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Synthetic Strategies Directed Towards 5a-Carbahexopyranoses and Derivatives Based on 6-*endo-trig* Radical Cyclizations

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Dedicated to Professor Dr. Benjamín Rodríguez on the occasion of his retirement

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Several synthetic strategies directed towards 5a-carbahexopyranoses and based on 6-*endo-trig* radical cyclization of unsaturated carbohydrate derivatives have been devised. Three elements for regiocontrol to optimize the 6-*endo*/5-*exo* ratio have been incorporated, and their efficiencies in directing 6-*endo* cyclizations have been evaluated. These elements – namely: i) the incorporation of a substituent at C-5 (radical numbering), ii) the use of a vinyl (rather than alkyl) radical, and iii) the inclusion of ring strain in the system – have proved useful when used in combination. The simultaneous presence of two of them also results in 6-*endo* selectivity. On another topic, the ozonation of the ensuing alkenylstananes to afford diols seems to be based on a tin-oxygen rearrangement, similar to that reported for related vinylsilanes, rather than on remarkable stabilities of tin-containing primary ozonides as we had previously suggested.

Introduction

Carbasugars, carbohydrate derivatives in which the ring oxygen has been replaced by a methylene group, were first conceived by McCasland and co-workers in 1966,[1] as carbohydrate mimetics[2] with enhanced chemical stabilities. Soon after McCasland's pioneering reports,[1,3] 5a-carba-α-D-galactopyranose (**2**, Figure 1) was isolated as a natural product from a fermentation broth of *Streptomyces* sp. MA-4145.[4] During the last four decades, and in parallel with the recognition of the relevant role played by carbohydrate derivatives in biological processes,[5] the synthesis,[6] biology and conformational aspects of carbasugars have been the subject of extensive studies.[7]

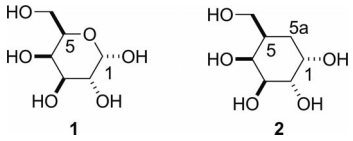
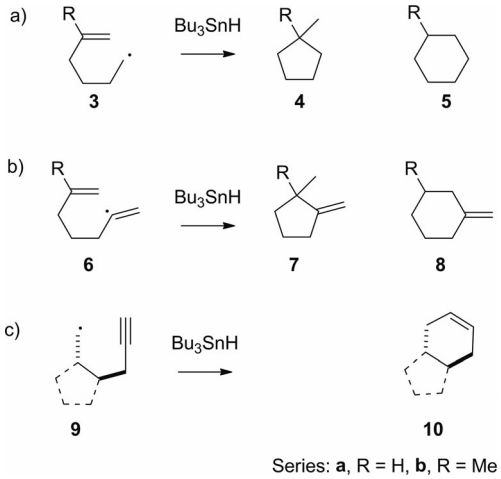


Figure 1. α-D-Galactopyranose (**1**) and 5a-carba-α-D-galactopyranose (**2**) as examples of a sugar and its carbasugar counterpart.

We are interested in the application of free radical processes to carbohydrate chemistry.[8] In this context we embarked some time ago on a project dealing with the synthesis of carbapyranose derivatives (5a-carbahexopyranoses)[9] through radical cyclization of the appropriate carbohydrate precursors. At the onset of this work, only a very few examples of radical cyclizations of sugar derivatives leading to carbapyranoses were known, and all of them were based on 6-*exo*-type cyclizations either of hept-6-enyl or of hept-6-ynyl radicals (radical numbering).[10,11,12]

On the other hand, six-membered rings could also be accessible through 6-*endo*-type cyclizations of hex-5-enyl radicals, and we were interested in evaluating the potential of such transformations for the preparation of carbapyranoses (Scheme 1, a, b). Radical cyclization of hex-5-enyl



Scheme 1. a), b) 6-*endo-trig* versus 5-*exo-trig*, and c) 6-*endo-dig* radical cyclizations of hex-5-enyl- (**3**, **6**) and hex-5-ynyl-type (**9**) radicals.

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radicals usually gives rise to cyclopentane derivatives through a predominant 5-*exo* ring-closure mode,[13] however, in a process governed by stereoelectronic rather than thermodynamic factors (Scheme 1, a).[14] Nevertheless, we were encouraged by the fact that the regiochemistry of the process can be influenced, and even reversed, to favour the formation of six-membered rings by factors other than stereoelectronic control.[15]

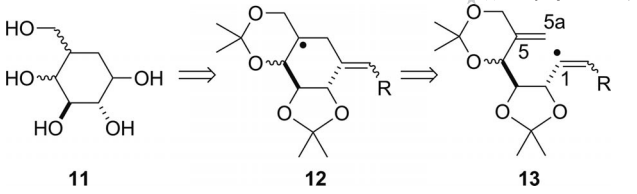
In this context, three main strategies had previously been used to induce 6-*endo* selectivity: *i*) the incorporation of a substituent at C-5 (Scheme 1, a, R ≠ H), *ii*) the use of a vinyl (rather than alkyl) radical (Scheme 1, b), and *iii*) the introduction of ring strain in the system (Scheme 1, c). With regard to issue *i*), the cyclization of **3a** (R = H) yields a 49:1 mixture of **4** and **5**, whereas the presence of a methyl group at C-5, as in **3b**, favours the formation of **5** over **4** (3:2 *endo*/*exo* ratio), a result that has been ascribed to an unfavourable steric effect in the 5-*exo* mode of cyclization.[16] The use of vinyl radicals [issue *ii*); e.g., **6**, Scheme 1, b] under tin hydride reaction conditions was independently studied by Beckwith's[17] and Stork's[18] groups. They found that although **6a** exclusively undergoes 5-*exo* cyclization, the ensuing kinetic radical undergoes an isomerisation to the thermodynamic methylenecyclohexane that is favoured at low concentrations of stannane. On the other hand, we have recently shown that 5-methyl-1-methylenehex-5-enyl radicals (e.g., **6b**) are able, unlike their demethyl analogues **6a**, to undergo "direct" 6-*endo-trig* ring closure that adds to the 6-*endo* regiochemistry of the transformation.[19] Finally, Hoffmann and co-workers found that five-membered rings with two appendages, bearing the radical and the radical acceptor in an *anti* disposition, undergo 6-*endo* ring closure rather than the potentially faster 5-*exo* cyclization, which is prevented by ring strain, as in issue *iii*) (Scheme 1, c).[20]

Here we give a full account of our studies in the evaluation of the regiodirecting factors favouring 6-*endo-trig* radical cyclization discussed above, as well as their application to carbohydrate substrates for the preparation of carbahexopyranoses and derivatives.[21]

Results and Discussion

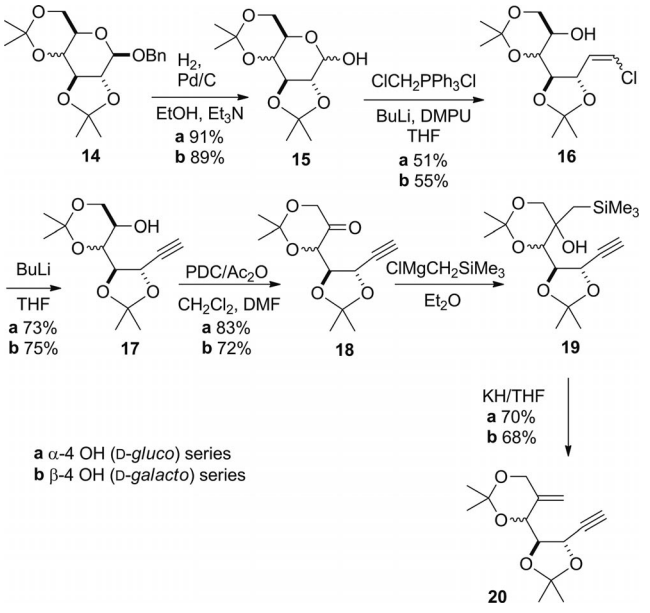
6-*endo-trig*-Radical Cyclization of Vinyl Radicals in Ring-Strained Systems

Our first approach to the preparation of carbapyranoses (e.g., **11**, Scheme 2) was based on the cyclization of the vinyl radicals **13**, incorporating the three regiodirecting factors discussed above: substitution at C-5, the presence of a vinyl radical, and fixing of the *anti* disposition of the carbon chains bearing the radical and the radical acceptor with the aid of an isopropylidene ring. The proposed strategy featured the generation of the stereogenic centre at C-5 (defining the D or L configuration) by reduction of the radicals **12** and the retrosynthetic correlation of the exocyclic vinyl group with the OH at C-1 in the carbasugar (Scheme 2).



Scheme 2. Retrosynthesis of the carbahexopyranoses **11** by 6-*endo-trig* radical cyclization of the carbohydrate-derived vinyl radicals **13**.

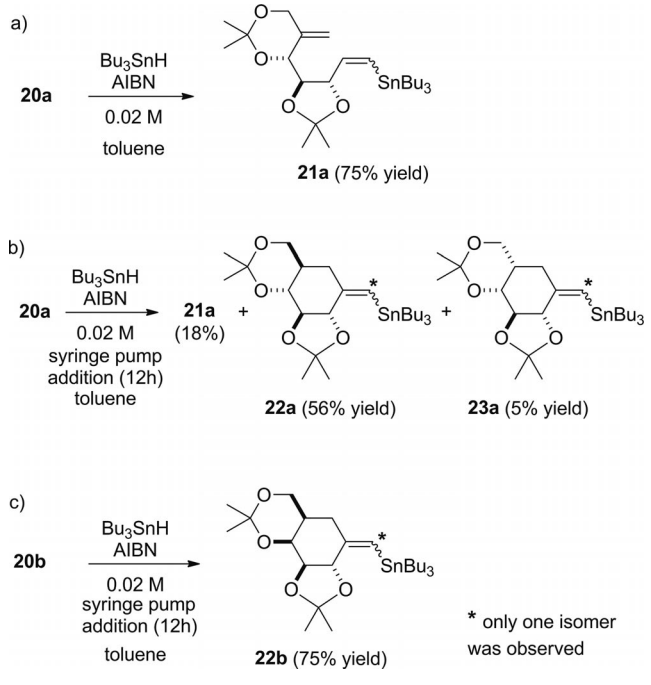
These structural requirements were met by sugars in which the OH groups at C-2 and C-3 displayed *anti* orientations, but with both configurations at C-4 being possible. On the other hand, it was intended to generate the vinyl radical by tributyltin hydride addition to a terminal alkyne (Scheme 2, R = $SnBu_3$).[22] The enynes **20a** and **20b**, based on D-glucose and D-galactose diacetonides, were chosen as our test candidates, and their preparation is outlined in Scheme 3. The synthesis of the alkynes **17a** and **17b** was carried out by the procedure of Toma and co-workers,[23] though with some modifications. We showed that hydrogenolysis of the β-benzyl gluco- and β-benzyl galactosides **14a** and **14b**, respectively, is a more reliable and higher-yielding process than the reported hydrogenolysis of mixtures of α- and β-benzyl glycosides.[24] Accordingly, the benzyl β-glycosides **14a** and **14b** were hydrogenolysed in the presence of Pd/C in ethanol containing triethylamine to give **15a** and **15b** in excellent yields. Next, Wittig treatment of these hemiacetals with (chloromethylene)triphenylphosphorane in the presence of *n*-butyllithium (BuLi) and DMPU in THF yielded 1:1 mixtures of the (*E*/*Z*)-chlorovinyl derivatives **16a** and **16b**. Dehydrohalogenation of the ethylenic derivatives with BuLi at –78 °C in THF, furnished the desired heptynitols **17a** and **17b** in good yields.



Scheme 3. Synthesis of the D-glucose- and D-galactose-derived enynes **20a** and **20b**, respectively.

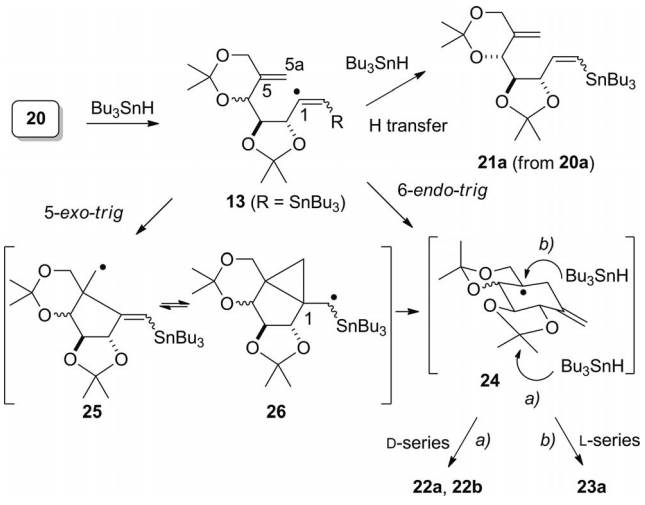
Oxidation of **17a** and **17b** proved troublesome. Application of Swern oxidation conditions[25] resulted in partial epimerization at C-4 of the ensuing ketones, which thus both gave mixtures of **18a** and **18b**. Dess–Martin reagent,[26] though, did allow the preparation of **18a** (68% yield) without epimerization, and so did the PDC/Ac_2O combination,[27] which was preferred for its simplicity and was also applied to the oxidation of **17b**. Methylenation of the ketones **18a** and **18b** was first attempted by Wittig olefination with methyltriphenylphosphonium bromide in the presence of different bases (*n*BuLi, *t*BuOK, sodium hexamethyldisilazane) at several temperatures, but proved unsuccessful. The use of Tebbe reagent[28] furnished access to the methylene derivatives **20** in small-scale reactions, but resulted in diminished reaction yields when the reaction was scaled up. The attempted use of Lombardo's methylenating reagent[29] was also unsuccessful. Finally, we were able to install the methylene group at C-4 by use of the two-step Peterson olefination procedure.[30] Treatment of the ketones **18a** or **18b** with trimethylsilylmethylmagnesium chloride in diethyl ether at 0 °C gave the silyl intermediates **19**, isolation of which prior to the next elimination step proved to be beneficial (KH/THF). Attempts to carry out the elimination without isolation of **19** resulted in the formation of desilylated methyl derivatives in a considerable extent.

An attempted radical cyclization with the glucose-derived enyne **20a** [Bu_3SnH (1.5 equiv.), toluene, 80 °C, 0.02 M] resulted in the formation of an open-chain alkenylstannane (Scheme 4, a). However, it was gratifying to observe that slow (syringe pump) addition of Bu_3SnH (1.5 equiv.) resulted in the formation of the tricyclic carbasugar derivatives **22a** (56% yield) and **23a** (5% yield) as major products (Scheme 4, b), along with some bicyclic alkenylstannanes **21a** (18% yield). Application of similar reaction conditions to the D-galactose isomer **20b** furnished the carbasugar derivative **22b** in a regio- and stereoselective manner and in 75% yield.



Scheme 4. Radical cyclization of the enynes **20a** and **20b**.

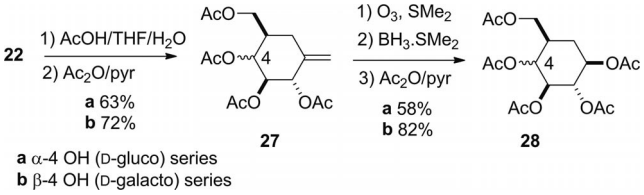
At high stannane concentrations (Scheme 4, a), hydrogen transfer from the tributyltin hydride takes place more rapidly than radical cyclization, to give the open-chain alkenylstannane[31] **21a** (see also **20a**→**13a**→**21a** in Scheme 5). At low stannane concentrations (syringe pump addition), though, the vinyl radical **13** (R = $SnBu_3$) is able to undergo the – slow – 6-*endo*-*trig* cyclization more rapidly than hydrogen transfer, thus leading to the tricyclic radical **24**. This undergoes a hydrogen transfer from Bu_3SnH and, depending on the approach of the incoming tributyltin hydride, gives the carbasugar derivatives **22** or **23** (only one isomeric alkene was observed in each case, but the stereochemistry has not been assigned). A completely stereoselective α-face hydrogen transfer was observed in the D-galactose derivative **13b** (leading to the 5a-carba-D-galactopyranose derivative **22b**), whereas in the D-glucose series (e.g., **13a**) a highly selective α-approach, leading preferentially to **22a**, could also be observed. An alternative route involving 5-*exo*-*trig* cyclization to generate the methylenecyclopentyltype radical **25**, and thence **24** via the cyclopropyl methyltype radical **26**, is less likely to happen because of the strain associated with the *trans*-2,3-*O*-isopropylidene ring.[21b]



Scheme 5. Regio- and stereoselectivity in the formation of the carbasugar derivatives **22** and **23** by radical cyclization of the diacetonide-enynes **20**.

The stereochemical outcomes of the reactions were confirmed by correlation of the resulting carbasugar derivatives with the previously reported 5a-carba-β-D-glucopyranose **28a** and 5a-carba-β-D-galactopyranose **28b**, as outlined in Scheme 6: acid treatment (AcOH/THF/H_2O) of the stannyl diacetonides **22a** and **22b** furnished destannylated tetraols that upon acetylation gave "carbasugar *exo*-glycals"[32] **27a** and **27b**, and subsequent ozonolysis followed by stereoselective reduction and acetylation yielded the previously described 5a-carba-β-D-glucopyranose pentaacetate

{**28a**,[33,34] $[\alpha]_D^{21}$ = +12.2 (*c* = 1.0, $CHCl_3$) [ref.[34b] +13.8 (*c* = 1.0, $CHCl_3$)]} and 5a-carba-β-D-galactopyranose pentaacetate {**28b**,[35] $[\alpha]_D^{21}$ = –3.4 (*c* = 0.4, $CHCl_3$)}.



