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Stereodivergent synthesis of 5a-carba-hexopyranoses from carbohydrates via 6-*exo*-*dig* radical cyclization: preparation of 5a-carba-β-D-manno-, α-D-allo-, β-L-talo- and α-L-gulopyranose pentaacetates from D-mannose

Ana M. Gómez,* Eduardo Moreno, Gerardo O. Danelón, Serafín Valverde and J. Cristóbal López*

Instituto de Química Orgánica General, CSIC, Juan de la Cierva 3, 28006 Madrid, Spain

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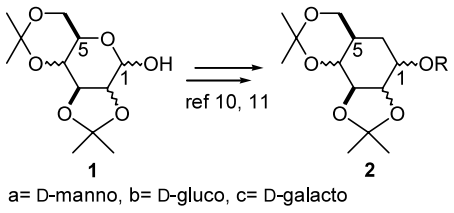
Abstract—Four carbasugars, 5a-carba-β-D-manno-, α-D-allo-, β-L-talo- and α-L-gulopyranose pentaacetates, have been prepared in a stereodivergent manner from D-mannose. Alkynyl derivatives of 2,3:4,6-di-*O*-isopropylidene-D-mannopyranose, which are prepared by homologation at C-1, by reaction with phenyl acetylide, undergo a 6-*exo*-*dig* radical cyclization, from a radical located at C-5, to yield a mixture of highly functionalized cyclohexanes. Some of these compounds, after transformation of their exocyclic double bond in a hydroxy function, were correlated with polyhydroxylated cyclohexanes, which were then selectively deoxygenated either at position C-4 or C-5a (carbohydrate numbering) to afford carbasugars of the D- or L- series.

1. Introduction

The term 'carbasugar' is used to describe monosaccharide analogues in which the ring oxygen has been replaced by a methylene group.[1] Carbasugars derived from hexopyranoses, 'carba-pyranoses' e.g. **2** were first prepared by McCasland et al.,[2] prior to their isolation from natural sources as components of biologically important antibiotics.[3] Many of these substances, owing to their close resemblance to carbohydrates,[2] are endowed with an interesting array of biological activities[4] which has triggered the development of a plethora of synthetic approaches for their preparation.[1,5–7]



Scheme 1. Correlation of carbohydrates with carbasugars.

As part of an ongoing program in our laboratory, aimed at the preparation of carbocycles from carbohydrates,[7–9] we have recently reported two synthetic strategies based on radical cyclizations for the preparation of carbasugars.[10,11] These methods, unlike others based on radical cyclizations,[12] were designed to correlate a given carbohydrate, **1**, with its corresponding carbasugar, **2** (Scheme 1).

Our reported strategy for the preparation of **2a** is outlined in Scheme 2.[11] The methylene group (C-5a) in carba-D-mannopyranose, **2a**, was retrosynthetically correlated, via polyoxygenated intermediate **3**, with the exocyclic double bond in alkenyl cyclohexane, **4**. The cyclohexane ring has been obtained by 6-*exo*-*dig* radical cyclization[13] of secondary radical, **I**, readily prepared from a carbohydrate-derived alkyne **5**.

These methods, although well suited for the preparation of common carbasugars, would face the problem of availability of the starting monosaccharides when the preparation of L-carbasugars or 'rare' D-carbasugars would be required. Hence, we focused our interest in the development of a stereodivergent approach to carbasugars, which starting from readily available monosaccharides, could allow access to a variety of carbasugars. In this context, we have found that our previous strategy[11] (Scheme 2) could be extended to the

* Corresponding authors. Fax: +34 915644853; e-mail: anago@iqog.csic.es; clopez@iqog.csic.es

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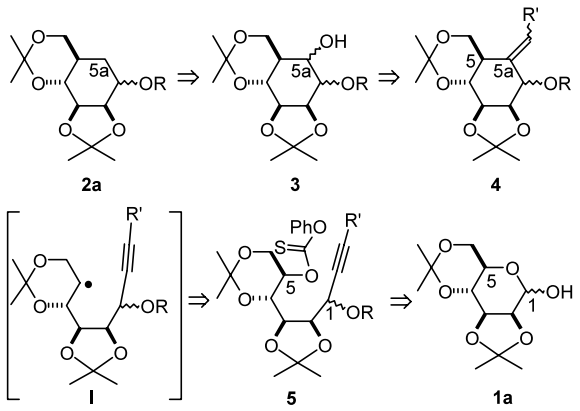
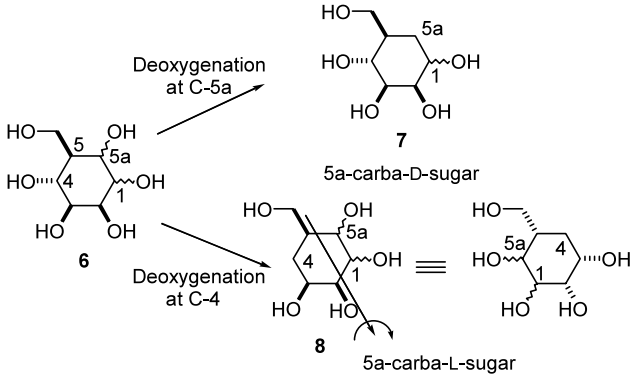


Scheme 2. Retrosynthesis of 5a-carba-D-mannopyranose from D-mannose.

preparation of different carbasugars. Herein, we disclose full details of this approach including the preparation of 5a-carba-β-D-manno-, 5a-carba-α-D-allo-, 5a-carba-β-L-talo- and 5a-carba-α-L-gulopyranose pentaacetates **52**, **63**, **45** and **57**, respectively, from D-mannose.

2. Stereodivergent strategy

The stereodivergent approach to carbasugars from D-mannose came from our observation that the key polyoxygenated intermediate **3**[14] (e.g. **6**, Scheme 3) could be transformed into a 5a-carba-D-sugar **7** or a 5a-carba-L-sugar derivative **8** by deoxygenation either at C-5a or at C-4, respectively.



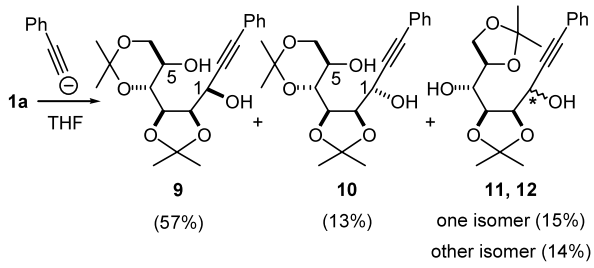
Scheme 3. Stereodivergent synthesis of carbasugars from polyoxygenated intermediates.

The approach also takes advantage of the fact that the radical cyclization of compound **5** yields compound **4** together with its epimer at C-5, vide infra, 5-*epi*-**4**. Both compounds have been used in the preparation of the carbasugars described in this article.

3. Study of the radical cyclization

3.1. Synthesis of the precursors for radical cyclization

The synthetic route started with 2,3:4,6-di-*O*-isopropylidene-D-mannopyranose, **1a**, readily obtained in one step from D-mannose.[15] Treatment of **1a** with excess phenylacetylide produced compounds, **9**–**12**, consisting of epimeric mixtures at C-1 of 2,3:4,6- **9** and **10** and migrated 2,3:5,6-di-*O*-isopropylidene derivatives **11** and **12** from which, the faster running diol **9**, could be easily isolated in 57% yield on multigram runs (Scheme 4). The stereochemistry at C-1 in alkynes **9** and **10** was assigned at a later stage in the synthesis, and no attempt was made to assign the stereochemistry at C-1 in compounds **11** and **12**.

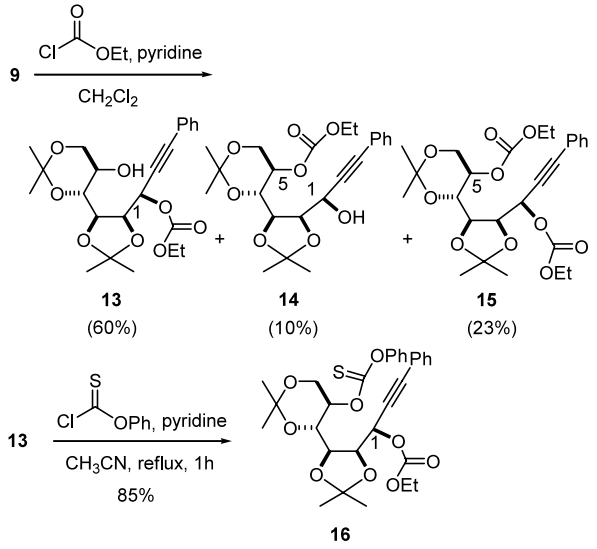


Scheme 4. Retrosynthesis of 5a-carba-D-mannopyranose from D-mannose.

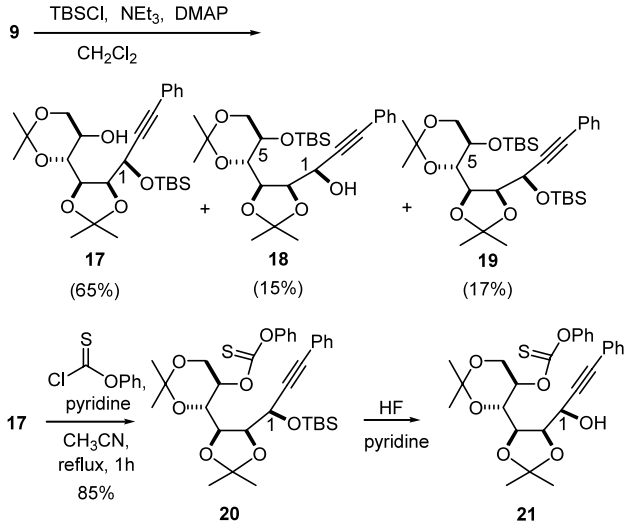
The next task to be undertaken was the selective protection of the 1-hydroxyl group (1-OH, carbohydrate numbering) prior to activation of the 5-OH of diol **9**. Accordingly, treatment of diol **9** with ethyl chloroformate/pyridine in dichloromethane yielded monocarbonate **13** as a very major isomer[16] (60%) together with mono- and dicarbonates **14** (10%) and **15** (23%), respectively (Scheme 5). To activate the 5-OH group, and allow generation of the requisite secondary radical (see **5** and **I**, Scheme 2), compound **13** was treated with an excess of phenyl chlorothionoformate[17,18] and pyridine in acetonitrile and refluxed for 1h to provide the desired thionocarbonate, **16**, in 85% yield.

Similar chemoselectivity was observed in the silylation of **9** (Scheme 6). Compound **17** (silylation at 1-OH) was produced again as a very major isomer (65%), and activation at 5-OH with phenyl chlorothionoformate paved the way to **20**. Deprotection of the silyl group at C-1 then produced **21**.

Cyclization precursors **23**, **27**, and **28** were prepared from diol **10** (Scheme 7). Initial attempts to prepare carbonate **22** by chemoselective reaction of **10** with ethyl chloroformate (as above) resulted only in complex reaction mixtures in which migration of the acetonides was detected. Conversely, silylation took place reasonably well and led to **23** (63% yield), along with disilyl derivative **24** (23%) and small amounts of **25** (4%). Activation of **23** with phenyl chlorothionoformate yielded **26**, from which alcohol **27**, and carbonate **28** were uneventfully prepared.



