

Hydrogen Atom Transfer Experiments Provide Chemical Evidence for the Conformational Differences between C- and O-Disaccharides

Elisa I. León,^[a] Angeles Martín,^{*[a]} Inés Pérez-Martín,^[a] Luis M. Quintanal,^[a] and Ernesto Suárez^{*[a]}

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The glycopyran-6-O-yl radical promoted hydrogen atom transfer reaction (HAT) between the two pyranose units of α -D-Manp-(1 \rightarrow 4)- α -D-Glcp and α -D-Manp-(1 \rightarrow 4a)-4a-carba- α -D-Glcp disaccharides provides supporting chemical evidence for the conformational differences between O- and C-glycosyl compounds. In the O-disaccharide the 6-alkoxyl radical, generated under oxidative or reductive conditions, abstracts exclusively the hydrogen at C-5' via a completely regioselective 1,8-HAT reaction. This may be attributable to the conformational restriction of the glycosidic and aglyconic bonds

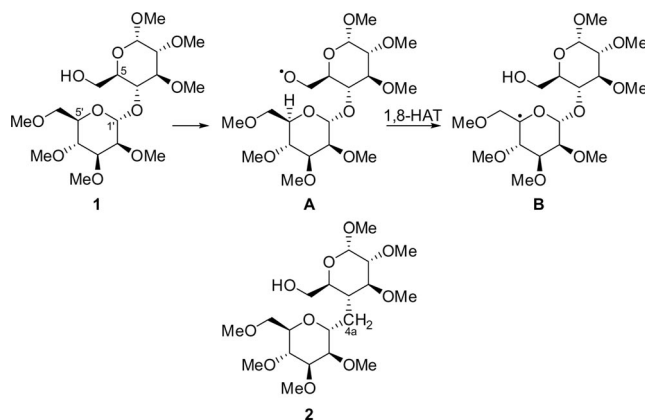
due principally to steric and stereoelectronic effects. On the contrary, very little regioselectivity is observed in the homologous C-disaccharide and a mixture of compounds generated by 1,5-, 1,6-, and 1,8-HAT processes where the abstraction occurs at hydrogen atoms positioned at C-4a, C-1', and C-5', respectively, has been obtained. This study has been extended to simpler O- and C-glycosides, where the aglycon was a straight *n*-alkyl alcohol tether of five atoms; in general, all of the results obtained are shown to be consistent with a major conformational flexibility of the C-glycosidic bond.

Introduction

C-Glycosides have recently attracted considerable synthetic attention in glycoconjugate chemistry because of their promising biological and therapeutical properties and in view of the increased detection of the C-glycosidic bond embodied in a variety of natural products.^[1] Due to the biological significance of these substances, especially as enzyme inhibitors, the comparison of the conformational behaviour of C-glycosides with the naturally occurring O-counterparts is an interesting research topic.^[2] The conformational studies have so far been carried out by using physical methods, particularly NMR spectroscopy (NOE analysis and coupling constants data) in combination with molecular mechanics and ab initio calculations. The obtained results show that the population distribution of conformers with respect to the orientation around the C-glycosidic linkages is mainly controlled by steric interactions. In contrast for natural O-glycosides, additional stereoelectronic and steric factors contribute to an increased rigidity around the glycosidic linkage.

In a previous paper from this laboratory, we described the 1,8-hydrogen atom transfer (1,8-HAT) between the two glucopyranose units of an α -D-Glcp-(1 \rightarrow 4)- β -D-Glcp disaccharide (D-maltose) through a nine-membered transition

state.^[3] The process occurs with absolute regioselectivity via an intramolecular radical mechanism in a completely analogous manner to the case described in Scheme 1 (A \rightarrow B). This methodology was later extended to many other (1 \rightarrow 4)-disaccharide models and may be synthetically useful for the remote functionalization of the C-5' carbon atom or for the specific inversion of the configuration at this centre.^[4]



Scheme 1. 1,8-HAT in α -D-Manp-(1 \rightarrow 4)- β -D-Glcp (1) O-disaccharide system.

Results and Discussion

During the course of this research, we became aware that this 1,8-HAT reaction, where geometric and stereoelectronic factors dominate, offers an unrivalled opportunity to

[a] Instituto de Productos Naturales y Agrobiología del C. S. I.C., Carretera de la Esperanza 3, 38206 La Laguna, Tenerife, Spain
Fax: +34-922-260-135
E-mail: angelesmartin@ipna.csic.es
esuarez@ipna.csic.es

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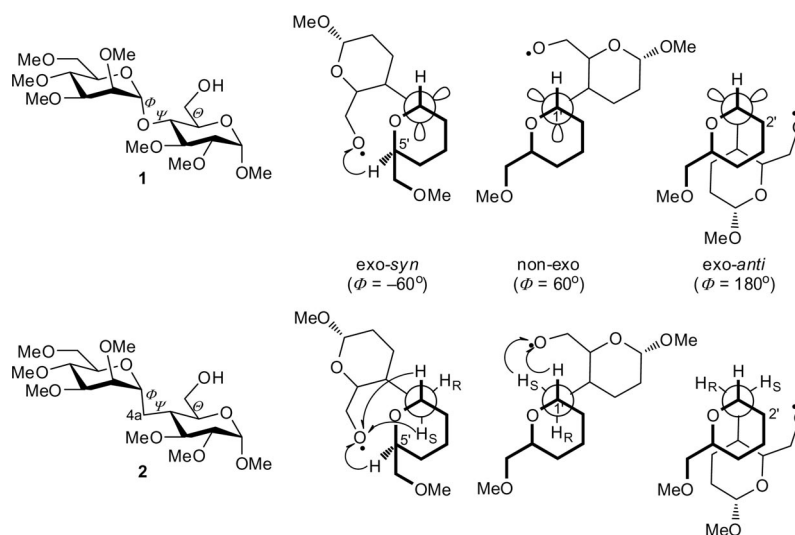
gain further insight into the conformational differences between O- and C-glycosides.

To probe the entropic barrier resulting from flexibility around the glycosidic bond in going from the conformationally restricted O-disaccharides to the more flexible C-disaccharides it was necessary to synthesize a relatively simple model system. In designing α -D-Manp-(1 \rightarrow 4)- α -D-Glcp disaccharide **1** and α -D-Manp-(1 \rightarrow 4a)-4a-carba- α -D-Glcp **2** as models for the HAT reaction, we were guided by a number of considerations. Firstly, in an α -D-manno configuration for the 4C_1 ring II of the disaccharide the 6-O-yl radical is ideally suited to permit hydrogen atom abstraction from almost all positions of the pyranose ring (specifically from C-1', C-2', C-3', and C-5'; C-4a would also be considered in C-disaccharides). Secondly, none of the three staggered conformations around the Φ_H angle for the 4C_1 chair (*exo-syn*, *exo-anti*, and non-*exo*) should undergo substantial steric interaction between the axial substituent at C-2' and the aglycon (scheme of Table 1). The influence of a C-2' equatorial substituent on the conformational equilibrium seems to be especially important in the absence of additional stereoelectronic effects, as in the case of C-glycosides. Finally, as determined by NMR and molecular dynamics, the *manno*-C-glycosyl compounds deviate significantly from the behaviour usually observed in O-glycosides, where the *exo-syn* is the preferred conformation, by presenting high percentages of the non-*exo* rotamer.^[2a]

A preliminary molecular mechanics study of our *manno*-models **1** and **2** is outlined in Table 1.^[5] These results are in general agreement with those previously reported for the totally unprotected disaccharides.^[2a] Comparing the increments of minimized energy observed for the different conformers *exo-syn*, non-*exo* and *exo-anti* for both models a major flexibility of the glycosidic bonds in the C-disaccharide is clearly distinguishable. Furthermore, in the C-disaccharide **2** a similar energy is observed for the *exo-syn* and non-*exo* conformations ($\Delta E \leq 1$ kcal mol⁻¹), indicative of the fact that, as commented previously, the non-*exo* conformation could be significantly populated.

We have calculated the distance between the oxygen at C-6 and the principal extractable protons as indicative of HAT reaction feasibility. It is generally accepted that distances of approx. 2.5–3 Å are required for the reaction to take place.^[6] On the basis of conformational energies and distances the predictable HAT reactions are outlined in the scheme of Table 1. In the case of O-disaccharide **1** only a 1,8-HAT reaction by abstraction of the H-5' is expected to be favourable. The situation is more complicated with the C-disaccharide **2** and 1,5-, 1,6- and 1,8-HAT processes may be operative via the two *exo-syn* conformational minima by abstraction of hydrogens H_S-4a, H-1' and H-5', respectively. Moreover, abstraction of hydrogens at H-1' and H_S-4a via the non-*exo* conformation may be also possible. Abstraction at 2' via the energetically disfavoured *exo-anti*

Table 1. Newman projections for the staggered conformations around the glycosidic torsion angle Φ in O- and C-disaccharides **1** and **2**.^[a]



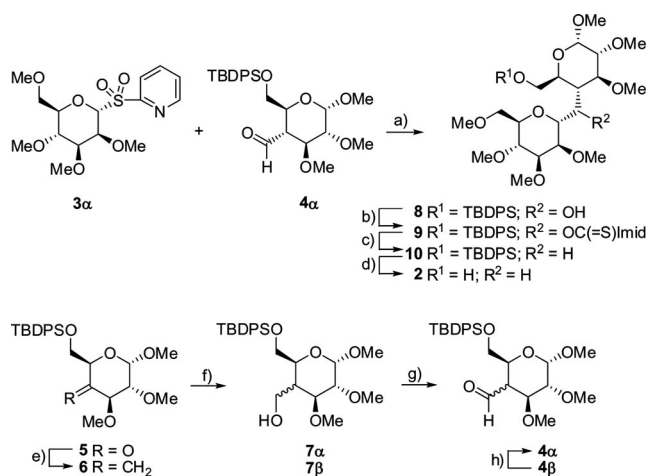
Substrate	Conformation ^[b]	Φ [°] ^[c]	Ψ [°] ^[d]	θ [°] ^[e]	$d_{O-5'}$ [Å] ^[f]	$d_{O-1'}$ [Å] ^[f]	d_{O-4a} [Å] ^[f]	$d_{O-2'}$ [Å] ^[f]	ΔE [kcal mol ⁻¹]
O-Disaccharide 1	<i>exo-syn</i>	-15.0	-24.8	172.2	2.6	4.3	—	5.4	0
	<i>exo-anti</i>	-121.7	-25.2	165.9	4.1	4.5	—	3.2	12.9
C-Disaccharide 2	<i>exo-syn</i>	-54.7	165.4	158.6	5.8	2.6	2.7	3.7	0
	<i>exo-syn</i>	-55.1	-29.8	146.7	2.9	5.3	2.5	5.4	0.3
	non- <i>exo</i>	50.1	14.9	154.9	5.1	2.9	2.7	5.1	1
	<i>exo-anti</i>	179.8	-0.3	154.7	5.5	4.3	2.5	2.6	7.1

[a] The arrows show the hydrogen atoms transfer reactions predicted by molecular mechanics calculations performed with AMBER* force field as implemented in MacroModel.^[5] [b] Staggered conformations around the glycosidic bond Φ . [c] Glycosidic bond, $\Phi = \text{H-1'-C-1'-O(C)-C-4}$. [d] Aglyconic bond, $\Psi = \text{C-1'-O(C)-C-4-H-4}$. [e] $\theta = \text{O-6-C-6-C-5-O}$ (Conformation tg). [f] Calculated distance from the O-radical to the corresponding hydrogen. In the graphic the methoxyl groups at C-2, C-3, C-2', C-3' and C-4' are omitted for clarity.

conformation does not seem to be a competitive 1,7-HAT reaction in either *O*-disaccharide **1** or *C*-disaccharide **2**. Therefore, one would expect that the HAT reaction on *O*-disaccharide **1** would be very regioselective, while a relatively complex mixture of compounds resulting from different 1,5-, 1,6-, and 1,8-HAT processes would be obtained if the reaction is performed with the *C*-disaccharide **2**.

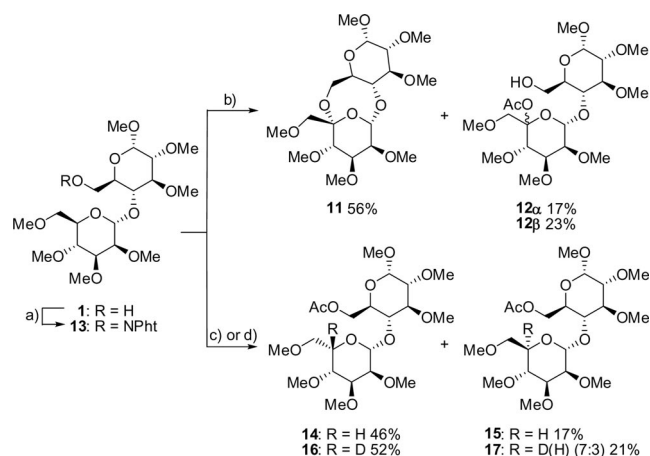
The required α -D-Manp-(1 \rightarrow 4)- α -D-Glcp disaccharide **1** was efficiently synthesized by the classical Lewis acid-mediated glycosylation of a suitably protected D-glucopyranose derivative as glycosyl acceptor with 2,3,4,6-tetra-*O*-methyl- α -D-mannopyranosyl trichloroacetimidate^[7] as glycosyl donor, as described in the Supporting Information.^[8]

The analogous *C*-disaccharide α -D-Manp-(1 \rightarrow 4a)-4a-carba- α -D-Glcp **2** was prepared as described in Scheme 2 employing a SmI₂-mediated *C*-glycosylation between the sulfone **3a** and the aldehyde **4a**.^[9] The pyridylsulfone **3** was synthesized by *S*-glycosidation of 2,3,4,6-tetra-*O*-methyl- α -D-mannopyranosyl trichloroacetimidate with 2-mercaptopyridine and subsequent oxidation according to well-established experimental procedures.^[9g] The aldehyde **4a** was in turn prepared from the known ketone **5**^[4a] via slightly modified literature procedures (see Supporting Information).^[10] This transformation requires Wittig methylenation to give olefin **6** and hydroboration using 9-BBN to afford a separable mixture of alcohols **7a** and **7b** in a 1:2 ratio which can be individually oxidized with PCC to aldehydes **4a** and **4b** (Scheme 2). The major undesired axial aldehyde **4b** with the wrong stereochemistry at C-4 was recycled into the required equatorial **4a** by base-catalyzed isomerisation.



Scheme 2. Synthesis of *C*-disaccharide α -D-Manp-(1 \rightarrow 4a)-4a-carba- β -D-Glcp (**2**): a) sulfone **3a** (2 equiv.), aldehyde **4a** (1 equiv.), SmI₂ (5.3 equiv.), THF, r.t., 20 min, 42%; b) 1,1-thiocarbonyldiimidazole (20 equiv.), MeCN, reflux, overnight, 79%; c) Ph₃SnH (3.3 equiv.), pentafluorophenol (2.5 equiv.), AIBN (0.1 equiv.), toluene, reflux, 1.5 h, 92%; d) TBAF (1.2 equiv.), THF, r.t., 7 h, 90%; e) methyltriphenylphosphonium bromide (6 equiv.), *n*BuLi, THF, -78 °C, 95%; f) 9-BBN (9 equiv.), THF, reflux, 4 h; then NaOH, H₂O₂ (30%), 0 °C, 0.5 h, **7a** (30%) and **7b** (57%); g) PCC, CH₂Cl₂, r.t., 2–3 h, 74–86%; h) TEA, 60 °C, 9 h, 75%. AIBN = azobisisobutyronitrile, TBAF = tetrabutylammonium fluoride.

After the reductive samariumation the *C*-disaccharide **8** was isolated in 42% yield as a single stereoisomer, no other isomers being detected by NMR in the crude reaction mixture.^[11] The H-1'-H-2' coupling constant could not be measured by inspection of the ¹H NMR spectrum by overlapping of the signals, but the C-1' stereochemistry was confirmed by NOE interactions between the bridge hydrogen and H-5' among others. The configuration of the newly formed hydroxy group was of no consequence and thus not determined. The deoxygenation of this hindered secondary alcohol was accomplished by triphenyltin hydride reduction of the 1*H*-imidazole-1-carbothioate intermediate **9** following a previously reported procedure.^[9h] Deprotection of the silyl ether **10** with TBAF afforded the required alcohol **2**. In this compound, it was possible to measure the coupling constant between H-1'-H-2' (*J* = 4.5 Hz) and it is in good agreement with those described for α -*C*-glycosides of D-manno configuration (vide infra). Moreover, to study the HAT reaction under reductive conditions and acquire additional insight into its mechanism, the phthalimido derivatives **13** (Scheme 3) and **22** (Scheme 5) were also prepared from the corresponding alcohol and *N*-hydroxyphthalimide under Mitsunobu conditions in accordance with a previously described protocol.^[12]



Scheme 3. HAT of α -D-Manp-(1 \rightarrow 4)- β -D-Glcp (**1**): a) DEAD (2.5 equiv.), *N*-hydroxyphthalimide (2 equiv.), PPh₃ (2.5 equiv.), THF, r.t., 1 h, 46%; b) DIB (2.5 equiv.), iodine (1 equiv.), CH₂Cl₂, reflux, 3 h; c) *n*Bu₃SnH (2 equiv.), AIBN (0.4 equiv.), PhH, reflux, 3.5 h; then Ac₂O, Py, r.t., 4 h; d) *n*Bu₃SnD (2.5 equiv.), AIBN (0.4 equiv.), PhH, reflux, 3.5 h; then Ac₂O, Py, r.t., 4 h. DEAD = diethyl azodicarboxylate, DIB = (diacetoxyiodo)benzene, NPhT = phthalimide.