Scheme 6. Preparation of 5a-carba-β-D-gluco- and 5a-carba-β-D-galactopyranose pentaacetates (**28a** and **28b**, respectively).

6-*endo* Radical Cyclization of Alkyl Radicals in Ring-Strained Systems

The substrates **29**–**32** (Figure 2) were also of interest for evaluation of the regiodirecting effect of the ring strain. These substrates, incorporating 2,3-*O*-isopropylidene rings (associated with ring strain), were precursors of alkyl radicals and therefore devoid of the *endo*-directing properties associated with the vinyl radical. [21b]

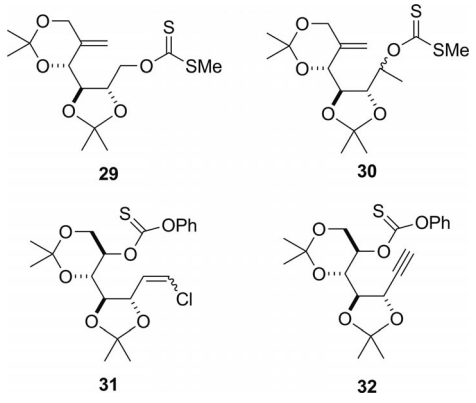


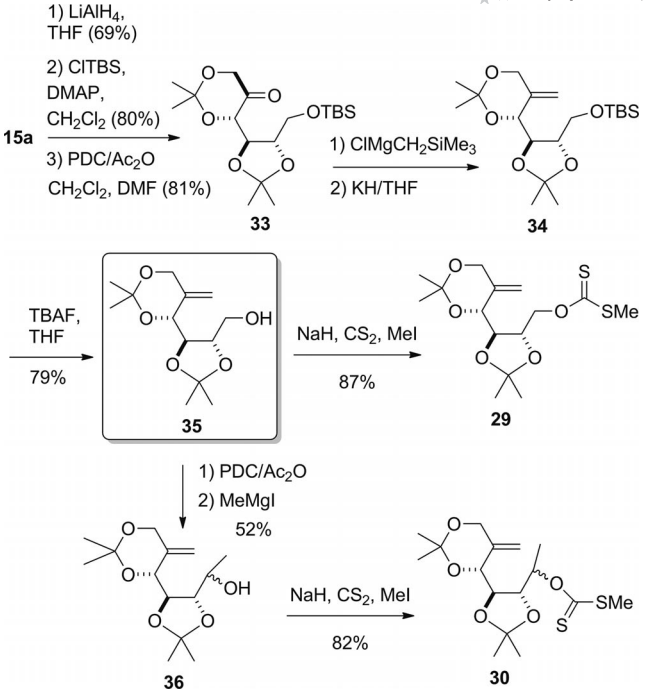
Figure 2. Precursors of alkyl radicals in ring-strained systems as potential substrates for 6-*endo* radical cyclization leading to carbasugar derivatives.

The synthetic route to the xanthates **29** and **30** started from the hemiacetal **15a** (Scheme 7). Reduction of **15a** ($LiAlH_4$) generated a diol[36] that could be selectively silylated at the primary position and subsequently oxidized (PDC/Ac_2O) to afford the ketone **33**. This was subjected to Peterson olefination to give the alkene **34**. Desilylation of **34** led to the primary alcohol **35**, which was transformed into the xanthates **29** and **30** (HNa, CS_2, MeI), the latter by an oxidation (PDC/Ac_2O) and MeMgI addition sequence.

The phenyl thionocarbonates **31** and **32** were prepared uneventfully by treatment of **16a** and **17a**, respectively, with phenyl chlorothionoformate [PhOC(S)Cl].

The radical cyclization of derivatives **29**–**32** was performed in toluene solution (0.02 M) at 85 °C by addition of Bu_3SnH (1.5 equiv.) and AIBN under argon (Table 1).

The cyclization of alkyl radicals arising from **29** and **30** took place in a 6-*endo-trig* manner to give the carbasugar derivatives **37** and **38**, respectively (Table 1, Entries *i* and *ii*).



Scheme 7. Synthesis of the xanthates **29** and **30** from the hemiacetal **15a**.

Table 1. Radical cyclization of xanthates **29**–**32** by treatment with Bu_3SnH (1.5 equiv.) and AIBN in toluene solution (0.02 M) at 85 °C under syringe pump addition conditions (6 h).

Entry	Xanthate	Product	Yield (%)
i	**29**	**37** + **41**	62
ii	**30**	**38**	64
iii	**31**	**39**	–
iv	**32**	**40**	–

For purposes of characterization, the tricyclic derivative **37** was readily transformed into its tetraacetate **41**, which displayed coupling constants consistent with a D-*gluco* derivative (e.g., 4-H, 4.96 ppm, t, *J* = 9.6 Hz), by acid hydrolysis

(AcOH/THF/H_2O 2:4:1) followed by acetylation (Ac_2O/pyridine) in 67% yield (Table 1, Entry *i*). Radical cyclization of the secondary alkyl radical arising from the xanthate **30** resulted in the stereoselective formation of the β-*C*-methyl 5a-carba-D-glucopyranose **38**, the stereochemistry of which at C-1 was inferred from the 2-H coupling constants $J_{1,2}$ = 8.8 Hz and $J_{2,3}$ = 9.0 Hz (Table 1, Entry *ii*).

In contrast, the cyclic secondary radicals arising from **31** and **32** (Table 1, Entries *iii* and *iv*, respectively) did not undergo cyclization, and only the deoxygenated derivatives **39** and **40** could be isolated. In our opinion the cyclic natures of the radicals complicate the approach from a steric standpoint, thus making the hydrogen transfer process faster than the cyclization step.

6-*endo* Radical Cyclization of Vinyl Radicals in Unstrained Systems

To evaluate enynes devoid of ring strain we selected the derivatives **42**–**44** (Figure 3). The D-mannose diacetonide **42**, unlike the enyne diacetonides **20a** and **20b**, contains a 2,3-*cis*-*O*-isopropylidene ring rather than the 2,3-*trans* isopropylidene system responsible for ring strain. The D-mannose- and D-glucose-derived enynes **43** and **44**, respectively, differ in the natures of their protecting groups, benzyl and acetyl groups having been chosen to evaluate their compatibilities with the reaction process.

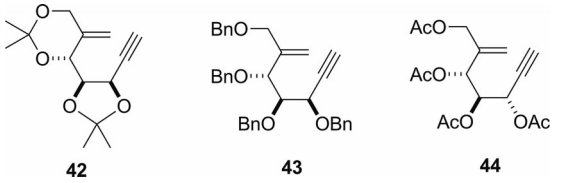
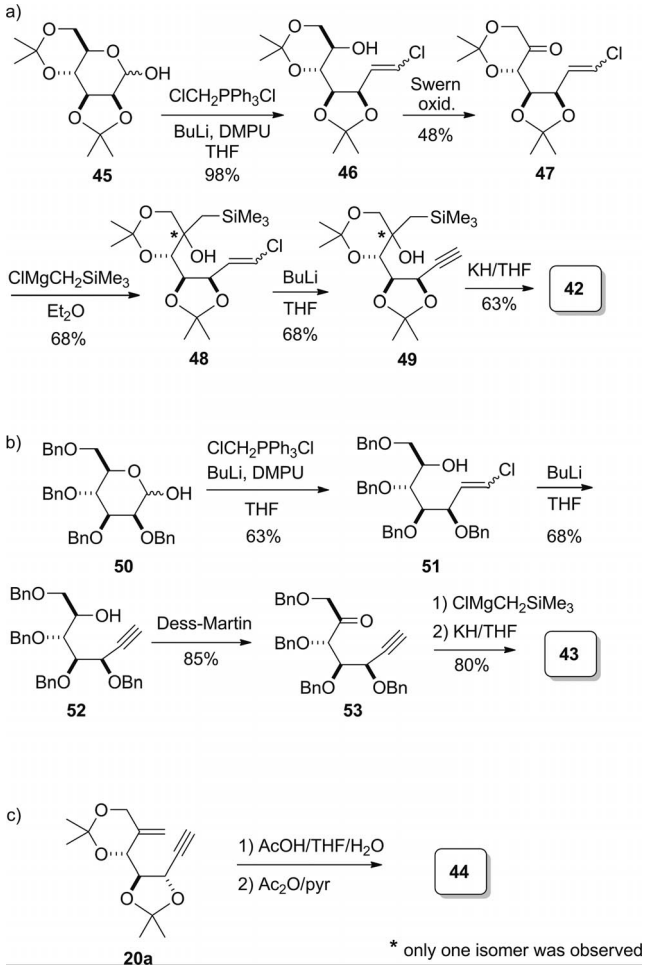


Figure 3. Enynes **42**–**44**, containing no *trans*-2,3-*O*-isopropylidene groups.

The D-mannose enyne **42** was prepared from mannose diacetonide (**45**[37]) through a synthetic route similar to that used for **20a** and **20b** (Scheme 8, a). A sequence consisting of a Wittig reaction, Swern oxidation (no epimerization at C-4 was observed), stepwise Peterson olefination and dehydrohalogenation then led to the enyne **42** in acceptable overall yield.

2,3,4,6-Tetra-*O*-benzyl-D-mannose (**50**)[38] was similarly subjected to a related reaction sequence to provide the enyne **43** (Scheme 8, b). Finally, mild acid hydrolysis of the isopropylidene groups in **20a** and subsequent acetylation paved the way to the tetraacetate **44** (Scheme 8, c).

Radical cyclization of the enynes **42**–**44**, at low stannane concentrations, in all cases furnished methylenecyclohexane derivatives (Table 2). We have previously shown that at low stannane concentrations the final "6-*endo*" regiochemistry is the result both of a direct 6-*endo*-*trig* cyclization and of a 5-*exo*-*trig* cyclization followed by rearrangement of the ensuing methylenecyclopentyl radicals.[21b] The tricyclic carbasugar precursors **54** and **55** were obtained in a 15:1 ratio (Table 2, Entry *i*), in favour of the D-carbasugar precursor



Scheme 8. Synthesis of the enynes **42**–**44**.

Table 2. Radical cyclization of the enynes **42**–**44** by treatment with Bu_3SnH (1.5 equiv.) and AIBN in toluene solution (0.02 M) at 85 °C under syringe pump addition conditions (6 h).

Entry	Enyne	Products (ratio)	Yield (%)
i	**42**	**54** (15:1) **55**	64
ii	**43**	**56** (1.6:1) **57**	80[a]
iii	**44**	**58** (1.4:1) **59**	64[a]

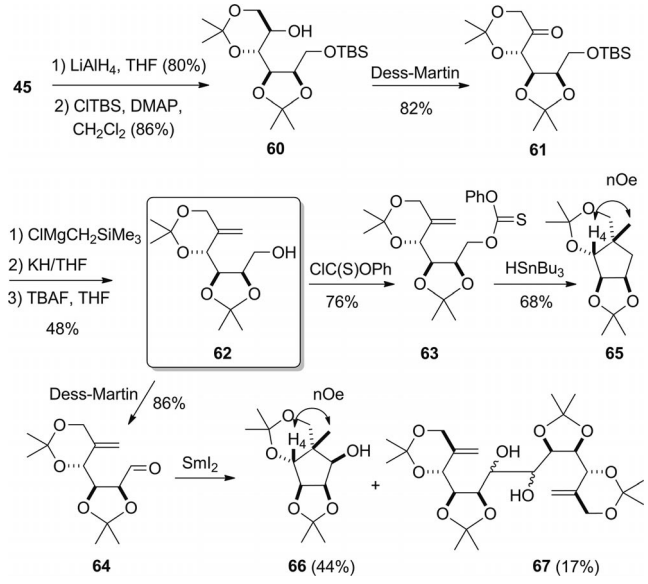
[a] The radical cyclizations were followed by destannylation through treatment with THF/H_2O/AcOH. The yields refer to the two-step transformations.

(i.e., **54**), a result consistent with previous observations on the tricyclic derivatives **22a**, **22b**, **37** and **38**. Benzyl and acyl groups could be used as protecting groups in these radical cyclizations without any appreciable presence of intramolecular hydrogen transfer from the former to the vinyl radical (Table 2, Entries *ii* and *iii*). The destannylated methylenecyclohexane derivatives **57** and **59** were obtained from the corresponding alkenylstannanes on treatment with THF/H_2O/AcOH.

Although from the examples in Table 2 it was clear that the presence of the *anti* 2,3-*O*-isopropylidene group is not a requirement for the cyclization to occur in a "6-*endo* mode" the presence of isopropylidene groups is highly advisable in terms of stereoselectivity of the process. Enynes **43** and **44**, without isopropylidene rings, afforded the methylenecyclohexanes **56/57** and **58/59**, respectively, without significant stereocontrol relative to the bicyclic enyne **42** (Table 2, compare Entry *i* with Entries *ii* and *iii*).

5-*exo* Radical Cyclization of Alkyl Radicals in Unstrained Systems

The phenylthionocarbonate **63** and the aldehyde **64** (Scheme 9), prepared by derivatization and oxidation, respectively, of the hydroxy alkene **62**, were used as precursors for the generation of unstrained alkyl radicals to test the regiochemistries in their radical cyclizations. Compound **62** was prepared uneventfully from the hemiacetal **45** by the transformations outlined in Scheme 9. Its synthesis was modelled after that of the alkene **35** (Scheme 7) and made use of related transformations.



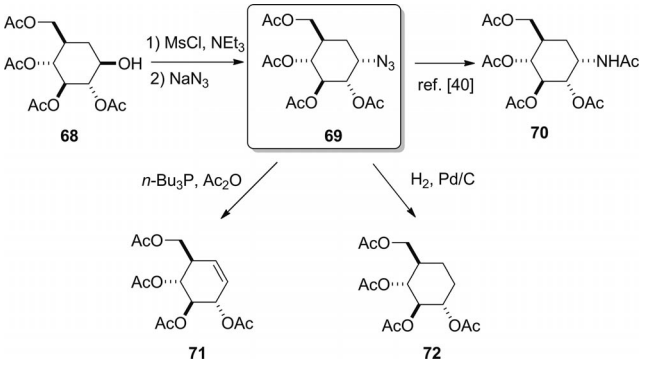
Scheme 9. Synthesis and radical cyclization of the unstrained radical precursors **63** and **64**.

The radical cyclization of **63**, under the previously described conditions, exclusively yielded the tricyclic cyclopentane derivative **65**, resulting from 5-*exo*-*trig* cyclization. The stereochemistry at the geminal carbon was unambiguously determined by an observed nOe between the angular methyl group and H-4. On the other hand, SmI_2-promoted carbonyl alkene cyclization[39] of the aldehyde **64** yielded the highly oxygenated cyclopentane derivative **66** along with the dimer **67** resulting from pinacol coupling.

These results serve to illustrate that the presence of alkyl substitution at C-5 (radical numbering) as the only regiodirecting factor is not sufficient to induce 6-*endo*-*trig* cyclization [compare the radical cyclization of **63** (Scheme 9) with that of **29** (Table 1, Entry *i*), in which ring strain was also present].

Synthesis of Carbasugar Derivatives – Formal Total Synthesis of Penta-*N*,*O*-acetylvalidamine

The methylenecyclohexane derivatives obtained by radical cyclization are useful precursors for the preparation of different carbasugar derivatives. The 5a-carba-β-D-glucose derivative **68** (Scheme 10), readily obtained by ozonolysis of **27a** (O_3, MeOH, –78 °C) followed by reduction with BH_3·SMe_2, for instance, yielded, after mesylation (MsCl, NEt_3) and nucleophilic substitution (NaN_3), the azido derivative **69**. This had been previously transformed into the penta-*N*,*O*-acetyl derivative of (+)-validamine (**70**) by treatment with Raney nickel and acetylation.[40]



Scheme 10. Synthetic transformations of the azido carbasugar **69**.

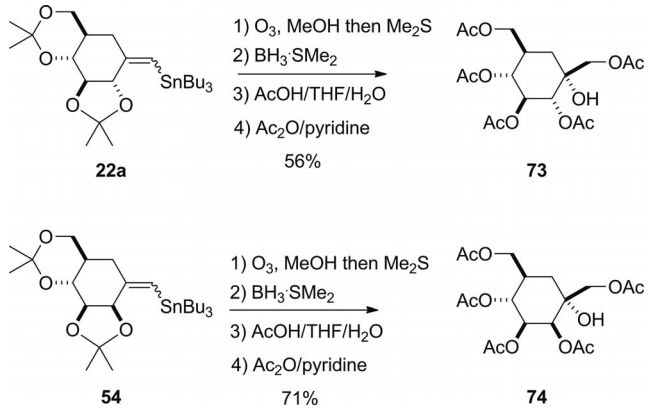
Treatment of the azide **69** with triphenylphosphane, in order to achieve a Staudinger reaction,[41] was very sluggish, which led us to use the more reactive $n$$Bu_3P$.[42] In our hands, however, only the olefin derivative **71** was obtained upon treatment of **69** with $n$$Bu_3P$.[43] The cyclohexene **71** is an interesting synthetic intermediate, because related olefins have been used by Plumet and co-workers in synthetic approaches to cyclophellitol.[44]

Finally, hydrogenolysis of **69** led to the 1-deoxy carbasugar derivative **72**, rather than to the expected amino derivative.