Scheme 5. Synthesis of precursor **16** for radical cyclization.

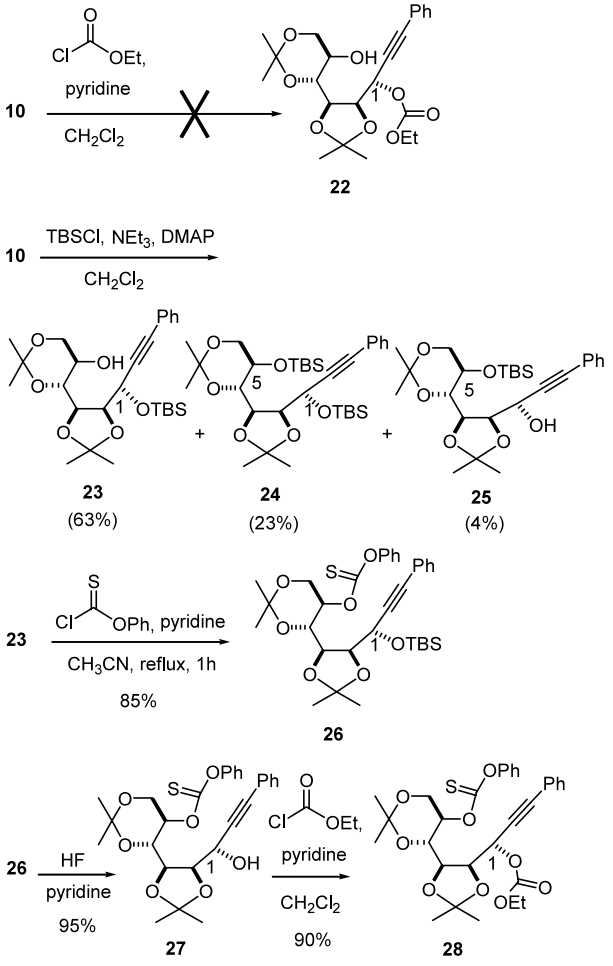


Scheme 6. Synthesis of precursors **20** and **21** for radical cyclization.

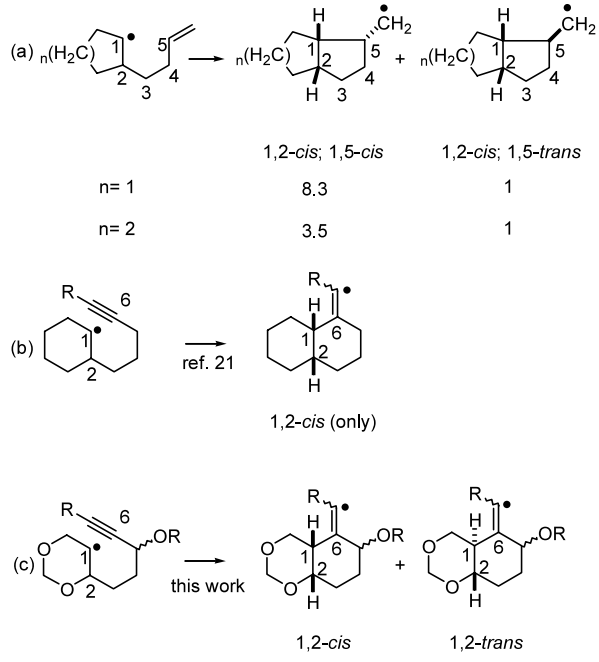
3.2. Stereochemical outcome of the 6-*exo*-*dig* radical cyclization: 6,6-*trans* versus 6,6-*cis* ring fusion

Although the carbasugars described in this paper have been prepared from the major isomer **9**, obtained by the addition of phenylacetylide to D-mannose diacetonide **1a**, similar chemistry could be carried out with **10**, leading to stereoisomeric carbasugars. Therefore, a study of the cyclization of the radical precursors prepared from **9** and **10** was conducted.

Radical ring closure of cyclic radicals onto alkenes, to afford fused systems, followed a very general pattern: that the ring fusion obtained was predominately or exclusively *cis* (1,2 *cis*, radical numbering) for 'small rings' ((a), Scheme 8).[19,20] Therefore, even in the case of 6,6-ring fusions, 1,2-*cis* selectivity leading to 6,6-*cis* ring fused systems would be expected ((a), $n=2$, Scheme



Scheme 7. Synthesis of precursors **26**, **27** and **28** for radical cyclization.

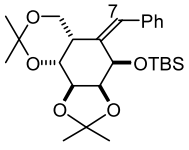
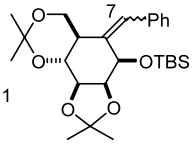
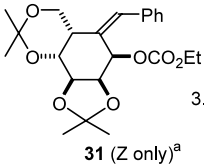
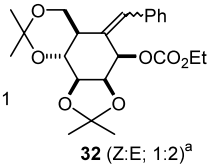
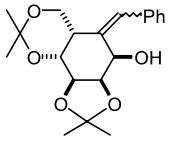
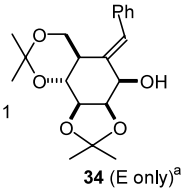
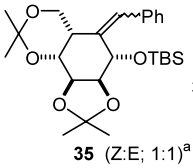
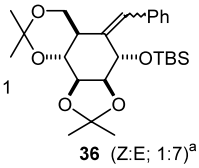
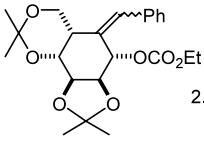
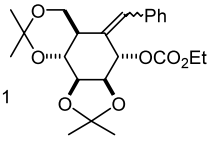
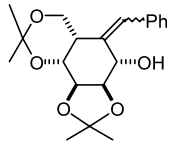
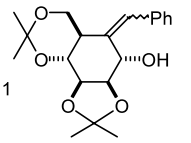


Scheme 8. Stereochemistry of radical cyclization of cyclic radicals onto alkenes and alkynes to afford bicyclic systems.

8).[19] Along these lines, radical ring closure of cyclic radicals onto alkynes, takes place with 1,2-*cis* selectivity to generate 6,6-*cis* ring fusion exclusively ((b), Scheme 8).[21]

The synthesis of 5a-carba-D-mannopyranose, in our initial work,[11] required the formation of an intermediate with 6,6-*trans* ring fusion ((c), Scheme 8) rather than the favored (and expected) 6,6-*cis* ring fusion. We have already disclosed some preliminary results, which indicated that changes in the protecting group on the hydroxy function α- to the radical acceptor could exert some stereocontrol in favor of the *trans* 6,6-ring fusion.[11] In this work, we have completed this study by investigating the effect of the change in the configuration of the hydroxyl group at C-1 in the stereochemistry of the radical cyclization.

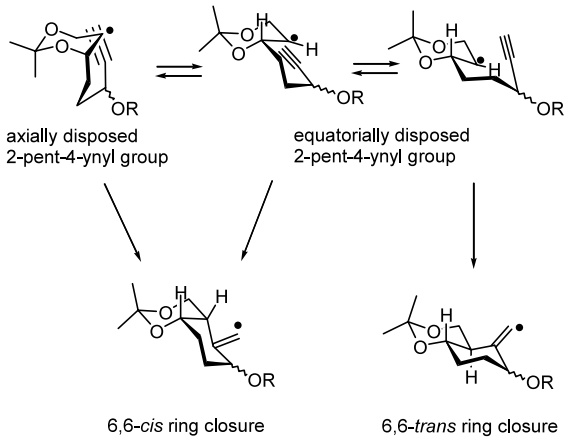
Table 1. Influence of the substituent and the stereochemistry at C-1 in the stereochemical outcome of the radical cyclization

Entry	Substrate	*cis*-fused	Ratio	*trans*-fused	Yield (%)
1	**20**	 **29** (Z only)[a]	1.5 : 1	 **30** (Z:E; 1:1)[a]	96
2	**16**	 **31** (Z only)[a]	3.3 : 1	 **32** (Z:E; 1:2)[a]	76
3	**21**	 **33** (Z:E; 1.9:1)[a]	4.2 : 1	 **34** (E only)[a]	49
4	**26**	 **35** (Z:E; 1:1)[a]	3.5 : 1	 **36** (Z:E; 1:7)[a]	90
5	**28**	 **37** (Z:E; 1.1:1)[a]	2.3 : 1	 **38** (Z:E; 1:1.7)[a]	78
6	**27**	 **39** (Z:E; 1:1)[a]	1.7 : 1	 **40** (Z:E; 1:1)[a]	57

[a]The stereochemistry at C-7 is referred to as Z:E followed by the ratio

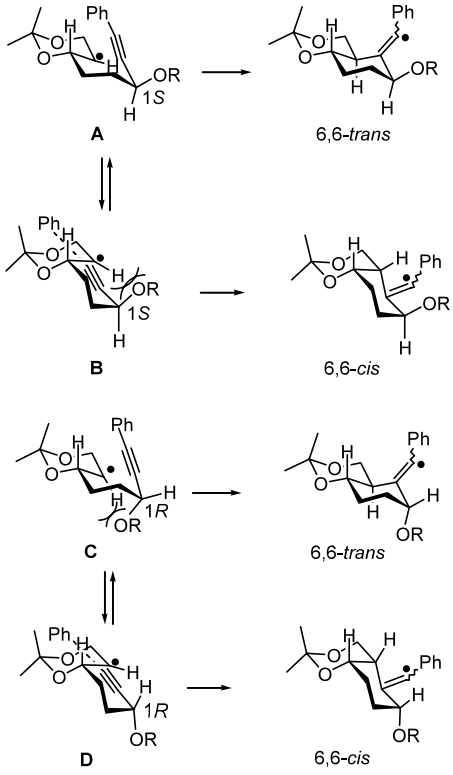
The results obtained for the radical cyclizations are outlined in Table 1. In accordance with literature precedents, adducts with 6,6-*cis* ring fusion prevailed in all cases. However, synthetically useful amounts of 6,6-*trans* isomers could be obtained by appropriate changes in the protecting group at 1-OH (entries 1 and 6). Accordingly, in precursors arising from **9** (1*S* isomers, entries 1–3), the use of a TBS protecting group (entry 1), resulted in a ratio in favor of the *trans* isomer (1.5:1 *cis*:*trans*), while cyclization of unprotected **21** favored formation of the *cis* isomer (entry 3, 4.2:1 *cis*:*trans*). An opposite tendency was found, however, in precursors arising from epimeric **10** [(1*R*) isomers, entries 4–6)]. The use of a silyl protecting group at 1-OH (as in **26**) favored formation of the *cis* isomer **35** (entry 4, 3.5:1 *cis*:*trans*), while the presence of a free hydroxyl group resulted in a higher proportion of *trans* isomer **40** (entry 6, 1.7:1 *cis*:*trans*). Derivatives with ethylcarbonyl substituents (entries 2 and 5) displayed an intermediate behavior in either series.

Radical ring closure in 2-but-3-enylcyclohexyl radicals (Scheme 8a) has been extensively studied by Rajan-Babu,[22] who has shown that transition states having an equatorial and an axial butenyl side chain may compete. In our case, radical cyclization of 2-pent-4-ynylcyclohexyl radicals could analogously take place with either axial or equatorial disposition of the side chain (Scheme 9). Axial orientation of the chain in the transition state, because of geometrical restrictions, would lead to *cis*-decalin type systems (6,6-*cis* ring fusion). On the other hand, an equatorial disposition of the side chain give rise to either *cis*- or *trans*-dioxadecalins depending on the substituent at C-1 (see Scheme 9).