Firstly, we carried out the HAT reaction with the *O*-disaccharide **1** under oxidative conditions by treatment with the DIB/iodine system, as shown in Scheme 3.^[3,4] The reaction afforded the trioxocane **11** as the main product (56%) and a partially separable mixture of isomeric acetates **12b** (23%) and **12a** (17%). It is evident that all three compounds are formed by the same C-5' radical intermediate promoted by the alkoxyl radical through an intramolecular 1,8-HAT reaction (Table 2, entry 1). Additional mechanistic features include oxidation of this newly formed *C*-radical to an oxonium ion by an excess of reagent, and finally reac-

tion with different nucleophilic trapping agents. The intramolecular reaction with the primary alcohol at C-6 affords trioxocane **11** while acetates **12** are formed intermolecularly by reaction with acetate anions coming from the DIB.

Table 2. HAT reactions in α -D-mannopyranosyl glycosides.

Entry	Substrate	Process	abst. 5' [%]	abst. 1' [%]	abst. 4a [%]	red. O [%] ^[a]
1	1	ox.	96	n.d.	—	—
2	13	red. ^[b]	67	n.d.	—	6
3	2	ox.	32	41	9	—
4	22	red. ^[b]	17	31	6	14
5	28	ox.	38	14	—	—
6	35	red. ^[b]	22	14	—	21
7	31	ox.	n.d.	55	32	—
8	42	red. ^[b]	n.d.	32	49	12

[a] Reduction of the alkoxyl radical prior to the abstraction reaction. [b] The yields of the reductive processes were calculated from the $n\text{Bu}_3\text{SnD/AIBN}$ experiment to evaluate the products with retention of configuration and the percentage of reduction of the alkoxyl radical prior to abstraction; n.d. = not detected.

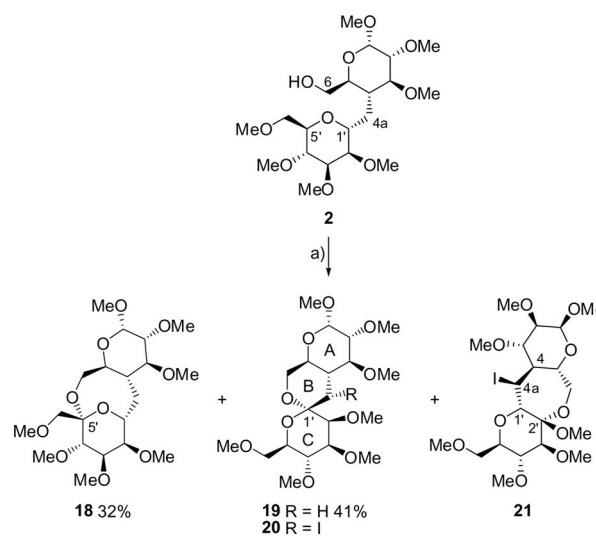
The stereochemistry of C-5' and the related conformation of ring II in acetates **12** deserve a brief comment. The observed pattern of J coupling constants between the ring protons indicates that, as expected, in **12 β** the β -L-gulo ring adopts a 1C_4 chair conformation while in the case of **12 α** the α -D-manno ring remains unchanged in a 4C_1 chair.

Next, the HAT reaction was carried out under reductive conditions with the phthalimide **13** by treatment with $n\text{Bu}_3\text{SnH/AIBN}$. In this case two compounds were obtained after acetylation to facilitate their chromatographic separation: disaccharide **14** (46%) formed by hydrogen abstraction at C-5' and radical quenching by the stannane with inversion of configuration and the acetyl derivative of the precursor alcohol **15** (17%) which, evidently, arises either by abstraction and retention of configuration at C-5' or simply by reduction of the 6-O-yl radical prior to the abstraction reaction, or most probably by a combination of these two mechanisms. In the inverted disaccharide **14** the initial α -D-mannopyranosyl moiety has been transformed into a β -L-gulopyranosyl derivative and consequently the pyranose ring has changed from 4C_1 to 1C_4 conformation as can be easily observed by ^1H NMR spectroscopy.

The reduction of phthalimide **13** using $n\text{Bu}_3\text{SnD}$ as reagent showed, after careful analysis of the isotopic distribution, a total substitution of deuterium at C-5' in compound **16** while 70% of deuterium labelling was found in the alcohol **17**, and therefore the direct reduction of the 6-O-yl radical is responsible for the 30% of unlabelled molecules.^[13] The deuterium is only incorporated at C-5', and there is no observable deuterium scrambling at other positions of the molecule within NMR detection limits. These results have also allowed us to establish that also under these reductive conditions only 1,8-HAT is taking place and that the abstraction at C-5' occurs in 67% yield with an inversion/retention ratio of approximately 3.5:1 (Table 2, entry 2).

We can conclude that the HAT reaction of α -D-Manp-(1 \rightarrow 4)- α -D-Glcp disaccharide **1** occurred with complete regioselectivity by exclusive abstraction of the hydrogen atom at C-5' in nearly quantitative global yield (96%) under oxidative conditions. Within the limits of NMR detection, no products coming from abstraction of other hydrogen atoms were detected in the reaction mixture.

The HAT reaction of the C-disaccharide α -D-Manp-(1 \rightarrow 4a)-4a-carba- β -D-Glcp (**2**) proved to be a much more complex process from the mechanistic standpoint. Under oxidative conditions the expected 1,3-dioxocane **18** coming from the abstraction of the H-5' was isolated, but only in 30% yield (Scheme 4). The major product was now the dioxaspirobicyclic **19** generated by 1,6-HAT between the alkoxyl radical and the hydrogen at C-1'.^[14] Moreover, two minor iodinated compounds **20** and **21** which were plausibly formed by two consecutive hydrogen abstractions were also isolated. The alkoxyl radical abstracted initially a hydrogen atom from the interconnecting C-4a through a very favourable 1,5-TS to give a δ -iodohydrin intermediate. This intermediate would then give by a second abstraction, either **20** through a 1,6-HAT or **21** by a 1,7-HAT, competitively.



Scheme 4. Oxidative HAT of α -D-Manp-(1 \rightarrow 4a)-4a-carba- β -D-Glcp (**2**); a) DIB (1.7 equiv.), iodine (1 equiv.), CH_2Cl_2 , $h\nu$, r.t., 1.5 h.

Some stereochemistry and conformational aspects of these compounds deserve brief comment. In compound **18** ring C conserves the 4C_1 chair conformation of its predecessor and the 1,3-dioxocane ring adopts a restricted boat-chair conformation as confirmed by NOESY correlations between the hydrogens at C-4a and H-2', H-3', H-3, and H-5. A similar conformation has been already observed for the 1,3,5-trioxocane ring present in **11**.^[3,4] The *trans*-fused dioxo[4.4.0]bicyclic system in compound **19** is conformationally locked and 4C_1 chairs are observed for rings A and B. The configuration of the spirocenter is *S* and ring C adopts also a 4C_1 chair conformation. This is confirmed by the coupling constants and the selected NOESY correlations between the axial H-4a and different hydrogens and methoxy groups of the adjacent rings, as shown in Fig-

ure 1.^[15] The nucleophilic intramolecular spirocyclization operates seemingly under thermodynamic control and the most stable conformation is formed in which each ring oxygen is axial with respect to the adjacent ring, thereby gaining maximum stability from the anomeric effect.^[16]

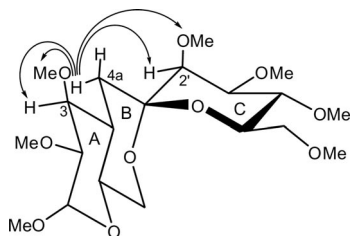


Figure 1. Proposed conformation and selected NOE correlations for spiroacetal **19**.

The ^1H NMR spectrum of **20** showed for the H-4a doublet an equatorial-axial coupling ($^3J(\text{H}4\text{a}, \text{H}4) = 2.8$ Hz, calcd. 3.2 Hz),^[17] confirming an *S* axial stereochemistry for the iodine atom beyond any doubt.

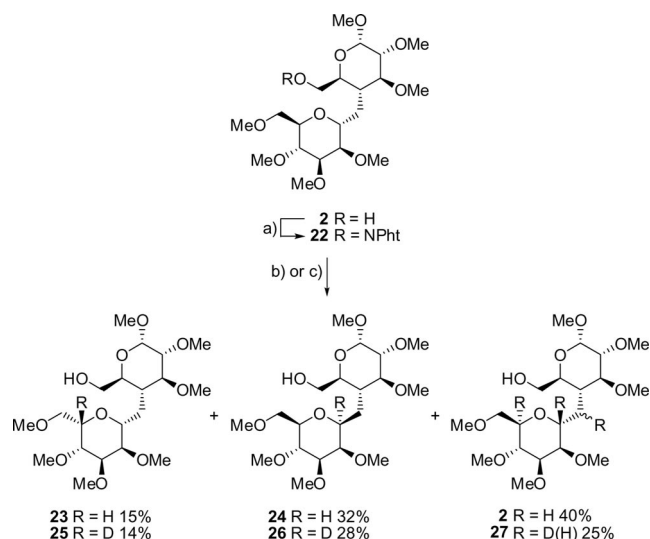
Although compound **21** could not be isolated in totally pure form, its structure has been tentatively assigned on the basis of ^1H and ^{13}C NMR spectroscopic evidence. An interesting feature of this structure is the quaternary hemiacetal carbon at C-2' ($\delta = 101.1$ ppm) which has been assigned by HMBC and HSQC experiments. The observed coupling pattern for the system H-1'-H-4a-H-4 [$^3J(\text{H}4\text{a}, \text{H}1') = 9.5$ and $^3J(\text{H}4\text{a}, \text{H}4) = 4.4$ Hz] is in good agreement with the calculated one [calcd. ($^3J(\text{H}4\text{a}, \text{H}1') = 10.0$ and $^3J(\text{H}4\text{a}, \text{H}4) = 5.6$ Hz)]^[17] and consistent with an *S* β -configuration for the iodine atom.

The reduction of phthalimide **22** by treatment with $n\text{Bu}_3\text{SnH}$ /AIBN led preferentially to the C-1' inverted alcohol **24** together with a smaller amount of the alcohol inverted at C-5' **23** (Scheme 5). The recovery starting alcohol **2** (40%) was formed probably by four different processes: stannane quenching with retention at C-1' and C-5', reduction of the C-4a-radical and reduction of the 6-*O*-alkoxyl radical. Repetition of the experiment with $n\text{Bu}_3\text{SnD}$ /AIBN confirmed this supposition, the isotopic distribution of product **27** measured by MS and ^1H NMR ($^1\text{H}/^2\text{H}$ -1'/ ^2H -5'/ ^2H -4a, 54:11:11:24) led to the calculated HATs and percentage of alkoxy radical reduction shown in Table 2 (entry 4).

Taking into account that in these reductive experiments there is no possibility of double abstraction processes, results are qualitatively similar to those obtained with the HAT oxidative approach (Table 2, entry 3).

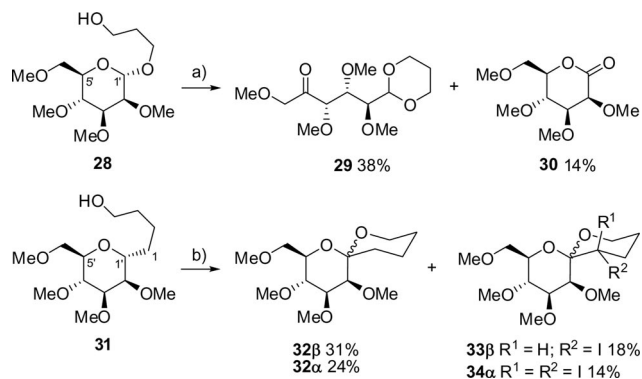
In striking contrast to the HAT reaction of *O*-disaccharide **1** where 1,8-hydrogen transfer was observed exclusively, in *C*-disaccharide **2** the process is less regioselective and reactions promoted by 1,5-, 1,6-, 1,7-, and 1,8-HAT to the 6-*O*-alkoxyl radical can compete (Table 2, entries 1–4).

At this stage, it is interesting to compare these results with those we obtained from simpler α -D-mannopyranosyl glycoside models **28** and **31**^[18] and that have been published previously as a preliminary communication (Scheme 6 and Scheme 7).^[19] In these cases, the aglycon was a simple *n*-



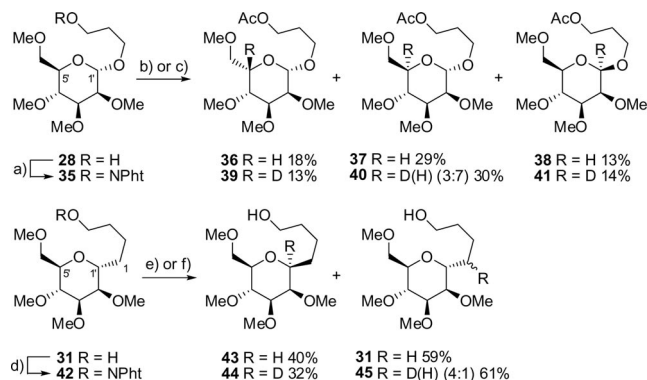
Scheme 5. Reductive HAT of α -D-Manp-(1 \rightarrow 4a)-4a-carba- β -D-Glcp (**2**): a) DEAD (2.5 equiv.), *N*-hydroxyphthalimide (2 equiv.), PPh_3 (2 equiv.), THF, 0 $^\circ\text{C}$, 2.5 h, 67%; b) $n\text{Bu}_3\text{SnH}$ (2 equiv.), AIBN (0.2 equiv.), PhH, reflux, 2 h; c) $n\text{Bu}_3\text{SnD}$ (2 equiv.), AIBN (0.2 equiv.), PhH, reflux, 3 h. Isotopic distribution of **27**: $^1\text{H}/^2\text{H}$ -1'/ ^2H -5'/ ^2H -4a, 54:11:11:24.

alkyl alcohol tether of five atoms, with the least possible conformational constraints, to avoid, as much as possible, destabilizing steric interactions in the HAT transition state.



Scheme 6. Oxidative HAT of *O*- and *C*-glycosides **28** and **31**; a) DIB (3.4 equiv.), iodine (2 equiv.), CH_2Cl_2 , $h\nu$, r.t., 8 h; b) DIB (1.7 equiv.), iodine (1 equiv.), CH_2Cl_2 , $h\nu$, r.t., 1 h.

The oxidative HAT reaction of *O*-glycoside **28** was accomplished with the DIB/ I_2 system to afford two compounds **29** and **30** (Scheme 6). The major product was the ketone **29** resulting from initial intramolecular 1,8-HAT of the 5'-hydrogen followed by acid-catalyzed rearrangement.^[20] The minor product was the known lactone **30**^[21] evidently formed by 1,6-HAT of the H-1' and subsequent acid hydrolysis of the spiro *ortho* ester intermediate (vide infra). The corresponding *C*-glycoside **31** did not lead to products of 1,8-HAT but instead gave principally a mixture of isomeric spiroacetals **32a** and **32b** through 1,6-HAT (Scheme 6). The formation of minor iodine compounds **33** and **34** probably involved a single or double abstraction at



Scheme 7. Reductive HAT of *O*- and *C*-glycosides **28** and **31**; a) DEAD (3 equiv.), *N*-hydroxyphthalimide (3 equiv.), PPh₃ (3 equiv.), THF, 0 °C, 1 h, 83%; b) *n*Bu₃SnH (2 equiv.), AIBN (0.2 equiv.), PhH, reflux, 3 h; then Ac₂O, Py, r.t., 4 h; c) *n*Bu₃SnD (2 equiv.), AIBN (0.2 equiv.), PhH, reflux, 4.75 h; then Ac₂O, Py, r.t., 4 h; d) DEAD (2.5 equiv.), *N*-hydroxyphthalimide (2.5 equiv.), PPh₃ (2.5 equiv.), THF, 0 °C, 2 h, 74%; e) *n*Bu₃SnH (1 equiv.), AIBN (0.1 equiv.), PhH, reflux, 1 h; f) *n*Bu₃SnD (1 equiv.), AIBN (0.1 equiv.), PhH, reflux, 1 h.

C-1 (1,5-HAT) and subsequent radical quenching by iodine atoms before the abstraction and ionic spirocyclization at C-1' could take place (Table 2, entries 5 and 7).