Ozonation of Alkenylstannanes – Mechanistic Considerations and Access to Carbasugar-Derived Ketoses.

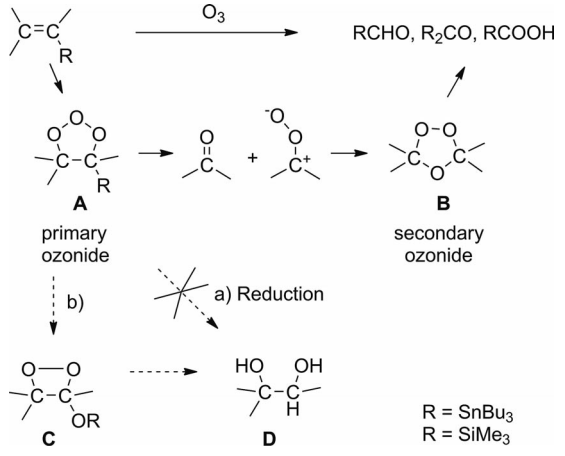
The alkenylstannanes used for radical cyclizations of enynes are useful substrates for further synthetic transformations.

In the route to C-1 ketones by ozonolysis of compounds **22a** and **54** (Scheme 11), we observed that, rather than double bond cleavage, these derivatives experienced a formal dihydroxylation process (without C–C bond cleavage) leading to the carbasugar-derived ketoses **73** and **74**, respectively.[45]



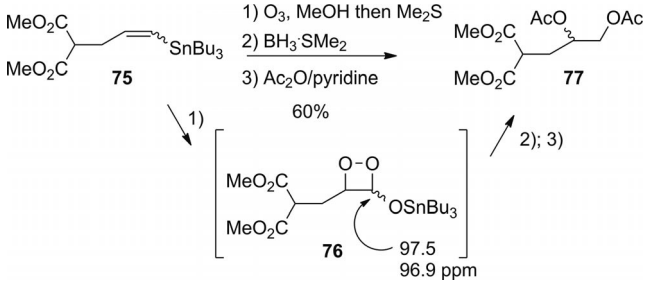
Scheme 11. Ozonation of the alkenylstannanes **22a** and **54**.

Although we had previously interpreted this behaviour in terms of a remarkably stable tin-substituted primary ozonide species [**A**, R = $SnBu_3$ (Scheme 12),[46] undergoing reduction prior to cycloreversion and recombination (**A**→**B**, Scheme 12) to give a diol without cleavage of the carbon-carbon bond (**A**→**D**, Scheme 12)], re-examination of our earlier proposal has led us to believe that a tin-oxygen rearrangement (**A**→**C**, R = $SnBu_3$, Scheme 12), similar to that observed in related ozonolysis of vinylsilanes (**A**→**C**, Scheme 12, R = $SiMe_3$),[47] is responsible for the observed results. In this context, work by Büchi and Wüest had shown that vinylsilanes, upon ozonization, evolved through dioxetane intermediates (**A**→**C**→**D**, Scheme 12) to give species **D** without C–C bond cleavage.



Scheme 12. Proposed reaction pathway for the ozonation of alkenylstannanes (R = $SnBu_3$, e.g. **22a** and **54**) and its relationship to that for alkenylsilanes (R = $SiMe_3$).

Our proposed revised reaction pathway is based on the above transformations of related alkenylsilanes and our own study of the transformations, as outlined in Scheme 13. The alkenylstannanes **75** [*Z*/*E* mixture, 1:1, prepared from the corresponding alkyne by radical-mediated stannylation ($HSnBu_3$, Et_3B)][48] were used as model compounds. Ozonolysis of the stannanes **75** (O_3, –78 °C) followed by reduction (BH_3·SMe_2) and acetylation produced the diacetates **77**. This transformation was repeated several times with similar results. One experiment was performed in CD_3OD, with recording of ^1H NMR and ^{13}C NMR spectra of the crude reaction mixture at –60 °C. The observed ^{13}C NMR chemical shifts – 97.5, 96.9, 91.0 and 84.7 ppm – seemed more consistent with two isomeric dioxetanes (i.e., **76**, structure type **C**, R = $SnBu_3$, Scheme 12) than with a stannylated primary ozonide (e.g., **A**, Scheme 12).



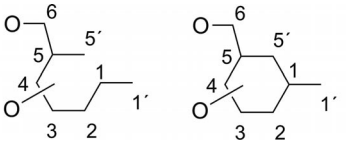
Scheme 13. Ozonation of the alkenylstannanes **75**.

Conclusions

Several synthetic strategies directed towards carbapyranoses and based on 6-*endo*-*trig* radical cyclizations of unsaturated carbohydrate derivatives have been developed. The issue of 6-*endo* versus 5-*exo* radical cyclization has been evaluated in different substrates. We considered three factors that might induce 6-*endo* radical cyclization over 5-*exo* ring closure: i) substitution at C-5 (radical numbering), ii) vinyl radical cyclization, and iii) ring strain. Substrates incorporating all three elements (i.e., **20a** and **20b**) evolve to give "6-*endo*" carbapyranose derivatives. 6-*endo* Cyclization was also observed in vinyl radicals in C-5 substituted, *non*-strained systems, as in **42**–**44**. The presence of ring strain and C-5 substitution is less clear-cut: 6-*endo* cyclizations were only observed from a primary radical and from a methyl-substituted secondary radical (i.e., those arising from **29** and **30**). Systems with C-5 substitution as the sole regiodirecting effect furnished compounds resulting from 5-*exo* radical cyclization (e.g., radical cyclizations of **62** and **64**). The compounds resulting from these radical cyclizations can be transformed into functionalized carbasugar derivatives. The azido derivative **69**, readily accessible by our methodology, for instance, has previously been used in the preparation of a peracetylated (+)-validamine derivative by Ogawa and co-workers.[40] Finally, we have re-examined our initially proposed reaction pathway for the ozonation of alkenylstannanes leading to diols, and we now propose a tin-oxygen rearrangement of the initially formed primary ozonide to a substituted dioxetane that is subsequently reduced to the diol, without C–C bond cleavage.

Experimental Section

General Remarks: All reactions were performed in dry flasks fitted with glass stoppers or rubber septa under a positive pressure of Ar unless otherwise noted. Air- and moisture-sensitive liquids and solutions were transferred by syringe or stainless steel cannula. Optical rotations were determined for solutions in chloroform. Flash column chromatography was performed with 230–400 mesh silica gel. Thin-layer chromatography was conducted on Kieselgel 60 F254 (Merck). Spots were observed first under UV irradiation (254 nm) and then by charring with a solution of aqueous H_2SO_4 (20%, 200 mL) in AcOH (800 mL). Anhydrous $MgSO_4$ or Na_2SO_4 were used to dry organic solutions during workup, and evaporation of the solvents was performed under vacuum with a rotary evaporator. Solvents were dried and purified by standard methods. Unless otherwise noted ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$ at 300 MHz and 50 MHz, respectively. Chemical shifts are expressed in parts per million (δ scale) downfield from tetramethylsilane and are referenced to residual protium in the NMR solvent ($CHCl_3$: δ = 7.25 ppm). The numbering pattern used for the ^1H NMR is illustrated below.



General Procedure A. Pd/C-Catalysed Hydrogenolysis of Benzyl Glycosides in a Parr Apparatus: Argon was passed through a solution of the compound (ca. 50–75 μmol) in EtOH/Et_3N (7:1, v/v, 10 mL) for 5 min, after which a catalytic amount of Pd/C (20 mg, 10 wt.-% Pd on C) was added. The reaction vessel was placed under vacuum and subsequently ventilated with hydrogen gas. This cycle was repeated one more time, after which the vessel was placed under hydrogen gas (25 psi) and mechanically shaken for 3 h. The Pd/C was removed by filtration through a Celite path, followed by thorough rinsing of the filter cake with EtOH. The filtrate was concentrated under vacuum and the residue was used in the next step without further purification.

General Procedure B. Wittig Treatment of Hemiketals with (Chloromethylene)triphenylphosphorane: A cooled (0 °C) solution of (chloromethylene)triphenylphosphonium chloride (3 mmol) in anhydrous THF (10 mL) was treated with *n*BuLi (3 mmol, 1.6 M in hexanes). The resulting solution was stirred for 15 min and a solution of the corresponding hemiketal (1 mmol) and DMPU (3 mmol) in THF (5 mL) was added dropwise. The temperature was allowed to rise slowly to room temp. and the reaction mixture was then stirred for a further 2 h at room temp. The reaction mixture was then poured into water (20 mL), extracted with CH_2Cl_2 (3 × 15 mL), dried and concentrated under reduced pressure. Purification of the residue by column chromatography gave the corresponding chloroolefins as 1:1 mixtures of *Z*/*E* isomers.

(*E*)- and (*Z*)-1-Chloro-1,2-dideoxy-3,4:5,7-di-*O*-isopropylidene-D-*gluco*-hept-1-enitol (16a):[23] This compound was prepared from the hemiketal **15a** (7.9 g, 30.4 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded (*E*)-**16a** (2.25 g, 25%) followed by (*Z*)-**16a** (2.24 g, 25%). For (*E*)-**16a**: $[\alpha]_D^{25}$ = –55.1 (*c* = 1.0, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.30 (dd, *J* = 13.5, 1.0 Hz, 1 H, 1′-H), 5.95 (dd, *J* = 13.5, 6.5 Hz, 1 H, 1-H), 4.57 (ddd, *J* = 8.1, 6.5, 1.0 Hz, 1 H, 2-H), 4.04 (dd, *J* = 8.1, 3.5 Hz, 1 H, 3-H), 3.90 (m, 2 H, 5-H, 6a-H), 3.77 (dd, *J* = 9.0, 3.5 Hz, 1 H, 4-H), 3.61 (dd, *J* = 13.0, 10.5 Hz, 1 H, 6b-H), 2.5 (m, 1 H, OH), 1.45 (s, 3 H, Me), 1.43 (s, 3 H, Me), 1.42 (s, 3 H, Me), 1.37 (s, 3 H, Me) ppm. For (*Z*)-**16a**: $[\alpha]_D^{25}$ = –3.2 (*c* = 3.0, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.24 (d, *J* = 7.5 Hz, 1 H, 1′-H), 5.84 (dd, *J* = 8.5, 7.5 Hz, 1 H, 1-H), 5.17 (t, *J* = 8.5 Hz, 1 H, 2-H), 4.06 (dd, *J* = 8.5, 2.5 Hz, 1 H, 3-H), 3.92 (m, 2 H, 5-H, 6a-H), 3.68 (dd, *J* = 8.5, 2.5 Hz, 1 H, 4-H), 3.62 (dd, *J* = 13.0, 10.5 Hz, 1 H, 6b-H), 2.0 (m, 1 H, OH), 1.46 (s, 3 H, Me), 1.44 (s, 6 H, 2× Me), 1.40 (s, 3 H, Me) ppm.

(*E*)- and (*Z*)-1-Chloro-1,2-dideoxy-3,4:5,7-di-*O*-isopropylidene-D-*galacto*-hept-1-enitol (16b):[23] This compound was prepared from the hemiketal **15b** (3.58 g, 13.8 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded (*E*)-**16b** (1.14 g, 28%) followed by (*Z*)-**16b** (1.10 g, 27%). For (*E*)-**16b**: $[\alpha]_D^{25}$ = –14.0 (*c* = 1.2, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.27 (dd, *J* = 13.5, 1.1 Hz, 1 H, 1′-H), 5.98 (dd, *J* = 13.5, 9.0 Hz, 1 H, 1-H), 4.31 (ddd, *J* = 7.5, 5.5, 1.1 Hz, 1 H, 2-H), 4.07 (dd, *J* = 12.5, 1.5 Hz, 1 H, 6a-H), 3.96 (dd, *J* = 8.5, 7.5 Hz, 1 H, 3-H), 3.84 (dd, *J* = 12.5, 2.0 Hz, 1 H, 6b-H), 3.80 (dd, *J* = 8.0, 1.5 Hz, 1 H, 4-H), 3.59 (m, 1 H, 5-H), 2.6 (d, *J* = 11.0 Hz, 1 H, OH), 1.46 (s, 3 H, Me), 1.40 (s, 9 H, 3× Me) ppm. For (*Z*)-**16b**: $[\alpha]_D^{25}$ = +38.2 (*c* = 1.8, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.20 (dd, *J* = 7.5, 1.1 Hz, 1 H, 1′-H), 5.81 (dd, *J* = 9.0, 7.5 Hz, 1 H, 1-H), 4.85 (ddd, *J* = 1.1, 7.5, 9.0 Hz, 2-H), 4.07 (dd, *J* = 12.5, 1.1 Hz, 1 H, 6a-H), 3.96 (dd, *J* = 8.5, 7.5 Hz, 1 H, 3-H), 3.86 (dd, *J* = 1.1, 8.5 Hz, 4-H), 3.84 (dd, *J* = 2.0, 12.5 Hz, 1 H, 6b-H), 3.62 (m, 1 H, 5-H), 2.67 (d, *J* = 11.0 Hz, 1 H, OH), 1.46 (s, 3 H, Me), 1.42 (s, 6 H, 2× Me), 1.40 (s, 3 H, Me) ppm.

General Procedure C. Dehydrohalogenation of 1-Chloroenitols: A solution of the appropriate 1-chloroenitol in dry THF (10 mL mmol^{-1}) was cooled to –78 °C and then treated with *n*BuLi (4 equiv.). After stirring for 2 h, and once TLC analyses showed total disappearance of the starting material, the reaction mixture was quenched with a saturated aqueous solution of NH_4Cl. After partitioning between water and diethyl ether, the organic layer was dried with $MgSO_4$ and concentrated. The ensuing residue was then purified by flash chromatography.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-D-*gluco*-hept-1-ynitol (17a):[23] This compound was prepared from the 1-chloroenitol **16a** (4.5 g, 15.4 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded **17a** (2.89 g, 73%). $[\alpha]_D^{25}$ = –49.1 (*c* = 1.6, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 4.74 (dd, *J* = 7.5, 2.0 Hz, 1 H, 2-H), 4.36 (dd, *J* = 7.5, 2.0 Hz, 1 H, 3-H), 3.91 (dd, *J* = 12.0, 5.5 Hz, 1 H, 5-H), 3.83 (ddd, *J* = 9.5, 9.0, 5.5 Hz, 1 H, 6a-H), 3.63 (dd, *J* = 12.0, 9.0 Hz, 1 H, 6b-H), 3.75 (dd, *J* = 9.5, 3.5 Hz, 1 H, 4-H), 2.52 (d, *J* = 2.0 Hz, 1 H, 1′-H), 2.30 (m, 1 H, OH), 1.50 (s, 3 H, Me), 1.46 (s, 3 H, Me), 1.42 (s, 3 H, Me), 1.38 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 110.9, 99.1, 81.2, 80.8, 74.6, 71.8, 64.3, 63.6, 27.9, 19.5 ppm. $C_{13}H_{20}O_5$ (256.29): calcd. C 60.92, H 7.87; found C 60.71, H 7.88.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-D-*galacto*-hept-1-ynitol (17b):[23] This compound was prepared from the 1-chloroenitol **16b** (2.2 g, 7.6 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded **17b** (1.45 g, 75%). $[\alpha]_D^{25}$ = –46.1 (*c* = 1.6, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 4.59 (dd, *J* = 4.5, 2.5 Hz, 1 H, 2-H), 4.34 (dd, *J* = 8.5, 2.5 Hz, 1 H, 3-H), 4.05 (dd, *J* = 12.5, 2.5 Hz, 1 H, 6a-H), 3.60 (m, 1 H, 5-H), 3.84 (dd, *J* = 12.5, 2.5 Hz, 1 H, 6b-H), 3.70 (dd, *J* = 8.5, 1.5 Hz, 1 H, 4-H), 2.51 (d, *J* = 2.5 Hz, 1 H, 1′-H), 2.64 (d, *J* = 11 Hz, 1 H, OH), 1.54 (s, 3 H, Me), 1.44 (s, 3 H, Me), 1.42 (s, 3 H, Me), 1.41 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 111.4, 99.1, 82.5, 79.6, 74.0, 73.6, 68.5, 65.5, 62.9, 29.3, 27.4, 26.1, 18.5 ppm. $C_{13}H_{20}O_5$ (256.29): calcd. C 60.92, H 7.87; found C 60.81, H 7.79.