Scheme 9. Possible dispositions on the radical cyclizations of 2-pent-4-ynyl cyclohexyl radicals.

Accordingly, in compounds arising from **9** [(1*S*) isomer, Scheme 10)] transition state **B**, leading to 6,6-*cis* isomers, would be more sensitive to steric interactions than transition state **A** (Scheme 10). Therefore, the use of a (bulky) silyl-protecting group resulted in a higher proportion of the 6,6-*trans* isomer when compared with



Scheme 10. Illustration of potential steric interaction that may destabilize the transition states with equatorial disposition of the side chain leading to product with 6,6-ring fusion.

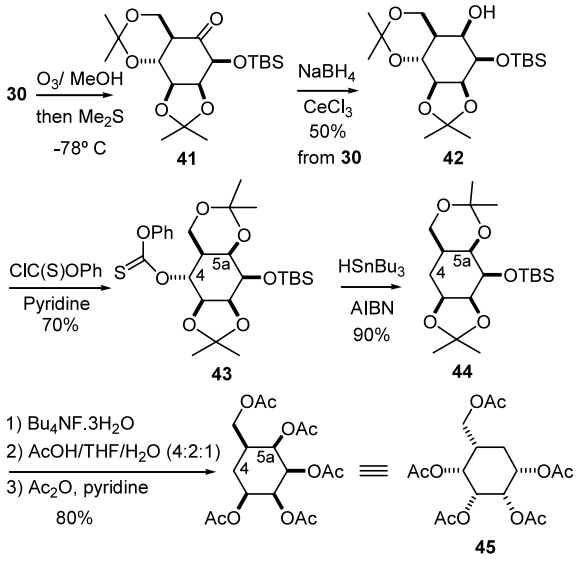
the cyclization of the corresponding free hydroxyl compound (compare entry 1 versus entry 3, Table 1). Conversely, the use of the more sterically demanding silyl substituent at 1-OH in compounds derived from **10** [(1*R*) isomer)] might result in a relatively high-energy transition state **C** leading to 6,6-*trans* isomers. By corollary, release of steric demands at C-1 in compounds arising from **10** [(1*R*) isomer)] would lead to higher amounts of bicycles with 6,6-*trans* ring junction (compare entry 4 versus entry 6, Table 1).

4. Synthesis of carbasugars

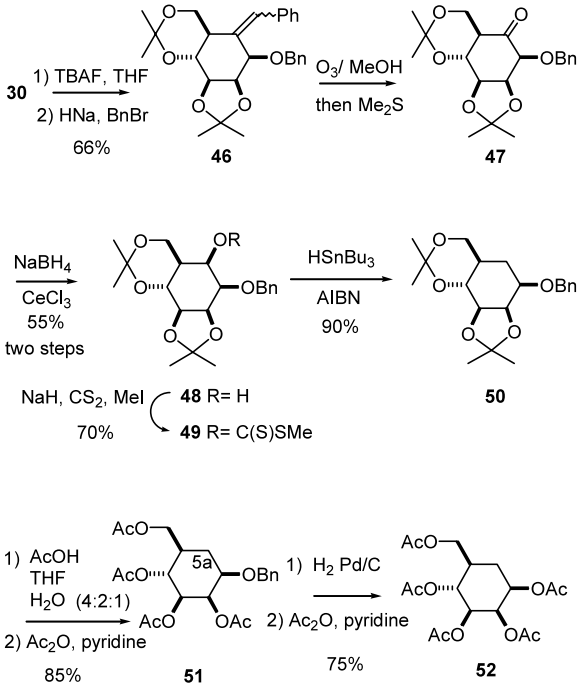
4.1. Syntheses of 5a-carba-β-L-talo- and 5a-carba-β-D-mannopyranose pentaacetates from compound 30

Compound **30** [two isomers at C-7, 1:1 ratio: δ 2.89 (ddt, $J_{4,5}=J_{5,6ax}=10.8$, $J_{5,6eq}=4.5$ Hz, $J_{5,Holef}=2.8$ Hz, H-5 one isomer), 2.48 (ddt, $J_{4,5}=J_{5,6ax}=11.1$ Hz, $J_{5,6eq}=5.1$ Hz, $J_{5,Holef}=2.3$ Hz, H-5 other isomer)] was transformed into carbasugars of the L-talo- and D-manno- series by deoxygenation at C-4 and C-5a, respectively, following the transformations outlined in Schemes 11 and 12.

Ozonolysis of **30** (Scheme 11) yielded ketone **41**, which upon reduction ($NaBH_4{\cdot}CeCl_3$) gave, in a stereoselective manner, the highly functionalized cyclohexane, **42**, (50%, two steps). The latter was then treated with phenyl chlorothionoformate in the presence of pyridine



Scheme 11. Synthesis of 5a-carba-β-L-talopyranose pentaacetate **45**.



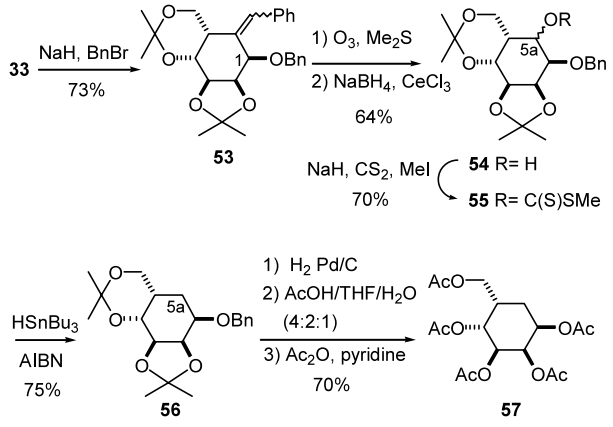
Scheme 12. Synthesis of 5a-carba-β-D-mannopyranose pentaacetate **52**.

to afford thiocarbonate **43** (70%), in which an unexpected rearrangement of the 4,6-*O*-isopropylidene group to a 5a,6-*O*-isopropylidene ring had taken place prior to the activation step at 4-OH. Compound **44**, which was smoothly obtained by treatment of **43** with tri-*n*-butyltin hydride (TBTH) in toluene, was then uneventfully transformed in 5a-carba-β-L-talopyranose pentaacetate **45**[23] {$[\alpha]_D^{21}=+5.2$ (*c* 0.4, $CHCl_3$), mp= 135–138°C}.

In order to carry out the deoxygenation at C-5a efficiently, the above-mentioned isopropylidene ring rearrangement had to be avoided. Therefore, a benzyl group, stable towards the reaction conditions for the installation of the xanthate, was placed at 1-OH (Scheme 12). Accordingly, after a change in the protecting group at 1-OH in **30** to afford **46** (OTBS→OBn), ozonolysis was carried out to yield ketone **47**, which upon stereoselective reduction ($BH_3{\cdot}SMe_2$ or $NaBH_4{\cdot}CeCl_3$) gave the cyclohexane **48** ($J_{5a,1}=3.8$ Hz) (55%, two steps). The hydroxy function at C-5a was deoxygenated under radical conditions, via its xanthate, **49**, to afford 5a-carba-D-mannopyranose derivative **50** (63%, two steps). Hydrolysis of the acetals followed by acetylation yielded benzyl derivative **51** (85%, two steps), which upon hydrogenation and acetylation gave 5a-carba-β-D-mannopyranose pentaacetate **52**[24–26] (75%, two steps) ($[\alpha]_D^{21}=+2.0$ (*c* 0.6, $CHCl_3$), mp = 116–118°C. Lit. ($[\alpha]_D^{21}=+2.9$ (*c* 1.1, $CHCl_3$), mp = 117–118°C);[24] ($[\alpha]_D^{21}=+2.53$ (*c* 1.67, $CHCl_3$), mp = 119°C);[25] ($[\alpha]_D^{21}=+2.9$ (*c* 1.28, $CHCl_3$), mp = 119°C).[26]

4.2. Synthesis of 5a-carba-α-D-allo- and 5a-carba-α-L-gulopyranose pentaacetates from compound 33

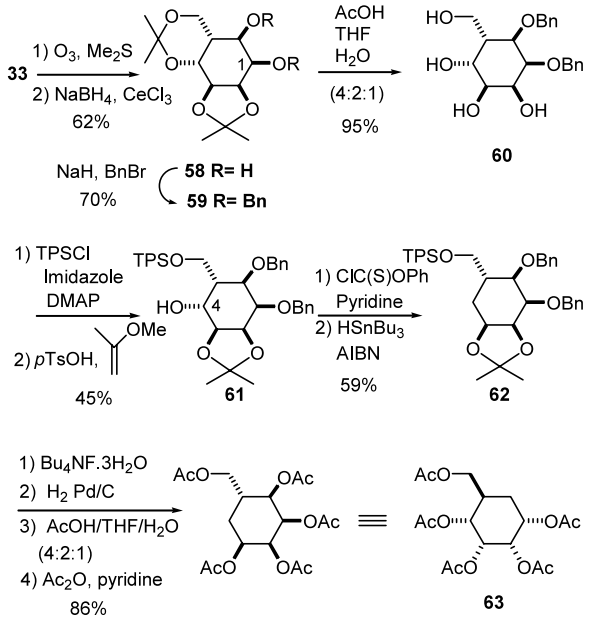
Compound **33** was transformed into carbasugars of the L-gulo- and D-allo- series by deoxygenation at C-5a and C-4, respectively, following the transformations outlined in Schemes 13 and 14.



Scheme 13. Synthesis of 5a-carba-β-L-gulopyranose pentaacetate **57**.

Protection of the 1-OH group in **33** as a benzyl ether led to **53** (Scheme 13), which upon ozonolysis and reduction afforded compound **54**, as a 1:1 epimeric mixture at C-5a. Deoxygenation at C-5a in **54**, via the corresponding xanthates, **55**, furnished L-gulo derivative **56**. Routine transformations in **56**, then led to 5a-carba-α-L-gulopyranose pentaacetate **57**.[27,28] ($[\alpha]_D^{21}=-34.0$ (*c* 0.32, $CHCl_3$), Lit. ($[\alpha]_D^{21}=-29.5$ (*c* 1.5, $CHCl_3$).[12]

The synthetic process for the deoxygenation at C-4 in compound **33** (Scheme 14) involved ozonolysis of the latter followed by reduction of the resulting carbonyl group to yield diol **58**, which was benzylated to afford



Scheme 14. Synthesis of 5a-carba-α-D-allopyranose pentaacetate **63**.

diacetonide **59**. Deprotection of the acid labile isopropylidene groups in **59** resulted in the formation of tetraol **60**. Transformation of **60** into compound **61**, in which the 4-OH group had been differentiated, was carried out through a sequence of reactions, which involved regioselective silylation of the primary hydroxyl group followed by selective protection of the *cis* diol moiety as an *O*-isopropylidene acetal. Deoxygenation at C-4, in compound **61** via the corresponding phenyl thiocarbonate paved the way to allo-derivative **62**, which upon conventional deprotection steps and acetylation led to 5a-carba-α-D-allopyranose **63**.[27,29,30] ($[\alpha]_D^{21}=+36.0$ (*c* 1.0, $CHCl_3$, mp = 95–98°C), Lit. ($[\alpha]_D^{21}=+78.7$ (*c* 1.5, $CHCl_3$, mp = 96–97°C).[13]

5. Summary

We have reported a stereodivergent strategy for the preparation of carbasugars from enantiomerically pure polyhydroxy methylenecyclohexanes, which are readily available by 6-*exo*-*dig* radical cyclization of monosaccharide-derived alkynes. In this approach, three (C-2, C-3 and C-4) out of the four stereogenic centers present in D-mannose are preserved in the polyoxygenated key methyl cyclohexane intermediates. The stereochemistry of the remaining stereogenic centers (C-1, C-5, C-5a) in the final carbasugars emanates from the synthetic steps in the sequence: (a) the stereochemistry at C-5 is related to the facial selectivity in the radical addition to the triple bond; (b) the configuration at C-1 arises from the nucleophilic addition of the acetylide to C-1; and (c) the stereocenter at C-5a is generated upon reduction of a keto group. During the course of this work, we have prepared carbasugars **45**, **52**, **57** and **63** from synthetic intermediates **4** and C-5-*epi*-**4**, which only differed in the stereochemistry at C-5. By corollary, the scope of

this methodology could still be enhanced by finding stereoselective transformations leading to polyoxygenated cyclohexanes epimeric at C-1 and C-5a. In this context, the use of the above strategy for the preparation of additional carbasugars and derivatives is underway in our laboratory and will be described in due course.