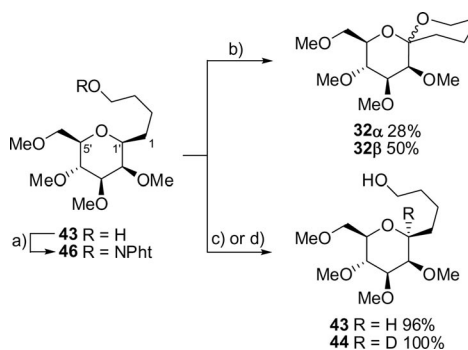
The results of the reductive HAT reaction for these models are outlined in Scheme 7. Under reductive conditions the phthalimide **35** was transformed into three compounds that were characterized after acetylation to facilitate the chromatographic separation:^[22] β-L-gulopyranoside derivative **36** formed by the 1,8-HAT process and inversion of configuration at C-5' (18%), β-D-mannopyranoside derivative **38** which, evidently, arises from 1,6-HAT, inversion of the radical at C-1', and axial quenching by the stannane (13%),^[23] and compound **37** with the starting α-D-mannopyranoside configuration (29%). Analogously to the disaccharide **15**, compound **37** may be formed by three different mechanisms: abstraction and retention of configuration at C-5' or at C-1' or simply by a failure of the hydrogen abstraction process and a reduction of the *O*-radical prior to the abstraction reaction, or by a mixture of these. Repetition of the reduction of the phthalimide **35** with *n*Bu₃SnD shed some more light on the mechanism. Analysis of the isotopic distribution in compounds **39** and **41** showed a complete substitution by deuterium at C-5' and C-1', respectively. On the other hand, only 30% of deuterium labeling was found at C-5' in compound **40**; no appreciable labeling at C-1' could be observed under the detection limits of the ¹H and ¹³C NMR spectroscopy (Table 2, entry 6). We therefore concluded that in compound **40** all the deuterium comes only from abstraction-retention at C-5' and that the reduction of the *O*-radical was responsible for the unlabeled molecules.

Several other conclusions can be drawn from the results presented above. For this *O*-glycoside the abstraction at C-5', through an apparently less stable nine-membered TS compete favourably with the abstraction at C-1' through a seven-membered TS (C-5':C-1' abstraction ratio of 6:4).

Interestingly, the abstraction at C-5' proceeded with an inversion-retention ratio of 6:4, while a complete inversion of configuration is observed during the abstraction at C-1'.^[23]

The results obtained for the reductive HAT reaction of the *C*-glycoside **42** are also illustrated in Scheme 7. NMR spectral analysis of compounds **43** and **31** and of their deuterated counterparts **44** and **45** revealed that the reaction proceeded by hydrogen abstraction at C-1' and C-1, but no abstraction at C-5' could be detected (Table 2, entry 8). As may be expected, the abstraction at C-1 is, in this *C*-glycoside, a competitive reaction since it presumably proceeds via a six-membered TS. The inversion of configuration at C-1' observed in compound **43** is in good agreement with the previously reported stabilization of the α-radical by the so-called radical anomeric effect.^[24]

The isomeric alcohol **43**, where the four-carbon tether at C-1' is now in β-equatorial position, offered the opportunity to clarify the 1,5- vs. 1,6-competitive HAT observed. As shown in Scheme 8, the alkoxyl radical generated from **43** under oxidative or reductive conditions abstracted exclusively the α-axial hydrogen at C-1' in high yield. Under reductive conditions total retention of configuration was observed (96% of starting alcohol **43** was obtained) but the *n*Bu₃SnD/AIBN experiment confirmed the quantitative abstraction (100% of deuterium incorporation was found in **44**). Interestingly, in this β-equatorial stereoisomer no detectable amount of products from abstraction at C-1 was observed. This may be rationalized by stereoelectronic effects that have a strong influence on the rate of hydrogen transfer.^[25] The axial hydrogen at C-1' in **43** is abstracted very much faster than the equatorial one of **31** and under these circumstances the 1,5-HAT reaction can not compete.



Scheme 8. HAT of a *C*-Glycoside derived from D-glycero-D-galactodecitol (**43**); a) DEAD (2.5 equiv.), *N*-hydroxyphthalimide (2.5 equiv.), PPh₃ (2.5 equiv.), THF, 0 °C, 2 h, 79%; b) DIB (1.7 equiv.), iodine (1 equiv.), CH₂Cl₂, *hν*, r.t., 0.5 h; c) *n*Bu₃SnH (1 equiv.), AIBN (0.1 equiv.), PhH, reflux, 1 h; d) *n*Bu₃SnD (1.5 equiv.), AIBN (0.2 equiv.), PhH, reflux, 1.5 h.

Conclusions

As far as we know, no example of an intramolecular HAT reaction able to discriminate between the hydrogens at C-5' and C-1' of α-D-*O*-glycopyranosyl compounds has been reported to date.^[26]

In the case of the simpler *C*-glycoside **31** and on the basis of electronic factors exclusively, the abstraction of the axial H-5' should be favoured over the equatorial H-1'. However, the reaction gave the opposite result: the abstraction occurred exclusively at H-1' (disregarding the abstraction at C-4a, 1,5-HAT) and no products coming from abstraction at H-5' could be detected. These results are in agreement with previous studies from our laboratory and others during the alkoxyl radical cyclization of different *C*-glycopyranosides with a similar *n*-alkyl alcohol tether of five atoms.^[27] Contrarily, for the *O*-glycoside **28** the axial H-5' was abstracted preferentially.

We believe that the expected greater conformational flexibility of the glycosidic bond in the *C*-glycoside is responsible for the observed results.^[2] This permits the electrophilic alkoxyl radical to abstract the electronically disfavoured equatorial H-1' through a more stable seven-membered TS. Due to a more restricted conformation of the *O*-glycosides the HAT reaction proceeded preferentially by abstraction of the favoured axial H-5' via a less stable nine-membered TS.

These results are in qualitative agreement with those obtained for the disaccharides **1** and **2**. In the *O*-disaccharide **1** the 6-*O*-yl radical triggered a 1,8-HAT reaction by exclusive abstraction of the H-5' with the glycosidic bond in the more stable *exo-syn* conformation. On the contrary, in *C*-disaccharide **2** products coming from 1,5-, 1,6-, 1,7-, and 1,8-HAT processes were isolated, with the spiroacetal **19**, from a 1,6-HAT abstraction of the H-1', as the major product.

Among the models described in this work two extreme situations can be observed: in *O*-disaccharide **1** with maximum steric and stereoelectronic effects, the abstraction occurs exclusively at H-5'. On the other hand, in the simpler *C*-glycoside **31**, where these effects are minimal and in consequence the glycosidic bond possesses higher flexibility, the abstraction is exclusively at H-1'. We believe that these experiments provided chemical evidence for the conformational differences between *C*- and *O*-disaccharides, at least in these *manno*-systems.

Experimental Section

General Methods: Melting points were determined with a hot-stage apparatus. Optical rotations were measured at the sodium line at ambient temperature in CHCl₃ solutions. IR spectra were recorded in film. NMR spectra were determined at 500 or 400 MHz for ¹H and 125.7 or 100.6 MHz for ¹³C in CDCl₃ or C₆D₆ as specified, in the presence of TMS as internal standard. For convenience, the atom-numbering system used throughout this section for the NMR assignment corresponds to that depicted in the corresponding Scheme although a IUPAC systematic nomenclature have been used. Mass spectra were recorded by using EI or ESI⁺ as specified in each case. Merck silica gel 60 PF (0.063–0.2 mm) was used for column chromatography. Circular layers of 1 mm of Merck silica gel 60 PF₂₅₄ were used on a Chromatotron for centrifugally assisted chromatography. Commercially available reagents and solvents were analytical grade or were purified by standard procedures prior to use. All reactions involving air- or moisture-sensitive materials

were carried out under a nitrogen atmosphere. The spray reagents for TLC analysis were conducted with 0.5% vanillin in H₂SO₄/EtOH (4:1) and further heating until development of color.

Oxidative HAT of Methyl 2,3,4,6-Tetra-*O*-methyl- α -D-mannopyranosyl-(1 \rightarrow 4)-2,3-di-*O*-methyl- α -D-glucopyranoside (1**):** A solution of **1** (100 mg, 0.227 mmol) in dry CH₂Cl₂ (8.5 mL) containing iodine (58 mg, 0.227 mmol) and DIB (124 mg, 0.385 mmol) in a flask protected from light with aluminium foil was stirred at reflux temperature under nitrogen for 2 h. After this time another portion of DIB (62 mg, 0.192 mmol) was added and heating at reflux was continued for an additional 1 h. The reaction mixture was then poured into 10% aqueous Na₂S₂O₃ and extracted with CH₂Cl₂. The organic extracts were dried with Na₂SO₄ and concentrated under reduced pressure. The residue was purified by chromatotron chromatography (hexanes/EtOAc, 2:8) to give in order of elution methyl 5',6-anhydro-2',3',4',6'-tetra-*O*-methyl- α -D-lyxo-hexos-5'-ulopyranosyl-(1 \rightarrow 4)-2,3-di-*O*-methyl- α -D-mannopyranoside (**11**) (56 mg, 0.128 mmol, 56%), methyl (5'*R*)-5-*O*-acetyl-2,3,4,6-tetra-*O*-methyl- α -L-ribo-hexos-5-ulopyranosyl-(1 \rightarrow 4)-2,3-di-*O*-methyl- α -D-glucopyranoside (**12b**) (25.6 mg, 0.051 mmol, 23%) and methyl (5'*S*)-5-*O*-acetyl-2,3,4,6-tetra-*O*-methyl- α -D-lyxo-hexos-5-ulopyranosyl-(1 \rightarrow 4)-2,3-di-*O*-methyl- α -D-glucopyranoside (**12a**) (19 mg, 0.038 mmol, 17%), as colourless oils.

Compound 11: [α]_D = +84.7 (*c* = 0.170, in CHCl₃). ¹H NMR (400 MHz, C₆D₆): δ = 3.02 (s, 3 H, OMe), 3.11 (dd, *J* = 3.4, 9.3 Hz, 1 H, 2-H), 3.19 (s, 3 H, OMe), 3.21 (s, 3 H, OMe), 3.27 (s, 3 H, OMe), 3.36 (s, 3 H, OMe), 3.42 (d, *J* = 10.3 Hz, 1 H, 6'-H_a), 3.55 (s, 3 H, OMe), 3.63 (s, 3 H, OMe), 3.67 (d, *J* = 10.3 Hz, 1 H, 6'-H_b), 3.76–3.79 (m, 3 H, 4-H, 3-H, 2'-H), 3.83 (m, 1 H, 5-H), 3.90 (dd, *J* = 3.7, 11.6 Hz, 1 H, 6-H_a), 4.10 (dd, *J* = 9.8, 11.4 Hz, 1 H, 6-H_b), 4.24 (dd, *J* = 2.9, 10.3 Hz, 1 H, 3'-H), 4.35 (d, *J* = 10.3 Hz, 1 H, 4'-H), 4.58 (d, *J* = 3.4 Hz, 1 H, 1-H), 5.31 (d, *J* = 1.6 Hz, 1 H, 1'-H) ppm. ¹³C NMR (100.6 MHz, C₆D₆): δ = 54.8 (CH₃, OMe), 58.0 (CH₃, OMe), 58.1 (CH₃, OMe), 59.1 (CH₃, OMe), 59.3 (CH₃, OMe), 61.05 (CH₃, OMe), 61.08 (CH₃, OMe), 65.2 (CH₂, C-6), 67.1 (CH, C-5), 72.9 (CH₂, C-6'), 77.5 (CH, C-4'), 78.3 (CH, C-3'), 78.7 (CH, C-2'), 80.0 (CH, C-4), 81.5 (CH, C-3), 82.4 (CH, C-2), 97.9 (CH, C-1), 99.4 (CH, C-1') 103.0 (C, C-5') ppm. IR (film): $\tilde{\nu}$ = 2931, 2828, 1101, 1064 cm⁻¹. MS (70 eV, EI): *m/z* (%) = 438 (<1) [M]⁺, 408 (<1), 365 (43), 233 (77), 75 (100). HRMS (EI): *m/z*: calcd. for C₁₉H₃₄O₁₁: 438.2101 [M]⁺; found 438.2102. C₁₉H₃₄O₁₁ (438.47): calcd. C 52.05, H 7.82; found C 52.35, H 7.49.

Compound 12a (mixture with compound 12b): ¹H NMR (400 MHz, C₆D₆): δ = 1.84 (s, 3 H, OAc), 3.06 (m, 1 H, 2-H), 3.07 (s, 3 H, OMe), 3.16 (s, 3 H, OMe), 3.20 (s, 3 H, OMe), 3.32 (s, 3 H, OMe), 3.37 (s, 3 H, OMe), 3.57–3.66 (m, 3 H, 5-H, 3-H, 2'-H), 3.59 (s, 3 H, OMe), 3.61 (s, 3 H, OMe), 3.95–3.99 (m, 2 H, 4-H, 6-H_a), 3.98 (d, *J* = 10.6 Hz, 1 H, 6'-H_a), 4.12 (dd, *J* = 2.1, 9.8 Hz, 1 H, 3'-H), 4.30 (m, 1 H, 6-H_b), 4.40 (d, *J* = 9.5 Hz, 1 H, 4'-H), 4.56 (d, *J* = 3.4 Hz, 1 H, 1-H), 4.60 (d, *J* = 10.6 Hz, 1 H, 6'-H_b), 5.33 (d, *J* = 2.4 Hz, 1 H, 1'-H) ppm. ¹³C NMR (100.6 MHz, C₆D₆): δ = 22.4 (CH₃, OAc), 54.8 (CH₃, OMe), 57.81 (CH₃, OMe), 57.84 (CH₃, OMe), 59.1 (CH₃, OMe), 60.8 (CH₃, OMe), 61.4 (CH₃, OMe), 61.5 (CH₃, OMe), 61.5 (CH₂, C-6), 71.8 (CH, C-3), 72.8 (CH₂, C-6'), 76.5 (CH, C-4'), 77.5 (CH, C-3'), 78.0 (CH, C-4), 79.1 (CH, C-5), 82.3 (CH, C-2'), 82.8 (CH, C-2), 97.6 (CH, C-1), 103.1 (CH, C-1'), 105.7 (C, C-5') 169.4 (C, OAc) ppm. MS (70 eV, EI): *m/z* (%) = 438 (1) [M – CH₃CO₂H]⁺, 421 (1), 393 (2), 145 (50), 101 (95), 88 (100). HRMS (EI): *m/z*: calcd. for C₁₉H₃₄O₁₁: 438.2101 [M – CH₃CO₂H]⁺; found 438.2107.

Compound 12b: [α]_D = +118.4 (*c* = 0.114, in CHCl₃). ¹H NMR (500 MHz, C₆D₆): δ = 1.76 (s, 3 H, OAc), 3.05 (s, 3 H, OMe), 3.10

(s, 3 H, OMe), 3.125 (m, 1 H, 2-H), 3.128 (s, 3 H, OMe), 3.14 (s, 3 H, OMe), 3.27 (s, 3 H, OMe), 3.36 (s, 3 H, OMe), 3.55 (dd, $J = 3.4, 8.4$ Hz, 1 H, 2'-H), 3.65 (dd, $J = 3.2, 3.2$ Hz, 1 H, 3'-H), 3.71 (s, 3 H, OMe), 3.75 (ddd, $J = 2.4, 2.4, 10.2$ Hz, 1 H, 5-H), 3.91 (dd, $J = 9.2, 9.2$ Hz, 1 H, 3-H), 3.97 (d, $J = 3.1$ Hz, 1 H, 4'-H), 4.05 (dd, $J = 2.5, 12.3$ Hz, 1 H, 6-H_a), 4.12 (s, 2 H, 6'-H₂), 4.18 (dd, $J = 9.0, 10.1$ Hz, 1 H, 4-H), 4.42 (dd, $J = 2.5, 12.6$ Hz, 1 H, 6-H_b), 4.67 (d, $J = 3.6$ Hz, 1 H, 1-H), 5.80 (d, $J = 8.4$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): $\delta = 21.6$ (CH_3 , OAc), 54.7 (CH_3 , OMe), 58.0 (CH_3 , OMe), 58.92 (CH_3 , OMe), 58.96 (CH_3 , OMe), 59.3 (CH_3 , OMe), 59.4 (CH_3 , OMe), 61.1 (CH_3 , OMe), 61.3 (CH_2 , C-6), 71.2 (CH_2 , C-6'), 71.5 (CH , C-5), 75.8 (CH , C-4'), 76.5 (CH , C-4), 78.1 (CH , C-2'), 78.3 (CH , C-3'), 82.6 (CH , C-2), 83.8 (CH , C-3), 98.0 (CH , C-1), 99.2 (CH , C-1'), 104.3 (C, C-5') 169.6 (C, OAc) ppm. IR (film): $\tilde{\nu} = 3534, 2935, 1738, 1370, 1245, 1103$ cm^{-1} . MS (70 eV, EI): m/z (%) = 438 (<1) [$M - \text{CH}_3\text{CO}_2\text{H}$] $^+$, 407 (<1), 365 (7), 278 (19), 145 (34), 101 (84), 88 (100). HRMS (EI): m/z : calcd. for $\text{C}_{19}\text{H}_{34}\text{O}_{11}$: 438.2101 [$M - \text{CH}_3\text{CO}_2\text{H}$] $^+$; found 438.2091. $\text{C}_{21}\text{H}_{38}\text{O}_{13}$ (498.52): calcd. C 50.59, H 7.68; found C 50.55, H 7.47.