General Procedure D. PDC/Ac_2O (Oxidation): A solution of the corresponding alcohol (1 mmol) in CH_2Cl_2 (3 mL) was added to a stirred, freshly prepared mixture of PDC (0.7 mmol) and acetic anhydride (3 mmol) in CH_2Cl_2 (3 mL). The mixture was stirred for 16 h at room temperature, after which Et_2O was added and the crude reaction product was filtered though a short pad of celite. The colourless eluate was concentrated to dryness under vacuum and the residue was purified by flash chromatography.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-6-oxo-*gluco*-hept-1-ynitol (18a): This compound was prepared from the hept-1-ynitol **17a** (2.80 g, 10.9 mmol) by the General Procedure. Purification (hexane/EtOAc 9:1) afforded the ketone **18a** (2.19 g, 83%). $[\alpha]_D^{25}$ = –193.9 (c = 1.0, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 4.73 (dd, J = 2.1, 7.0 Hz, 1 H, 2-H), 4.50 (m, 1 H), 4.31 (m, 2 H), 4.05 (d, J = 16.8 Hz, 1 H, 6a-H), 2.54 (d, J = 2.1 Hz, 1 H, 1-H), 1.45 (s, 9 H, 3× Me), 1.40 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 206.1, 111.3, 100.8, 80.4, 79.6, 75.0, 73.1, 66.9, 65.9, 26.4, 26.3, 24.1, 23.4 ppm. $C_{13}H_{18}O_5$ (254.12): calcd. C 61.40, H 7.14; found C 61.26, H 7.16.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-6-oxo-D-*gluco*-hept-1-ynitol (18b): This compound was prepared from the hept-1-ynitol **17b** (1.45 g, 5.7 mmol) by the General Procedure. Purification (hexane/EtOAc 9:1) afforded the ketone **18b** (1.2 g, 72%). $[\alpha]_D^{25}$ = +114.1 (c = 0.9, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 4.87 (dd, J = 2.2, 6.8 Hz, 1 H, 2-H), 4.50 (dd, J = 3.5, 6.8 Hz, 1 H, 3-H), 4.44 (d, J = 3.5 Hz, 1 H, 4-H), 4.30 (dd, J = 16.9, 1.3 Hz, 1 H, 6a-H), 4.04 (d, J = 16.9 Hz, 1 H, 6b-H), 2.53 (d, J = 2.2 Hz, 1 H, 1′-H), 1.52 (s, 3 H, Me), 1.48 (s, 6 H, 2× Me), 1.41 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 206.0, 106.9, 96.6, 76.1, 75.4, 70.3, 69.2, 62.4, 61.5, 22.0, 21.8, 19.6, 18.9 ppm. $C_{13}H_{18}O_5$ (254.12): calcd. C 61.40, H 7.14; found C 61.31, H 7.09.

General Procedure E. Peterson Olefination: A solution of the appropriate ketone in anhydrous diethyl ether (10 mL mmol^{-1}) was cooled to 0 °C under argon. (Trimethylsilylmethyl)magnesium chloride (4 equiv., 1 M solution in diethyl ether) was added dropwise. The resulting slightly yellow solution was then stirred at room temp. for 6 h. The reaction mixture was quenched with ammonium chloride and diluted with diethyl ether. The organic layer was separated and the aqueous layer was extracted three times with diethyl ether. The combined ethereal extracts were washed with saturated aqueous sodium chloride solution, dried ($MgSO_4$) and concentrated under reduced pressure. The residue was then subjected to flash chromatography (hexane/EtOAc 95:5).

The resulting silyl derivative, dissolved in dry THF (10 mL mmol^{-1}), was treated at 0 °C with an excess of potassium hydride (freed of the mineral oil by hexane washings) dispersed in THF (2 mL). The mixture was stirred for 20 min and then carefully quenched by addition of MeOH. Once the hydrogen evolution was complete, diethyl ether was added and the resulting solution was treated with water. The aqueous layer was extracted three times with diethyl ether. The combined organic extracts were dried and concentrated under reduced pressure. The residue was then purified by flash chromatography.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-6-methylene-D-*gluco*-hept-1-ynitol (20a): This compound was prepared from the ketone **18a** (1.92 g, 7.6 mmol) by the General Procedure. Purification (hexane/EtOAc 9:1) afforded the enyne **20a** (1.34 g, 70%). $[\alpha]_D^{25}$ = –142.7 (c = 1.0, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.04 (s, 1 H, 5′a-H), 5.02 (s, 1 H, 5′b-H), 4.49 (dd, J = 7.3, 2.1 Hz, 1 H, 2-H), 4.30 (m, 4 H), 2.54 (d, J = 2.1 Hz, 1 H, 1′-H), 1.50 (s, 3 H, Me), 1.43 (s, 6 H, 2× Me), 1.40 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 142.3, 110.0, 108.5, 99.9, 82.1, 82.0, 74.5, 69.2, 66.2, 64.2, 26.9, 26.3, 22.9 ppm. $C_{14}H_{20}O_4$ (252.31): calcd. C 66.65, H 7.99; found C 66.38, H 7.75.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-6-methylene-D-*galacto*-hept-1-ynitol (20b): This compound was prepared from the ketone **19b** (1.23 g, 4.85 mmol) by the General Procedure. Purification (hexane/EtOAc 9:1) afforded the enyne **20b** (831 mg, 68%). $[\alpha]_D^{25}$ = +29.4 (c = 0.8, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.18 (s, 1 H, 5′a-H), 5.02 (s, 1 H, 5′b-H), 4.76 (dd, J = 6.8, 2.1 Hz, 1 H, 2-H), 4.30 (m, 4 H), 2.54 (d, J = 2.1 Hz, 1 H, 1′-H), 1.54 (s, 3 H, Me), 1.47 (s, 3 H, Me), 1.44 (s, 3 H, Me), 1.39 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 141.6, 111.3, 109.7, 99.5, 82.4, 82.2, 73.9, 71.7, 67.6, 64.2, 27.3, 26.9, 26.2, 22.1 ppm. $C_{14}H_{20}O_4$ (252.31): calcd. C 66.65, H 7.99; found C 66.43, H 7.83.

General Procedure F. Bu_3SnH-Induced Radical Cyclization: A thoroughly degassed solution of the appropriate acyclic derivative in toluene (0.02 M) was heated at 80 °C under argon. A solution of Bu_3SnH (1.5 equiv.) and AIBN (0.3 equiv.) in toluene (3 mL) was then added by syringe-driven pump over 12 h. After cooling, the reaction mixture was concentrated in vacuo and the residue was purified by flash chromatography.

2,3:4,6-Bis-*O*-(1-methylethylidene)-1-(tributylstannyl)methylene-5a-carba-D-glucopyranose (22a) and 2,3:4,6-Bis-*O*-(1-methylethylidene)-1-(tributylstannyl)methylene-5a-carba-D-glucopyranose (23a): These compounds were prepared from the enyne **20a** (450 mg, 1.8 mmol) by the General Procedure for cyclization. Purification (hexane/EtOAc 98:2) afforded the corresponding acyclic alkenylstannanes **21a** (176 mg, 18%), followed by 5a-carba-L-glucopyranose and the 5a-carba-D-glucopyranose derivatives **23a** (48 mg, 5%) and **22a** (548 mg, 56%) respectively.

22a: $[\alpha]_D^{25}$ = +8.2 (c = 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 5.60 (t, J = 1.7 Hz, 1 H, 1′-H), 3.99 (dd, J = 9.2, 1.7 Hz, 1 H, 2-H), 3.87 (t, J = 9.2 Hz, 1 H, 4-H), 3.76 (dd, J = 11.2, 4.6 Hz, 1 H, 6a-H), 3.69 (t, J = 11.2 Hz, 1 H, 6b-H), 3.41 (t, J = 9.2 Hz, 1 H, 3-H), 2.15 (dd, J = 13.9, 4.1 Hz, 1 H, 5′a-H), 1.95 (t, J = 13.9 Hz, 1 H, 5′b-H), 1.75 (m, 1 H, 5-H), 1.52 (s, 3 H, Me), 1.47 (s, 3 H, Me), 1.45 (m, 6 H, CH_2), 1.44 (s, 6 H, 2× Me), 1.29 (sext, J = 7.2 Hz, 6 H, CH_2Me), 0.88 (m, 6 H, CH_2Sn), 0.87 (t, J = 7.2 Hz, 9 H, Me) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 147.8, 115.7, 110.6, 99.0, 81.6, 80.6, 73.8, 64.3, 39.5, 36.7, 29.6, 29.2, 27.3 (×3), 27.0, 26.8, 19.2 (×3), 13.7 (×3), 11.8 (×3) ppm. $C_{26}H_{46}O_4Sn$ (543.37): calcd. C 57.69, H 8.56; found C 57.43, H 8.37.

23a: $[\alpha]_D^{25}$ = –72.4 (c = 0.16, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 5.68 (s, 1 H, 1′-H), 4.13 (m, 2 H, 2-H, 4-H), 3.78 (m, 2 H, 3-H, 6a-H), 3.47 (dd, J = 11.5, 8.7 Hz, 1 H, 6b-H), 2.57 (dt, J = 14.2, 2.0 Hz, 1 H, 5′a-H), 2.35 (m, 1 H, 5-H), 2.02 (dd, J = 14.1, 3.6 Hz, 1 H, 5′b-H), 1.35 (s, 3 H, Me), 1.33 (s, 3 H, Me), 1.29 (m, 6 H, CH_2), 1.28 (s, 3 H, Me), 1.27 (s, 3 H, Me), 1.24 (m, 6 H, CH_2Me), 0.89 (m, 6 H, CH_2Sn), 0.87 (t, J = 7.2 Hz, 9 H, Me) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 148.0, 133.4, 109.3, 99.0, 81.3, 79.5, 75.1, 68.2, 36.4, 34.9, 29.6, 29.4, 28.9 (×3), 27.0 (×3), 26.5, 13.5 (×3), 10.2 (×3) ppm. $C_{26}H_{46}O_4Sn$ (543.37): calcd. C 57.69, H 8.56; found C 57.51, H 8.40.

2,3:4,6-Bis-*O*-(1-methylethylidene)-1-(tributylstannyl)methylene-5a-carba-D-galactopyranose (22b): This compound was prepared from the enyne **20b** (150 mg, 0.6 mmol) by the General Procedure. Purification (hexane/EtOAc 98:2) afforded the carbagalacto derivative **22b** (196 mg, 71%). $[\alpha]_D^{25}$ = +10.5 (c = 1.6, $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 5.53 (br. s, 1 H, 1′-H), 4.51 (m, 2 H, 2-H, 4-H), 4.15 (dd, J = 16.2, 2.8 Hz, 1 H, 6a-H), 3.58 (d, J = 12.2 Hz, 1 H, 6b-H), 3.31 (dd, J = 9.9, 2.7 Hz, 1 H, 3-H), 2.95 (t, J = 14.3 Hz, 1 H, 5′a-H), 2.15 (dd, J = 14.3, 5.3 Hz, 1 H, 5′b-H), 1.49

(s, 3 H, Me), 1.46 (m, 7 H, CH_2, 5-H), 1.45 (s, 6 H, 2× Me), 1.42 (s, 3 H, Me), 1.27 (sext, J = 7.2 Hz, 6 H, CH_2Me), 0.88 (m, 6 H, CH_2Sn), 0.87 (t, J = 7.2 Hz, 9 H, Me) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 151.0, 118.0, 110.0, 98.6, 82.8, 76.1, 66.5, 63.6, 37.1, 35.2, 29.6, 29.3, 27.4 (×3), 27.2, 26.6 (×3), 18.7, 13.7 (×3), 11.8 (×3) ppm. $C_{26}H_{46}O_4Sn$ (543.37): calcd. C 57.69, H 8.56; found C 57.37, H 8.43.

General Procedure G. Hydrolysis Under Acidic Conditions Followed by Acetylation: A stirred solution of the appropriate vinyltrialkyltin derivative (1 mmol) in THF/H_2O (15 mL, 2:1, v/v) was treated with acetic acid (15 mL), heated in an oil bath for 5 h and then concentrated in vacuo. The residue was then taken up in pyridine and treated with Ac_2O for 24 h. The solvent was removed in vacuo and the residue was purified by flash chromatography.

2,3,4,6-Tetra-*O*-acetyl-1-deoxy-1-methylene-5a-carba-D-glucopyranose (27a): This compound was prepared from the vinyltrialkyltin derivative **22a** (300 mg, 0.55 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded **27a** (118 mg, 63%). $[a]_D^{25}$ = +3.2 (c = 0.9, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.37 (br d, J = 9.7 Hz, 1 H, 2-H), 5.14 (t, J = 9.7 Hz, 1 H, 4-H), 4.98 (m, 3 H, 3-H, 1′-H), 4.08 (dd, J = 11.3, 5.0 Hz, 1 H, 6a-H), 3.97 (dd, J = 11.3, 3.3 Hz, 1 H, 6b-H), 2.51 (dd, J = 11.5, 4.8 Hz, 1 H, 5′a-H), 2.20 (m, 1 H, 5-H), 2.18 (t, J = 11.5 Hz, 1 H, 5′b-H), 2.14 (s, 3 H, Me), 2.10 (s, 3 H, Me), 2.05 (s, 3 H, Me), 2.03 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 170.8, 170.0, 169.9, 169.6, 139.3, 110.1, 75.0, 72.9, 71.5, 63.2, 40.2, 33.0, 20.7, 20.6 (×3) ppm. $C_{16}H_{22}O_8$ (342,13): calcd. C 56.14, H 6.48; found C 55.89, H 6.31.

2,3,4,6-Tetra-*O*-acetyl-1-deoxy-1-methylene-5a-carba-D-galactopyranose (27b): This compound was prepared from the vinyltrialkyltin derivative **22b** (52 mg, 0.11 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded **27b** (22 mg, 72%). $[a]_D^{25}$ = +1.6 (c = 0.5, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.58 (m, 2 H, 2-H, 4-H), 4.99 (s, 1 H, 1′a-H), 4.88 (s, 1 H, 1′b-H), 4.85 (dd, J = 10.6, 7.4 Hz, 1 H, 3-H), 3.94 (m, 2 H, 2×6-H), 2.30 (m, 2 H), 2.13 (m, 1 H), 2.12 (s, 6 H, 2× Me), 2.04 (s, 3 H, Me), 2.00 (s, 3 H, Me) ppm. ^{13}CNMR (300 MHz, $CDCl_3$): δ = 170.8, 170.1, 170.0, 169.9, 140.0, 109.7, 73.3, 71.3, 68.5, 63.0, 38.4, 31.2, 29.7, 20.8, 20.7, 20.6 ppm. $C_{16}H_{22}O_8$ (342,13): calcd. C 56.14, H 6.48; found C 56.01, H 6.23.

General Procedure H. Ozonolysis Followed by Stereoselective Reduction and Acetylation: Ozone was bubbled through a cold (–78 °C) solution of the appropriate "carbasugar *exo*-glycal" **27** (0.5 mmol) in MeOH (5 mL) until the solution appeared faintly blue. A stream of argon was then bubbled through the reaction mixture until the blue colour had disappeared. Dimethyl sulfide (0.3 mL) was added dropwise to this solution and the reaction mixture was allowed to warm to room temperature and stirred for 1 h. Concentration in vacuo provided the crude ketone as a colourless oil. This was dissolved in THF (3 mL) and cooled (0 °C), and $BH_3{\cdot}SMe_2$ was added dropwise. The mixture was allowed to warm to room temp. for 1 h and MeOH was added to destroy excess hydride.

1,2,3,4,6-Penta-*O*-acetyl-5a-carba-β-D-glucopyranose (28a): Compound **27a** (41 mg, 0.12 mmol) was subjected to General Procedure G followed by standard acetylation to give compound **28a** (27 mg, 58%) after silica gel column chromatography (hexane/EtOAc 7:3). $[a]_D^{25}$ = +12.2 (c = 1.0, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.17 (t, J = 9.4 Hz, 1 H, 3-H), 5.11 (t, J = 9.4 Hz, 1 H, 2-H), 5.03 (dd, J = 10.6, 9.4 Hz, 1 H, 4-H), 4.93 (m, 1 H, 1-H), 4.08 (dd, J = 11.3, 5.0 Hz, 1 H, 6a-H), 3.95 (dd, J = 11.3, 3.2 Hz, 1 H, 6b-H), 2.20 (m, 1 H), 2.06 (m, 1 H), 2.05 (s, 3 H, Me), 2.02 (s, 3 H, Me), 2.01 (s, 3 H, Me), 1.99 (s, 3 H, Me), 1.56 (m, 1 H) ppm. $C_{17}H_{24}O_{10}$ (388.14): calcd. C 52.57, H 6.23; found C 52.18, H 6.17.

1,2,3,4,6-Penta-*O*-acetyl-5a-carba-β-D-galactopyranose (28b): Compound **27b** (20 mg, 0.05 mmol) was subjected to the General Procedure to give compound **28b** (18 mg, 82%) after silica gel column chromatography (hexane/EtOAc 7:3). $[a]_D^{25}$ = –3.4 (c = 0.4, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.50 (t, J = 3.0 Hz, 1 H, 4-H), 5.40 (t, J = 10.0 Hz, 1 H, 2-H), 4.94 (ddd, J = 11.5, 10.0, 5.0 Hz, 1 H, 1-H), 4.87 (dd, J = 3.1, 10.0 Hz, 1 H, 3-H), 3.99 (dd, J = 8.7, 11.0 Hz, 1 H, 6a-H), 3.86 (dd, J = 6.1, 11.0 Hz, 1 H, 6b-H), 2.17 (m, 1 H, 5-H), 2.14 (s, 3 H, Me), 2.05 (s, 6 H, 2× Me), 2.03 (s, 3 H, Me), 1.99 (s, 3 H, Me), 1.98 (m, 1 H, 5′a-H), 1.67 (q, J = 12.8 Hz, 1 H, 5′b-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 170.7, 170.1, 170.0, (×2), 169.9, 72.0, 71.3, 70.7, 67.5, 62.7, 34.7, 27.0, 20.9 (×2), 20.7 (×2), 20.6 ppm. $C_{17}H_{24}O_{10}$ (388.14): calcd. C 52.57, H 6.23; found C 52.41, H 6.08.