6. Experimental

6.1. General methods

All reactions were performed in dry flasks fitted with a glass stopper or rubber septa under a positive pressure of argon, unless otherwise noted. Air- and moisture-sensitive liquids and solutions were transferred via syringe or stainless steel cannula. Flash column chromatography was performed employing 230–400 mesh silica gel. Thin-layer chromatography was conducted in Kieselgel 60 F_{254} (Merck). Detection was first by UV (254 nm) then charring with a solution of 20% aqueous sulfuric acid (200 mL) in acetic acid (800 mL). Anhydrous $MgSO_4$ or $NaSO_4$ was used to dry the organic solutions during work-ups, and the removal of the solvents was done under vacuum with a rotoevaporator. Solvents were dried and purified using standard methods. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$ at 300, 400 or 500 and 75 or 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). The structural assignment for C-7 was carried out by diagnostic nuclear Overhauser effect (NOE) between the vinylic hydrogen (H-7) and either H-1 or H-5 in at least one of the isomeric *E*:*Z* pairs.

6.2. General procedure for the preparation of phenyl thiocarbonates

A solution of the corresponding alcohol in acetonitrile (20 mL/mmol) was treated with pyridine (3 equiv.) and phenyl chlorothionoformate (3 equiv.). 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.

6.3. General procedure for radical cyclization

A thoroughly degassed (argon) solution of thiocarbonate in toluene (0.02 M) was heated to 85°C under argon. A solution of HBu_3Sn (1.6 equiv.) and AIBN (0.1 equiv.) in toluene (5 mL/mmol) was then added and the reaction mixture was kept at that temperature over 12 h. After cooling, the organic solvent was evaporated and the residue purified.

6.4. General procedure for ozonolysis

Ozone was bubbled through a solution of the corresponding olefin in MeOH:CH_2Cl_2 (1:1 mixture, 20 mL/mmol) at −78°C until TLC showed complete consumption of the starting compound, oxygen was then bubbled through the solution for 5 min. Next, the mixture was treated with dimethyl sulfide (1 mL/mmol) and the solution was allowed to warm to room temperature over 2 h. After stirring for an additional 1 h, the solvent was removed and the residue purified by flash chromatography.

6.5. General procedure for reduction with $NaBH_4$·$CeCl_3$

To a solution of the corresponding ketone in MeOH (20 mL/mmol) $CeCl_3 \cdot H_2O$ (2 equiv.) was added under a stream of argon. The mixture was cooled to 0°C, treated with $NaBH_4$ (4 equiv.) and then allowed to warm to room temperature and stirred overnight. The reaction mixture was then diluted with EtOAc and washed with water and brine. The organic layer was dried and concentrated to give a residue, which was purified by flash chromatography.

6.6. General procedure for radical deoxygenation of thionoformates or xanthates

A thoroughly degassed (argon) solution of the substrate in toluene (0.02 M) was heated to 85°C. A solution of $HSnBu_3$ (1.6 equiv.) and AIBN (0.1 equiv.) in toluene (5 mL/mmol) was then added and the reaction mixture was kept at that temperature for 30 min. After cooling, the organic solvent was evaporated and the residue purified by flash chromatography.

6.7. General method for sequential isopropylidene group hydrolysis–peracetylation

The compound containing the isopropylidene group was dissolved in a previously prepared mixture of AcOH/THF/H_2O 4:2:1 (10 mL/mmol). The resulting solution was warmed to 85°C, and stirred at that temperature until consumption of the starting material was observed (TLC, usually between 40 and 60 min). The reaction mixture was then evaporated. The crude polyols were subjected to standard acetylation conditions by treatment with pyridine and excess of acetic anhydride. After stirring overnight, the mixture was concentrated to yield a crude material, which was purified by flash chromatography.

6.8. 1-Phenyl-1,2-dideoxy-4,5:6,8-di-*O*-isopropyliden-D-talo-D-glycero-oct-1-yne 9

To a solution of phenylacetylene (12.6 mL, 115.3 mmol) in dry THF (100 mL) under argon at −78°C was added BuLi (86.4 mmol, 54 mL solution 1.6 M in *n*-hexane). A solution of **1a** (7.5 g, 28.8 mmol) in dry THF (80 mL) was added dropwise and the reaction mixture was allowed to reach room temperature after which time, stirring was continued for 10 h. The reac-

tion mixture was then diluted with Et_2O (250 mL) and washed with water. The organic layer was dried and concentrated and the residue was purified by flash chromatography (hexane–EtOAc 8:2) to give diols **9** (5.9 g, 57%), **10** (1.4 g, 13%), **11** (1.6 g, 15%) and **12** (1.5 g, 14%). For **9**: mp = 52–55°C, $[\alpha]_D^{21}$ −43.4 (*c* 0.4, $CHCl_3$), ^1H NMR (200 MHz, $CDCl_3$) δ (ppm): 7.45–7.39 (m, 2H); 7.33–7.29 (m, 3H); 4.89 (dd, *J* = 4.8, 8.8 Hz, 1H); 4.67 (dd, *J* = 1.5, *J* = 6.9 Hz, 1H); 4.43 (dd, *J* = 4.8, *J* = 6.9 Hz, 1H); 4.30 (dd, *J* = 1.5, 8.4 Hz, 1H); 4.26 (d, *J* = 8.8 Hz, 1H); 4.02 (m, 1H); 3.91 (dd, *J* = 5.4, 10.9 Hz, 1H); 3.67 (dd *J* = 9.3, 10.9 Hz, 1H); 2.16 (d, *J* = 5.6 Hz, 1H); 1.57 (s, 3H); 1.55 (s, 3H); 1.46 (s, 3H); 1.40 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 131.6, 128.6, 128.3, 122.3, 108.9, 99.5, 87.7, 85.6, 78.8, 74.7, 71.9, 64.5, 63.0, 62.1, 28.4, 26.4, 25.4, 19.2. MS *m*/*e* = 347.1 (M^+−15). Anal. calcd for $C_{20}H_{26}O_6$: C, 66.28; H, 7.23. Found: C, 65.98; H, 6.94.

6.9. 1-Phenyl-1,2-dideoxy-4,5:6,8-di-*O*-isopropyliden-3-*O*-(tert-butyldimethylsilyl)-D-talo-D-glycero-oct-1-yne 17

To a solution of diol **9** (5 g, 13.8 mmol) in dry CH_2Cl_2 (110 mL) containing Et_3N (2.9 mL, 20.7 mmol) was added *tert*-butyldimethylchlorosilane (TBSCl) (2.7 g, 17.94 mmol) and 4-dimethylaminopyridine (100 mg). The solution was stirred at room temperature for 48 h. The mixture was then diluted with CH_2Cl_2 and washed with water. The organic layer was dried (Na_2SO_4) and concentrated, giving a residue which was purified by flash chromatography (hexane–EtOAc 9:1) to give silylethers **17** (4.3 g, 65%), **18** (1.02 g, 15%) and **19** (1.36 g, 17%). For **17**: mp = 49–51°C; $[\alpha]_D^{21}$ −32.25 (*c* 0.67, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.48–7.45 (m, 2H), 7.32–7.30 (m, 3H), 4.95 (d, *J* = 9.0 Hz, 1H), 4.46 (dd, *J* = 1.2, 6.3 Hz, 1H), 4.35 (dd, *J* = 6.3, 9.0 Hz, 1H), 3.99–3.87 (m, 3H), 3.63 (dd, *J* = 10.2, 12.7 Hz, 1H); 1.55 (s, 3H), 1.51 (s, 3H), 1.43 (s, 3H), 1.41 (s, 3H), 0.92 (s, 9H), 0.26 (s, 3H), 0.23 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 131.7 (×2), 128.4, 128.2 (×2), 122.7, 109.8, 98.6, 89.0, 86.5, 79.6, 75.0, 72.5, 64.9, 63.2, 62.8, 28.5, 26.4, 26.1, 25.8 (×3), 19.8, 18.1, −3.1, −4.2. MS *m*/*e* = 476.3 (M^+), 461.3 (M^+−15). Anal. calcd for $C_{26}H_{40}O_6Si$: C, 65.51; H, 8.46. Found: C, 65.55; H, 8.70.

6.10. 1-Phenyl-1,2-dideoxy-7-*O*-(phenoxythiocarbonyl)-4,5:6,8-di-*O*-isopropyliden-3-*O*-(*tert*-butyldimethylsilyl)-D-talo-D-glycero-oct-1-yne 20

Prepared from alcohol **17** following the general procedure for the preparation of phenyl thionoformates, (85% yield). White solid: mp = 53–57°C, $[\alpha]_D^{21}$ −61.5 (*c* 0.6, $CHCl_3$), IR (thin film): 1200 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.51–7.09 (m, 10H), 5.55 (dt, *J* = 4.3, 8.2 Hz, 1H), 4.96 (d, *J* = 9.0 Hz, 1H), 4.35 (m, 3H), 4.20 (dd, *J* = 4.5, 12.7 Hz, 1H), 3.95 (dd, *J* = 4.3, 12.7 Hz, 1H), 1.56 (s, 6H), 1.44 (s, 3H), 1.43 (s, 3H), 0.94 (s, 9H), 0.28 (s, 3H), 0.26 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 194.3, 153.5, 131.8 (×2), 129.5 (×2), 128.5, 128.2 (×2), 126.5, 122.7, 121.9 (×2), 110.2, 100, 88.8, 86.6, 79.5, 75.5, 75.8, 68.7, 62.7, 61.5, 26.3, 26.1, 25.8 (×3), 22.6, 22.2, 18.1, −3.0, −4.1.). Anal. calcd for $C_{33}H_{44}O_7SSi$: C, 64.67; H, 7.24. Found: C, 65.49; H, 7.56.