Reductive HAT of Methyl 2,3,4,6-Tetra-O-methyl- α -D-mannopyranosyl-(1 \rightarrow 4)-2,3-di-O-methyl-6-O-phthalimido- α -D-glucopyranoside (13). Method A ($n\text{Bu}_3\text{SnH/AIBN}$): A solution of phthalimide **13** (100 mg, 0.170 mmol) in dry benzene (12 mL) containing $n\text{Bu}_3\text{SnH}$ (68 μL , 0.255 mmol) and AIBN (5.5 mg, 0.034 mmol) was heated at reflux temperature under nitrogen for 2.5 h. After this time another portion of $n\text{Bu}_3\text{SnH}$ (23 μL , 0.086 mmol) and AIBN (5.5 mg, 0.034 mmol) were added and heating at reflux was continued for an additional 1 h. After cooling at room temperature the mixture was concentrated under reduced pressure. The residue was dissolved in CH_3CN , washed with n -hexane and the combined more polar extracts were concentrated under reduced pressure. A solution of the residue in dry pyridine (3 mL) containing Ac_2O (1 mL) was stirred at room temperature for 4 h. The mixture was then poured into 10% aqueous HCl and extracted with CH_2Cl_2 . The organic layer was washed with aqueous saturated NaHCO_3 , dried with Na_2SO_4 and concentrated under reduced pressure. The residue was purified by chromatotron chromatography (hexanes/EtOAc, 4:6) to give in order of elution methyl tetra-O-methyl- β -L-gulopyranosyl-(1 \rightarrow 4)-6-O-acetyl-2,3-di-O-methyl- α -D-glucopyranoside (**14**) (38 mg, 0.078 mmol, 46%) and methyl 2,3,4,6-tetra-O-methyl- α -D-mannopyranosyl-(1 \rightarrow 4)-6-O-acetyl-2,3-di-O-methyl- α -D-glucopyranoside (**15**) (14 mg, 0.029 mmol, 17%), both as colourless oils.

Compound 14: [α]_D = +89.6 ($c = 0.240$, in CHCl_3). ^1H NMR (500 MHz, C_6D_6): $\delta = 1.75$ (s, 3 H, OAc), 3.11 (s, 3 H, OMe), 3.136 (s, 3 H, OMe), 3.138 (dd, $J = 3.6, 8.9$ Hz, 1 H, 2-H), 3.16 (s, 3 H, OMe), 3.18 (s, 3 H, OMe), 3.28 (dd, $J = 1.4, 3.6$ Hz, 1 H, 4'-H), 3.29 (s, 3 H, OMe), 3.36 (s, 3 H, OMe), 3.46 (dd, $J = 3.1, 8.1$ Hz, 1 H, 2'-H), 3.55 (dd, $J = 5.9, 9.2$ Hz, 1 H, 6'-H_a), 3.67 (dd, $J = 3.6, 3.6$ Hz, 1 H, 3'-H), 3.68 (dd, $J = 7.6, 9.2$ Hz, 1 H, 6'-H_b), 3.75 (s, 3 H, OMe), 3.85–3.91 (m, 2 H, 4-H, 3-H), 4.01 (ddd, $J = 1.9, 6.7, 8.9$ Hz, 1 H, 5-H), 4.14 (ddd, $J = 1.4, 6.2, 7.6$ Hz, 1 H, 5'-H), 4.64 (dd, $J = 6.7, 12.3$ Hz, 1 H, 6-H_a), 4.65 (d, $J = 3.6$ Hz, 1 H, 1-H), 4.83 (dd, $J = 2.2, 12.0$ Hz, 1 H, 6-H_b), 5.43 (d, $J = 8.1$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): $\delta = 20.6$ (CH_3 , OAc), 54.8 (CH_3 , OMe), 58.1 (CH_3 , OMe), 58.4 (CH_3 , OMe), 58.8 (CH_3 , OMe), 59.3 (CH_3 , OMe), 59.5 (CH_3 , OMe), 61.1 (CH_3 , OMe), 64.6 (CH_2 , C-6), 69.0 (CH , C-5), 71.160 (CH_2 , C-6'), 71.9 (CH , C-5'), 76.3 (CH , C-4), 77.522 (CH , C-4'), 80.0 (CH , C-2'), 82.5 (CH , C-2), 84.0 (CH , C-3), 97.7 (CH , C-1), 101.7 (CH , C-1'), 170.0 (C, OAc) ppm. IR (film): $\tilde{\nu} = 2906, 1739, 1243, 1048, 1033$ cm^{-1} . MS (70 eV, EI): m/z (%) = 450 (<1) [$M - \text{CH}_3\text{OH}$] $^+$, 419

(<1), 307 (48), 247 (100). HRMS (EI): m/z : calcd. for $\text{C}_{20}\text{H}_{34}\text{O}_{11}$: 450.2101 [$M - \text{CH}_3\text{OH}$] $^+$; found 450.2108. $\text{C}_{21}\text{H}_{38}\text{O}_{12}$ (482.53): calcd. C 52.27, H 7.94; found C 52.28, H 7.91.

Compound 15: [α]_D = +62.3 ($c = 0.960$, in CHCl_3). ^1H NMR (400 MHz, C_6D_6): $\delta = 1.77$ (s, 3 H, OAc), 3.06 (dd, $J = 3.4, 9.5$ Hz, 1 H, 2-H), 3.08 (s, 3 H, OMe), 3.09 (s, 3 H, OMe), 3.27 (s, 3 H, OMe), 3.33 (s, 3 H, OMe), 3.35 (s, 3 H, OMe), 3.48 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.69–3.82 (m, 7 H), 3.89 (dd, $J = 9.8, 9.8$ Hz, 1 H, 4'-H), 4.01 (ddd, $J = 1.9, 5.0, 9.8$ Hz, 1 H, 5'-H), 4.39 (dd, $J = 4.8, 12.2$ Hz, 1 H, 6-H_a), 4.58 (d, $J = 3.4$ Hz, 1 H, 1-H), 4.67 (dd, $J = 2.1, 11.9$ Hz, 1 H, 6-H_b), 5.55 (d, $J = 1.9$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (100.6 MHz, C_6D_6): $\delta = 20.5$ (CH_3 , OAc), 54.8 (CH_3 , OMe), 57.3 (CH_3 , OMe), 57.6 (CH_3 , OMe), 58.6 (CH_3 , OMe), 59.1 (CH_3 , OMe), 60.4 (CH_3 , OMe), 60.8 (CH_3 , OMe), 63.9 (CH_2 , C-6), 68.8 (CH , C-5), 72.4 (CH_2 , C-6'), 73.9 (CH , C-5'), 76.9 (CH , C-4'), 77.3 (CH , C-4), 78.3 (CH , C-2'), 82.0 (CH , C-3'), 82.6 (CH , C-2), 83.8 (CH , C-3), 97.4 (CH , C-1), 100.2 (CH , C-1'), 170.0 (C, OAc) ppm. IR (film): $\tilde{\nu} = 2906, 1742, 1241, 1048$ cm^{-1} . MS (70 eV, EI): m/z (%) = 419 (1) [$M - \text{CH}_3\text{OH} - \text{CH}_3\text{O}$] $^+$, 405 (1), 307 (100). HRMS (EI): m/z : calcd. for $\text{C}_{19}\text{H}_{31}\text{O}_{10}$: 419.1917 [$M - \text{CH}_3\text{OH} - \text{CH}_3\text{O}$] $^+$; found 419.1927. $\text{C}_{21}\text{H}_{38}\text{O}_{12}$ (482.53): calcd. C 52.27, H 7.94; found C 52.25, H 8.03.

Method B ($n\text{Bu}_3\text{SnD/AIBN}$): A solution of phthalimide **13** (82 mg, 0.140 mmol) in dry benzene (10 mL) containing $n\text{Bu}_3\text{SnD}$ (56 μL , 0.210 mmol) and AIBN (4.6 mg, 0.028 mmol) was heated at reflux temperature under nitrogen for 2.5 h. After this time another portion of $n\text{Bu}_3\text{SnD}$ (37 μL , 0.138 mmol) and AIBN (4.6 mg, 0.028 mmol) were added and heating at reflux was continued for an additional 1 h. After cooling at room temperature the mixture was concentrated under reduced pressure. The residue was dissolved in CH_3CN , washed with n -hexane and the combined more polar extracts were concentrated under reduced pressure. A solution of the residue in dry pyridine (3 mL) containing Ac_2O (1 mL) was stirred at room temperature for 4 h. The mixture was then poured into 10% aqueous HCl and extracted with CH_2Cl_2 . The organic layer was washed with aqueous saturated NaHCO_3 , dried with Na_2SO_4 and concentrated under reduced pressure. The residue was purified by chromatotron chromatography (hexanes/EtOAc, 4:6) to give in order of elution methyl 2,3,4,6-tetra-O-methyl- β -L-(5'- ^2H)-gulopyranosyl-(1 \rightarrow 4)-6-O-acetyl-2,3-di-O-methyl- α -D-glucopyranoside (**16**) (35 mg, 0.072 mmol, 52%) and methyl 2,3,4,6-tetra-O-methyl- α -D-[5'- ^2H]mannopyranosyl-(1 \rightarrow 4)-6-O-acetyl-2,3-di-O-methyl- α -D-glucopyranoside (**17**) (14 mg, 0.029 mmol, 21%, $^1\text{H}/^2\text{H}$, 30:70), as colourless oils.

Compound 16: ^1H NMR (500 MHz, C_6D_6): $\delta = 1.75$ (s, 3 H, OAc), 3.11 (s, 3 H, OMe), 3.136 (s, 3 H, OMe), 3.137 (dd, $J = 3.6, 9.2$ Hz, 1 H, 2-H), 3.16 (s, 3 H, OMe), 3.18 (s, 3 H, OMe), 3.27 (d, $J = 3.6$ Hz, 1 H, 4'-H), 3.29 (s, 3 H, OMe), 3.36 (s, 3 H, OMe), 3.45 (dd, $J = 2.8, 8.1$ Hz, 1 H, 2'-H), 3.54 (d, $J = 9.2$ Hz, 1 H, 6'-H_a), 3.66 (dd, $J = 3.4, 3.4$ Hz, 1 H, 3'-H), 3.68 (d, $J = 9.2$ Hz, 1 H, 6'-H_b), 3.75 (s, 3 H, OMe), 3.85–3.91 (m, 2 H, 4-H, 3-H), 4.00 (ddd, $J = 2.2, 6.7, 8.9$ Hz, 1 H, 5-H), 4.64 (dd, $J = 6.7, 12.0$ Hz, 1 H, 6-H_a), 4.65 (d, $J = 3.4$ Hz, 1 H, 1-H), 4.83 (dd, $J = 2.2, 11.8$ Hz, 1 H, 6-H_b), 5.43 (d, $J = 8.1$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): $\delta = 20.6$ (CH_3 , OAc), 54.8 (CH_3 , OMe), 58.1 (CH_3 , OMe), 58.4 (CH_3 , OMe), 58.8 (CH_3 , OMe), 59.3 (CH_3 , OMe), 59.5 (CH_3 , OMe), 61.1 (CH_3 , OMe), 64.6 (CH_2 , C-6), 69.0 (CH , C-5), 71.091 (CH_2 , C-6'), 76.3 (CH , C-4), 77.47 (CH , C-3'), 77.522 (CH , C-4'), 80.0 (CH , C-2'), 82.5 (CH , C-2), 84.0 (CH , C-3), 97.7 (CH , C-1), 101.6 (CH , C-1'), 170.0 (C, OAc) ppm. MS (70 eV, EI): m/z (%) = 452 (<1) [$M - \text{CH}_3\text{O}$] $^+$, 307 (43), 247 (70), 88 (100). HRMS (EI): m/z : calcd. for $\text{C}_{20}\text{H}_{34}^2\text{HO}_{11}$: 452.2242 [$M - \text{CH}_3\text{O}$] $^+$; found 452.2242.

Compound 17: ^1H NMR (500 MHz, C_6D_6): δ = 1.77 (s, 3 H, OAc), 3.06 (dd, J = 3.4, 9.3 Hz, 1 H, 2-H), 3.087 (s, 3 H, OMe), 3.090 (s, 3 H, OMe), 3.28 (s, 3 H, OMe), 3.33 (s, 3 H, OMe), 3.35 (s, 3 H, OMe), 3.48 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.70–3.82 (m, 7 H), 3.894 (d, J = 9.0 Hz, 4'-H-D), 3.897 (dd, J = 9.3, 9.3 Hz, 1 H, 4'-H), 4.01 (ddd, J = 1.7, 5.1, 9.9 Hz, 1 H, 5'-H), 4.40 (dd, J = 5.1, 12.1 Hz, 1 H, 6-H_A), 4.57 (d, J = 3.7 Hz, 1 H, 1-H), 4.67 (dd, J = 2.2, 11.9 Hz, 1 H, 6-H_B), 5.55 (d, J = 2.0 Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): δ = 20.5 (CH₃, OAc), 54.8 (CH₃, OMe), 57.3 (CH₃, OMe), 57.6 (CH₃, OMe), 58.6 (CH₃, OMe), 59.1 (CH₃, OMe), 60.4 (CH₃, OMe), 60.8 (CH₃, OMe), 63.9 (CH₂, C-6), 68.8 (CH, C-5), 72.312 (CH₂, C-6'-D), 72.376 (CH₂, C-6'-H), 73.9 (CH, C-5'-H), 76.894 (CH, C-4'-D), 76.947 (CH, C-4'-H), 77.3 (CH, C-4), 78.3 (CH, C-2'), 81.9 (CH, C-3'), 82.6 (CH, C-2), 83.8 (CH, C-3), 97.4 (CH, C-1), 100.2 (CH, C-1'), 170.0 (C, OAc) ppm. MS (70 eV, EI): m/z (%) = 451 (<1) [$M - \text{CH}_3\text{OH}$]⁺, 450 (<1), 307 (19), 247 (26), 88 (100). HRMS (EI): m/z : calcd. for $\text{C}_{20}\text{H}_{34}\text{O}_{11}$: 451.2164 [$M - \text{CH}_3\text{OH}$]⁺; found 451.2179.

Oxidative HAT of Methyl 2,3,4,6-Tetra-*O*-methyl- α -D-mannopyranosyl-(1 \rightarrow 4a)-2,3-di-*O*-methyl-4a-carba- α -D-glucopyranoside (2). A solution of the alcohol **2** (64 mg, 0.146 mmol) in dry CH_2Cl_2 (7 mL) containing DIB (80 mg, 0.248 mmol) and iodine (29 mg, 0.146 mmol) under nitrogen was irradiated with two 80 W tungsten-filament lamps at room temperature for 1.5 h. The mixture was then poured into 10% aqueous $\text{Na}_2\text{S}_2\text{O}_3$ and extracted with CH_2Cl_2 , dried with Na_2SO_4 and concentrated under reduced pressure. Chromatography of the residue (hexanes/EtOAc, 2:8 \rightarrow 0:1) afforded in order of elution: a mixture of methyl (4a*S*)-1'-6-anhydro-(2',3',4',6'-tetra-*O*-methyl- α -D-manno-hex-1'-ulopyranosyl)-(1 \rightarrow 4a)-2,3-di-*O*-methyl-4a-iodo-4a-carba- α -D-glucopyranoside (**20**) and methyl (2*S*,4*S*)-2',6-anhydro-(2',3',4',6'-tetra-*O*-methyl- α -D-arabino-hex-2'-ulopyranosyl)-(1 \rightarrow 4a)-2,3-di-*O*-methyl-4a-iodo-4a-carba- α -D-glucopyranoside (**21**) (9 mg, 0.016 mmol, 9%), methyl 1'-6-anhydro-(2',3',4',6'-tetra-*O*-methyl- α -D-manno-hex-1'-ulopyranosyl)-(1 \rightarrow 4a)-2,3-di-*O*-methyl-4a-carba- α -D-glucopyranoside (**19**) (26.1 mg, 0.06 mmol, 41%), and methyl (5'*R*)-5'-6-anhydro-(2',3',4',6'-tetra-*O*-methyl- α -D-lyxo-hexos-5'-ulopyranosyl)-(1 \rightarrow 4a)-2,3-di-*O*-methyl-4a-carba- α -D-glucopyranoside (**18**) (20 mg, 0.046 mmol, 32%). Careful purification by chromatography of the mixture of iodo compounds **20** and **21** allowed isolation of small amounts of pure **20** together with enriched fractions of **21**.