General Procedure I. $LiAlH_4$ Reduction Followed by Silylation: A solution of the appropriate hemiketal (1 mmol) in anhydrous THF (1 mL mmol^{-1}) was added under argon to a cooled (0 °C) suspension of $LiAlH_4$ (3 mmol) in dry THF (1 mL mmol^{-1}). The resulting mixture was stirred at room temp. for 2 h, diluted with diethyl ether and quenched by dropwise addition of saturated aqueous sodium sulfate (Na_2SO_4). After the mixture had been stirred for 20 min, the resulting white solid was filtered through a pad of celite, and the solvent was evaporated under reduced pressure. The residue was then subjected to flash chromatography (hexane/EtOAc 7:3). A solution of the thus-obtained diol in CH_2Cl_2 (5 mL mmol^{-1}) was treated with Et_3N (1.5 mmol), *tert*-butyldimethylchlorosilane (3 equiv.) and 4-DMAP (0.1 mmol) and then stirred at room temperature until all the starting material had been consumed (usually 10–12 h). The reaction mixture was quenched with aqueous sodium hydrogencarbonate and diluted with CH_2Cl_2. The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2. The combined organic extracts were washed with water and saturated aqueous sodium chloride solution, dried ($MgSO_4$) and concentrated under reduced pressure. The residue was then subjected to flash chromatography (hexane/EtOAc 8:2).

1-(*tert*-Butyldimethylsilyl)-2,3:4,6-di-*O*-isopropylidene-5-oxo-D-glucitol (33): This compound was prepared from the hemiketal **15a** (13.4 g, 38 mmol) by General Procedure I. Purification afforded the glucitol derivative (7.8 g, 55% overall). $[a]_D^{25}$ = –10.6 (c = 1.0, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 4.29 (m, 1 H, 6a-H), 4.13 (dd, J = 7.5, 4.8 Hz, 1 H, 4-H), 3.77 (m, 6 H), 3.27 (d, J = 1.6 Hz, 1 H, OH), 1.47 (s, 3 H, Me), 1.43 (s, 3 H, Me), 1.41 (s, 3 H, Me), 1.40 (s, 3 H, Me), 0.91 (s, 9 H, 3× Me), 0.10 (s, 6 H, 2× Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 109.3, 98.9, 79.2, 76.6, 73.9, 65.0, 64.0, 63.8, 38.5, 27.1, 26.8, 26.0 (×2), 25.7 (×3), 19.4, 18.5 ppm. EI-MS: m/z = 376.0 $[M]^+$. $C_{18}H_{36}O_6Si$ (376.56): calcd. C 57.41, H 9.64; found C 57.36, H 9.43.

This material (7.5 g, 20.71 mmol) was subjected to the General Procedure for oxidation with PDC/Ac_2O (Procedure C) to give the ketone **33** (6.2 g, 81%) after silica gel column chromatography (hexane/EtOAc 8:2). $[a]_D^{25}$ = –88.2 (c = 0.4, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 4.47 (dd, J = 7.2, 2.3 Hz, 1 H, 3-H), 4.34 (d, J = 16.0 Hz, 1 H, 6a-H), 4.30 (br. s, 1 H, 4-H), 4.21 (dt, J = 7.2, 4.2 Hz, 1 H, 2-H), 4.02 (d, J = 16.0 Hz, 1 H, 6b-H), 3.91 (dd, J = 10.4, 4.2 Hz, 1 H, 1a-H), 3.68 (dd, J = 10.4, 7.2 Hz, 1 H, 1b-H), 1.52 (s, 3 H, Me), 1.50 (s, 3 H, Me), 1.45 (s, 3 H, Me), 1.41 (s, 3 H, Me), 0.90 (s, 9 H, 3× Me), 0.10 (s, 6 H, 2× Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.3, 110.0, 100.8, 77.6, 75.6, 74.3, 67.0, 64.3, 30.3, 27.3, 26.3, 25.9 (×2), 25.6 (×3), 24.0, 23.5 ppm.

EI-MS: m/z = 374.0 $[M]^+$. $C_{18}H_{34}O_6Si$ (374.54): calcd. C 57.72, H 9.15; found C 57.59, H 9.03.

1-(*tert*-Butyldimethylsilyl)-5-deoxy-2,3:4,6-di-*O*-isopropylidene-5-methylene-D-glucitol (34): This compound was prepared from the ketone **33** (6.2 g, 16.5 mmol) by the General Procedure. Purification (hexane/EtOAc 9:1) afforded **34** (3.7 g, 81%). $[\alpha]_D^{25}$ = –49.3 (c = 0.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.05 (dd, J = 12.5, 1.6 Hz, 2 H, 5′-H), 4.32 (m, 5 H), 3.84 (dd, J = 10.6, 4.0 Hz, 1 H, 6a-H), 3.76 (dd, J = 10.6, 4.0 Hz, 1 H, 6b-H), 1.45 (s, 3 H, Me), 1.44 (s, 6 H, 2× Me), 1.42 (s, 3 H, Me), 0.92 (s, 9 H, 3× Me), 0.10 (s, 6 H, 2× Me) ppm. ^{13}CNMR (75 MHz, $CDCl_3$): δ = 143.3, 109.7, 108.3, 99.9, 79.2, 76.1, 69.8, 64.6, 64.3, 27.5, 26.9, 26.7, 26.0 (×3), 23.0, 18.5 (×2) ppm. $C_{19}H_{36}O_5Si$ (372,57): calcd. C 61.25, H 9.74; found C 60.91, H 9.53.

General Procedure J. Unmasking of *tert*-Butyldimethylsilyl Ethers: A stirred solution of the appropriate silyl derivative (1 mmol) in THF (15 mL) was treated with TBAF (3 mmol) and then stirred for 4 h, after which the reaction mixture was washed consecutively with saturated aqueous sodium hydrogencarbonate solution and water. The organic layer was then dried and concentrated, and the residue was purified by flash chromatography (hexane/EtOAc 7:3).

5-Deoxy-2,3:4,6-di-*O*-isopropylidene-5-methylene-D-glucitol (35): This compound was prepared from **34** (3.7 g, 9.9 mmol) by General Procedure J. Purification afforded the derivative **35** (2.0 g, 79%). $[\alpha]_D^{25}$ = –10.9 (c = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 5.08 (dd, J = 12.6, 1.3 Hz, 2 H, 5′-H), 4.52 (br. s, 1 H, 4-H), 4.25 (m, 4 H), 3.82 (dd, J = 10.2, 4.0 Hz, 1 H, 1a-H), 3.66 (dd, J = 10.2, 4.0 Hz, 1 H, 1b-H), 2.61 (br. s, 1 H, OH), 1.44 (s, 6 H, 2× Me), 1.43 (s, 3 H, Me), 1.40 (s, 3 H, Me) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 142.5, 109.6, 109.3, 100.2, 78.3, 77.6, 69.5, 64.6, 62.8, 27.4, 26.9 (×2), 23.2. API-ES (positive): m/z = 539 $[2M + Na]^+$, 281 $[M + Na]^+$. $C_{13}H_{22}O_5$ (258.31): calcd. C 60.45, H 8.58; found C 60.37, H 8.59.

5-Deoxy-2,3:4,6-di-*O*-isopropylidene-1-methyl-5-methylene-D-glucitol (36): This compound was prepared from the alcohol **35** (90 mg, 0.35 mmol) by General Procedure D. The resulting aldehyde was immediately dissolved in dry Et_2O and then treated at 0 °C with methylmagnesium iodide (0.90 mmol, 3.3 mL, 3.0 M solution in diethyl ether). The reaction mixture was allowed to reach room temperature and then stirred for 6 h. Diethyl ether was then added and the resulting solution was treated with aqueous NH_4Cl. The aqueous layer was extracted three times with diethyl ether. The combined organic extracts were dried and concentrated under reduced pressure. The residue was then purified by flash chromatography to provide the alcohol **36** as a 1:1 mixture of diastereomers. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 143.1, 142.6, 109.3, 109.2, 108.7, 108.6, 100.5, 100.2, 80.4, 80.1, 79.1, 77.9, 69.8, 68.3, 67.6, 64.7, 64.6, 64.5, 27.7, 27.4, 26.9, 23.3, 23.2, 20.3, 19.3 ppm. API-ES (positive): m/z = 295 $[M + Na]^+$.

General Procedure K. Preparation of the Methyl Xanthates 29–30: NaH (1.5 mmol) was added under argon to a cooled (0 °C) solution of the appropriate alcohol (1 mmol) in dry THF. The resulting suspension was stirred for 15 min, after which CS_2 (2 mmol) was added. Stirring was continued for 15 min and the reaction mixture was then treated with MeI (5 mmol) and stirred at room temperature for an additional 1 h. After the starting materials had been consumed, the mixture was diluted with Et_2O and washed with brine. The organic layer was then dried, concentrated in vacuo, subjected to fast silica gel column chromatography and used without further characterization.

General Procedure L. Preparation of the Phenyl Thiocarbonates 31, 32 and 63: A solution of the appropriate alcohol (1 mmol) in acetonitrile (50 mL mmol^{-1}) was treated with pyridine (3 mmol) and phenyl chlorothionoformate (3 mmol). The reaction mixture was heated at 85 °C for 1 h, after which it was cooled to room temperature and then quenched with water. The solution was diluted with CH_2Cl_2 and washed successively with HCl (10%), saturated $NaHCO_3$ and brine. The organic phase was dried, filtered and concentrated under vacuum.

1-Deoxy-2,3,4,6-tetra-*O*-acetyl-5a-carba-D-glucopyranose (41): This compound was prepared from the xanthate **29** (97 mg, 0.29 mmol) by the General Procedure for HBu_3Sn-induced radical cyclization (Procedure F). Purification of the crude material by flash chromatography (hexane/EtOAc 8:2) afforded the cyclohexane derivative **37** (45 mg, 64%). $[\alpha]_D^{25}$ = –5.6 (c = 0.7, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.65 (m, 5 H), 2.1 (m, 5 H), 1.44 (s, 6 H, 2× Me), 1.43 (s, 6 H, 2× Me) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 110.6, 99.0, 78.3, 75.4, 73.8, 64.4, 39.4, 30.6, 29.7, 27.4, 26.8, 22.3, 19.3 ppm. EI-MS: m/z = 243.0 $[M + H]^+$.

For the purpose of correct characterization, the tricyclic derivative **37** (45 mg, 0.18 mmol) was uneventfully converted into its tetraacetate by General Procedure F (flash chromatography, hexane/EtOAc 9:1) to give **41** (40 mg, 67%). $[\alpha]_D^{25}$ = +18.6 (c = 0.14, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 5.07 (t, J = 9.6 Hz, 1 H, 3-H), 4.96 (t, J = 9.6 Hz, 1 H, 4-H), 4.88 (m, 1 H, 2-H), 4.05 (dd, J = 9.0, 5.0 Hz, 1 H, 6a-H), 3.94 (dd, J = 9.0, 3.4 Hz, 1 H, 6b-H), 2.15 (m, 1 H, 5′-H), 2.02 (s, 3 H, Me), 2.01 (s, 3 H, Me), 2.00 (s, 6 H, 2× Me), 1.96 (m, 1 H, 5-H), 1.92–1.87 (m, 3 H, 5′-H, 1-H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 171.0, 170.2, 170.1, 170.0, 75.0, 72.2, 71.8, 63.6, 43.9, 40.2, 29.7, 28.4, 23.5, 20.7, 15.2. API-ES (positive): m/z = 683 $[2M + Na]^+$, 353 $[M + Na]^+$. $C_{15}H_{22}O_8$ (330.33): calcd. C 54.54, H 6.71; found C 54.47, H 6.62.

1-Deoxy-2,3:4,6-di-*O*-isopropylidene-1-methyl-5a-carba-β-D-glucopyranoside (38): This compound was prepared from the xanthate **30** (150 mg, 0.37 mmol) by the General Procedure for HBu_3Sn-induced radical cyclization (Procedure F). Purification of the crude material by flash chromatography (hexane/EtOAc 98:2) afforded the cyclohexane derivative **38** (59 mg, 64%). $[\alpha]_D^{25}$ = –8.4 (c = 0.2, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.71 (m, 3 H), 3.44 (t, J = 9.0 Hz, 1 H, 3-H), 3.04 (dd, J = 8.8, 9.0 Hz, 1 H, 2-H), 1.88 (m, 1 H, 1-H), 1.74 (m, 1 H, 5-H), 1.60 (m, 1 H, 5′a-H), 1.53 (m, 1 H, 5′b-H), 1.48 (s, 3 H, Me), 1.41 (s, 12 H, 3× Me) ppm. ^{13}C NMR ($CDCl_3$, 50 MHz): δ = 110.9, 99.9, 83.7, 73.9, 64.4, 39.0, 34.2, 32.5, 27.8 (×2), 26.8 (×2), 17.5, 13.6 ppm. API-ES (positive): m/z = 535 $[2M + Na]^+$, 279 $[M + Na]^+$. $C_{14}H_{24}O_4$ (256.34): calcd. C 65.60, H 9.44; found C 65.46, H 9.52.

(*Z*)-1-Chloro-1,2,6-trideoxy-3,4:5,7-di-*O*-isopropylidene-D-*gluco*-hept-1-enitol (39): This compound was prepared from the thiocarbonate (*Z*)-**31** (110 mg, 0.259 mmol) by General Procedure F. The crude material was purified by flash chromatography (hexane/EtOAc 8:2 to 7:3) to give **39** (47 mg, 65%) followed by the alcohol (*Z*)-**16** (24 mg, 31%). For **39**: $[\alpha]_D^{25}$ = +8.7 (c = 0.25, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 6.26 (d, J = 7.3 Hz, 1 H, 1′-H), 5.84 (dd, J = 8.4, 7.3 Hz, 1 H, 1-H), 4.98 (t, J = 8.4 Hz, 1 H, 2-H), 3.95–4.02 (m, 2 H), 3.86 (ddd, J = 11.9, 5.7, 1.5 Hz, 1 H, 6a-H), 3.72 (dd, J = 8.4, 4.7 Hz, 1 H, 3-H), 1.80 (m, 1 H, 5a-H), 1.48 (s, 3 H), 1.45 (s, 3 H), 1.44 (s, 3 H), 1.42 (s, 3 H), 1.37 (m, 1 H, 5b-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 129.7, 122.7, 110.2, 98.7, 83.1, 71.8, 68.5, 59.6, 29.9, 27.3, 27.0, 26.8, 19.3 ppm. API-ES (positive): m/z = 299.0 $[M + Na]^+$. $C_{13}H_{21}ClO_4$ (276.76): calcd. C 56.42, H 7.65; found C 56.30, H 7.58.

1,2,6-Trideoxy-3,4:5,7-di-*O*-isopropylidene-D-*gluco*-hept-1-ynitol (40): This compound was prepared from the thiocarbonate **32** (100 mg, 0.25 mmol) by General Procedure F. The crude mate-

rial was purified by flash chromatography (hexane/EtOAc 9:1 3) to give compound **40** (20 mg, 33%) as a colourless oil. $[\alpha]_D^{25}$ = +14.5 (c = 0.15, $CHCl_3$). ^1H NMR ($CDCl_3$, 300 MHz): δ = 4.52 (dd, J = 7.3, 2.1 Hz, 1 H, 2-H), 4.08 (dd, J = 7.3, 5.4 Hz, 1 H, 3-H), 4.00 (ddd, J = 11.9, 5.6, 2.7 Hz, 1 H, 4-H), 3.98 (ddd, J = 12.1, 6.3, 2.7 Hz, 1 H, 6a-H), 3.88 (ddd, J = 11.8, 5.6, 1.7 Hz, 1 H, 6b-H), 2.53 (d, J = 2.1 Hz, 1 H, 1′-H), 1.86 (ddt, J = 17.8, 12.1, 5.6 Hz, 1 H, 5a-H), 1.50 (s, 3 H, Me), 1.48 (s, 3 H, Me), 1.43 (s, 3 H, Me), 1.42 (s, 3 H, Me), 1.39 (m, 1 H, 5b-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 113.3, 98.7, 83.8, 77.4, 74.8, 68.9, 66.2, 59.4, 29.6, 26.8, 26.7, 26.3, 19.3 ppm. API-ES (positive): m/z = 263.0 [M + Na]$^+$. $C_{13}H_{20}O_4$ (240.30): calcd. C 64.98, H 8.39; found C 64.93, H 8.33.