6.11. 1-Phenyl-1,2-dideoxy-7-*O*-(phenoxythiocarbonyl)-4,5:6,8-di-*O*-isopropyliden-D-talo-D-glycero-oct-1-yne 21

To a cooled (0°C) solution of **20** (700 mg, 1.14 mmol) in dry THF (25 mL) was added a solution prepared with hydrogen fluoride–pyridine complex (7.5 mL), pyridine (15 mL) and dry THF (30 mL). The solution was warmed to room temperature and stirred for 36 h. The mixture was again cooled to 0°C, and the reaction was quenched by slow addition of saturated $NaHCO_3$ solution and extracted with Et_2O (3×50 mL). The combined organic extracts were washed with saturated $NaHCO_3$ and water and dried. Evaporation of the solvents gave a residue that was purified by chromatography (hexane–EtOAc 9:1) to yield **21** (470 mg, 82%): $[\alpha]_D^{21}$ −20.6 (*c* 0.6, $CDCl_3$). ^1H NMR (200 MHz, $CDCl_3$) δ (ppm): 7.46–7.02 (m, 10H), 5.59 (ddd, *J* = 5.1, 6.4, 8.7 Hz, 1H), 4.96 (dd, *J* = 4.9, 8.2 Hz, 1H), 4.65 (d, *J* = 8.7 Hz, 1H), 4.49–4.44 (m, 2H), 4.27 (dd, *J* = 5.1, 12.1 Hz, 1H), 3.93 (dd, *J* = 6.4, 12.1 Hz, 1H), 3.67 (d, *J* = 8.2 Hz, 1H), 1.58 (s, 6H), 1.47 (s, 3H), 1.41 (s, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ (ppm): 193.9, 153.5, 131.8 (×2), 129.5 (×2), 128.6, 128.3 (×2), 126.7, 122.3, 121.7 (×2), 109.4, 100.4, 87.8, 85.5, 78.8, 75.9, 75.3, 68.6, 62.0, 60.9, 26.8, 26.3, 25.5, 21.1. MS *m*/*e* 483.1 (M^+−15). Anal. calcd for $C_{27}H_{30}O_7S$: C, 65.04; H, 6.06. Found: C, 65.38; H, 6.25.

6.12. (3a*S*,4*S*,5a*R*,9a*R*,9b*S*)-5-Benzylidene-2,2,8,8-tetramethylhexahydro-3aH-[1,3]dioxolo[4,5-h][1,3]benzodioxin-4-yl *tert*-butyl(dimethyl)silyl ether 30

Radical cyclization of thiocarbonate **20** (2.5 g, 4.1 mmol) afforded after (hexane–EtOAc 95:5) compound **29** (only the *Z* isomer was detected) (1.09 g, 58%) followed by **30** as a 1:1 mixture of *Z*/*E* isomers (721 mg, 38%). For **30**: ^1H NMR (for two isomers, 300 MHz, $CDCl_3$) δ (ppm): 7.35–7.30 (m, 8H), 7.28 (m, 2H), 6.55 (d, *J* = 2 Hz, 1H), 6.50 (d *J* = 2.7 Hz, 1H), 5.05 (s, 1H), 4.85 (m, 2H), 4.37 (s, 1H), 4.23–4.18 (m, 4H), 4.15 (dd, *J* = 5.0, 10.9 Hz, 1H), 3.96 (t, *J* = 10.9 Hz, 1H), 3.82 (dd *J* = 4.5, 11.0 Hz, 1H), 3.57 (t, *J* = 11 Hz, 1H), 2.89 (ddt, *J* = 2.8, 4.5, 10.8 Hz, 1H); 2.48 (ddt, *J* = 2.3, 5.1, 11.1 Hz, 1H); 1.56 (s, 3H), 1.55 (s, 6H), 1.54 (s, 3H), 1.49 (s, 3H), 1.48 (s, 3H), 1.44 (s, 3H), 1.37 (s, 3H), 0.95 (s, 9H); 0.81 (s, 9H), 0.16 (s, 3H), 0.14 (s, 3H), −0.23 (s, 3H), −0.41 (s, 3H). ^{13}C NMR (for two isomers, 50 MHz, $CDCl_3$) δ (ppm): 136.1, 135.8, 135.7, 134.6, 131.6, 129.3, 128.6 (×2), 128.5 (×2), 128.0 (×2), 127.7 (×2), 127.3, 127.1, 109.3 (×2), 99.0, 98.9, 76.5, 76.2, 75.8, 75.5, 75.4, 71.8, 71.3, 65.5, 65.3, 62.5, 38.3, 36.9, 29.5, 29.4, 26.0, 25.8, 25.6 (×3), 25.5 (×3), 24.0, 23.7, 19.4, 19.3, 17.7, 17.6, −4.9, −4.6, −5.1, −5.4.). Anal. calcd for $C_{26}H_{40}O_5Si$: C, 67.79; H, 8.75. Found: C, 67.97; H, 8.83.

6.13. (3a*R*,4*S*,5*E*,5a*S*,9a*R*,9b*S*)-5-Benzylidene-2,2,8,8-tetramethyl hexahydro-3aH-[1,3]dioxolo[4,5-h][1,3]-benzodioxil-4-ol (*Z*)-33 and (3a*R*,4*S*,5*Z*,5a*S*,9a*R*,9b*S*)-5-benzylidene-2,2,8,8-tetramethyl hexahydro-3aH-[1,3]dioxolo[4,5-h][1,3]benzodioxil-4-ol (*E*)-33

Radical cyclization of **21** (400 mg, 0.8 mmol) afforded after flash chromatography (hexane–EtOAc 9:1) (*Z*)-**33** (68 mg, 24%) followed by (*E*)-**33** (45 mg, 16%) and (*E*)-**34** (28 mg, 10%). For (*Z*)-**33**: mp = 142–144°C, $[\alpha]_D^{21}$ +58.5 (*c* 0.6, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.38–7.19 (m, 5H), 6.94 (s, 1H), 4.84 (t, *J* = 3.7 Hz, 1H), 4.54 (dd, *J* = 1.8, 3.8 Hz, 1H), 4.28–4.17 (m, 4H), 2.89 (m, 1H), 2.40 (s, 1H), 1.56 (s, 3H), 1.51 (s, 3H), 1.40 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 137.2, 135.9, 130.4, 128.6 (×2), 128.1 (×2), 126.8, 108.7, 99.2, 76.4, 75.2, 69.2, 66.2, 61.7, 33.1, 29.1, 26.1, 24.6, 19.4. MS *m*/*e*: 346.2 (M^+), 331.1 (M^+–15). Anal. calcd for $C_{20}H_{26}O_5$: C, 69.34; H, 7.56. Found: C, 69.60; H, 7.80. For (*E*)-**33**: $[\alpha]_D^{21}$ +22.7 (*c* 0.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.37–7.20 (m, 5H), 6.70 (s, 1H), 4.87 (m, 1H), 4.58 (dd, *J* = 4.2, 7.2 Hz, 1H), 4.48 (dd, *J* = 3.8, 7.2 Hz, 1H), 4.32 (t, *J* = 3.8 Hz, 1H), 3.85 (dd, *J* = 5.6, 11.7 Hz, 1H), 3.60 (dd, *J* = 4.3, 11.7 Hz, 1H), 3.31 (m, 1H), 2.28 (d, *J* = 10.9 Hz, 1H), 1.43 (s, 3H), 1.38 (s, 3H), 1.37 (s, 3H), 1.35 (s, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ (ppm): 138.8, 136.1, 128.5 (×2), 128.1 (×2), 126.5, 124.5, 109.9, 98.0, 76.7, 74.9, 68.9, 65.8, 62.5, 33.4, 28.4, 26.1, 24.6, 20.3. Anal. calcd for $C_{20}H_{26}O_5$: C, 69.34; H, 7.56. Found: C, 69.66; H, 7.78.

6.14. (3a*S*,4*S*,5*R*,5a*S*,9a*R*,9b*S*)-4-{[Tertbutyl(dimethyl)-silyl]oxy}-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h][1,3]benzodioxin-5-ol 42

Ozonolysis of olefin **30** (500 mg, 1.33 mmol) afforded ketone **41**, which without further purification was reduced ($NaBH_4$ and $CeCl_3$, general method). Flash chromatography (hexane–EtOAc 8:2) yielded alcohol **42** (210 mg, 50%) as a white solid: mp = 86–88°C, $[\alpha]_D^{21}$ −29.9 (*c* 0.6, $CDCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$) δ (ppm): 4.31 (t, *J* = 4.7 Hz, 1H), 4.28 (dd, *J* = 7.8, 11.6 Hz, 1H), 4.17 (t, *J* = 11.3 Hz, 1H), 3.96 (dd, *J* = 4.7, 7.8 Hz, 1H), 3.84 (t, *J* = 4.7 Hz, 1H), 3.76 (dd, *J* = 4.9, 11.3 Hz, 1H), 3.72 (m, 1H), 2.73 (s, 1H), 1.55 (s, 3H), 1.50–1.40 (m, 1H), 1.51 (s, 3H), 1.41 (s, 3H), 1.33 (s, 3H), 0.91 (s, 9H), 0.13 (s, 3H), 0.12 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 109.5, 99.0, 78.4, 77.4, 70.4, 70.3, 68.8, 61.1, 37.7, 29.6, 28.7, 25.8, 25.7 (×3), 19.1, 18.2, −4.6, −4.7. Anal. calcd for $C_{20}H_{26}O_5$: C, 58.73; H, 9.34. Found: C, 59.02; H, 9.56.

6.15. *O*-(3a*S*,4*S*,4a*R*,8a*S*,9*R*,9a*S*)-4-{[Tertbutyl(dimethyl)silyl]oxy}-2,2,6,6-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h][1,3]benzodioxin-9-yl-*O*-phenyl thiocarbonate 43

Colorless oil, (189 mg, 70%): $[\alpha]_D^{21}$ −28.3 (*c* 0.6, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$) δ (ppm): 7.43–7.10 (m, 5H), 6.38 (dd, *J* = 8.2 Hz, 11.2 Hz, 1H), 4.32 (t, *J* = 8.2 Hz, 1H), 4.18 (m, 2H), 4.00 (dd, *J* = 2.6, 7.8 Hz, 1H), 3.91 (dd, *J* = 9.1, 11.1 Hz, 1H), 3.78 (dd *J* = 5.1, 11.1 Hz, 1H), 2.05 (m, 1H), 1.40 (s, 9H), 1.37 (s, 3H), 0.96 (s, 9H), 0.12 (s, 3H), 0.11 (s, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ (ppm): 195.0, 155.6, 129.6 (×2), 126.4 (×2), 120.6, 110.0, 99.9, 82.1, 77.2, 74.7, 69.8, 67.3, 60.0, 39.3, 27.3, 26.4, 25.9 (×3), 24.4, 23.1, 18.2, −4.2, −4.5.

6.16. 1,2:4,6-Di-*O*-Isopropilidene-3-*O*-tertbutyldimethyl-silyl-5a-carba-β-L-talopyranose 44

Colorless oil, (114 mg, 90%): $[\alpha]_D^{21}$ −10.2 (*c* 0.5, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 4.08 (dt, *J* = 6.2, 10.6 Hz, 1H), 3.97 (dd, *J* = 3.8, 6.2 Hz, 1H), 3.89 (t, *J* = 3.8 Hz, 1H), 3.84 (t, *J* = 3.8 Hz, 1H), 3.78 (dd, *J* = 4.0, 11.0 Hz, 1H), 3.55 (dd, *J* = 6.1, 11.0 Hz, 1H), 2.17 (q, *J* = 12.0 Hz, 1H), 1.60–1.48 (m, 2H, H5), 1.56 (s, 3H), 1.41 (s, 3H), 1.40 (s, 3H), 1.34 (s, 3H), 0.93 (s, 9H), 0.11 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 108.9, 99.4, 75.3, 74.1, 70.9, 68.2, 63.7, 33.5, 28.7, 27.6, 26.5, 26.1 (×3), 26.0, 25.1, 18.2, −4.3, −4.5.