Compound 18: $[\alpha]_{\text{D}} = +38.7$ (c = 0.390, in CHCl_3). ^1H NMR (500 MHz, C_6D_6): δ = 1.70 (ddd, J = 7.3, 13.6, 13.6 Hz, 1 H, 4a-H_A), 1.72 (ddd, J = 1.9, 7.3, 13.6 Hz, 1 H, 4a-H_B), 1.97 (dddd, J = 1.9, 6.6, 10.4, 10.4 Hz, 1 H, 4-H), 3.13 (s, 3 H, OMe), 3.15 (s, 3 H, OMe), 3.17 (s, 3 H, OMe), 3.21 (s, 3 H, OMe), 3.25 (dd, J = 3.5, 9.5 Hz, 1 H, 2-H), 3.31 (dd, J = 1.6, 3.0 Hz, 1 H, 2'-H), 3.37 (dd, J = 9.5, 10.7 Hz, 1 H, 3-H), 3.38 (s, 3 H, OMe), 3.45 (d, J = 10.4 Hz, 1 H, 6'-H_A), 3.57 (s, 3 H, OMe), 3.65 (ddd, J = 3.8, 10.4, 10.4 Hz, 1 H, 5-H), 3.67 (s, 3 H, OMe), 3.72 (d, J = 10.4 Hz, 1 H, 6'-H_B), 3.89 (dd, J = 4.1, 11.3 Hz, 1 H, 6-H_B), 3.94 (dd, J = 2.8, 10.1 Hz, 1 H, 3'-H), 4.05 (dd, J = 10.7, 10.7 Hz, 1 H, 6-H_A), 4.22 (ddd, J = 1.6, 7.3, 12.0 Hz, 1 H, 1'-H), 4.36 (d, J = 10.4 Hz, 1 H, 4'-H), 4.73 (d, J = 3.2 Hz, 1 H, 1-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): δ = 31.9 (CH₂, C-4a), 43.9 (CH, C-4), 54.8 (CH₃, OMe), 57.2 (CH₃, OMe), 57.5 (CH₃, OMe), 58.1 (CH₃, OMe), 59.1 (CH₃, OMe), 61.0 (CH₃, OMe), 61.1 (CH₃, OMe), 65.5 (CH₂, C-6), 70.7 (CH, C-5), 73.2 (CH₂, C-6'), 74.4 (CH, C-1'), 77.8 (CH, C-4'), 78.7 (CH, C-3'), 79.2 (CH, C-2'), 80.3 (CH, C-3), 84.4 (CH, C-2), 98.0 (CH, C-1), 103.4 (C, C-5') ppm. IR (film): $\tilde{\nu}$ = 2944, 2836, 1191, 1141 cm^{-1} . MS (ESI⁺): m/z (%) = 459 (100) [$M + \text{Na}$]⁺. HRMS (ESI⁺): m/z : calcd. for $\text{C}_{20}\text{H}_{36}\text{O}_{10}$: 459.2206 [$M + \text{Na}$]⁺; found

459.2203. $\text{C}_{20}\text{H}_{36}\text{O}_{10}$ (436.50): calcd. C 55.03, H 8.31; found C 55.33, H 7.99.

Compound 19: $[\alpha]_{\text{D}} = +174.8$ (c = 0.076, in CHCl_3). ^1H NMR (500 MHz, C_6D_6): δ = 1.11 (dd, J = 12.3, 12.3 Hz, 1 H, 4a-H_A), 2.25 (dddd, J = 3.7, 10.5, 10.5, 12.1 Hz, 1 H, 4-H), 2.78 (dd, J = 3.7, 13.3 Hz, 1 H, 4a-H_B), 3.14 (dd, J = 3.4, 9.2 Hz, 1 H, 2-H), 3.17 (s, 6 H, 2 \times OMe), 3.22 (s, 3 H, OMe), 3.33 (s, 3 H, OMe), 3.33 (d, J = 3.1 Hz, 1 H, 2'-H), 3.37 (dd, J = 9.3, 10.7 Hz, 1 H, 3-H), 3.40 (s, 3 H, OMe), 3.42 (s, 3 H, OMe), 3.49 (s, 3 H, OMe), 3.59 (dd, J = 1.8, 10.7 Hz, 1 H, 6-H_A), 3.65 (dd, J = 5.4, 10.5 Hz, 1 H, 6-H_B), 3.70 (m, 1 H, 5-H), 3.75–3.82 (m, 4 H, 6'-H₂, 5'-H, 4'-H), 3.88 (dd, J = 2.9, 9.0 Hz, 1 H, 3'-H), 4.72 (d, J = 3.5 Hz, 1 H, 1-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): δ = 33.7 (CH₂, C-4a), 40.7 (CH, C-4), 54.9 (CH₃, OMe), 57.7 (CH₃, OMe), 57.8 (CH₃, OMe), 59.2 (CH₃, OMe), 60.2 (CH₃, OMe), 60.5 (CH₃, OMe), 61.3 (CH₃, OMe), 62.6 (CH₂, C-6'), 67.1 (CH, C-5), 72.4 (CH₂, C-6), 73.1 (CH, C-5'), 77.2 (CH, C-4'), 80.6 (CH, C-3), 81.2 (CH, C-2'), 83.9 (CH, C-3'), 84.0 (CH, C-2), 99.1 (CH, C-1), 99.2 (C, C-1') ppm. IR (film): $\tilde{\nu}$ = 2916, 2828, 1195, 1096, 960 cm^{-1} . MS (70 eV, EI): m/z (%) = 436 (<1) [M]⁺, 391 (<1), 261 (25), 88 (100). HRMS (EI): m/z : calcd. for $\text{C}_{20}\text{H}_{36}\text{O}_{10}$: 436.2308 [M]⁺; found 436.2323. $\text{C}_{20}\text{H}_{36}\text{O}_{10}$ (436.50): calcd. C 55.03, H 8.31; found C 55.21, H 8.13.

Compound 20: ^1H NMR (500 MHz, C_6D_6): δ = 1.87 (ddd, J = 2.8, 10.1, 10.1 Hz, 1 H, 4-H), 3.09 (s, 3 H, OMe), 3.10 (s, 3 H, OMe), 3.17 (s, 3 H, OMe), 3.23 (s, 3 H, OMe), 3.25 (dd, J = 3.5, 9.1 Hz, 1 H, 2-H), 3.45 (s, 3 H, OMe), 3.53 (dd, J = 1.6, 10.7 Hz, 1 H, 6'-H_A), 3.59 (dd, J = 5.7, 10.7 Hz, 1 H, 6'-H_B), 3.64 (s, 3 H, OMe), 3.72 (dd, J = 9.8, 9.8 Hz, 1 H, 4'-H), 3.76 (s, 3 H, OMe), 3.77 (ddd, J = 1.3, 5.7, 9.8 Hz, 1 H, 5'-H), 3.80–3.87 (m, 3 H, 6-H₂, 3'-H), 3.98 (dd, J = 9.8, 9.8 Hz, 1 H, 3-H), 4.27 (ddd, J = 6.3, 9.8, 9.8 Hz, 1 H, 5-H), 4.30 (d, J = 2.8 Hz, 1 H, 2'-H), 4.64 (d, J = 3.5 Hz, 1 H, 1-H), 5.26 (d, J = 2.8 Hz, 1 H, 4a-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): δ = 36.7 (CH, C-4a), 44.8 (CH, C-4), 55.2 (CH₃, OMe), 57.6 (CH₃, OMe), 57.8 (CH₃, OMe), 59.1 (CH₃, OMe), 60.5 (CH₃, OMe), 60.9 (CH₃, OMe), 61.5 (CH₃, OMe), 63.2 (CH₂, C-6), 64.3 (CH, C-5), 72.2 (CH₂, C-6'), 73.8 (CH, C-5'), 76.9 (CH, C-4'), 80.1 (CH, C-3), 80.3 (CH, C-2'), 84.4 (CH, C-3'), 85.2 (CH, C-2), 99.0 (CH, C-1), 99.9 (C, C-1') ppm. MS (ESI⁺): m/z (%) = 585 (100) [$M + \text{Na}$]⁺. HRMS (ESI⁺): m/z : calcd. for $\text{C}_{20}\text{H}_{35}\text{InaO}_{10}$: 585.1186 [$M + \text{Na}$]⁺; found 585.1188.

Compound 21: From spectroscopic data obtained from an enriched mixture of **20** and **21**, only clearly distinguished signals are reported: ^1H NMR (500 MHz, C_6D_6): δ = 1.76 (ddd, J = 4.1, 10.1, 10.1 Hz, 1 H, 4-H), 3.10 (s, 3 H, OMe), 3.12 (s, 3 H, OMe), 3.25 (s, 3 H, OMe), 3.38 (dd, J = 3.2, 8.8 Hz, 1 H, 2-H), 3.45 (s, 3 H, OMe), 3.50 (s, 3 H, OMe), 3.52 (s, 3 H, OMe), 3.68 (dd, J = 8.8, 8.8 Hz, 1 H), 3.73 (s, 3 H, OMe), 3.98 (m, 1 H, 5-H), 4.15 (dd, J = 9.5, 9.5 Hz, 1 H, 3-H), 4.59 (d, J = 9.5 Hz, 1 H, 1'-H), 4.65 (d, J = 4.1 Hz, 1 H, 1-H), 5.29 (dd, J = 4.4, 9.5 Hz, 1 H, 4a-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): δ = 31.6 (CH, C-4a), 44.2 (CH, C-4), 51.4 (CH₃, OMe), 55.1 (CH₃, OMe), 57.4 (CH₃, OMe), 59.3 (CH₃, OMe), 60.5 (CH₃, OMe), 61.1 (CH₃, OMe), 61.5 (CH₃, OMe), 64.1 (CH₂, C-6), 69.5 (CH, C-5), 72.0 (CH₂, C-6'), 75.0 (CH), 78.4 (CH), 82.2 (CH, C-3), 84.3 (CH, C-2), 84.9 (CH, C-1'), 87.3 (CH), 98.7 (CH, C-1), 101.1 (C, C-2') ppm.

Reductive HAT of Methyl 2,3,4,6-Tetra-*O*-methyl- α -D-mannopyranosyl-(1 \rightarrow 4a)-2,3-di-*O*-methyl-6-*O*-phthalimido-4a-carba- α -D-glucopyranoside (22). Method A ($n\text{Bu}_3\text{SnH/AIBN}$): A solution of the phthalimide **22** (29 mg, 0.05 mmol) in dry benzene (3.57 mL) containing $n\text{Bu}_3\text{SnH}$ (13.4 μL , 0.05 mmol) and AIBN (0.8 mg, 0.005 mmol) was heated at reflux for 1 h under N_2 . After this time another portion of $n\text{Bu}_3\text{SnH}$ (13.4 μL , 0.05 mmol) and AIBN

(0.8 mg, 0.005 mmol) were added and the heating at reflux was continued for an additional 1 h. After cooling to room temperature the mixture was concentrated under reduced pressure. The residue was dissolved in CH₃CN, washed with *n*-hexane and the combined more polar extracts were concentrated under reduced pressure. The residue was purified by chromatotron chromatography (CHCl₃/MeOH, 99.5:0.5) to give in order of elution methyl (2,3,4,6-tetra-*O*-methyl-β-D-mannopyranosyl)-(1→4a)-2,3-di-*O*-methyl-4a-carba-α-D-glucopyranoside (**24**) (7 mg, 0.016 mmol, 32%) and methyl (2,3,4,6-tetra-*O*-methyl-β-L-gulopyranosyl)-(1→4a)-2,3-di-*O*-methyl-4a-carba-α-D-glucopyranoside (**23**) (3.2 mg, 0.007 mmol, 15%), and starting alcohol (**2**) (8.8 mg, 0.02 mmol, 40%).

Compound 23: [α]_D = +109.4 (*c* = 0.160, in CHCl₃). ¹H NMR (500 MHz, C₆D₆): δ = 1.47 (ddd, *J* = 2.8, 10.7, 14.8 Hz, 1 H, 4a-H_a), 2.09 (ddd, *J* = 2.2, 5.0, 14.8 Hz, 1 H, 4a-H_b), 2.21 (dddd, *J* = 2.5, 5.1, 10.7, 10.7 Hz, 1 H, 4-H), 3.107 (s, 3 H, OMe), 3.109 (s, 3 H, OMe), 3.13 (s, 3 H, OMe), 3.16 (s, 3 H, OMe), 3.18 (s, 3 H, OMe), 3.20 (m, 2 H), 3.23 (s, 3 H, OMe), 3.24 (dd, *J* = 1.6, 3.8 Hz, 1 H, 4'-H), 3.44 (dd, *J* = 6.0, 9.1 Hz, 1 H, 6'-H_a), 3.58 (m, 3 H), 3.63 (s, 3 H, OMe), 3.65 (dd, *J* = 9.5, 9.5 Hz, 1 H, 3-H), 3.96 (m, 1 H, 6-H_a), 4.01 (m, 1 H, 6-H_b), 4.08 (ddd, *J* = 1.6, 7.3, 7.3 Hz, 1 H, 5'-H), 4.15 (ddd, *J* = 2.2, 10.7, 10.7 Hz, 1 H, 1'-H), 4.76 (d, *J* = 3.5 Hz, 1 H, 1-H) ppm. ¹³C NMR (125.7 MHz, C₆D₆): δ = 31.7 (CH₂, C-4a), 39.6 (CH, C-4), 54.7 (CH₃, OMe), 56.7 (CH₃, OMe), 57.5 (CH₃, OMe), 58.4 (CH₃, OMe), 58.7 (CH₃, OMe), 58.9 (CH₃, OMe), 61.0 (CH₃, OMe), 63.1 (CH₂, C-6), 71.55 (CH₂, C-6'), 72.9 (CH), 73.3 (CH), 73.54 (CH, C-5'), 75.5 (CH, C-1'), 77.75 (CH, C-4'), 80.7 (CH), 83.2 (CH, C-3), 84.2 (CH), 98.5 (CH, C-1) ppm. IR (film): $\tilde{\nu}$ = 3509, 2916, 1097 cm⁻¹. MS (ESI⁺): *m/z* (%) = 461 (100) [M + Na]⁺. HRMS (ESI⁺): *m/z*: calcd. for C₂₀H₃₈NaO₁₀: 461.2363 [M + Na]⁺; found 461.2362. C₂₀H₃₈O₁₀ (438.52): calcd. C 54.78, H 8.73; found C 54.83, H 8.37.

Compound 24: [α]_D = +50.8 (*c* = 0.240, in CHCl₃). ¹H NMR (400 MHz, C₆D₆): δ = 1.91 (m, 2 H, 4a-H_a, 4-H), 2.08 (m, 1 H, 4a-H_b), 3.02 (dd, *J* = 2.8, 9.1 Hz, 1 H, 3'-H), 3.20 (s, 3 H, OMe), 3.21 (s, 3 H, OMe), 3.23 (s, 3 H, OMe), 3.25 (dd, *J* = 3.5, 9.1 Hz, 1 H, 2-H), 3.27 (s, 3 H, OMe), 3.29 (dd, *J* = 1.0, 2.8 Hz, 1 H, 2'-H), 3.38 (ddd, *J* = 2.5, 6.6, 9.1 Hz, 1 H, 5'-H), 3.41 (s, 3 H, OMe), 3.43 (ddd, *J* = 1.0, 3.5, 9.1 Hz, 1 H, 1'-H), 3.47 (s, 3 H, OMe), 3.49 (dd, *J* = 9.5, 9.5 Hz, 1 H, 4'-H), 3.51 (s, 3 H, OMe), 3.53 (dd, *J* = 6.6, 10.4 Hz, 1 H, 6'-H_a), 3.56 (dd, *J* = 2.2, 10.4 Hz, 1 H, 6'-H_b), 3.66 (dd, *J* = 9.1, 10.1 Hz, 1 H, 3-H), 3.78 (dd, *J* = 4.7, 11.4 Hz, 1 H, 6-H_a), 3.91 (ddd, *J* = 2.2, 5.4, 10.7 Hz, 1 H, 5-H), 4.07 (dd, *J* = 1.9, 11.7 Hz, 1 H, 6-H_b), 4.78 (d, *J* = 3.5 Hz, 1 H, 1-H) ppm. ¹³C NMR (125.7 MHz, C₆D₆): δ = 29.33 (CH₂, C-4a), 40.6 (CH, C-4), 54.6 (CH₃, OMe), 57.3 (CH₃, OMe), 57.4 (CH₃, OMe), 58.8 (CH₃, OMe), 60.0 (CH₃, OMe), 60.6 (CH₃, OMe), 61.1 (CH₃, OMe), 64.0 (CH₂, C-6), 72.6 (CH, C-5), 73.0 (CH₂, C-6'), 75.64 (CH, C-1'), 77.6 (CH, C-4'), 79.00 (CH, C-5'), 79.02 (CH, C-2'), 79.7 (CH, C-3), 84.2 (CH, C-2), 87.7 (CH, C-3'), 97.7 (CH, C-1) ppm. IR (film): $\tilde{\nu}$ = 3483, 2925, 1094 cm⁻¹. MS (ESI⁺): *m/z* (%) = 461 (100) [M + Na]⁺. HRMS (ESI⁺): *m/z*: calcd. for C₂₀H₃₈NaO₁₀: 461.2363 [M + Na]⁺; found 461.2365. C₂₀H₃₈O₁₀ (438.52): calcd. C 54.78, H 8.73; found C 54.68, H 8.64.

Method B (*n*Bu₃SnD/AIBN): A solution of the phthalimide **22** (30 mg, 0.051 mmol) in dry benzene (3.8 mL) containing *n*Bu₃SnD (13.8 μL, 0.051 mmol) and AIBN (0.8 mg, 0.005 mmol) was heated at reflux for 2 h under N₂. After this time another portion of *n*Bu₃SnD (13.8 μL, 0.051 mmol) and AIBN (0.8 mg, 0.005 mmol) were added and the heating at reflux was continued for an additional 1 h. After cooling to room temperature the mixture was concentrated under reduced pressure. The residue was dissolved in

CH₃CN, washed with *n*-hexane and the combined more polar extracts were concentrated under reduced pressure. The residue was purified by chromatotron chromatography (CHCl₃/MeOH, 99.5:0.5) to afford in order of elution methyl 2,3,4,6-tetra-*O*-methyl-β-D-(1'-²H)mannopyranosyl-(1→4a)-2,3-di-*O*-methyl-4a-carba-α-D-glucopyranoside (**26**) (6.4 mg, 0.014 mmol, 28%), methyl 2,3,4,6-tetra-*O*-methyl-β-L-(5'-²H)gulopyranosyl-(1→4a)-2,3-di-*O*-methyl-4a-carba-α-D-glucopyranoside (**25**) (3.2 mg, 0.007 mmol, 14%) and deuterated starting alcohol (**27**) (5.6 mg, 0.013 mmol, 25%, ¹H/²H-1'/²H-5'/²H-4a, 54:11:11:24).