(*E*)- and (*Z*)-1-Chloro-1,2-dideoxy-3,4:5,7-di-*O*-isopropylidene-D-*manno*-hept-1-enitol (46): This compound was prepared from the hemiketal **45** (1.02 g, 3.92 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded (*E*)-**46** (560 mg, 49%), followed by (*Z*)-**46** (556 mg, 48%). Although both isomers were uneventfully used as a mixture in the synthetic route, they were separated for the purpose of correct characterization. For (*E*)-**46**: $[\alpha]_D^{25}$ = –79.0 (c = 0.1, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.24 (d, J = 13.4 Hz, 1 H, 1′-H), 6.13 (dd, J = 13.4, 10.9 Hz, 1 H, 1-H), 4.67 (dd, J = 10.8, 8.7 Hz, 1 H, 2-H), 4.47 (dd, J = 8.7, 1.6 Hz, 1 H, 3-H), 3.88 (m, 2 H, 5-H, 6a-H), 3.61 (m, 1 H, 4-H), 3.56 (dd, J = 8.7, 1.6 Hz, 1 H, 6b-H), 2.62 (br. s, 1 H, OH), 1.51 (s, 3 H, Me), 1.45 (s, 3 H, Me), 1.40 (s, 3 H, Me), 1.34 (s, 3 H, Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 124.7, 111.8, 105.1, 94.0, 70.3, 69.0, 68.3, 60.2, 58.0, 24.0, 21.8, 21.3, 14.5 ppm. EI-MS: m/z = 292.0 [M]$^+$. $C_{13}H_{21}ClO_5$ (292.11): calcd. C 53.33, H 7.23; found C 53.19, H 7.18. For (*Z*)-**46**: $[\alpha]_D^{25}$ = –10.1 (c = 0.14, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.19 (dd, J = 7.2 Hz, 1 H, 1′-H), 6.06 (t, J = 7.2 Hz, 1 H, 1-H), 5.23 (dd, J = 7.1, 1.2 Hz, 1 H, 2-H), 4.62 (dd, J = 7.1, 1.2 Hz, 1 H, 3-H), 3.88 (m, 2 H, 5-H, 6a-H), 3.61 (m, 1 H, 4-H), 3.44 (dd, J = 8.7, 1.9 Hz, 1 H, 6b-H), 2.58 (d, J = 4.8 Hz, 1 H, OH), 1.52 (s, 3 H, Me), 1.40 (s, 3 H, Me), 1.39 (s, 3 H, Me), 1.38 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 129.1, 120.2, 109.5, 98.4, 74.7, 73.4, 72.7, 64.7, 62.2, 28.4, 26.2, 25.7, 18.9 ppm. EI-MS: m/z = 292.0 [M]$^+$. $C_{13}H_{21}ClO_5$ (292.11): calcd. C 53.33, H 7.23; found C 53.11, H 7.05.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-6-oxo-D-*manno*-hept-1-ynitol (47): Dry DMSO (0.54 mL, 7.66 mmol) was slowly added under an inert atmosphere to a cold (–78 °C) stirred solution of oxalyl chloride (965 μL, 5.75 mmol) in dry CH_2Cl_2 (5 mL). After the evolution of gas had ceased, the alcohol **46** (1.12 g, 3.83 mmol) dissolved in dry CH_2Cl_2 (10 mL) was slowly added. After 30 min Et_3N was added and the reaction mixture was allowed to warm to room temperature. After 45 min, the mixture was quenched by the addition of water. The organic phase was separated and the aqueous phase was washed with CH_2Cl_2. The collected organic phases were then washed with brine. The resulting organic solution was dried, concentrated and purified by flash chromatography (hexane/EtOAc 80:20) to give compound **47** (520 mg, 48%). For (*E*)-**47**: $[\alpha]_D^{25}$ = –157.1 (c = 0.2, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.22 (d, J = 13.2 Hz, 1 H, 1′-H), 6.12 (t, J = 13.2 Hz, 1 H, 1-H), 4.8 (t, J = 13.2 Hz, 1 H, 2-H), 4.62 (m, 1 H, 3-H), 4.28 (d, J = 15.0 Hz, 1 H, 6a-H), 4.21 (s, 1 H, 4-H), 3.96 (d, J = 15.0 Hz, 1 H, 6b-H), 1.49 (s, 3 H, Me), 1.48 (s, 3 H, Me), 1.46 (s, 3 H, Me), 1.35 (s, 3 H, Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.9, 129.4, 123.3, 110.0, 101.0, 76.8, 74.3, 73.3, 67.0, 26.5, 25.7, 24.1, 23.9 ppm. EI-MS: m/z = 290.0 [M]$^+$. $C_{13}H_{19}ClO_5$ (290.74): calcd. C 53.70, H 6.59; found C 53.49, H 6.38. For (*Z*)-**46**: $[\alpha]_D^{25}$ = –197.2 (c = 0.18, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.24 (dd, J = 7.2, 1.0 Hz, 1 H, 1′-H), 6.09 (t, J = 7.2 Hz, 1 H, 1-H), 5.29 (dd, J = 7.2 Hz, 1 H, 2-H), 4.90 (d, J = 7.2 Hz, 1 H, 3-H), 4.29 (d, J = 16 Hz, 1 H, 6a-H), 4.12 (s, 1 H, 4-H), 3.98 (d, J = 16 Hz, 1 H, 6b-H), 1.50 (s, 3 H, Me), 1.48 (s, 3 H, Me), 1.43 (s, 3 H, Me), 1.38 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 207.8, 129.4, 121.2, 109.9, 101.0, 75.5, 74.6, 73.3, 67.0, 26.5, 25.6, 24.1, 23.9 ppm. EI-MS: m/z = 290.0 [M]$^+$. $C_{13}H_{19}ClO_5$ (290.74): calcd. C 53.70, H 6.59; found C 53.54, H 6.28.

(*Z*)- and (*E*)-1-Chloro-1,2-dideoxy-3,4:5,7-di-*O*-isopropylidene-6-(trimethylsilyl)methyl-D-*manno*-hept-1-enitol (48): A solution of the ketone **47** (520 mg, 1.79 mmol) in anhydrous diethyl ether (5 mL) was cooled under argon to 0 °C. [(Trimethylsilyl)methyl]magnesium chloride (7.16 mmol, 7.16 mL, 1 M solution in diethyl ether) was added dropwise. The resulting slightly yellow solution was then stirred at room temp. for 6 h. The reaction mixture was quenched with ammonium chloride and diluted with diethyl ether. The organic layer was separated; the aqueous phase was extracted three times with diethyl ether. The combined ethereal extracts were washed with saturated aqueous sodium chloride solution, dried ($MgSO_4$) and concentrated under reduced pressure. The residue was then subjected to flash chromatography (hexane/EtOAc 95:5) to afford (*E*)-**48** (350 mg, 47%), followed by (*Z*)-**48** (107 mg, 20%). Although both isomers were uneventfully used as a mixture in the synthetic route, they were separated for the purpose of correct characterization. For (*E*)-**48**: $[\alpha]_D^{25}$ = –79.1 (c = 0.1, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.22 (d, J = 13.4 Hz, 1 H, 1′-H), 6.12 (t, J = 13.2 Hz, 1 H, 1-H), 4.78 (t, J = 13.2 Hz, 1 H, 2-H), 4.76 (d, J = 13.2 Hz, 1 H, 3-H), 3.92 (s, 1 H, 6a-H), 3.62 (s, 1 H, 6b-H), 1.58 (s, 3 H, Me), 1.47 (s, 3 H, Me), 1.41 (s, 3 H, Me), 1.39 (s, 3 H, Me), 1.10 (d, J = 12.0 Hz, 1 H, CH_2Si), 0.68 (d, J = 12.0 Hz, 1 H, CH_2Si), 0.03 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 129.6, 122.9, 110.4, 98.5, 76.2, 75.4, 74.2, 73.2, 71.2, 29.4, 26.2, 25.7, 24.6, 18.5, 0.7 (×3) ppm. EI-MS: m/z = 378.0 [M]$^+$. For (*Z*)-**48**: $[\alpha]_D^{25}$ = –77.0 (c = 0.34, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 6.18 (dd, J = 7.4 Hz, 1 H, 1′-H), 6.02 (t, J = 7.4 Hz, 1 H, 1-H), 5.19 (t, J = 7.4 Hz, 1 H, 2-H), 4.78 (dd, J = 7.3 Hz, 1 H, 3-H), 4.16 (s, 1 H, 4-H), 3.62 (s, 1 H, 6a-H), 3.39 (s, 1 H, 6b-H), 1.55 (s, 3 H, Me), 1.43 (s, 3 H, Me), 1.37 (s, 3 H, Me), 1.36 (s, 3 H, Me), 1.01 (d, J = 12.8 Hz, 1 H, CH_2Si), 0.68 (d, J = 12.0 Hz, 1 H, CH_2Si), 0.03 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 129.8, 120.0, 110.0, 98.4, 76.4, 75.4, 73.0, 70.4, 70.1, 29.3, 26.1, 25.6, 24.6, 18.4, 0.5 (×3) ppm. EI-MS (positive): m/z = 378.0 [M]$^+$.

1,2-Dideoxy-3,4:5,7-bis-*O*-(1-methylethylidene)-6-(trimethylsilyl)-methyl-*manno*-hept-1-ynitol (49): This compound was prepared from the 1-chloroenitol **48** (457 mg, 1.2 mmol) by General Procedure D. Purification (hexane/EtOAc 7:3) afforded **49** (280 mg, 68%). $[\alpha]_D^{25}$ = –25.5 (c = 0.9, $CHCl_3$). ^1H NMR (200 MHz, $CDCl_3$): δ = 4.86 (dd, J = 6.7, 2.2 Hz, 1 H, 2-H), 4.52 (dd, J = 8.5, 2.5 Hz, 1 H, 3-H), 3.88 (d, J = 2.0 Hz, 1 H, 7a-H), 3.66 (m, 2 H, 2 6-H), 2.53 (d, J = 2.2 Hz, 1 H, 1′-H), 1.49 (s, 3 H, Me), 1.38 (s, 6 H, 2× Me), 1.25 (s, 3 H, Me), 0.98 (d, J = 12.0 Hz, 1 H, CH_2Si), 0.62 (d, J = 12.0 Hz, 1 H, CH_2Si), 0.07 (s, 9 H, $SiMe_3$) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 111.5, 98.5, 78.3, 76.4, 74.8, 73.9, 69.9, 69.7, 67.5, 29.0, 25.9, 25.5, 23.7, 17.9, 0.3 (×3) ppm.

1,2-Dideoxy-6-methylene-3,4:5,7-bis-*O*-(1-methylethylidene)-D-*manno*-hept-1-ynitol (42): This compound was prepared from the alkyne **49** (280 mg, 0.82 mmol) by the General Procedure. Purification (hexane/EtOAc 95:5) afforded the enyne **42** (132 mg, 63%). $[\alpha]_D^{25}$ = –40.0 (c = 0.92, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 4.97 (s, 2 H, 5′-H), 4.84 (dd, J = 6.0, 2.1 Hz, 1 H, 4-H), 4.70 (m, 1 H, 2-H), 4.37 (t, J = 6.0 Hz, 1 H, 3-H), 4.27 (dd, J = 14.2, 1.4 Hz, 1 H), 2.54 (d, J = 2.2 Hz, 1 H), 1.56 (s, 3 H, Me), 1.46 (s, 3 H,

Me), 1.42 (s, 3 H, Me) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 142.8, 110.8, 108.6, 100.1, 79.4, 78.0, 71.6, 67.4, 64.2, 53.4, 27.3, 27.0, 26.0, 23.0 ppm. $C_{14}H_{20}O_4$ (252.31): calcd. C 66.65, H 7.99; found C 66.38, H 7.75.

(*E*)- and (*Z*)-3,4:5,7-tetra-*O*-benzyl-1-chloro-1,2-dideoxy-D-*manno*-hept-1-enitol (51): This compound was prepared from the hemiketal **50** (5.4 g, 10 mmol) by the General Procedure. Purification (hexane/EtOAc, 7:3) afforded (*E*)-**51** (2.1 g, 35%), followed by (*Z*)-**51** (1.6 g, 28%). Although both isomers were uneventfully used as a mixture in the synthetic route, they were separated for the purpose of correct characterization. For (*E*)-**51**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.26 (m, 20 H, Ph), 6.31 (d, J = 13.4 Hz, 1 H, 1′-H), 6.00 (dd, J = 13.4, 8.5 Hz, 1 H, 1-H), 4.58 (d, J = 11.5 Hz, 1 H, CH_2Ph), 4.56 (m, 6 H, 3 CH_2Ph), 4.22 (d, J = 11.5 Hz, 1 H, CH_2Ph), 4.12 (dd, J = 13.4, 8.5 Hz, 1 H, 2-H), 4.00 (m, 1 H, 5-H), 3.86 (m, 2 H, 3-H, 4-H), 3.66 (dd, J = 9.6, 3.3 Hz, 1 H, 6a-H), 3.58 (dd, J = 9.6, 5.4 Hz, 1 H, 6b-H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.2, 137.9, 137.8, 137.7, 132.0, 128.5 (×2), 128.4 (×2), 128.3 (×2), 128.2 (×4), 127.8 (×4), 127.7 (×2), 127.6 (×2), 127.5 (×2), 122.3, 80.3, 78.3, 77.9, 74.6, 73.9, 73.2, 71.0, 70.2, 69.9 ppm. API-ES (positive): m/z = 595.0 [M + Na]$^+$. For (*Z*)-**51**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.21–7.05 (m, 20 H), 6.37 (dd, J = 7.3 Hz, 1 H, 1′-H), 5.96 (dd, J = 9.1, 7.3 Hz, 1 H, 1-H), 4.82 (dd, J = 9.3, 6.1 Hz, 1 H, 2-H), 4.62 (m, 7 H, CH_2Ph), 4.30 (d, J = 12.4 Hz, 1 H, CH_2Ph), 4.01 (m, 1 H, 5-H), 3.98 (dd, J = 6.5, 3.1 Hz, 1 H, 3-H), 3.82 (dd, J = 7.7, 3.5 Hz, 1 H, 4-H), 3.63 (m, 2 H, 6-H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.2, 137.9, 137.8, 137.7, 132.0, 128.5 (×2), 128.4 (×3), 128.3 (×4), 128.2 (×5), 127.8 (×5), 127.7 (×4), 127.6 (×3), 127.5 (×2), 122.3, 80.4, 78.7, 74.2, 74.0, 73.9, 73.3, 71.1, 70.4, 70.2 ppm. EI-MS: m/z = 292.0 [M]$^+$.

3,4:5,7-Tetra-*O*-benzyl-1,2-dideoxy-D-*manno*-hept-1-ynitol (52): This compound was prepared from the 1-chloroenitol **51** (1.5 g, 2.6 mmol) by the General Procedure. Purification (hexane/EtOAc 7:3) afforded **52** (900 mg, 68%). $[\alpha]_D^{25}$ = –12.3 (c = 0.5, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.20 (m, 20 H, Ph), 4.93 (d, J = 11.0 Hz, 1 H, CH_2Ph), 4.79 (d, J = 11.0 Hz, 1 H, CH_2Ph), 4.66 (d, J = 11.0 Hz, 1 H, CH_2Ph), 4.40 (m, 4 H, CH_2Ph), 4.32 (d, J = 11.4 Hz, 1 H, CH_2Ph), 3.97 (dd, J = 7.0, 2.3 Hz, 1 H, 3-H), 3.94 (m, 1 H, 5-H), 3.75 (dd, J = 8.2, 2.8 Hz, 1 H, 4-H), 3.52 (m, 2 H, 6-H), 2.50 (d, J = 2.0 Hz, 1 H, 1′-H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.1 (×2), 137.9, 137.4, 128.4 (×2), 128.3 (×4), 128.2 (×4), 128.1 (×4), 127.9, 127.8, 127.7, 127.6, 127.5, 81.3, 80.1, 77.8, 75.7, 74.7, 73.9, 73.3, 71.0, 70.4, 69.8, 68.7 ppm. API-ES (positive): m/z = 559.0 [M + Na]$^+$. $C_{35}H_{36}O_5$ (536.26): calcd. C 78.33, H 6.76; found C 78.19, H 6.53.

3,4:5,7-Tetra-*O*-benzyl-1,2-dideoxy-6-oxo-D-*manno*-hept-1-ynitol (53): A stirred solution of hept-1-ynitol **52** (4 g, 7.48 mmol) in dry CH_2Cl_2 (50 mL) was treated with Dess–Martin periodinane (3.48 g, 8.23 mmol) and then stirred for 1 h, after which the reaction mixture was washed consecutively with saturated aqueous sodium hydrogen carbonate solution and water. The organic layer was then dried and concentrated, and the residue was purified by flash chromatography (hexane/EtOAc 8:2) to afford the ketone **53** (3.4 g, 85%). $[\alpha]_D^{25}$ = –98.4 (c = 0.3, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.27 (m, 20 H, Ph), 4.93 (d, J = 10.8 Hz, 1 H, CH_2Ph), 4.84 (d, J = 11.4 Hz, 1 H, CH_2Ph), 4.51–4.15 (m, 11 H), 4.14 (dd, J = 8.1, 2.7 Hz, 1 H), 2.59 (d, J = 2.1 Hz, 1 H, 1-H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 208.4, 137.5, 137.4, 137.1, 136.9, 128.5 (×4), 128.4 (×4), 128.3 (×2), 128.2 (×2), 128.1 (×3), 127.9 (×3), 127.8 (×2), 83.4, 81.5, 81.0, 75.8, 75.3, 74.6, 74.4, 73.2, 70.5, 67.9 ppm. API-ES (positive): m/z = 557.0 [M + Na]$^+$. $C_{35}H_{34}O_5$ (534.24): calcd. C 78.63, H 6.41; found C 78.51, H 6.38.