6.17. 1,2,3,4,6-Penta-*O*-Acetyl-5a-carba-β-L-talopyranose 45

To a solution of **44** (100 mg, 0.27 mmol) in THF (10 mL) was added Bu_4NF (208 mg, 0.81 mmol, 3 equiv.) and the reaction mixture was stirred overnight. Then the reaction was diluted with CH_2Cl_2 and washed with water and brine. The organic layer was dried, filtered and concentrated to give a residue, which was purified by flash chromatography (hexane–EtOAc 1:1) to yield 1,2:4,6-di-*O*-isopropylidene-5a-carba-β-L-talopyranose ($[\alpha]_D^{21}$ −12.9 (*c* 0.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 4.30 (t, *J* = 4.6 Hz, 1H), 4.18 (m, 2H), 4.09 (dd, *J* = 3.0, 11.6 Hz, 1H), 3.76 (dt, *J* = 4.6, 10.4 Hz, 1H), 3.60 (dd, *J* = 2.2, 11.6 Hz, 1H), 2.86 (d, *J* = 10.4 Hz, 1H), 2.26 (dt, *J* = 10.6, 13.3 Hz, 1H), 1.62–1.49 (m, 1H), 1.57 (s, 3H), 1.46–1.30 (m, 1H); 1.45 (s, 3H); 1.43 (s, 3H); 1.37 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 109.1, 99.4, 74.8, 74.3, 69.2, 67.9, 64.1, 31.1, 29.5, 28.4, 26.2, 26.1, 18.9. This compound was then submitted to the standard procedure for cleavage of the isopropylidene group and peracetyation to furnish pentaacetate **45** (84 mg, 80%): mp = 135–138°C, $[\alpha]_D^{21}$ +5.2 (*c* 0.4, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ (ppm): 5.49 (t, *J* = 3.1 Hz, 1H), 5.38 (t, *J* = 2.9 Hz, 1H), 4.93 (m, 2H), 4.05 (dd, *J* = 8.8, 11.1 Hz, 1H), 3.91 (dd, *J* = 6.3, 11.1 Hz, 1H), 2.20–2.10 (m, 1H), 2.11 (s, 3H), 2.07 (s, 3H), 2.02 (s, 3H), 1.99 (s, 3H), 1.96 (s, 3H), 1.88 (q, *J* = 12.5 Hz, 1H), 1.69 (dt, *J* = 4.0, 12.5 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 170.8, 170.1, 170.0, 169.8, 169.6, 69.0, 68.9, 68.7, 66.1, 63.0, 29.7, 23.5, 26.8 (×2), 20.7, 20.6, 20.5. Anal. calcd for $C_{17}H_{24}O_{10}$: C, 52.57; H, 6.23. Found: C, 52.71; H, 6.43.

6.18. (3a*R*,4*R*,5a*R*,9a*S*,9b*S*)-5-Benzylidene-4-(benzyl-oxy)-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo-[4,5-h][1,3]benzodioxine 46

To a solution of **30** (700 mg, 1.52 mmol) in THF (52 mL) was added Bu_4NF (2.4 g, 9.12 mmol) and the reaction mixture was stirred overnight. The reaction was then diluted with CH_2Cl_2 and washed with water and brine. The organic layer was dried, filtered and concentrated to give a residue which was purified by

flash chromatography (hexane–EtOAc 8:2). The pure-material (380 mg, 1.10 mmol) was then dissolved in dry THF (45 mL) and treated with NaH (79 mg 60%, 1.97 mmol) at 0°C for 30 min. Then the mixture was treated with benzyl bromide (170 μL, 1.43 mmol) and Bu_4NI (405 mg, 1.1 mmol). After 3 h the reaction was diluted with Et_2O and washed with water. The organic phase was dried, concentrated and the residue purified by flash chromatography (hexane–EtOAc 9:1) to yield **46** as an inseparable 4:1 mixture of isomers (308 mg, 66%). ^{1}H NMR (200 MHz, $CDCl_3$, only signals for the main isomer are shown) δ (ppm): 7.40–7.20 (m, 10H), 6.52 (d, $J=2.7$ Hz, 1H), 4.79 (dd, $J=7.4$, 11.0 Hz, 1H), 4.68 (d, $J=12.4$ Hz, 1H), 4.59 (d, $J=12.4$ Hz, 1H), 4.36–4.22 (m, 2H), 4.12 (m, 1H), 3.79 (dd, $J=4.5$, 11.1 Hz, 1H), 3.42 (t, $J=11.1$ Hz, 1H), 2.86 (ddt, $J=2.7$, 4.5, 11.1 Hz, 1H), 1.56 (s, 3H), 1.55 (s, 3H), 1.39 (s, 3H), 1.38 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 138.6, 136.2, 134.1, 131.9, 131.6, 128.7 (×2), 128.3 (×2), 128.1 (×2), 127.7, 127.3, 127.1 (×2), 126.9, 110.2, 110.1, 99.2, 99.1, 82.1, 76.7 (×2), 76.1, 75.9, 72.7, 72.6, 71.9, 70.9, 70.4, 64.8, 62.4, 37.4, 36.8, 29.6 (×2), 26.3, 26.1, 24.9, 24.6, 19.4 (×2). Anal. calcd for $C_{27}H_{32}O_5$: C, 74.29; H, 7.39. Found: C, 74.51; H, 7.27.

6.19. (3a*R*,4*R*,5*R*,5a*S*,9a*S*,9b*S*)-4-(Benzyloxy)-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h][1,3]-benzodioxin-5-ol 48

Ozonolysis of olefin **46** (270 mg, 0.61 mmol) afforded ketone **47** which, without further purification was reduced ($NaBH_4$ and $CeCl_3$, general method). Purification was carried out by flash chromatography (hexane–EtOAc 8:2) to yield alcohol **48** (122 mg, 55% overall): $[\alpha]_D^{21}$ −42.2 (*c* 0.62, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.40–7.24 (m, 5H), 4.79 (d, $J=12.4$ Hz, 1H), 4.67 (d, $J=12.4$ Hz, 1H), 4.42 (t, $J=4.5$ Hz, 1H), 4.26 (dd, $J=7.8$, 11.6 Hz, 1H), 4.15 (t, $J=11.3$ Hz, 1H), 3.94 (m, 2H), 3.73 (dd, $J=4.9$, 11.3 Hz, 1H), 3.51 (t, $J=3.6$ Hz, 1H), 2.72 (s, 1H), 1.56 (s, 3H), 1.49 (s, 3H), 1.42 (m, 1H), 1.38 (s, 3H), 1.36 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 137.1, 128.6 (×2), 128.2, 127.9 (×2), 110.0, 99.1, 78.5, 75.7, 74.4, 70.6, 69.0, 66.9, 61.1, 37.7, 29.6, 28.6, 26.1, 19.1.

6.20. 2,3:4,6-Di-*O*-isopropylidene-1-*O*-benzyl-5a-carba-β-D-mannopyranose 50

Alcohol **48** (112 mg, 0.31 mmol) was dissolved in dry THF (15 mL) and treated with NaH (25 mg 60%, 0.62 mmol) at 0°C for 30 min. Then, the mixture was treated with CS_2 (37.4 μL, 0.62 mmol) at room temperature for 60 min after which time MeI was added (130 μL, 2.1 mmol). Stirring was maintained for additional 30 min and then the reaction was diluted with CH_2Cl_2, washed with water, dried and concentrated to give a residue which was chromatographed (hexane–EtOAc 8:2) to give xanthate **49** (98 mg, 70%). This material was dissolved in toluene and the general procedure for radical deoxygenation was carried out to afford a residue which was purified by flash chromatography (hexane–EtOAc 7:3) to yield **50** (67 mg, 90%). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.26–7.22 (m, 5H), 4.65 (d, $J=12.6$ Hz, 1H), 4.57 (d, $J=12.6$ Hz, 1H), 4.33 (t, $J=4.3$ Hz, 1H), 3.84 (dd, $J=4.9$, 7.8 Hz, 1H), 3.69–3.53 (m, 4H), 1.50 (m, 1H), 1.51 (s, 3H), 1.40 (s, 3H), 1.35 (s, 3H), 1.34 (s, 3H), 1.35–1.19 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 138.2, 128.4 (×2), 127.8 (×3), 110.3, 99.8, 78.6, 75.2, 74.8, 74.0, 70.9, 64.1, 33.1, 29.7, 28.4, 26.2, 26.0, 18.0.

6.21. 2,3:4,6-Tetra-*O*-Acetyl-1-*O*-benzyl-5a-carba-β-D-mannopyranose 51

Compound **50** (270 mg, 0.61 mmol) was submitted to the procedure for cleavage of the isopropylidene group followed by acetylation. The residue was purified by flash chromatography (hexane–EtOAc 6:4) to yield **51** as white solid (53 mg, 85%): mp = 113–115°C, $[\alpha]_D^{21}$ +9.96 (*c* 0.78, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33–7.26 (m, 5H), 5.77 (s, 1H), 5.23 (t, $J=10$ Hz, 1H), 4.88 (dd, $J=2.9$, 10.0 Hz, 1H), 4.63 (d, $J=11.6$ Hz, 1H), 4.42 (d, $J=11.6$ Hz, 1H), 4.02 (m, 2H), 3.59 (m, 1H), 2.18 (s, 3H), 2.06 (s, 3H), 2.03 (s, 3H), 2.00 (s, 3H), 2.00–1.90 (m, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 170.8, 170.4, 170.2, 170.1, 137.4, 128.5 (×2), 127.9, 127.7 (×2), 73.6, 72.2, 70.8, 69.5, 68.2, 63.9, 35.9, 28.6, 21.0, 20.8 (×2), 20.7. Anal. calcd for $C_{20}H_{28}O_5$: C, 68.94; H, 8.10. Found: C, 69.12; H, 8.25.

6.22. 1,2,3,4,6-Penta-*O*-Acetyl-5a-carba-β-D-mannopyranose 52

A solution of benzyl ether **51** (50 mg, 0.12 mmol) in MeOH (32 mL) was hydrogenolyzed in the presence of 10% Pd/C (10 mg) at 35 psi at room temperature for 60 min. The reaction mixture was filtered, through a short pad of Celite, and concentrated to give a residue, which was acetylated. The reaction mixture was concentrated and the crude material purified by flash chromatography (hexane–EtOAc 7:3) to yield carba-β-D-mannopyranose pentaacetate **52** (33 mg, 75% overall): mp = 116–118°C, $[\alpha]_D^{21}$ +2.0 (*c* 0.6, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 5.49 (t, $J=2.7$ Hz, 1H), 5.15 (t, $J=10.1$ Hz, 1H), 4.89 (dd, $J=2.7$, 10.1 Hz, 1H), 4.88 (m, 1H), 3.99 (dd, $J=5.6$, 11.3 Hz, 1H), 3.93 (dd, $J=3.5$, 11.3 Hz, 1H), 2.11 (s, 3H), 2.00 (s, 3H), 2.00–1.89 (m, 2H), 1.97 (s, 3H), 1.94 (s, 3H), 1.91 (s, 3H), 1.79 (q, $J=12.5$ Hz, 1H): ^{1}H NMR (400 MHz, C_6D_6) δ (ppm): 5.86 (t, $J=2.6$ Hz, 1H), 5.46 (t, $J=0.3$ Hz, 1H), 5.01 (dd, $J=2.6$, 10.3 Hz, 1H), 4.72 (ddd, $J=2.6$, 4.7 Hz, $J=12.4$ Hz, 1H), 4.06 (dd, $J=5.3$, 11.3 Hz, 1H), 3.74 (dd, $J=3.5$, 11.3 Hz, 1H), 1.86 (q, $J=12.4$ Hz, 1H), 1.72–1.68 (m, 1H), 1.69 (s, 3H), 1.67 (s, 6H), 1.65 (s, 3H), 1.61 (s, 3H), 1.44–1.34 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 171.0 (×2), 170.8 (×3), 72.7, 70.8, 70.2, 69.4, 64.7, 37.9, 28.3, 21.7 (×3), 21.5 (×2). Anal. calcd for $C_{17}H_{24}O_{10}$: C, 52.57; H, 6.23. Found: C, 52.71; H, 6.43.