Compound 25: ¹H NMR (500 MHz, C₆D₆): (most significant signals) δ = 1.47 (ddd, *J* = 2.8, 10.7, 14.8 Hz, 1 H, 4a-H_a), 2.09 (ddd, *J* = 2.2, 5.1, 14.8 Hz, 1 H, 4a-H_b), 2.21 (dddd, *J* = 2.5, 5.0, 10.7, 10.7 Hz, 1 H, 4-H), 3.11 (s, 6 H, 2×OMe), 3.13 (s, 3 H, OMe), 3.16 (s, 3 H, OMe), 3.18 (s, 3 H, OMe), 3.23 (s, 3 H, OMe), 3.63 (s, 3 H, OMe), 3.98 (m, 2 H, 6-H₂), 4.15 (ddd, *J* = 2.2, 10.7, 10.7 Hz, 1 H, 1'-H), 4.76 (d, *J* = 3.5 Hz, 1 H, 1-H) ppm. ¹³C NMR (125.7 MHz, C₆D₆): δ = 31.7 (CH₂, C-4a), 39.6 (CH, C-4), 54.7 (CH₃, OMe), 56.7 (CH₃, OMe), 57.5 (CH₃, OMe), 58.4 (CH₃, OMe), 58.7 (CH₃, OMe), 58.9 (CH₃, OMe), 61.0 (CH₃, OMe), 63.1 (CH₂, C-6), 71.55 (CH₂, C-6'), 72.9 (CH), 73.3 (CH), 75.5 (CH, C-1'), 77.68 (CH, C-4'), 80.7 (CH, C-), 83.2 (CH, C-3), 84.2 (CH), 98.5 (CH, C-1) ppm. MS (ESI⁺): *m/z* (%) = 462 (100) [M + Na]⁺. HRMS (ESI⁺): *m/z*: calcd. for C₂₀H₃₇²HNaO₁₀: 462.2425 [M + Na]⁺; found 462.2429.

Compound 26: ¹H NMR (500 MHz, C₆D₆): δ = 1.89 (dd, *J* = 3.5, 14.5 Hz, 1 H, 4a-H_a), 1.92 (dddd, *J* = 3.2, 4.7, 10.7, 10.7 Hz, 1 H, 4-H), 2.08 (br. dd, *J* = 4.4, 14.2 Hz, 1 H, 4a-H_b), 3.02 (dd, *J* = 2.9, 9.0 Hz, 1 H, 3'-H), 3.19 (s, 3 H, OMe), 3.20 (s, 3 H, OMe), 3.22 (s, 3 H, OMe), 3.25 (dd, *J* = 3.5, 9.2 Hz, 1 H, 2-H), 3.27 (s, 3 H, OMe), 3.29 (d, *J* = 2.8 Hz, 1 H, 2'-H), 3.38 (ddd, *J* = 2.2, 6.3, 9.5 Hz, 1 H, 5'-H), 3.41 (s, 3 H, OMe), 3.47 (s, 3 H, OMe), 3.49 (dd, *J* = 9.5, 9.5 Hz, 1 H, 4'-H), 3.51 (s, 3 H, OMe), 3.53 (dd, *J* = 6.3, 10.4 Hz, 1 H, 6'-H_a), 3.56 (dd, *J* = 2.5, 10.4 Hz, 1 H, 6'-H_b), 3.66 (dd, *J* = 9.0, 10.3 Hz, 1 H, 3-H), 3.79 (m, 1 H, 6-H_a), 3.91 (ddd, *J* = 2.2, 5.4, 10.7 Hz, 1 H, 5-H), 4.09 (dd, *J* = 1.9, 11.7 Hz, 1 H, 6-H_b), 4.79 (d, *J* = 3.5 Hz, 1 H, 1-H) ppm. ¹³C NMR (100.6 MHz, C₆D₆): δ = 29.25 (CH₂, C-4a), 40.6 (CH, C-4), 54.6 (CH₃, OMe), 57.3 (CH₃, OMe), 57.4 (CH₃, OMe), 58.8 (CH₃, OMe), 60.0 (CH₃, OMe), 60.6 (CH₃, OMe), 61.1 (CH₃, OMe), 64.0 (CH₂, C-6), 72.6 (CH, C-5), 73.0 (CH₂, C-6'), 77.6 (CH, C-4'), 78.88 (CH, C-2'), 78.99 (CH, C-5'), 79.7 (CH, C-3), 84.1 (CH, C-2), 87.7 (CH, C-3'), 97.7 (CH, C-1) ppm. MS (ESI⁺): *m/z* (%) = 462 (100) [M + Na]⁺. HRMS (ESI⁺): *m/z*: calcd. for C₂₀H₃₇²HNaO₁₀: 462.2425 [M + Na]⁺; found 462.2431.

Compound 27: ¹³C NMR (100.6 MHz, C₆D₆): δ = 30.15 (CH₂, C-4a-D), 30.39 (CH₂, C-4a), 39.89 (CH, C-4-D), 39.98 (CH, C-4), 54.7 (CH₃, OMe), 57.0 (CH₃, OMe), 57.4 (CH₃, OMe), 57.9 (CH₃, OMe), 58.4 (CH₃, OMe), 58.9 (CH₃, OMe), 60.9 (CH₃, OMe), 62.9 (CH₂, C-6), 71.56 (CH₂, C-6'-D), 71.67 (CH₂, C-6'), 71.81 (CH, C-1'-D), 71.87 (CH, C-1'), 72.95 (CH, C-4'-D), 72.99 (CH, C-4'), 73.66 (CH, C-5'), 77.4 (CH, C-5), 78.4 (CH, C-3'), 79.1 (CH, C-2'), 82.9 (CH, C-3), 84.2 (CH, C-2), 98.3 (CH, C-1) ppm. MS (ESI⁺): *m/z* (%) = 462 (100) [M + Na]⁺, 461 (15) [M + Na]⁺. HRMS (ESI⁺): *m/z*: calcd. for C₂₀H₃₇²HNaO₁₀: 462.2425 [M + Na]⁺; found 462.2425; calcd. for C₂₀H₃₈NaO₁₀: 461.2363 [M + Na]⁺; found 461.2362.

Oxidative HAT of 3-Hydroxypropyl 2,3,4,6-Tetra-*O*-methyl-α-D-mannopyranoside (28**):** A solution of the alcohol **28** (43 mg, 0.146 mmol) in dry CH₂Cl₂ (6 mL) containing DIB (80 mg, 0.248 mmol) and iodine (37 mg, 0.146 mmol) was irradiated with two 80 W tungsten-filament lamps at room temperature under ni-

trogen for 5.5 h. After this time another portion of DIB (80 mg, 0.248 mmol) and iodine (37 mg, 0.146 mmol) was added and irradiation was continued for an additional 2.5 h. The reaction mixture was then poured into water, extracted with CH_2Cl_2 and the organic layer washed with 10% aqueous $\text{Na}_2\text{S}_2\text{O}_3$, dried with Na_2SO_4 and the solvents evaporated in vacuo. The residue was purified by chromatotron chromatography (hexanes/EtOAc, 35:65) to give in order of elution the known 2,3,4,6-tetra-*O*-methyl-D-mannono-1,5-lactone (**30**)^[21] (4.7 mg, 0.02 mmol, 14%) and 2,3,4,6-tetra-*O*-methyl-D-lyxo-hexos-5-ulose propane-1,3-diyl diacetal (**29**) (16.3 mg, 0.056 mmol, 38%).

Compound 29: M. p. 60.6–62.5 °C (*n*-hexane/acetone). $[\alpha]_{\text{D}} = -40.5$ ($c = 0.365$, in CHCl_3). ^1H NMR (500 MHz, CDCl_3): $\delta = 1.35$ (dddd, $J = 1.3, 1.3, 2.6, 2.6, 13.5$ Hz, 1 H, 2- H_a), 2.17 (dddd, $J = 5.0, 5.0, 12.5, 12.5, 12.5$ Hz, 1 H, 2- H_b), 3.32 (s, 3 H, OMe), 3.38 (dd, $J = 1.7, 8.9$ Hz, 1 H, 2'-H), 3.43 (s, 3 H, OMe), 3.45 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.68 (dd, $J = 3.2, 8.8$ Hz, 1 H, 3'-H), 3.74–3.80 (m, 2 H), 3.92 (d, $J = 3.2$ Hz, 1 H, 4'-H), 4.15–4.21 (m, 2 H), 4.33 (d, $J = 18.2$ Hz, 1 H, 6'- H_a), 4.39 (d, $J = 18.2$ Hz, 1 H, 6'- H_b), 4.71 (d, $J = 1.7$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, CDCl_3): $\delta = 25.7$ (CH_2 , C-2), 59.4 (CH_3 , OMe), 59.8 (CH_3 , OMe), 60.2 (CH_3 , OMe), 60.5 (CH_3 , OMe), 67.0 (CH_2), 67.4 (CH_2), 76.7 (CH_2 , C-6'), 79.4 (CH , C-2'), 80.9 (CH , C-3'), 86.5 (CH , C-4'), 101.1 (CH , C-1'), 208.3 (C, C-5') ppm. IR (film): $\tilde{\nu} = 2929, 2849, 1731, 1103$ cm^{-1} . MS (70 eV, EI): m/z (%) = 292 (<1) $[\text{M}]^+$, 247 (1), 219 (8), 131 (15), 87 (100). HRMS (EI): m/z : calcd. for $\text{C}_{13}\text{H}_{24}\text{O}_7$: 292.1522 $[\text{M}]^+$; found 292.1484. $\text{C}_{13}\text{H}_{24}\text{O}_7$ (292.33): calcd. C 53.41, H 8.28; found C 53.60, H 8.35.

Compound 30: $[\alpha]_{\text{D}} = +56.1$ ($c = 0.130$, in CHCl_3). ^1H NMR (500 MHz, CDCl_3): $\delta = 3.42$ (s, 3 H, OMe), 3.46 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.54 (dd, $J = 1.4, 7.4$ Hz, 1 H, 4-H), 3.60 (s, 3 H, OMe), 3.62 (dd, $J = 3.8, 10.9$ Hz, 1 H, 6- H_a), 3.65 (dd, $J = 5.1, 10.9$ Hz, 1 H, 6- H_b), 3.84 (dd, $J = 1.6, 2.8$ Hz, 1 H, 3-H), 4.07 (d, $J = 2.8$ Hz, 1 H, 2-H), 4.17 (ddd, $J = 3.7, 5.0, 7.1$ Hz, 1 H, 5-H) ppm. ^{13}C NMR (125.7 MHz, CDCl_3): $\delta = 57.6$ (CH_3 , OMe), 58.7 (CH_3 , OMe), 59.2 (CH_3 , OMe), 59.5 (CH_3 , OMe), 71.8 (CH_2 , C-6), 77.2 (CH , C-4), 77.6 (CH , C-2), 78.2 (CH , C-5), 78.9 (CH , C-3), 168.9 (C, C-1) ppm. IR (film): $\tilde{\nu} = 2932, 2832, 1772, 1186, 1100$ cm^{-1} . MS (70 eV, EI): m/z (%) = 234 (7) $[\text{M}]^+$, 161 (2), 101 (85), 88 (100). HRMS (EI): m/z : calcd. for $\text{C}_{10}\text{H}_{18}\text{O}_6$: 234.1103 $[\text{M}]^+$; found 234.1094. $\text{C}_{10}\text{H}_{18}\text{O}_6$ (234.25): calcd. C 51.27, H 7.75; found C 51.30, H 7.74.

Reductive HAT of 3-(Phthalimidoxy)propyl 2,3,4,6-Tetra-*O*-methyl- α -D-mannopyranoside (35). Method A ($n\text{Bu}_3\text{SnH/AIBN}$): A solution of phthalimide **35** (115 mg, 0.262 mmol) in dry benzene (19.5 mL) containing $n\text{Bu}_3\text{SnH}$ (70 μL , 0.264 mmol) and AIBN (4.3 mg, 0.026 mmol) was heated at reflux temperature for 1.5 h. After this time another portion of $n\text{Bu}_3\text{SnH}$ (70 μL , 0.264 mmol) and AIBN (4.3 mg, 0.026 mmol) were added and heating at reflux was continued for an additional 1.5 h. After cooling to room temperature the reaction mixture was concentrated under reduced pressure. The residue was dissolved in CH_3CN , washed with *n*-hexane and the combined more polar extracts were concentrated under reduced pressure. Acetylation of the crude residue in dry pyridine (3 mL) containing Ac_2O (1 mL) at room temperature for 4 h gave after column chromatography (hexanes–EtOAc, 65:35 \rightarrow 55:45) the following compounds (in order of elution): 3-acetyloxypropyl 2,3,4,6-tetra-*O*-methyl- β -L-gulopyranoside (**36**) (16.6 mg, 0.049 mmol, 18%), 3-acetyloxypropyl 2,3,4,6-tetra-*O*-methyl- α -D-mannopyranoside (**37**) (26 mg, 0.077 mmol, 29%), and 3-acetyloxypropyl 2,3,4,6-tetra-*O*-methyl- β -D-mannopyranoside (**38**) (11.1 mg, 0.033 mmol, 13%), as colourless oils.

Compound 36: $[\alpha]_{\text{D}} = +48.4$ ($c = 0.320$, in CHCl_3). ^1H NMR (500 MHz, CDCl_3): $\delta = 1.89$ –1.95 (m, 2 H, 2- H_2), 2.02 (s, 3 H, OMe), 3.25 (dd, $J = 3.4, 8.4$ Hz, 1 H, 2'-H), 3.37 (dd, $J = 1.5, 3.7$ Hz, 1 H, 4'-H), 3.38 (s, 3 H, OMe), 3.44 (s, 3 H, OMe), 3.47 (s, 3 H, OMe), 3.51 (m, 1 H, 6'- H_a), 3.52 (s, 3 H, OMe), 3.55–3.60 (m, 2 H, 6'- H_b , 1- H_a), 3.76 (dd, $J = 3.5, 3.5$ Hz, 1 H, 3'-H), 3.93–3.97 (m, 2 H, 5'-H, 1- H_b), 4.15 (t, $J = 6.5$ Hz, 2 H, 3- H_2), 4.64 (d, $J = 8.0$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, CDCl_3): $\delta = 20.9$ (CH_3 , OAc), 29.0 (CH_2 , C-2), 58.8 (CH_3 , OMe), 59.1 (CH_3 , OMe), 59.2 (CH_3 , OMe), 59.6 (CH_3 , OMe), 61.7 (CH_2 , C-3), 65.8 (CH_2 , C-1), 71.0 (CH_2 , C-6'), 71.5 (CH , C-5'), 75.9 (CH , C-4'), 76.7 (CH , C-3'), 78.2 (CH , C-2'), 100.8 (CH , C-1'), 171.1 (C, OAc) ppm. IR (film): $\tilde{\nu} = 1736$ cm^{-1} . MS (70 eV, EI): m/z (%) = 277 (2) $[\text{M} - \text{C}_2\text{H}_3\text{O}_2]^+$, 219 (4), 187 (8), 101 (100). HRMS (EI): m/z : calcd. for $\text{C}_{13}\text{H}_{25}\text{O}_6$: 277.1651 $[\text{M} - \text{C}_2\text{H}_3\text{O}_2]^+$; found 277.1709. $\text{C}_{13}\text{H}_{25}\text{O}_8$ (336.38): calcd. C 53.56, H 8.39; found C 53.66, H 8.12.