3,4:5,7-Tetra-*O*-benzyl-1,2-dideoxy-6-methylene-D-*manno*-hept-1-ynitol (43): This compound was prepared from the ketone **53** (520 mg, 0.97 mmol) by the General Procedure. Purification (hexane/EtOAc 8:2) afforded the enyne **43** (350 mg, 80%). $[\alpha]_D^{25}$ = –59.6 (c = 0.3, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.27 (m, 20 H, Ph), 5.30 (s, 2 H, 5′-H), 4.82 (d, J = 11.2 Hz, 1 H, CH_2Ph), 4.66 (d, J = 11.6 Hz, 1 H, CH_2Ph), 4.61 (d, J = 11.2 Hz, 1 H, CH_2Ph), 4.50 (d, J = 12.0 Hz, 1 H, CH_2Ph), 4.36 (m, 3 H, CH_2Ph), 4.29 (dd, J = 5.6, J = 2.0 Hz, 1 H, 2-H), 4.19 (m, 2 H, 4-H, CH_2Ph), 3.94 (d, J = 12.0 Hz, 1 H, 6a-H), 2.85 (d, J = 12.0 Hz, 1 H, 6b-H), 3.77 (t, J = 5.6 Hz, 1 H, 3-H), 2.40 (d, J = 2.0 Hz, 1 H, 1′- H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 142.5, 138.5, 138.3, 138.2, 137.8, 128.3 (×4), 128.2 (×4), 128.0 (×2), 127.9 (×2), 127.8 (×2), 127.5 (×4), 127.4 (×2), 116.8, 81.8, 81.0, 75.3, 75.1, 72.7, 71.2, 70.6, 70.3, 69.8 ppm. API-ES (positive): m/z = 555.0 [M + Na]$^+$. $C_{13}H_{22}O_5$ (258.31): calcd. C 60.45, H 8.58; found C 60.27, H 8.33.

3,4:5,7-Tetra-*O*-acetyl-1,2-dideoxy-6-methylene-D-*gluco*-hept-1-ynitol (44): This compound was prepared from the enyne **20a** (180 mg, 0.71 mmol) by General Procedure F. Purification (hexane/EtOAc 9:1) afforded **44** (900 mg, 68%). $[\alpha]_D^{25}$ = +46.9 (c = 1.0, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.67 (d, J = 3.6 Hz, 1 H, 4-H), 5.57 (dd, J = 2.0, 7.0 Hz, 1 H, 2-H), 5.48 (dd, J = 3.6, 7.0 Hz, 1 H, 3-H), 5.31 (d, J = 14.0 Hz, 2 H, 5′-H), 4.71 (d, J = 13.2 Hz, 1 H, 6a-H), 4.57 (d, J = 13.2 Hz, 1 H, 6b-H), 2.56 (d, J = 2.0 Hz, 1 H, 1′-H), 2.13 (s, 6 H, 2× Ac), 2.12 (s, 3 H, Ac), 2.09 (s, 3 H, Ac) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 170.6, 169.5 (×2), 139.11, 118.3, 111.7, 81.6, 80.9, 76.3, 72.1, 72.0, 64.4, 62.9, 29.0, 20.9, 20.8, 20.6 ppm. API-ES (positive): m/z = 363.2 [M + Na]$^+$. $C_{16}H_{20}O_8$ (340,33): calcd. C 56.47, H 5.92; found C 56.33, H 5.78.

2,3:4,6-Bis-*O*-(1-methylethylidene)-1-(tributylstannylmethylene)-5a-carba-D-mannopyranose (54) and 2,3:4,6-Bis-*O*-(1-methylethylidene)-1-(tributylstannylmethylene)-5a-carba-L-mannopyranose (55): These compounds were prepared from the enyne **42** (450 mg, 1.8 mmol) by the General Procedure for cyclization. Purification (hexane/EtOAc 98:2) afforded the methylenecyclohexanes **55** (39 mg, 4%) and **54** (587 mg, 60%).

Compound 55 (unassigned 4:1 *Z*/*E* mixture of stannanes): ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.12 (s, 1 H, 1′-H), 4.58 (d, J = 4.3 Hz, 1 H), 4.12 (dd, J = 4.3, 5.9 Hz, 1 H), 3.75 (m, 2 H), 3.62 (t, J = 8.5 Hz, 1 H), 2.12 (m, 2 H), 1.91 (dd, J = 10.4, 2.9 Hz, 1 H), 1.33 (s, 3 H), 1.31 (s, 3 H), 1.30 (m, 6 H), 1.29 (s, 3 H), 1.27 (s, 3 H), 1.24 (m, 6 H), 0.89 (m, 6 H), 0.87 (t, J = 7.2 Hz, 9 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 148.2, 133.4, 109.3, 98.9, 81.3, 79.2, 74.7, 64.0, 35.7, 32.3, 29.5, 28.9 (×3) 28.2, 27.1 (×3), 27.0, 26.1, 13.5 (× ·3), 10.0 (×3) ppm. API-ES (positive): m/z = 544 [M + H]$^+$.

Compound 54 (one unassigned isomer): ^{1}H NMR ($CDC1_3$, 300 MHz): δ = 5.91 (s, 1 H, 1′-H), 4.43 (d, J = 7.2 Hz, 1 H, 2-H); 4.00 (m, 3 H), 3.54 (dd, J = 2.2, 11.5 Hz, 1 H, 6b-H), 2.61 (m, 2 H, 5′a-H, 5-H), 2.02 (m, 1 H, 5′b-H), 1.35 (s, 3 H, Me), 1.33 (s, 3 H, Me), 1.29 (m, 6 H, CH_2), 1.28 (s, 3 H, Me), 1.27 (s, 3 H, Me), 1.24 (m, 6 H, CH_2CH_3), 0.89 (m, 6 H, CH_2Sn), 0.87 (m, 9 H, CH_2CH_3) ppm. ^{13}C NMR: δ = (50 MHz, $CDCl_3$): 148.0, 133.4, 109.3, 99.0, 81.3, 79.5, 75.1, 68.2, 36.4, 34.9, 29.6, 29.4, 28.9 (×3), 27.0 (×3), 26.5, 13.5 (×3), 10.2 (×3) ppm. API-ES (positive): m/z = 544 [M + H]$^+$. $C_{26}H_{46}O_4Sn$ (543.37): calcd. C 57.69, H 8.56; found C 57.39, H 8.23.

Methylene-2,3:4,6-tetra-*O*-benzyl-5a-carba-D-mannopyranose (56) and Methylene-2,3:4,6-tetra-*O*-benzyl-5a-carba-1-mannopyranose (57): These compounds were prepared from the enyne **43** (450 mg, 0.8 mmol) by the General Procedure for cyclization. Purification

(hexane/EtOAc 98:2) afforded the corresponding stannylated methylenecyclohexanes, which were dissolved in THF/H_2O (5 mL, 2:1, v/v), treated with acetic acid (2 mL) and then heated in an oil bath for 10 h. After concentration in vacuo, the residue was purified by flash chromatography (hexane/EtOAc 9:1) to give an inseparable mixture (1.6:1, 341 mg, 80%) of the stereoisomers **56** (major compound) and **57** (minor isomer). For the major isomer: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.32 (m, 20 H, Ph), 5.03 (s, 1 H, 1′-H), 4.99 (d, 1 H, CH_2Ph), 4.85 (s, 1 H, 1′-H), 4.50 (m, 7 H, CH_2Ph), 4.07 (d, *J* = 3.0 Hz, 1 H, 2-H), 3.99 (dd, *J* = 10.1, 9.4 Hz, 1 H, 4-H), 3.61 (m, 2 H, 6-H), 3.47 (dd, *J* = 9.4, 3.2 Hz, 1 H, 3-H), 2.42 (t, *J* = 13.0 Hz, 1 H, 5′a-H), 2.31 (dd, *J* = 13.4, 4.7 Hz, 1 H, 5′b-H), 1.78 (m, 1 H, 5-H) ppm. For the minor isomer: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.15 (m, 20 H, Ph), 5.10 (s, 1 H, 1′-H), 4.99 (s, 1 H, 1′-H), 4.58 (m, 8 H, CH_2-Ph), 4.16 (m, 1 H, 2-H), 3.87 (dd, *J* = 3.2, 1.8 Hz, 1 H, 4-H), 3.73 (m, 1 H, 3-H), 3.54 (dd, *J* = 7.9, 9.9, 6a Hz, 1 H -H), 3.35 (dd, *J* = 7.9, 9.8 Hz, 1 H, 6b-H), 2.40 (m, 1 H, 5-H), 2.28 (dd, *J* = 13.8, 4.7 Hz, 1 H, 5′a-H), 1.78 (m, 1 H, 5′b-H) ppm. For the mixture: ^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.8, 139.0, 138.9, 138.6, 138.3, 128.3, 128.2, 128.2, 128.1, 128.0, 127.9, 127.7, 127.7, 127.6, 127.5, 127.5, 127.4, 127.3, 114.3, 84.8 (×2), 81.7, 80.8, 78.7, 78.1 (×2), 77.9 (×2), 77.2, 76.9, 75.2 (×2), 73.0, 72.9, 72.6, 72.5, 71.7 (×2), 70.9, 70.8, 70.6, 69.7, 68.8 (×2), 43.1, 37.8, 31.8, 31.5 ppm. API-ES (positive): *m*/*z* = 557.0 [M + Na]$^+$. $C_{36}H_{38}O_4$ (534.68): calcd. C 80.87, H 7.16; found C 80.61, H 7.33.

Methylene-2,3:4,6-tetra-*O*-acetyl-5a-carba-D-glucopyranose (58) and Methylene-2,3:4,6-tetra-*O*-acetyl-5a-carba-1-glucopyranose (59): These compounds were prepared from the enyne **44** (100 mg, 0.18 mmol) by the General Procedure for cyclization. Purification (hexane/EtOAc 98:2) afforded the corresponding stannylated methylenecyclohexanes, which were dissolved in THF/H_2O (3 mL, 2:1, v/v), treated with acetic acid (1 mL) and then heated in an oil bath for 10 h. After concentration in vacuo, the residue was purified by flash chromatography (hexane/EtOAc 9:1) to give an inseparable mixture (1.4:1, 39 mg, 64%) of the stereoisomers **58** (major compound) and **59** (minor isomer). For the mixture. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.91 (m, 2 H), 5.10 (m, 7 H), 4.24 (dd, *J* = 5.0, 10.6 Hz, 1 H), 4.09 (dd, *J* = 5.0, 11.6 Hz, 1 H), 4.02 (m, 3 H), 2.52 (m, 2 H), 2.16 (m, 2 H), 2.13 (s, 3 H), 2.11 (s, 3 H), 2.09 (s, 3 H), 2.08 (s, 3 H), 2.06 (s, 3 H), 2.04 (s, 3 H), 2.04 (s, 3 H), 2.03 (s, 3 H), 2.02 (m, 1 H), 1.68 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 170.8, 170.6, 170.5 (×2), 170.1, 170.0, 169.9, 169.8, 139.2, 137.7, 113.2, 110.1, 74.9, 73.1, 72.9, 71.5, 71.4, 71.2, 63.2, 61.6, 40.1, 36.3, 33.0, 31.0, 27.8, 26.7, 20.8 (×2), 20.7, 20.6 (×2), 20.5, 20.4 (×2) ppm. API-ES: 365 [M + Na]$^+$. $C_{16}H_{22}O_8$ (342.34): calcd. C 56.13, H 6.43; found C 55.94, H 6.31.

1-*tert*-Butyldimethylsilyl-2,3:4,6-di-*O*-isopropylidene-D-mannitol (60): This compound was prepared from the hemiketal **45** (8.7 g, 38 mmol) by General Procedure I. Purification afforded the alcohol **60** (12.3 g, 86% overall). $[\alpha]_D^{25}$ = –40.6 (*c* = 1.0, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.41 (dd, *J* = 3.4, 6.7 Hz, 1 H), 4.35 (dd, *J* = 7.8, 15.5 Hz, 1 H), 3.77–3.96 (m, 5 H), 3.58–3.68 (m, 1 H), 1.52 (s, 6 H, Me), 1.44 (s, 3 H, Me), 1.40 (s, 3 H, Me), 0.93 (s, 9 H, Me), 0.14 (s, 6 H, Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 109.0, 98.5, 77.4, 75.3, 72.4, 64.9, 63.4, 61.9, 28.5, 26.7 (×2), 25.2 (×3), 19.3 (×2), –5.4 ppm. EI-MS: *m*/*z* = 376.0 [M]$^+$. $C_{18}H_{36}O_6Si$ (376.56): calcd. C 57.41, H 9.64; found C 57.36, H 9.43.

1-*tert*-Butyldimethylsilyl-2,3:4,6-di-*O*-isopropylidene-5-oxo-D-mannitol (61): A stirred solution of the alcohol **60** (10.5 g, 28.7 mmol) in dry CH_2Cl_2 (50 mL) was treated with Dess–Martin periodinane (17 g, 40 mmol) and then stirred for 4 h, after which the reaction mixture was washed consecutively with saturated aqueous sodium hydrogencarbonate solution and water. The organic layer was then dried and concentrated, and the residue was purified by flash chromatography (hexane/EtOAc 95:5) to afford the ketone **61** (8.7 g, 82%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.66 (dd, *J* = 3.0, 6.0 Hz, 1 H), 4.60 (dd, *J* = 1.2, 3.0 Hz, 1 H), 4.36 (dd, *J* = 9.0, 15.0 Hz, 1 H), 4.30 (dd, *J* = 2.2, 17.2 Hz, 1 H), 3.85–4.02 (m, 3 H), 1.53 (s, 3 H), 1.50 (s, 6 H), 1.37 (s, 3 H), 0.92 (s, 9 H), 0.10 (s, 6 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.6, 109.2, 100.9, 76.5, 75.2, 73.9, 66.8, 61.8, 26.6 (×2), 23.7 (×3), 22.1 (×2), 18.2, –5.4 (×2) ppm. EI-MS: *m*/*z* = 374.0 [M]$^+$. $C_{18}H_{34}O_6Si$ (374.54): calcd. C 57.72, H 9.15; found C 57.60, H 9.23.

2,3:4,6-Di-*O*-isopropylidene-5-methylene-D-mannitol (62): This compound was prepared from **61** (2.51 g, 3.3 mmol) by General Procedure E for olefination followed by General Procedure J for desylilation. Purification (hexane/EtOAc 7:3) afforded the derivative **62** (827 mg, 48%). $[\alpha]_D^{25}$ = –93.6 (*c* = 1.2, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 5.02 (br. s, 1 H, 5′a-H), 5.02 (br. s, 1 H, 5′b-H), 4.39 (d, *J* = 13.5 Hz, 1 H, 6a-H), 4.34–4.54 (m, 3 H, 2-H, 3-H, 4-H), 4.27 (d, *J* = 13.5 Hz, 1 H, 6b-H), 3.87 (dd, *J* = 5.0, 12.0 Hz, 1 H, 1a-H), 3.79 (dd, *J* = 4.1, 12.1 Hz, 1 H), 1.60 (s, 3 H, Me), 1.51 (s, 3 H, Me), 1.47 (s, 3 H, Me), 1.43 (s, 3 H, Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.7, 108.6, 107.6, 99.8, 77.5, 76.8, 66.8, 64.2, 61.1, 26.4, 26.3, 25.2, 22.3 ppm. API-ES (positive): *m*/*z* = 539 [2 M + Na]$^+$, 281 [M + Na]$^+$. $C_{13}H_{22}O_5$ (258.31): calcd. C 60.45, H 8.58; found C 60.27, H 8.33.

1-*O*-Phenyl 2,3:4,6-Di-*O*-isopropylidene-5-methylene-D-mannitol Carbonothioate (63): This compound was prepared from the alcohol **62** (150 mg, 0.58 mmol) by General Procedure L. Purification (hexane/EtOAc 9:1) afforded the derivative **63** (174 mg, 76%). $[\alpha]_D^{25}$ = –2.6 (*c* = 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 7.38–6.98 (m, 5 H), 4.95 (s, 1 H, 5′a-H), 4.92 (d, *J* = 2.0 Hz, 1 H, 5′b-H), 4.58 (dd, *J* = 6.4, 4.6 Hz, 1 H, 1a-H), 4.50 (dd, *J* = 6.6 Hz, 1 H, 1b-H), 4.39 (m, 1 H), 4.25 (dd, *J* = 13.2, 1.2 Hz, 1 H, 6a-H), 4.10 (d, *J* = 13.4 Hz, 1 H, 6b-H), 1.48 (s, 3 H, Me), 1.40 (s, 3 H, Me), 1.34 (s, 3 H, Me), 1.33 (s, 3 H, Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 195.4, 143.5, 129.8 (×2), 126.9, 122.1 (×2), 115.7, 110.1, 100.3, 108.4, 77.8, 74.7, 73.6, 69.4, 64.7, 27.0, 26.9, 25.7, 22.9 ppm.