6.23. (3a*R*,4*R*,5*Z*,5a*S*,9b*S*)-5-Benzylidene-4-(benzyloxy)-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h][1,3]benzodioxine 53

A solution of (*Z*)-**33** (290 mg, 0.84 mmol) in dry DMF at 0°C (15 mL) was treated with NaH (67.2 mg 60%,

1.68 mmol) and the reaction mixture was allowed to warm to room temperature. Stirring was continued for 20 min and benzyl bromide (150 μL, 1.26 mmol) was added. After 6 h the reaction was diluted with Et_2O and washed with water. The organic phase was dried, concentrated, and the residue purified by flash chromatography (hexane–EtOAc 95:5) to yield (*Z*)-**53** (292 mg, 80%): mp = 75–78°C, $[\alpha]_D^{21}$ +68.2 (*c* 0.8, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.28–7.10 (m, 10H), 6.97 (s, 1H), 4.62 (d, *J* = 5.0 Hz, 1H), 4.58 (dd, *J* = 1.2, 4.0 Hz, 1H), 4.37 (t, *J* = 5.0 Hz, 1H), 4.29 (d, *J* = 12.2 Hz, 1H), 4.20 (dd, *J* = 4.0, 12.0 Hz, 1H), 4.18 (m, 1H), 4.12 (dd, *J* = 2.4, 12.0 Hz, 1H), 4.10 (d, *J* = 12.2 Hz, 1H), 2.86 (m, 1H), 1.53 (s, 3H), 1.49 (s, 3H), 1.38 (s, 3H), 1.30 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 137.9, 136.7, 134.8, 130.6, 128.5 (×2), 128.0 (×2), 127.8 (×2), 127.7 (×2), 127.2, 126.6, 109.1, 99.1, 76.6, 75.6, 73.4, 70.2, 68.8, 61.4, 34.1, 28.7, 25.5, 25.4, 19.3. MS *m*/*e*: 436.2 (M^+).

6.24. (3a*R*,4*R*,5a*R*,9a*S*,9b*S*)-4-(Benzyloxy)-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h][1,3]benzodioxin5-ol 54

Ozonolysis of olefin **53** (270 mg, 0.61 mmol) afforded the corresponding ketone which was filtered through silica gel and then immediately subjected to reduction with $NaBH_4$ and $CeCl_3$. Flash chromatography of the residue (hexane–EtOAc 8:2) yielded an inseparable, 1:1 mixture of isomeric alcohols **54** (142 mg, 64% overall). ^1H NMR (for two isomers, 300 MHz, $CDCl_3$) δ (ppm): 7.31–7.20 (m, 10H), 4.87 (d, *J* = 12.2 Hz, 1H), 4.81 (d, *J* = 12.2 Hz, 1H), 4.79 (d, *J* = 12.2 Hz, 1H), 4.70 (d, *J* = 12.2 Hz, 1H,), 4.52 (m, 2H), 4.28–4.13 (m, 4H), 4.09–3.92 (m, 8H), 3.00 (d, *J* = 7.2 Hz, 1H), 2.86 (d, *J* = 8.6 Hz, 1H), 2.23 (m, 1H), 1.90 (m, 1H), 1.50 (s, 3H), 1.44 (s, 3H), 1.43 (s, 3H), 1.39 (s, 3H), 1.34 (s, 3H), 1.33 (s, 3H), 1.27 (s, 3H), 1.16 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 137.8, 129.8, 128.5 (×2), 128.3 (×4), 128.1 (×2), 127.9, 127.6, 109.4, 109.0, 99.2, 98.7, 78.0, 76.3, 76.1, 75.7, 75.2, 74.8, 73.4, 72.6, 71.3, 68.7, 67.6, 66.9, 63.6, 60.7, 38.5, 32.6, 29.4, 29.1, 26.2 (×2), 23.9, 23.8, 18.9, 18.5. MS *m*/*e*: 364.2 (M^+), 349.2 (M^+−15). Anal. calcd for $C_{20}H_{28}O_6$: C, 65.91; H, 7.74. Found: C, 66.13; H, 7.89.

6.25. 1-*O*-Benzyl-2,3:4,6-di-*O*-Isopropylidene-5a-carba-α-L-gulopyranose 56

Alcohols **54** (110 mg, 0.30 mmol) were dissolved in dry THF (15 mL) and treated with NaH (24 mg 60%, 0.60 mmol) at 0°C for 30 min. Then, the mixture was treated with CS_2 (36.2 μL, 0.60 mmol) at room temperature for 60 min after which MeI was added (124 μL, 2 mmol). Stirring was maintained for additional 30 min and then the reaction was diluted with CH_2Cl_2, washed with water, dried and concentrated to give a residue which was chromatographed (hexane–EtOAc 8:2) to give a 1:1 mixture of xanthates **55** (96 mg, 75%). This mixture was deoxygenated and the residue purified by flash chromatography (Hexane–EtOAc 7:3) to yield carbagulose derivative **56** (66 mg, 90%). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.42–7.28 (m, 5H), 4.70 (d, *J* = 12.4 Hz, 1H), 4.62 (d, *J* = 12.4 Hz, 1H), 4.45 (dd, *J* = 2.7, 7.3 Hz, 1H), 4.11 (dd, *J* = 2.0, 7.3 Hz, 1H), 4.10 (m, 1H), 4.02 (dd, *J* = 1.6, 11.5 Hz, 1H), 3.94 (t, *J* = 2.0 Hz, 1H), 3.54 (d, *J* = 11.5 Hz, 1H), 1.62–1.33 (m, 3H); 1.48 (s, 3H), 1.39 (s, 3H), 1.35 (s, 3H), 1.21 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 138.4, 128.3 (×2), 128.1 (×2), 127.6, 108.9, 98.4, 76.4, 73.4, 71.5, 70.7, 68.2, 65.4, 29.3, 27.0, 26.3, 24.2, 24.1, 18.8.

6.26. 1,2,3,4,6-Penta-*O*-Acetyl-5a-carba-α-L-gulopyranose 57

A solution of benzyl ether **56** (50 mg, 0.15 mmol) in MeOH (25 mL) was hydrogenolyzed in the presence of 10% Pd/C (10 mg) at 35 psi at room temperature for 60 min. The reaction mixture was filtered through a short pad of Celite and concentrated to give a residue which was subjected to the general procedure for the cleavage of the isopropylidene moiety. After acetylation, the reaction mixture was concentrated and the crude material purified by flash chromatography (hexane–EtOAc 6:4) to yield carba-α-L-gulopyranose pentaacetate **57** (39 mg, 70% overall): $[\alpha]_D^{21}$ −34.1 (*c* 0.3, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm): 5.28–5.20 (m, 4H), 4.11–3.98 (m, 2H), 2.60 (m, 1H), 2.07 (s, 3H), 2.06 (s, 3H), 2.05 (s, 3H), 2.05–2.02 (m, 2H), 2.04 (s, 3H), 2.03 (s, 3H). ^1H NMR (300 MHz, C_6D_6) δ (ppm): 5.83 (dd, *J* = 3.2, 6.5 Hz, 1H), 5.72 (m, 2H), 5.61 (dt, *J* = 3.0, 6.7 Hz, 1H), 4.24 (dd, *J* = 7.0, 10.8 Hz, 1H), 4.02 (dd, *J* = 6.7, 10.8 Hz, 1H), 2.76 (m, 1H), 1.96 (m, 2H), 1.97 (s, 3H), 1.91 (s, 3H), 1.90 (s, 3H), 1.89 (s, 3H), 1.80 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 169.8, 169.7, 169.5, 169.4, 169.3, 69.1, 68.3, 67.5, 62.9, 53.3, 30.2, 26.9, 20.5, 20.3, 20.2, 20.0, 18.5. MS *m*/*e*: 411.2 ($M+Na^+$). Anal. calcd for $C_{17}H_{24}O_{10}$: C, 52.57; H, 6.23. Found: C, 52.81; H, 6.51.

6.27. (3a*R*,4*R*,5*R*,5a*R*,9a*S*,9b*S*)-4-(Benzyloxy)-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h][1,3]-benzodioxin-5-ol 58

Ozonolysis of olefin **33** (270 mg, 0.78 mmol) yielded the corresponding ketone which was filtered through silica gel (hexane–EtOAc 8:2) and then immediately reduced with $NaBH_4$ and $CeCl_3$. Flash chromatography (hexane–EtOAc 8:2) yielded alcohol **58** (133 mg, 62%): mp = 102–104°C. ^1H NMR (200 MHz, $CDCl_3$) δ (ppm): 4.48 (dd, *J* = 3.3, 6.8 Hz, 1H), 4.23–4.02 (m, 5H), 2.85 (d, *J* = 6.7 Hz, 1H), 2.40 (d, *J* = 10.9 Hz, 1H), 1.84 (m, 1H), 1.50 (s, 3H), 1.45 (s, 3H), 1.37 (s, 3H), 1.33 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 109.9, 98.9, 76.0, 75.6, 68.7, 67.6, 67.2, 62.3, 36.9, 29.5, 26.3, 24.0, 18.5. Anal. calcd for $C_{20}H_{28}O_6$: C, 65.91; H, 7.74. Found: C, 66.23; H, 7.87.

6.28. (3a*R*,4*R*,5*R*,5a*R*,9a*S*,9b*S*)-4,5-Bis-(benzyloxy)-2,2,8,8-tetramethylhexahydro-3aH-[1,3]-dioxolo[4,5-h]-[1,3]benzodioxine 59

Diol **58** (290 mg, 0.84 mmol) was converted into the dibenzylether following the conditions previously described for **53**. Flash chromatography (hexane–EtOAc 95:5) gave **59** (267 mg, 70%) as a colorless oil.

^{1}H NMR (200 MHz, $CDCl_3$) δ (ppm): 7.40–7.35 (m, 4H), 7.33–7.20 (m, 6H), 4.78 (d, $J=11.8$ Hz, 1H); 4.68 (d, $J=11.8$ Hz, 1H), 4.54 (d, $J=11.8$ Hz, 1H), 4.44 (d, $J=11.8$ Hz, 1H), 4.43 (m, 1H), 4.20 (dd, $J=4.8$, 6.2 Hz, 1H), 4.12 (dd, $J=1.5$, 11.9 Hz, 1H), 3.98–3.91 (m, 3H), 3.79 (dd, $J=2.3$, 10.4 Hz, 1H), 2.25 (ddd, $J=2.6$, 4.5, 10.4 Hz, 1H), 1.43 (s, 6H), 1.31 (s, 3H), 1.27 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 138.8, 138.5, 128.2 (×2), 128.1 (×4), 127.7 (×2), 127.5, 127.2, 109.1, 98.8, 76.5, 74.5, 74.4, 74.3, 73.2, 72.1, 68.2, 59.8, 39.5, 29.6, 25.7, 25.5, 18.8.

