHCl_3$). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.3, 20.4, 20.5 (*C*H_3CO), 22.9, 26.3 (*C*$H_2$$CH_2$N), 33.2 ($CH_2$ spacer), 37.6 (CH_2NH), 50.7, 51.2 (*C*H_2N*C*H_2), 61.7 (C-6), 67.8 (C-4), 69.5 (C-2), 73.3 (C-3), 75.4 (C-5), 82.7 (C-1), 169.1, 169.6, 170.2 (C=O). − IR (KBr): $\tilde{\nu}$ = 3388 (NH), 2947 (CH_3 and CH_2), 1752 (C=O), 1223 (OCOCH_3).

Glucodendrimer **8b**: Compound **6b** (1.05 g, 1.82 mmol) was added to a solution of **1b** (204.2 mg, 0.0285 mmol) in CH_2Cl_2 (10 ml) and the reaction mixture was stirred overnight. After dilution with CH_2Cl_2 (40 ml), the solution was washed with saturated aqueous Na_2CO_3 (5 × 30 ml, usually 1−3 h was required for the complete separation of layers), dried with Na_2SO_4 , filtered and concentrated to give **8b** (0.99 g, 0.0271 mmol, 95%) as a slightly yellow foam. − $[\alpha]_D^{20}$ = −28 (*c* = 0.55, $CHCl_3$). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.1, 20.3 (*C*H_3CO), 24.9, 28.0, 28.9, 30.4, 35.6 (CH_2 spacer), 26.0 (*C*$H_2$$CH_2$N), 36.8 ($CH_2$NH), 50.4 (*C*$H_2$N*C*$H_2$), 61.6 (C-6), 67.8 (C-4), 69.4 (C-2), 73.3 (C-3), 75.2 (C-5), 83.0 (C-1), 168.8, 168.9, 169.5, 170.0 (CH_3CO), 173.1 (CONH). − IR (KBr): $\tilde{\nu}$ = 3316 (NH), 2941 and 2860 (CH_3 and CH_2), 1755 (C=O), 1228 (OCOCH_3).

Glucodendrimer **8c**: Compound **6c** (1.17 g, 1.81 mmol) was added to a solution of **1b** (202.6 mg, 0.0283 mmol) in CH_2Cl_2 (10 ml) and the reaction mixture was stirred overnight. After dilution with CH_2Cl_2 (40 ml), the solution was washed with saturated aqueous Na_2CO_3 (5 × 30 ml, usually 1−3 h was required for the complete separation of layers), dried with Na_2SO_4 , filtered and concentrated to give **8c** (1.08 g, 0.0263 mmol, 93%) as a slightly yellow foam. − $[\alpha]_D^{20}$ = −17 (*c* = 0.56, $CHCl_3$). − ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.3, 20.5 (*C*H_3CO), 24.3 (CH_2*C*$H_2$$CH_2NCH_2$), 25.7, 28.6, 29.0, 29.4, 29.8, 36.3 (CH_2 spacer), 26.9 (NCH_2*C*$H_2$$CH_2$NH), 37.4 ($CH_2$NH), 51.0 and 51.9 (*C*$H_2$N*C*$H_2$), 61.9 (C-6), 68.1 (C-4), 69.6 (C-2), 73.6 (C-3), 75.5 (C-5), 83.3 (C-1), 169.1, 169.2, 169.8, 170.3 (CH_3CO), 173.7 (NHCO). − IR (KBr): $\tilde{\nu}$ = 3422 (NH), 2928 and 2854 (CH_3 and CH_2), 1756 (C=O), 1228 (OCOCH_3).

Glucodendrimer **9a**: A solution of **8a** (0.21 g, 6.5 μmol) in a mixture of dry CH_2Cl_2 (2 ml) and dry MeOH (3 ml) was treated with 1 M MeONa in MeOH (0.5 ml) and stirred for about 15 min at room temperature. A white precipitate was formed, the mixture was concentrated and the residue was dissolved in water (6 ml) and MeOH (1 ml). The solution was stirred overnight at room temperature, before being neutralized with 1 M HCl to pH = 6, concentrated to 1 ml and subjected to dialysis in water. This procedure furnished pure **9a** (0.17 g, 7.63 μmol, 85%) as a glass-like compound. − $[\alpha]_D^{20}$ = −31 (*c* = 1.8, H_2O). − ^{13}C NMR (100.6 MHz, D_2O): δ = 23.2, 26.3 (*C*$H_2$$CH_2$N), 36.0 ($CH_2$ spacer), 39.7 (CH_2NH), 52.4, 53.2, 53.9 (*C*H_2N*C*H_2), 63.7 (C-6), 72.2, 75.0, 79.9, 82.7 (C-2, C-3, C-4, C-5), 87.9 (C-1), 175.6 (CONH). − IR (KBr): $\tilde{\nu}$ = 3421 (NH), 2924 (CH_2), 1752 (C=O).

Glucodendrimer **9b**: A solution of **8b** (427 mg, 11.7 μmol) in a mixture of dry CH_2Cl_2 (2 ml) and dry MeOH (3 ml) was treated with 1 M MeONa in MeOH (0.5 ml) and stirred for about 15 min at room temperature. A white precipitate was formed, the mixture was concentrated and the residue was dissolved in water (6 ml) and MeOH (1 ml). The solution was stirred overnight at room temperature, before being neutralized with 1 M HCl to pH 6, concentrated to 1 ml and subjected to dialysis in water. This procedure furnished pure **9b** (0.23 g, 8.89 μmol, 76%) as a glass-like compound. − $[\alpha]_D^{20}$ = −29 (*c* = 2.27, H_2O). − ^{13}C NMR (100.6 MHz, D_2O): δ = 23.4, 26.6 (*C*$H_2$$CH_2$N), 27.8, 30.4, 31.8, 32.5 (CH_2 spacer), 38.5 (SCH_2), 39.3 (CH_2NH), 53.2, 54.0 (*C*H_2N*C*H_2), 63.8 (C-6), 72.4, 75.2, 80.1, 82.7 (C-2, C-3, C-4, C-5), 88.1 (C-1), 179.5 (CONH). − IR (KBr): $\tilde{\nu}$ = 3416 (NH), 2927 (CH_2), 1755 (C=O).

Glucodendrimer **9c**: A solution of **8c** (558 mg, 13.6 mmol) in a mixture of dry CH_2Cl_2 (2 ml) and dry MeOH (3 ml) was treated with 1 M MeONa in MeOH (0.5 ml) and stirred for about 15 min at room temperature. A white precipitate was formed, the mixture was concentrated and the residue was dissolved in water (6 ml) and MeOH (1 ml). The solution was stirred overnight at room temperature, before being neutralized with 1 M HCl to pH = 6, concentrated to 1 ml and subjected to dialysis in a water/methanol (1:1) mixture. This procedure furnished pure **9c** (0.24 g, 7.9 mmol, 58%) as a glass-like compound. − ^{13}C NMR (100.6 MHz, D_2O/CD_3OD): δ = 22.4, 25.6 (*C*$H_2$$CH_2$N), 27.0, 30.0, 30.6, 30.8, 31.1, 31.2 (CH_2 spacer), 37.3 (SCH_2), 38.0 (CH_2NH), 52.0 (*C*H_2N*C*H_2), 62.7 (C-6), 71.2, 74.2, 79.1, 81.5 (C-2, C-3, C-4, C-5), 86.9 (C-1), 176.9 (CONH). − IR (KBr): $\tilde{\nu}$ = 3425 (NH), 2929 (CH_2), 1751 (C=O).

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