5-Deoxy-2,3:4,6-di-*O*-isopropylidene-5-methylene-D-mannose (64): A stirred solution of the alcohol **62** (200 mg, 0.77 mmol) in dry CH_2Cl_2 (10 mL) was treated with Dess–Martin periodinane (358 mg, 0.85 mmol) and then stirred for 1 h, after which the reaction mixture was washed consecutively with saturated aqueous sodium hydrogencarbonate solution and water. The organic layer was then dried and concentrated, and the residue was purified by flash chromatography (hexane/EtOAc 8:2) to afford the aldehyde **64** (170 mg, 86%). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 9.64 (s, 1 H), 5.03 (s, 1 H), 4.98 (s, 1 H), 4.78 (m, 1 H), 4.42 (m, 2 H), 4.27 (d, *J* = 13.4 Hz, 1 H), 4.18 (d, *J* = 13.1 Hz, 1 H), 1.59 (s, 3 H), 1.31 (s, 3 H), 1.39 (s, 3 H), 1.37 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 201.3, 142.0, 108.5, 111.3 (×2), 100.0, 80.2, 79.9, 67.9, 64.5, 27.0, 26.4, 25.3, 21.8 ppm. This compound proved to be not very stable and was used in the next step directly after purification.

(1*R*,2*S*,3*R*,4*R*)-1,2:3,4-Di-*O*-isopropylidene-1-methylcyclopentane-1,2,3,4-tetraol (65): This compound was prepared from the thiocarbonate **63** (174 mg, 0.44 mmol) by the General Procedure for cyclization. Purification (hexane/EtOAc 8:2) afforded the derivative **65** (72 mg, 68%). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 4.77 (t, *J* = 6.3, 1 H, 6.0 Hz, 2-H), 4.37 (d, *J* = 6.0 Hz, 1 H, 3-H), 3.94 (s, 1 H, 4-H), 3.60 (d, *J* = 12.0 Hz, 1 H, 6a-H), 3.40 (d, *J* = 12.0 Hz, 1 H, 6b-H), 2.38 (dd, *J* = 14.4, 6.3 Hz, 1 H, 1-H), 1.59 (d, *J* = 14.4 Hz,

1 H, 1′-H), 1.48 (s, 3 H, Me), 1.38 (s, 3 H, Me), 1.32 (s, 3 H, Me), 1.27 (s, 3 H, Me), 1.07 (s, 3 H, Me) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 109.8, 97.4, 87.0, 80.7, 80.1, 66.7, 39.4, 38.9, 29.1, 25.5, 23.1, 21.7, 18.6 ppm. API-MS (positive): *m*/*z* = 265 [M + Na]$^+$. $C_{13}H_{22}O_4$ (242.15): calcd. C 64.44, H 9.15; found C 64.36, H 9.23.

Alcohol 66: The aldehyde **64** (150 mg, 0.58 mmol) was dissolved in THF (10 mL), HMPA (0.5 mL, 2.9 mmol) and *t*BuOH (121 μL, 1.8 mmol) in a dry flask flushed with argon. A solution of SmI_2 in THF (0.1 M, 128 μL, 1.8 mmol) was added to this solution at –78 °C. After a few minutes of stirring the reaction mixture was allowed to warm to room temperature and then stirred for an additional 10 min. The mixture was then quenched with saturated aqueous $NaHCO_3$ and diluted with ethyl acetate, and the organic phase was washed with water. The aqueous phase was extracted three times with ethyl acetate and the combined organic layers were washed with brine, dried with $MgSO_4$ and concentrated in vacuo. Further purification was achieved by flash chromatography on silica gel (hexane/EtOAc 80:20). This afforded the cyclization product **66** (66 mg. 44%), along with the dimer **67** (50 mg, 17%).

66: $[\alpha]_D^{25}$ = +50.4 (*c* = 0.62, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 4.68 (t, *J* = 6.0 Hz, 1 H), 4.44 (d, *J* = 6.0 Hz, 1 H), 4.35 (d, *J* = 6.0 Hz, 1 H), 4.03 (s, 1 H), 3.65 (d, *J* = 12.1 Hz, 1 H), 3.57 (d, *J* = 12.1 Hz, 1 H), 1.53 (s, 3 H), 1.43 (s, 3 H), 1.34 (s, 3 H), 1.33 (s, 3 H), 0.93 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 110.8, 97.4, 83.5, 78.7, 77.3, 72.9, 64.9, 40.7, 29.1, 25.3, 23.3, 18.5, 15.1 ppm. API-ES (positive): *m*/*z* = 269 [M + Na]$^+$. $C_{12}H_{22}O_5$ (246.15): calcd. C 58.52, H 9.00; found C 58.29, H 8.96.

67: ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 5.03 (br. s, 1 H), 4.99 (br. s, 1 H), 4.75 (br. s, 1 H), 4.54 (m, 1 H), 4.25–4.38 (m, 3 H), 4.19 (d, *J* = 12.6 Hz, 1 H), 1.51 (s, 3 H), 1.49 (s, 3 H), 1.43 (s, 3 H), 1.35 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.3, 108.9, 107.7, 99.4, 78.3, 76.5, 69.6, 69.3, 64.8, 26.9, 26.5, 25.8, 22.9 ppm.

2,3,4,6-Tetra-*O*-acetyl-5a-carba-β-D-glucopyranose (68): Compound **27a** (130 mg, 0.41 mmol) was subjected to General Procedure G to give compound **68** (81 mg, 56%) after silica gel column chromatography (hexane/EtOAc 7:3). $[\alpha]_D^{25}$ = +18.6 (*c* = 0.86, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.94 (m, 3 H), 4.02 (dd, *J* = 11.5, 5.0 Hz, 1 H, 6a-H), 3.97 (dd, *J* = 11.5, 3.3 Hz, 1 H, 6b-H), 3.65 (m, 1 H, 1-H), 2.51 (dd, *J* = 11.5, 5.0 Hz, 1 H, 5a-H), 2.18 (t, *J* = 11.5 Hz, 1 H, 5a-H), 2.20 (m, 1 H), 2.05 (s, 3 H, Ac), 2.03 (s, 3 H, Ac), 2.01 (s, 3 H, Ac), 2.00 (s, 3 H, Ac), 1.62 (m, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 170.6 (×2), 170.2 (×2), 71.9, 70.5, 66.8, 67.9, 62.8, 39.9, 38.1, 20.8, 20.7 (×2), 20.2 ppm. API-MS (positive): *m*/*z* = 369 [M + Na]$^+$, 347 [M + 1]$^+$ (20). $C_{15}H_{22}O_9$ (346.13): calcd. C 52.02, H 6.40; found C 52.12, H 6.27.

2,3,4,6-Tetra-*O*-acetyl-1-azido-5a-carba-α-D-glucopyranose (69): Methanesulfonyl chloride (21 μL, 0.27 mmol) was added at 0 °C to a solution of the alcohol **68** (81 mg, 0.23 mmol) and triethylamine (42 μL, 0.3 mmol), in dichloromethane (30 mL). The solution was stirred at room temp. for 0.5 h and water was then added. The aqueous phase was reextracted with CH_2Cl_2 and the combined organic extracts were dried and concentrated in vacuo to give a residue that was directly dissolved in dry DMF. Sodium azide (250 mg, 3.45 mmol) was added, and the resulting solution was heated at 85 °C for 48 h, during which considerable darkening occurred. The reaction mixture was diluted with CH_2Cl_2 (50 mL) and washed with water (20 mL). The aqueous layer was extracted with CH_2Cl_2 and the combined organic solutions were washed with water. Concentration of the dried (magnesium sulfate) solution in vacuo yielded a syrup, which was purified by flash chromatography (hexane/EtOAc 70:30) to give the azide **69** (65 mg, 76%) $[\alpha]_D^{25}$ = +38.5 (*c* = 1.035, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.43 (t, *J* = 12.0 Hz, 1 H, 3-H), 5.01–4.92 (m, 2 H), 4.16 (m, 1 H), 4.09 (dd, *J* = 11.6, 3.2 Hz, 1 H, 6a-H), 3.88 (dd, *J* = 11.6, 3.0 Hz, 1 H, 6b-H), 2.20 (m, 1 H, 5- H), 2.05 (s, 3 H, Ac), 2.04 (s, 3 H, Ac), 2.03 (s, 3 H, Ac), 2.02 (s, 3 H, Ac), 1.99 (t, *J* = 1.0 Hz, 1 H, 5a-H), 1.62–1.68 (m, 1 H, 5a-H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 166.2, 165.5 (×2), 165.4, 69.1, 66.8, 66.6, 58.3, 54.3, 31.1, 24.5, 16.2, 16.1 (×2), 16.0 (×2 ppm.) API-MS (positive): *m*/*z* = 394 [M + Na]$^+$. $C_{15}H_{21}N_3O_8$ (371.13): calcd. C 48.52, H 5.70; found C 48.39, H 5.57.

(1*R*,2*R*,3S,6*R*)-6-(Acetoxymethyl)cyclohex-4-ene-1,2,3-triyl Triacetate (71): PBu_3 (200 μL, 0.8 mmol) was added to a solution of **69** (150 mg, 0.4 mmol) in anhydrous CH_2Cl_2 (10 mL) and the mixture was stirred at room temp. for 1 h. The reaction mixture was then cooled to –78 °C, Ac_2O (20 μL, 0.9 mmol) and Et_3N (40 μL, 0.9 mmol) were added, and after the mixture had been allowed to warm to room temperature it was stirred overnight and then concentrated to dryness. The resulting residue was dissolved in pyridine (3.0 mL), and Ac_2O (1.5 mL) was added dropwise at 0 °C. The mixture was stirred for 4 h at room temp. and the solvent was removed under vacuum. The residue was purified by column chromatography on silica gel (hexane/EtOAc 7:3) to yield the title compound **71** (93.1 mg, 71%): $[\alpha]_D^{21}$ = +0.19 (*c* = 0.30, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 5.07 (t, *J* = 9.6 Hz, 1 H, 3-H), 4.96 (t, *J* = 9.6 Hz, 1 H, 4-H), 4.88 (m, 1 H, 2-H), 4.05 (dd, *J* = 9.0, 5.0 Hz, 1 H, 6a-H), 3.94 (dd, *J* = 9.0, 3.4 Hz, 1 H, 6b-H), 2.15 (m, 1 H, 5a-H), 2.1 (s, 3 H, Ac), 2.05 (s, 6 H, 2× Ac), 2.0 (s, 3 H, Ac), 1.96 (m, 1 H, 5-H), 1.87 (m, 3 H, 1-H, 5a-H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 166.0, 165.5 (×2), 164.2, 75.0, 72.2, 71.8, 63.6, 43.9, 40.2, 29.7, 28.4, 23.5, 20.7, 15.2 ppm. API-MS (positive): *m*/*z* = 353 [M + Na]$^+$. $C_{15}H_{22}O_8$ (330.13): calcd. C 54.54, H 6.71; found C 54.65, H 6.83.

(1*S*,2*R*,3*R*,4*R*)-4-(Acetoxymethyl)cyclohexane-1,2,3-triyl Triacetate (72): Argon was passed through a solution of **69** (10 mg, 0.03 mmol) in MeOH (2 mL) for 5 min, after which a catalytic amount of Pd/C (50 mg, 10 wt.-% Pd on C) was added. The reaction vessel was placed under vacuum and subsequently ventilated with hydrogen gas. This cycle was repeated one more time, after which the vessel was placed under hydrogen gas (25 psi) and mechanically shaken for 2 h. The Pd/C was removed by filtration through celite, followed by thorough rinsing of the filter cake with MeOH. The filtrate was concentrated under vacuum and the residue was purified by silica gel flash chromatography (hexane/EtOAc 8:2) to afford compound **72** (5.1 mg, 58%): $[\alpha]_D^{21}$ = +0.18 (*c* = 0.33, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 5.72 (d, *J* = 15.3 Hz, 1 H, H_{sp2}), 5.64 (d, *J* = 15.3 Hz, 1 H, H_{sp2}), 5.57 (m, 1 H, 4-H), 5.31 (m, 2 H, 3-H, 2-H), 4.15 (dd, *J* = 11.6, 4.0 Hz, 1 H, 6a-H), 4.02 (dd, *J* = 11.6, 5.1 Hz, 1 H, 6b-H), 2.81 (m, 1 H, 5-H), 2.07 (s, 3 H, Ac), 2.06 (s, 6 H, 2× Ac), 2.05 (s, 3 H, Ac) ppm. ^{13}C NMR = ($CDCl_3$, 75 MHz): δ = 166.0, 165.5 (×2), 165.3, 128.4, 126.5, 72.7, 72.1, 69.1, 63.0, 41.4, 21.0, 20.9, 20.8 (×2) ppm. API-MS (positive): *m*/*z* = 351 [M + Na]$^+$, 345 [M + NH_4]$^+$. $C_{15}H_{20}O_8$ (328.12): calcd. C 54.87, H 6.14; found C 54.73, H 5.98.

General Procedure M. Ozonation of Vinylstannanes: A solution of the appropriate olefin in MeOH (20 mL mmol^{-1}) at –78 °C was bubbled through with ozone for 15 min, after which oxygen was bubbled through the solution for 5 min. Next, the mixture was treated with borane-methyl sulfide complex (BMS) (2.5 mmol mmol^{-1}) and allowed to warm to room temperature over 2 h. After the mixture had been stirred for 1 h, the solvent was removed and the residue was dissolved in a previously prepared mixture of AcOH/THF/H_2O (4:2:1, 4 mL). The resulting solution

was warmed to 85 °C and stirred at that temperature for 2 h. The reaction mixture was then concentrated and the residue was subjected to standard acetylation conditions by treatment with pyridine and excess of acetic anhydride. The product was isolated by flash chromatography with silica gel.

(1*R*,2*R*,4*R*,5*R*,6*S*)-5,6-Bis(acetoxy)-2,4-bis[(acetoxy)methyl]-2-hydroxycyclohexyl Acetate (73): The olefin **22a** (168 mg, 0.31 mmol) was subjected to ozonation by the General Procedure. The residue was purified by column chromatography on silica gel (hexane/EtOAc 1:1) to yield the title compound **73** (73 mg, 57%): m.p. 61–63 °C. $[a]_D^{21}$ = +15.6 (*c* = 0.5, $CHCl_3$). ^1H NMR (300 MHz): δ = 5.40 (t, *J* = 9.8 Hz, 1 H), 5.10 (d, *J* = 9.8 Hz, 1 H), 5.05 (t, *J* = 9.8 Hz, 1 H), 4.15 (m, 2 H), 3.98 (t, *J* = 11.2 Hz, 1 H), 3.90 (t, *J* = 11.2 Hz, 1 H), 2.45 (m, 1 H), 2.42 (br. s, 1 H), 2.09 (s, 3 H), 2.08 (s, 3 H), 2.07 (s, 3 H), 2.03 (s, 3 H), 1.98 (s, 3 H), 1.98 (s, 3 H), 1.91 (dd, *J* = 3.7, 14.4 Hz, 1 H), 1.67 (t, *J* = 14.4 Hz, 1 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 170.8, 170.5, 170.1, 169.9, 169.3, 72.8, 72.4, 71.0, 66.9, 63.0, 60.4, 34.5, 33.0, 20.8, 20.7, 20.6, 20.5, 20.4 ppm. $C_{18}H_{26}O_{11}$ (418.15): calcd. C 51.67, H 6.26; found C 51.39, H 6.13.

(1*R*,2*S*,3*S*,4*R*,6*R*)-2,3-Bis(acetoxy)-4,6-bis[(acetoxy)methyl]-4-hydroxycyclohexyl Acetate (74): The olefin **54** (85 mg, 0.16 mmol) was subjected to ozonation by the General Procedure. The residue was purified by column chromatography on silica gel (hexane/EtOAc, 1:1) to yield the title compound **73** (47 mg, 71% overall yield). $[a]_D^{21}$ = –2.6 (*c* = 0.8, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 5.27 (dd, *J* = 3.2, 10.1 Hz, 1 H), 5.23 (m, 1 H), 5.13 (t, *J* = 10.1 Hz, 1 H), 4.14 (d, *J* = 11.7 Hz, 1 H), 4.04 (dd, *J* = 5.6, 11.3 Hz, 1 H), 3.9 (dd, *J* = 3.7, 11.3 Hz, 1 H), 3.74 (d, *J* = 11.7 Hz, 1 H), 2.74 (br. s, 1 H), 2.36 (m, 1 H), 2.05 (s, 3 H), 2.01 (s, 3 H), 2.00 (s, 3 H), 1.97 (s, 3 H), 1.89 (s, 3 H), 1.64 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 171.0, 170.8 (×2), 170.2, 169.5, 72.3, 71.6, 69.8, 69.3, 67.4, 63.8, 35.0, 31.2, 20.8, 20.7 (×2), 20.6 (×2) ppm. API-ES (positive): *m*/*z* = 441.2 $[M + Na]^+$, 859.2 $(2M+Na)^+$. $C_{18}H_{26}O_{11}$ (418.15): calcd. C 51.67, H 6.26; found C 51.43, H 6.04.

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