6.29. Preparation of tetraol 60

Prepared from diacetonide **59** (50 mg, 0.11 mmol) according to the general procedure (hexane–EtOAc 3:7). Colorless oil: $[\alpha]_D^{21}$ +69.5 (*c* 1.1, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.36 (m, 5H), 7.33 (m, 5H), 4.94 (d, $J=11.2$ Hz, 1H), 4.72 (d, $J=11.6$ Hz, 1H), 4.65 (d, $J=11.2$ Hz, 1H), 4.55 (d, $J=11.6$ Hz, 1H), 4.21 (s, 2H), 4.11 (m, 1H), 3.08 (m, 3H), 3.74–3.60 (m, 3H), 3.08 (m, 1H), 2.39 (s, 1H), 2.25 (m, 1H). ^{13}C NMR (50 MHz, $CDCl_3$) δ (ppm): 137.7, 137.6, 128.4 (×2), 128.3 (×2), 127.8 (×3), 127.7, 127.6 (×2), 79.7, 75.7, 75.6, 74.5, 72.6, 71.9, 67.1, 61.9, 37.2.

6.30. (3a*S*,4*R*,5*S*,6*R*,7*R*,7a*R*)-6,7-Bis-(benzyloxy)-5-({[tertbutyl(dimethyl)silyl]oxy}methyl)-2,2-dimethylhexahydro-1,3-benzodioxyl-4-ol 61

To a solution of tetraol **60** (240 mg, 0.64 mmol) in DMF was added imidazole (56 mg, 0.83 mmol) and *tert*-butyldiphenylchlorosilane (TPSCl) (194 mg, 0.70 mmol) and the reaction mixture was stirred at room temperature for 12 h. The crude was then diluted with Et_2O and washed with water. The organic layer was dried and concentrated, giving a residue which was purified by flash chromatography (hexane–EtOAc 1:1) to yield an intermediate silyl ether: $[\alpha]_D^{21}$ +31.4 (*c* 1.1, $CHCl_3$). ^{1}H NMR (300 MHz, C_6D_6) δ (ppm): 7.66–7.62 (m, 5H), 7.42–7.36 (m, 5H), 7.25–7.19 (m, 10H), 4.87 (d, $J=11.1$ Hz, 1H), 4.71 (d, $J=11.3$ Hz, 1H), 4.59 (d, $J=11.1$ Hz, 1H), 4.50 (d, $J=11.3$ Hz, 1H), 4.37–4.27 (m, 3H), 4.07–3.98 (m, 4H), 3.85 (m, 1H), 3.48 (m, 1H), 2.83 (m, 1H), 2.27 (m, 1H), 1.09 (s, 9H). ^{13}C NMR (50 MHz, $CDCl_3$) δ (ppm): 137.7, 135.5, 135.4, 132.1, 131.8, 129.9, 128.4 (×2), 128.3 (×2), 127.8 (×4), 127.7 (×4), 127.5, 127.3, 80.0, 75.1, 74.9, 73.9 (×2), 71.8, 67.3, 63.7, 36.9, 26.7 (×3), 18.9. This material was then dissolved in DMF (30 mL) and sikkon (200 mg), 2-methoxypropene (114 μL, 1.2 mmol) and *p*-toluenesulfonic acid (15 mg) were added. After 2 h, CH_2Cl_2 was added and the reaction mixture was filtered through a small pad of Celite. The filtrate was washed with $NaHCO_3$ and water. The organic layer was dried and concentrated to give a residue which was purified by flash chromatography (hexane–EtOAc 9:1) affording cyclohexane **61** (176 mg, 45% two steps): $[\alpha]_D^{21}$ +27.2 (*c* 0.6, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.80–7.60 (m, 6H), 7.48–7.34 (m, 6H), 7.33–7.22 (m, 6H), 7.18–7.13 (m, 2H), 4.83 (d, $J=12.1$ Hz, 1H), 4.68 (d, $J=12.1$ Hz, 1H), 4.58 (d, $J=11.6$ Hz, 1H), 4.45 (dt, $J=2.8$, 4.7 Hz, 1H), 4.37 (dd, $J=3.6$, 7.0 Hz, 1H), 4.28 (dd, $J=4.7$, 7.0 Hz, 1H), 4.27 (d, $J=11.6$ Hz, 1H); 4.15 (t, $J=3.6$ Hz, 1H), 3.99 (d, $J=3.0$ Hz, 1H), 3.98 (d, $J=3.0$ Hz, 1H), 3.84 (dd, $J=3.6$, 8.3 Hz, 1H), 3.54 (d, $J=2.8$ Hz, 1H), 2.38 (ddt, $J=3.0$, 4.7, 8.3 Hz, 1H), 1.50 (s, 3H), 1.37 (s, 3H), 1.05 (s, 9H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 138.8, 138.6, 135.7 (×2), 135.6 (×2), 132.5, 132.4, 130.0, 129.9, 128.2 (×4), 127.9 (×2), 127.8 (x2), 127.7 (×2), 127.4 (×2), 127.3, 127.2, 109.5, 77.9, 74.6, 74.4, 74.2, 73.6, 72.1, 71.2, 63.5, 41.2, 26.1 (×3), 26.4, 24.8, 19.1. MS *m*/*e*: 637.1 (M^+–15). Anal. Calcd for $C_{40}H_{48}O_6Si$: C, 73.58; H, 7.41. Found: C, 73.78; H, 7.65.

6.31. 3,4-Di-*O*-benzyl-6-*O*-tertbutyldiphenylsilyl-1,2-*O*-isopropyliden-5a-carba-α-D-allopyranose 62

Alcohol **61** (152 mg, 0.23 mmol) was converted in the corresponding thiocarbonate according to conditions described in the general procedure. After aqueous work-up the crude material was dissolved in toluene and the general procedure for the radical deoxygenation was carried out to afford a residue which was purified by flash chromatography (hexane–EtOAc 7:3) to yield carba-allose derivative **62** (84 mg, 58%): $[\alpha]_D^{21}$ +50.5 (*c* 0.6, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.65–7.61 (m, 4H); 7.44–7.19 (m, 16H), 4.84 (d, $J=12.1$ Hz, 1H), 4.72 (d, $J=12.1$ Hz, 1H), 4.54 (d, $J=11.7$ Hz, 1H), 4.44 (dt, $J=5.5$, 6.5 Hz, 1H), 4.37 (d, $J=11.7$ Hz, 1H), 4.18 (dd, $J=4.3$, 6.5 Hz, 1H), 3.96 (dd, $J=2.4$, 4.3 Hz, 1H), 3.89 (dd, $J=3.9$, 9.9 Hz, 1H), 3.62 (dd, $J=2.8$, 9.9 Hz, 1H), 3.47 (dd, $J=2.4$, 8.7 Hz, 1H), 2.38 (m, 1H), 2.17 (dt, $J=5.5$, 14.6 Hz, 1H), 1.94 (ddd, $J=5.5$, 8.7, 14.6 Hz, 1H), 1.51 (s, 3H), 1.37 (s, 3H), 1.05 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 138.9, 138.6, 135.6 (×4), 133.4, 129.6 (×2), 128.2 (×2), 128.1 (×2), 127.7 (×2), 127.6 (×4), 127.4 (×3), 127.3, 127.2, 108.0, 76.9, 75.6, 74.3, 73.7, 72.7, 71.5, 64.6, 35.6, 28.2, 26.9 (×3), 26.2, 25.1, 19.2. MS *m*/*e*: 636 (M^+), 621 (M^+–15).

6.32. 1,2,3,4,6-Penta-*O*-acetyl-5a-carba-α-D-allopyranose 63

Desilylation of **62** (84 mg, 0.13 mmol) was carried out as described for **30**. Flash chromatography (hexane–EtOAc 7:3) yielded 3,4-*O*-isopropylidene-1-*O*-benzyl-5a-carba-α-D-allopyranose (mp = 59–61°C), $[\alpha]_D^{21}$ +120.9 (*c* 0.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm): 7.45–7.40 (m, 3H), 7.33–7.25 (m, 7H), 4.88 (d, $J=12.0$ Hz, 2H), 4.72 (d, $J=12.0$ Hz, 2H), 4.54 (d, $J=11.7$ Hz, 2H), 4.29 (d, $J=11.7$ Hz, 2H), 4.27 (m, 1H), 4.09 (t, $J=5.1$ Hz, 1H), 3.96 (dd, $J=2.2$, 5.1 Hz, 1H), 3.68 (dd, $J=3.4$, 10.7 Hz, 1H), 3.54 (dd, $J=6.2$, 10.7 Hz, 1H), 3.23 (dd, $J=2.2$, 10.0 Hz, 1H), 2.53 (m, 1H), 2.11 (ddd, $J=3.0$, 5.2, 15.0 Hz, 1H), 1.51 (ddd, $J=5.2$, 11.1, 15.0 Hz, 1H), 1.50 (s, 3H), 1.36 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 138.8, 138.7, 128.5 (×2), 128.1 (×2), 128.0 (×2), 127.9, 127.8 (×2), 127.3, 109.2, 80.2, 75.7, 74.3, 73.3, 72.2, 70.9, 65.6, 35.6, 27.6, 26.0, 25.5. MS *m*/*e*: 398.2 (M^+), 383.2 (M^+–15). Anal. calcd for $C_{24}H_{30}O_5$: C, 72.32; H, 7.59. Found: C, 72.07; H, 7.82. This compound was hydrogenolyzed under the same conditions as for **56**, to give a residue, which was

subjected to the general procedure for the cleavage of the isopropylidene moiety. After acetylation, the reaction mixture was concentrated and the crude material purified by flash chromatography (hexane–EtOAc 6:4) to yield carba-α-D-allopyranose pentaacetate **63** (43 mg, 86% overall): mp = 95–98°C, $[\alpha]_D^{21}$ +36.0 (*c* 1.0, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ (ppm): 5.54 (t, $J = 3.1$ Hz, 1H), 5.38 (m, 1H), 4.96 (t, $J = 3.1$ Hz, 1H), 4.89 (dd, $J = 3.1$, 11.3 Hz, 1H), 4.18 (dd, $J = 4.7$, 11.3 Hz, 1H), 4.00 (dd, $J = 2.9$, 11.3 Hz, 1H), 2.56 (m, 1H), 2.14 (s, 3H), 2.11 (s, 3H), 2.10 (s, 3H), 2.02 (s, 3H), 2.01 (m, 1H), 2.00 (s, 3H), 1.71 (dt, $J = 2.9$, 14.0 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm): 170.8, 170.1, 170.0, 169.7, 169.6, 69.3, 68.9, 68.5, 67.1, 63.0, 30.7, 29.3, 20.9, 20.8, 20.7, 20.6, 20.5. Anal. calcd for $C_{17}H_{24}O_{10}$: C, 52.57; H, 6.23. Found: C, 52.76; H, 6.51.

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