Compound 37: $[\alpha]_{\text{D}} = +49.7$ ($c = 1.190$, in CHCl_3). ^1H NMR (500 MHz, CDCl_3): $\delta = 1.88$ (qui, $J = 6.3$ Hz, 2 H, 2- H_2), 2.02 (s, 3 H, OMe), 3.37 (s, 3 H, OMe), 3.38 (dd, $J = 9.4, 9.4$ Hz, 1 H, 4'-H), 3.45 (s, 3 H, OMe), 3.46 (dd, $J = 3.7, 9.0$ Hz, 1 H, 3'-H), 3.47 (m, 1 H, 1- H_a), 3.47 (s, 3 H, OMe), 3.49 (s, 3 H, OMe), 3.51–3.58 (m, 4 H, 6'- H_2 , 5'-H, 2'-H), 3.76 (ddd, $J = 6.2, 6.2, 9.9$ Hz, 1 H, 1- H_b), 4.19 (ddd, $J = 6.3, 6.3, 11.1$ Hz, 1 H, 3- H_a), 4.24 (ddd, $J = 6.4, 6.4, 11.0$ Hz, 1 H, 3- H_b), 4.85 (d, $J = 1.8$ Hz, 1 H, 1'-H) ppm. ^1H NMR (500 MHz, C_6D_6): $\delta = 1.64$ (qui, $J = 6.5$ Hz, 2 H, 2- H_2), 1.68 (s, 3 H, OMe), 3.21 (ddd, $J = 6.2, 6.2, 9.8$ Hz, 1 H, 1- H_a), 3.23 (s, 3 H, OMe), 3.23 (s, 3 H, OMe), 3.26 (s, 3 H, OMe), 3.46 (s, 3 H, OMe), 3.49 (dd, $J = 2.0, 2.8$ Hz, 1 H, 2'-H), 3.62 (dd, $J = 2.0, 10.5$ Hz, 1 H, 6'- H_a), 3.66 (dd, $J = 5.5, 10.5$ Hz, 1 H, 6'- H_b), 3.67 (dd, $J = 3.0, 9.0$ Hz, 1 H, 3'-H), 3.71 (ddd, $J = 6.5, 6.5, 9.5$ Hz, 1 H, 1- H_b), 3.72 (dd, $J = 9.3, 9.3$ Hz, 1 H, 4'-H), 3.83 (ddd, $J = 2.0, 5.5, 9.3$ Hz, 1 H, 5'-H), 4.03 (ddd, $J = 6.4, 6.4, 11.0$ Hz, 1 H, 3- H_a), 4.07 (ddd, $J = 6.3, 6.3, 11.0$ Hz, 1 H, 2- H_b), 4.81 (d, $J = 1.9$ Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, CDCl_3): $\delta = 20.8$ (CH_3 , OAc), 28.6 (CH_2 , C-2), 57.7 (CH_3 , OMe), 58.9 (CH_3 , OMe), 59.1 (CH_3 , OMe), 60.5 (CH_3 , OMe), 61.4 (CH_2 , C-3), 63.9 (CH_2 , C-1), 71.4 (CH , C-5'), 71.7 (CH_2 , C-6'), 76.4 (CH , C-4'), 77.1 (CH , C-2'), 81.2 (CH , C-3'), 96.9 (CH , C-1'), 171.0 (C, OAc) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): $\delta = 20.4$ (CH_3 , OAc), 29.0 (CH_2 , C-2), 57.2 (CH_3 , OMe), 58.9 (CH_3 , OMe), 59.0 (CH_3 , OMe), 60.5 (CH_3 , OMe), 61.3 (CH_2 , C-3), 64.0 (CH_2 , C-1), 72.6 (CH_2 , C-6'), 72.8 (CH , C-5'), 77.2 (CH , C-4'), 77.5 (CH , C-2'), 82.6 (CH , C-3'), 98.1 (CH , C-1'), 170.0 (C, OAc) ppm. IR (film): $\tilde{\nu} = 1739$ cm^{-1} . MS (70 eV, EI): m/z (%) = 235 (<1) $[\text{M} - \text{C}_5\text{H}_9\text{O}_2]^+$, 219 (1), 161 (11), 101 (100). HRMS (EI): m/z : calcd. for $\text{C}_{10}\text{H}_{19}\text{O}_6$: 235.1182 $[\text{M} - \text{C}_5\text{H}_9\text{O}_2]^+$; found 235.1152. $\text{C}_{15}\text{H}_{28}\text{O}_8$ (336.38): calcd. C 53.56, H 8.39; found C 53.50, H 8.49.

Compound 38: $[\alpha]_{\text{D}} = -58.3$ ($c = 0.060$, in CHCl_3). ^1H NMR (500 MHz, CDCl_3): $\delta = 1.89$ –1.99 (m, 2 H, 2- H_2), 2.04 (s, 3 H, OAc), 3.17 (dd, $J = 3.2, 9.0$ Hz, 1 H, 3'-H), 3.26 (ddd, $J = 1.8, 5.6, 9.5$ Hz, 1 H, 5'-H), 3.32 (dd, $J = 9.1, 9.5$ Hz, 1 H, 4'-H), 3.39 (s, 3 H, OMe), 3.48 (s, 3 H, OMe), 3.49 (m, 1 H, 1- H_a), 3.51 (s, 3 H, OMe), 3.58 (dd, $J = 5.9, 10.7$ Hz, 1 H, 6'- H_a), 3.61 (s, 3 H, OMe), 3.66 (dd, $J = 1.9, 10.2$ Hz, 1 H, 6'- H_b), 3.66 (d, $J = 3.5$ Hz, 1 H, 2'-H), 4.02 (ddd, $J = 5.9, 5.9, 9.7$ Hz, 1 H, 1- H_b), 4.14 (ddd, $J = 6.2, 6.3, 11.0$ Hz, 1 H, 3- H_a), 4.19 (ddd, $J = 6.3, 6.3, 11.0$ Hz, 1 H, 3- H_b), 4.36 (s, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, CDCl_3): $\delta = 20.9$ (CH_3 , OAc), 28.9 (CH_2 , C-2), 57.4 (CH_3 , OMe), 59.3 (CH_3 , OMe), 60.7 (CH_3 , OMe), 61.5 (CH_2 , C-3), 61.7 (CH_3 , OMe), 66.3 (CH_2 , C-1), 72.0 (CH_2 , C-6'), 75.6 (CH , C-5'), 76.5 (CH , C-4'), 76.879 (CH , C-2'), 83.9 (CH , C-3'), 101.6 (CH , C-1'), 171.1 (C, OAc) ppm. IR (film): $\tilde{\nu} = 1737$ cm^{-1} . MS (70 eV, EI): m/z (%) = 235 (<1) $[\text{M} - \text{C}_5\text{H}_9\text{O}_2]^+$, 219 (<1), 187 (1), 101 (89), 88 (100).

HRMS (EI): m/z : calcd. for $C_{10}H_{19}O_6$: 235.1182 [$M - C_5H_9O_2$] $^+$; found 235.1197. $C_{15}H_{28}O_8$ (336.38): calcd. C 53.56, H 8.39; found C 53.41, H 8.15.

Method B ($nBu_3SnD/AIBN$): A solution of phthalimide **35** (120 mg, 0.273 mmol) in dry benzene (20.5 mL) containing nBu_3SnD (74 μ L, 0.273 mmol) and AIBN (4.5 mg, 0.027 mmol) was heated at reflux temperature for 3.5 h. After this time another portion of nBu_3SnD (74 μ L, 0.273 mmol) and AIBN (4.5 mg, 0.027 mmol) were added and heating at reflux was continued for an additional 1.25 h. After cooling to room temperature the reaction mixture was concentrated under reduced pressure. The residue was dissolved in CH_3CN , washed with n -hexane and the combined more polar extracts were concentrated under reduced pressure. Acetylation of the crude residue in dry pyridine (3 mL) containing Ac_2O (1 mL) at room temperature for 4 h gave after silica gel column chromatography (hexanes/EtOAc, 65:35 \rightarrow 55:45) the following compounds (in order of elution): 3-acetyloxypropyl 2,3,4,6-tetra-*O*-methyl- β -L-(5- 2H)gulopyranoside (**39**) (11.7 mg, 0.035 mmol, 13%), 3-acetyloxypropyl 2,3,4,6-tetra-*O*-methyl- α -D-[5- 2H]mannopyranoside (**40**) (27.5 mg, 0.082 mmol, 30%, $^1H/^2H$ ratio, 7:3), and 3-acetyloxypropyl 2,3,4,6-tetra-*O*-methyl- β -D-(1- 2H)mannopyranoside (**41**) (13 mg, 0.038 mmol, 14%), all as colourless oils.

Compound 39: 1H NMR (500 MHz, $CDCl_3$): δ = 1.89–1.95 (m, 2 H, 2- H_2), 2.03 (s, 3 H, OMe), 3.26 (dd, J = 3.1, 8.0 Hz, 1 H, 2'-H), 3.37 (d, J = 3.4 Hz, 1 H, 4'-H), 3.39 (s, 3 H, OMe), 3.44 (s, 3 H, OMe), 3.47 (s, 3 H, OMe), 3.50 (d, J = 10.3 Hz, 1 H, 6'- H_a), 3.52 (s, 3 H, OMe), 3.58 (d, J = 9.5 Hz, 1 H, 6'- H_b), 3.58 (ddd, J = 6.5, 6.5, 9.5 Hz, 1 H, 1- H_a), 3.76 (dd, J = 3.4, 3.4 Hz, 1 H, 3'-H), 3.95 (ddd, J = 6.1, 6.1, 9.5 Hz, 1 H, 1- H_b), 4.15 (t, J = 6.1 Hz, 2 H, 3- H_2), 4.65 (d, J = 8.0 Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, $CDCl_3$): δ = 20.9 (CH_3 , OAc), 29.0 (CH_2 , C-2), 58.8 (CH_3 , OMe), 59.1 (CH_3 , OMe), 59.2 (CH_3 , OMe), 59.6 (CH_3 , OMe), 61.7 (CH_2 , C-3), 65.8 (CH_2 , C-1), 70.933 (CH_2 , C-6'), 75.893 (CH, C-4'), 76.7 (CH, C-3'), 78.2 (CH, C-2'), 100.8 (CH, C-1'), 171.1 (C, OAc) ppm. MS (70 eV, EI): m/z (%) = 220 (<1) [$M - C_5H_9O_3$] $^+$, 188 (1), 101 (77), 88 (100). HRMS (EI): m/z : calcd. for $C_{10}H_{18}^2HO_5$: 220.1295 [$M - C_5H_9O_3$] $^+$; found 220.1262.

Compound 40: 1H NMR (500 MHz, C_6D_6): δ = 1.64 (qui, J = 6.5 Hz, 2 H, 2-H), 1.68 (s, 3 H, OAc), 3.21 (ddd, J = 6.2, 6.2, 9.8 Hz, 1 H, 1- H_a), 3.24 (s, 3 H, OMe), 3.25 (s, 3 H, OMe), 3.27 (s, 3 H, OMe), 3.48 (s, 3 H, OMe), 3.49 (dd, J = 2.0, 2.8 Hz, 1 H, 2'-H), 3.63 (dd, J = 2.0, 10.5 Hz, 1 H, 6'- H_a), 3.66 (dd, J = 5.5, 10.5 Hz, 1 H, 6'- H_b), 3.69–3.75 (m, 3 H, 4'-H, 3'-H, 1- H_b), 3.84 (ddd, J = 2.0, 5.5, 9.3 Hz, 1 H, 5'-H), 4.03 (ddd, J = 6.4, 6.4, 11.0 Hz, 1 H, 3- H_a), 4.07 (ddd, J = 6.3, 6.3, 11.0 Hz, 1 H, 3- H_b), 4.82 (d, J = 1.8 Hz, 1 H, 1'-H) ppm. ^{13}C NMR (125.7 MHz, C_6D_6): δ = 20.4 (CH_3 , OAc), 29.0 (CH_2 , C-2), 57.2 (CH_3 , OMe), 58.9 (CH_3 , OMe), 59.0 (CH_3 , OMe), 60.5 (CH_3 , OMe), 61.3 (CH_2 , C-3), 64.0 (CH_2 , C-1), 72.547 (CH_2 , C-6'-D), 72.607 (CH_2 , C-6'-H), 72.8 (CH, C-5'), 77.112 (CH, C-4'-D), 77.173 (CH, C-4'-H), 77.5 (CH, C-2'), 82.6 (CH, C-3'), 98.1 (CH, C-1'), 170.0 (C, OAc) ppm. MS (70 eV, EI): m/z (%) = 220 (<1) [$M - C_5H_9O_3$] $^+$, 219 (<1), 188 (1.2), 187 (1.3), 101 (100). HRMS (EI): m/z : calcd. for $C_{10}H_{18}^2HO_5$: 220.1295 [$M - C_5H_9O_3$] $^+$; found 220.1274.

Compound 41: 1H NMR (400 MHz, $CDCl_3$): δ = 1.89–1.98 (m, 2 H, 2- H_2), 2.04 (s, 3 H, OAc), 3.17 (dd, J = 3.2, 9.0 Hz, 1 H, 3'-H), 3.26 (ddd, J = 1.8, 5.8, 9.8 Hz, 1 H, 5'-H), 3.32 (dd, J = 8.7, 9.5 Hz, 1 H, 4'-H), 3.39 (s, 3 H, OMe), 3.48 (s, 3 H, OMe), 3.49 (m, 1 H, 1- H_a), 3.51 (s, 3 H, OMe), 3.58 (dd, J = 6.1, 10.3 Hz, 1 H, 6'- H_a), 3.61 (s, 3 H, OMe), 3.65 (dd, J = 1.9, 10.6 Hz, 1 H, 6'- H_b), 3.66 (d, J = 3.2 Hz, 1 H, 2'-H), 4.02 (ddd, J = 5.8, 5.8, 9.5 Hz, 1 H, 1- H_b), 4.13 (ddd, J = 6.4, 6.4, 11.1 Hz, 1 H, 3- H_a), 4.18 (ddd, J =

6.6, 6.6, 11.1 Hz, 1 H, 3- H_b) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.9 (CH_3 , OAc), 28.9 (CH_2 , C-2), 57.3 (CH_3 , OMe), 59.2 (CH_3 , OMe), 60.7 (CH_3 , OMe), 61.5 (CH_2 , C-3), 61.7 (CH_3 , OMe), 66.2 (CH_2 , C-1), 71.9 (CH_2 , C-6'), 75.6 (CH, C-5'), 76.4 (CH, C-4'), 76.733 (CH, C-2'), 83.9 (CH, C-3'), 171.1 (C, OAc) ppm. MS (70 eV, EI): m/z (%) = 236 (<1) [$M - C_5H_9O_2$] $^+$, 220 (1), 188 (1), 162 (10), 101 (100). HRMS (EI): m/z : calcd. for $C_{10}H_{18}^2HO_6$: 236.1244 [$M - C_5H_9O_2$] $^+$; found 236.1247.

Oxidative HAT of 2,6-Anhydro-7,8,9-trideoxy-1,3,4,5-tetra-O-methyl-D-glycero-D-manno-decitol (31): A solution of alcohol **31** (18 mg, 0.062 mmol) in CH_2Cl_2 (3.5 mL) containing DIB (34 mg, 0.105 mmol) and iodine (16 mg, 0.062 mmol) under nitrogen was irradiated with two 80 W tungsten-filament lamps at room temperature for 1 h. The reaction mixture was then poured into 10% aqueous $Na_2S_2O_3$ and extracted with CH_2Cl_2 , dried with Na_2SO_4 , and concentrated. Chromatotron chromatography of the reaction residue (hexanes/EtOAc, 85:15) gave in order of elution 1,5-anhydro-4,4-diiodo-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl- α -D-mannodec-5-ulopyranose (**34a**) (4.6 mg, 0.009 mmol, 14%), 1,5-anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl- α -D-mannodec-5-ulopyranose (**32a**) (4.3 mg, 0.015 mmol, 24%), 1,5-anhydro-2,3,4-trideoxy-4-iodo-6,7,8,10-tetra-*O*-methyl-D-glycero- β -D-talo-dec-5-ulopyranose (**33b**) (4.5 mg, 0.011 mmol, 18%), and 1,5-anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl- β -D-mannodec-5-ulopyranose (**32b**) (5.6 mg, 0.019 mmol, 31%) as colourless oils.

Compound 32a: [a] $_D$ = +73.2 (c = 0.220, in $CHCl_3$). 1H NMR (500 MHz, $CDCl_3$): δ = 1.37 (ddd, J = 4.2, 13.2, 13.2 Hz, 1 H, 1- H_a), 1.48–1.62 (m, 3 H, 3- H_2 , 2- H_a), 1.81 (dddd, J = 3.9, 5.9, 13.4, 13.4 Hz, 1 H, 2- H_b), 2.06 (m, 1 H, 1- H_b), 3.33 (d, J = 3.1 Hz, 1 H, 2'-H), 3.36 (dd, J = 9.5, 9.5 Hz, 1 H, 4'-H), 3.40 (s, 3 H, OMe), 3.46 (ddd, J = 2.0, 5.3, 10.1 Hz, 1 H, 5'-H), 3.49 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.54 (s, 3 H, OMe), 3.54–3.63 (m, 5 H, 6'- H_2 , 4- H_2 , 3'-H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 18.4 (CH_2 , C-2), 25.1 (CH_2 , C-3), 31.2 (CH_2 , C-1), 58.0 (CH_3 , OMe), 59.4 (CH_3 , OMe), 60.5 (CH_3 , OMe), 60.6 (CH_2 , C-4), 61.8 (CH_3 , OMe), 71.6 (CH, C-5'), 72.1 (CH_2 , C-6'), 76.8 (CH, C-4'), 81.2 (CH, C-2'), 82.7 (CH, C-3'), 98.2 (C, C-1') ppm. IR (film): $\tilde{\nu}$ = 2825 cm^{-1} . MS (70 eV, EI): m/z (%) = 290 (<1) [M] $^+$, 289 (3), 257 (1), 225 (1), 101 (59). HRMS (EI): m/z : calcd. for $C_{14}H_{26}O_6$: 290.1729 [M] $^+$; found 290.1720. $C_{14}H_{26}O_6$ (290.36): calcd. C 57.91, H 9.03; found C 57.93, H 8.90.

Compound 32b: [a] $_D$ = –62.6 (c = 0.700, in $CHCl_3$). 1H NMR (500 MHz, $CDCl_3$): δ = 1.38 (ddd, J = 4.2, 13.4, 13.4 Hz, 1 H, 1- H_a), 1.51–1.72 (m, 4 H, 3- H_2 , 2- H_2), 1.95 (ddd, J = 2.8, 2.8, 13.7 Hz, 1 H, 1- H_b), 3.35 (dd, J = 8.7, 8.7 Hz, 1 H, 4'-H), 3.35 (d, J = 3.4 Hz, 1 H, 2'-H), 3.40 (s, 3 H, OMe), 3.41 (m, 2 H, 5'-H, 3'-H), 3.47 (s, 3 H, OMe), 3.49 (s, 3 H, OMe), 3.58 (s, 3 H, OMe), 3.60 (dd, J = 6.2, 10.6 Hz, 1 H, 6'- H_a), 3.66 (dd, J = 2.5, 10.6 Hz, 1 H, 6'- H_b), 3.70 (ddd, J = 2.5, 2.5, 11.2 Hz, 1 H, 4- H_a), 4.04 (ddd, J = 3.1, 12.0, 12.0 Hz, 1 H, 4- H_b) ppm. ^{13}C NMR (125.7 MHz, $CDCl_3$): δ = 17.7 (CH_2 , C-3), 25.1 (CH_2 , C-2), 28.2 (CH_2 , C-1), 57.7 (CH_3 , OMe), 59.2 (CH_3 , OMe), 60.3 (CH_3 , OMe), 61.9 (CH_2 , C-4), 61.9 (CH_3 , OMe), 72.8 (CH_2 , C-6'), 73.6 (CH, C-5'), 77.0 (CH), 80.5 (CH), 81.8 (CH, C-3'), 98.4 (C, C-1') ppm. IR (film): $\tilde{\nu}$ = 2830, 1107 cm^{-1} . MS (70 eV, EI): m/z (%) = 245 (8) [$M - C_2H_5O$] $^+$, 213 (4), 153 (19), 101 (100). HRMS (EI): m/z : calcd. for $C_{12}H_{21}O_5$: 245.1389 [$M - C_2H_5O$] $^+$; found 245.1391. $C_{14}H_{26}O_6$ (290.36): calcd. C 57.91, H 9.03; found C 57.93, H 8.98.

Compound 33b: [a] $_D$ = –22.3 (c = 0.430, in $CHCl_3$). 1H NMR (500 MHz, $CDCl_3$): δ = 1.35–1.39 (m, 1 H, 3- H_a), 1.83 (dddd, J = 4.4, 4.4, 13.2, 13.2, 13.2 Hz, 1 H, 3- H_b), 2.25–2.30 (m, 1 H, 2- H_a), 2.55 (dddd, J = 3.9, 12.9, 12.9, 12.9 Hz, 1 H, 2- H_b), 3.39 (s, 3

H, OMe), 3.46 (s, 3 H, OMe), 3.49 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.67–3.72 (m, 3 H, 6'-H_a, 4-H_a, 4'-H), 3.74 (dd, $J = 4.8$, 4.8 Hz, 1 H, 3'-H), 3.77 (dd, $J = 5.9$, 10.1 Hz, 1 H, 6'-H_b), 3.95 (d, $J = 5.0$ Hz, 1 H, 2'-H), 3.99 (ddd, $J = 5.6$, 5.6, 5.6 Hz, 1 H, 5'-H), 4.07 (ddd, $J = 2.5$, 11.2, 13.2 Hz, 1 H, 4-H_b), 4.63 (dd, $J = 4.5$, 12.9 Hz, 1 H, 1-H) ppm. ¹³C NMR (125.7 MHz, CDCl₃): $\delta = 28.7$ (CH₂, C-3), 32.3 (CH, C-1), 33.2 (CH₂, C-2), 57.7 (CH₃, OMe), 57.8 (CH₃, OMe), 58.8 (CH₃, OMe), 59.3 (CH₃, OMe), 60.5 (CH₂, C-4), 72.1 (CH₂, C-6'), 72.9 (CH, C-5'), 76.3 (CH, C-3'), 76.7 (CH, C-4'), 77.4 (CH, C-2'), 97.2 (C, C-1') ppm. IR (film): $\tilde{\nu} = 2929$, 2827, 1454, 1193, 1101 cm⁻¹. MS (70 eV, EI): m/z (%) = 416 (2) [M]⁺, 371 (1), 289 (8), 257 (4). HRMS (EI): m/z : calcd. for C₁₄H₂₅IO₆: 416.0696 [M]⁺; found 416.0688. C₁₄H₂₅IO₆ (416.25): calcd. C 40.40, H 6.05; found C 40.65, H 5.96.

Compound 34a: [α]_D = +36.4 ($c = 0.220$, in CHCl₃). ¹H NMR (500 MHz, CDCl₃): $\delta = 1.12$ (m, 1 H, 3-H_a), 2.14 (dddd, $J = 3.5$, 6.2, 12.3, 12.3, 14.1 Hz, 1 H, 3-H_b), 2.67 (dddd, $J = 1.5$, 3.2, 3.2, 14.4 Hz, 1 H, 2-H_a), 3.08 (ddd, $J = 3.8$, 12.6, 14.7 Hz, 1 H, 2-H_b), 3.42–3.44 (m, 2 H, 5'-H, 4'-H), 3.49 (s, 3 H, OMe), 3.51 (s, 3 H, OMe), 3.53 (s, 3 H, OMe), 3.56 (dd, $J = 2.9$, 9.4 Hz, 1 H, 3'-H), 3.60–3.70 (m, 4 H, 6'-H₂, 4-H₂), 3.78 (s, 3 H, OMe), 4.05 (d, $J = 2.9$ Hz, 1 H, 2'-H) ppm. ¹³C NMR (125.7 MHz, CDCl₃): $\delta = 7.8$ (C, C-1) 27.0 (CH₂, C-3), 50.1 (CH₂, C-2), 58.1 (CH₃, OMe), 60.1 (CH₂, C-4), 60.1 (CH₃, OMe), 60.7 (CH₃, OMe), 61.0 (CH₃, OMe), 72.1 (CH₂, C-6'), 74.0 (CH, C-5'), 75.7 (CH, C-4'), 81.6 (CH, C-2'), 84.2 (CH, C-3'), 96.7 (C, C-1') ppm. IR (film): $\tilde{\nu} = 2925$, 2852, 1456, 1196, 1103 cm⁻¹. MS (70 eV, EI): m/z (%) = 542 (6) [M]⁺, 415 (53), 288 (100), 253 (23). HRMS (EI): m/z : calcd. for C₁₄H₂₄I₂O₆: 541.9662 [M]⁺; found 541.9666. C₁₄H₂₄I₂O₆ (542.15): calcd. C 31.02, H 4.46; found C 31.25, H 4.46.

Reductive HAT of 2,6-Anhydro-7,8,9-trideoxy-1,3,4,5-tetra-*O*-methyl-10-*O*-*N*-phthalimido-*D*-glycero-*D*-manno-decitol (42). Method A (*n*Bu₃SnH/AIBN): A solution of phthalimide **42** (29 mg, 0.066 mmol) in dry benzene (5 mL) containing *n*Bu₃SnH (18 μ L, 0.066 mmol) and AIBN (1 mg, 0.007 mmol) was heated at reflux temperature for 1 h. After cooling to room temperature the reaction mixture was concentrated under reduced pressure. The residue was dissolved in CH₃CN, washed with *n*-hexane and the combined more polar extracts were concentrated under reduced pressure. The residue was purified by column chromatography (hexanes/EtOAc, 25:75) to give in order of elution the β -alcohol **43** (7.8 mg, 0.027 mmol, 40%) and the α -alcohol **31** (11.4 mg, 0.039 mmol, 59%) which had physical and spectroscopic properties identical to those of the product prepared in the Supporting Information.

Compound 43: [α]_D = -22.5 ($c = 0.40$, in CHCl₃). ¹H NMR (500 MHz, CDCl₃): $\delta = 1.40$ –1.62 (m, 5 H, 3-H₂, 2-H₂, 1-H_a), 1.82 (m, 1 H, 1-H_b), 3.18 (dd, $J = 3.1$, 9.5 Hz, 1 H, 3'-H), 3.20–3.24 (m, 2 H, 5'-H, 1'-H), 3.34 (dd, $J = 9.5$, 9.5 Hz, 1 H, 4'-H), 3.37 (s, 3 H, OMe), 3.47 (dd, $J = 0.6$, 2.8 Hz, 1 H, 2'-H), 3.511 (s, 3 H, OMe), 3.513 (s, 3 H, OMe), 3.52 (dd, $J = 6.4$, 10.4 Hz, 1 H, 6'-H_a), 3.57 (s, 3 H, OMe), 3.62 (dd, $J = 2.0$, 10.6 Hz, 1 H, 6'-H_b), 3.64 (ddd, $J = 2.2$, 6.4, 6.4 Hz, 2 H, 4-H₂) ppm. ¹³C NMR (100.6 MHz, CDCl₃): $\delta = 22.1$ (CH₂, C-2), 30.6 (CH₂, C-1), 32.5 (CH₂, C-3), 57.7 (CH₃, OMe), 59.1 (CH₃, OMe), 60.6 (CH₃, OMe), 61.6 (CH₃, OMe), 62.5 (CH₂, C-4), 72.2 (CH₂, C-6'), 77.0 (CH, C-4'), 77.523 (CH, C-2'), 78.4 (CH, C-2'), 79.2 (CH, C-5'), 86.8 (CH, C-3') ppm. IR (film): $\tilde{\nu} = 3472$ cm⁻¹. MS (70 eV, EI): m/z (%) = 293 (2) [M + H]⁺, 275 (23), 211 (8), 101 (100). HRMS (EI): m/z : calcd. for C₁₄H₂₉O₆: 293.1964 [M + H]⁺; found 293.1957. C₁₄H₂₈O₆ (292.37): calcd. C 57.51, H 9.65; found C 57.54, H 9.57.

Method B (*n*Bu₃SnD/AIBN): A solution of phthalimide **42** (30 mg, 0.069 mmol) in dry benzene (5.1 mL) containing *n*Bu₃SnD (19 μ L,

0.069 mmol) and AIBN (1.1 mg, 0.007 mmol) was heated at reflux temperature for 1 h. After cooling to room temperature the reaction mixture was concentrated under reduced pressure. The residue was dissolved in CH₃CN, washed with *n*-hexane and the combined more polar extracts were concentrated under reduced pressure. The residue was purified by silica gel column chromatography (hexanes/EtOAc, 25:75) to give in order of elution 5,9-anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl-*D*-(5-²H)-glycero-*D*-galacto-decitol (**44**) (6.5 mg, 0.022 mmol, 32%) and 2,6-anhydro-7,8,9-trideoxy-1,3,4,5-tetra-*O*-methyl-*D*-[7-²H]-glycero-*D*-manno-decitol (**45**) (12.3 mg, 0.042 mmol, 61%, ¹H/²H ratio, 1:4).

Compound 44: ¹H NMR (500 MHz, CDCl₃): $\delta = 1.40$ –1.62 (m, 5 H, 3-H₂, 2-H₂, 1-H_a), 1.82 (m, 1 H, 1-H_b), 3.18 (dd, $J = 3.1$, 9.5 Hz, 1 H, 3'-H), 3.23 (ddd, $J = 1.7$, 6.0, 9.7 Hz, 1 H, 5'-H), 3.34 (dd, $J = 9.5$, 9.5 Hz, 1 H, 4'-H), 3.37 (s, 3 H, OMe), 3.47 (d, $J = 3.1$ Hz, 1 H, 2'-H), 3.511 (s, 3 H, OMe), 3.513 (s, 3 H, OMe), 3.52 (dd, $J = 6.2$, 10.4 Hz, 1 H, 6'-H_a), 3.57 (s, 3 H, OMe), 3.62 (dd, $J = 2.0$, 10.6 Hz, 1 H, 6'-H_b), 3.64 (ddd, $J = 2.2$, 6.4, 6.4 Hz, 2 H, 4-H₂) ppm. ¹³C NMR (125.7 MHz, CDCl₃): $\delta = 22.1$ (CH₂, C-2), 30.486 (CH₂, C-1), 32.5 (CH₂, C-3), 57.7 (CH₃, OMe), 59.1 (CH₃, OMe), 60.6 (CH₃, OMe), 61.6 (CH₃, OMe), 62.5 (CH₂, C-4), 72.3 (CH₂, C-6'), 77.1 (CH, C-4'), 77.502 (CH, C-2'), 79.2 (CH, C-5'), 86.8 (CH, C-3') ppm. MS (70 eV, EI): m/z (%) = 276 (10) [M - OH]⁺, 257 (2), 101 (100). HRMS (EI): m/z : calcd. for C₁₄H₂₆²HO₅: 276.1921 [M - OH]⁺; found 276.1924.

Compound 45: ¹H NMR (500 MHz, CDCl₃): $\delta = 1.36$ –1.69 (m, 5 H, 3-H₂, 2-H₂, 1-H), 3.34 (dd, $J = 3.4$, 3.4 Hz, 1 H, 2'-H), 3.36 (s, 3 H, OMe), 3.37 (m, 1 H, 4'-H), 3.40 (s, 3 H, OMe), 3.467 (s, 3 H, OMe), 3.469 (s, 3 H, OMe), 3.48 (m, 1 H, 3'-H), 3.55–3.63 (m, 5 H, 6'-H₂, 5'-H, 4-H₂), 3.94 (dd, $J = 4.0$, 9.8 Hz, 1 H, 1'-H) ppm. ¹³C NMR (125.7 MHz, CDCl₃): $\delta = 21.857$ (CH₂, C-2-D), 21.953 (CH₂, C-2-H), 28.681 (CHD, t, ¹J_{C,D} = 19 Hz, C-1-D), 29.034 (CH₂, C-1-H), 32.3 (CH₂, C-3), 57.6 (CH₃, OMe), 57.8 (CH₃, OMe), 59.1 (CH₃, OMe), 59.7 (CH₃, OMe), 62.6 (CH₂, C-4), 71.8 (CH₂, C-6'), 72.183 (CH, C-1'-D), 72.247 (CH, C-1'-H), 72.5 (CH, C-5'), 76.8 (CH, C-4'), 78.4 (CH, C-2'), 79.7 (CH, C-3') ppm. MS (70 eV, EI): m/z (%) = 293 (1) [M]⁺, 269 (7), 267 (5), 216 (7). HRMS (EI): m/z : calcd. for C₁₄H₂₇²HO₆: 293.1949 [M]⁺; found 293.1953.

Oxidative HAT of 5,9-Anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl-*D*-glycero-*D*-galacto-decitol (43): A solution of alcohol **43** (25 mg, 0.086 mmol) in CH₂Cl₂ (3.5 mL) containing DIB (47 mg, 0.146 mmol) and iodine (22 mg, 0.086 mmol) under nitrogen was irradiated with two 80 W tungsten-filament lamps at room temperature for 0.5 h. The reaction mixture was then poured into 10% aqueous Na₂S₂O₃ and extracted with CH₂Cl₂, dried with Na₂SO₄, and concentrated. Chromatography of the residue (hexanes/EtOAc, 7:3) gave in order of elution 1,5-anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl- α -*D*-manno-dec-5-ulopyranose **32a** (7 mg, 0.024 mmol, 28%) and 1,5-anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl- β -*D*-manno-dec-5-ulopyranose **32b** (12.5 mg, 0.043 mmol, 50%), which had physical and spectroscopic properties identical to those of the products previously obtained (vide supra).

Reductive HAT of 5,9-Anhydro-2,3,4-trideoxy-6,7,8,10-tetra-*O*-methyl-1-*O*-phthalimido-*D*-glycero-*D*-galacto-decitol (46). Method A (*n*Bu₃SnH/AIBN): A solution of phthalimide **46** (47 mg, 0.107 mmol) in dry benzene (8.1 mL) containing *n*Bu₃SnH (29 μ L, 0.107 mmol) and AIBN (1.8 mg, 0.011 mmol) was heated at reflux temperature for 1 h. After cooling to room temperature the reaction mixture was concentrated under reduced pressure. The residue was dissolved in CH₃CN, washed with *n*-hexane and the combined more polar extracts were concentrated under reduced pressure. The

residue was purified by column chromatography (hexanes/EtOAc, 3:7) to give the β -alcohol **43** (30 mg, 0.103 mmol, 96%) which had physical and spectroscopic properties identical to those of the product obtained in the Supporting Information.

Method B ($n\text{Bu}_3\text{SnD/AIBN}$): A solution of phthalimide **46** (60 mg, 0.137 mmol) in dry benzene (10.3) containing $n\text{Bu}_3\text{SnD}$ (37 μL , 0.137 mmol) and AIBN (2.2 mg, 0.014 mmol) was heated at reflux temperature under nitrogen for 1 h. After this time another portion of $n\text{Bu}_3\text{SnH}$ (18.5 μL , 0.068 mmol) and AIBN (2.2 mg, 0.014 mmol) were added and heating at reflux was continued for an additional 0.5 h. After cooling at room temperature the mixture was concentrated under reduced pressure. The residue was dissolved in CH_3CN , washed with n -hexane and the combined more polar extracts were concentrated under reduced pressure. The residue was purified by column chromatography (hexanes/EtOAc, 3:7), to give 5,9-anhydro-2,3,4-trideoxy-6,7,8,10-tetra- O -methyl-D-(5- ^2H)-glycero-D-galacto-decitol **44** (40 mg, 0.136 mmol, 100%) which had physical and spectroscopic properties identical to those of the product previously obtained (vide supra).

Supporting Information (see also the footnote on the first page of this article): A complete description of experimental details of precursors and analytical data for all new compounds can be found in the online version.

Acknowledgments

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